GCE Annual Report Research Findings
September 2010

Context
The central paradigm of GCE-II is that variability in estuarine ecosystem processes is primarily mediated by the mixture of fresh and salt water flows across the coastal landscape. The project is focused on 5 main, inter-related questions:

Q1: What are the long-term patterns of environmental forcing to the coastal zone?

Q2: How do the spatial and temporal patterns of biogeochemical processes, primary production, community dynamics, decomposition, and disturbance vary across the estuarine landscape, and how do they relate to environmental gradients?

Q3: What are the underlying mechanisms by which the freshwater-saltwater gradient drives ecosystem change along the longitudinal axis of an estuary?

Q4: What are the underlying mechanisms by which proximity of marshes to upland habitat drives ecosystem change along lateral gradients in the intertidal zone?

Q5: What is the relative importance of larval transport versus the conditions of the adult environment in determining community and genetic structure across both the longitudinal and lateral gradients of the estuarine landscape?

Q1: What are the long-term patterns of environmental forcing to the coastal zone?

Coastal ecosystems are influenced by the characteristics of the upstream watershed (e.g., land use, slope), by those of the ocean (e.g., wave climate, sea level), and by those of the atmosphere (e.g., temperature, precipitation). The GCE project collects data on local climate (temperature, precipitation, wind speed and direction) and on the water chemistry of the tributaries that discharge into the Altamaha River. We also obtain data from other organizations (NWS, USGS, NOAA, and other sources) on river discharge, watershed characteristics, human population demographics, sea level, oceanographic conditions, and climate.

Atmospheric forcing
Meteorological stations, operated and maintained by various institutions affiliated with the GCE LTER program, are used to characterize the weather and climate within the GCE LTER domain. The station at Marsh Landing, which is operated in collaboration with SINERR, serves as our primary LTER meteorological station for inter-comparison studies and ClimDB. The station at Hudson Creek in Meridian is operated in cooperation with the USGS NWIS. Both near-real-time and historic data and plots from these and other relevant climate stations are publicly accessible on the GCE Data Portal website (http://gce-lter.marsci.uga.edu/portal/monitoring.htm).

This past year, A. Burd (UGA) and J. Sheldon (UGA) continued their analysis of variability in freshwater delivery to the GCE domain in relation to various climate indices: the Southern Oscillation Index (SOI), the North Atlantic Oscillation (NAO), and the Bermuda High Index (BHI). Results of this research were presented at both the 2009 LTER All Scientists Meeting and the Coastal and Estuarine Research Federation (CERF) conference. They are now extending this work to include the effects of the Atlantic Multidecadal Oscillation (AMO) and different El Niño
indices (e.g. the Niño4 index which highlights teleconnections with the central Pacific El Niño as opposed to the more well known east Pacific El Niño). They are also investigating improved algorithms for filling data gaps.

**Oceanographic forcing**

We obtain real-time monitoring data on oceanographic conditions from the National Data Buoy Center’s station at Gray’s Reef (Station 41008), which is approximately 39 km from the University of Georgia Marine Institute in the Gray’s Reef National Marine Sanctuary. We also obtain sea level data from the NOAA/NOS Center for Operational Oceanographic Products and Services web site (http://tidesandcurrents.noaa.gov/) for station ID 8670870 (Fort Pulaski, GA). Data are extracted from the CO-OPS web pages, standardized, and documented using GCE-LTER metadata templates.

D. Di Iorio (UGA) used data from these gauges to compare sea level height with winds. She found that sea level is positively correlated ($r=0.53$) with along shore winds (winds from the NNE) and negatively correlated ($r=-0.37$) with cross shore winds (winds from the WNW), both with p-values <0.05. During the fall and winter seasons Nor'easter storms create downwelling favorable conditions, which cause onshore transport and hence inundation in the estuaries. During spring and summer, winds are primarily from the southwest, which promotes offshore transport and thus reduced sea surface heights near shore. Offshore transport during spring could also be enhanced by increased river discharge during this time.

**Upstream forcing**

The USGS gauge at Doctortown (Station 02226000) provides near real-time data on discharge into the Altamaha River estuary. We use data harvesting technology developed by GCE to automatically download and process data from USGS so that it is documented and standardized to compatible units and date formats for comparison with other GCE monitoring data, providing GCE investigators with high quality standardized data in various file formats to support synthetic research projects. River discharge over the course of the project shows a change from a wet period (2003-2005) to drought conditions (2006-2008) with a recovery in spring 2009.

S. Joye (UGA) continues to work with J. Sandow (Aquatic Research South) to monitor nutrients in the river water entering the GCE domain via the Altamaha River and its tributaries. The Joye lab (under the guidance of K. Hunter, UGA) analyzes samples to determine concentrations of dissolved inorganic nutrients (DIN, DIP, and DSI species), dissolved organic nutrients (DOC, DON, and DOP), and total suspended solids. S. Schaefer (UGA Ph.D. student, Alber) is working to understand which sources of N to a watershed reach the water, and what transformations occur as it is transported downstream to the coast. As part of this, she is using NO$_3^-$ isotopes to provide insight into N sources and transformations within the Altamaha River watershed, where we have detailed data on sub-watershed N inputs.

The GCE project is also involved in a cross-site initiative (Maps and Locals) led by R. Pontius (PIE), G. Kofinas and N. Sayles (JRN) to use spatial representation of land cover and land use to identify patterns of landscape change in regions in and around LTER sites. As a result of last year’s supplemental support, researchers from PIE have been working with classified maps of the GCE from 5 time points (1974, 1985, 1991, 2001, and 2005). To date, this effort has resulted
in presentations at the GCE LTER annual meeting as well as the Annual Association of American Geographer's conference.

**Q2: How do the spatial and temporal patterns of biogeochemical processes, primary production, community dynamics, decomposition, and disturbance vary across the estuarine landscape, and how do they relate to environmental gradients?**

Variability in external forcing is manifest as environmental gradients (e.g., in salinity or nutrients) within the coastal landscape. We collect data on physical oceanographic conditions, nutrients, and organisms in the water column, and intertidal marsh soil, plant, microbial, and animal dynamics. Although data are collected throughout the domain, we primarily focus on conditions in the Duplin River, which is at the heart of our system. The variables of interest to us span all five of the LTER core research areas.

**Water column**

**Moorings**

Long-term measurements of conductivity, temperature, and sub-surface pressure are collected every 30 minutes at 8 moorings distributed across the GCE domain (see [http://gce-lter.marsci.uga.edu/public/research/mon/sounds_creeks.htm](http://gce-lter.marsci.uga.edu/public/research/mon/sounds_creeks.htm)). MicroCAT sondes are cleaned and inspected biweekly to minimize data loss due to fouling, and logged data are manually downloaded on a bimonthly to quarterly basis by GCE field technicians (J. Shalack, D. Saucedo, UGAMI). Data are processed by W. Sheldon (UGA) and D. Di Iorio.

This past year, Di Iorio, in collaboration with R. Castelao (UGA), used the Regional Ocean Modeling System (ROMS) to develop a highly idealized model representation of the Altamaha-Doboy-Sapelo estuarine complex and the adjacent coastal ocean. They used a periodic implementation of the model, with a domain extending 80 km offshore and 43 km alongshore. A constant inflow of 600 m$^3$s$^{-1}$ is imposed at the head of the Altamaha River throughout the simulation (results are qualitatively similar if the inflow is set at 300 m$^3$s$^{-1}$). The model is forced by tides and by upwelling favorable winds at 0.03 Pa for 20 days, followed by downwelling favorable winds for the following 20 days.

An EOF decomposition of the resulting surface salinity field from the model run (Figure 1) reveals a picture that is generally consistent with a separate EOF analysis conducted last year to evaluate the variability observed in mooring observations. The first EOF of the model, which explains 84% of the total variance, is negative over most of the domain and intensifies within 5 km of the coast, in the Altamaha River, and near the mouths of Doboy and Sapelo Sounds. This mode represents the system-wide freshening caused by the constant supply of freshwater from the Altamaha River, which occurs primarily during upwelling favorable winds. This is in keeping with the first EOF of the mooring observations, which was correlated with river discharge. However, the model results show an out of phase response near the heads of Sapelo and Doboy Sounds that was not observed in the mooring data. This may have occurred because no freshwater input was imposed on the headwaters of those estuaries in the model. The second EOF of the model reveals an out of phase response between the Altamaha River and Doboy and
Sapelo Sounds that is related to changes in wind forcing and coastal sea level. This is again consistent with the EOF analysis of the mooring observations.

Despite its great simplicity, it is encouraging to see that this idealized model is able to capture the dominant modes of salinity variability in the system, including the out-of-phase response observed in the Altamaha River and Doboy/Sapelo Sounds. A proposal has been submitted to NSF to collect the necessary observations and support the modeling required to follow up on this initial work.

**Cruises**

We run regular cruises to measure the surface water concentrations of dissolved and particulate materials at core stations located across the GCE domain. Samples from the monitoring cruises are collected by D. Saucedo and analyzed by the Joye lab (S. Joye, K. Hunter). Constituents analyzed include dissolved inorganic nutrients ($\text{NO}_2^-$, $\text{NO}_3^-$, $\text{NH}_4^+$, $\text{HPO}_4^{2-}$, and $\text{H}_2\text{SiO}_4^{2-}$), dissolved organic nutrients (DOC, TDN, DON, TDP, and DOP), chlorophyll $\alpha$, total suspended sediment, and particulate CN. We also deploy a Sea Bird CTD to collect vertical profiles of conductivity, temperature, and dissolved oxygen at each station.

M. Booth (UGAMI) completed an analysis comparing microbial diversity in all three domains of life at four of the GCE sites from samples collected as part of the NSF-funded MIRADA I project led by L. Amaral-Zettler (MBL); a paper on these results is currently in prep. She is currently using supplemental funds to analyze a subset of archived DNA samples collected.
during GCE cruises over a 14 month period to evaluate temporal trends in microbial diversity in the GCE domain. Pyrosequencing analysis will commence in September 2010.

**Marshes**

**Soil processes**

The ability of estuarine marshes to grow upwards or accrete vertically is controlled by both physical and biological processes. Under the direction of C. Craft (IU), we measure vertical accretion and sedimentation using sedimentation-erosion tables (SETs) and feldspar marker layers to evaluate the effects of freshwater pulsing on long-term stability of tidal marshes. We also measure changes in marsh surface elevation and sediment deposition every six months at the ten GCE domain sites and at three sites of a directed study on Dean Creek.

C. Craft worked with funding from the USEPA (Science to Achieve Results Program) and US DOE (National Institute for Climatic Change Research Program) to measure rates of carbon (C) sequestration, nutrient (N, P) accumulation, and mineral sediment deposition in tidal wetlands along the salinity gradients of three riverine estuaries (Ogeechee, Altamaha, and Satilla) on the Georgia coast. The accumulations of organic C, nutrients, and sediment exhibited bell-shaped

![Figure 2](image.png)  
Figure 2. Carbon sequestration, N and P accumulation, and mineral sediment deposition of tidal forests (swamps) and marshes of the Georgia Coast. Tidal marsh data are from Loomis and Craft (2010). Means denoted by the same letter are not significantly different (p<0.05) according to the Ryan-Einot-Gabriel-Welsch Multiple Range Test.
curves along the estuarine continuum, with low rates of C, N, P, and sediment accumulation at both ends of the salinity gradient, in tidal (fresh) swamp forests and in salt marshes (Figure 2), and higher rates in mid-reaches of the estuaries, in the tidal fresh- and brackish-water marshes. Although accumulation rates are relatively low in tidal swamp forests, their unique position at the head of the estuarine continuum enables them to intercept pollutants, especially N, that can cause eutrophication in downstream habitats.

**Plant dynamics**

S. Pennings (UH) and his lab monitor plant biomass with the goal of testing the hypothesis that end-of-year biomass varies as a function of freshwater discharge from the Altamaha River (especially in low-marsh plots), local rainfall (especially in high-marsh plots), and average sea level. Plants have been monitored non-destructively (stem counts, heights, flowering status) in October of every year since 2000. A rigorous analysis of these data leading to a publication is planned for the 2010-2011 academic year. In a separate set of plots, Pennings is testing the hypothesis that annual variation in high-marsh plant species composition is driven by variation in rainfall. Pennings has monitored mid-summer plant composition at permanent plots located on 3 types of vegetation borders (*Spartina alterniflora-Juncus roemerianus, S. alterniflora*-meadow, meadow-*Juncus roemerianus*), at two sites each, since 1996. Vegetation composition in these plots is dynamic and appears to be related to variation in rainfall, although more years of data are needed to test this hypothesis rigorously. Finally, Pennings is conducting parallel experiments in GA and AL to examine how rapidly marsh vegetation can recover from disturbance, and the role of competition in secondary succession. To date, succession has been fastest in plots on the *Spartina alterniflora*-meadow borders, which have already converged on control plot values, and slowest in the *J. roemerianus* plots, which are still early in the successional trajectory. Removal treatments indicate that competition plays a strong role in mediating the composition of the vegetation in each zone.

Pennings is also collaborating on a large-scale project to develop a synthetic understanding of plant zonation patterns in Georgia tidal marshes, evaluating 1) spatial associations between different plant species and abiotic conditions, 2) the results of experiments transplanting plants into new habitats and removing neighbors, 3) the results of experiments altering abiotic conditions, 4) variation among 55 sites in vegetation zonation patterns, and 5) temporal variation in plant community composition. This work is being written up for *Ecological Monographs*, with a submission planned during the 2010-2011 academic year.

**Additional plant studies**

Caroline McFarlin (UGA PhD student, Alber) is working to evaluate how *S. alterniflora* responds to disturbances, and to determine how the loss of *S. alterniflora* affects marsh support of benthic and epifaunal invertebrate communities. This year she completed experimental manipulations of factors that negatively affect *S. alterniflora*, including sudden dieback, wrack accumulation, general herbivory, and snail damage.

**Animal dynamics**

B. Silliman (UF) and his lab are continuing to document the patterns of macroorganisms across the GCE domain. In surveys of the GCE sites, they found similar patterns in the densities of mud snails and ribbed mussels: both were rare along the Altamaha River (sites 7, 8, and 9) and
highest at site 10 on Sapelo Island (Figure 3). This survey data provides good baseline data for long term monitoring and good insight into the patchy nature of the animals, but does not help test whether there is a true pattern in animal densities across the barrier island – mid-estuary – mainland gradient. To assess this possibility, in the fall of 2010, we will enumerate densities of these species and the other dominant marsh invertebrates in a highly replicated transect with 8 barrier island marshes, 8 mid-estuary marshes, and 8 mainland marshes. This design will allow a true test of the hypothesis that barrier island systems support higher marsh animal densities.

Since 2000, S. Pennings and his lab have collected annual data on grasshopper abundance to test the hypothesis that it varies as a function of site characteristics and angiosperm production. Based on the first decade of data, they hypothesize that vigorous growth of creekbank *Spartina* in one year leads to high egg production by grasshoppers, leading to high grasshopper population densities the following year. A rigorous synthesis of the complete data record is planned for the
2010-2011 academic year.

**Additional animal studies**

Pennings is also conducting additional studies of animal food webs. A paper by J. Jimenez (former UH Ph.D. student, Pennings) focusing on the arthropod food web of *Spartina alterniflora* is currently in review. At a larger spatial scale, Pennings worked with C. Ho (former UH Ph.D. student) to evaluate whether high-latitude plants are better food for herbivores than low-latitude plants by conducting growth experiments in the greenhouse. Preliminary results support this hypothesis but suggest that the results may vary among feeding guilds. To the extent that superior foods lead to larger body sizes, high-quality plants at high latitudes could be one mechanism behind Bergmann’s rule (animals are larger at high latitudes). A manuscript discussing this idea was published in the *American Naturalist* (Ho et al. 2010) and attracted considerable attention from the popular press, leading to a AAAS radio interview. An additional manuscript is in review.

**Microbes**

Current microbial work in GCE-II includes our focus on biogeochemical processes in the water column as described above, our collaboration with SIMO (http://simo.marisci.uga.edu/), and studies of microbial food webs and decomposition processes. Studies of microbial food webs were conducted by M. First (former UGA PhD student, Hollibaugh) and focused on spatial and temporal variation in the food web. One major conclusion was that protists are unlikely to exert strong top-down control on microbial populations (First 2008; First and Hollibaugh 2008; First et al. 2009). Studies of decomposition were conducted by J. Lyons (former UGA PhD student, Alber and Hollibaugh) and focused on characterizing the ascomycetes involved in the decomposition of various *Spartina* species collected from salt marshes along the east, Gulf, and west coasts (Lyons 2007; Lyons et al. 2009). Fungal communities differed in composition and diversity among different species of *Spartina*, but did not show a clear geographic pattern within species.

Collaboration with the SIMO project led to a paper on the metatranscriptome of ammonia-oxidizing organisms, predominantly ammonia-oxidizing archaea (AOA), in the GCE domain. We were able to test hypotheses about the (unknown) biochemical pathway of ammonia oxidation in archaea and compare the contribution of ammonia-oxidizing bacteria (AOB) versus AOA. A paper describing this study is in press in the ISME Journal and the data have been presented at various national meetings and in symposia. This study continues ongoing work on this topic by Hollibaugh (UGA) and collaborator J. Caffrey (UWF) funded by the Chemical Oceanography program of NSF.

**Duplin River estuary**

The Duplin River estuary represents a core focus of our efforts to produce an integrated understanding of both water and marsh processes in estuaries. We are working to develop a detailed spatial understanding of the system that will allow us to address the interactions between the estuarine water and the extensive intertidal areas that surround it.
Hydrological studies

This past year, we used ROA funds to work with R. Viso (CCU) to produce a detailed bathymetric map of the Duplin River using a multibeam echosounder. High-resolution bathymetric soundings were gridded at 25 cm in the horizontal and 1 cm in the vertical, revealing a wide range of riverbed and seafloor characteristics (Figure 4). Viso attended the GCE annual meeting in January to present the initial results of this effort, along with a CCU undergraduate (Ron Cash), who presented a poster.

The variety of bedforms imaged by the echosounder will provide a basis for assessment of sediment transport and the complex interplay between water movement, sediment types, and flow channel geometry. The multibeam data have been integrated with LIDAR data collected previously at the field site. This data merger was undertaken by a senior undergraduate student at CCU (Lindsay Harmon under the direction of Viso) in collaboration with Christine Hladik (UGA PhD student, Alber). The result is a continuous digital elevation model (DEM) of the Duplin River and surrounding marsh system (see Figure 5) that is gridded at 0.5, 1.0 and 2.0 m resolution in the horizontal. The DEM will also provide a basis for flow modeling of the site. This past summer, Amaury Bazerole (undergraduate,
Univ. of Toulon and the Var, France) worked under the direction of D. Di Iorio to develop a non-overlapping unstructured grid of the domain using SMS software, as a first step towards developing a 3-D hydrographic model.

**Remote sensing**
Hladik continued her work to characterize the patterns of marsh plant distribution in the salt marshes in relation to elevation. She collected over 1,500 ground control points using a real-time kinematic (RTK) GPS unit for six plant species and two non-vegetated cover classes (salt pan and intertidal mud), and then compared their elevations with elevations derived from LIDAR data. Figure 6 shows the mean error in ground elevation (LIDAR relative to RTK GPS) associated with each cover class. Preliminary analyses of a subset of these points show a significant relationship ($p<0.05$) between plant height and LIDAR error ($R^2=0.32$). The RTK GPS data on elevation were used to validate the Duplin flooding model created by F. Andrade (U. Lisbon) and J. Blanton (SKIO); the corrected DEM will also be used for the modeling efforts described above. Once this effort is complete, Hladik will be in a position to use information on vegetation coverage to correct the LIDAR and develop a corrected digital elevation model for the region. This will then be used to model potential changes in vegetation as a consequence of external forcing such as sea level rise.

**Flux tower**
We are in the process of setting up a flux tower that will be used to monitor CO₂, H₂O and heat fluxes between the intertidal marsh and the atmosphere based on eddy covariance methodology. The flux tower, along with other meteorological sensors, will be used to understand the processes that influence ecosystem-level carbon exchange between a *S. alterniflora*-dominated salt marsh and the atmosphere. The planned system is similar to that being used at other coastal LTER sites (including FCE, VCR, and PIE) and will enable us to collaborate and compare our results across the network of LTER sites. This past year we purchased the equipment necessary for this system and identified a tidal creek along the Duplin River as a potential site that is ideally suited to understand budgets of carbon, water and heat.

**Q3: What are the underlying mechanisms by which the freshwater-saltwater gradient drives ecosystem change along the longitudinal axis of an estuary?**
The data collected to answer GCE question 1 (external forcing to the domain) and question 2 (patterns within the domain) can be used to describe the longitudinal salinity gradient of the estuary over time and space, and to examine how well salinity correlates with observed patterns.
in ecosystem processes. This portion of the project is under the direction of Joye, with involvement from co-PIs Pennings, Craft, C. Meile (UGA), and Alber (UGA).

**Salt and sulfate manipulation**
To predict how future changes in salinity distributions might affect the ecosystem, it is necessary to understand the mechanisms that drive these patterns. In particular, we are interested in separating the effects of salt from those of sulfate on ecosystem processes, given that these factors are correlated across the estuarine gradient. The plan for this portion of the project is to set up a field experiment at a freshwater site along the Altamaha River about 30 km from the ocean (in the vicinity of GCE 7). The experiment will consist of four treatments in which freshwater sediments will be amended with increasing salinity (from 0 to 10) and/or sulfate (proportional increases, from 0 to 9 mM) in an orthogonal design over 12 months. In addition to the field experiment, the effect of short-term variations in substrate concentrations, ionic strength, pH, and H$_2$S on potential rates of nitrification, denitrification, methane oxidation, methanogenesis, and sulfate reduction will be evaluated in slurry experiments in the laboratory.

This past summer, C. Comerford (UGA Ph.D. student, Joye) and S. Jones (UGA REU student, Joye) built and tested several prototype systems designed to deliver salt and sulfate to marsh soil, including two types of drip irrigation and refitted piezometers. Their preliminary conclusion is that piezometers are the best option for delivering materials to specified depths, but testing is still underway.

**Additional studies**
We have conducted several other projects that address the general issue of variation along the estuary. In one project, Craft, Pennings, and Joye received leveraged funding from an EPA grant to examine how ecosystem services vary among tidal fresh, brackish, and marine marshes. An overview of the results of this collaborative project were published in Frontiers in Ecology and the Environment (Craft et al. 2009), and a more detailed manuscript describing vegetation patterns was published in Estuaries and Coasts (Wieski et al. 2010). More recently, Craft received funding from US DOE (National Institute for Climatic Change Research Program) to

![Figure 7. Sorption/desorption of inorganic N (NH$_4$-N) and P (PO$_4$-P) during five simulated tidal cycles using ambient concentrations in river water. During each simulated tidal cycle, intact soil cores were inundated to 5 cm depth for 6 hours. Means denoted by the same letter are not significantly different (p<0.05) according to the Ryan-Einot-Gabriel-Welsch Multiple Range Test. From Loomis and Craft (2010).](image)
evaluate how saltwater intrusion might affect N and P cycling in tidal forests. He measured N and P sorption in healthy tidal forests of the Ogeechee, Altamaha, and Satilla Rivers and in a tidal forest (South Newport River) that currently experiences saltwater intrusion (salinity 5 measured in March 2009). In a laboratory experiment, tidal forest soils from all 4 sites sorbed P from river water over simulated tidal cycles (Figure 7). NH4-N was also sorbed in soils from the three truly freshwater forests (34-60% of river water NH4-N), whereas soils from the South Newport River released NH4-N to overlying floodwaters. Initial release of NH4-N by South Newport River soils was >350% of ambient river water NH4-N concentration, but this declined to 36% after five sequential simulated tidal inundations. This release is attributed to the effect of salt water intrusion, which has been shown to increase sulfate reduction, organic matter mineralization, and NH4-N release in tidal freshwater marsh soils (Weston et al. 2006).

Q4: What are the underlying mechanisms by which proximity of marshes to upland habitat drives ecosystem change along lateral gradients in the intertidal zone?

The GCE project is investigating the underlying mechanisms by which proximity of marshes to upland habitat drives ecosystem change along lateral gradients in the intertidal zone. Our approach to this question involves taking advantage of marsh hammocks as natural laboratories for evaluating the influences of landscape structure and freshwater input on marsh processes. Our activities this past year included processing geological samples; collecting data from instrumented hammocks; and greenhouse studies to support our modeling efforts. This portion of the project is under the direction of Alber and C. Alexander (SkIO), with involvement from co-PIs Pennings, Joye, Burd, Meile, B. Moore (USC), and V. Thompson (OSU).

Intensive hammock research

In 2008 two hammocks were selected for detailed study: HNi1 is west of and adjacent to Blackbeard Island to the north of Sapelo Island; PCI29 is adjacent to the south end of Sapelo Island. These hammocks are of similar size, with similar vegetation zones in the high marsh. We set up transects that run from the nearby upland (Blackbeard and Sapelo Islands, respectively), through the marsh, and up and over each hammock to the marsh adjacent to the Sound (Sapelo and Doboy, respectively), and established groundwater sampling wells at each site.

Pressure, salinity, and temperature loggers were placed into selected wells at both sites to collect data at 10-minute intervals. Wells have been sampled every other month since August 2008 to determine concentrations of dissolved nutrients, ions, and gases. To date, we have found that concentrations of most chemical constituents tend to be higher in the groundwater than in surface water collected from the sites. Concentrations of dissolved organic carbon (DOC) as high as 9 mM have been observed in the groundwater, and DOC in nearby surface water is consistently hundreds of micromolar. Concentrations of dissolved inorganic nitrogen tend to be dominated by ammonium, which is not surprising since the groundwater is anoxic and sulfidic. Dissolved organic nitrogen (DON) is also an important nitrogen pool at these sites. DON accounts for a greater fraction of the total dissolved nitrogen pool at HNi1 (30-90%) than at PCI29 (20-70%). These data will be used to evaluate groundwater flow underneath the hammocks.
Stratigraphic data

Sediment cores collected from the two intensive-study hammocks were analyzed for sedimentological properties by Alexander. The cores from HNi1 generally exhibit profiles consistent with a storm sand body deposited onto back-barrier marsh by storm and/or overwash processes. A single, continuous marsh deposit, dated by AMS $^{14}$C at about 3700 and 3100 y BP at 4 m and 1 m below the marsh surface, respectively, underlies the hammock and constrains its age to less than ~3500 years old, making it of Holocene origin. The sands are normally graded and show a transition from coarse- to fine-grained sand upcore. Sedimentary structures in the cores suggest that energetic forces washed beach sand back onto the marsh, creating a shore-parallel, linear sand body that has been modified over the past few thousand years.

Contrary to our expectations, PCi29 is not of Pleistocene origin. Cores from PCi29, along with AMS $^{14}$C and OSL dating, suggest that this hammock has had a complicated history spanning multiple environments of deposition. Three $^{14}$C dates for the island (from 2.5-4 m below the ground surface) all fall within a narrow range of 2150-2250 y BP, suggesting that the island formed quickly and also dates to the Holocene. The diverse sediments and coarse grain sizes associated with the hammock suggest that it formed within an energetic environment (Figure 8).

Figure 8. Core 5 from hammock PCi29 near the south end of Sapelo Island. Panels show stratigraphic interpretation, average grain size, and percent sand, silt, and clay.
Its location adjacent to Doboy Sound would indicate that it was at the paleo-sound/inlet margin approximately 2000 years ago. This hammock also has extensive evidence for early human occupation, and carbonate concretions are common in the soil, a direct result of leaching of shell middens created on the upland by inhabitants.

In 2009 we vibracored a transect of cores on three additional hammocks (PNi12, Mary’s Hammock, and Jack Hammock) to include true Pleistocene hammocks in our detailed core analysis. PNi12 is underlain by a hard-pan (humate) deposit, which is commonly observed in the larger Pleistocene islands of the Georgia coast. In all three hammocks, a stiff Pleistocene mud is observed underlying the sandy island deposits at ~1-2 m below the surface. Thus, both Pleistocene and Holocene hammocks appear to rest upon older salt marsh, with the level of consolidation determining the substrate character. Grain size and x-radiography illustrate the differences in sedimentary processes important in the genesis of each of these features.

Theses analyses will allow us to locate former ground surfaces and understand the depositional history of the marsh surrounding the hammock as related to changes in sea level.

**Plant model**

To investigate how changes in the relative amounts of groundwater and sub-surface flow affect plant species growth and competition, Burd and Y. Jung (UGA Ph.D. student) have begun working on a model representing the growth of three grass species (*Spartina alterniflora, Juncus roemerianus, and Borrichia frutescens*). An initial salt marsh ecosystem model, based on one developed by Wiegert and Wetzel, is in the final stages of development and will provide a contextual basis for the three-species model.

In order to help parameterize the model, we are collecting data on high marsh plant communities and associated soils. As described above (Duplin River remote sensing), Hladik is providing extensive data on the elevations at which different plant species grow by combining LIDAR and RTK GPS technologies. In 2009 we collected light profiles and associated data on plant heights and densities in stands of *S. alterniflora, J. roemerianus*, and *B. frutescens*. We also collected data on soil texture, porewater content, and porewater salinity from stands of the same three plant species. Finally, we collected pre-dawn xylem pressure potential readings on all three species of plants to determine if plants are in fact rooting in the soils that we are sampling. (In theory, pre-dawn XPP readings are in equilibrium with soil water potentials.) We have also conducted two greenhouse experiments to evaluate the sensitivity of these three plants to 1) varying levels of shade (0 to 80% of light blocked) and salinity (0 to 60), and 2) varying levels of soil waterlogging, in order to help parameterize the model. Results are being analyzed, but preliminary results indicate that the three plant species differ in their responses to these abiotic factors.

**Archeological studies**

We are particularly interested in the distribution of shell deposits left by the Native American occupants, because such deposits affect soil chemistry and landform exposure, and therefore may mediate high-marsh ecosystem processes by affecting the quality and quantity of water reaching the high marsh. This past year, Thompson and J. Turck (UGA PhD student, Garrison) collected oxygen isotope and salinity data from clams and oysters from archaeological deposits. They can use these data to investigate the salinities of the organisms that past peoples were exploiting,
which might indicate how far they were traveling with catches. This will potentially aid in understanding human use of hammocks. They are currently working on a paper for the Journal of Archaeological Science.

Q5: What is the relative importance of larval transport versus the conditions of the adult environment in determining community and genetic structure across both the longitudinal and lateral gradients of the estuarine landscape?

We have documented a variety of distribution patterns of different plant and invertebrate species across the GCE domain. Some of the variation in population density is likely driven by longitudinal and lateral gradients in the estuarine environment (Questions 3 and 4). However, population density may also be affected by transport mechanisms and larval shadows that affect larval delivery, habitat suitability for adults, and competition. We are using a combination of recruitment studies, transplant studies, and genetic approaches to begin to understand these patterns. This portion of the project is led by Pennings in conjunction with Silliman, J. Wares (UGA), and D. Bishop (UGA).

Mechanisms explaining plant distributions
H. Guo (UH PhD student, Pennings) has conducted a series of transplant experiments over the past three years to explain patterns of vegetation composition, diversity, and productivity in the GCE domain. Guo transplanted three species each of salt, brackish, and freshwater marsh plants to replicate fresh, brackish, and saline sites, with and without competition. Plants were transplanted in March of each year and harvested, dried, and weighed each October after 7 months of growth. Sites were categorized into 5 regions of salinity (fresh, brackish, low salinity, medium salinity, and high salinity) based on GCE water column monitoring and porewater salinity data collected by Guo. Results from these studies indicated that the freshwater plants were excluded from saltier sites by physical stress (they died with or without neighbors), and that the intensity of competition increased at less-saline sites, excluding salt marsh species. There were hints of facilitation of some plant species by background vegetation at the saltiest sites. These results suggest that salinity and plant-plant interactions are the primary drivers of vegetation pattern along the estuarine salinity gradient.

Mechanisms explaining animal distributions
The Silliman lab continued their studies of the relative effects of habitat quality, larval transport, and predation in governing invertebrate densities across the GCE domain. This includes: 1) surveys of adult populations, 2) assessment of recruitment rates, and 3) experimental evaluation of predation. In 2009 they found a strong impact of both distance from ocean and marsh zone on densities of adult periwinkle snails and recruits of these snails and barnacles. The pattern was consistent across both species and life stages (Figures 9 and 10). Densities were highest in the barrier-island marshes followed by mid-estuary and then mainland marshes (P < 0.01, all cases). There was also a strong main effect of marsh zone (P < 0.01, all cases), but no interaction between marsh zone and distance. In the case of adult snails, density was always higher in the short Spartina zone, while the opposite pattern was true for barnacle and snail recruits.

These patterns suggest a strong recruitment shadow effect, where larval supply to marshes is highest closest to the ocean source and trails off toward the mainland. Combined with adult density surveys and tethering experiments (Figure 11) showing strong, consistent predation
across all tall *Spartina* zone sites but lower rates in the short *Spartina* zone, these data indicate that population outbreaks and high densities of marsh invertebrates occur in areas where recruitment is high enough to overcome losses due to high predation, i.e., short *Spartina* zones on barrier islands.
Figure 9. Densities of adult snails, oysters, mussels, and barnacles along a distance-from-ocean gradient (island-near; mid-estuary; and mainland-far) in both short and tall Spartina zones in 2009.

<table>
<thead>
<tr>
<th>Effect</th>
<th>df</th>
<th>F</th>
<th>P</th>
<th>F</th>
<th>P</th>
<th>F</th>
<th>P</th>
</tr>
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<td>0.70</td>
<td>0.32</td>
<td>8.5</td>
<td>0.0008</td>
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<tr>
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<td>0.48</td>
<td>0.18</td>
<td>7.6</td>
<td>0.0087</td>
</tr>
<tr>
<td>Distance x Zone</td>
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<td>0.29</td>
<td>0.85</td>
<td>0.32</td>
<td>0.45</td>
<td>0.6405</td>
</tr>
</tbody>
</table>

Figure 10. Densities of snail, oyster, mussel, and barnacle recruits along a distance-from-ocean gradient (island-near; mid-estuary; and mainland-far) in both short and tall Spartina zones in 2009.

<table>
<thead>
<tr>
<th>Effect</th>
<th>df</th>
<th>F</th>
<th>P</th>
<th>F</th>
<th>P</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0.01</td>
<td>11.17</td>
<td>0.0001</td>
<td>1.33</td>
<td>0.27</td>
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<tr>
<td>Marsh Zone</td>
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<td>0.18</td>
<td>0.01</td>
<td>0.087</td>
<td>15.92</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Distance x Zone</td>
<td>2</td>
<td>1.15</td>
<td>0.33</td>
<td>0.36</td>
<td>0.70</td>
<td>1.77</td>
<td>0.18</td>
</tr>
</tbody>
</table>

17
In addition, the Pennings lab is investigating the distribution of grasshoppers across the estuarine landscape. Marsh grasshoppers tend to be abundant at marsh sites near upland habitats, but rare at marsh sites far from uplands. A growth experiment in the summer of 2010 ruled out the possibility that this pattern was caused by variation in plant quality that affected grasshopper growth or survival. We plan to conduct future research to test additional hypotheses that could explain this distribution pattern.
Project Management

GCE administration
Day-to-day project administration is shared by Alber and Pennings, with support from the GCE Executive Committee (Hollibaugh, Joye, W. Sheldon, Burd). Project management involves submitting supplementary proposals, overseeing the core budget (including setting up subcontracts, approving purchase orders, travel, etc.), taking care of routine reporting, supervising core project personnel, and writing letters of support for collaborative projects. Pennings also continued administrative duties related to field efforts, including supervising field technicians at Sapelo Island and overseeing repair and maintenance of boats and field instruments.

We conducted our annual GCE-LTER meeting in January 2010 in Athens, GA. The meeting was attended by the following members of our scientific advisory committee: Jane Caffrey (UWF), Wim Kimmerer (SFSU), Cathy Pringle (UGA), and George Jackson (TAMU). Iris Anderson (VIMS/VCR) and Mark Hay (Georgia Tech) were unable to attend the meeting but continue to serve on the committee.

LTER network activities
As detailed below, GCE scientists are actively collaborating on cross-site comparisons and are involved in network planning and governance.

- Pennings completed a 3-year term on the LTER network Executive Board in May 2010.
- Alber and Pennings attended the LTER Science Council Meeting at PIE in May 2010.
- Alber has been involved in a broad effort to evaluate the effects of climate change on coastal systems. Alber and C. Hopkinson (UGA) helped to run a workshop on coastal climate effects at the All Scientists Meeting in September 2009 and then worked with Colin Polsky (PIE), Evelyn Gaiser (FCE), and Kirstin Dow (BES) to convene a working group on coastal vulnerability to sea level. The group met in Athens, GA in February 2010.
- Craft organized an LNO-sponsored workshop on Tidal Marsh Accretion Modeling on Sapelo Island in July 2010. The group is currently writing a proposal as a direct result of the meeting.
- Pennings received the “Merit Award” for excellence in research from the Society of Wetland Scientists at their annual meeting in Utah. The award recognized Pennings’ work on latitudinal gradients in species interactions, a research program that seeks to determine how results from the GCE extrapolate to other coastal sites at different latitudes.
- The GCE is participating in the “Maps and Locals” initiative that grew out of the Social-Ecological Systems (SES) cross-site workshop in Puerto Rico in December 2008. A meeting is planned for October 2010 in Fairbanks, AL.
- Craft collaborated with R. Jaffe and M. Zwilling (FCE) to collect samples to characterize DOC along the salinity gradient of the Altamaha River.
We also have a strong network presence in terms of information management, through the activities of W. Sheldon and J. Carpenter (UGA). Over the past year GCE IM staff served the network in the following capacities:

- Sheldon co-authored a prospectus regarding opportunities for improving LTER data management systems and making legacy LTER network data available to NEON and other observatories. The report has been submitted to NSF for consideration.
- Sheldon served as co-chair of the LTER Network Information System Advisory Committee, which is developing a cyber-infrastructure implementation plan for the LTER network.
- Sheldon participated in an NSF-funded DataONE workshop to define best practices and curricula for a national Ecological Informatics training program. This workshop produced over 50 best practice recommendations and curricula for 4 major informatics courses, which are being vetted and organized into a database for dissemination.
- Sheldon led the NISAC review of the LNO Operational Plan for supplementary ARRA funding, and met with LTER Executive Committee members, LNO, and external advisors to revise the plan in January 2010.
- GCE continues to host the USGS Data Harvesting Service for HydroDB (see http://gce-lter.marsci.uga.edu/public/im/tools/usgs_harvester.htm). Data from 57 USGS stream flow gauging stations are automatically harvested on a weekly basis for 11 LTER sites (AND, BES, CWT, FCE, GCE, KBS, KNZ, LUQ, NTL, PIE, SBC) and one USFS site.
- We are working closely with the IM program at CWT, providing GCE bibliography and metadata databases and helping to modify them for CWT use; providing web application hosting to leverage GCE-developed web applications and web services for their new web site; and providing near-real-time USGS streamflow data harvesting, including automated plots and metadata generation for 5 stations.
- Sheldon is participating in a web services working group to define standards and best practices for deploying this technology in LTER. This group is assisting LNO with redesigning core support databases to improve functionality and add web service interfaces to streamline use.
- Carpenter served as a lead developer of a cross-site, web-based mapping application for the LTER GIS working group; coordinated collection of GIS data describing research areas for all 26 LTER sites; and attended a project workshop at LNO.
Information Management

Overview
Information Management at the GCE site is led by W. Sheldon; J. Carpenter assisted Sheldon and served as our GIS specialist until June 2010, but left the project and was replaced by T. Douce (UGA) in July 2010. A major focus of Information Management effort during the past year has been completing updates to the GCE information system to support comprehensive management of research project information linked to over-arching research questions, personnel, LTER core areas, and research products (data, publications, reports, imagery). We also developed new web services to provide programmatic access to personnel, data catalog, research project, and geographic information stored in GCE databases. We are currently collaborating with information managers at 3 other LTER sites (CWT, MCR, SBC) to develop an enhanced database model for managing data set metadata (based on the current GCE_Metabase), and we have assisted the CWT-LTER site with adopting the GCE bibliographic, geographic, and metadata databases and MATLAB data processing toolbox. In addition, we have continued to participate in several LTER working group initiatives to improve standardization of data search and access across LTER sites through adoption of controlled vocabularies and common web services.

IT infrastructure
We currently operate three production servers to support GCE research and operations, including a general database server, a web application server, and an enterprise geodatabase server. We also operate an additional server to support GCE software development and provide web-based access to software source code and XML data. All servers are equipped with RAID-5 hard drive configurations and uninterruptible power supplies to provide fault tolerance; utilize secure transport protocols for off-site access; and are backed up daily to disk and weekly to tape to protect against data loss. We currently have approximately 5 TB of secure disk storage available for GCE use at UGA, in addition to an LTO-3 tape backup system and 2 TB of hard disk storage on Sapelo Island.

We also manage five high performance workstations to support core GCE information management activities as well as several field computers. We provide database client software and ArcGIS software and licenses to GCE investigators, staff, students, and affiliates in the Dept. of Marine Sciences at UGA and the UGA Marine Institute on Sapelo Island to support working with data in relational and GIS databases and general GIS analyses.

Spatial data management and GIS
The primary focus of spatial data management activities during 2009 was developing an interactive Internet mapping application to enable users to search for GCE data geographically (http://gce-lter.marsci.uga.edu/public/gis/gcewebmap.html), and work has continued in 2010 to enhance this resource (Figure 12).

We chose the Google Maps™ Application Programming Interface (API) to develop this web application based on performance, seamless satellite imagery, lack of cost, familiarity to the public, and large developer community. We currently provide access to several GCE spatial datasets through this application. We also continue to maintain a comprehensive collection of
reference GIS data (e.g. aerial and satellite imagery, elevation, land use/land cover) and GCE spatial research data in two ArcSDE geodatabases. A 1 m² elevation dataset of the Duplin River is now available in .grid and .img formats for compatibility with several common GIS software packages.

Two additional production geodatabases were also added in 2009-2010 for managing and correcting GPS data from GCE field research projects and for storing newly-acquired LIDAR data. We also used an OCE equipment supplement in 2009 to purchase a Trimble® Real Time Kinematic (RTK) Global Positioning System (GPS) to collect geographic data at sub-centimeter vertical and horizontal accuracy. This level of positional accuracy is required to characterize the extremely subtle topography of coastal marshes and to perform QA/QC for LIDAR data. During 2010 we used this RTK GPS system to acquire precise elevation data for moored sondes (continuous temperature, conductivity, pressure loggers), groundwater wells, and permanent plant monitoring plots to support research on groundwater dynamics and effects of sea-level change in the GCE domain.

We continue to provide mapping and geo-analytical support for all GCE projects, maintain the ArcSDE server, edit content for GIS-based web pages, manage spatial data for GCE personnel.
use, post-process all GPS data, and create reference maps of study sites for GCE publications and presentations. Metadata for all GIS datasets are created regularly and updated when new information becomes available. GIS data from the Hammock study is currently being processed for inclusion in the GCE Data Catalog and LNO Data Catalog (Metacat). General GIS files are distributed in various formats through the GCE file archive (http://gce-lter.marsci.uga.edu/public/app/resource_search.asp).

**Website development**

This year we designed comprehensive new web pages describing the GCE research program (http://gce-lter.marsci.uga.edu/public/research/research.htm). W. Sheldon, working in collaboration with other LTER information managers in 2009, developed an XML schema and web-based application for managing research project information, including descriptions of each over-arching research question and our approach, with links to information about each component project and associated products (data, publications, and reports). He also developed a relational database, database interface forms, and web services to generate the XML documents for GCE projects. We have now finished populating the database with information from completed and ongoing research projects and provide a dynamic project list and interactive search form on the GCE web site, with links to associated GCE research questions, personnel, data, and publications (http://gce-lter.marsci.uga.edu/public/research/projects.asp). In addition to

![Image of a website page with a search form and links to project information.](image)

**Figure 13.** GCE study site description page, which includes an embedded Google Map and link to Google Earth KML file, both based on new GCE mapping web services.
providing more detailed information about GCE research, this addition to our web site provides a powerful new way to discover and access data and information resulting from our work that will support cross-site searches for related LTER research.

We also developed a series of new REST web services to provide programmatic access to information stored in GCE databases (site condition information, personnel, datasets, research projects, geographic information). For example, web services are available for retrieving tide predictions across the GCE domain, geographic information for GCE study sites and point locations (as Google Earth KML), personnel directory information, and data sets. These web services support various functionalities on the GCE web site (e.g. study site map, Figure 13) and

<table>
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<th>Table 1. GCE data downloads summarized annually by data set theme and by user affiliation.</th>
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<td><strong>Theme</strong></td>
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<td>--------------------------------</td>
</tr>
<tr>
<td>Various (custom file)</td>
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<td>Terrestrial Insect Ecology</td>
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<tr>
<td>Real-time Climate</td>
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<tr>
<td>Pore-water Chemistry</td>
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<td>Plant Ecology</td>
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<tr>
<td>Phytoplankton Productivity</td>
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<td>Physical Oceanography</td>
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<tr>
<td>Organic Matter/Decomposition</td>
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<td>Multi-Disciplinary Study</td>
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<td>479</td>
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<td>364</td>
<td>238</td>
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</table>
also provide a means of retrieving structured information about the GCE project for inclusion in LTER network databases or content aggregators. We are also currently collaborating with LTER Network Information System developers and other LTER information managers to define standards and best practices for deploying web services in the LTER network.

Web site and data access statistics
Public downloads of GCE data sets from Fall 2001 to Fall 2010 are summarized in Table 1. Since January 2001, nearly 1.6 million GCE web pages have been viewed by more than 460,000 visitors from 227 distinct countries and territories (based on web log analysis and DNS resolution). Over 5000 visitors viewed 15-35,000 web pages each month (excluding malicious requests and hits from web indexing spiders). Following the home page, the file archive, species list, personnel directory, bibliography, and EML metadata pages were the most popular pages requested in 2009-2010, respectively. Table 1 shows website activity broken down by data set theme and user affiliation. Downloads by GCE participants are not currently tracked, due to open data access policies within the project. We observed a substantial drop in data requests through external metadata catalogs, such as the LNO Metacat server, after 2008. This was primarily due to the ending of the SEEK project and reduction in use of GCE and other EML-described data to develop, test, and demonstrate the Kepler workflow software. There was a concurrent drop in data access by the LNO.

Software development
We have continued to enhance the GCE Data Toolbox for MATLAB software and offer this toolbox for public download on our web site (http://gce-lter.marsci.uga.edu/public/im/tools/data_toolbox.htm) and on the LTER Information Management web site (http://intranet.lternet.edu/im/project/gce_toolbox). In 2010 we established a dedicated software development web site for this toolbox (https://gce-svn.marsci.uga.edu/trac/GCE_Toolbox) to provide web-based SVN access, project tracking, support tickets, and a Wiki for producing documentation. Nearly 3000 web visitors have registered and downloaded this software to date, and in September 2010 this software will be re-factored and released under an open source license to promote broader re-use across the LTER network and scientific community.

The GCE Data Toolbox software can now be used to mine data from the NOAA National Climatic Data Center directly over the Internet, in addition to data from the USGS National Water Information System, LTER ClimDB/HydroDB, and NOAA Hydro-meteorological Automated Data System, then resample and integrate data to produce derived data products with structured metadata. This software is therefore useful for a broad range of data synthesis tasks beyond primary data processing. The GCE Data Toolbox has been adopted by the CWT-LTER project for processing data from their new synoptic monitoring program. Other LTER sites (e.g. SEV, SBC, PIE) have also expressed interest in using this software for managing sensor data.

Support for LTER network science and synthesis
We fully participate in all LTER Network Information System modules, including the all-site bibliography, Data Catalog (Metacat), personnel directory, and SiteDB, as well as new initiatives such as ProjectDB (for archiving information about LTER research projects) and EcoTrends. The GCE Information System natively supports all LTER standards and protocols, and we have
implemented automatic harvesting and synchronization where supported by the LTER Network Office (e.g. EML metadata and bibliographic information). We have contributed all available data from 3 long-term climate stations and 1 streamflow station to ClimDB/HydroDB. Additionally, we used GCE data processing technology to develop an automated USGS data harvesting service, allowing 11 LTER sites and 1 USFS site to contribute streamflow data to HydroDB on a weekly basis without additional effort (http://gce-lter.marsci.uga.edu/public/im/tools/usgs_harvester.htm).

In 2009 we helped LNO develop and test a centralized data access server (DAS) architecture to provide authenticated and logged access to LTER data in compliance with the agreed-upon network data access policy. All GCE EML documents stored in the LTER Data Catalog now include DAS data distribution URLs to support this new endeavor. We also support the XML-based EML 2 metadata standard adopted by LTER in all GCE databases, allowing us to dynamically generate EML 2.1.0 for all data sets in our catalog, as well as species lists, personnel entries, and bibliographic citations. Our EML implementation is among the most comprehensive in LTER, supporting metadata-mediated data access and integration (Level 5 in the EML Best Practices guidelines, a document created by a working group chaired by W. Sheldon). We also helped define and prototype standards for harvesting EML for inclusion in the KNB Metacat repository and the NBII Metadata Clearinghouse, greatly increasing the exposure of GCE data (and the LTER Network) to potential data users in the scientific community.

This past year, W. Sheldon participated in a working group to develop a community standard for documenting research projects and managing research project information in a shared database, and the new GCE research projects database and web pages were developed using this new candidate standard. Consequently, query and display templates and web services developed for GCE can now be used by any other LTER site that adopts this technology. Similarly, J. Carpenter developed interactive web maps (based on Google Maps API) in collaboration with an LTER GIS working group to provide access to LTER site information and data. This application is being finalized for hosting on the LTER network web site, and individual map pages can be shared with any interested LTER site to provide similar capabilities on their web site.

Finally, we are collaborating with information managers from CWT, SBC, MCR, and other sites to revise the GCE metadata database model (GCE_Metabase) to support multi-table data sets, GIS data, and LTER controlled keyword and attribute name vocabularies that are under development. CWT has already implemented the current GCE_Metabase as well as the GCE bibliographic database (GCE_Biblio), and we are providing web application hosting and web services to support web-based access to their database instances. SBC, MRC, and several other LTER sites are interested in using the GCE_Metabase as a starting point for a network-wide metadata model, and we are fully supporting that effort as well.
GCE Bibliography – Project Year 10

Journal Articles


Books and Book Sections


Theses and Dissertations


Conference Posters and Presentations

Alber, M. 2009. Presentation: Overview Coastal Georgia Colloquium. , Savannah, Georgia.


Marczak, L. Presentation: Top-down control dominates latitudinal variation in bottom-up forces on a herbivore community. Organized Oral Session, “Latitudinal gradients in consumer-
resource interactions: bridging the gap between pattern and process". 2010 annual meeting of the Ecological Society of America, August 1-6, 2010, Pittsburgh, PA.


Reports