Project Management

Project Administration

James Hollibaugh, Dept. of Marine Sciences, UGA; Steven C. Pennings, Univ. of Houston

Administrative responsibilities have included organizing the GCE annual meeting, participating in LTER network coordinating committee meetings, including the All Scientists meeting, and dealing with accounting, reporting and supplementary and continuation funding paperwork. A major administrative duty this past year was preparing for and hosting the NSF mid-term site review, then responding to the report of the review committee. Science oversight involves coordinating the efforts of scientists in different aspects of the study, and negotiating agreements with different agencies to supplement monitoring efforts. Although he is now at the University of Houston, Dr. Steven Pennings continues to be involved deeply in the field program and to function as the field coordinator. This arrangement has been in place for approximately 16 months and appears to be working smoothly. Dr. Pennings work was funded through the University of Georgia Marine Institute prior to his relocation, but we have set up a subcontract directly with the University of Houston for his future funding, beginning with this year. Our third year of Schoolyard LTER support provided an opportunity for teachers to participate in field research at the GCE-LTER site during the summer of 2003. Immediate supervision of the Schoolyard LTER is currently being provided by J.T. Hollibaugh, with the actual teacher training effort lead by Ms Trisha Hembree. Ms Hembree has been successful in augmenting the Schoolyard funds with a grant from the Eisenhower Foundation.

Web Site, Database, and Information Management Activities

Wade Sheldon, Dept. of Marine Sciences, UGA

Overview

Information management activities this year were largely focused on strengthening existing ties between project databases, data processing technology and GCE web sites, improving access to near-real-time and historic monitoring data relevant to the GCE domain, and adding support for newly-adopted LTER metadata standards to our integrated information system. We also improved our information technology
infrastructure this year by acquiring an automated DLT tape backup system and an additional IM workstation to support new data harvesting applications described below.

Near-real-time Climate and Hydrographic Data

The primary GCE climate station at Marsh Landing on Sapelo Island was brought into full compliance with LTER Level 2 climate monitoring standards this year. Various technical issues were finally resolved and the LiCor pyranometer sensor installed on the station in 2002 was brought online in December 2003 to collect total solar radiation data. All required parameters are now being measured at 15-minute intervals, and daily summary data are contributed to ClimDB (the LTER all-site climate database) on a semi-monthly to monthly basis as described below.

The automated near-real-time data harvesting system, developed in November 2002 with supplemental NSF funding for ClimDB/HydroDB participants, was also significantly enhanced this year. Data is now collected every 12 hours from the Marsh Landing climate station, and every 1 hour from the USGS meteorological and hydrographic station at Meridian Landing on the mainland and from the USGS gauging station on the Altamaha River near Doctortown, Georgia. Data are automatically standardized to GMT time and metric units, documented and subjected to multiple quality-control checks, then are uploaded in various standard file formats to the GCE web server to provide immediate access to project participants. Web pages and graphics are also automatically generated after each data harvest, allowing users to view pages containing thumbnail images of all parameters plotted by week or month, linked to full-size presentation-quality plots. This automated data acquisition, processing, and plotting provides GCE participants with up-to-date information on recent site conditions and high quality data sets optimized for synthesis with other project data on a continual basis.

At the end of each month, the Information Manager reviews all recently harvested data and quality control flags and documentation are finalized. Following this review, data from each station are added to the GCE long-term monitoring database and also automatically formatted and submitted to ClimDB to provide immediate public access. Work is also underway to develop a page describing recent site conditions on the public GCE WWW site -- this page will provide an integrated overview of emerging patterns in climate and hydrographic data as they develop across the GCE domain.

GCE data harvesting technology was also made available to the larger LTER community this year, through the development of the USGS Data Harvesting Service for HydroDB (see http://gce-lter.marsci.uga.edu/lter/research/tools/usgs_harvester.htm). As of January 2004, data from 43 USGS streamflow gauging stations are being harvested on a weekly basis for nine LTER sites (AND, FCE, GCE, KBS, KNZ, LUQ, NTL, PIE, SBC) and one USFS site. Recent provisional and finalized data are automatically acquired, standardized, quality-checked, formatted, and uploaded to HydroDB. This service provides the LTER community with the best available stream flow and precipitation data for synthetic research at no cost to individual site research programs.

Software Development

We have continued to improve the GCE Data Toolbox for MATLAB software this year and offer a compiled version of this toolbox for public download on our web site.
(see http://gce-lter.marsci.uga.edu/lter/research/tools/data_toolbox.htm). Significant new features include: standard import filters for NCDC climate data and USGS data, on-demand harvesting of USGS data from any real-time station via the Internet, and interactive importing and filtering of data from non-standard text files. Over 600 individuals have downloaded the toolbox over the past year, including Information Managers from several other LTER sites. In particular, the NTL LTER site is exploring the adoption of quality control and plotting routines in this toolbox for their new real-time buoy data acquisition system.

In addition to providing stand-alone versions of MATLAB software, we have also begun to develop web-based implementations of these tools using the MATLAB Web Server. For example, MATLAB-based applications on the private GCE web site allow GCE participants to customize data sets prior to downloading (i.e. data file format, metadata detail and format, quality-control flag handling) and generate statistical summary reports. Interactive web applications for data transformation and plotting are also in development.

**Support for EML Metadata**

The Ecological Metadata Language 2.0.0 specification, an XML-based metadata standard developed for the ecological community, was finalized in December 2002 and in Spring 2003 the LTER Coordinating Committee voted to accept the IM Committee recommendation and recognize EML 2.0 as the official metadata standard for the LTER Network and Network Information System.

Modifications to the integrated GCE information system were completed in November 2003, and EML metadata is now available for all data sets in the GCE Data Catalog (http://gce-lter.marsci.uga.edu/lter/asp/db/data_catalog.asp). Dynamically generated EML documents and corresponding data files are offered as an alternative to formatted text metadata and standard text and MATLAB distribution files on the detail page for each data set. Support was also added for directly accessing data via EML documents hosted in external metadata servers, while logging data access locally for reporting purposes. This system will support grid-based computing initiatives being proposed by the LTER Network Information System Advisory Group without compromising site control over data and metadata content, version control and accessibility.

EML metadata documents, fully conforming to EML schema version 2.0.0, are available for each data set at two levels of detail. *Basic EML Metadata* contains general data set information, including geographic, temporal and taxonomic coverage, and is optimized for data set discovery in general-purpose metadata catalogs. *Complete EML Metadata* contains all discovery information plus complete details about the processing, structure and distribution of the data table, optimized for automated access and analysis of GCE data sets.

The GCE EML implementation is currently the most comprehensive in the LTER network, completely supporting the top “tier” of functionality identified for Network Information System development (i.e. metadata-mediated data set integration). Work is underway at the LTER Network Office and NCEAS to incorporate GCE EML in centralized Metacat servers on an ongoing basis to support cross-site LTER data searches and synchronization with federal metadata repositories.
Data Catalog Additions

Data submissions from both monitoring and directed study programs continued to increase this year, with 122 data sets added to the catalog since January 2003. An additional 16 data sets have also been submitted and 8 annual data sets from our continuous salinity and temperature-monitoring network are currently being finalized. These additions will bring the total number of accessioned GCE data sets to 204. Public data download statistics are provided below.

Web Site Additions

A semi-private web site, the GCE Data Portal, was established in April 2003 to provide convenient access to information and relevant data from GCE monitoring partners and public agencies (UGAMI, SINERR, USGS, NWS, NOAA). Data are harvested or regularly acquired and then processed using GCE technology to produce standardized metadata, data products, and plots optimized for inter-comparison with GCE project monitoring data. Examples of processing steps include renaming columns, unit inter-conversion, date/time conversion to GMT, addition of calculated date/time columns, geographic coordinate re-projection, additional QA/QC flagging to indicate questionable or invalid values, and generation of metadata (documentation) based on templates developed for each data source. In addition to GCE participants and the monitoring partners themselves, access is regularly granted to academic researchers, students, and Schoolyard LTER participants to augment data available on the public GCE web site.

A project calendar web application was also developed this year to promote communication within the project; all GCE participants can add events to the calendar, and event details are stored in a relational database to support dynamic calendar generation and searching. A general file upload application was added to the private web site to simplify the submission of data and documents to the GCE IM office, and a separate file upload application was created to allow authorized investigators to contribute files and photographs for immediate inclusion in the online taxonomic database.

Several enhancements were also made to the GCE Data Catalog web application, including automatic display of cross-referenced data sets, referenced species records (i.e. linked to the taxonomic database), and publications (i.e. linked to the bibliographic database). As mentioned above, additional options to display metadata in EML format and download data sets in user-customized MATLAB and text formats were also added this year.
Web Site and Data Access Statistics

GCE public web site statistics for Year 4 (filtered to remove invalid requests and web indexing spiders) are listed to the left. This represents a two-fold increase in web visitors compared to the same time period in 2002 (26,069 visitors). Although most page requests originated in the U.S. (75.8%), requests were logged from 139 distinct countries and territories overall (based on Internet domain analysis).

The software tools, data catalog, and taxonomic database web pages were the most frequently requested. Web activity peaked at nearly 6000 visitors in October following the LTER All-Scientists meeting, presumably in response to numerous presentations given by GCE participants.

Public downloads of GCE data sets in Year 4 are listed below. Note that many data sets from Year 2 and Year 3 efforts were not publicly accessible due to data release restrictions, and that downloads by GCE participants are not included. Educators and academic researchers accounted for the majority of data requests.

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Public downloads of GCE data sets in Year 4 are listed below. Note that many data sets from Year 2 and Year 3 efforts were not publicly accessible due to data release restrictions, and that downloads by GCE participants are not included. Educators and academic researchers accounted for the majority of data requests.

<table>
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<th>Downloads</th>
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### Public downloads of the GCE Data Toolbox for MATLAB (software for metadata-driven data analysis and display of ecological data, including all GCE data sets) during year 4 are listed to the left.

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<th>Downloads</th>
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### Annual Meeting

We conducted our fourth GCE-LTER annual meeting in January, 2004, in Athens Georgia. We presented and discussed our results to date and solicited feedback from our scientific advisory committee: Iris Anderson (VIMS/VCR), Jack Gallagher (U. Del), Chuck Hopkinson (MBL/PIE), George Jackson (TAMU), Jane Caffrey (UWF) and Wim Kimmerer (SFSU). A major focus of this meeting was to begin planning our renewal proposal.

### Environmental Forcing Functions

#### Sound and River Dynamics

Daniela Di Iorio, Dept. of Marine Sciences, UGA; Jack Blanton, Skidaway Institute Of Oceanography

**Quarterly monitoring of CTD**

In spring 2003 when Altamaha River transport was high (1800m$^3$s$^{-1}$), transects of conductivity-temperature-depth and optical backscatter were made together with surface and bottom water samples filtered for total suspended sediments. The optical sensor was calibrated and during this survey a maximum suspended sediment
concentration (~30mg/l) always appeared at the head of salt (or tide) which is indicative of an estuarine turbidity maximum (ETM). During low water the ETM is at the head of salt at kilometer 0, and there is also enhanced suspended sediment concentrations at Altamaha kilometer 6 (AL+06). At high water the ETM is clearly located at AL+06, which also corresponds to the head of tide (salt). Thus it appears that the region surrounding AL+06 is characterized as an entrapment zone as a result of convergence, or by the existence of an estuarine turbidity maximum. This seems to suggest that this area entraps particles, retains zooplankton and promotes the recruitment of fish. Independent measurements of fish density along the Altamaha River using hydroacoustic surveying do in fact show that fish concentrations are greatest at AL+06. The physical processes that result in a convergence at this location are not clear. During other seasonal sampling times, the relative optical backscatter and fish densities were also enhanced at AL+06, regardless of the freshwater discharge. These results are consistent with the one-dimensional optimum boundary box model developed by Sheldon and Alber (2003), which is used to simulate movement of dissolved pollutants or other conservative constituents through the Altamaha River Estuary.

Directed studies of turbulence and external forcing

A field experiment was carried out from Mar 25-Apr 3, 2003, a period that corresponded to a time of significant freshwater discharge. This data set provides a great opportunity for comparison with previous data sets when the freshwater discharge was much lower. The flow regime was strongly ebb-dominated with a net out flow of 18 cm/s. This high flow resulted in strongly sheared and strongly stratified conditions during ebb tide with corresponding high levels of turbulent kinetic energy, and hence high kinetic energy dissipation and production rates compared to the flood phase. Moored instrumentation consisted of deployments on the northern and southern side of Altamaha Sound as well as a mooring at 10 m depth on the shelf (outside the Altamaha ebb shoaling region). Measurements showed a 3 cm difference in sea surface heights between the northern and southern banks. During the flood (ebb) tide, the flow was concentrated on the northern (southern) side with greater sea surface height. This has implications for strong secondary circulations (cross channel flows).

A steady state spectral wave model (STWAVE) developed my McKee, Sherlock and Resio was acquired for modeling wave propagation into Altamaha Sound. Model results confirm our observations that during low water there is very little wave activity and that during flood tide the wave radiation stress is increased. Model and data comparisons were also made with wave-current interactions and results show that the ebb shoaling is the dominant mechanism that reduces the wave radiation stress into the estuary rather than the current velocities. This ebb/flood asymmetry has implications for marsh flooding processes, particularly if combined with wind forcing, because wave propagation contributes to mass transport. Data processing and analysis continues for previous data sets collected. Extensive roving ADCP data has been acquired for Altamaha and Doboy sounds and the data has been cleaned and binned into a horizontal and vertical mesh grid. We are now in the process of looking at spatial variations in turbulence and flow characteristics.
All of this data processing is being carried out by Mr. KiRyong Kang (a PhD graduate student) funded by the LTER project. He completed his oral exams on Sept 5, 2003 and has successfully been admitted to candidacy.

Sea level fluctuations induced by winds on the continental shelf

Lee Couey, an REU student from Georgia Institute of Technology, examined the effect of wind velocity on residual water levels in the Altamaha and Sapelo estuaries. The data were obtained from the GCE-LTER monitoring network. Cross-correlation analyses were performed using the network's low-passed sub-surface pressure data together with low-passed wind velocities from the Grays Reef buoy, located offshore of the GCE-LTER site. Alongshore winds were found to correlate 10 to 30 percent higher than cross-shore winds. Residual water levels at stations closest to the ocean produced higher rates of correlation for long-shore winds when lagging water level 12 to 15 hours. Stations located upriver showed higher rates of correlation than stations closest to the ocean for long-shore winds when lagging water level 12 to 21 hours. The study indicates that wind stress causes water levels to rise as much as 60 centimeters and fall as much as 55 centimeters in a span of one to two days. When these "subtidal" fluctuations occur at spring tide, intertidal areas are subjected to larger than normal periods of inundation and drying.

XXX

Residence times in the Altamaha River Estuary

Merryl Alber and Joan Sheldon, Dept. of Marine Sciences, University of Georgia

We continue to improve our SqueezeBox program, which can construct 1-D models of the Altamaha River estuary for different river inflow rates. Enhancements this year have included 1) expanding the types of mixing time scales the model can calculate, to include average residence time from any point in the estuary, 2) improving routines for saving model run data, 3) improving both tables and charts that display model run data, and 4) improving internal data handling for more realistic model behavior at boundary conditions (very high flow, low flow) and in preparation for new features to be added.

On a simpler level, estimates of flushing times are important for interpreting observations of water quality, phytoplankton dynamics, etc. All that is required to determine the flushing time is information on freshwater inflow and salinity from the time of the observation. Our goal is to use near-real-time information on freshwater inflow (from the USGS gage at Doctortown) and salinity (from the YSI monitor at the Sapelo Island National Estuarine Research Reserve) so that flushing times can be estimated in an automated fashion using our date-specific method (Alber and Sheldon 1999). We have done some preliminary correlations between the SINERR gage and the Altamaha sondes, and they are reliable enough to proceed with this project when the YSI goes online. Our plan is to work with Wade Sheldon on this project so that flushing times will be available on the GCE web site for very recent conditions.

We are also expanding our flushing time work beyond the Altamaha River estuary. J. Sheldon gave a theoretical talk at the 2003 Estuarine Research Federation meeting in Seattle on estuarine turnover times, and demonstrated that turnover times
calculated using “fraction of freshwater” models are equivalent to those using tidal prism models. Although the two methods are appropriate for different circumstances, this insight means that turnover times calculated by these two methods can be compared. This work has been written up for publication. Finally, M. Alber and J. Sheldon are collaborating with a team led by R.W. Howarth at Cornell to develop a classification scheme for the comparative analysis of the sensitivity of coastal ecosystems to nutrient inputs. This involves estimating flushing times for various U.S. estuaries with a consistent methodology and using that information as input for a simple model that could assist managers in evaluating how particular coastal marine ecosystems or sets of ecosystems respond to the interacting stressors of nutrient loading, sediment loading, and hydrologic variability.

**Circulation and biogeochemical fluxes in the Duplin River**

**Jack Blanton, Skidaway Institute of Oceanography; Daniela Di Iorio, Dept. of Marine Sciences, UGA**

Seven GCE-LTER PIs participated in a directed study of the exchange processes between a large tidal creek and its adjacent intertidal areas – DUPLEX I. The study focused on the time period of 12-21 August 2003 - a time when metabolic activity in the study area was at its annual maximum. High-resolution sampling of geochemical variables was undertaken to see if changes can be detected between water that goes onto the marsh and that which comes off. Attention focused on sampling small peripheral creeks which drain the marsh and on measuring spatial changes of tidal currents and other properties. Part of the study was designed to place the detailed work in the Duplin into a larger context by measuring and comparing metabolic rates in the marsh-estuarine-shelf continuum. This work included measurements of the amount of inorganic carbon generated as well as the rate of carbon export. Data analyses, taking place during 2004, will be looking for non-conservative behavior of nutrients along the Duplin using field data described below.

The following components made up the study:

- Tidal asymmetry - hydrodynamic model validation (Blanton/Di Iorio)
- Lateral structure of along-channel flow (Di Iorio/Blanton)
- Salt flux estimates (Di Iorio)
- Exchange between marsh and creek, nitrification rates (Joye/Ruppel)
- Suspended particulate matter, PC/PN/PP, chlorophyll (Joye)
- Water column nitrification, respiration, production (Hollibaugh/Cai/Joye)
- Benthic fluxes and primary production (Joye)
- DIC and pCO studies (Cai)
- Distribution of DIC on the continental shelf (Cai)
- Pore water/Groundwater (Joye)
- Processes affecting recruitment of blue crab larvae (Bishop)

Long-term moorings (Fig. 1) were in place for more than a month to place the data from the various components into perspective. Each mooring contained
instruments to measure vertical profiles of currents, near-bottom measurements of water pressure (depth), salinity and temperature.

The data at these fixed locations were complimented by axial and lateral surveys of the tidal river from a fast, instrumented boat conducted at spring and neap tide. The circulation data will be an important component in furthering the development and validation of a numerical hydrodynamic model of the Duplin River, now under development at the Federal University of Rio Grande, Brazil.

Figure 1: Map of Duplin River study area showing locations of in situ measurements of currents, temperature, salinity, bottom pressure and water-column sampling. See Figure 2 for station locations in the upper Duplin.

Piezometers with temperature sensors were deployed throughout the intertidal area - mostly in the upper end of the Duplin River (Fig. 2). Samples were taken at depths of +10 cm, -50 cm, -100 cm and -200 cm (negative values denote distance below the sediment surface). The temperature data were used to track groundwater, which is expected to be colder than surface water during August. Water samples were collected from the piezometers at different times during the tidal cycle.

Surveys for pCO2, DO and water column parameters were conducted at high water (HW) and low water (LW) along the Duplin (Fig. 2). Suspended particulate matter, PC/PN/PP, chlorophyll, DIC and alkalinity were also measured. Surface samples were taken at all seven stations while bottom samples were taken at Stations 1,2,3 and 4.

GCE graduate student B. Giri (J.T. Hollibaugh) examined ammonia oxidation rates in water samples. A gradient was identified along the Duplin that reversed between high and low tide.
Groundwater hydrology
Carolyn Ruppel, Georgia Tech

Research activities
In Year 4, we installed new monitoring wells at GCE3 to better define submarsh freshwater flow from the upland, and conducted new geophysical surveys at sites GCE6 (Dean’s Creek) and GCE3. We conducted new water level monitoring experiments with long-term transducer installations at GCE3 and Moses Hammock (GCE10); completed sediment logging using formalized analysis procedures on continuous sediment cores collected at many GCE sites during the past 3 years; acquired numerous samples for C-14 dating of sedimentary accretion processes; built a variable density flow model of submarsh flow at GCE3; completed a manuscript and the post-review revisions on a paper linking groundwater chemistry and microbial processes at GCE10; received reviews on 2 research papers submitted in spring 2003; made presentations at several major meetings; worked on time series analysis of long-term climate records maintained by the GCE database; and participated in a proposal that, if successful, would have funded comparative research between GCE groundwaters and those obtained from wells in the Okatee watershed and piezometers at Baruch Institute. Although we could not actively participate in the summer 2003 Duplex I experiment due to oceangoing cruises, pressure transducers were in place in monitoring wells adjacent to the Duplin River during part of the experiment.

Coastal groundwater flux
During the first few years of the GCE-LTER project, the emphasis of the groundwater program has gradually shifted from the upland-estuary interface to the complete upland-marsh-estuary system. The integration of marsh hydrology into the groundwater studies...
has led to a better understanding of the role of groundwater-surface water interactions in coastal groundwater flux and contributions to the rapidly growing subdiscipline of saltmarsh hydrodynamics.

Site GCE3 has emerged as the key focus of groundwater-surface water exchange studies designed to serve the eventual goal of quantifying groundwater flow into the marsh-estuary system. Building on previous geophysical, geochemical, and hydrologic research at two groundwater monitoring well transects stretching from upland to the tidal creek at this site, we have expanded our studies of submarsh freshwater flow using a range of overlapping techniques and surveys. Two new monitoring wells installed at strategic locations along one of the extant upland-to-tidal creek well transects have provided better spatial control on the outflow of freshwater from the upland to the submarsh. Logs of continuous sediment cores obtained at the locations of the new wells show that the more saline of the 2 new wells is sited in a thick, monotonous clay unit. In contrast, the screened interval of the fresher well intersects a porous sand layer capped by thick, low permeability clay. These observations, coupled with permeability constraints derived from new aquifer (slug) tests and spectral analyses of new water level monitoring data, lead us to conclude that permeability contrasts exercise the primary control on flow and transport processes associated with the interaction of fresh groundwater originating in the upland and saline surface water delivered by tidal inundation and saline groundwater introduced from the tidal creek.

A new variable density flow model constructed by P. Fulton, now a PhD student in hydrology at University of Wyoming but formerly a student and technician on the GCE-LTER project, has been applied to analyze submarsh flow at Site GCE3. Using a permeability field that varies both laterally and vertically, a defined freshwater flow at the upland boundary, and a saltwater hydrostatic condition at the tidal creek boundary, his model produces a pattern of submarsh freshwater flow beneath overlying saline saturated sediments. This pattern is similar to that observed using hydrogeophysical imaging techniques and inferred from groundwater geochemical analyses. While this model is still first-order, we have noted that the freshwater reaches the surface in the near-upland region, in the type of “finger” usually attributed to small-scale convection processes in the classic Elder problem (saline over fresh water, with density and compositionally driven convection). We also note that the model can reproduce the gross characteristics of the observed fresh and saline water distribution without including periodic tidal inundation of the marsh or periodic oscillations of the tidal creek. These processes would impose additional, periodic boundary conditions on the top and tidal creek edge of the 2D model.

**Lithologic logging**
A major effort during Year 4 has been the completion of formal lithologic logs on ~15 stored continuous sediment cores obtained during installation of monitoring wells at GCE 4 (Visitors’ Center marsh), GCE3 (North Sapelo transect 2), and GCE10 (Moses Hammock—marsh wells). These logs, which take approximately 1 week each to complete, include information about sediment lithology and mineralogy, angularity, sorting, grain size, Munsell color, unit thickness, nature of unit contacts, fine-scale
sedimentary structures, and fossils. In addition, numerous samples of wood, roots, and other organic material were collected for C-14 dating. With the completion of these logs, we currently have no stored core material awaiting analysis.

The logs constrain the relative permeabilities of various units within the salt marshes and, in some cases, make it possible to connect lithologic units between monitoring wells, thereby delineating “aquifers” within the submarsh and identifying areas where infiltration during tidal inundation may be important. The logs also highlight the differences among the various salt marshes—salt marsh adjacent to a Pleistocene hammock (GCE10), adjacent to a typical maritime forest (GCE3) on the ocean side of the barrier complex, and adjacent to a more unusual maritime forest and an upland and river that appear to be significant sources of freshwater input (GCE4) on the mainland side of the GCE-LTER. Despite the seeming similarity of the marsh grass populations and their distribution in the various salt marshes, the lithologic logs underscore significant differences in drainage, energy of sediment deposition, and rate of sediment deposition even over distances as short as a few meters.

**Physical and Chemical Controls on Salt Marsh Ecology**

Within the past year, we have completed baseline integrations of marsh plant distributions with physical and chemical controls on surface and groundwater hydrology along upland-marsh-tidal creek transects at GCE3, GCE4, and GCE6. For these studies, we have (a) logged the density, height, and identification of marsh plants; (b) measured near-surface pore water conductivity (through either direct measurements in holes < 20 cm deep or through centrifuging of dried soil samples); (c) sampled and analyzed deep groundwaters (GCE3 and GCE4), and (d) compiled sediment lithologies (GCE3 and GCE4). To study the complete conductivity structure of marsh pore waters from the surface to several meters depth, we have employed DC resistivity surveys and sometimes EM induction surveys.

In the literature, various chemical and physical controls have been discussed in terms of their impact on marsh plants. These factors, which are largely inseparable, include drainage, frequency of tidal inundation, salinity, microelevation, nutrient supply, and predators and disease. At present, our studies focus on measuring parameters that can assist in quantifying the first 4 of these factors. Because some of our research was conducted during the dormant period for salt marsh grasses (February 2003, at GCE3), we do not yet have data sets that compare conditions in the hydrologically-instrumented salt marshes at the same times of year. The Year 3 report detailed some of our preliminary data and findings. In Year 4, we did the first fully integrated study at GCE3 and tested a new method to determine near-surface pore water conductivities. We also determined that the near surface pore water conductivity distribution is completely discontinuous from the deeper submarsh conductivity distribution, as expected given the very low permeabilities of near-surface marsh sediments at several of the GCE study sites.
Analysis of Seasonal and Multiannual Data Sets

In the past year, we have collected two major new data sets on water level and temperature fluctuations in monitoring well networks. The first of these datasets was acquired at GCE3 (North Sapelo), where the datasets captured significant differences in the response of the monitoring wells to pressure and temperature forcing. For example, the results demonstrate that an upland well and a well located tens of meters into the marsh at this site experienced long-term groundwater cooling associated with seasonal cooling during the January-February 2003 period. At the same time, a monitoring well located between the upland and marsh wells just described experienced much more oscillatory temperature fluctuations, indicative of significant hydraulic connectivity between the tidal creek (which had similar fluctuations) and this well. First order spectral analysis of the data also reveals that the marsh and upland sediments have the previously demonstrated filtering effect on the frequency components in the tidal fluctuations, with higher frequency components (e.g., M2) damped out at the expense of lower frequency components (e.g., Mf). However, for the marsh-based well that appears to be hydraulically connected to the tidal creek based on an analysis of the temperature data, this filtering effect is far less pronounced, and the pressure wave associated with tidal pumping appears to be propagated into this part of the submarsh aquifer with relatively little distortion of its frequency content.

The second new water level and temperature data set is a several-months-long time series collected on the tidal creek side of Moses Hammock. In fact, we attempted to collect this data set 3 times during the past year, each time meeting with various obstacles related to instrumentation. During the final attempt, which partially overlapped with the Duplex I experiment, the transducer set in the tidal creek was lost either through vandalism or a boat accident that sheared the PVC housing for the deployment below the low water mark. However, we were still able to obtain complete time series data in marsh-based wells adjacent to theDuplin River and in some wells at the edge of the upland, providing for the first time some control over the complete change in the characteristics of water level fluctuations as the tidal pressure is propagated into the creek bank and upland. The water level fluctuation data from these wells reveal the same pronounced asymmetry as earlier observed in upland-only datasets. Such asymmetry contrasts sharply with the highly sinusoidal and to first-order symmetric oscillations of the tidal creek. In 2002, we postulated that the asymmetry in water level fluctuations within the formation may be rooted in a combination of nonlinear effects associated with the sloping creek bank and significant permeability changes from the creek bank to the permeable upland. With the new data, we can track the evolution of the asymmetric components with distance from the tidal creek and conduct a higher quality analysis of these nonlinear effects, which have been considered in only a cursory way in the literature. A Georgia Tech graduate student has undertaken numerical modeling of the nonlinear flow equation in an attempt to address this problem more thoroughly than published analytical solutions that yield unrealistic results for many combinations of tidal forcing frequencies.

We have also used several of the long term monitoring data sets in analyses in support of both education-based research and our LTER research. For example, we have
conducted extensive time and frequency domain analyses of the ~35 year climate records for trends in temperature and precipitation and used USGS discharge and salinity records maintained by the GCE-LTER to understand the balance between freshwater and saltwater inundation at GCE4. Portions of the climate record have been linked to dendrochronologic measurements undertaken by the EAS4420 class and been used in assessing how representative a period was used for sampling to support a redox zonation study that has been revised for Journal of Hydrology.

Patterns of dissolved and suspended material
James T. Hollibaugh, Samantha Joye, and Merryl Alber University of Georgia

Quarterly water column monitoring
During Year 4, Matthew Erickson from the Joye laboratory served as chief scientist on the LTER quarterly monitoring cruises. We collected a total of 309 samples to determine concentrations of dissolved nutrients (NO$_2^-$, NO$_3^-$, NH$_4^+$, HPO$_4^{2-}$, and H$_2$SiO$_4^{2-}$), dissolved organics (DOC, TDN, DON, TDP, and DOP), chlorophyll a, total suspended sediments, particulate CN, particulate P and Fe, and dissolved gases (CH$_4$ and N$_2$O, only 25 samples for dissolved gases were collected). All analyses, less TDP and dissolved gases, have been completed. In June, September and December, water samples from the core monitoring stations, and a limited number of transect stations, were collected to quantify potential rates of nitrification (NTR) and methane oxidation (MOX) and interactions between MOX and NTR.

Spatial and temporal variations among the study sites were apparent. Highest H$_2$SiO$_4^{2-}$ concentrations were present in Sapelo Sound, followed by Altamaha Sound and Doboy Sound. In Sapelo and Altamaha sounds, H$_2$SiO$_4^{2-}$ concentrations decreased with distance from the mouth. DIN/DSi ratios were < 1 at all sites, suggesting N limitation of plankton. DIN concentrations were usually highest in Altamaha Sound and DIP concentrations were low in all sounds. The DIN:DIP ratio was < 16, suggesting N limitation, in Sapelo and Doboy sounds throughout the year. However, the DIN:DIP ratio varied seasonally in Altamaha Sound, suggesting N limitation in spring and summer and strong P limitation (DIN:DIP>50) during fall and winter. Similar to observations in previous years, DON and DOP concentrations were high, often exceeding inorganic nutrient concentrations. DOC concentrations showed strong seasonal variations in Altamaha and Doboy sounds (highest in spring, > 1000 μM and lowest in winter, ~300 μM).

Rates of potential methane oxidation were high (up to 3 μM/d) and rates of nitrification were low (usually < 50 nM/d). The presence of methane tended to inhibit nitrification. Rates of both processes in bottom waters often exceeded those in surface waters. Methanotrophy was stimulated by ammonium addition, suggesting that methanotrophs are nitrogen limited.

We also sampled particulate material for analysis of carbon and nitrogen content and chlorophyll concentrations at all 10 permanent GCE sampling sites as part of the quarterly water column monitoring effort.
River delivery of dissolved and suspended material

During Year 4, we received a total of 48 Altamaha River samples (about 4 samples a month). We have analyzed over 200 river samples since the LTER project began. Samples are analyzed to determine concentrations of DIN, DIP, DSi species, organics (DOC, DON, and DOP) and major ions. A paper describing temporal variations in concentration and estimates of nutrient, dissolved organic matter loading rates to the estuary, and an evaluation of the estuarine response, is being prepared for publication (by Nat Weston).

M. Thoresen, a Ph.D. student in M. Alber’s lab, has also completed a two year study of POC variability in the Duplin River at different spatial (headwaters, mouth) and temporal (tidal, lunar, seasonal) scales. This work was presented at the spring meeting of SEERS, and is currently being written up as part of her doctoral dissertation.

Responses of Estuarine Processes to Environmental Forcing

Soil Processes: Sedimentation, Organic Matter Accumulation and Marsh Stability

Chris Craft, Sean Graham and Christina Pruett, Indiana University

Overview

We are measuring marsh accretion, sedimentation and soil organic matter (SOM) accumulation in nine estuarine marshes that vary in freshwater versus marine inputs of water and sediment. Rates of mineral sediment deposition and SOM accumulation are measured over scales of years (feldspar marker - sediment only), decades ($^{137}$Cs) and centuries ($^{210}$Pb) to elucidate the role of episodic disturbance on marsh stability.

Marsh Accretion

Cesium-137 derived vertical accretion (3.8±0.3 mm/yr) and organic C (110±1 g/m$^2$/yr) accumulation were greater in estuarine marshes of freshwater-dominated watersheds (e.g. Altamaha River) than in marshes of marine-dominated watersheds (Sapelo River, Doboy Sound) (1.5±0.2 mm/yr, 40±4 g C/m$^2$/yr) (Figure 1). There was no difference in mineral sediment deposition among marshes of freshwater (700±220 g/m$^2$/yr), mixed (660±260 g/m$^2$/yr) and marine-dominated (660±430 g/m$^2$/yr) watersheds. Percent soil organic matter (SOM) was greater in freshwater-dominated marshes (20±4%) than in marine-dominated marshes (8±2%). Higher soil organic C levels in Altamaha River marshes suggest that SOM is proportionally more important to accretion in freshwater- than in marine-dominated marshes.
Within a given watershed, no clear difference was observed in vertical accretion, sedimentation or organic C accumulation along the gradient from terrestrial (landward) to marine-dominated (seaward) marshes. Across all sites, accretion, sedimentation and organic C, N and P accumulation were consistently greater in levee marshes as compared to interior marshes.

**Marsh Stability**

SET measurements following installation and six-month equilibration revealed that, during the first six months (Dec. 2001-May 2002), most marshes subsided (Figure 2). The greatest subsidence occurred in marshes of freshwater-dominated watersheds whose soils contained more organic matter (see Table 2), silt and clay than the other marshes. Subsidence likely is the result of a four-year drought that dried out the marsh surface and compacted the soils. Marsh surface elevation rebounded during following six months (May – Dec. 2002) after the drought abated (Figure 2). During this time interval, surface elevation increased more in freshwater-dominated marshes than in marine-dominated marshes. We will continue to monitor changes in marsh surface elevation to document the long-term response of GCE LTER marshes to freshwater pulsing, sediment supply and rising sea level.
Examination of feldspar marker layers indicates that most GCE marshes are in equilibrium with apparent sea level rise along the Georgia coast (1.6 mm/yr). Exceptions include (1) marshes along the freshwater-dominated Altamaha River where vertical accretion is greater than the current rate of sea level rise and (2) incipient marshes developing on submerging uplands of marine-dominated watersheds (e.g. Eulonia) where freshwater and sediment inputs are low. Additional work using $^{210}$Pb and feldspar marker layers is underway to evaluate patterns of marsh accretion over temporal scales of months to centuries. Future work will evaluate the effects of freshwater pulsing on decomposition and soil respiration of GCE marshes.

**Groundwater Biogeochemistry**

Samantha Joye, Dept. of Marine Sciences, UGA

We analyzed 106 groundwater samples from sites on Sapelo Island and a companion study site in the Satilla River during year 4. These samples were analyzed to determine concentrations of nutrients, organic C-N-P, and redox parameters. Groundwater from monitoring wells (installed by Carolyn Ruppel) was collected using a peristaltic pump. Wells were purged and allowed to refill before sampling. Biogeochemical analyses were conducted in Joye’s UGA laboratory. The Moses Hammock upland wells were characterized by low concentrations of nutrients (DIN=17 to 50 µM; DIP=2-5 µM), and the marsh wells generally have higher DIN concentrations. Chloride concentrations were lower in the upland than marsh wells (by about 5%). Chloride to sulfate ratios showed evidence of sulfate reduction in marsh wells and in one upland well (MW0214). Dissolved concentrations of reduced iron were lower in marsh wells (<10 µM) than upland wells (>20 µM with high variability observed between
Sulfide concentrations were higher (~100 µM) in marsh wells than in upland (~10 µM) wells. Groundwater methane and nitrous oxide concentrations (5-12 µM and 0.2 to 0.4 µM, respectively) were supersaturated but were much lower than concentrations in creekbank porewater. Dissolved organic carbon concentrations were comparable in upland and marsh wells.

**Sediment Biogeochemistry and Modeling**

Samantha Joye, Dept. of Marine Sciences, UGA

**The Duplin River Experiment**

During August 2003, we (Bill Porubsky, Matt Erickson, and Liliana Velasquez) participated in the Duplin River experiment (DUPLEX). We measured concentrations of nutrients, organics, suspended particles (TSS and CHN) and chlorophyll at seven sampling stations (1-Marsh Landing, 2-Barn Creek, 3-Bend, 4-Moses Hammock, 5-Fork, 6-Flume Dock, and 7-Left Fork) in Duplin River. River samples were collected at high and low water on spring and neap tides. There was a slightly higher TSS load at low water on the spring tide, particularly at stations 4 through 7. Nutrient, particulate and chlorophyll a concentrations varied slightly between sites, depth (surface vs. bottom) and time (spring vs. neap).

Samples from nine of the Moses Hammock monitoring wells were collected on spring (8/14) and neap (8/19) tides. Nutrient concentrations were higher in samples collected on the neap tide, though DOC concentrations did not vary.

Most of our effort in the DUPLEX experiment was to quantify sediment-water fluxes of nutrients and organic matter. Flux cores (12 cm diameter, 20 cm sediment, 20 cm water column) were collected on August 11, 2003. Twelve cores were collected, 3 from the left (L) fork of the Duplin, 3 from the right (R) fork of the Duplin, and six from a site on the L fork of the Duplin that had an abundant benthic microalgal community (based on visual inspection). (Left and right refer to the position when facing the fork from the Duplin River). The cores from the left vs. right forks (3 each) were used to examine the variability in fluxes on these locations. These 6 cores were incubated at in situ temperature and light levels between August 12 and 15. Each core was sampled 8 times and the following species were quantified: O₂, N₂ (28, 29, and 30), N₂O, CH₄, pH, NOₓ, NO₂, NO₃, TDN, DON, PO₄, TDP, DOP, H₂S, Fe, Mn, Si, DIC, and DOC. This data set (912 points) showed little difference between fluxes of the measured variables in the left versus right forks of the Duplin River. One of the few notable differences was the slightly higher Si efflux in cores from the right fork.

The remaining six cores (all collected from the L fork) were used to evaluate the impact of benthic primary production on rates of sediment-water fluxes and on the pathway of nitrogen processing. Three replicates were incubated at in-situ temperature and light conditions (referred to as “LIGHT”) and the three replicates were incubated at in situ temperature in the dark (referred to as “DARK”). The experiment was run for 8 days, with sampling performed at dawn and dusk. On 16 August, each of the cores was spiked with 100 µM of ¹⁵N-NO₃ and the ¹⁵N label was tracked into N₂ and NH₄ pools at each subsequent sampling time point. Upon termination of the experiment, benthic microalgae were collected from each core to quantify the ¹⁵N signature of the primary
producers. The data were analyzed with regard to light (i.e. flux during the light period of incubation in light treatments, flux during the dark period of incubation in light treatments, and flux in the dark treatment), and to examine differences in fluxes before and after the $^{15}$N-NO$_3$ spike. Oxygen fluxes showed production during the light incubation periods (as expected). The highest O$_2$ uptake rates were observed during the dark phase of incubation of light cores. NH$_4$ fluxed from the sediment to the overlying water in dark incubated cores but light-incubated cores exhibited NH$_4$ uptake during light and dark phases of incubation. Similarly, PO$_4$ and Fe$^{2+}$ fluxed from dark cores but not from light cores. NO$_3$ ($^{15}$N) uptake rates were much higher in light cores than in dark cores. Silicate uptake rates were highest in light cores (dark cores exhibited a flux of silicate from the sediment to the overlying water). N$_2$O production was orders of magnitude higher in dark cores compared to light cores. The dark core N$_2$O fluxes averaged 11 µmol/m$^2$/d.

Most of the $^{15}$N (>90%) added to light cores ended up in primary producer biomass and the primary producer $^{15}$NO$_3$ uptake rate was >10 mmol/m$^2$/d. In light cores, dissimilatory nitrate reduction to ammonium (DNRA) was negligible and denitrification (DNF) accounted for about 6% of $^{15}$NO$_3$ uptake (0.5 mmol/m$^2$/d). In dark cores, about 40% of the $^{15}$NO$_3$ was denitrified (2.5 mmol/m$^2$/d), less than 3% was processed via DNRA (<0.1 mmol/m$^2$/d) and 60% ended up in primary producer biomass (6 mmol/m$^2$/d). With this data, we cannot determine absolutely whether the microphytobenthos took up $^{15}$NO$_3$ or $^{15}$NH$_4$ (produced by DNRA). The latter possibility appears more likely to us and will be addressed in future experiments.

We also determined benthic chlorophyll $a$ concentration and gross rates of oxygenic photosynthesis (GOP). GOP rates were determined using O$_2$ microelectrodes. Chlorophyll $a$ concentrations in samples from the left fork (167±22 mg/m$^2$) were higher than those from the right fork (105±25 mg/m$^2$). Similarly, the chlorophyll $a$ concentrations in samples from Moses Hammock (86±30 mg/m$^2$) were slightly lower than concentrations in samples collected from across the river (on the creekbank at the L side of the channel; 122±20 mg/m$^2$). Rates of GOP were comparable (about 10 mmol O$_2$/m$^2$/h) in samples from the L fork, R fork and MH site. Samples from the left side of the Duplin across from MH were substantially lower (about 1 mmol O$_2$/m$^2$/h).

**Plant Production**

**Steve Pennings, University of Houston**

Plant biomass monitoring tests the hypothesis that end-of-year biomass varies as a function of 1) freshwater discharge from the Altamaha and 2) average sea level. In 2000 we set up permanent plots at all 10 LTER monitoring sites. Plots were established at creek-bank and mid-marsh sites (8 plots/zone/site). Plants were non-destructively monitored (stem counts, heights, flowering status) in October of 2000, 2001, 2002 and 2003. Soil organic content was measured by ashing cores collected adjacent to each plot in October 2000. Stem samples were taken adjacent to plots in 2002, measured, dried and weighed, in order to generate regression relationships between height and mass. These permanent plots are also proving useful in documenting spatial and
temporal variation in disturbance from physical (wrack) and biotic (grazing) sources. Normal rainfall in 2003 following several drought years produced increased biomass of *Spartina alterniflora* in creek-bank plots, but mid-marsh plots were little affected.

**Fungal Crop**

Steve Newell, UGA Marine Institute

The fourth year of monitoring documented the extents of autumnal accumulation of living fungal biomass (with ergosterol as the proxy) within standing-decaying, ramet-forming marsh macrophytes, and rates of expulsion of sexual spores (ascospores), with fungal-species determination. Data for the 2003 fungal-monitoring effort is still being processed, but one item within the data set is clearly different from previous years -- *Phaeosphaeria halima*, which is ordinarily the distinctly less sexually productive species of this ascomycetous genus within the decomposer community of standing-decaying smooth cordgrass (*Spartina alterniflora*) (Bot. Mar. 44:277-285), exhibited its greatest ascospore-expulsion rates among the four years of monitoring. Its ascospores were more abundant than those of *P. spartinicola* in 8 of 16 cases; the average for the previous three years of monitoring was 2.6 of 16. Eventually it may be that clear differences in activities of particular sectors of the fungal community within the marsh will be found to be good indicators of environmental change.

The previously reported distribution of living-fungal content in autumnal standing-decaying leaves was confirmed in 2003’s monitoring -- lower fungal content was again found for the predominant marsh plants of the fresher-water sites. I also conducted a survey of fungal activity in spring of 2002, over a range of salinity within the GCE sampling area (note that winter and spring are seasons of high fungal activity; Aquat. Microb. Ecol. 32:95-103). This survey provides a link between the annual fungal monitoring performed throughout the GCE site framework, and the Decomposer Consortium Experiments, performed at GCE site 6 (high salinity). Ergosterol contents varied as would have been predicted from the autumnal monitoring: higher for the high-salinity plants, lower for the low-salinity plants. But results for the activity measurements (growth rates, respiration per unit ergosterol), which were measured at water saturation, were distinctly higher for the fresher-water plants! I hypothesize that the fresher-water plants have leaf microstructures that inhibit water availability as provided by dew set (the major wetting phenomenon for standing-decaying leaves; Aquat. Bot. 60: 325-335). Thus, the standing-dead leaves of the fresher-water sites are primed for fungal activity to take place after the leaves decay enough to fall to the sediment, where they would be persistently water-saturated.

An adjunct proposal submitted in parallel to my GCE/LTER research in 2002 was funded in early 2003 by NSF/DEB; $112,185, 3 years) -- the central goal of the proposal was to attempt to develop a new method for measuring fungal productivity. The method would not require the use of radioisotopes (as in the acetate-into-ergosterol method that I designed [Chapter 18 of Methods in Microbiology 30]), and instead would involve fluorometric monitoring of the rate of incorporation of a tagged precursor into fungal chitin. This work has hit an early snag -- the fluorometric precursor to fungal chitin, 6-O-dansyl N-acetylglucosamine, was to have been synthesized by the Molecular Probes
Custom Synthesis Department, but MP has not yet succeeded in the synthesis, after three attempts (note that this complicated synthesis has only been successfully performed once [according to the literature]). It is hoped that further trials in early 2004 will be successful; otherwise, the research will move to its fallback position -- testing of the replacement of carbon-14 by tritium (advantage: shorter half-life of the radioisotope) in the acetate-to-ergosterol method.

Collaborative research with a scientist from Brown University was performed in 2002/2003 as a part of my GCE/LTER effort. Brian Silliman and I designed experiments to learn why saltmarsh periwinkles (*Littoraria irrorata*) devote some of their grazing time to surfaces of green living leaves. (These snails routinely graze standing-decaying leaves of smooth cordgrass [*Spartina alterniflora*], and gain most of their nutrition from this food.) The green leaves have high ferulic acid content, which is the probable reason that they are much less palatable to periwinkles than the decaying leaves, in which decomposer ascomycetes destroy the ferulic acid. We discovered that periwinkles commonly make small wounds on green leaves. These wounds are then invaded by the usual marsh ascomycetous fungi. The snails subsequently revisit the wounds, and eat the fungal-invaded material surrounding the grazing wounds. This series of events represents a primitive microbial-gardening phenomenon, and results in lower productivity of the cordgrass. Our results are on their way to press (Proc. Natl. Acad. Sci., December 2003).

**Plant Community Ecology**

**Steven Pennings, Univ. of Houston; Merryl Alber, Dept of Marine Sciences, UGA**

**Responses to eutrophication**

In collaboration with Caroline McFarlin (M.S. student), and Steven Newell, S. Pennings is examining spatial variation in nutrient effects on marsh community structure. The border between two dominant marsh plants, *Spartina alterniflora* and *Juncus roemerianus*, was fertilized at 19 sites within the LTER domain for two years. Across all sites there was a strong increase in biomass of live and dead *S. alterniflora* and a decrease in biomass of live and dead *J. roemerianus* in fertilized plots. Decomposer fungi on dead *S. alterniflora* leaves did not increase per unit of dead leaf, but did increase on a per-plot basis. Herbivorous grasshoppers increased in abundance, but detritivorous snails did not. All responses varied among sites. We are exploring correlations between edaphic variables and responses to fertilization to see if we can explain any of the site to site variation. C. McFarlin will graduate in spring of 2004.

**Annual variation in vegetation borders**

S. Pennings is testing the hypothesis that annual variation in marsh plant species composition is driven by variation in rainfall. Salt marsh vegetation often consists of discrete stands with abrupt borders between different species or associations. I have 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 will be needed to rigorously test this hypothesis.

**Secondary succession of marsh vegetation in GA and AL**

S. Pennings is conducting parallel experiments in GA and AL to examine 1) how rapidly marsh vegetation can recover from disturbance, and 2) the role of competition in secondary succession. In 3 vegetation zones (Spartina alterniflora-meadow border, meadow-Juncus roemerianus border, J. roemerianus zone) at each of 2 marshes in each state, I cleared replicate 3 x 3 m plots using herbicide and clipping and maintained plots free of vegetation for 2 years. Control plots were marked but unmanipulated. In 2000 individual plots were divided into two or four quadrants, depending on the diversity of the vegetation in each zone, with one quadrant allowed to recover without further manipulation and the other quadrant(s) treated by periodically removing 1 or 2 dominant plant species occurring in each zone. To date, succession has been fastest in plots on the Spartina alterniflora-meadow border, 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.

**Factors controlling plant distributions**

We are continuing to study the factors that control plant distributions along the estuarine continuum. S. White, a Ph.D. student in M. Alber’s lab, has completed both field and greenhouse experiments designed to investigate the relative importance of salinity, sulfate, and competition in influencing the relative distribution of S. alterniflora and S. cynosuroides. This work was presented at several meetings this past year (SEERS, ESA, ERF) and is currently being written up as part of her doctoral dissertation.

**Phenotypic and genetic variation in salt marsh plant species**

Lisa Donovan and Christina Richards, Botany Department, UGA

Our directed study under the GC-LTER has consisted of 4 studies. We have previously presented results from three studies investigating plant strategies that may have evolved in response to the heterogeneity of the marsh environment. The first study showed that 12 plant species express a broad range of phenotypes that are correlated with environmental factors in Sapelo Island salt marshes. This study was presented as a poster in 2000 at the ESA annual meeting, in 2001 at the GC-LTER annual meeting and at the 2002 National Estuarine Research Reserve (NERR) annual meeting. The manuscript is currently in review at *Plant Ecology*. The second study, done in the controlled environment of a greenhouse, suggested that some traits in Borrichia frutescens are differentiating in response to salt while others are plastic. These results were formally presented at the 2001 ESA annual meeting and the manuscript is in preparation for submission to *Evolutionary Ecology*. The third study, based on allozyme markers, revealed that clone size in Borrichia frutescens and Spartina alterniflora is not as large as we anticipated, and genetic structure is significantly explained by the
environmental gradients in the marsh. The results for *B. frutescens* were presented at 5 national meetings this summer: SSE (oral), ESA (oral), ERF (poster), LTER (poster) and NERR (poster). The manuscript is in preparation for submission to *Ecology*.

For the fourth study, we set up 2 large field experiments to further investigate how natural selection acts in populations of the C$_3$ composite *Borrichia frutescens*. *Spartina alterniflora* has been eliminated from these studies due to the magnitude of the design necessary to closely examine patterns of natural selection in the field. Data was collected on the transplants throughout the summer and the experiments were harvested this fall. The plants need to be processed for submission to the ICP and UGA Chemical Analysis Lab for elemental analyses. When this data is collected in early spring 2004, we will complete the manuscript.

**Benthic invertebrates**

**Merryl Alber and Dale Bishop, UGA Dept of Marine Sciences**

The invertebrate monitoring group has continued to meet the mandate of the LTER program of tracking the population changes of salt marsh species important to the trophic structure and function of the estuarine system. In 2003, samples were collected at all 10 GCE-LTER marsh monitoring sites in May and October. The infauna and epifauna mollusc samples and crab counts are processed and await quality control checking before being posted to the web database.

In addition to the regular monitoring efforts we have two ongoing projects designed to assess biodiversity and occurrence of non-indigenous species within selected sub-habitats of the GCE-LTER domain. First, oyster reef faunal surveys were expanded to include four sites in Doboy Sound and the Duplin River. Second, we are monitoring the non-indigenous green porcelain crab, *Petrolisthes armatus*, which was first observed in 2001. This year, two other non-indigenous species were also observed in the GCE-LTER domain. The green mussel, *Perna viridis*, was collected from Marsh Landing Dock in October, 2003, and the swimming crab, *Callinectes exasperatus*, was collected in the Duplin. Both newly-reported species have been posted to the GCE-LTER taxonomic database and to the national Non-indigenous Aquatic Species database hosted by the USGS. Results from these projects were presented at both the 2003 Estuarine Research Federation meeting and the annual meeting of the National Estuarine Research Reserve Association.

In August, 2003, D. Bishop participated in the Duplex I effort in the Duplin River. He sampled crustacean larvae at sites selected based on differences in their predicted hydrodynamic regimes to test the hypothesis that hydrodynamic forces play a key role in invertebrate larval recruitment within the estuary. Preliminary results from this effort suggest that there are differences in the settlement patterns of the blue crab along the Duplin River. These recruitment data, linked with hydrodynamic and other environmental data, may help us understand the steady decline of the commercially important blue crab.

M. Thoresen, a Ph.D. student in M. Alber’s lab, has completed a study of the trophic linkage between benthic diatoms and oysters, *Crassostrea virginica*. This work
was presented at the ERF meeting in Seattle, and is currently being written up as part of her doctoral dissertation.

Finally, the GCE-LTER web site taxonomic database continues to be revised and updated. Newly recorded species of invertebrates and fish are being added on a continuing basis, and D. Bishop has worked with W. Sheldon and S. Pennings to refine the definitions of habitat types to allow for searches at a finer scale.

**Grasshopper abundance**

Steven Pennings, University of Houston

I am testing the hypothesis that grasshopper abundance varies among sites and years as a function of site characteristics and angiosperm production. Grasshoppers were visually counted on transects (mid-marsh, 8-10/site) at the 10 LTER monitoring sites in August 2000, 2001, 2002 and 2004. Grasshopper populations were dominated by two common taxa. Densities differed more than ten-fold among sites. The rank-order of sites was similar among years, suggesting that some sites consistently supported high grasshopper populations and other sites consistently supported low populations. Expanded monitoring at 30 sites in 2003 indicated that grasshoppers were common at sites with extensive adjacent upland, but were absent at mid-estuary sites that had extensive *Spartina* zones but lacked upland habitats. I hypothesize that grasshoppers require upland or high-marsh habitats in order to over-winter. Although 2000-2002 were drought years and 2003 experienced more normal rainfall, grasshopper densities in 2003 were similar to those in previous years, suggesting that rainfall does not directly drive annual variation in grasshopper abundances.

**Phytoplankton and bacterioplankton production and biomass**

Robert E. Hodson and Edward S. Sheppard, Dept. of Marine Sciences, UGA

Production-irradiance curves and bacterioplankton growth rates (L-leucine incorporation into protein) were measured at all monitoring stations on all of the quarterly monitoring cruises during 2003. Data are being analyzed and readied for incorporation into models of phytoplankton and bacterioplankton productivity.

**Microbial decomposer consortia directed study**

Mary Ann Moran, James T. Hollibaugh, Dept. of Marine Sciences, UGA; Steven Newell, UGA Marine Institute

The directed study of cooperation/competition among bacterial and ascomycetous fungal decomposers of *Spartina alterniflora* was largely completed in Year 3. This research has shown that fungal decomposer communities are dominated by a relatively few species clusters, while bacterial communities are more diverse and contain major taxa that have not been cultured. There is low spatial variability in composition of both bacterial and fungal decomposers (based on T-RFLP analysis of
16S rRNA genes and ITS regions), but clear seasonal shifts in major players are evident. Two functional genes of importance in decomposition (bacterial ring-cleavage dioxygenase pcaGH and fungal laccase) both have high diversity within salt marsh decomposer communities. In Year 4, we continue baiting experiments that began as part of this directed study. These studies show a highly specialized bacterial decomposer community that becomes established regardless of fungal competitors or physical/chemical forces in the salt marsh.

**Water Column Respiration and CO$_2$ Chemistry**

Wei-Jun Cai, Dept. of Marine Sciences, UGA

Our group is collecting surface water inorganic carbon data (pCO$_2$, DIC, alkalinity) and using them as an integrated measure of biological activity in the coastal water of Georgia. They also measured water column respiration rate based on DIC release during dark incubations. These data clearly show that the marshes are a significant source of CO$_2$ to coastal waters and that the marsh and estuarine waters are highly heterotrophic.

A 3-year monitoring program in the Duplin River next to Sapelo Island allowed us to estimate a total DIC output from the U.S. South Atlantic Bight (SAB) salt marshes as $\sim 0.7 \times 10^{12}$ gC yr$^{-1}$. Adding a riverine flux of $0.6 \times 10^{12}$ gC yr$^{-1}$ (Cai and Wang 1998), the total DIC flux from the land side is about $1.3 \times 10^{12}$ gC yr$^{-1}$. Several offshore cruises along a transect in the central SAB allow an estimate of DIC export to the open ocean as $2.7 \times 10^{12}$ gC yr$^{-1}$, and a CO$_2$ flux to the atmosphere as $2.7 \times 10^{12}$ gC yr$^{-1}$. Therefore, we concluded that the SAB continental shelf is net heterotrophic and the net ecosystem heterotrophy must be on the order of $4.0 \times 10^{12}$ gC yr$^{-1}$. This net heterotrophy is only 10% of the primary production in the shelf, much smaller than indicated by previous studies, which were based on production and respiration rates. It also reveals that organic carbon output from the marshes may be underestimated.

**Education and Human Resources**

**Schoolyard LTER**

Patricia Hembree, University of Georgia

To date, the GCE schoolyard program has provided a total of 55 teacher positions – and those teachers have now served over 5300 K-12 students in Georgia. Funding for the program thus far includes $45,000 from the LTER Schoolyard supplemental grants and over $70,000 from Georgia's Teacher Quality Higher Education Program – a federally funded program through the United States Department of Education as a part of the No Child Left Behind Act. There have been four national and five regional presentations given in the area of educational research by the coordinator, and a six part set of papers by past participants on the use of the GCE-LTER science in the classroom.
The current workshop design is based upon state and national standards for science and mathematics education as well as those standards set for teacher education (see table below for details). The program assigns teachers to join graduate students and GCE-LTER scientists for a week as collaborative team members conducting field work on Sapelo Island. The emphasis is placed on opportunities for the teachers to develop or enhance appreciation for and understanding of the science and mathematics behind GCE-LTER research. This workshop capitalizes on the way field science activities differ from the traditional school-based or laboratory-based science – a view that teachers rarely get to see, much less come to understand as something to be included in a typical curriculum. Intending to be consistent with the goals of the LTER Network, support for the teacher/participants in S.A.P.E.L.O. is over long temporal and broad spatial scales – teachers may participate for as many seasons as they desire and teachers from all teaching situations and areas of Georgia may apply. This long term aspect of teacher participation provides unique mentorships on multiple levels. More importantly, it provides teachers with a sense of continuity within the research process and a depth of understanding about those processes that can never be replicated in textbooks. Additionally, teachers are supported throughout the academic year by letters, emails, and telephone contact between participants and GCE-LTER personnel, classroom visits by the Schoolyard coordinator, a return trip to Sapelo Island in the late fall, and modest funds to purchase classroom materials. The teachers are given a collection of reference books and receive financial support to attend a professional conference.

This Schoolyard program is meant to complement, not compete, with the existing education programs on the Georgia coast. These existing programs include summer courses for educators that are taught at the Marine Education Center and Aquarium at Skidaway, day tours for school groups by the Sapelo Island National Estuarine Research Reserve, and the many wonderful programs for student and teacher groups conducted by a variety of private and public facilities along the coast. The Schoolyard program differs from these programs in that it focuses on establishing a long-term partnership between the GCE-LTER and schools through the teachers.

### GCE Schoolyard Funding

<table>
<thead>
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<th>Year</th>
<th>NSF Schoolyard</th>
<th>Eisenhower/ITQ</th>
<th>Total</th>
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<tr>
<td>2002</td>
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Pre-service science teachers – End of program experience on Sapelo (currently not funded through the two grants, but part of the outreach program).

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of student-teachers</th>
</tr>
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<tr>
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<tr>
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<tr>
<td>Totals</td>
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</table>

Field Methods Class, GA Tech
Carolyn Ruppel, GA Tech

The GCE LTER was the focus of the Spring 2003 EAS 4420 Environmental Field Methods class at Georgia Tech, serving 15 graduating seniors required to complete the course to earn their B.S. degrees. Students studied a range of topics including aerosols in the coastal zone, coastal zone morphology, estuarine dynamics, groundwater geochemistry and flow, ecological processes in uplands and marshes, coastal zone development policies, the role of the coastal zone in modulating climate, and long-term sea level and climate trends. Field research included installation of new monitoring wells, groundwater and surface water sampling, geophysical site characterization, ecological mapping, and a variety of atmospheric measurements.

Personnel supported by the GCE-LTER:

Dale Bishop, Post-doctoral associate, UGA
Vladimir Samarkin, Post-doctoral associate, UGA
Wade Sheldon, Management Information Specialist, UGA
Julie Amft, Research Coordinator, SkIO
Amy Eisin, Technician, GA Tech
Matthew Erickson, Research Coordinator, UGA
Ken Helm, Field technician, UGAMI
Trent Moore, Research Coordinator, SkIO
Joan Sheldon, Research Coordinator, UGA
Monica Watkins, Technician, UGA
Candice Crutcher, Ph.D. student, IU
K. Kang, Ph.D. student, UGA
Rosalynn Lee, Ph.D. student, UGA
Bill Porubsky, Ph.D. student, UGA
Christina Richards, Ph.D. student, UGA
Merrilee Thoresen, Ph.D. student, UGA
Nathaniel Weston, Ph.D. student, UGA
Susan White, Ph.D. student, UGA
Amanda Wrona, Ph.D. student, UGA
Trisha Hembree, D. Ed. student, UGA
Gayle Albers, M.S. student, UGA
Erin J. Biers, M.S. student, UGA
Ryan Brown, M.S. student, GA Tech
Sean Graham, M.S. student and Research Technician, IU
Josh Hall, M.S. student, IU
L. Caroline McFarlin, M.S. student, UGA
Matthew Ogburn, M.S. student, UGA
Liliana Velasquez, M.S. student, UGA
Rose Asher, undergraduate research assistant, UGA
Justin Bartlett, REU student, Georgia Tech
Jennifer Britt, REU student, Georgia Institute of Technology
Lee Couey, REU student, Georgia Institute of Technology
Jon Clarke, undergraduate research assistant, UGA
Ray Dixon, undergraduate research assistant, UGA
Brian Dolan, undergraduate research assistant, GA Tech
Amy Kunza, undergraduate research assistant, UH
Steven O’Connell, undergraduate research assistant, UGA
Christina Pruett, undergraduate research assistant, IU
Rochelle Randall, REU student, Savannah State University
Tiffany Roberts, undergraduate research assistant, UGA
Jacob Shalack, undergraduate research assistant, UGA
Josh West, undergraduate research assistant, GA Tech

Broader Impacts

PI Outreach

M. Alber:
- We have begun a long-term monitoring program that examines differences in fouling communities along salinity gradients as part of the yearly field experience for the undergraduate course in Marine Biology (MARS 3450) taught by Mary Ann Moran and Merry Alber. The first data set collected for the study is
M. Alber received funding from Georgia Sea Grant to provide summer support to an undergraduate student working on salt marsh dieback.

**D. Bishop:**
- Dale Bishop was one of eight invited speakers who participated in a public symposium sponsored by The Nature Conservancy and Sapelo Island National Estuarine Research Reserve entitled: *South Georgia Invasive Species Workshop*. He presented the results of his research on the green porcelain crab to an audience of Conservancy, DNR, academic and conservation professionals as well as interested private citizens.
- In July, as part of the GCE-LTER Schoolyard program, Dale Bishop guided a team of six teachers into the challenging world of invertebrate sampling on oyster reefs. The teachers assisted in sampling for invasive species and other oyster reef fauna. The group of teachers independently produced a poster, detailing their experiences, to be used back in their classrooms.
- Three species of non-indigenous invertebrates have been collected from the GCE-LTER domain. These collections have been documented for the public in the GCE-LTER taxonomic database and the national Non-indigenous Aquatic Species database of the United States Geological Survey (http://nas.er.usgs.gov/).
- The taxonomic database and the GCE-LTER web site continue to produce opportunities for public education. Questions about project design, grasshopper grazing effects and marsh reconstruction have been addressed by D. Bishop, S. Pennings and M. Alber. Questions have come from government employees and students across the nation.

**J. Blanton:**
- Lectured on the physical oceanography of coastal environments used data from the GCE-LTER monitoring program to illustrate the changing character of the tide as well as how the tide affected the salinity environment in the LTER domain. These lectures were part of the masters course in the Department of Marine Science at Savannah State University (MS5202).

**C. Craft:**

**L. Donovan:**
- The broader impacts of the research include unique opportunities for hands on participation in the scientific process for many students at all educational levels. This work has involved help from many students, and in particular female students. UGA undergraduates who have helped in the field collecting data and
plant material as well in the lab preparing samples and running gels include Janine Cousins, Trisha Rodriguez, Erica Boerma and Jennifer Lance.

- In addition, this work has involved many female graduate students, postdocs and technicians including Tracy Buck, Susan White, Amy Bouck, Jill Johnston, Regina Baucom, Stephanie Held and Keirith Snyder. Interactions with these scientists and others have been essential to accomplish fieldwork, data analysis and interpretation, writing and presentation.

S. Newell:

- My collaborative research on snail/fungal interactions drew interest from the popular press, and I gave several interviews to reporters on this topic (e.g., Science News 164:358. December 2003).

S. Pennings:

- Member of LTER cross-site synthesis group examining whether the traits of plant species can predict different responses by different taxa in fertilization experiments.
- Instructor for GCE Schoolyard LTER. Sapelo Island, Georgia, 2003

C. Ruppel:

- Using Year 3 supplementary funds, we acquired a transducer with telemetry capabilities for installation in a marsh-based monitoring well at GCE3, the Visitors’ Center site, as part of a public outreach effort highlighting dynamic processes in the environment and the integration of physical, chemical, and ecological processes within the GCE-LTER framework. After initial problems with the system and return of the transducer to the manufacturer, we successfully tested the telemetry capabilities in the laboratory in late October 2003. Installation will proceed in early spring 2004.
- We have fielded numerous inquiries about our hammock-based hydrology program. It is clear that we have in hand the most complete hydrologic data set ever assembled for a Georgia marsh hammock, and such data may inform coastal stakeholders during decision making on development and conservation projects.

W. Sheldon:

- Continues to serve on the LTER Information Management Executive committee
- Served on the NSF review panel for the Sevilleta LTER project
- Gave 3 invited presentations on GCE information management technology at the LTER All-scientists meeting in Seattle, WA.

The Georgia Coastal Research Council

The GCE-LTER program is now an official sponsor of the Georgia Coastal Research Council (GCRC), which is a forum for the integration of science and management in the State of Georgia. The GCRC meets regularly with the state DNR to discuss their
scientific needs, which puts us in a strong position to share our results with state and local decision-makers, and to be responsive to emerging coastal management issues. Highlights from this past year include:

- **GCRC web site (http://www.marsci.uga.edu/coastalcouncil)** -- The GCRC web site currently includes profiles of 68 scientists and managers, including many GCE scientists; summaries of research projects in coastal Georgia; meeting summaries; and information on focus areas. Since the initial public viewing in January 2003, the site has logged 1200 unique ‘hits’ and more than 2300 total visits including viewers from 31 nations.

- **Response to inquiries** – The GCRC is becoming known as an organization that can facilitate technical interactions. Over the past year, the GCRC has responded to requests to identify scientists that would be appropriate to participate in specific activities (i.e. a regional workshop to study the effect of docks, preparation of a federally-mandated list of Georgia marine managed areas, and a meeting on open water marsh management practices for mosquito control) and to review proposed regulations (i.e. amending beach re-nourishment guidelines). They have also responded to requests to identify managers who would be interested in scientific collaborations as well as requests for data (i.e. the hydrographic record from the recent drought; a quantification of river flow leaving the state).

- **Freshwater inflow** – The GCRC has been involved in discussions with State officials as they seek to evaluate how changes in freshwater inflow affect estuaries. This past year a collaborative effort was launched between the state Environmental Protection Division and the Army Corps of Engineers regarding setting inflow standards for the Altamaha River estuary (http://155.82.250.23/garbs/Shared%20Documents/Information%20Bulletin.doc). The GCE research on freshwater inflow is directly relevant to this effort and is being represented at these meetings.

- **Marsh dieback** – The GCRC has taken a lead role in coordinating endeavors to determine the cause and extent of the marsh dieback problem in coastal Georgia. The protocol developed by the marsh monitoring subcommittee is being used quarterly at seven affected sites to help track the progress and potential recovery of these areas, and data collected with the standardized protocol are collated and made available through the web site. The GCRC is currently organizing a workshop for scientists investigating vegetative die-off in Georgia and Louisiana to discuss the technical aspects of dieback assessment and research into both causation and restoration. The scientific meeting will be followed by a public outreach session for Georgia stakeholders.

**Media Coverage**

- **Fall/03** “**UGA researchers seek causes of ‘Marsh plague’ that is spreading along state’s coastal area**” The Franklin Chronicle. Article about marsh dieback in coastal Georgia. Featured interview with T. Hollibaugh

- **Fall/03** “**Why is the coastal marsh grass dying?**” LTER Network Newsletter. Article by M. Alber and J.T. Hollibaugh on marsh dieback in coastal Georgia.
6/03 “*Sapelo’s golden celebration!*” Georgia Magazine. LTER scientists interviewed regarding the UGA Marine Institute on Sapelo Island.

5/03 “*Researchers track marsh die-back*” Savannah Morning News. M. Alber interviewed regarding marsh die-off in coastal Georgia.

3/03 “*Hundreds of acres of marsh plants dying on coast*” Charleston Port and Courier, M. Alber interviewed regarding marsh die-off in the S. Atlantic Bight.

3/03 “*Marsh Reality.*” The Univ. of Georgia Columns. M. Alber and T. Hollibaugh interviewed regarding the work of the GCRC and the GCE-LTER with regard to marsh die-off in coastal Georgia.

2/03 “*Salt marsh dead zones causing concern on Georgia’s coast.*” Athens Banner Herald. M. Alber interviewed regarding marsh die-off in coastal Georgia.

1/03 “*Coastal marshes dying*” The Red and the Black. LTER scientists interviewed regarding marsh die-off in coastal Georgia.

1/03 “*Marsh die-off*” Savannah Morning News. Discussion of the marsh die-off meeting hosted by the Georgia Coastal Research Council.

**Additional Funding**

**Merryl Alber:**

Title: Research Experience for Undergraduates: Characterization of Salt Marsh Die-back Areas in Coastal Georgia.

Source: Georgia College Sea Grant Program

Duration: May 2003 – April 2004

Total: $5,160

Title: Salt Marsh Dieback in the South Atlantic Bight.

Source: Georgia Coastal Resources Division.

Duration: August 2003 – July 2004

Total: $9,020

**T. Dale Bishop:**

Received funding from the Sapelo Island National Estuarine Research Reserve to expand the green porcelain crab population monitoring program

Received $1,500 from SINERR to be used as a training grant for an undergraduate student interested in decapod crustacean biology and taxonomy

**Jackson Blanton, Daniela Di Iorio:**

Funding from the following grants were used to leverage field activities associated with the DUPLEX and quarterly monitoring studies

- NOAA Coastal Zone Management Grant (Blanton)
- NOAA Land Use-Coastal Ecosystem Study (J. Blanton)
- GA Sea Grant (Di Iorio)
Steve Pennings, University of Houston
Title: Latitudinal gradients in plant palatability in Atlantic coast salt marshes, S. Pennings (PI)
Source: NSF, Ecology panel
Duration: January, 2002-December, 2004
Total: $314,125
(This project is comparing plant-herbivore interactions in northeastern versus southeastern salt marshes. Several of the study sites overlap with LTER sites (GCE and PIE), and the results of this study will provide information on insect distributions and plant-herbivore interactions that will be of relevance to the three Atlantic Coast LTER salt marsh sites.)

Title: Environmental variation and the diversity of Texas salt marsh plant communities, S. Pennings (PI)
Source: Environmental Institute of Houston
Duration: January 2004-August 2004
Total: $12,875
(This project is comparing plant diversity patterns in Texas salt marshes with those in GA salt marshes, with the goal of understanding controls on diversity. GA study sites are within the GCE-LTER domain, and the result will provide information on how plant diversity patterns within GA marshes compare to those in other geographic regions.)

Publications

**Peer-reviewed Journal Articles**

**Published and Accepted**


Submitted


Books


Theses and Dissertations

Posters and Presentations


Hollibaugh, J.T., 2003. Metagenomic analysis of natural microbial communities, Presentation at the LTER All Scientists Meeting, Seattle, WA.


Ruppel, C., Linking physics, chemistry, and ecology across the upland-estuary interface: hydrology of clastic salt marshes, Massachusetts Institute of Technology, Dept. of Civil and Environmental Engineering, Parsons Lab, May 2003.


Sheldon, W.M., 2003. GCE Data Toolbox -- metadata-based tools for automated data processing and analysis, Presentation at the 2003 LTER All-Scientists Meeting, Seattle, WA.


Sheldon, W.M., Moran, M.A. and Hollibaugh, J.T., 2003. Efforts to Link Ecological Metadata with Bacterial Gene Sequences at the Sapelo Island Microbial Observatory, Presentation at the 2003 LTER All-Scientists Meeting, Seattle, WA.


Thoresen, M. and Alber, M., 2003. POC concentrations over different scales of variability in a tidal inlet (Duplin River, Georgia), Southeastern Estuarine Research Society meeting, Atlantic Beach, NC.

Thoresen, M. and Alber, M., 2003. Temporal and spatial dynamics of seston in the Duplin River: Implications for oyster food resources, LTER All-Scientists Meeting, Seattle, WA.


White, S. and Alber, M., 2003. Salinity, sulfate, and competition: exploring interactions and impacts on *Spartina alterniflora* and *S. cynosuroides* growth, Southeastern Estuarine Research Society meeting, Atlantic Beach, NC.


Reports