Findings

Upland:

Measurements of plant mortality and productivity on Hog Island indicate that Hurricane Isabel and its associated flooding had relatively modest effects on island vegetation. The extensive woody *Myrica cerifera* shrublands experienced only limited mortality, primarily at the seaside edges of thickets or on tall shoots where salt-spray exposure was particularly intense. Mortality may have been limited by the timing of Isabel, since the storm struck during the fall when evapotransporation rates are normally starting to decrease.

Low altitude oblique aerial photographs of shrub thickets on northern Hog Island in October of 2003. Despite extensive flooding, the only evidence of mortality is along the seaside edge of the thickets and on tall branches of interior shrubs.

Long-term nitrogen experiments on a chronosequence of dunes and swales on northern Hog Island continue to yield interesting results. After seven growing seasons, results suggested more intense negative effects of competition in nitrogen-fertilized plots. Greater cover of *Ammophila brevigulata* in fertilized plots suggests *Ammophila* is in a better position to compete for light with enhanced aboveground dominance. Diversity was lower in fertilized plots on all but the dune formed in 1967 and diversity decreased most dramatically in fertilized plots on the oldest dune. The increase in total density with fertilization as diversity decreased, coupled with the shifting composition of Ammophila and other dominants, appears to support the interspecific competitive exclusion hypothesis. Changes in the positions of free surfaces (groundwater level in particular) appear to influence plant community composition.

On the dune pimples environmental data, such as depth to water table, height above marsh, aspect, soil texture, and total C:N are being used with ordination techniques, primarily canonical correspondence analysis (CCA), to quantify their relationship with the species distribution patterns. Preliminary analyses suggest a strong influence of elevation and water availability on species distribution. Addition of more variables, such as different soil nutrients will help explain finer differences in species composition.

Faunal surveys focusing on small mammal species on low-lying barrier islands following Hurricane Isabel, showed species-specific effects. All the low-lying islands (Chimney-pole Mash, Ship Shoal Island and Myrtle Island) showed evidence of major flooding (wrack deposition in upland areas, debris deposited in the branches of *Iva* shrubs), but despite the flooding, small mammals were found on all of the islands. Surviving animals must have either climbed shrubs, floated on wrack or swam throughout the period of peak flooding on all these islands, as even the highest areas on these islands showed evidence of flooding during at least some part of the storm. *Oryzomys palustris* (rice rat), the most widely distributed species on the Virginia Barrier Islands, was trapped on all of the islands following Hurricane Isabel (see table). Only on Myrtle Island were there ìmissingî species. Despite the visible presence of remaining grassland habitat, the meadow vole (*Microtus pennsylvanicus*) was not trapped, nor was the house mouse (*Mus musculus*). During October and November of 2004 we will be conducting additional trapping on Myrtle to confirm the loss of these species. Preliminary assessment of the disease status of small mammals was instigated during 2004, using samples collected as part of the Ship Shoal and Myrtle Island trapping. Fecal and blood samples were analyzed by UVA veterinarian Sandy Feldman using genetic and antibody assays. The preliminary analyses of 12 fecal samples found evidence of *Samonella* sp. in 33% of the samples, but showed an absence of *Campylobacter* and *Shigella* sp. Analysis of four blood samples found antibodies for a hantavirus variant in populations on Myrtle Island, but none on Ship Shoal Island. We will be collecting additional samples to verify and extend these results.

Island	**Species before Hurricane Isabel**	**Species trapped after Hurricane Isabel**
Chimney Pole Marsh	*Oryzomys palustris*	*Oryzomys palustris*
Ship Shoal	*Oryzomys palustris, Microtus pennsylvanicus*	*Oryzomys palustris, Microtus pennsylvanicus*
Mytle	*Oryzomys palustris, Microtus pennsylvanicus, Mus musculus*	*Oryzomys palustris*

Our efforts at integrating primary production data from different areas within the island and marsh systems is indicating a high degree of complexity. The interannual coherence of primary production is not strong among island dunes, swales and high slat marsh; but the rainfall in early spring may be an important control. A draft heuristic model has been created to help integrate future analytical efforts. (Christian, Young, Day, Porter).

As part of a MS thesis, graduate student Rachel Rounds (working with PI Erwin) elevated small areas on five marsh/shellpile sites to test for species responses in nesting; she found that none of the 4 species showed a strong preference for the elevated plots. However, hatching success in colonies was strongly correlated with higher elevation nest sites. Social attraction among species, and past nesting experience, even at lower elevations, may overwhelm any tendencies to seek the highest elevations.

Lagoon:

Our monitoring of base flow nutrient loading from 14 tidal creeks into the VCR lagoons over both wet and dry years showed that nitrate comprised 66-98% of the total nitrogen loading, and that amount of forest cover and developed land in the watershed explained 86% of the baseflow nitrate loading rate. Working with Iris Anderson, M.S. student Jen Wu Stanhope also showed that nutrient loading was higher to lagoons in the northern portion of the Delmarva Peninsula where poultry farms influenced water quality. M.S. student Diane Barnes worked with Karen McGlathery and Jay Zieman to link the nutrient loading and water quality of the creeks to benthic faunal diversity. Her worked showed that despite variation in agricultural land use from 28 ñ 91 % in the watersheds of the southern portion of the peninsula, there was no measurable impact on benthic macroinvertebrates. Instead, it was the local environment, in particular the width of the forested riparian zone and its effect on nutrient processing and organic matter loading, that influenced benthic biodiversity.

Aaron Mills and his students have shown that denitrification can account for all of the observed NO3- removal from the groundwater discharging into Cobb Mill Creek. Nitrate-removal rates in cores extracted from the stream bed were capable of removing all nitrate from a 20 mg NO3- -N/L solution of artificial groundwater at discharge rates that were up to 5 times faster than observed *in situ*. Nitrate profiles in the sediment of Cobb Mill Creek show a strong decrease in NO3- in the top 50 cm of the sediments with the greatest change in nitrate concentration occurring in the upper 20 cm. In this same region, the highest measured denitrification rate potentials were observed and that was also the location of the highest number of denitrifying organisms. The latter were enumerated using a most-probable-number approach adapted for molecular (PCR of the *nos*Z or nitrous oxide reductase gene). During this year, we initiated a large flume installation which isolates a segment of the hillslope and stream sediments. This facility will allow mass balance measurement of nitrate transport in a fashion similar to the core studies, and it will permit field experiments to be conducted that investigate the effect of transient events on sediment and bank biogeochemistry.

A collaborative research effort supported by the LTER, US EPA, and NOAA Air Resources Laboratory quantified dry-deposition inputs of major atmospheric nitrogen species (including gaseous NH_3 and HNO_3 and particulate NH_4^+, NO_3^-, NO_2^-, and organic nitrogen) during summer at Lewes, Delaware on the Delmarva Peninsula. Results indicate that dry deposition contributed approximately 43% to total atmospheric nitrogen deposition in this region. Under all flow conditions, dry deposition of $NH_{3(g)}$ comprised the largest fraction of total nitrogen dry deposition (averaging 60%); $HNO_{3(g)}$ and NO_3^- also contributed considerably (averaging 25% and 8%, respectively). During onshore flow, scavenging of $HNO_{3(g)}$ by sea-salt aerosols shifted the phase-partitioning and relative dry fluxes of total NO_3 ($HNO_{3(g)} + NO_3^-$) towards particulate NO_3^-.

Iris Anderson and Karen McGlathery have used the watershed and atmosphere nutrient loading data as input to a nitrogen budget to distinguish the relative importance of

HIB N SOURCES & SINKS ($kgN\ y^{-1}$)	
Allochthonous Sources	
Base flow	20,869
Direct atmospheric deposition	118,050
Surface water runoff	6,261
Direct groundwater discharge	6,956
Autochthonous Sources	
N remineralization	1,549,528
N fixation	757,125
TOTAL SOURCES	**2,458,789**
Nitrogen Sinks	
Macroalgal demand	116,565
Benthic microalgal demand	2,485,546
Phytoplankton demand	363,691
Marsh demand	337,983
Denitrification	46,128
TOTAL SINKS	**3,349,913**

allochthonous vs. autochthonous sources in satisfying the nitrogen demand of the primary producers within the system. Data inputs to the budget included direct atmospheric deposition, monthly base flow, seasonal sediment gross N remineralization, gross primary production by benthic micro- and macroalgae and phytoplankton, sediment water - nitrogen fluxes in both subtidal and intertidal habitats, and sediment N cycling rates including nitrification, denitrification, and N fixation. The results indicate that the allochthonous sources of groundwater and atmospheric deposition account for less than 5% of the total nitrogen demand of the primary producers in the coastal lagoon. By far the most important nitrogen support autotrophs in the lagoon is remineralization in the sediments.

Work by Karen McGlathery and her students has focused on the role that macroalgae play in shallow coastal lagoons. As watersheds become developed on the Delmarva Peninsula, nutrient enrichment will likely be a more important driver of processes in the VCR lagoons and this is likely to result in the occurrence of macroalgal blooms. Interactions between bloom-forming macroalgae and benthic fauna play a key role in the response of shallow coastal systems to external nutrient loading. McGlatheryís Ph.D. student Jenn Rosinksi showed that the negative consequences of nutrient enrichment on benthic fauna, namely the loss of biodiversity and associated functions (i.e. bioturbation), occur earlier in the eutrophication process than previously believed, before macroalgal blooms form. Trophic models showed that mesograzers could control macroalgal bloom formation at low to moderated nutrient loading. However, advection by wind is important in the development of macroalgal blooms in shallow systems such as Hog Island Bay, and this can counteract the effects of consumer control on macroalgal proliferation, emphasizing the important coupling of biological and physical processes in shallow coastal ecosystems.

Invasions by alien marine organisms have accelerated in the last century often, with unknown ecological and economic consequences. The macroalga *Codium fragile* ssp. *tomentosoides* has been reported to be a dominant species in numerous invaded low energy estuaries and lagoons. McGlatheryís Ph.D. student Mads Thomsen showed that in Hog Island Bay shows that *C. fragile* is successful compared to native species in eastern North American turbid lagoons by having high tolerance to annual temperature and light fluctuations, by having moderate growth over a long growing season, and by being an effective colonizer of hard substrates in the shallow subtidal zone. However, *C. fragile* was inferior to many native taxa when considering the effects of polychaete facilitation, mudsnail grazing, intertidal desiccation, enhanced nutrient levels, and cover of drift algal or sediments. The two latter stresses are associated with anthropogenic impacts, and were

also detrimental to the oyster *C. virginica*. Since *C. virginica* is an important facilitator of *C. fragile* increased eutrophication and coastal development could have an even more pronounced negative effect on *C. fragile* distribution and abundance than originally thought.

Our physical model of sediment resuspension and the link to light availability in the water column of Hog Island Bay has set the stage for a new initiative to recolonize eelgrass to Hog Island Bay. The system underwent a state change in the 1930ís, with the complete loss of eelgrass due to the combined effect of disease and storms, and now is poised for a state change back to eelgrass dominance. The model predicts that over 50% of the lagoon bottom has suitable light conditions to support eelgrass growth and indicates the sites where recolonization is most likely to succeed. We have used this information to guide our initial efforts in seeding the lagoon bottom. In 2005, we will expand this into a large scale experimental effort aimed at understanding the role of eelgrass as a foundation species in coastal lagoons.

Work by Linda Blum and her students focus on organic matter accumulation, associated microbial communities, and patterns of spatial and temporal distribution of microbial communities and their activity in salt marshes and tidal creeks. Her group has shown that the spatial and temporal distribution of microbial communities in Machipongo (seaside) and Nassawadox (Chesapeake Bay) tidal creeks demonstrated clear spatial structuring of the bacterial community structure not unlike that seen for macroorganisms and a repeatable temporal structure over a two year period. The important role of environmental structuring in driving the variability in the bacterial community was also observed. Although the spatial structures of abundance, composition, and diversity were comparable in the two systems, the two systems are clearly unique as evidenced by the low genetic compositional similarity of the microbial communities within the mesohaline regions of Machipongo and Nassawadox Creeks.

Marsh:

In the face of high levels of relative sea level rise (3.5 mm/yr), a critical question for marsh studies is whether the marshes will be able to gain enough elevation via accretion to survive in the future. Mid-lagoon islands are of special interest, since they are cut off from sediment sources available to island and upland marshes. At most sites studied, the ability of marsh elevation (data from Surface Elevation Table data and cores) to maintain pace with sea-level rise is not sufficient to preclude inundation. Marsh losses have occurred at 4 of 5 sites investigated based on 40-60 yrs of remote sensing data. Marsh gain has occurred at the southernmost site, Mockhorn Island VA, in spite of obvious conversion of uplands to salt marshes in parts of the island. Species of waterbirds particularly at risk are Forster's Terns, Clapper Rails, and Seaside and Sharp-tailed Sparrows (Erwin, Christian, Blum).

Preliminary results from a long-term pumping experiment wherein seawater is pumped onto areas of a mainland salt marsh indicate that little change has occurred in species

composition due to pumping, indicating the resilience of the communities. However, we have been able to see significant effects of headwater erosion of creeks and disturbance events. (Christian, Brinson)

On the theoretical level, network analysis has been used to analyze the marsh system. New work with random networks has demonstrated that some information theoretic metrics do not stabilize in their response to network structure until networks are larger than normal empirical networks. (Christian)

Upper Phillips Creek Marsh was the site of a large area of dead marsh during the summer of 2004. Preliminary sampling indicates that the dead marsh appears to result from no growth in areas rather than growth and subsequent death. We are continuing investigations of this phenomenon and are working with researchers from other parts of the country that have experienced similar dieoffs. (Christian, Blum).
Experiments to designed to alter the sediment biogeochemical processes potentially affecting organic matter accumulation show that the activity of the fiddler crab, *Uca pugnax*, may be an critical determinant of sediment organic matter accumulation rates in Delmarva Peninsula salt marshes. In marshes where fiddler crabs were active, organic matter content was always lower than in marshes where fiddler crabs were absent. Construction of artificial crab burrows in organic rich marshes did not effect sulfate reduction rates even though decomposition rates were greater, suggesting that aerobic decay was responsible for the faster decay where fiddler crabs are active.

On the marsh surface, rates of organic matter decay are positively correlated with temperature, but not by the types of microbes decaying the material. The amount of rainfall occurring during the decay period determined the microbial decay community composition and microbial biomass was a significant proportion of total detritial carbon (> 50% of the total detritial C mass) suggesting that detritivores eating decaying litter on the marsh surface are deriving significant proportions of their nutritional requirements from the microbial decay community.

Over the past year, analysis of measures of accretion of both mineral and organic materials has provided insight into marsh geomorphology and transgression in response to changing sea level. One of the working hypotheses that Blum has focused on during the past 10 years is that differences in root production and decomposition among the low, mid, and high marsh zones in Phillips Creek Marsh contributes to geomorphic changes that result in transgression. Based on a recent synthesis of her long-term measures of organic matter accumulation, Blum estimated the maximum rate of vertical accretion attributable to organic matter accumulation for the three marsh zones. The low-marsh value (1.8 mm yr^{-1}) is approximately half the rate of sea level rise reported for this portion of the Delmarva Peninsula (range 2.5- 3.5 mm yr^{-1}); however, mineral sediment deposition in this region may be sufficient for vertical accretion to maintain the low marsh elevation. Mid-marsh organic matter accretion was 2.5 to 3.5 times greater than sea level rise, while the high-marsh value was also half that of sea level rise. These values of accretion are comparable with accretion and elevation measured with other techniques in the same marsh (SET, Brinson, Christian, Blum). The lower belowground accretion and

higher rates of decay of *J. roemerianus*, a dominant plant in the high marsh, that Blum has measured indicates that in those regions of the high marsh where *J. roemerianus* occurs in monoculture are not accreting vertically as rapidly as the low and mid marsh. Yet the *J. roemerianus* patches in the high marsh are stable or expanding (Brinson, Christian). Thus, a positive feedback may be occurring in Phillips Creek Marsh where plant stresses from ponded water trapped behind the elevated mid marsh cause vertical accretion deficits that in turn increase flooding stress on the *S. patens*-*D. spicata* plant community in high marsh region immediately adjacent to the mid marsh. This suggests that mid and high marsh regions colonized by *S. patens* and *D. spicata* in transgressing salt marshes are most susceptible to ecogeomorphic change initiated by rise in sea-level surface and that the focus of future studies should be on the role of the *S. patens*-*D. spicata* plant communities in the high marsh transition to low marsh. This work is synthesized in a book chapter currently in press.

Measurement of surface elevation tables at a variety of scales (monthly, weekly, and daily) and prior to and after major disturbance events show sediment deposition on the marsh surface occurs as pulses associated with hurricanes and extra tropical storms. Between these disturbance events, the deposited materials are slowly eroded from the marsh surface. Thus, the frequency of major storms the marsh determines the extent of mineral sediment deposition in Phillips Creek Marsh. (Blum, Wiberg)

A primary focus of our research efforts on the island marshes continues to be the role of grazers in controlling *Spartina alterniflora* production, Past M.S. student Brian Silliman (supervised by PI Zieman) made significant contributions in understanding top-down controls on marsh productivity when he found that snails had a hitherto grossly underestimated impact on *Spartina alterniflora* productivity. Additional grazers on marsh grasses are now under investigation. M.S. Student Nicola McGroff (supervised by PI Zieman) examined the effect of the grasshopper *Orchelium fidicinium* on *Spartina alterniflora*. *O. fidicinium*, an active grazer during May through September. It is the only insect chewing grazer on *S. alterniflora* and is an obligate consumer of *S. alterniflora*. It eats by scraping the surface off the leaf, forming rectangular translucent wound. These wounds become infected, inhibit translocation of fluids into the plant, and cause premature senescence of the leaf. Snails

Variable	Exclusion	Ambient	Triple	Significance
% Leaves grazed	Decreased	Increased	Increased	Inclusion > exclusion
% Plants grazed	Decreased	Increased	Increased	Inclusion > exclusion
Dry Biomass	Decreased	Decreased	Decreased	None
Stem density	Increased	Decreased	Increased	None
Water content	Increased	Increased	Increased	Excl<Ambient<Triple
Plant Height	Increased	Increased	Decreased	None
# Dead Leaves	Decreased	Increased	Increased	Exclusion<Inclusions
# Live leaves	Decreased	Increased	Increased	Exclusion<Inclusions
Litter	---	---	Increased	None
% plant nitrogen	---	Increased	---	None
% plant carbon	Decreased	---	---	none
% Blooming	Increased	Increased	Decreased	None
Root biomass 0-10	Increased	Decreased	Increased	Ambient and triple changes
Sed. Organic matter 0-2	Decreased	Increased	Increased	Exclusions< Inclusions
Microalgal Biomass	---	---	---	None
% sed. Carbon 0-2	Decreased	---	---	None
% sed. Nitrogen 0-2	---	Increased	---	None
Sed NH_4 0-2	---	Increased	Increased	None

Summary of impacts of grasshopper grazing from McGroffís thesis

are prone to feeding over the grasshopper wounds. This finding suggests that the grasshoppers may facilitate the snail impact on marsh productivity. Small changes in grasshopper populations can elicit changes in both above and belowground environments of the salt marsh (see Table).

We continue our studies of the role of physical and biological factors influencing marsh productivity and plant distribution. M.S. student Rachel Michaels (supervised by PI Zieman) has been studying how the burrowing activity of fiddler crabs (*Uca* sp.) influences sediment structure and pore water chemistry (cm^2 - m^2 scale). This study showed that the extent of drainage and sediment characteristics determine the effects that fiddler crab burrows have on pore water chemistry and growth of *S. alterniflora* and that crab burrows affect the surrounding sediment pore water to a distance of at least 9 cm from the burrow edge The burrowing activity of fiddler crabs is thus important in increasing the heterogeneity of marsh sediments. M.S. student Lynette Winters (supervised by PI Zieman) investigated the growth and morpohological plasticity of the common high-salinity marsh plant *Salicornia virginica*, which is unique in that it occurs throughout the marsh independent of elevation range. This plant has been studied abundantly on the west coast, but very little on the east and gulf coasts, despite its ubiquity. She found that morphology, density and productivity all change with elevation, and that plants were the most branched and had the highest productivity at the highest elevation. Middle and low marsh plants were the tallest whereas plants in the low marsh had the highest belowground biomass. The highest growth was found was in hypersaline, oxygenated clay soils with high ammonium concentrations. When sods containing *Salicornia* were transplanted from the low marsh to the high marsh, they became taller and more branched, resembling the native high marsh plants. Invasive species are important on the marshes in addition to the VCR lagoons. M.S. student Thomas Mozder (supervised by PI Zieman) has been investigating the ecological interrelationships of the invasive reed *Phragmites australis,* particularly its ability to assimilate dissolved organic nitrogen. Genetic research has identified eleven native and one introduced haplotype of the common reed, *Phragmites australis* in North America. The cryptic invasion of the introduced haplotype M is thought to be responsible for the expansion of *Phragmites australis* in North America. In recent years, dissolved organic nitrogen (DON) has been demonstrated to be a significant source of nitrogen in many ecosystems ranging from aquatic tundra to coastal lagoons, yet nutrient budgets in temperate tidal marshes overlook organic nitrogen as a potential source of nitrogen. To test the hypothesis that there are differences in the ability to assimilate DON between *Phragmites* haplotypes and the dominant marsh grass *Spartina alterniflora*, short-term nutrient uptake experiments were preformed using dually labelled, ^{15}N and ^{13}C, nutrients on two haplotypes of *P. australis* (native, type F, and non-native, type M) and *Spartina alterniflora*. This work has shown thus far that both dominant species have the ability to utilize DON directly, which may allow them to bypass the rate-limiting step of microbial nutrient cycling. Future field and laboratory experiments will determine the relative importance of DON in the field. The data suggests that DON may be an important and overlooked pool of nitrogen, which may account for the net deficit of nitrogen in marsh nitrogen budgets. Similar results indicating the importance of DON have been found for lagoon macrophytes by former Ph.D. student Christy Tyler (supervised by Karen McGlathery).