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COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

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University of Georgia Research Foundation Inc
616 Boyd GSRC
Athens, GA. 306027411

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TITLE OF PROPOSED PROJECT **LTER: Georgia Coastal Ecosystems-II**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 4,919,998	60 months	11/15/06	

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Project Summary

Intellectual Merit: The Georgia Coastal Ecosystems (GCE) LTER program, located on the central Georgia coast, was established in 2000. The study domain encompasses three adjacent sounds (Altamaha, Doboy, Sapelo) and includes upland (mainland, barrier islands, marsh hammocks), intertidal (fresh, brackish and salt marsh) and submerged (river, estuary, continental shelf) habitats. Patterns and processes in this complex landscape vary spatially within and between sites, and temporally on multiple scales (tidal, diurnal, seasonal, and interannual). Overlain on this spatial and temporal variation are long-term trends caused by climate change, sea level rise, and human alterations of the landscape. These long-term trends are likely to manifest in many ways, including changes in water quality, river discharge, runoff and tidal inundation patterns throughout the estuarine landscape. The overarching goal of the GCE program is **to understand the mechanisms by which variation in the quality, source and amount of both fresh and salt water create temporal and spatial variability in estuarine habitats and processes, in order to predict directional changes that will occur in response to long-term shifts in estuarine salinity patterns**.

The objectives of the current funding cycle are 1) to continue to document long-term patterns of environmental forcing to the coastal zone, 2) to link environmental forcing to observed spatial and temporal patterns of biogeochemical processes, primary production, community dynamics, decomposition and disturbance, 3) to investigate the underlying mechanisms by which environmental gradients along the longitudinal (freshwater-saltwater) and 4) lateral (upland-subtidal) axes of estuaries drive ecosystem change, and 5) to explore the relative importance of larval transport and the conditions of the adult environment in determining community and genetic structure across both the longitudinal and vertical gradients of the estuary. To meet these objectives, we utilize a suite of approaches including long-term monitoring of abiotic drivers and ecosystem responses; manipulative and natural experiments designed to enable us to examine the importance of key ecosystem drivers; and modeling.

Broader impacts: The goal of GCE outreach is to enhance scientific understanding of Georgia coastal ecosystems by teachers and students, coastal managers, and the general public. The GCE schoolyard program is built around long-term contact and mentoring of educators, and has involved 40 teachers to date. At the college level, both undergraduate and graduate students are routinely incorporated into our work, and several investigators have integrated GCE research into the classroom. To reach coastal managers, we partner with the Georgia Coastal Research Council (GCRC) to promote science-based management of Georgia coastal resources by facilitating information transfer between scientists and managers. The GCRC has representation from 9 Universities, 6 Federal agencies, and 4 State and regional agencies. It hosts workshops, assists management agencies with scientific assessments, and distributes information on coastal issues. To reach the general public, GCE scientists routinely participate in public meetings and workshops, and we partner with non-profit organizations on the Georgia coast to address questions of public interest. Data collected by the GCE-LTER project can be accessed by other scientists and the general public via our website (http://gce-lter.marsci.uga.edu/lter/), which uses a state-of-the-art information system to manage and display information on study sites, research, taxonomy, data sets, publications, and project administration.

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*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

Section 1: Results of Prior LTER Support

The Georgia Coastal Ecosystems (GCE) LTER project, located on the central Georgia coast, was established in 2000 (this is our first renewal proposal). The GCE domain is sited along three adjacent sounds (Altamaha, Doboy, Sapelo) and encompasses upland (mainland, barrier islands, marsh hammocks), intertidal (fresh, brackish and salt marsh) and submerged (river, estuary, continental shelf) habitats. Patterns and processes in this complex landscape vary on multiple scales, both spatially (within and between sites) and temporally (tidal, diurnal, seasonal, and interannual). Overlain on this spatial and temporal variation are long-term trends caused by increasing human population density, which influences land and water use patterns; climate change, which affects sea level rise and precipitation patterns; and other alterations, such as dredging or changes in fishing strategies. The goal of the GCE program is **to understand the mechanisms by which variation in the quality, source and amount of both fresh and salt water create temporal and spatial variability in estuarine habitats and processes, in order to predict directional changes that will occur in response to long-term shifts in estuarine salinity patterns**. To do this, we seek to understand how coastal processes respond to environmental forcing, and to determine which scales of variability are of primary importance.

During our first funding cycle, we developed a program of research activity addressing the five LTER core areas (primary production, populations, organic matter cycling, inorganic nutrients, disturbance), established information management and project management protocols, participated in LTER network activities, and established a strong outreach program. Since 2000, GCE researchers have produced over 100 publications, including 19 theses and dissertations. These accomplishments have created a strong foundation for the ambitious plan we propose for the next funding cycle.

1.1. Scientific activities. Both the monitoring and directed research activities of GCE-I were focused on evaluating temporal and spatial variation in environmental forcing and ecosystem response. Monitoring occurs at a grid of ten sites that are distributed along an onshore-offshore gradient across our domain and span the full range from tidal fresh to tidal marine habitats. The program was designed to support all GCE research areas by documenting temporal and spatial variation in key ecosystem variables, including measurements of the atmosphere, groundwater, riverine inputs, the water column within the estuaries, and intertidal areas (marsh sediments, vegetation, and invertebrates). To support this program, we installed a variety of permanent plots and instruments, often in collaboration with other organizations (Sapleo Island National Estuarine Research Reserve, United States Geological Survey, National Atmospheric Deposition Program). Monitoring data are available on our web-accessible public data catalog. We have also identified relevant long-term datasets collected by these and other agencies (National Oceanographic and Atmospheric Administration, National Weather Service) and are making these available through our data portal (http://gce-lter.marsci.uga.edu/portal/monitoring.htm).

Our research program has examined a variety of estuarine processes at temporal scales ranging from hourly (variation in turbulent mixing; Kang and Di Iorio 2005) to decadal (changes in Altamaha River discharge and chemistry; Weston et al., submitted.), and at spatial scales ranging from individual plots (plant genetics; Richards et al. 2004, 2005) to the continental shelf (carbon export; Wang and Cai 2004) to the entire Atlantic Coast (latitudinal variation in herbivory and decomposition; Newell et al. 2000; Pennings and Silliman 2005). We have worked on topics ranging from molecular taxonomy (Buchan et al. 2002) to microbial community ecology (Lyons et al. 2005) to trophic interactions (Thoresen and Alber, submitted; Zimmer et al. 2004). Here, we highlight the results of selected studies that evaluated changes in water inflow (river, ground, or ocean water) and the effects of these changes on marsh and estuarine processes, because the current proposal builds directly on these topics.

Freshwater-marine gradients. The Altamaha River is the largest source of freshwater to the GCE domain. Median flow from the Altamaha is 245 m^3s^{-1}, although flows vary considerably over both seasonal and interannual scales. On an annual scale, discharge peaks in Feb-April and is low during the summer. The early years of GCE-I encompassed most of a 4-year drought (1999-2002) that reduced median discharge to 81 $m^3 s^{-1}$, which was reflected in increased salinities at all GCE sites. Nutrient concentrations vary with river discharge: Nitrate + nitrite (NO_x) dominates dissolved nitrogen flux during low river discharge whereas dissolved organic nitrogen (DON) increases in importance during high flow (Weston et al. 2003).

Freshwater inflow patterns, along with tidal forces, determine salt distributions in the GCE domain. The Georgia coast has a semi-diurnal tidal regime, with a tidal height of 1.8 m (neap) to 2.4 m (spring). The tide reaches the ocean stations within 10 minutes of the same phase, and propagates to the upstream edge of the domain within about 1.5 h (Blanton unpublished). The main tidal constituent is the semi-diurnal lunar (M2), which exceeds other tidal constituents 10-fold. Frictional forces induced by bottom drag produce the quarter-diurnal M4 constituent, which distorts the tidal wave as it progresses upstream (Friedrichs and Aubrey 1988; Blanton et al. 2002). The relative phase of M4 to M2 indicates that the ebb tide is about the same length and strength as the flood in Sapelo Sound, whereas Altamaha Sound is dominated by ebb flows due to pressure gradients associated with freshwater discharge.

Differences in the magnitudes of the fresh and saltwater flows across time and space affect a variety of ecosystem processes, including water chemistry, soil accumulation, biogeochemical cycling and the ecology of multiple taxa and interactions (Alber 2002). For example, dissolved inorganic nitrogen concentrations are highest in Altamaha Sound (implying a riverine source), whereas the highest silicate concentrations are observed in Sapelo Sound with decreasing concentrations upstream (suggesting an oceanic source). Both dissolved organic carbon (DOC) concentrations and the ratio of dissolved inorganic nitrogen to phosphorus (DIN:DIP) vary seasonally in Altamaha Sound as a result of seasonality in river discharge and within-sound biological processing. Carbon cycling is also affected by variations in salinity: Weston et al. (2006a) found that sulfate reduction rates in soils increased at higher salinities, resulting in doubled decomposition rates. These data help explain observed decreases in rates of soil accumulation (burial of C and N) at high salinity (and sulfate) vs. low salinity (and sulfate) sites (Craft submitted). *A major goal of GCE-II will be to separate, via experiments and modeling, the roles of salinity versus sulfate in driving longitudinal (down-estuary) patterns of biogeochemistry, soil accumulation, and species composition.*

Groundwater inflows. Groundwater enters the GCE domain via sub-marsh flow, at seepage fronts, and as baseflow to tidal creeks. During GCE-I we used a combination of geophysical and hydrological methods to determine hydraulic conductivity across the upland-marsh interface. We installed monitoring well fields at three sites (GCE 3, 4, 10), characterized sediments, and used noninvasive methods to delineate water levels and interfaces (electromagnetic data, ground-penetrating radar) (Schultz and Ruppel 2005). We found considerable heterogeneity in hydraulic conductivity both within (Fulton et al. 2001) and among sites, depending on microtopography, soil type, the morphology of the creek/marsh interface, and the degree of macropore development (Schultz and Ruppel 2002). Schultz and Ruppel (2002) concluded that a significant fraction of groundwater discharge into estuaries occurs as either baseflow into tidal creeks or as submarsh flow (although the relative importance of these two pathways has not yet been determined).

The chemistry of groundwater differs from that of surface water (Snyder et al. 2004; Joye et al. 2006, submitted). Groundwater from Sapelo Island was higher in DIP and organic C, N and P than was Altamaha River water (Porubsky et al., in prep.). The lunar cycle affected water chemistry: groundwater was more saline and reduced during neap tides and less saline and more oxidized during spring tides (Porubsky et al., in prep.). This redox switch resulted in higher concentrations of nitrate in groundwater on spring tides and higher concentrations of ammonium, phosphate, reduced iron and hydrogen sulfide on neap tides. The biogeochemical mechanisms underlying this switch are under investigation. Because groundwater flow alters porewater salinity and nutrient chemistry, it is likely to be an important factor in determining the productivity and distribution of plants and animals. *A second major goal of GCE-II will be to test hypotheses about the importance of groundwater-derived inputs of freshwater to adjacent marsh systems.*

Population and genetic responses to abiotic variation. Marsh plants respond to spatial variation in abiotic conditions at multiple scales. At the scale of individual sites, plants respond to environmental gradients through phenotypic plasticity rather than adaptation (Richards et al. 2005). Among sites, zonation patterns differed as a function of water column salinity and the nature of the marsh-upland interface (Pennings, unpublished). Along an estuary, plant community types shifted from salt to brackish to freshwater, with some evidence that these shifts correspond to high-tide (as opposed to average) salinity (Higinbotham et al. 2004). The factors structuring marsh plant communities differed between GA and New England because of geographic differences in soil salinities and salinity tolerances of the flora (Pennings et al. 2003; 2005b). Photosynthesis varied as a function of the daily and monthly tidal cycles, and end-of-season biomass varied among years as a function of salinity (Pennings unpublished). The severe drought in 1999-2002 altered plant zonation patterns in individual marshes (Pennings unpublished), altered the distribution of marsh community types along the estuary (White 2004), and likely contributed to widespread marsh “dieback” (Ogburn and Alber in press).

Marsh invertebrates also show striking differences in abundance among sites and over time. Some species are more common where larval influx from the ocean is likely to be high; others are associated with low (or high) salinity habitats; and others appear to require adjacent upland habitats (Bishop and Pennings unpublished). The 1999-2002 drought sharply reduced populations of estuarine macroinvertebrates typically found in low-salinity conditions. Biomass of fungi in decomposing leaves varied little among years or marsh elevation, but peaked in winter and spring (Newell 2001). Fungal biomass did not vary within a plant species across the estuarine salinity gradient, or across latitude, but plant species typical of brackish and freshwater sites had lower fungal contents (Newell et al. 2000; Newell 2003). Plants varied in palatability to herbivores across edaphic gradients within sites (Goranson et al. 2004), and also geographically (Pennings et al. 2001; Pennings and Silliman 2005; Salgado and Pennings 2005). *A third major goal of GCE-II will be to determine the relative contributions of recruitment and post-recruitment performance in creating spatial patterns in plant and animal abundance and genetic structure across the GCE landscape.*

Long-term changes. We expect that anthropogenically-driven changes in surface flow (increased water withdrawal), decreases in groundwater infiltration (increases in overland runoff associated with development), and increases in seawater inflow (sea level rise) will combine to affect abiotic conditions (i.e. nutrient and sulfate concentrations, salinity, soil moisture), that will in turn affect estuarine resources (species composition, abundance and distribution; primary and secondary production). These predicted shifts in the quality, source and amount of both fresh and saltwater to the study domain will result in long-term directional changes in ecosystem processes. *Our monitoring program is designed to detect these long-term changes against a spatially and temporally varying background, and to support hypothesis-driven experimental work designed to unravel their mechanisms and determine their importance.*

1.2. Information management. Despite being a new project, we have developed an IM approach that meets the highest LTER IM standards (Section 4). We have established a comprehensive information system (GCE-IS), based on relational database and dynamic web application technology, to manage and display information on study sites, research, taxonomy, data sets, publications, and project administration. We have developed a suite of software tools for metadata-based data processing, quality control, and analysis, and coupled these tools with the GCE-IS to support dynamic metadata generation and automated data distribution via a web-based data catalog and MATLAB client applications. All LTER network standards and protocols are fully supported by the GCE-IS, and EML 2.0 metadata (exceeding Level 5 of the EML Best Practices guidelines) is automatically generated for all data sets (278 as of Dec. 2005). We have also assumed a leadership role in IM at the Network level. Our Information Manager, Wade Sheldon, formerly served on the LTER IM Executive Committee and was recently appointed to the LTER NIS Advisory Committee. He has also led a working group at LNO, served as editor of the LTER DataBits newsletter, and assisted information managers from five other LTER sites in developing EML implementations. He developed the USGS Data Harvesting Service for HydroDB (http://gce-lter.marsci.uga.edu/lter/research/tools/usgs_harvester.htm), co-authored the specification used to harvest EML documents from LTER sites, and pioneered dynamic synchronization of EML metadata with the LNO Metacat server and NBII Metadata Clearinghouse. The rapid adoption of emerging network standards at GCE has also benefited projects such as NCEAS, SEEK and NBII which use GCE metadata and data to design and test the next generation of data discovery and integration tools.

1.3. Program management. At the beginning of GCE-I, the program was administered by Hollibaugh and Pennings, with Project Director Hollibaugh making most administrative decisions with input from Pennings and other senior co-PIs. As the project matured, and with encouragement from the mid-term site review, we developed a formal Executive Committee (EC) and adopted formal bylaws (Section 3). The program is now governed by the EC, which has assumed responsibility for administration and oversight. The EC communicates electronically on a daily basis and meets several times per year. The full GCE membership meets once per year to review progress and plan upcoming activities. This meeting is attended by our Advisory Committee, which provides input on all aspects of project research and administration. Sub-groups of scientists meet informally throughout the year to work on joint research activities. GCE scientists have obtained more than $6,600,000 in external funding for additional projects that coordinate with the GCE program to achieve shared objectives (see Budget Justification).

1.4. Network participation. We have been in the forefront of network IM activities, as described above and in Sections 4 and 5. We have also participated in several cross-site research activities. Pennings is a member of the cross-site nitrogen fertilization synthesis group, which has published two papers (Pennings et al. 2005a; Suding et al. 2005) with two more in preparation. Craft has participated in the working group synthesizing data on organic matter preservation in wetland soils. Research by Newell and Pennings on latitudinal gradients in fungal decomposition and plant-herbivore interactions has compared results from multiple coastal LTER and NERR sites, and Hollibaugh is involved in a similar comparison focused on ammonia oxidation. In GCE-II, we explicitly fund three cross-site comparisons (the cross-site fertilization synthesis group [see UH budget justification], the effect of upland habitats on biodiversity in coastal systems [Section 2, question 4], and large scale genetic patterns [Section 2, question 5]). Finally, several of us (Burd, Sheldon, Hollibaugh, Joye and Alber) participated in LTER Planning Grant activities, and Hollibaugh is on the organizing committee for the upcoming All Scientist's meeting. We are scheduled to host an LTER CC meeting in the spring of 2008.

1.5. Outreach and Human Resources. Thirty undergraduates and 38 graduate students have participated in GCE research, with 19 graduate students completing degrees. GCE-I involved scientists and students from 5 institutions (UGA, GA Tech, SKIO, IU, UH), and we continue to attract new collaborators from a variety of institutions as we move forward (Section 3). During GCE-I we developed a schoolyard program built around long-term contact and mentoring of educators that has involved 40 teachers to date. Our schoolyard coordinator, Hembree, has raised external funds to almost triple schoolyard funding, made 14 presentations at science education conferences, and co-authored the Education Handbook for system-wide SLTER programs (Section 5). We partnered with the Georgia Coastal Research Council (GCRC) to promote science-based management of Georgia coastal resources by facilitating information transfer between scientists and managers. The GCRC, which is headed by Alber, has 86 affiliated scientists, with representatives from 9 Universities, 6 Federal agencies, and 4 State and regional agencies. The GCRC hosts workshops, assists management agencies with scientific assessments, and distributes information on coastal issues (Section 5). Finally, we have developed partnerships with the Altamaha Riverkeeper, Georgia Department of Natural Resources (DNR), the National Atmospheric Deposition Program (NADP), the Sapelo Island National Estuarine Research Reserve (SINERR), the Nature Conservancy (TNC) and the United States Geological Survey (USGS) to collect data of mutual interest.

Section 2: Project description

INTRODUCTION

The GCE LTER project (**Fig. 2-1**) is located along three adjacent sounds on the Georgia coast (Altamaha, Doboy, Sapelo) and encompasses upland (mainland, barrier islands, marsh hammocks), intertidal (fresh, brackish and salt marsh) and submerged (river, estuary, continental shelf) habitats. The Altamaha River is the largest source of freshwater to the GCE domain and provides a natural gradient of freshwater inflow to the sites. It drains a watershed of 36,700 km^2 and is relatively unmanipulated (2 dams far upstream, free-flowing for approximately 200 km). On the ocean side, the domain is bounded by the South Atlantic Bight, which extends from Cape Hatteras, NC to West Palm Beach, FL. The broad expanse of the Continental Shelf in this area helps to protect the coast from wave and storm activity but it also serves to funnel the tides, which are semi-diurnal and range in height from 1.8 m (neap) to 2.4 m (spring).

Over the coming decades, the Georgia coast (like all coastal areas) is expected to experience substantial changes due to factors such as climate change, sea level rise, and human alterations of the landscape. In addition, the landscape likely bears legacies of several thousand years of human occupation (Thompson et al. 2004), although these have been poorly documented. These effects are likely to be manifest in many ways, including major changes in runoff and inundation patterns throughout the estuarine landscape. **The overarching goal of the GCE LTER is to understand the mechanisms by which variation in the quality, source and amount of both fresh and salt water create temporal and spatial variability in estuarine habitats and processes, in order to predict directional changes that will occur in response to long-term shifts in estuarine salinity patterns**.

Coastal areas are among the most developed regions on Earth. More than 50% of the U.S. population now lives in coastal counties, which comprise only 17% of the land area (U.S. Commission on Ocean Policy, 2004); a larger fraction of the population impacts these environments intermittently via recreational and vocational activities. Ten thousand new housing units were built in coastal Georgia from 1999 to 2001, and the coastal population is expected to double in the next 25 years (State of the Coast Report, 2004). This increase in population and accompanying land use change affects downstream water quality: over the past 18 y, Verity (2002; Verity et al., submitted) has documented significant increases in the concentrations of nutrients and chlorophyll *a* and significant decreases in oxygen concentrations in Georgia coastal waters. Humans can also affect downstream water delivery either directly, via flow diversion, channel modifications, reservoirs and dams, point source discharges; or indirectly, via changes in land cover, which affect the proportion of overland runoff versus groundwater infiltration. These types of changes are causing coastal managers throughout the world to consider water withdrawal policies that can protect estuarine environments (reviewed in Alber 2002). The state of GA is currently working to set appropriate targets for water permitting that will protect downstream resources, and one of us (Alber) is serving as a technical advisor to the Georgia Environmental Protection Division for this process.

Future climate change will also affect freshwater delivery to the coast (Boesch et al. 2000). Miller and Russell (1992) predicted that the annual average discharge of 25 of the 33 largest rivers of the world would increase under a scenario in which atmospheric CO_2 doubled.

In the Altamaha River, one commonly used climate change model (the Hadley model) predicts that flow will increase by as much as 55% by the end of the century, whereas the drier, hotter Canadian model predicts that inflow will decrease (Wolock and McCabe 1999; Boesch et al. 2000). Regardless of the directional change in flow, most models agree that there will be an increase in extreme rainfall events and thus increased variability of freshwater runoff in the future. Despite the uncertainty involved in predicting future inflow changes, there is ample evidence that climate oscillations over interannual and decadal timescales affect the inflow of freshwater to coastal systems. During GCE-I, a 4-year drought (1999-2002) reduced median discharge from 245 to 81 $m^3 s^{-1}$, causing increased salinity and altered water quality throughout the GCE domain. During drought years, concentrations of DON were elevated 2-3 fold above average flow conditions, and DON exceeded DIN by a factor of 2-3. The drought also resulted in upstream shifts in the distribution of both plants and animals along the estuarine gradient (White 2004; Bishop, unpubl.) and has been tied to observations of marsh dieback (Silliman et al. 2005).

Finally, sea level is inexorably rising along the low-gradient coastal plain environments of the world. Under all model scenarios, the rate of sea-level rise is expected to increase over the coming decades as higher global temperatures accelerate both glacial melting and expansion of ocean and coastal waters (IPCC, 2001). In Georgia, sea level is rising at a rate of 0.3 cm/y (NOAA 2001). Low-lying intertidal areas are particularly sensitive to these changes, as only slight variations in vertical position can affect large parts of the landscape. Modest increases in sea level increase the productivity of marsh plants and increase rates of marsh accretion (Morris and Haskin 1990; Morris et al. 2002), but rapid rates of sea level rise will "drown" marshes that cannot accrete fast enough to keep pace with sea level. As the land/water boundary encroaches steadily onto the upland, the increased hydraulic head will cause saltwater to intrude further into coastal aquifers (Michael et al. 2005; Schultz and Ruppel, 2002), changing the quality and quantity of potable groundwater. Rising sea levels will also drive salty surface water further inland, causing fresh and brackish marshes to convert to salt marshes, and will increase the extent of coastal flooding during storm surges from Atlantic hurricanes and Nor'eastern storms.

CONCEPTUAL MODEL

During GCE-I, we began to describe the patterns of variability in estuarine processes with an emphasis on water inflow as a primary environmental forcing function. The Altamaha River exports large amounts of freshwater to Altamaha Sound. This freshwater can reach adjacent estuarine areas by flowing through the wetland complex or by tidal inputs of the Altamaha plume into other sounds. We found that 75% of the variability in salinity in the Altamaha estuary can be explained by discharge alone (Sheldon and Alber 2005). As one moves from Altamaha to Sapelo Sound the correlation of salinity with discharge has an increasing time lag, from 1 to 8 d (Di Iorio unpublished). However, at site GCE 1 (downstream from a small watershed), salinity is most strongly correlated with local precipitation with a 5.1 d lag, suggesting groundwater inputs. As a result of these differences in freshwater inflow, Altamaha Sound has low and variable salinities, whereas salinities at most sites in Sapelo and Doboy Sounds are higher and fairly stable. We documented the marked spatial variation in freshwater inflow across the domain and put this information together into a conceptual model of the relative importance of different water flow pathways through the three sounds (**Fig. 2-2**). This model has allowed us to interpret broad-scale spatial patterns across the domain, such as the differences in decomposition rates between fresh, brackish and salt marshes (**Fig. 2-3**).

We now propose to add a more detailed understanding of the movement of water between subtidal, intertidal and terrestrial habitats to this conceptualization (**Fig. 2-2**). This expansion takes into account not only freshwater-marine gradients along the longitudinal axis of the estuary, but also the lateral gradients that include tidal exchange on and off the marsh platform and water flow from the upland (in the form of both groundwater and overland runoff), as well as direct precipitation and evapotranspiration. Changes in the quantity or quality of water in any of these flow paths can potentially affect habitat conditions, biogeochemical cycles, and ecosystem dynamics. For example, locations with enhanced groundwater discharge near GCE-10 have higher concentrations of both N and P relative to river or sound water (Porubsky and Joye, unpublished).

During GCE-II, we will continue our focus on patterns of variability, but we will also work to elucidate the mechanisms that underlie this variation and in particular the extent to which gradients in water inflow drive landscape patterns. In so doing, we recognize the necessity of evaluating the interaction of inflow-driven changes with other factors that influence estuarine processes (i.e. geologic setting, organismal interactions, etc.). **The central paradigm of GCE-II is that variability in estuarine ecosystem processes is primarily mediated by the mixture of fresh and salt water flow across the coastal landscape.** This proposal seeks to answer 5 main inter-related questions:

In order to be able to understand the effects of external drivers such as climate change, sea level rise, and anthropogenic alterations of the landscape, we need to document their patterns over both time and space. **Question 1 (Q1):** ***What are the long-term patterns of environmental forcing to the coastal zone?***

Variability in external forcing (documented in Q1) is manifest as environmental gradients (e.g., gradients in salinity or nutrients) within the coastal landscape. These environmental gradients cause variations in local biological, chemical, and geological processes, which in turn may feed back to affect environmental gradients. This complex set of interactions produces the observed ecosystem patterns across the landscape. In order to understand these interactions, it is necessary to describe temporal and spatial patterns of biotic and abiotic variables. The variables of interest to us span all five of the LTER core research areas. **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?***

The data collected to answer questions 1 and 2 can be used to describe the longitudinal salinity gradient of the estuary over time and space, and examine how well salinity correlates with observed patterns in ecosystem processes. 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 that of sulfate on ecosystem processes, given that these factors are correlated across the estuarine gradient. **Q3:** ***What are the underlying mechanisms by which the freshwater-saltwater gradient drives ecosystem change along the longitudinal axis of an estuary?*** Similarly, data collected to answer questions 1 and 2 can be used to describe lateral gradients in the intertidal zone (from the creek edge to the marsh/upland interface) and the extent to which they are correlated with changes in groundwater discharge and/or runoff from adjacent uplands. In order to predict how future changes in these inputs might affect coastal ecosystems, it is again necessary to understand the mechanisms that drive these patterns. **Q4:** ***What are the underlying mechanisms by which proximity of marshes to upland habitat drives ecosystem change along lateral gradients in the intertidal zone?***

Populations of plants and animals vary across the estuarine landscape. Some of the variation in population density is likely driven by variations in salinity, as noted above (Questions 3 and 4). However, population density may also be affected by transport mechanisms and larval shadows that affect larval delivery, the presence of adjacent upland habitat, habitat suitability for adults, and competition. **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?***

PROPOSED RESEARCH

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

In order to forecast the future state of coastal ecosystems to environmental change, we need to document long-term patterns of environmental forcing to the coastal zone. We accomplish this goal through our monitoring program and by synthesizing long-term datasets. Long-term monitoring data serve three purposes. First, they provide a context for short-term studies by documenting contemporaneous environmental conditions. Second, because these data are collected at frequent intervals, they provide information on short-term temporal variation in environmental forcing (e.g., daily, tidal, lunar and seasonal patterns). Third, given enough years of data, we can search for long-term trends.

The GCE monitoring program (**Table 2-1**) directly collects or obtains from other organizations data on local climate (temperature, precipitation, wind speed and direction), Altamaha River discharge and water chemistry, and sea level fluctuations associated with tides and storms. Additional oceanographic and climate data from offshore locations in the South Atlantic Bight are available from the SABSOON network. Additional climate data from stations throughout the Altamaha River watershed are available through NWS.

Some long-term data on environmental forcing in the coastal zone are already available from NWS, USGS, NOAA and other sources. During GCE-I we obtained and began retrospective analyses of several such datasets. Sea level is rising along the Georgia coast, but with considerable variation at decadal and annual scales (**Fig. 2-4**). Over the last several decades, local precipitation and Altamaha River discharge varied seasonally (**Fig. 2-5**) but did not show clear long-term directional patterns (**Fig. 2-6**). Nitrogen loading to the watershed, however, has increased in concert with alterations in land use (development) and increases in atmospheric deposition and fertilizer use (Weston et al., submitted). Consequently, concentrations of dissolved N and chlorophyll in the estuary increased by factors of 4 and 3.6, respectively (Schaeffer and Alber, unpublished).

During GCE-II we will continue to 1) monitor patterns of environmental forcing and the propagation of freshwater to the coastal zone, 2) obtain relevant long-term datasets from other organizations, and 3) synthesize these data to identify long-term trends driving coastal ecosystems. In particular, the UGA Marine Extension Service is compiling all available historic water quality observations for the Georgia coast into a single GIS. When the project is complete, we (Alber) will take advantage of this information and work with Marine Extension to integrate it with the GCE-LTER database.

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?

We are interested in 1) how variability in environmental forcing (Q1) creates environmental gradients (e.g., gradients in salinity or nutrients) within our study area, and 2) how these environmental gradients affect a variety of ecosystem processes. Questions 3-5 below address aspects of this problem in detail, but we also address it more generally through our monitoring program.

The 10 GCE monitoring sites are distributed along an onshore-offshore gradient across three sounds (**Fig. 2-1**) and experience different patterns of environmental forcing (**Fig. 2-2**). To document environmental gradients across the GCE landscape, we monitor water column salinity, temperature, and pressure every 30 min, and measure nutrient chemistry, and chlorophyll concentrations monthly (**Table 2-1**). During GCE-II we will also deploy Solinst$^{®}$ temperature, salinity and pressure loggers adjacent to the sediment elevation tables to record short term variability on the marsh platform at each site. These instruments will allow us to rigorously link tidal fluctuations in the water column to patterns of marsh inundation and salinity variation in the pore water. We measure upland and marsh groundwater levels and chemistry monthly at permanent wells installed at sites 3, 4 and 10 and will install wells at additional marsh hammock sites during GCE-II. To document ecosystem responses to environmental gradients, we monitor soil accumulation, compaction and decomposition, and plant and animal biomass, densities, and community composition (**Table 2-1**).

Spatial variability in environmental forcing creates a wide range of environmental conditions across the GCE monitoring sites, which range from tidal fresh to tidal marine systems (**Table 2-2).** Daily variation in Altamaha River discharge is reflected in the salinity regime at most GCE sites (**Table 2-3**). An exception to this is site 1, where salinity is better correlated with recent precipitation than with river discharge, suggesting a higher degree of groundwater influence. Annually, Altamaha River discharge peaks in Feb-April, whereas coastal precipitation peaks in late summer (**Fig. 2-5**). On an interannual scale, Altamaha River discharge and coastal precipitation are quite variable and do not show clear directional trends (**Fig. 2-6**).

Spatial variation in water inflow contributes to the observed patterns of water column chemistry. Dissolved and particulate carbon and nutrients (N, P, Si) and iron varied among the three sounds, with the highest DIN concentrations in the upper Altamaha indicating riverine input and high DOC and low N:P ratios on the landward site of Sapelo Sound suggesting groundwater input **(Table 2-4**). However, biological processes also drive variability: we have observed internal processing of DON to NO_3 via ammonification and subsequent nitrification in

Altamaha Sound, creating a mid-estuarine peak in NO_3 (Joye, unpublished data). Spatial variation in salinity was also related to soil properties. Vertical accretion, percent organic C, N, N:P and accumulation of organic C and N were negatively correlated with salinity (**Fig. 2-3**, Craft, submitted). Finally, spatial variation in salinity was correlated with the distributions of many plant and animal species (**Fig. 2-7**). The underlying mechanisms driving population patterns are explored in detail in question 5 below.

We are currently using these monitoring data to explore spatial variation in ecosystem processes (e.g., questions 3, 4 and 5 all will rely on background data provided by the monitoring program). In addition, we expect to eventually correlate annual variation in estuarine processes with Altamaha River discharge, rainfall, sea level and resulting salinity patterns. For example, changes in Altamaha River discharge are reflected in salinity and water quality, with NO_x dominating dissolved nitrogen loading during low flow but DON increasing in importance during high flow (Weston et al. 2003), and annual monitoring has identified considerable variability in plant biomass, the proportion of stems flowering, and the location of borders between vegetation zones (**Fig. 2-8**). Similarly, annual monitoring of invertebrates has identified considerable temporal variation in abundance and distribution patterns across the GCE domain. Initial data suggest that temporal population variation of plants and animals is correlated with environmental drivers, but rigorously documenting these relationships will require much more than 6 years of data. We anticipate that a major goal of GCE-III will be to synthesize data on annual variation in abiotic forcing and ecosystem response.

In addition to our core monitoring program, we have obtained external funding for several other projects that will address how ecosystem processes in the GCE domain are driven by environmental forcing. Craft, Pennings, and Joye were funded by EPA to forecast how rising sea levels will affect ecosystem services of tidal fresh, brackish and salt marshes on the Georgia coast. Alber and Joye (along with Mark Hester and Irv Mendelssohn) have EPA funding to evaluate the effects of drought-induced plant mortality on key ecosystem services provided by salt marshes (eutrophication control, carbon sequestration, sustainable habitat, and faunal support). Joye has been funded by Georgia Sea Grant to study how groundwater influences marsh and tidal creek processes at Moses Hammock (GCE 10). Finally, Bishop is working with SINERR and the LTER Schoolyard Program to monitor the populations of invasive green porcelain crabs (*Petrolisthes armatus*) at selected GCE sites.

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

Background: We have used salinity as a first approximation to explain differences among fresh, brackish, and marine tidal marshes. However, salt is not the only ecologically relevant component of seawater: saltwater has not only higher ionic strength compared to freshwater, but also about 280 times more sulfate (SO_4^{2-}). Differences in biogeochemical redox zonation and soil metabolism between freshwater and saltwater sediments result from differences in SO_4^{2-} availability: in SO_4^{2-}-poor freshwater sediments, terminal metabolism is dominated by methanogenesis and iron reduction, whereas in SO_4^{2-}-rich marine sediments, it is dominated by SO_4^{2-} reduction (Capone and Kiene 1988). Sulfides are toxic to both plants and animals, and increased sulfate availability may constrain the distributions of plants and animals lacking adaptations to high sulfide concentrations. Conversely, increased sulfate availability may facilitate the invasion of plants with a high metabolic requirement for sulfate (Stribling 1997). We propose to refine the initial "salinity" perspective of GCE-I by experimentally decoupling the importance of salinity and sulfate in order to improve our mechanistic understanding of seawater intrusion and ecosystem change along salinity gradients. We hypothesize that variation in sulfur is as important as variation in salinity in producing variation in biogeochemical processes, soil structure and species distributions between tidal freshwater and marine marshes.

In GCE-I we conducted a laboratory experiment using flow-through bioreactors to evaluate the time scale upon which geochemical and microbial dynamics were influenced by moderate changes in salinity (Weston et al. 2006a). A 10‰ increase in salinity resulted in rapid and dramatic changes in microbial activity, materials fluxes, and organic carbon mineralization rates. Ammonium release from sediments increased rapidly in response to increased salinity; most of the ammonium was desorbed at low salinity (~7‰; **Fig. 2-9**). After a week of increased salinity, rates of organic carbon mineralization were significantly higher at 10‰ salinity relative to freshwater controls (**Fig. 2-10**); sulfate reduction rapidly replaced methanogenesis as the dominant metabolic mode of sediment microorganisms in the salinity-amended treatments. Increased salinity resulted in a number of other significant biogeochemical changes (**Table 2-5**), including transient uptake of inorganic phosphate into calcium phosphate minerals, persistent increases in silicate release, and increased rates of organic carbon cycling. Increased SO_4^{2-} availability may therefore result in a cascade of effects that impact the pathways and rates of elemental transformation and recycling efficiency of other elements, including C, N, P, S and Fe.

Other work from GCE-I also indicates that tidal marsh soil and sediment properties are strongly linked to freshwater input through sulfate effects on carbon cycling. Freshwater promotes organic C (and N) accumulation (**Fig. 2-3**) through its effect on decomposition rate, not primary productivity (Craft, submitted). There was little difference in above- or below-ground emergent production among salt, brackish and tidal freshwater marshes. However, in situ decomposition of roots was significantly greater in salt marshes than in brackish and tidal freshwater marshes. In addition, the rate of decomposition was positively related to salinity ($r^2=0.58$, $p<0.05$), possibly as a result of both direct (availability of sulfate) and indirect (abundance of fiddler crabs) effects. Sulfate availability may thus profoundly affect the preservation of organic matter in soils, and hence sediment accretion rates and the ability of marshes to keep pace with rising sea level.

Approach: The centerpiece of the work will be an integrated effort to quantify the interplay between geochemical factors, microbial activity, soil preservation, and populations of plants and animals in marsh sediments. Our objectives are: 1) to document existing down-estuary patterns of salinity and sulfate, sediment biogeochemical parameters, soil characteristics, and plant and animal populations, 2) to experimentally assess the responses of sediment biogeochemistry, microbial activity, soil characteristics, decomposition rates, and plant and animal populations to increased salt and sulfate availability, and 3) to integrate the results in a quantitative framework using mathematical models. The methods to be used and specific hypotheses to be addressed are presented in **Tables 2-6** and **2-7**, respectively.

Survey: A field crew will survey soil bulk properties (Craft), geochemical speciation and redox zonation (Joye), vegetation light profiles and plant and invertebrate distributions and biomass (Alber) at 20 stations spanning the full range of the Altamaha estuary from freshwater to fully marine areas (**Table 2-6**). Sampling will be conducted twice during summer (June and August) and will focus on the mid-marsh zone where the experiment will be conducted, although some parallel measurements will also be made at the creekbank. The goal of the survey will be to quantify existing down-estuary patterns of important variables, identify an appropriate site for the experimental manipulation, and generate quantitative predictions for the experiment. Survey data will be analyzed with multivariate regression techniques, including path analysis, to identify relationships between salinity, sulfate, biogeochemical, soil and biotic variables. Results will be interpreted in the broader context provided by the continuous salinity measurements collected as part of the core monitoring program (**Table 2-1**).

Experiment: Based on the results of the survey, we will 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 (control, salinity-amended, sulfate-amended and salinity+sulfate-amended) in which freshwater sediments will be amended with increasing salinity (from 0 to 10 PSU) and/or sulfate (proportional increases, from 0 to 9 mM) in an orthogonal design over 12 months. We will increase pore water ionic strength and/or sulfate concentrations in 3 x 3 m plots (n=6/treatment, separated by > 3 m) by regular additions of NaCl or Na_2SO_4 to shallow (40-cm deep, 5-cm diameter) piezometers (multiple piezometers per plot) made of PVC with regular perforations 5 to 40 cm below the soil surface. Pore water salinity, sulfate and sulfide levels will be monitored weekly in the center of each plot, and additions will be adjusted as needed. The stabilized salinity and sulfate levels will then be maintained over the course of the project. Plots with different treatments will be interspersed within the site and will be maintained weekly by a field technician, who will also be responsible for coordinating sampling in the experimental plots.

We will monitor changes in pore water and solid phase geochemistry and microbial activity, sediment CH_4/CO_2 fluxes (Joye), soil elevation, organic content and C, N and P pools (Craft), epibenthic and infaunal invertebrate abundance, and plant composition and productivity (Pennings) in experimental plots. Samples for determination of nutrients and dissolved gas concentrations will be collected using a piezometer in the center of the plot. Locations for destructive sampling (e.g., cores for organic content) will be mapped within each plot so that they can be avoided in future sampling. Geochemical processes and gas fluxes from soil surfaces will be monitored quarterly while soil bulk properties, light profiles, and plant and invertebrate populations will be monitored annually. Microbial activity will be compared with existing data from sites that were established during GCE-I (Weston et al. 2006b) in conjunction with the Sapelo Island Microbial Observatory (http://simo.marsci.uga.edu/). In addition to the field experiment, the effect of short term variations in substrate concentrations, ionic strength, pH, and H_2S on potential rates of nitrification, denitrification, methane oxidation, methanogenesis and sulfate reduction will be evaluated in slurry experiments in the laboratory (Joye and Hollibaugh 1995; Rysgaard et al. 1999). These data will be used to tune the quantitative model described below.

To expand the number of species for which we can make inferences from this experiment, we (Pennings) will transplant selected plants (likely *Aster tenuifolius*, *A. novae-angliae*, *Scirpus americanus*, *Juncus roemerianus, Polygonum* sp.) and invertebrates (likely bivalves *Polymesoda caroliniana* and *Geukensia demissa*, gastropods *Melampus bidentatus*, *Detracia floridana* and *Littoraria irrorata*) into the experimental plots once salinity and sulfate conditions have stabilized in year 2 or 3 of the experiment (n=2/plot, to be treated as subsamples). Plants will be potted in sandy soil (to facilitate rapid equilibration with new abiotic conditions), acclimated in the lab for 2 weeks, and transplanted into experimental plots for 4 months. Invertebrates will be caged within experimental plots so that they are exposed to ambient sediment conditions for 6 months (Silliman and Bertness 2002). Gastropods will be provided with a standard diet in excess within cages. Transplants will be located in a delimited subsection of each 3 x 3 m plot, well away from locations used for biogeochemical sampling. Experimental data will be analyzed with repeated-measures ANOVA, with salt and sulfate as main effects. These experiments will test the hypothesis that sulfur is more important than salt in creating conditions inimical to species typical of freshwater marshes, and in creating conditions that favor the invasion of brackish marsh species. More specific hypotheses are listed in **Table 2-7**.

Biogeochemical modeling: A numerical reaction-transport model (RTM) will be developed to assess bottom-up control of marsh biogeochemical processes (Meile). It will include descriptions of organic matter breakdown, solid phase formation, and reoxidation reactions (Boudreau 1996; Soetaert and Herman 1996; Wang and Van Cappellen 1996) and use kinetic formulations for microbial metabolic reactions which account for inhibition and competition for reactants (substrates) by competitive reaction pathways. Results from laboratory slurry experiments will be used parameterize the model. In particular, we will use data on the effects of substrate concentrations, temperature, ionic strength, pH, and H_2S on N and S cycling, as well as the role of temperature variations on breakdown of organic matter (Weston and Joye 2005). The reactive transport model will build on our existing tools, and include a flexible and user-friendly interface where advances in our understanding of coupled biogeochemical interactions can be easily incorporated (Regnier et al. 1997; Meile 2003; Aguilera et al. 2005). Model results will be calibrated by comparison to field data (concentration and rate profiles). The RTM will be used to systematically interpret the measured chemical and microbial gradients in terms of reaction pathways, transport rates and fluctuations in boundary conditions, with particular attention to how alteration of external forcings affects elemental budgets, benthic fluxes, redox zonation, pathway competition, microbial-geochemical couplings and nutrient regeneration. Although the model will be a general description of marsh biogeochemical processes, and hence widely-applicable to a range of problems, the short-term goal of the model will be to evaluate our understanding of marsh biogeochemistry by comparing model output with biogeochemical patterns observed in the salt-amended and sulfate-amended experimental plots.

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

Background: Marshes occur adjacent to terrestrial habitats, and this ecotone between terrestrial and wetland habitats is characterized by increased spatial heterogeneity compared to either marshes or uplands alone. Many species need both habitats in order to survive and may transfer materials between them. For example, egrets and other shore birds feed in the marshes but roost in (and defecate from) trees on hammocks (small islands surrounded by marsh) or other upland areas (Depkin et al. 2005). Grasshoppers feed in the marsh but may retreat to upland habitats during extreme high tides and/or to lay their eggs (Pennings, pers. obs.). Semi-terrestrial crabs, *Armases*, live in the marsh but frequently forage more than 100 m inland during periods of high humidity (Pennings et al. 1998). One can think of isolated upland areas within expanses of marsh as "keystone structures" (sensu Tews et al. 2004), providing critical resources and shelter for terrestrial organisms that use marshes, in the same way that as clumps of trees growing in African savannas are considered essential habitat for a variety of organisms (Dean et al. 1999).

In addition to providing habitat, upland areas also deliver freshwater to adjacent marshes as both overland runoff and through various groundwater flow paths (Schultz and Ruppel 2002; **Fig. 2-11**). In the Duplin River near GCE 10, thermal infrared images provide direct evidence of groundwater discharge associated with Moses Hammock (**Fig. 2-12**). This observation is supported by evidence from radium isotopes, which reveal a large enrichment in the Duplin estuary compared to Georgia coastal waters (by a factor of 2-3) that can be explained by the discharge of radium-enriched groundwater (Moore, unpublished data). Despite the importance of groundwater inputs to marsh ecosystems (Mitsch and Gosselink 1993), we lack a predictive understanding of the nature and importance of these flows to adjacent marshes. However, work in New England has indicated that development of uplands strongly affects plant communities in adjacent marshes, likely by mediating the quantity and quality of freshwater input into the high marsh (Silliman and Bertness 2004).

Upland habitats within the GCE domain include the continental mainland and barrier islands as well as a diverse array of marsh hammocks, which are upland areas nested between the mainland and larger barrier islands. There are approximately 1,670 marsh hammocks in coastal Georgia, ranging in size from less than a hectare to tens of hectares (**Fig. 2-13**). Most are remnants of high ground of either Pleistocene (1,110 hammocks) or Holocene (294) age, but there are also man-made hammocks that have developed from dredge spoil or ballast stones (70). Although many of the largest hammocks are developed and have paved roads and houses associated with them, the majority are currently uninhabited. Most, however, were utilized to varying degrees by humans (primarily Native American) in the past, as evidenced by discarded shell deposits and signs of agricultural activity.

The studies proposed here will be focused primarily on high-marsh communities, as the underlying question is whether (and how) freshwater from an adjacent upland controls marsh plant and invertebrate distributions. There is evidence that it does. Research at North Inlet, SC demonstrated that soil salinity and plant community composition can be related to the direction of the hydraulic head, with salt-tolerant plants such as *Salicornia* and *Borrichia* growing in salty areas with downwelling flow, and *Juncus* dominating in areas with upwelling flow, where soil salinities were lowest (Thibodeau 1998; Gardner et al. 2002). However, there are few studies that have explicitly examined the connection between surficial groundwater and the root zone of marsh plants. Vegetation studies during GCE-I were not focused on groundwater influence, per se, but we have shown a) greater variability in pore water salinity in areas dominated by *Borrichia* as compared to *Juncus*, with parallel patterns in the variability associated with net carbon assimilation by the two plants (Pennings and Moore, submitted); b) positive relationships between the amount of upland influence (a proxy for freshwater inflow) and the heights of both *Juncus* and *Spartina* (McFarlin 2004); c) a positive relationship between upland influence and dominance of the marsh by *Juncus* versus other plant species (Pennings et al. unpublished); d) a drought-induced shift in the *Spartina/Juncus* border towards dominance by *S. alterniflora* (Pennings, unpublished, **Fig. 2-8**) and e) improved performance by *Juncus* at the expense of other marsh plants when plots were watered to reduce salinity (Pennings et al. 2005b, Pennings, unpublished, **Fig. 2-14**). Taken together, these observations suggest that the composition of high-marsh plant communities is likely to be a function of delivery of freshwater from adjacent uplands, but this linkage has not been rigorously established.

Approach: The large number and diversity of hammocks in terms of size, development, and origin provide a natural laboratory for evaluating the influence of landscape structure and freshwater input on marsh processes. Studies of hammocks will also serve the needs of the state of GA by providing scientific input into ongoing policy debates regarding the environmental effects of coastal development. Marsh hammocks have become an attractive location for residential growth, and there are several legal disputes regarding the appropriate factors that should be considered when permitting access to hammocks across state-protected marshlands. The resolution of these disputes has been hampered by a lack of scientific information regarding the ways in which upland characteristics might affect the surrounding marshland (Consensus Solutions 2003). Here we propose a combination of observational, modeling, and experimental studies geared towards describing how (and whether) differences in the characteristics of upland environments can affect the adjacent marsh. A set of predictions is in **Table 2-8**. Our goal is to be to able to add information on upland-marsh linkages to our initial description of broad spatial gradients in freshwater inflow across the GCE domain (**Fig. 2-15**).

Survey: We (Alber, Alexander, Joye, Pennings, Thompson) will conduct a broad survey of marshes associated with hammocks representing a range of sizes and origin (n = 30 Pleistocene, 10 Holocene, 10 dredge spoil and 10 ballast stone). This survey will focus on undeveloped hammocks, to allow us to characterize how natural hammocks interact within the landscape. We will also seek additional funding from the State of Georgia to add a set of developed hammocks to this survey. We will use a variety of methods to do a basic categorization of each site in terms of its geomorphology, stratigraphy, flora and fauna (**Table 2-9**). We will augment this survey by sampling stations along the Duplin River with and without visible groundwater input (n = 10 each) based on thermal infrared images to be obtained in the summer of 2006. This aspect of the study will be further enhanced by hyperspectral imaging of the Duplin River, also planned for the summer of 2006, which will provide information on vegetation type and productivity (Schalles 2006) that can then be analyzed in a GIS to determine whether there is a predictive relationship between the presence of groundwater and plant composition (or productivity). Finally, for comparative purposes, we will use the same survey methods to sample the 10 GCE monitoring sites, which vary in terms of their associated upland habitat.

Survey data will be evaluated by regression, ANOVA, and multivariate and spatial statistics techniques (*e.g.,* spatial correlation and empirical orthogonal functions) (Legendre and Legendre 1998; Burd and Jackson 2002) to assess correlative, spatial and temporal relationships between a series of independent (i.e. upland physical characteristics) and dependent (i.e. marsh biodiversity, plant and animal distributions) variables. In particular, we are interested in documenting the distribution and extent of plants and animals at the marsh-upland interface where *Juncus romerianus* and/or *Borrichia frutescens* generally occur as a halo surrounding the hammock, at elevations above those where *Spartina alterniflora* is found (**Fig. 2-16**) and will investigate the role of hammock size, elevation, origin and groundwater flow on vegetation and animal distribution (**Table 2-8**). ***We hypothesize that uplands of different size (ranging from***

small to large hammocks to mainlands) will support a different extent of upland marsh, with different associated fauna because we expect that 1) groundwater input to adjacent marshes will increase with increasing upland size and 2) only larger uplands will support populations of vertebrates (birds, raccoons, deer) that forage in the marsh. ***We further hypothesize that hammocks of different elevation will have different associated marsh plant and invertebrate communities*** because we expect that elevation will affect the hydraulic gradient and hence groundwater inflow to the adjacent marsh. We anticipate correlations among some of our independent variables (i.e. hammock origin will likely correlate with soil composition, with ballast stone islands being coarsest, Holocene islands comprised of sand and Pleistocene islands with a higher silt and clay content), and will explore the data appropriately to account for these relationships.

Cross-site comparison: Although our studies are focused primarily on the marsh, we anticipate that isolated uplands in the form of marsh hammocks will represent "hotspots" of increased biodiversity in the coastal landscape, akin to the role of isolated wetlands in the terrestrial landscape (Tiner et al. 2002). Given that isolated uplands are common in coastal areas, we propose a cross-site component to this study to be done in conjunction with investigators at the Florida Coastal Everglades (FCE) LTER (where tree islands are common) and the Virginia Coast Reserve (VCR) LTER (which has a series of back barrier islands). We will evaluate plant and animal diversity along standard transects that run from a wetland, over an upland and back to the wetland to determine whether the biodiversity "boost" from an upland is similar (and similarly related to size) across these different coastal landscapes. ***We hypothesize that the transition from wetland to upland will result in a sharp increase in biodiversity***. FCE investigators hypothesize that uplands represent areas of high nutrient concentration in the landscape, and will work with us to test this hypothesis. We anticipate that these data will stimulate proposals for more extensive cross-site comparisons of patterns and processes related to landscape heterogeneity (either more detailed studies of landscape heterogeneity in coastal systems, broader comparisons of landscape heterogeneity across a wider range of LTER sites and habitat types, or both).

Intensive characterization: The marsh/upland surveys described above are designed to evaluate how high marsh habitats are related to a range of upland characteristics, but they will not provide detailed measurements of water flow paths or biogeochemical processes, both of which we hypothesize serve to mediate the observed distributions of plants and animals (**Table 2-8**). We therefore plan intensive studies designed to characterize freshwater inflow to high marsh communities in more detail, to relate it to upland characteristics, and to determine how it affects marsh community structure. The choice of the intensive study locations will be based on the information collected in the broad initial survey, but we anticipate selecting two sets of hammocks, 2 of Pleistocene and 2 of Holocene origin, because we expect that differences in origin and age will influence sediment characteristics: Pleistocene hammocks (2 MY-10 KY) are erosional remnants of older landforms and typically exhibit soil development and heterogenous internal layering, whereas Holocene hammocks (<10 KY) are relict dune ridges that consist of permeable, unconsolidated sands. Study locations for the Holocene hammocks have not yet been selected, but the Pleistocene hammocks will be located adjacent to the Duplin River (**Fig. 2-13**) where we already have a great deal of information on inundation patterns (inundation analysis of the Duplin will be completed early in GCE-II) and groundwater characteristics (site GCE-10).

At each of the intensively-studied hammocks, we will obtain a variety of measurements in addition to those collected during the survey. Hammock age (obtained by optical stimulated luminescence, Ivester et al. 2001; Leigh et al. 2003) and the detailed stratigraphic relationships between the hammock interior, marsh/upland transition zone and nearshore marshes will be documented. We will install groundwater monitoring wells to provide access to groundwater, for water table measurements, and for pumping tests (to determine permeability) at the upland edge (**Fig. 2-15**), and will delineate distinct surface, subsurface and creek water end members using radium isotopes (^{224}Ra, ^{223}Ra, ^{226}Ra, ^{228}Ra) measured by delayed coincidence counting and gamma-ray spectrometry (Moore and Arnold 1996). In the marsh, we will install depth-stratified piezometer arrays (**Fig. 2-15**) and use an AMS® soil water sampler to obtain porewater and groundwater samples for measurements of nutrients at 10-40 cm intervals throughout the upper 2 m of soil. Soil temperature profiles and the duration of inundation will also be measured (continuous loggers), as will evapotranspiration (Mao et al. 2002), all of which are necessary for determining sub-surface flow patterns in the marsh (see Modeling, below). In order to better understand the interactions between marsh and groundwater-influenced pore water characteristics over time, we will measure both the vegetation and benthic invertebrate distribution in the intensively monitored areas. These measurements will include measurements of the rooting depth, transpiration, drought stress (pre-dawn xylem pressure potential) and gas exchange of individual plants.

To assess competitive performance, we (Pennings) will also perform an experimental manipulation of the vegetation in the high marsh habitat, which is generally dominated by either *Borrichia* or *Juncus*. We have already established that *Borrichia* does poorly when transplanted into *Juncus*-dominated areas because of competition from *Juncus* (Pennings et al. 2005b), but we have not done the converse experiment, nor have these observations been coupled to measurements of freshwater availability. As part of this project, we (Pennings) will perform reciprocal transplants of *Juncus* and *Borrichia* into both types of habitat, with and without neighbors. ***We predict that in high marsh habitats with low freshwater delivery only Borrichia will thrive, whereas at sites with consistent freshwater inflow Borrichia will be competitively excluded in the presence of Juncus.*** Differences in freshwater inflow will likely affect animals as well, with some taxa responding directly to changes in groundwater flow conditions, and others responding to changes in the plant community because they use plants as food or habitat. We will therefore conduct parallel experiments with high-marsh macroinvertebrates that are associated with the two different types of hydrological conditions (Silliman). For example, the high-marsh clam *Polymesoda*, which is associated with moderate salinity conditions, will be transplanted into the high marsh in areas with high and low freshwater inflow, and success measured as survival and growth.

Modeling: Large scale shallow subsurface flow patterns between hammock and creeks will be established by building upon available finite element codes (Comsol 2005, Meile and Tuncay 2005). Measured hydraulic head and permeability measurements will be spatially interpolated (Harvey and Gorelick 1995, Wen 1996, de Marsily et al. 2005). Together with infiltration/evapotranspiration rate estimates they will be employed to assess water movement using a Darcy approximation and water continuity (e.g. Richards 1931, Voss and Provost 2002, Ursino et al. 2004). Given the uncertainty in driving forces and observed heterogeneity in marsh soil hydraulic conductivities (Schultz and Ruppel 2002), model simulations will be validated by the radium based water balance. Water fluxes to and from marsh soils will be assessed following

Gardner and Reeves (2002). Vertically resolved fluid transport estimates will be validated using temperature profiles (e.g., Kurian 1999).

To investigate how changes in the relative amounts of groundwater and sub-surface flow affect plant species growth and competition, we will develop a plant model linked to the water model described above (**Fig. 2-15**). The plant model (Burd) will involve explicit descriptions of plant below- and above ground biomass of *Spartina*, *Juncus* and *Borrichia*, with particular attention to rooting depth (since that will affect pore water availability and quality). The biomass models will be driven primarily by irradiance within the canopy, salinity and sediment nutrient availability (Morris 1982; Morris 1989; Bradley and Morris 1991; Dai and Wiegert 1996; Burd and Dunton 2001; Eldridge et al. 2004). Competition between the species will be based upon salt tolerance and light competition. The plant model will be coupled with nutrient distributions computed from a simplified soil model (see Q 3) in order to predict changes in the distribution of *Spartina*, *Juncus* and *Borrichia* with changes in surficial groundwater. Results from the plant manipulations will be compared with model predictions and used to help refine the model assumptions.

Manipulative experiments: Finally, we are interested in understanding the effects of manipulating water flow on marsh processes. We will explore this in three ways. First, we will take advantage of the "natural experiments" currently being performed on the Georgia coast by working with the state DNR to sample hammocks that are slated for development. Development, and the associated increase in impervious surface, is expected to alter freshwater flow patterns by increasing the proportion of overland sheet flow at the expense of groundwater infiltration, which we anticipate will alter water availability for the upland edge vegetation. We will therefore collect pre-development data at hammocks slated for development on the vegetation (i.e. the location of the *Juncus/Spartina* border; mapping of *Borrichia* and *Juncus* zones) as well as some simple measures of groundwater distribution (i.e. water level, salinity), which we can revisit over time. One of us (Alexander) serves on the State Marshland Protection Committee and so is in an excellent position to know about specific projects as they are proposed. This information will be used as preliminary data to develop a more extensive proposal to the State of Georgia to evaluate effects of hammock development. Second, the finite element model validated at the intensive study sites will be used to estimate the impact of surface sealing associated with hammock development on subsurface-surface water distribution and flow patterns. Plant responses will be inferred using altered groundwater input estimates as forcing functions in the plant model. Third, we will use both experimental results and modeling predictions to guide us in initiating a long-term experiment designed to alter the water balance and flow patterns within designated portions of hammocks monitored during our intensive studies. We anticipate that this experiment will involve "paving" an appropriate area of the upland consistent with statewide building setbacks from the marsh (25') with heavy plastic sheeting. This should increase overland runoff at the expense of infiltration, which should influence pore water dynamics and hence the marsh community. This manipulation will be ongoing to allow us to evaluate the long-term consequences of flow alteration, which we expect will affect a variety of ecosystem processes.

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?

Background: Almost all taxa examined, from marine invertebrates to plants to herbivorous insects, vary in abundance among our sites (Bishop and Pennings, unpublished). Salt marsh ecologists have a good understanding of how abiotic and biotic factors interact to control distributions of plant species across elevation gradients within single marshes (Pennings and Bertness 2001). Much less work has been done at the landscape scale, but we do have a preliminary understanding of the processes that mediate plant distributions along the salinity gradients of estuaries (Crain et al. 2004; Higinbotham et al. 2004). Less is known about the mechanisms that influence the distribution of marine or terrestrial invertebrates along the estuary, with the exception of a few commercially-important species.

We are interested in the distributions of both plants and animals with a range of life histories. Salt marsh plants are highly clonal, and their population distributions will be determined in large part by the performance of established clones. Similarly, populations of animals with direct development will be affected primarily by adult performance and reproduction at each site. In contrast, populations of animals with planktonic larvae are likely to be highly affected by factors mediating the movement of larvae and subsequent recruitment to each site. Ecologists working in rocky intertidal (Connell et al. 1997; Connolly and Roughgarden 1998; Connolly et al. 2001) and coral reef (Connell et al. 1997; Hughes et al. 1999; 2002) habitats have extensively addressed the roles of recruitment, competition and predation in producing population and genetic structure across the landscape (Caley et al. 1996). In contrast, these processes are only beginning to be addressed in soft-sediment systems (Hughes and Stachowicz 2004), and very few studies have been done in salt marsh habitats.

Species with planktonic larvae will recruit most heavily at sites where currents carry abundant larvae from source populations (Leonard et al. 1998). Sites that are "downstream" of suitable sites may experience a recruitment "shadow" because most competent larvae in the water column have already settled (Victor 1986), and sites without an upstream source of larvae will also experience low recruitment (Possingham and Roughgarden 1990) (**Fig. 2-17**). In contrast, currents may have little influence on recruitment of marine invertebrates with direct development, insects or plants (except for those with floating seeds). Moreover, larvae of some marine invertebrates from estuarine habitats behaviorally exploit or defeat current patterns, potentially obscuring simple relationships between currents and larval supply.

Once they are established, the performance of plants or animals will be affected by habitat quality. The landscape distribution of different habitat types (upland, intertidal, subtidal) will interact with spatially variable inputs of fresh and sea water to create a mosaic of habitat patches with varying suitability for any particular species. Habitat quality will not necessarily correlate with recruitment or population density. As described above, planktonic larvae may never reach high-quality sites if these sites lack an upstream source of larvae or are downstream from other high-quality sites. Similarly, species requiring upland habitat for some phase of their life cycle will rarely colonize high quality marsh patches far from upland patches. Although estuarine scientists have long appreciated that particular species may be confined to particular salinity regions of an estuary, variation in salinity alone is unlikely to explain population patterns because many species are tolerant of a wide range of salinities. Moreover, GCE sampling has documented that landscape factors not correlated with salinity are also correlated with distribution patterns. For example, the gastropod *Littoraria* is more abundant at barrier island sites than at mainland sites (even when these do not differ much in salinity), whereas grasshoppers are abundant at sites adjacent to upland (either barrier island or mainland) and absent at mid-estuary sites (**Fig. 2-7**).

Finally, performance will also depend on interactions with competitors and consumers. High competition or predation may lead to low survival and growth, even if sites are otherwise of high quality. In particular, high recruitment of a species is likely to produce intense intraspecific competition, leading to a negative correlation between recruitment and individual size. Variation in habitat quality and interactions with conspecifics and other species may lead to different patterns of local selection across the landscape, with different genotypes dominating the adult population at different sites, even if the recruit population is well mixed across sites.

The approach that we take here of comparing multiple plant and animal species with a range of life histories will represent a major step forward in our understanding of population distributions in estuarine habitats. We will address three major questions: **1) What are the relative contributions of recruitment and post-recruitment survival in explaining variation in population distributions across the GCE landscape? 2) How do these processes differ among species as a function of life history? 3) How do patterns of genetic diversity correlate with patterns of functional diversity?** Addressing these questions for a range of taxa will build an understanding of the factors mediating large-scale distribution patterns of coastal species that is unmatched for any estuarine system, and will provide an interesting contrast to results from the PISCO program that is addressing similar questions in rocky intertidal systems on the Pacific Coast of the U.S. (Connolly et al. 2001).

Approach: We will address these questions using a suite of methods that have been refined in rocky intertidal and coral reef systems. In particular, we will document distribution patterns, measure recruitment using larval traps, outplant species with and without competition to measure post-recruitment survival and growth, use molecular tools to identify patterns of genetic structure across sites, and use cellular automata models to explore how various mechanisms might create population structure across the landscape. We will use a comparative approach, working with a range of species chosen for ecological importance, experimental tractability, and contrasting life histories.

Adult distributions: To document distribution patterns, we (Bishop, Pennings, Silliman) will continue our monitoring program, which provides data on the abundance (and in many cases, size and reproductive status) of selected plants, marine invertebrates and insects at two intertidal elevations at all GCE sites (**Table 2-1**). In years 1 and 2 we will conduct additional targeted sampling to document densities and sizes of taxa that are poorly sampled by our routine monitoring program. For example, the marsh mussel *Geukensia demissa* is poorly sampled by our routine monitoring program because it has a low density but highly aggregated distribution that needs to be sampled using plots much larger than those we routinely employ.

Larval recruitment: To measure spatial patterns of recruitment of macroinvertebrates with planktonic larvae, we (Bishop, Silliman) will deploy a suite of larval traps (**Table 2-10**) at the 9 main GCE sites in years 1 and 2. In some cases, additional sites will be added to increase site-level replication for tests of focused hypotheses about how particular landscape features mediate recruitment patterns. Otherwise, the statistical approach will be to correlate recruitment with adult densities across the 9 sites to evaluate how well recruitment predicts adult density. The different types of traps will target all the common species with planktonic larvae except a few for which we lack appropriate trap designs (e.g., *Polymesoda*). Traps will be deployed repeatedly to ensure we capture periods of peak recruitment for each target species. Traps with short deployment periods will be deployed during both spring and neap tide cycles to compare high- and low-amplitude tidal cycles. Similar larval traps have been used extensively to document recruitment in other habitats (Connolly et al. 2001). Because larval traps integrate larval supply over their entire deployment period, only capture larvae that are competent to recruit, and effectively sample species that may be rare in the plankton, they are a more cost-effective and appropriate tool for our purposes than plankton tows.

Post-recruitment processes: To measure post-recruitment survival and growth, we (Pennings, Silliman) will outplant selected plant and animal taxa (**Table 2-11**) at the 9 main GCE sites in years 1-4, focusing on species that are the most amenable to these experiments and that provide interesting life-history or distribution comparisons. When appropriate, outplants will be done with and without competition, and data will be analyzed with two-way ANOVA (with site and treatment as main effects). Outplants of many species will be conducted in cages that will exclude consumers from both competition treatments (Silliman and Bertness 2002). In other cases, we will be able to distinguish mortality (or partial damage) due to consumers from that due to abiotic stress, and will take this into account during analyses. Rigorously documenting effects of consumers on all the target species with manipulative experiments would be a very intensive project beyond the scope of this proposal, but if observations indicate that consumers affect the landscape distribution of particular species we will pursue this in future work (e.g., a proposal examining predator effects on *Littoraria* is in development by Silliman).

Genetic structure: We (Wares) will use standard molecular (DNA-based) markers to identify patterns of genetic structure across sites and compare these relationships among different taxa (**Table 2-12**) in years 1 and 2. We will use assignment tests and analysis of molecular variance (Excoffier et al. 1992; Excoffier et al. in press) to describe the spatial genetic structure of adult populations in order to identify sites that are likely exchanging recruits freely and sites that are isolated from others, and to identify sites with reduced genetic variation indicative of strong local selection. Detailed models of isolation and migration patterns will be developed (Hey and Nielsen 2004). To the extent that each species is a replicate analysis of the GCE sites (Wares and Cunningham 2001), we should be able to gain insights into population structure even if some species are only analyzed with a single universal mtDNA locus. We are particularly interested in comparing species with high and low dispersal ability, expecting the latter to show more population structure, and in comparing free-spawning invertebrates with those that have direct sperm transfer, expecting the former to have much higher inbreeding structure (Addison and Hart 2005). Comparisons of inbreeding structure (as measured by F_{is} statistics) may reveal otherwise unrecognized spatial population structure, variation in rates of molecular evolution in certain taxa, or high variance in reproductive success that may differ among sites in the GCE system (Turner et al. 2002).

Modeling: We (Burd) will investigate population patterns across the landscape using cellular automata models in order to examine potential impacts of physical processes and landscape structure on recruitment processes. These models will be phenomenological, similar to those developed by Roughgarden and collaborators (Possingham et al., 1994; Alexander and Roughgarden, 1996) to explore patterns of larval dispersal and recruitment of Pacific Coast rocky intertidal species. These models will be used to identify and rule out possible mechanisms producing recruitment patterns, and to support the development of sampling strategies to test more detailed hypotheses about recruitment of particular species. Our long-term goal is to incorporate lessons learned from these models and our recruitment sampling into a hydrodynamic model of the GCE system. Zheng et al. (2004) have developed hydrodynamic models of other systems on the Georgia coast, and Georgia Sea Grant has plans to apply this model to the Altamaha system. If this application is successful, we will build on it in our subsequent work.

Linkage to questions 3 and 4: Inputs of freshwater from precipitation, overland flow, groundwater and rivers create both longitudinal and lateral gradients in salinity and chemistry across the estuarine landscape. As a result, populations vary in their distributions along both axes. Variation in sulfate concentration may be particularly important because microbial processes in waterlogged soils convert sulfate to sulfide, which is toxic to many plants and animals. Thus, the issues discussed in questions 3 and 4 also have fundamental consequences for the distribution of species across the landscape. As described in those sections, we (Pennings, Silliman) will conduct outplant experiments with both plants and animals as part of these projects, and the population studies in questions 3, 4, and 5 will be mutually informative.

Cross-site efforts: Our long-term goal is not only to understand population processes at the GCE site, but to place these in the context of the entire Atlantic Coast. To this end, the genetic studies will include samples from VCR (Virginia), PIE (Massachusetts) and the GTM NERR (Florida). In addition, Pennings and Silliman plan to continue externally funded work studying plant-herbivore interactions along the Atlantic Coast of the U.S.

INTEGRATION

We are using a combination of monitoring, experiments, and modeling to understand the drivers of change in estuarine ecosystems. This proposal also addresses all the major suggestions of the mid-term site review team.

Monitoring: Our monitoring program is designed to support all GCE research areas by documenting temporal and spatial variation in key ecosystem variables. As such, it provides a large-scale and long-term perspective on the research questions that we ask and stimulates new questions. We have repeatedly referred to our monitoring program in discussing Questions 1-5, above. Here, we briefly summarize it for completeness.

The monitoring program addresses the five LTER core areas and includes measurements of the atmosphere, river inputs, the water column within the sounds, marsh sediments, marsh vegetation, and marsh invertebrates (**Table 2-1**). Each component includes a variety of measurements at various spatial and temporal scales. The program proposed here essentially extends the monitoring program developed during GCE-I for an additional six years (for a total of 12 y). Minor modifications to the program to improve cost-effectiveness and value include 1) reducing the frequency of invertebrate sampling from twice to once a year, 2) increasing the frequency of sound water column sampling from quarterly to monthly while reducing the number of variables measured, and 3) adding continuous measurements of salinity, temperature and pressure to marsh soils. We are adding a second full-time technician position at Sapelo Island. The two field technicians will conduct most of the field work for the monitoring program, with training, QA/QC and data analysis provided by the appropriate supervisory PIs.

Various aspects of the program involve collaborations with other agencies, including SINERR, USGS and NADP. We have also identified relevant long-term datasets collected by other agencies and are making these available through our data portal (http://gce-lter.marsci.uga.edu/portal/monitoring.htm). For example, we obtain oceanographic data from NOAA, climate data from NWS, Duplin River water quality data from SINERR and Altamaha River discharge data from USGS. Many of these datasets extend back several decades.

Experiments. With this proposal, we are initiating two major field manipulations to evaluate the effects of changes in water flow. By manipulating salt and sulfate concentrations in a freshwater marsh, we will be able to evaluate both the short- and long-term responses of the microbial, plant, and invertebrate communities to an increase in salinity. Salinity might increase throughout Georgia estuaries as the result of several different mechanisms (i.e. sea level rise, climate change, upstream consumption). Separating salt from sulfur will improve our mechanistic understanding as to which of these is actually driving observed changes along salinity gradients. By manipulating the flow of upland water into the high marsh, we will be able to evaluate how a shift from groundwater to overland runoff affects the adjacent community. This type of shift is designed to mimic flow changes that will occur in response to increased development in the watershed (i.e. an increase in impervious surface). Once again, the long-term nature of this experiment means that we will be in a position to evaluate both the immediate and long-term effects of these changes, and how they might interact with natural variation in river discharge, sea level, and climate. We are also taking advantage of the natural experiments being performed by developers (i.e., construction on hammocks) to document how development of coastal hammocks affects marsh communities. In addition, our studies of population distributions will involve a diverse suite of experiments, some of which will be nested within the salt/sulfate and upland linkage studies (Questions 3 and 4).

Modeling. The mid-term review team encouraged us to better develop the modeling elements of the project. We have done this in a variety of ways. The site-scale modeling pertaining to the salt/sulfate focus area (Q3) will form the basis for a simplified reaction network to be used in the plant model, and the larger scale water flow assessment (Q4) will provide the quantitative framework for scenario analysis for plant scale simulations (Q 4). Cellular automata models will be integrated with population studies (Q5). In addition, we (Alber) have developed a desktop modeling tool (called SqueezeBox) that can be used to predict salinity distributions and estuary residence times for various flow rates in the Altamaha (Sheldon and Alber 2002). We have recently received external funding (Georgia DNR) to extend Squeezebox to model non-conservative tracers (i.e. nutrients), and we will take advantage of the GCE data for calibration and validation. We expect that a major focus of future work during GCE-III will be to link annual variation in abiotic forcing (Q1) to variation in ecosystem/population processes (Q2), and anticipate that this effort will also involve a major modeling component.

Synthesis. The mid-term review team encouraged us to ensure that the various aspects of our research were well integrated. We have addressed this recommendation in three ways. First, as described above, we have integrated synthetic modeling approaches throughout all the major aspects of our work. Second, we have proposed three major field efforts (addressing questions 3, 4 and 5) that are intentionally multi-disciplinary. Each will unite several of our PIs around a common field effort. Third, we have budgeted for three postdocs in years 5 and 6 who will be tasked specifically with assisting synthesis efforts for questions 3, 4 and 5. The work done during this funding cycle will provide information on how alterations in freshwater flow (either longitudinal changes in the salinity gradient or lateral changes in the relative amount of groundwater versus overland runoff), will affect estuarine ecosystems (in terms of nutrient cycling, microbial communities, plant productivity, decomposition, and plant and animal populations). Our long-term goal is to create an integrated model that predicts how various scenarios of changes in long-term drivers (i.e., sea level rise, changes in precipitation, water withdrawal from rivers) will affect marsh function.

Other recommendations of the mid-term review team. The mid-term review team suggested that we increase our attention to higher trophic levels. In this proposal, our population work in questions 3, 4 and 5 focuses on both plants and animals. In addition, we continue to monitor both plant and animal populations (Question 2). The mid-term review team also encouraged us to develop cross-site collaborations. In this proposal we explicitly fund cross-site research on 1) effects of upland habitats on species diversity (a comparison between VCR, GCE and FCE), 2) effects of nitrogen fertilization on plant diversity at multiple LTER sites (assisting an existing cross-site synthesis group), and 3) genetic structure of coastal populations (VCR, GCE and GTM NERR). Work by several of our PIs (especially Craft, Pennings and Silliman) has an explicit geographic component and will likely lead to more cross-site collaborations in the future.

Finally, the mid-term review team encouraged us to expand our capability for dealing with spatial data and GIS. In response to this, we are hiring an assistant IM with formal GIS training. This person will provide GIS support for the project and will also assist Sheldon with routine input and QA/QC of datasets. As described in the bridge funding supplement proposal (a supplemental proposal requested by NSF that would fund GCE from May 1 to November 15 to coordinate our funding cycle with that of other LTER sites), a major activity during the summer of 2006 will be to obtain data layers of the Duplin River watershed that will be incorporated into a GIS framework. The immediate goal of the GIS analysis will be to determine whether elevation and the presence of groundwater inputs predict plant composition and productivity at the landscape scale. This will help answer some of the basic questions about upland-marsh linkages that we will address during GCE-II. One of our new PIs (Alexander) also has GIS capabilities, which will be used for analyzing and integrating the data collected during the hammock survey (Question 4). We will continue to develop our GIS capabilities over time and anticipate that this will prove useful in addressing a variety of additional research questions during GCE-II and in the future.

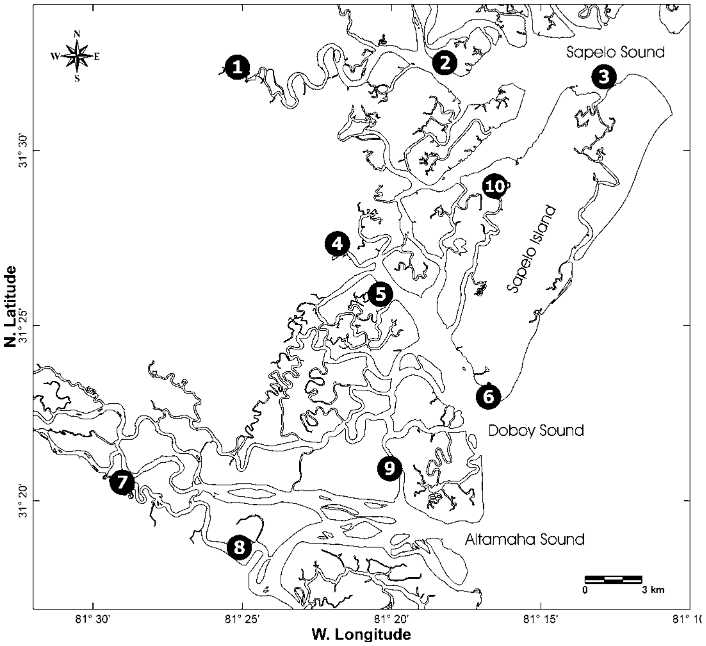


Fig. 2-1. GCE domain on the coast of Georgia, with core study sites marked. Sites are located on an onshore-offshore gradient on three sounds that differ in freshwater input. Altamaha sound, to the south, receives large amounts of freshwater discharge from the Altamaha River. Doboy and Sapelo sounds have no permanent river inflows. Site 10 is located on the Duplin River on the west side of Sapelo Island.

Fig. 2-2. Conceptual models guiding GCE research. **Left:** Longitudinal perspective showing relative contributions of river discharge, groundwater flow, oceanic influence and net flow in three coastal sounds. **Right:** Lateral movement of water among subtidal, intertidal and upland habitats; A & B: river discharge and tidal flow combine to move water up and downstream, C: tidal exchange brings water on and off the marsh platform, D: precipitation, E: precipitation leads to overland flow (runoff) if soils are saturated or impermeable, F & G: groundwater may flow directly into the marsh or may transit under the marsh to emerge sub-tidally, H: evapotranspiration. By layering this model on top of the landscape model on the left, we will gain a more sophisticated understanding of spatial variation in ecosystem processes across the GCE landscape.

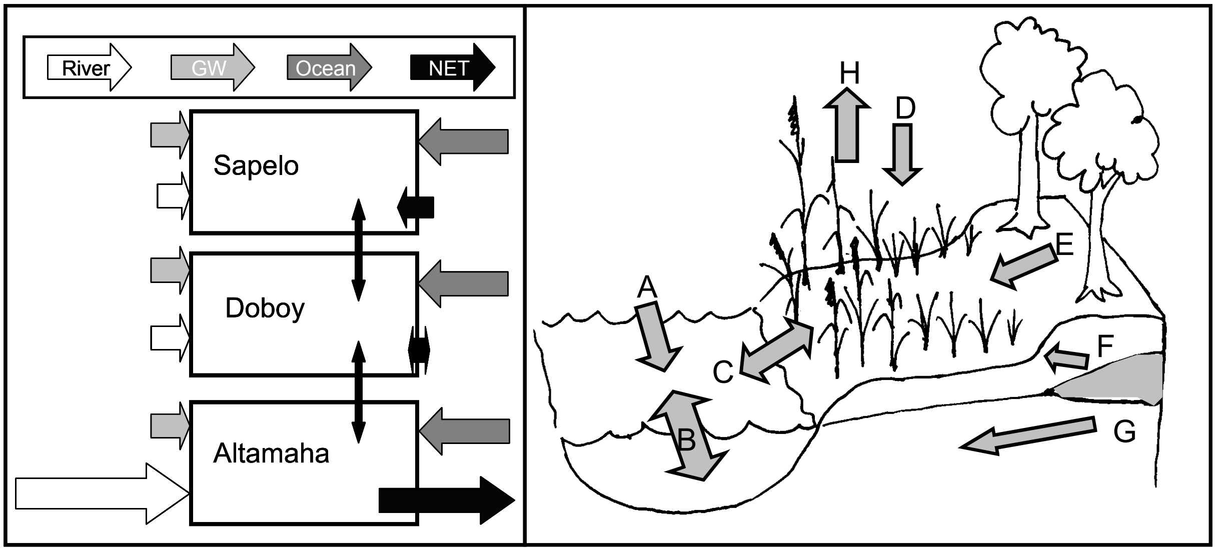
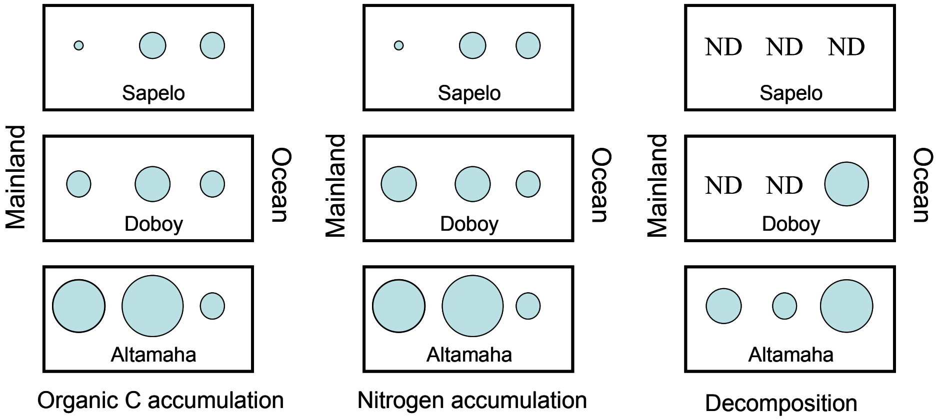


Fig. 2-3. Relative amounts of organic carbon (g $m^{-2}y^{-1}$) and nitrogen (g $m^{-2}y^{-1}$) accumulation across the landscape in comparison to decomposition rates (kg y^{-1}). C and N accumulation are highest in freshwater and brackish marshes (upper Altamaha Sound) whereas decomposition rates are highest in salt marshes (lower Altamaha Sound, lower Doboy Sound). ND: Not determined (Craft, submitted).



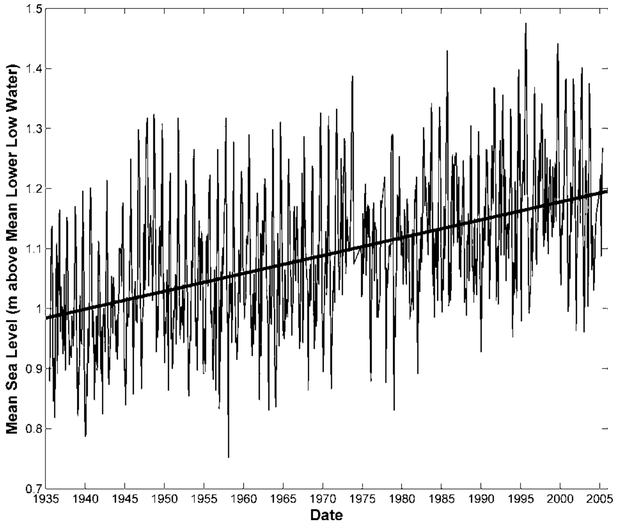


Fig. 2-4. Sea level has risen about 0.3 cm/yr over the last 50 years along the Georgia coast. Variation about this trend reveals an annual fluctuation of about 20-30 cm caused by the annual increase in specific volume of the North Atlantic Ocean from solar heating. Less obvious are fluctuations over a time scale of several years due to interannual variations in atmospheric pressure and the wind field associated with it. Data are from CO-OPS station 8670870 at Fort Pulaski, Savannah, Georgia. NOAA Center for Operational Oceanographic Products and Services (www.co-ops.nos.noaa.gov).

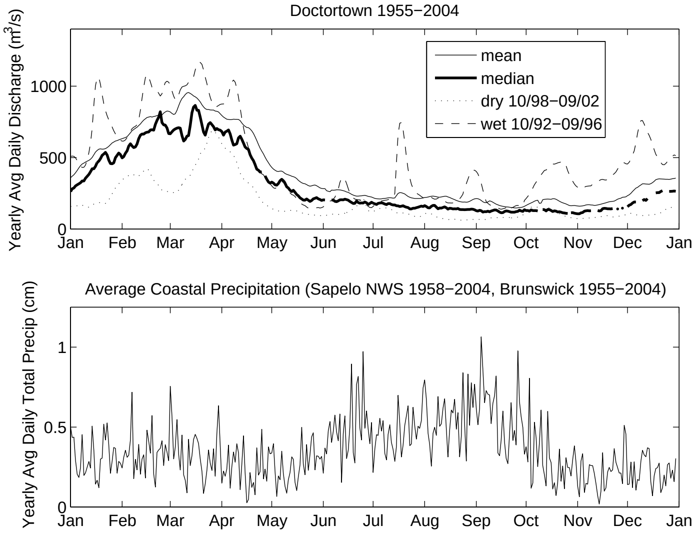


Fig. 2-5. Annual cycle of freshwater input into the GCE domain. **Top:** Altamaha River discharge at Doctortown GA, 50 year daily mean and median, with extreme dry and wet periods superimposed. Data from USGS. **Bottom:** precipitation at Brunswick and Sapelo Island GA National Weather Stations (patterns were similar and were averaged). Data from NWS.

Table 2-1. Monitoring program for GCE-II. PIs responsible for supervising each aspect of the monitoring program are indicated in parentheses. LTER core areas are 1: primary production, 2: populations, 3:organic matter cycling, 4: inorganic nutrients, 5: disturbance.

Type	Location	Frequency	Core Area & Variables Measured
Atmospheric			
Weather stations, collaborations with SINERR, USGS (Di Iorio)	Sites 4, 6	Every 15 min	Abiotic driver of areas 1-5: > level 2 stations, measuring PAR, temperature, relative humidity, rainfall, wind speed and direction, barometric pressure
Wet deposition, collaborations with SINERR, NADP (Joye)	Site 6	Weekly	4: Hydrogen (acidity as pH), sulfate, nitrate, ammonium, chloride, base cations (such as calcium, magnesium, potassium, sodium)
Water			
Altamaha River chemistry (Joye)	Head of tide	Weekly or more often	3, 4: DIN, DIP, DSi species, organics (DOC, DON, DOP), major ions, chlorophyll, CN
Altamaha tributaries chemistry (Joye)		Quarterly	3, 4: As above
Groundwater chemistry (Joye)	Sites 4, 10	Monthly	3, 4: Dissolved nutrients (NO_2^-, NO_3^-, NH_4^+, HPO_4^{2-}, $H_2SiO_4^{2-}$), dissolved organics (DOC, TDN, DON, TDP, DOP), redox species, salts
Sound chemistry, collaborations with SINERR, USGS (Joye)	Sites 1-9	Monthly	1, 3, 4: Dissolved nutrients (NO_2^-, NO_3^-, NH_4^+, HPO_4^{2-}, $H_2SiO_4^{2-}$), dissolved organics (DOC, TDN, DON, TDP, DOP), chlorophyll *a*, total suspended sediments, particulate CN, particulate P and Fe
Sound hydrography (Di Iorio)	Sites 1-9	Every 30 min	Abiotic driver of areas 1-5: Salinity, temperature, pressure
Marshes			
Soil accretion (Craft)	Sites 1-10	Quarterly	3: Sediment accretion, elevation, compaction
Soil flooding (Craft)	Sites 1-10	Every 1 min	Abiotic driver of areas 1-5: Salinity, temperature, pressure in soils
Plant productivity (Pennings)	Sites 1-10, 2 zones	Annual	1: Stem density, height, flowering status, calculated biomass, in 2 marsh zones
Disturbance (Pennings)	Sites 1-10	Annual	5: Wrack and biotic disturbance in permanent vegetation plots
Plant distribution (Pennings)	Site 6	Annual	2: Community composition in 3 types of vegetation mixtures
Plant distribution (Alber)	Altamaha Sound stations	Every 2 y	1, 2: Stem density, height, flowering status of *Spartina alterniflora* versus *S. cynosuroides* in creekbank plots
Marsh Invertebrates (Bishop, Pennings)	Sites 1-10, 2 zones	Annual	2: Density and size of benthic macroinvertebrates in 2 marsh zones
Insects (Pennings)	Sites 3-10	Annual	2: Density of grasshoppers in transects

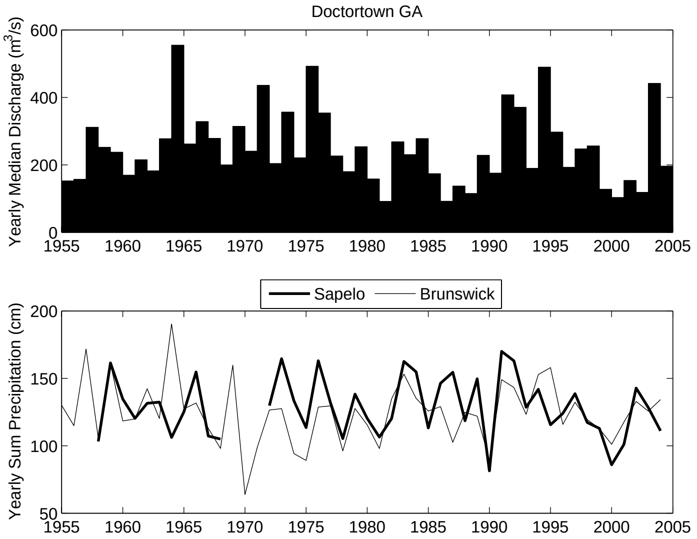


Fig. 2-6. Annual variation in pattern of freshwater input into the GCE domain. **Top:** Altamaha River discharge at Doctortown GA. Data from USGS. Note low discharge in 1999-2002, and earlier but shorter droughts in the 1980s. **Bottom:** precipitation at Sapelo Island and Brunswick NWS stations. Data from NWS.

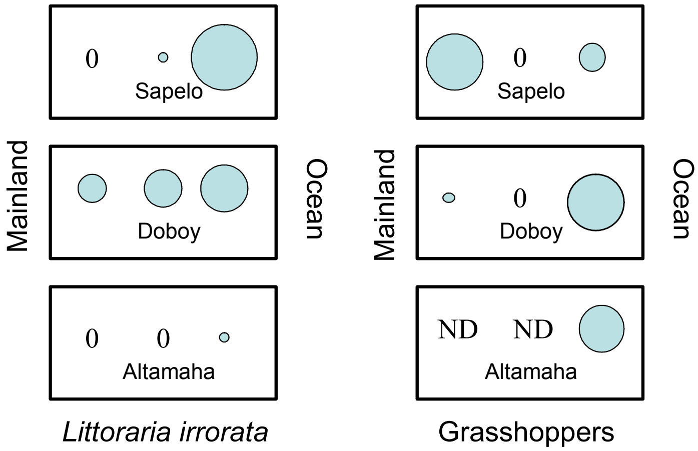


Fig. 2-7. Examples of differing population patterns across the landscape. The gastropod *Littoraria* (left) is most abundant at the oceanic end of each sound, and is rare in Altamaha Sound, whereas grasshoppers (right) are absent in the middle of each sound, where upland habitat is lacking. ND=not determined.

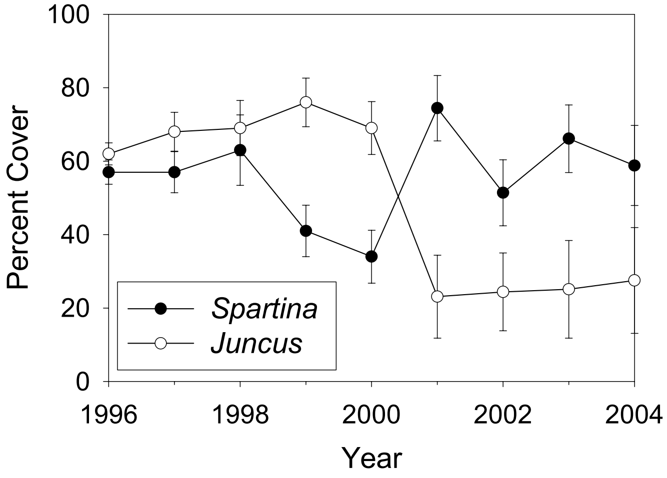


Fig. 2-8. Changes in the location of the *Juncus/Spartina* border at GCE-6. In 2001, two years after the drought began, the *Juncus* border retreated and the *Spartina* border expanded (documented as changes in percent cover in permanent plots located on the border). This 1-2 year lag in *Juncus* response to the drought is likely due to its abundant belowground reserves (Pennings, unpublished).

Table 2-2. Salinity statistics for GCE sites in 2002 (a drought year) and 2003 (a wet year). GCE sites range from almost completely freshwater (7) to brackish and variable (1, 9) to fully marine (2, 3, 6). All sites have a strong (2-3m) tidal range.

	Mean ± 1 SD		**Minimum**		**Maximum**	
Station	**2002**	**2003**	**2002**	**2003**	**2002**	**2003**
Sapelo Sound						
1 (landward)	13.9 ± 10.8	12.2 ± 9.4	0.07	0.03	32.5	28.1
2 (middle)	28.9 ± 2.8	24.7 ± 3.5	18.5	9.5	34.0	30.1
3 (ocean)	31.7 ± 1.5	28.2 ± 2.5	25.8	17.5	34.6	34.2
Doboy Sound						
4 (landward)	25.9 ± 3.3	20.6 ± 4.4	11.7	8.0	32.0	25.6
5 (middle)						
6 (ocean)	29.3 ± 2.4	25.1 ± 3.9	22.2	9.3	34.5	33.5
Altamaha Sound						
7 (landward)	0.3 ± 0.5	0.06 ± 0.03	0.05	0.03	10.5	0.6
8 (middle)	5.5 ± 5.2	1.4 ± 2.5	0.06	0.04	29.6	16.9
9 (ocean)	18.9 ± 8.5	12.0 ± 9.6	0.2	0.04	34.1	31.5

Table 2-3. Correlation of salinity at GCE sites (time-lagged) with Altamaha River discharge or local precipitation (denoted with *) for the period Nov 2001 to Nov 2004.

Station	**Lag (d)**	**Time-lagged r**
Sapelo Sound		
1 (landmost)	5.1*	0.39
2 (middle)	6.7	0.68
3 (ocean)	7.6	0.72
Doboy Sound		
4 (landmost)	6.3	0.82
5 (middle)		
6 (ocean)	6.0	0.81
Altamaha Sound		
7 (landmost)	1.4	0.33
8 (middle)	2.5	0.60
9 (ocean)	3.3	0.75

Table 2-4. Concentrations of DOC and DIN (µM) and molar ratios of DIN:DIP measured quarterly at GCE sites (2001-2003). Data shown are mean ± 1 SD.

Station	**DOC**	**DIN**	**DIN:DIP**	**n**
Sapelo Sound				
1 (landmost)	1532 ± 950	7.4 ± 6.5	3.4 ± 2.2	25
2 (middle)	409 ± 151	4.7 ± 5.8	4.6 ± 4.9	54
3 (ocean)	308 ± 101	3.1 ± 3.4	4.4 ± 4.2	47
Doboy Sound				
4 (landmost)	525 ± 227	4.2 ± 3.1	8.7 ± 16.7	29
5 (middle)	418 ± 262	4.9 ± 5.7	12.0 ± 16	50
6 (ocean)	328 ± 197	3.8 ± 4.3	10.2 ± 15	48
Altamaha Sound				
7 (landmost)	678 ± 316	14.0 ± 8.5	36.5 ± 48	51
8 (middle)	683 ± 318	13.5 ± 7.6	27.7 ± 30.2	51
9 (ocean)	510 ± 313	6.0 ± 5.1	23.2 ± 36.4	51

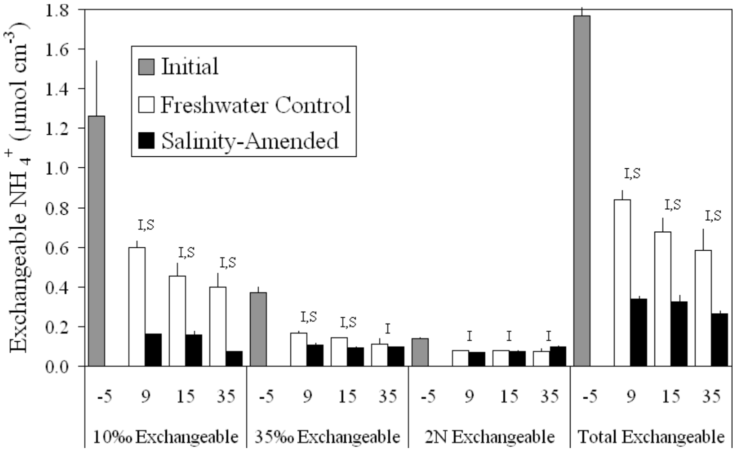


Fig. 2-9. Solid phase ammonium distributions in sediment cores (3-5 cm depth) extracted in 10‰, 35‰, or 2N KCl (summed as total exchangeable NH_4^+). Cores were maintained in flow-through reactors in fresh or salt water and sampled 5 d before and 9, 15 and 35 d after the salinity treatment was implemented. Statistical differences between reactors and initial sediment (I) and between control and salinity-amended reactors (S) are noted (Weston et al. 2006a).

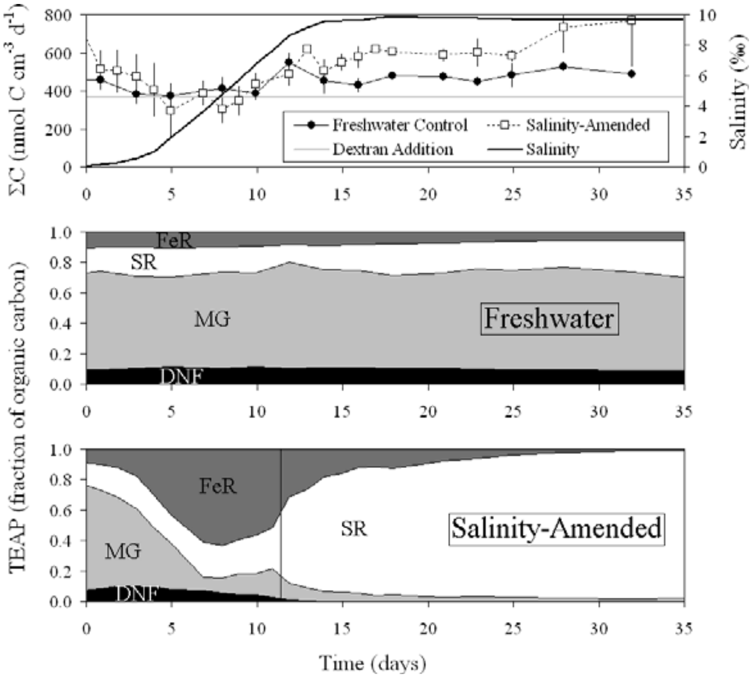


Fig. 2-10. Total carbon production ($\Sigma DIC+CH_4$ production) in control and salinity-amended reactors (top). Dashed line indicates amount of organic carbon added to reactors (nmol C cm^{-3} d^{-1}), right axis indicates salinity in the salinity-amended reactors. Estimated contribution of denitrification (DNF), methanogenesis (MG), sulfate reduction (SR) and iron reduction (FeR) to total organic carbon oxidation in (middle) control and (bottom) salinity-amended flow-through reactors (Weston et al. 2006a).

Table 2-5. Total export from freshwater and salinity-amended sediment flow-through reactors (μmol cm^{-3}) of ammonium (NH_4^+), phosphate (HPO_4^{2-}), silicate (SiO_3^{2-}), reduced iron (Fe^{2+}), methane (CH_4), total inorganic carbon ($\sum C= DIC+CH_4$), and *in situ* carbon (C) from the Altamaha River, and the percent change due to salinity intrusion. These data show increases in C, N, P, Si and Fe export and in total carbon mineralization when salinity intrusion occurred.

	Freshwater	Salinity-Intrusion	Percent Change
NH_4^+	2.84	3.71	30.7
HPO_4^{2-}	1.58	1.90	20.7
SiO_3^{2-}	11.54	15.96	38.3
Fe^{2+}	4.86	12.08	148.6
CH_4	6.93	1.61	-76.8
$\sum C$	16.21	20.29	25.2
in situ C	3.72	7.80	109.7

Table 2-6. General methods for freshwater-marine survey and salt/sulfate experiment.

Soil bulk properties (Craft).	Temperature, porosity, bulk density, grain size, organic content, pools of C, N and P at surface (0-5 cm) and depth (5-10 cm).
Geochemical Speciation and Redox Zonation—pore water (Joye).	Samples (0-5, 10-15, and 25-30 cm depths) analyzed for dissolved gases: $O_2/N_2/Ar$ via membrane inlet mass spectrometry (Kana et al., 1998), CH_4 and N_2O via gas chromatography; alkalinity: titration; dissolved inorganic carbon: infrared detection; pH: high impedance electrometer; redox species: Fe^{2+} and H_2S via colorimetric assay (Joye et al. 1996); nutrients: colorimetric assays following digestion for organic components (Joye et al. 1996); sulfate/chloride: ion chromatography; DOC: high temperature combustion; and volatile fatty acids: HPLC.
Geochemical Speciation and Redox Zonation—soil (Craft and Joye)	Samples (0-15, 15-30 cm depths) analyzed for bulk density, nutrients (C, N, P), carbon quality (lignin, cellulose, water soluble extractives), cation exchange capacity, and exchangeable cations at start of experiment and again after 2-3 years. Annually, sediment cores (40 cm) will be sectioned at 5 cm intervals and analyzed for acid volatile (AVS) and chromium-reducible (CRS) sulfides, and sequential extractions for Fe, P, and Mn.
Rates of microbially-mediated processes (Joye)	Samples (5 depths) incubated at in situ temperature in winter and summer. SO_4^{2-} reduction: ^{35}S tracer techniques (Jorgensen 1978; Hurtgen et al. 1999); methane oxidation: $^{14}CH_4$ techniques (Joye et al. 1999); methane production: conversion of ^{14}C-labeled precursors (CO_2 and acetate) to $^{14}CH_4$ (Orcutt et al. in press).
Benthic Fluxes, Decomposition and Soil Accretion/Subsidence (Craft and Joye)	CO_2, CH_4, and N_2O fluxes: short-term *in situ* incubations of sediments using flux chambers and a LICOR trace gas analyzer; decomposition: three substrates (live roots, cellulose strips and wooden dowel rods) analyzed periodically for changes in organic C, N, P and organic matter quality (e.g. lignin, roots only); soil surface elevation: rod sedimentation-erosion tables (SET) (Cahoon et al. 2002) measured every six months.
Microbial community composition (Joye)	Phospholipid fatty acids will be used as an index for microbial abundance. PLFAs will be extracted and quantified using gas chromatography (Boschker et al 1999; Weston & Joye 2005)
Plants (Pennings, Alber)	Light profiles: 1-m Delta-T sunscan wand; non-destructive measures of plant size: stem counts, heights, leaf counts and flowering status in 1 x 1 m quadrats; photosynthesis and transpiration: ADC LCA-4 portable infrared gas analyzer on cloudless days in summer: biomass: at the end of the experiment plants will be harvested, sorted to species, dried and weighed. Transplant methods are described in text.
Invertebrates (Pennings)	Benthic macroinvertebrates and crab burrows: counts in 0.5 x 0.5 m quadrats; infauna: counts of invertebrates retained on 0.5 mm sieve from benthic cores (5 cm diameter, 10 cm depth). Transplant methods are described in text.

Table 2-7. Detailed hypotheses for salt and sulfur addition experiment.

Geochemical Speciation and Redox Zonation	The speciation and vertical distribution of sediment organics and nutrients will be strongly influenced by salinity via abiotic ionic strength effects, changes in microbial activity due to changes in TEA availability, and by H_2S-mediated abiotic reactions.
Rates of transformation and flux	The pattern of TEA use over depth will be correlated with sulfate availability. Domination of metabolism by sulfate reduction as opposed to methanogenesis will alter rates of carbon metabolism and trace gas (CH_4, CO_2) flux.
Decomposition/ Soils	Marsh soil properties will be structured by sulfate more than by salt. Increased sulfate will accelerate decomposition, reduce soil organic C pools and lead to soil subsidence. Increased salt will increase exchangeable sodium on cation exchange sites and promote soil salinization, but will not affect soil organic C pools nor promote soil subsidence.
Plants	Both increased sulfate availability and increased salinity will decrease photosynthesis (gas exchange) and standing stocks of freshwater marsh plants (due to sulfide toxicity and salt stress), but sulfate will have stronger effects than salt. Light availability will increase, facilitating invasion by plants typical of brackish marshes. Experimental results will converge slowly with transect data because it will take time for plants from downstream habitats to invade experimental plots. Transplanted brackish-marsh plants will die in control plots due to competition for light, but will perform well in salt or sulfate plots that have increased light availability due to poor growth of freshwater plants.
Invertebrates	Both increased sulfate availability and increased salinity will decrease populations of freshwater invertebrates (due to sulfide toxicity and salt stress), but sulfate will have stronger effects on freshwater invertebrates than salt. Conversely, salt will be more important than sulfate in mediating the invasion of brackish-marsh invertebrates. Experimental results will converge slowly with survey data because it will take time for invertebrates from downstream habitats to invade experimental plots. Transplanted brackish-marsh invertebrates will die in control plots due to osmotic stress but will perform better in salt and sulfate+salt plots.

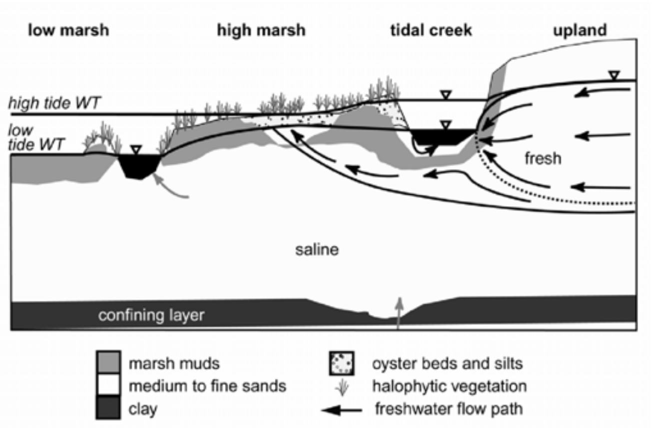
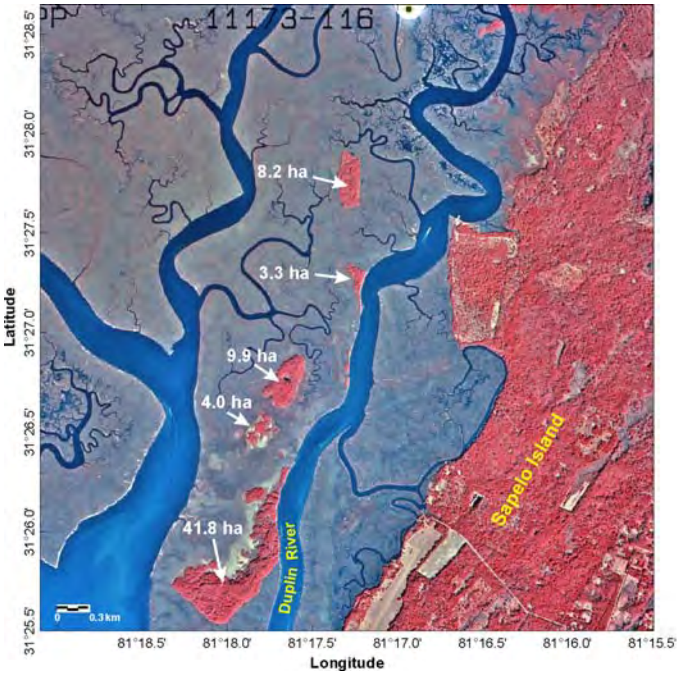


Fig. 2-11. Schematic representation of the distribution of hydrofacies and possible flow path regimes at the margin between upland and salt marsh. Arrows depict flow paths for fresh and saline groundwater. The presence of low permeability material near the tidal creek-aquifer boundary may lead to a more diffuse region of groundwater discharge (Schultz and Ruppel 2002).

Fig. 2-12. Thermal images of Moses Hammock showing groundwater discharge. Freshwater appears white because it is cold. **Top:** Surficial groundwater flow at edge of Moses Hammock. **Bottom:** Sub-marsh groundwater inputs along the bend of a tidal creek.

Fig. 2-13. Aerial photograph showing hammocks dotting the marsh landscape. These are Pleistocene hammocks, ranging in size from 3.3 to 41.8 ha.



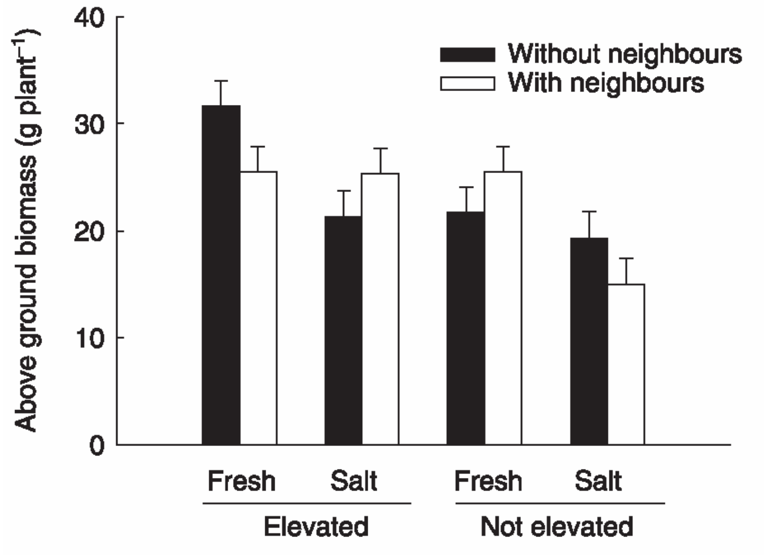


Fig. 2-14. Impact of edaphic conditions on competition between *Spartina alterniflora* and *Juncus roemerianus*: field experiment. Data (means ± 1 SE) are dry mass of *Juncus* transplanted into the middle of the *Spartina* zone such that soil level of the transplant was elevated above or flush with ('not elevated') the ambient soil; transplants were watered with freshwater to reduce salinity ('fresh') or not watered ('salt'). n = 15 individuals per treatment combination. (Pennings et al. 2005b).

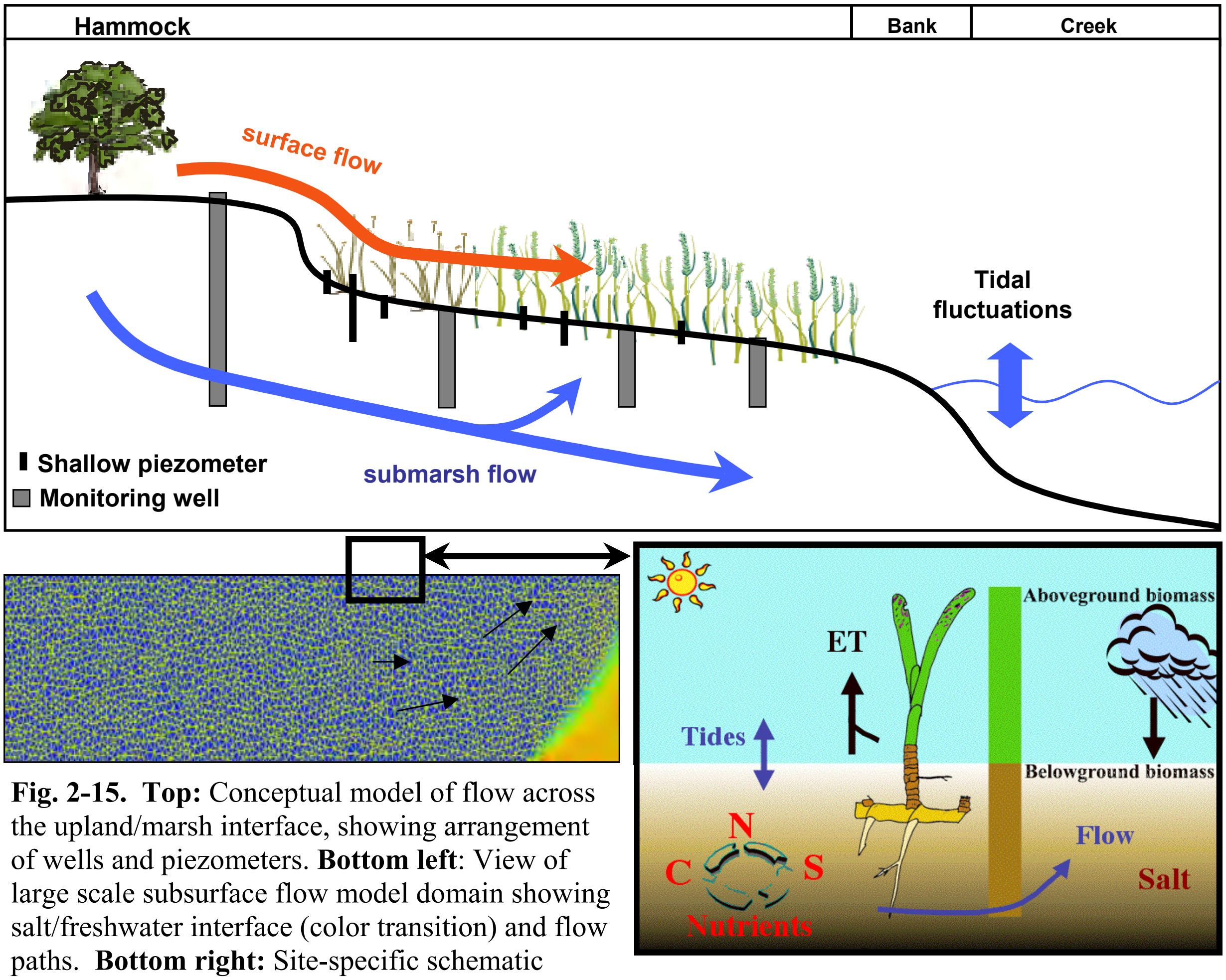


Fig. 2-15. Top: Conceptual model of flow across the upland/marsh interface, showing arrangement of wells and piezometers. **Bottom left**: View of large scale subsurface flow model domain showing salt/freshwater interface (color transition) and flow paths. **Bottom right:** Site-specific schematic showing interactions between soil and plant models, including water flow and nutrient cycling.

Table 2-8. Predictions for how changes in hammock size, sediment, and slope will affect marsh characteristics. ↑ and ↓ denote increases and decreases in the relevant variable.

Source of variation	**FW inflow**	**Pore water**	**Plants**	**Animals**
Increased size of upland (predictions also apply to ↑ upland influence, ↑elevation)	↑ head	↓ salinity ↓ variability	↑ extent of high marsh ↑ *Juncus*, ↓ *Borrichia* in high marsh ↑ plant production (normalized to elevation) ↑ herbivore damage	↑ abundance, diversity of terrestrial animals ↑ abundance of less salt-tolerant benthic invertebrates
Increased % sand (related to origin?)	↑groundwater infiltration	↓ salinity ↑ flowthrough rates	↑ *Borrichia*, ↓ *Juncus*	↑abundance of less salt-tolerant benthic invertebrates
Increased slope on upland edge	↓ infiltration	↑ salinity ↓ variability	↓ extent of high marsh ↑ *Borrichia*, ↓ *Juncus*	↓ abundance of less salt-tolerant benthic invertebrates

Table 2-9. Variables, methodology and sampling strategy for hammock survey. PIs responsible for supervising each aspect of the work are indicated in parentheses.

Independent variables	**Methodology**	**Sampling strategy**
Upland Area (Alexander)	GIS (ARCGIS 9.1)	Select hammocks that cover a broad size range
Upland Shape (i.e. aspect ratio) (Alexander)	GIS (ARCGIS 9.1/ERDAS IMAGINE 8.7	Identify marshes with more or less upland influence
Upland Origin (Alexander)	Inferred from maps (GIS), with cores (surficial sediment texture; optically stimulated luminescence data) on selected hammocks	Sample 30 hammocks of Pleistocene origin (the most common); 10 each of Holocene, dredge spoil, and ballast stone origin
Evidence of Human Presence (Thompson)	Fixed survey with shovel tests (30 cm diameter) to identify prehistoric/historic occupation	Shovel tests at 20-30 m intervals. Reduced to 10 m if cultural materials located, to define extent and depth of occupation.
Upland Elevation (Maximum, Avg); slope of upland/marsh interface (Alber)	Standard surveying equipment	Transect across hammock into marsh
Water table height (measured), Hydraulic head (calculated), permeability, salinity of surficial aquifer (Joye)	Drive point wells to measure height of water table, resistivity, pumping tests	Wells at hammock midpoint and edge. Pumping tests at selected sites.
Sediment type across upland/marsh boundary (Joye)	Manual surficial sampling and auger core at marsh edge	Transect across hammock into marsh
Dependent variables		
Extent of upland and mid-marsh (Alber)	Distance to *Spartina* edge	4 transects per hammock (1 in each compass direction), augmented with aerial photography/GIS
Vegetation in upland marsh (including relative amounts of *Juncus*, *Borrichia*) (Alber)	Standard LTER methods	Quadrats along transect from upland to *Spartina* zone
Upland marsh benthic invertebrate diversity and abundance (Pennings)	Standard LTER methods	Same as above
Terrestrial-dependent herbivores (marsh grasshoppers, deer) (Pennings)	Abundance and damage scores for marsh grasshoppers; direct counts, prints, and droppings for deer	Visual observations along transect from upland to creek
Vertebrate presence Terrestrial-dependent animals (i.e. birds, raccoons, deer) (Alber)	Observations of footprints, scat, nests, direct counts, other indicators	Same as above

Fig. 2-16. Vegetation map showing marsh plant distribution in relation to elevation. In this example, *Juncus* can be seen growing at the upland edge on the right, and on the left a combination of *Juncus* and *Borrichia* are found on the remnants of a small hammock which has been submerged due to rising sea level. Note that the *Juncus/Spartina* border occurs within the 3-4 ft contour, but is not a direct function of elevation (Alexander, unpublished).

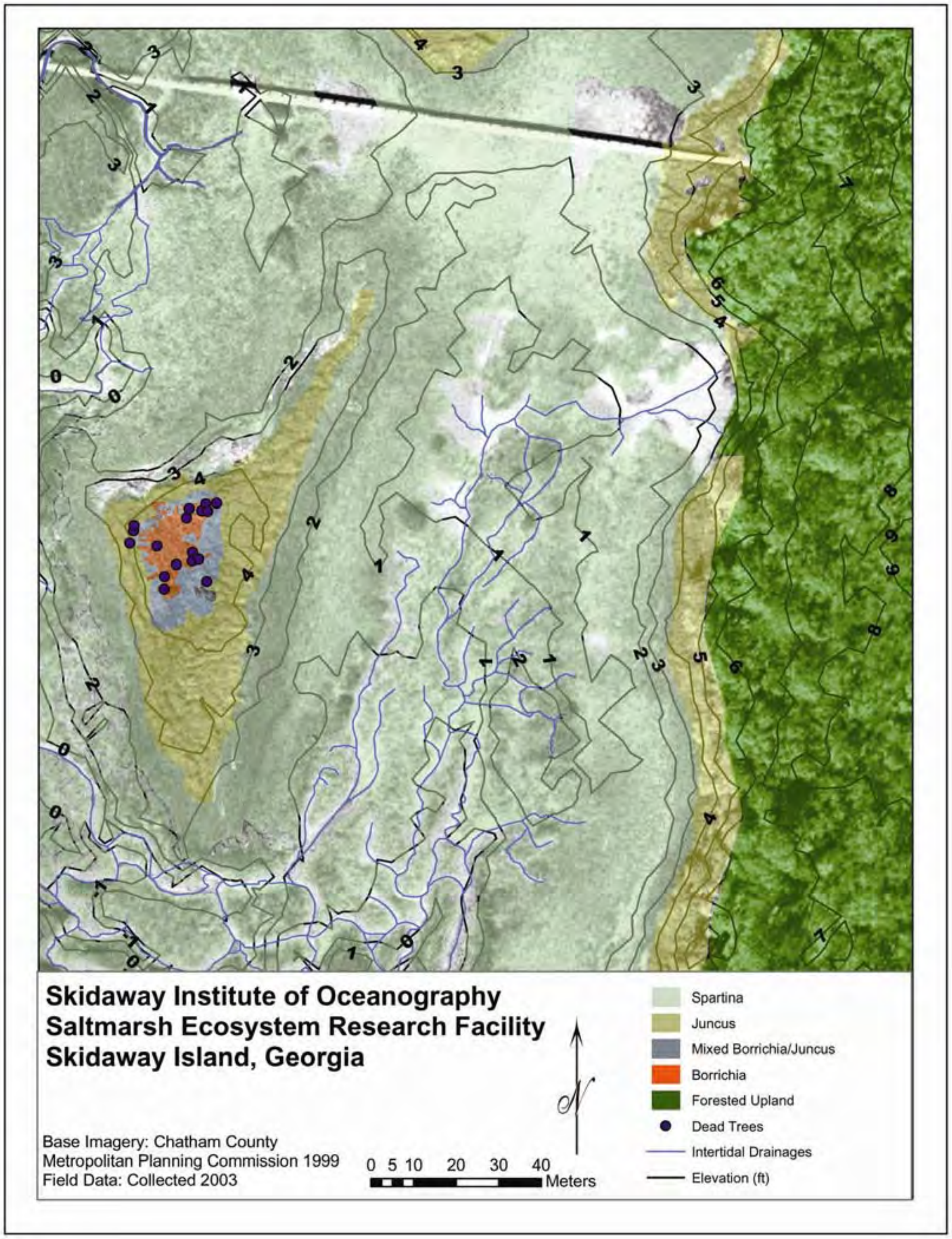


Fig. 2-17. Processes hypothesized to affect delivery of planktonic larvae to the GCE domain. Larvae that develop in the ocean and enter the sounds through tidal transport are likely to settle upon reaching the first suitable habitat. As a result, water reaching sites closer to the mainland will be progressively depleted of larvae and recruitment diminished (arrow A). This may lead to lower population densities at progressively inland sites, as shown for *Littoraria* (Fig. 2-7). Strong net export of water through Altamaha Sound (arrow B) will tend to prevent import of larvae from the ocean. This may lead to low population densities at Altamaha Sound sites, as shown for *Littoraria* (Fig. 2-7).

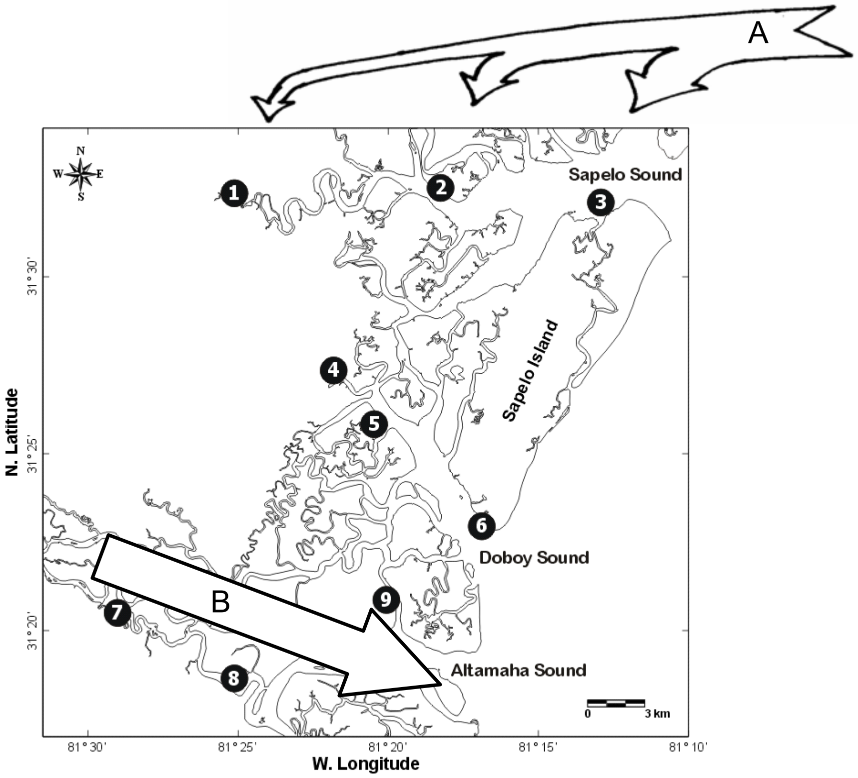


Table 2-10. Larval traps. Traps will be deployed repeatedly to capture periods of high recruitment of all target species. Hogs-hair filter traps will be deployed on both spring and neap tides to document effects of tidal amplitude. N=5-10 replicates/trap design/date/site.

Type	Deployment	Target species
Geukensia shells (Silliman)	Caged, mid marsh on substrate, 8 wk exposure	*Geukensia demissa*
Crassostrea shells (Bishop)	Mesh bag, on reef, 8 wk exposure	*Crassostrea virginica, Perna viridis, Petrolisthes armatus*
PVC spat collectors (Bishop)	Subtidal, 4 wk exposure	*Crassostrea virginica*
Spartina live and dead stems (Silliman)	Caged plants and stems, mid marsh, 4 wk exposure	*Littoraria irrorata, Melampus bidentatus*
Hogs-hair filter material (Bishop)	Water column near bottom, 1 d exposure	Crabs, especially *Uca* spp., mud crabs, *Petrolisthes* and blue crab *Callinectes sapidus*.
PVC plates with 3M Saf-T-Walk (Bishop)	Water column near surface, 4 wk exposure	*Chthamalus fragilis*, *Balanus eburneus*, *Perna viridis*

Table 2-11. Outplant experiments. Work will focus on the most tractable species and those that provide interesting life-history or distribution contrasts. Most experiments will be done in the mid-marsh because this habitat is the most logistically tractable, but some will target mud-flat or oyster reef species. N=10 replicates/treatment/site/species.

Species	Methods and variables	Notes
Marine invertebrates (Silliman)		
Littoraria irrorata	Caged at low and ambient densities, 6 months, shell height	Abundant marsh gastropod, varies strongly in density among sites
Melampus bidentatus	As *Littoraria*	Abundant marsh gastropod, varies strongly in density among sites
Ilyanassa obsoleta	Tagged snails released at ambient densities (caging is difficult in mudflat habitat), shell height	Abundant mudflat gastropod
Geukensia demissa	As *Littoraria*	Abundant marsh bivalve, density patchy on small and site scales
Polymesoda caroliniana	As *Littoraria*	Bivalve typical of brackish sites, range contracted during drought and expanded after
Crassostrea virginica	As *Littoraria*	Oysters
Petrolisthes armatus	Caged at low and ambient densities, 3 mo, mass and carapace width	Invasive crab on oyster reef
Chthamalus fragilis	Outplanted on PVC plates at low and high densities, 6 mo, diameter	Common barnacle, settles on plant stems
Insects (Pennings)		
Orchelimum fidicinum	Caged at low densities in areas with and without *Littoraria*, 2 wks, mass	Abundant marsh grasshopper, varies in density among sites, *Littoraria* may be a competitor
Marsh Plants (Pennings)		
Spartina alterniflora	Planted with and without competition, 6 months, height, # of shoots and flowers, biomass	Dominant at salty sites
Batis maritima	As above	Subordinate at salty sites
Aster tenuifolius	As above	Subordinate at salty, brackish sites
Limonium carolinianum	As above	Subordinate at salty, brackish sites
Juncus roemerianus	As above	Dominant at brackish sites
Scirpus americanus	As above	Subordinate at brackish sites
Zizaniopsis milacea	As above	Dominant at fresh sites
Polygonum sp.	As above	Common subordinate at fresh sites
Aster novae-angliae	As above	Common subordinate at fresh sites

Table 2-12. Species for genetic analysis. We (Wares) will conduct preliminary analyses on all species (n=20/sp.), then focus in-depth work (n=60/sp.) on the species/comparisons that appear to be most tractable. Free-spawning invertebrates (Bivalvia and Polychaeta) are indicated by "FS".

Marine invertebrates	Larval planktonic period	Notes
Gastropoda		
Littoraria irrorata	6-8 wks	Abundant and important
Melampus bidentatus	2 wks	Patchy distribution
Ilyanassa obsoleta	4-8 wks	Abundant on mud banks
Urosalpinx cinerea	0	Abundant on oyster reefs
Bivalvia		
Geukensia demissa FS	5-6 wks	Abundant in marsh
Crassostrea virginica FS	2-3 wks	Commercially important, creates subtidal structure
Perna viridis FS	2 wks	Invasive species
Polymesoda caroliniana FS	2-3 wks	Patchy distribution
Crustacea		
Uca pugnax	2 wks	Abundant and important
Petrolisthes armatus	2 wks	Invasive species
Chthamalus fragilis	4-6 wk	Lives on *Spartina* stems
Cyathura polita	0	Common isopod
Orchestia grillus	0	Common amphipod
Ulorchestia spartinophylla	0	Amphipod associated with *Spartina* stems
Polychaeta		
Neanthes succinea FS	2-3 wks	Widespread
Manayunkia aesuarina FS	0	Broods larvae
Phyllodoce fragilis FS	2-4 wks	Oyster reef associate
Orthoptera	**Dispersal ability**	**Notes**
Orchelimum fidicinium	Strong flier	Abundant and important
Hesperotettix floridensis	Wingless	Patchy distribution
Conocephalus spartinae	Wingless	Patchy distribution
Plants	**Dispersal ability**	**Notes**
Spartina alterniflora (wind pollinated)	Good (floating seeds and shoots)	Most abundant salt marsh plant
Juncus roemerianus (wind pollinated)	Moderate (small seeds)	Very abundant at brackish marshes
Iva frutescens (insect pollinated)	Poor (heavy seeds)	Dominant high marsh shrub
Solidago sempervirens (insect pollinated)	Good (wind-dispersed)	Common high marsh forb

Section 3: Project Management

GCE scientists are classified as either Project Investigators or Affiliated Professionals. PIs are scientists with a major commitment to GCE research. They are typically funded through the GCE and are expected to participate regularly and fully in site research, project meetings, and decision-making. Affiliated Professionals have an interest in GCE research, may be pursuing independently funded research at the GCE sites, and follow our data reporting protocols, but are not obligated to participate in GCE activities at a high level. The entire GCE membership meets once a year. Meetings last 1.5 days and focus on reviewing research progress and planning future activities. GCE annual meetings are attended by our Advisory Committee (**Table 3-1**), and at the end of each meeting they provide input to the GCE program on all aspects of project research and administration. Committee members represent a breadth of disciplines from both inside and outside LTER.

At the beginning of our first funding period, the GCE was administered by Hollibaugh and Pennings, with Project Director Hollibaugh making most administrative decisions with input from co-PI Pennings and other co-PIs who were listed as senior investigators. As the program matured, and with the encouragement of the mid-term site review, we developed a formal Executive Committee (EC) and adopted formal bylaws (http://gce-lter.marsci.uga.edu/lter/files/docs/GCE_Bylaws_01-Jun-2005.pdf). The project is now governed by the EC, which has assumed responsibility for administration and oversight. The EC consists of the lead and co-PIs, 3 additional PIs, and the Information Manager. All major project decisions are now made by the EC, with input or final approval solicited from the larger GCE membership. The EC discusses GCE issues by email on a daily basis. EC meetings are held several times a year, with Pennings (University of Houston) included by web-cam or traveling to UGA when possible. EC members have administrative responsibility for different aspects of the GCE program (**Table 3-2**), and to this end communicate and meet with appropriate subgroups of personnel as needed. Procedures for election and removal of EC members by the GCE membership are detailed in our bylaws.

We are making one major personnel change from GCE-I. Once the renewal is processed, we will initiate paperwork to facilitate a change of PI from Hollibaugh to Alber, who will represent the GCE to NSF and the LTER network. Alber has been actively involved in research on the Georgia coast since the Georgia Rivers LMER program began in 1994, and also participates in estuarine research at the national level (Regional Coordinator for the NOAA National Eutrophication Assessment effort, Board member of the Estuarine Research Federation, panelist for Heinz Center study on Coastal Zone Management). Pennings will continue as co-PI, and Hollibaugh will remain on the EC to ensure a smooth transition. The remaining membership of the EC (Joye, Sheldon, and Burd) will remain stable, creating continuity between the first and second funding periods.

We are also making some more minor personnel changes. First, as suggested by the mid-term site review, we are adding an additional IM position to provide backup and assistance to Sheldon. Second, we expect some turnover within the PI and Affiliated Professional ranks. Some scientists will leave the project or reduce their involvement due to retirement, moves, changes in research interest, or reduced funding. At the same time, we are excited to be involving a number of new scientists in GCE research. Silliman (UF) and Wares (UGA) will bring expertise in invertebrate ecology and genetics to the group. Alexander (SkIO) is a geologist who has worked extensively with the State of Georgia on issues relating to hammock ecology and management. Moore (USC) has expertise in using radium isotopes to determine groundwater flows into coastal systems. Meile (UGA) will work with Burd on modeling. Thompson (USC), an archaeologist, will help us begin to put our work into the context of past human occupation of Georgia coastal systems. Our goal in involving new scientists has been to provide necessary new areas of expertise, ensuring that we are addressing questions from a diverse, multi-disciplinary perspective.

We continue to base our field research out of UGA's Marine Institute on Sapelo Island, and Pennings will remain in his role as the primary facilitator of field operations. Although he has held a faculty position at the University of Houston for several years, he continues to base his field research program out of the Marine Institute and is in residence there for most of the summer. As a result, he is at the field sites more consistently than other PIs. The director of the Marine Institute is a faculty member of the Department of Marine Sciences at UGA who interacts closely with the GCE. A new dormitory and renovations to a large classroom at the Marine Institute should be completed soon, enabling GCE meetings to be held there as well as providing improved accommodations for researchers working at the GCE sites.

GCE scientists have been quite successful in obtaining additional grants from NSF, EPA and other sources (**Section 7, Budget Descriptions**) that coordinate with the GCE program. We encourage sharing of staff, equipment and funding among these projects to their mutual benefit, and make their data available through the GCE web site. Communication among projects is facilitated by the overlap of senior personnel and by reports from related projects at the annual meeting.

We also encourage non-LTER scientists to become affiliated with the GCE project by extolling the twin benefits of working at Sapelo Island and working with the LTER. The UGA Marine Institute is a world-renowned center for marsh research, allowing access to pristine marshes that have a rich history of previous research that provides context for new studies. The LTER program offers the opportunity to coordinate with ongoing and past research at a network of sites, with ready access to datasets through our web site. We expose new scientists to GCE research through seed funding and postdoctoral positions, with the hope that they will generate external funding to continue their work. We work with these scientists to develop new research proposals, and we write letters of support for related proposals.

Table 3-1. Current Advisory Committee. Members are appointed to indefinite terms by the Executive Committee as detailed in GCE bylaws (http://gce-lter.marsci.uga.edu/lter/files/docs/GCE_Bylaws_01-Jun-2005.pdf). We expect to rotate some new members onto the Advisory Committee during GCE-II to replace retiring members.

Personnel	Expertise
Iris Anderson Virginia Institute of Marine Science	LTER (VCR), N and C cycling, microbial ecology
Jane Caffrey, University of West Florida	Biogeochemistry, ecosystem metabolism
Jack Gallagher, University of Delaware	Plant ecology and physiology
Chuck Hopkinson, Ecosystems Center, Marine Biological Laboratory	LTER (PIE), ecosystems ecology
George Jackson Texas A&M University	Oceanography, modeling
Wim Kimmerer San Francisco State University	Estuarine ecology, modeling

Table 3-2. Executive Committee. Members are elected for renewable 6-year terms, to include the year preceding and the first five years of each NSF proposal, following procedures detailed in GCE bylaws (http://gce-lter.marsci.uga.edu/lter/files/docs/GCE_Bylaws_01-Jun-2005.pdf).

Personnel	Administrative Responsibilities
James Hollibaugh, Lead PI	Represent GCE to NSF and LTER network Lead administrator
Merryl Alber, Incoming Lead PI	Will assume lead PI role early in GCE-II Oversee Upland-Marsh Linkage research
Steven Pennings, Co-PI	Field operations Oversee Population Distribution research
Samantha Joye	Oversee Freshwater-Marine Linkage research
Adrian Burd	Oversee modeling
Wade Sheldon	Information Management

Section 4: Information Management

4.1. Information Management Approach at GCE. Development of the GCE Information Management program during GCE-I was guided by the following goals:

- Develop procedures and technology to facilitate efficient acquisition, standardization, analysis and synthesis of all GCE data
- Develop an integrated information system to manage all products of GCE research, support site science, and build a well-documented archive of long-term ecological observations
- Establish web sites to provide secure, convenient access to project information and research results for GCE members, the LTER Network, and the scientific community
- Support all LTER Network Information System protocols and standards to facilitate network-level science, cross-site comparisons and large-scale synthetic research.

Our information management system continues to evolve in response to changing technology and project and network requirements, but we have met or exceeded these initial goals at both the project and network level. We have also developed a number of innovative informatics approaches, database designs and software applications in the course of establishing our system, and we have openly shared these with the LTER and broader scientific community.

4.2. GCE Information System. The GCE information system is housed in the Dept. of Marine Sciences at the University of Georgia due to the remoteness of the study area and superior network and computing infrastructure at UGA. The system is highly centralized, with user access primarily provided through public and private web sites and network applications (see below). This approach accommodates the wide geographic distribution of project participants and the large array of computer platforms and operating systems in use by GCE investigators.

IT Resources. During GCE-I we acquired a high performance, fault-tolerant database server (running SQL Server 2000), dedicated web server, software development server, network-attached storage server with 0.5 TB RAID array (for investigator use), high performance workstations, field notebook computer, and DLT tape autoloader system for backing up all these systems. Existing IT services provided by UGA and the LTER network are used to provide email accounts and mailing lists, and each participant's home institution provides basic connectivity and computer support. Network- and application-layer firewalls and secure transport protocols (SSH, SFTP, HTTPS) are employed to prevent unauthorized access to GCE network resources.

Data Acquisition. Data from instrumented monitoring sites, such as weather stations, are automatically downloaded via modem or HTTP every 1-12 hours to computers in the GCE IM office, and data from moored instruments are transmitted immediately after downloading (semi-monthly). Data from cruises, marsh monitoring, and individual PI research projects are submitted to the IM office at varying intervals, depending on project schedules. Raw data and other submissions are organized in a data file management system that is mirrored between servers and routinely backed up to tape and DVD, which are stored off-site to protect against data loss.

Data Processing and Quality Control. In order to standardize the processing, quality control, and analysis of all GCE project data, we developed a well-defined standard for storing tabular data along with structured metadata, QC/QA rules and flags. We also developed a toolbox of metadata-driven MATLAB programs (GCE Data Toolbox) for working with this standard (http://gce-lter.marsci.uga.edu/lter/research/tools/data_toolbox.htm), which we have shared with the scientific community (1820 public downloads since 2002). Data from various sources, including spreadsheets, MATLAB files, instrument data loggers, and SQL database queries, are converted to GCE data structures for validation, QC/QA analysis, and post-processing. Metadata are initially added from pre-defined templates or imported directly from the GCE metadata database (below), and then augmented with information derived from analyzing the data set itself (e.g. geographic lookups, date/time analysis, numeric ranges). All transformations and data changes are automatically documented throughout processing, resulting in comprehensive metadata that describe the complete lineage of the data set. Finalized data sets are archived in native data structure format as well as standard text and MATLAB formats.

Databases. We have also developed relational databases to manage data set metadata, geographic information, bibliographic citations, personnel information, taxonomic records, data access logs and project administration information (e.g. calendar, committees, and votes). These databases are tightly integrated based on shared keys and referential integrity constraints, and provide comprehensive information for automatic metadata creation and dynamic web applications. Access to these databases is provided through web applications (below) and custom database interfaces. Databases have also been developed for integrating long-term climate and hydrographic monitoring data, and interfaces to query these databases are under development.

Web Sites. During GCE-I we established a comprehensive public web site to disseminate information about the GCE project and provide access to research products and related information (http://gce-lter.marsci.uga.edu/lter/). We also established a password-protected web site for project participants containing submission forms, proprietary files, provisional data, and other project resources. In addition, we recently established a public "Data Portal" web site (http://gce-lter.marsci.uga.edu/portal/) to provide access to maps, photographs and ancillary data from monitoring partners and public agencies, standardized for comparison with GCE data.

A variety of dynamic web applications have been developed to provide integrated access to information stored in GCE databases. For example, the GCE Data Catalog (http://gce-lter.marsci.uga.edu/lter/asp/db/data_catalog.asp) is a fully automated, searchable data catalog and data distribution system. Data set detail pages provide comprehensive summary information, including links to referenced personnel, study sites, taxonomic information, publications, and other data sets. Links to downloadable metadata (in text and EML 2 formats) and version-controlled data files are dynamically generated based on release information stored in the metadata database. Other web-database applications include a searchable bibliography (>1400 citations from GCE, UGA Marine Institute and Georgia Rivers LMER libraries), taxonomic database with links to photos and relevant data, study site descriptions with links to data sets, publications and geographic locations, and a project web calendar. These applications provide web visitors many ways to navigate the GCE web site and discover relevant information.

Use of the GCE web site has increased steadily since its introduction in 2001, with over 500,000 total page views from over 150,000 visitors (excluding indexing spiders), representing 168 countries. In 2005 approximately 6000 visitors accessed our public web site each month.

4.3. Integration of IM with the Research Program. Information management is integrated into all phases of the GCE research program. The IM serves on the GCE Executive Committee and regularly interacts with PIs and students in research planning, data analysis, integration and publication. Specific examples of IM involvement in research activities are listed in **Table 4.1**.

4.4. Data Access Policy and Data Distribution. Data sets are added to the data catalog soon after submission. Data set summaries and metadata are publicly available immediately. Data from monitoring activities and individual investigator studies are available immediately to GCE participants and to the public within 1 or 2 years, respectively, in compliance with the LTER Network data access policy. Data sets are versioned to indicate changes since initial release, and a change notification service is provided to users on request. Data files are provided in multiple formats optimized for various end-user applications, and MATLAB Web Server applications have been developed to provide custom-formatted text and MATLAB files and statistical summaries for all data sets in the GCE catalog and data portal site. As of December 2005 there were 278 online data sets in the GCE data catalog and 145 in the GCE data portal.

4.5. Support for LTER Network Science and Synthesis. We participate fully in all LTER NIS modules, including the All-site Bibliography, Data Table of Contents, Data Catalog (Metacat), personnel directory and SiteDB. The GCE Information System natively supports all LTER standards and protocols, and we have implemented automatic harvesting and synchronization where supported by LNO. 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 10 LTER sites and 1 USFS site to contribute streamflow data to HydroDB on a weekly basis with no additional effort (**http://gce-lter.marsci.uga.edu/lter/research/tools/usgs_harvester.htm**).

We also comprehensively support the XML-based EML 2.0 metadata standard adopted by LTER in all GCE databases, allowing us to dynamically generate EML for all data sets in our catalog, as well as species lists, personnel entries and bibliographic citations. GCE was the first LTER site to fully support EML 2, and our rapid implementation has facilitated adoption of this standard across LTER and aided in development of EML-based applications at LNO, NCEAS and NBII. 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 Wade Sheldon, GCE IM). 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 (**Fig. 4-1**).

4.6. New Directions for GCE-II. In GCE-II we will build on the strong data management framework we have already established to create a comprehensive "decision support system" for GCE research. We will continue our development of integrated, web-accessible databases and metadata-based analysis tools to support dynamic synthesis of GCE data, adding explicit support for spatial data products (in standard GIS formats) in association with proposed marsh and hammock studies. We will also continue to collaborate with other LTER sites and software developers at LNO, NCEAS and SEEK to develop standards and approaches for automating analysis and synthesis of ecological data based on structured metadata (e.g. EML).

Fig. 4-1. A wide variety GCE data sets have been downloaded by a diverse array of parties inside and outside LTER. Public downloads have increased sharply as our catalog has grown, particularly after metadata synchronization with the KNB Metacat and NBII began in 2004.

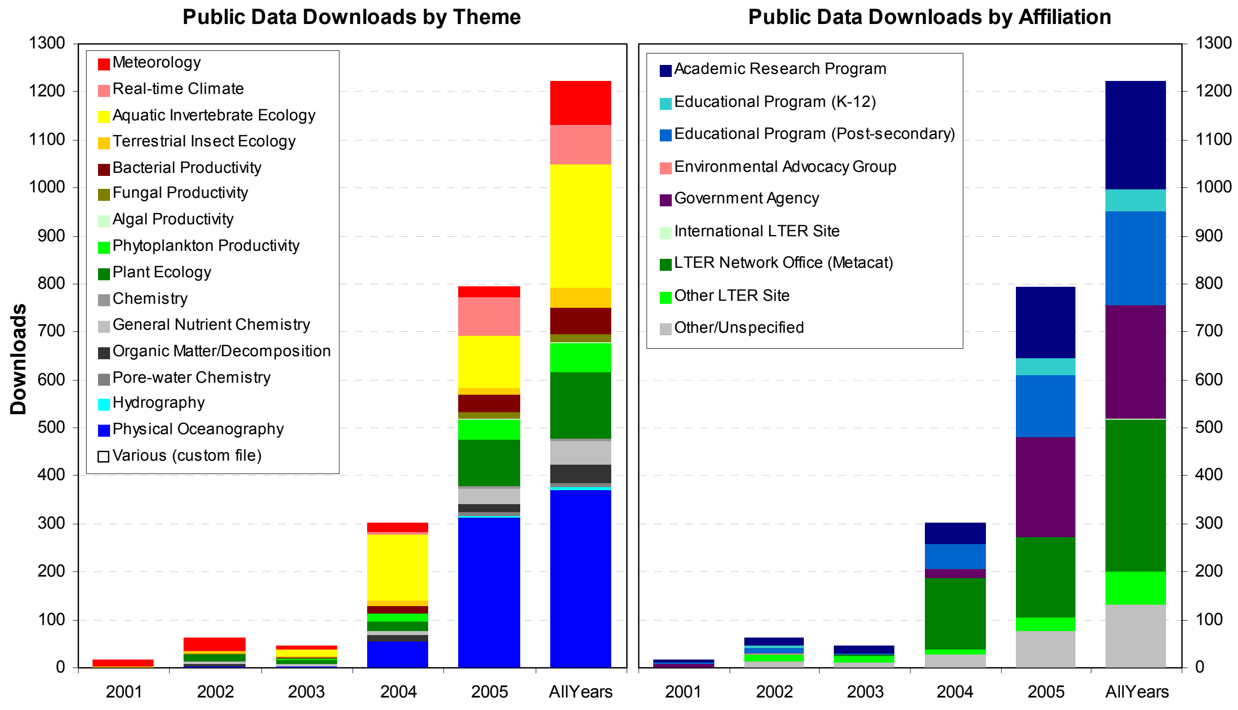


Table 4-1. Integration of Information Management with the GCE Research Program.

Research Phase	**Information Management Support**
Study Design	Provide historic data, logistical resources (e.g. maps, reports)
Data Collection	Provide log sheets, data entry forms, advice on site standards/best practices, and develop automatic harvesters and import filters
Data Analysis	Provide data processing assistance, software tools, statistical reports
Quality Control	Provide assistance, software tools for data validation and QA/QC flagging (algorithmic and manual)
Presentation/Publication	Provide analytical assistance, ancillary data (standardized for comparison), maps and aerial photos
Metadata Creation	Provide metadata forms, templates, metadata-importing, data mining tools for automatic metadata generation
Archival	Provide file conversions, data set standardization, cataloging, secured storage, and backup
Reporting	Compile data user-ship profiles and collate PI contributions for inclusion in annual reports
Synthesis	Provide ancillary data, software tools for data conversion, re-sampling, sub-setting, filtering, search and integration

Section 5: Outreach

The goal of GCE outreach is to enhance scientific understanding of Georgia coastal ecosystems by the public, coastal managers, and scientists. To this end, we run a schoolyard program, support the Georgia Coastal Research Council (GCRC), train undergraduate and graduate students, and interact with scientists inside and outside the LTER network. In the coming funding cycle, our primary goal will be to strengthen the 3 central elements of our outreach program: the schoolyard, GCRC, and student training.

Schoolyard. Educational research has shown that one-time events are largely ineffective in improving teacher skills or epistemology. Our program, built around long-term contact with educators, is obtaining lasting results: over 90 % of teachers remain invested, incorporating GCE science concepts into their curriculum. We host two 10-day workshops on Sapelo Island each summer. Each includes some new and some returning teachers (**Table 5-1**). Teachers split their time between working on GCE research alongside GCE scientists and discussing ways to implement GCE science into their classrooms. Participants remain in touch electronically with each other and GCE scientists throughout the year. Evaluations indicate that the teachers' epistemology of science has been revised to include a more sophisticated, constructivist view of science as active, temporary, and local, and that teachers report a new sense of empowerment and comfort in their practice. In addition to improving their skills, participants serve as mentors for other teachers in their schools and have presented 9 papers on the use of GCE science in the classroom at state and national conferences (gce-lter.marsci.uga.edu/lter/education/schoolyardpubs.htm). Our schoolyard coordinator (Hembree) has raised external funds to almost triple schoolyard funding, made 14 presentations based on the schoolyard at science education conferences, participated in meetings about developing a cross-site teacher education program, and co-authored the Education Handbook for system-wide SLTER programs (http://intranet.lternet.edu/committees/education/LTER%20Educ%20Hndbk092905.doc). In addition to ongoing evaluations by Hembree, the program has been evaluated for 2 years by science education researcher G. M. Bowen, UNB, Canada. We will continue to support the schoolyard program in the next funding cycle, and we are also in the process of developing a book focused on salt marshes for the LTER children's book series.

GCE scientists also speak directly to the public in a variety of forums. For example, Bishop spoke in a public symposium sponsored by TNC and SINERR on invasive species in Georgia. GCE personnel gave interviews on marsh dieback to Georgia Magazine, Savannah Morning News, Charleston Port and Courier, Athens Banner Herald, and other media. Research by Silliman and Newell on snail/fungal interactions led to several interviews (e.g., Science News 164:358. December 2003). Research by Joye on sediment biogeochemistry (published in PNAS) was featured on the NSF website and in newspapers in the US, Europe, and Asia.

Georgia Coastal Research Council. We provide outreach to coastal resource managers by partially supporting the GCRC, which is headed by Alber. The GCRC has 86 affiliated scientists from 9 Universities, 6 Federal agencies, and 4 State and regional agencies. It promotes science-based management of coastal resources by hosting workshops, assisting management agencies with scientific assessments, and distributing information on coastal issues (**Table 5-2**). GCRC presentations have ranged from invited briefings to the Georgia legislature and the Georgia DNR Emerging Leaders Program to more traditional venues such as the Ecological

Society of America and the Coastal States Organization. Other presentations have been geared towards the general public, with audiences such as the Georgia River Network and the Georgia DNR Community Docks & Marinas Stakeholder Group.

An example of the GCRC in action was its response to the dieback of marsh vegetation along the Georgia coast in 2002 and 2003. The GCRC set up monitoring and remote sensing subcommittees, collated monitoring results, and wrote a technical report summarizing research on dieback in other areas. In 2004 the GCRC and investigators from Louisiana organized a workshop to exchange technical information. One outcome was a collaborative proposal to study dieback in both states, which was recently funded by the USEPA.

We will continue to support the GCRC in the next funding cycle and use it to communicate the results of our research to coastal managers in a timely manner. In particular, our new work on marsh-upland linkages will be of great interest to the State. How much Georgia should regulate the development of small marsh islands (hammocks) is currently a highly contentious issue, and coastal managers need a better scientific understanding of hammocks to develop regulations that will withstand legal challenges.

Students. We routinely incorporate undergraduate and graduate students in our work. To date, 32 undergraduates from UGA, GA Tech, IU, UH, Savannah State and U. Kiel have participated in GCE research. In addition, classes at Georgia Tech (Environmental Field Methods) and UGA (Marine Biology) have field components based on GCE research (http://gce-lter.marsci.uga.edu/lter/education/education.htm). Two postdocs and 38 graduate students have been involved in GCE research, and 19 have completed degrees (10 M.S. and 9 Ph.D.). As the GCE program matures, we expect to continue and improve on our strong record in this area.

LTER network and broader scientific community. In our first funding cycle, GCE outreach to the LTER network occurred primarily through our IM position. Sheldon has served on key LTER committees (NIS Advisory Committee and IM Exec), developed web sites to manage IM meeting logistics, and assisted IMs at other LTER sites with EML metadata adoption and real-time data harvesting. He has broadly shared technology and approaches developed at GCE through presentations, Databits articles, and distribution of software programs and database diagrams. He also lectured on taxonomic database development at an OBFS informatics training course. In addition, Sheldon, Hollibaugh and Alber participated in the LTER Planning Grant "Meeting of 100" in FL, Hollibaugh is on the organizing committee for the upcoming All Scientist's meeting, and Alber served on the Human Dimensions Working Group. In the next funding cycle, we expect to remain heavily involved in network activities.

Outreach to the broader scientific community occurs routinely through participation in meetings and workshops and service on editorial, grant review, and advisory panels. On the Georgia coast, we partner with organizations such as the Altamaha Riverkeeper, DNR, NADP, SINERR, TNC and USGS to collect data of mutual interest. For example, GCE is currently working with SINERR to examine how increasing tidal circulation by replacing a culvert with a bridge will affect the health of a large marsh upstream of the culvert on Sapelo Island.

Table 5-1. GCE schoolyard teachers, students impacted, and funding.

Year	New teachers	Returning teachers	Teacher slots	Students Impacted	NSF Funding	External Funding
2000-1	6	Not applicable	6	620	$15,000	
2001-2	5	5	10	982	$15,000	
2002-3	8	9	17	1732	$15,000	$28,607
2003-4	14	8	22	2021	$15,000	$48,035
2004-5	4	13	17	1361	$15,000	$44,038
2005-6	3	14	17	1304	$15,000	$45,605
Totals	**40**		**89**	**8020**	**$90,000**	**$166,285**

Table 5-2. GCRC activities.

Technical Summaries and Reports– Reports are generally written in response to requests by specific agencies (i.e. Georgia DNR, National Park Service). GCRC reports since 2002:
The effects of changing freshwater inflow to estuaries: A Georgia perspective
Background information on marsh dieback.
Georgia Coastal Research Council - Proceedings of the marsh dieback workshop
Marinas: Best management practices & water quality.
Vegetative buffers in the coastal zone
Environmental effects of docks and marinas
Herbicide use near coastal marshlands
Coastal water resources and watershed conditions at Cumberland Isl. National Seashore, GA
Coastal water resources and watershed conditions at Fort Pulaski National Monument, GA.

Workshop organization –
2/04 Marsh Dieback Workshop - 65 scientists from academia, state and federal agencies
2/04 Marsh Dieback Public Information Session – 80 attendees
9/02 Coastal Georgia Colloquium - 30 academic scientists + 20 agency scientists

Georgia Water Resources Conference – This biannual conference focuses on water issues and attracts managers and scientists from throughout the State. GCRC/GCE papers since 2001:
Schaefer, S. 2005 *Trends in agricultural sources of nitrogen in the Altamaha River…*
Sheldon, J. 2005 *Simulating material movement through the lower Altamaha River…*
Alber, M. 2005 *Water quality conditions near Cumberland Island, Georgia.*
Albers, G. 2003 *A vegetative survey of back-barrier islands near Sapelo Island, Georgia.*
Alber, M. 2003 *Georgia Coastal Research Council: A forum for scientists and managers.*
Sheldon, J. 2003 *Comparing transport times through salinity zones …using SqueezeBox.*
Weston, N. 2003 *Nutrients and dissolved organic matter in the Altamaha River …*
Kang, K. 2003 *Some physical factors that may affect turbulent mixing in Altamaha Sound…*
White, S. 2003 *Spartina species zonation along the Altamaha River Estuary*
Alber, M. 2001 *Water use patterns in the watersheds of the Georgia Riverine Estuaries*
Smith, C. 2001 *Linking shifts in historic estuarine vegetation to salinity changes using a GIS*
Blanton, J. 2001 *Salinity responses … to seasonal changes in freshwater discharge*

Website – (www.marsci.uga.edu/coastalcouncil)- 982 HTML pages, 54 PDF documents, and more than 7,000 links. (~ 110 unique visitors each month.)

Listserv – 101 managers and scientists receive regular updates.

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Supplement A. Publications resulting from GCE-I. In addition, GCE scientists presented 40 posters and gave 109 oral presentations at scientific meetings (including 27 posters and 45 presentations given by graduate and undergraduate students).

Journal Articles

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Accession	*Dataset Title*	*Lead PI*	*Period*	*Status*
	Algal Productivity (LTER Core Area: Primary Production)			
ALG-GCED-0304a	Benthic chlorophyll concentrations and gross oxygenic photosynthesis rates in surficial estuarine intertidal sediments at sites on Sapelo Island and near the Satilla River from January, April, June and July 2001	Joye	2001	P
ALG-GCED-0304c	Benthic chlorophyll, density, porosity, and organic content concentrations and gross oxygenic photosynthesis rates in surficial estuarine intertidal sediments at sites on Sapelo Island and near the Satilla River from January, April, June and July 2001	Joye	2001	P
ALG-GCED-0304b	Benthic chlorophyll concentrations and gross oxygenic photosynthesis rates in surficial estuarine intertidal sediments at sites on Sapelo Island and near the Satilla River from June and August 2002	Joye	2002	P
ALG-GCED-0304d	Benthic chlorophyll, density, porosity, and organic content concentrations in surficial estuarine intertidal sediments at sites on Sapelo Island and near the Satilla River from June and August 2002	Joye	2002	P
	Aquatic Invertebrate Ecology (LTER Core Area: Population Studies)			
INV-GCEM-0305a1	Mollusc population abundance monitoring: Fall 2000 mid-marsh and creekbank infaunal and epifaunal mollusc abundance based on collections from GCE marsh, monitoring sites 1-10	Bishop	2000	P
INV-GCEM-0305a2	Mollusc population size distribution monitoring: Fall 2000 mid-marsh and creekbank infaunal and epifaunal mollusc size distributions based on collections from GCE marsh, monitoring sites 1-10	Bishop	2000	P
INV-GCEM-0210a	Crab population monitoring: Fall 2001 mid-marsh and creekbank crab abundances based on hole counts at GCE marsh, monitoring sites 1-10	Bishop	2001	P

** Status: P = public access, R = restricted access (public access within 2 years)*

Accession	Dataset Title	Lead PI	Period	Status
INV-GCEM-0209	Crab population monitoring: Spring 2001 mid-marsh and creekbank crab abundances based on hole counts at GCE marsh, monitoring sites 1-10	Bishop	2001	P
INV-GCEM-0301a	Mollusc population abundance monitoring: Fall 2001 mid-marsh and creekbank infaunal and epifaunal mollusc abundance based on collections from GCE marsh, monitoring sites 1-10	Bishop	2001	P
INV-GCEM-0305b1	Mollusc population abundance monitoring: Spring 2001 mid-marsh and creekbank infaunal and epifaunal mollusc abundance based on collections from GCE marsh, monitoring sites 1-10	Bishop	2001	P
INV-GCEM-0301b	Mollusc population size distribution monitoring: Fall 2001 mid-marsh and creekbank infaunal and epifaunal mollusc size distributions based on collections from GCE marsh, monitoring sites 1-10	Bishop	2001	P
INV-GCEM-0305b2	Mollusc population size distribution monitoring: Spring 2001 mid-marsh and creekbank infaunal and epifaunal mollusc size distributions based on collections from GCE marsh, monitoring sites 1-10	Bishop	2001	P
INV-GCEM-0210c	Crab population monitoring: Fall 2002 mid-marsh and creekbank crab abundances based on hole counts at GCE marsh, monitoring sites 1-10	Bishop	2002	P
INV-GCEM-0210b	Crab population monitoring: Spring 2002 mid-marsh and creekbank crab abundances based on hole counts at GCE marsh, monitoring sites 1-10	Bishop	2002	P
INV-GCEM-0412b1	Mollusc population abundance monitoring: Fall 2002 mid-marsh and creekbank infaunal and epifaunal mollusc abundance based on collections from GCE marsh, monitoring sites 1-10	Bishop	2002	P
INV-GCEM-0412a1	Mollusc population abundance monitoring: Spring 2002 mid-marsh and creekbank infaunal and epifaunal mollusc abundance based on collections from GCE marsh, monitoring sites 1-10	Bishop	2002	P
INV-GCEM-0412b2	Mollusc population size distribution monitoring: Fall 2002 mid-marsh and creekbank infaunal and epifaunal mollusc size distributions based on collections from GCE marsh, monitoring sites 1-10	Bishop	2002	P
INV-GCEM-0412a2	Mollusc population size distribution monitoring: Spring 2002 mid-marsh and creekbank infaunal and epifaunal mollusc size distributions based on collections from GCE marsh, monitoring sites 1-10	Bishop	2002	P

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Accession	Dataset Title	Lead PI	Period	Status
INV-GCEM-0401	Fall 2003 crab population monitoring: mid-marsh and creekbank abundance based on crab hole counts at GCE marsh, monitoring sites 1-10	Bishop	2003	P
INV-GCEM-0502a1	Mollusc population abundance monitoring: Fall 2003 mid-marsh and creekbank infaunal and epifaunal mollusc abundance based on collections from GCE marsh, monitoring sites 1-10	Bishop	2003	R
INV-GCEM-0501a1	Mollusc population abundance monitoring: Spring 2003 mid-marsh and creekbank infaunal and epifaunal mollusc abundance based on collections from GCE marsh, monitoring sites 1-10	Bishop	2003	R
INV-GCEM-0502a2	Mollusc population size distribution monitoring: Fall 2003 mid-marsh and creekbank infaunal and epifaunal mollusc size distributions based on collections from GCE marsh, monitoring sites 1-10	Bishop	2003	R
INV-GCEM-0501a2	Mollusc population size distribution monitoring: Spring 2003 mid-marsh and creekbank infaunal and epifaunal mollusc size distributions based on collections from GCE marsh, monitoring sites 1-10	Bishop	2003	R
INV-GCEM-0305	Spring 2003 crab population monitoring: mid-marsh and creekbank abundance based on crab hole counts at GCE marsh, monitoring sites 1-10	Bishop	2003	P
INV-GCEM-0411b	Fall 2004 crab population monitoring: mid-marsh and creekbank abundance based on crab hole counts at GCE marsh, monitoring sites 1-10	Bishop	2004	P
INV-GCEM-0411a	Spring 2004 crab population monitoring: mid-marsh and creekbank abundance based on crab hole counts at GCE marsh, monitoring sites 1-10	Bishop	2004	P
INV-GCEM-0511	Fall 2005 crab population monitoring: mid-marsh and creek bank abundance based on crab hole counts at GCE marsh, monitoring sites 1-9	Bishop	2005	R
	Bacterial Productivity (LTER Core Area: Population Studies)			
BCT-GCEM-0303a	June 2001 surface water bacterial abundance at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2001	P
BCT-GCEM-0302a	June 2001 surface water bacterial productivity at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2001	P
BCT-GCEM-0303c	November 2001 surface water bacterial abundance at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2001	P

** Status: P = public access, R = restricted access (public access within 2 years)*

Accession	*Dataset Title*	*Lead PI*	*Period*	*Status*
BCT-GCEM-0302c	November 2001 surface water bacterial productivity at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2001	P
BCT-GCEM-0303b	October 2001 surface water bacterial abundance at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2001	P
BCT-GCEM-0302b	October 2001 surface water bacterial productivity at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2001	P
BCT-GCEM-0303f	December 2002 surface water bacterial abundance at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2002	P
BCT-GCEM-0302f	December 2002 surface water bacterial productivity at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2002	P
BCT-GCEM-0303d	March 2002 surface water bacterial abundance at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2002	P
BCT-GCEM-0302d	March 2002 surface water bacterial productivity at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2002	P
BCT-GCEM-0303e	September 2002 surface water bacterial abundance at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2002	P
BCT-GCEM-0302e	September 2002 surface water bacterial productivity at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2002	P
BCT-GCEM-0511c	December 2003 surface water bacterial abundance at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2003	P
BCT-GCEM-0511c2	December 2003 surface water bacterial productivity at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2003	P
BCT-GCEM-0511a	June 2003 surface water bacterial abundance at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2003	P
BCT-GCEM-0511a2	June 2003 surface water bacterial productivity at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2003	P
BCT-GCEM-0305a	March 2003 surface water bacterial abundance at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2003	P
BCT-GCEM-0305	March 2003 surface water bacterial productivity at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2003	P

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Accession	Dataset Title	Lead PI	Period	Status
BCT-GCEM-0511b	September 2003 surface water bacterial abundance at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2003	P
BCT-GCEM-0511b2	September 2003 surface water bacterial productivity at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2003	P
BCT-GCEM-0511d	March 2004 surface water bacterial abundance at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2004	P
BCT-GCEM-0511d2	March 2004 surface water bacterial productivity at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2004	P
BCT-GCEM-0511e	May 2004 surface water bacterial abundance at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2004	P
BCT-GCEM-0511e2	May 2004 surface water bacterial productivity at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2004	P
	Chemistry (LTER Core Area: Movement of Inorganic Matter)			
CHM-GCED-0303b	Surface water DIC, total alkalinity, and pH for the June 2001 Georgia Coastal Ecosystems LTER oceanographic survey	Cai	2001	P
CHM-GCED-0303a	Surface water DIC, total alkalinity, and pH for the March 2001 Georgia Coastal Ecosystems LTER oceanographic survey	Cai	2001	P
CHM-GCED-0303d	Surface water DIC, total alkalinity, and pH for the November 2001 Georgia Coastal Ecosystems LTER oceanographic survey	Cai	2001	P
CHM-GCED-0303c	Surface water DIC, total alkalinity, and pH for the October 2001 Georgia Coastal Ecosystems LTER oceanographic survey	Cai	2001	P
	Fungal Productivity (LTER Core Area: Movement of Organic Matter)			
FNG-GCEM-0102	Fall 2000 fungal monitoring -- marshgrass ergosterol content and ascospore release rates at 10 GCE sampling sites	Newell	2000	P
FNG-GCEM-0112	Fall 2001 fungal monitoring -- marshgrass ergosterol content and ascospore release rates at 10 GCE sampling sites	Newell	2001	P
FNG-GCEM-0301	Fall 2002 fungal monitoring -- marshgrass ergosterol content and ascospore release rates at 10 GCE sampling sites	Newell	2002	P

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Accession	*Dataset Title*	*Lead PI*	*Period*	*Status*
FNG-GCEM-0401	Fall 2003 fungal monitoring -- marshgrass ergosterol content and ascospore release rates at 10 GCE sampling sites	Newell	2003	P
	General Nutrient Chemistry (LTER Core Area: Movement of Inorganic Matter)			
NUT-GCEM-0206	October 2001 water column particulate carbon and nitrogen concentrations for Georgia Coastal Ecosystems LTER sampling sites	Alber	2001	P
NUT-GCEM-0210	Water quality monitoring on the Altamaha River and major tributaries from September 2000 through November 2001	Hollibaugh	2000-2001	P
	Geology (LTER Core Area: Movement of Organic Matter)			
GEL-GCEM-0508a	Marsh soil characteristics at nine GCE-LTER sampling sites in May 2001	Craft	2001	R
GEL-GCEM-0508b	Sediment elevation measurements for 10 GCE-LTER sampling sites from December 2001 to May 2005	Craft	2001-2005	R
GEL-GCEM-0508c	Soil accretion at 10 GCE marsh sampling sites from December 2001 to May 2005	Craft	2001-2005	R
	Hydrography (LTER Core Area: None)			
HYD-GCES-0508b	Monthly sea-level summary data for the Fort Pulaski, Georgia, water level station (NOAA/NOS CO-OPS ID 8670870) from 01-Jan-1936 to 31-Dec-2004	Sheldon	1915-2004	P
HYD-GCES-0508a	Annual summaries of daily observations from the USGS Streamflow Gauging Station on the Altamaha River near Doctortown, Georgia, for 1932 to 2004	Sheldon	1932-2004	P
	Meteorology (LTER Core Area: None)			
MET-GCES-0508b	Annual summaries of daily climatological observations from the National Weather Service weather station at Brunswick, Georgia for 1915 to 2004	Sheldon	1915-2004	P
MET-GCEM-0109	Daily climatological observations from Sapelo Island, Georgia, from May 1957 through July 2001	Sheldon	1957-2001	P
MET-GCES-0508a	Annual summaries of daily climatological observations from the National Weather Service weather station at the UGA Marine Institute on Sapelo Island, Georgia for 1958 to 2004	Sheldon	1958-2004	P
MET-GCEM-0108	Daily climatological observations from Sapelo Island, Georgia, from June 1980 through June 2001	Sheldon	1980-2001	P

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Accession	*Dataset Title*	*Lead PI*	*Period*	*Status*

Organic Matter/Decomposition (LTER Core Area: Movement of Organic Matter)

Accession	*Dataset Title*	*Lead PI*	*Period*	*Status*
ORG-GCEM-0508b	Root Decomposition and root in-growth rates for GCE marsh sites 6-9 from June 2003 to June 2004	Craft	2003-2004	R
ORG-GCEM-0508a	Soil respiration and temperature measurements at 5 GCE-LTER sampling sites from June 2003 to March 2005	Craft	2003-2005	R
ORG-GCEM-0303a	June 2001 surface water dissolved organic carbon concentrations at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2001	P
ORG-GCEM-0303c	November 2001 surface water dissolved organic carbon concentrations at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2001	P
ORG-GCEM-0303b	October 2001 surface water dissolved organic carbon concentrations at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2001	P
ORG-GCEM-0303f	December 2002 surface water dissolved organic carbon concentrations at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2002	P
ORG-GCEM-0303d	March 2002 surface water dissolved organic carbon concentrations at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2002	P
ORG-GCEM-0303e	September 2002 surface water dissolved organic carbon concentrations at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2002	P
ORG-GCEM-0511e	December 2003 surface water dissolved organic carbon concentrations at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2003	P
ORG-GCEM-0511a	June 2003 surface water dissolved organic carbon concentrations at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2003	P
ORG-GCEM-0305	March 2003 surface water dissolved organic carbon concentrations at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2003	P
ORG-GCEM-0511b	September 2003 surface water dissolved organic carbon concentrations at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2003	P
ORG-GCEM-0511c	June 2003 surface water dissolved organic carbon concentrations at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2004	P
ORG-GCEM-0511d	May 2004 surface water dissolved organic carbon concentrations at ten Georgia Coastal Ecosystems LTER sampling sites	Hodson	2004	P

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Accession	Dataset Title	Lead PI	Period	Status
ORG-GCEM-0101	Fall 2000 soil organic content survey -- ash-free dry weight analysis for soil samples from 10 GCE LTER sampling sites	Pennings	2000	P

Physical Oceanography (LTER Core Area: Movement of Inorganic Matter)

Accession	Dataset Title	Lead PI	Period	Status
PHY-GCEM-0303a1	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE1_Hydro (Sapelo River near Eulonia, Georgia) from 13-Sep-2001 through 31-Dec-2001	Blanton	2001	P
PHY-GCEM-0303b1	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE2_Hydro (Four Mile Island, Georgia) from 26-Oct-2001 through 31-Dec-2001	Blanton	2001	P
PHY-GCEM-0303c1	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE3_Hydro (Sapelo Sound north of Sapelo Island, Georgia) from 08-Aug-2001 through 31-Dec-2001	Blanton	2001	P
PHY-GCEM-0303e1	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE7_Hydro (Altamaha River near Carrs Island, Georgia) from 10-Aug-2001 through 31-Dec-2001	Blanton	2001	P
PHY-GCEM-0303f1	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE8_Hydro (Altamaha River near Aligator Creek) from 26-Oct-2001 through 31-Dec-2001	Blanton	2001	P
PHY-GCEM-0303a2	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE1_Hydro (Sapelo River near Eulonia, Georgia) from 01-Jan-2002 through 31-Dec-2002	Blanton	2002	P
PHY-GCEM-0303b2	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE2_Hydro (Four Mile Island, Georgia) from 01-Jan-2002 through 31-Dec-2002	Blanton	2002	P
PHY-GCEM-0303c2	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE3_Hydro (Sapelo Sound north of Sapelo Island, Georgia) from 01-Jan-2002 through 31-Dec-2002	Blanton	2002	P
PHY-GCEM-0303d1	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE6_Hydro (Doboy Sound south of Sapelo Island, Georgia) from 25-Feb-2002 through 31-Dec-2002	Blanton	2002	P

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Accession	*Dataset Title*	*Lead PI*	*Period*	*Status*
PHY-GCEM-0303e2	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE7_Hydro (Altamaha River near Carrs Island, Georgia) from 01-Jan-2002 through 31-Dec-2002	Blanton	2002	P
PHY-GCEM-0303f2	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE8_Hydro (Altamaha River near Aligator Creek) from 01-Jan-2002 through 31-Dec-2002	Blanton	2002	P
PHY-GCEM-0303g1	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE9_Hydro (Altamaha River near Rockdedundy Island, Georgia) from 25-Feb-2002 through 31-Dec-2002	Blanton	2002	P
PHY-GCEM-0403a	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE1_Hydro (Sapelo River near Eulonia, Georgia) from 01-Jan-2003 through 31-Dec-2003	Blanton	2003	P
PHY-GCEM-0403h	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE10_Hydro (Duplin River west of Sapelo Island, Georgia) from 17-Jul-2003 through 31-Dec-2003	Blanton	2003	P
PHY-GCEM-0403b	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE2_Hydro (Four Mile Island, Georgia) from 01-Jan-2003 through 31-Dec-2003	Blanton	2003	P
PHY-GCEM-0403c	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE3_Hydro (Sapelo Sound north of Sapelo Island, Georgia) from 01-Jan-2003 through 06-Nov-2003	Blanton	2003	P
PHY-GCEM-0403d	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE6_Hydro (Doboy Sound south of Sapelo Island, Georgia) from 01-Jan-2003 through 31-Dec-2003	Blanton	2003	P
PHY-GCEM-0403e	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE7_Hydro (Altamaha River near Carrs Island, Georgia) from 01-Jan-2003 through 31-Dec-2003	Blanton	2003	P
PHY-GCEM-0403f	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE8_Hydro (Altamaha River near Aligator Creek, Georgia) from 01-Jan-2003 through 31-Dec-2003	Blanton	2003	P

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Accession	*Dataset Title*	*Lead PI*	*Period*	*Status*
PHY-GCEM-0403g	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE9_Hydro (Altamaha River near Rockdedundy Island, Georgia) from 01-Jan-2003 through 31-Dec-2003	Blanton	2003	P
PHY-GCEM-0505a	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE1_Hydro (Sapelo River near Eulonia, Georgia) from 01-Jan-2004 through 31-Dec-2004	Blanton	2004	P
PHY-GCEM-0505h	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE10_Hydro (Duplin River west of Sapelo Island, Georgia) from 01-Jan-2004 through 31-Dec-2004	Blanton	2004	P
PHY-GCEM-0505b	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE2_Hydro (Four Mile Island, Georgia) from 01-Jan-2004 through 31-Dec-2004	Blanton	2004	P
PHY-GCEM-0505c	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE3_Hydro (Sapelo Sound north of Sapelo Island, Georgia) from 05-May-2004 through 31-Dec-2004	Blanton	2004	P
PHY-GCEM-0505d	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE6_Hydro (Doboy Sound south of Sapelo Island, Georgia) from 01-Jan-2004 through 31-Dec-2004	Blanton	2004	P
PHY-GCEM-0505e	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE7_Hydro (Altamaha River near Carrs Island, Georgia) from 01-Jan-2004 through 31-Dec-2004	Blanton	2004	P
PHY-GCEM-0505f	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE8_Hydro (Altamaha River near Aligator Creek, Georgia) from 01-Jan-2004 through 31-Dec-2004	Blanton	2004	P
PHY-GCEM-0505g	Continuous salinity, temperature and depth measurements from moored hydrographic data loggers deployed at GCE9_Hydro (Altamaha River near Rockdedundy Island, Georgia) from 01-Jan-2004 through 31-Dec-2004	Blanton	2004	P
PHY-GCEM-0211d1	November 2001 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2001	P
PHY-GCEM-0211a1	November 2001 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2001	P

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Accession	*Dataset Title*	*Lead PI*	*Period*	*Status*
PHY-GCEM-0211b1	November 2001 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Duplin River transect	Di Iorio	2001	P
PHY-GCEM-0211c1	November 2001 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2001	P
PHY-GCEM-0211d2	November 2001 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2001	P
PHY-GCEM-0211a2	November 2001 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2001	P
PHY-GCEM-0211b2	November 2001 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Duplin River transect	Di Iorio	2001	P
PHY-GCEM-0211c2	November 2001 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2001	P
PHY-GCEM-0210e1	October 2001 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2001	P
PHY-GCEM-0210a1	October 2001 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2001	P
PHY-GCEM-0210c1	October 2001 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Inner Marsh transect	Di Iorio	2001	P
PHY-GCEM-0210b1	October 2001 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2001	P
PHY-GCEM-0210d1	October 2001 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2001	P
PHY-GCEM-0210e2	October 2001 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2001	P
PHY-GCEM-0210a2	October 2001 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2001	P
PHY-GCEM-0210c2	October 2001 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Inner Marsh transect	Di Iorio	2001	P
PHY-GCEM-0210b2	October 2001 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2001	P

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Accession	*Dataset Title*	*Lead PI*	*Period*	*Status*
PHY-GCEM-0210d2	October 2001 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2001	P
PHY-GCEM-0111d	Spring 2001 CTD profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2001	P
PHY-GCEM-0111c	Spring 2001 CTD profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2001	P
PHY-GCEM-0111b	Spring 2001 CTD profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2001	P
PHY-GCEM-0111a	Spring 2001 CTD profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2001	P
PHY-GCEM-0205d	Spring 2001 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2001	P
PHY-GCEM-0205c	Spring 2001 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2001	P
PHY-GCEM-0205b	Spring 2001 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2001	P
PHY-GCEM-0205a	Spring 2001 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2001	P
PHY-GCEM-0304c1	December 2002 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2002	P
PHY-GCEM-0304a1	December 2002 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2002	P
PHY-GCEM-0304d1	December 2002 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Inner Marsh transect	Di Iorio	2002	P
PHY-GCEM-0304b1	December 2002 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2002	P
PHY-GCEM-0304e1	December 2002 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2002	P
PHY-GCEM-0304c2	December 2002 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2002	P
PHY-GCEM-0304a2	December 2002 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2002	P

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Accession	Dataset Title	Lead PI	Period	Status
PHY-GCEM-0304d2	December 2002 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Inner Marsh transect	Di Iorio	2002	P
PHY-GCEM-0304b2	December 2002 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2002	P
PHY-GCEM-0304e2	December 2002 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2002	P
PHY-GCEM-0301b1	June 2002 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2002	P
PHY-GCEM-0301a1	June 2002 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2002	P
PHY-GCEM-0301c1	June 2002 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2002	P
PHY-GCEM-0301b2	June 2002 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2002	P
PHY-GCEM-0301a2	June 2002 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2002	P
PHY-GCEM-0301c2	June 2002 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2002	P
PHY-GCEM-0212e1	March 2002 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2002	P
PHY-GCEM-0212a1	March 2002 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Doboy River transect	Di Iorio	2002	P
PHY-GCEM-0212c1	March 2002 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Inner Marsh transect	Di Iorio	2002	P
PHY-GCEM-0212b1	March 2002 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2002	P
PHY-GCEM-0212d1	March 2002 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2002	P
PHY-GCEM-0212e2	March 2002 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2002	P

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Accession	***Dataset Title***	***Lead PI***	***Period***	***Status***
PHY-GCEM-0212a2	March 2002 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Doboy River transect	Di Iorio	2002	P
PHY-GCEM-0212c2	March 2002 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Inner Marsh transect	Di Iorio	2002	P
PHY-GCEM-0212b2	March 2002 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2002	P
PHY-GCEM-0212d2	March 2002 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2002	P
PHY-GCEM-0302e1	September 2002 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2002	P
PHY-GCEM-0302a1	September 2002 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2002	P
PHY-GCEM-0302b1	September 2002 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Inner Marsh transect	Di Iorio	2002	P
PHY-GCEM-0302c1	September 2002 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2002	P
PHY-GCEM-0302d1	September 2002 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2002	P
PHY-GCEM-0302e2	September 2002 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2002	P
PHY-GCEM-0302a2	September 2002 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2002	P
PHY-GCEM-0302b2	September 2002 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Inner Marsh transect	Di Iorio	2002	P
PHY-GCEM-0302c2	September 2002 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2002	P
PHY-GCEM-0302d2	September 2002 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2002	P
PHY-GCEM-0401a1	December 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2003	P

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Accession	*Dataset Title*	*Lead PI*	*Period*	*Status*
PHY-GCEM-0401f1	December 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2003	P
PHY-GCEM-0401c1	December 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Duplin River transect	Di Iorio	2003	P
PHY-GCEM-0401d1	December 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Inner Marsh transect	Di Iorio	2003	P
PHY-GCEM-0401b1	December 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2003	P
PHY-GCEM-0401e1	December 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2003	P
PHY-GCEM-0401a2	December 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2003	P
PHY-GCEM-0401f2	December 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2003	P
PHY-GCEM-0401c2	December 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Duplin River transect	Di Iorio	2003	P
PHY-GCEM-0401d2	December 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Inner Marsh transect	Di Iorio	2003	P
PHY-GCEM-0401b2	December 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2003	P
PHY-GCEM-0401e2	December 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2003	P
PHY-GCEM-0308c1	June 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2003	P
PHY-GCEM-0308a1	June 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2003	P
PHY-GCEM-0308d1	June 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Duplin River transect	Di Iorio	2003	P
PHY-GCEM-0308e1	June 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Inner Marsh transect	Di Iorio	2003	P

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Accession	*Dataset Title*	*Lead PI*	*Period*	*Status*
PHY-GCEM-0308b1	June 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2003	P
PHY-GCEM-0308f1	June 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2003	P
PHY-GCEM-0308c2	June 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2003	P
PHY-GCEM-0308a2	June 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2003	P
PHY-GCEM-0308d2	June 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Duplin River transect	Di Iorio	2003	P
PHY-GCEM-0308e2	June 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Inner Marsh transect	Di Iorio	2003	P
PHY-GCEM-0308b2	June 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2003	P
PHY-GCEM-0308f2	June 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2003	P
PHY-GCEM-0305a1	March 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2003	P
PHY-GCEM-0305f1	March 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2003	P
PHY-GCEM-0305c1	March 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Duplin River transect	Di Iorio	2003	P
PHY-GCEM-0305d1	March 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Inner Marsh transect	Di Iorio	2003	P
PHY-GCEM-0305b1	March 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2003	P
PHY-GCEM-0305e1	March 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2003	P
PHY-GCEM-0305a2	March 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2003	P

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Accession	*Dataset Title*	*Lead PI*	*Period*	*Status*
PHY-GCEM-0305f2	March 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2003	P
PHY-GCEM-0305c2	March 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Duplin River transect	Di Iorio	2003	P
PHY-GCEM-0305d2	March 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Inner Marsh transect	Di Iorio	2003	P
PHY-GCEM-0305b2	March 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2003	P
PHY-GCEM-0305e2	March 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2003	P
PHY-GCEM-0310c1	September 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2003	P
PHY-GCEM-0310a1	September 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2003	P
PHY-GCEM-0310d1	September 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Duplin River transect	Di Iorio	2003	P
PHY-GCEM-0310e1	September 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Inner Marsh transect	Di Iorio	2003	P
PHY-GCEM-0310b1	September 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2003	P
PHY-GCEM-0310f1	September 2003 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2003	P
PHY-GCEM-0310c2	September 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2003	P
PHY-GCEM-0310a2	September 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2003	P
PHY-GCEM-0310d2	September 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Duplin River transect	Di Iorio	2003	P
PHY-GCEM-0310e2	September 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Inner Marsh transect	Di Iorio	2003	P

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Accession	Dataset Title	Lead PI	Period	Status
PHY-GCEM-0310b2	September 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2003	P
PHY-GCEM-0310f2	September 2003 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2003	P
PHY-GCEM-0404a1	March 2004 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2004	P
PHY-GCEM-0404e1	March 2004 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2004	P
PHY-GCEM-0404c1	March 2004 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Inner Marsh transect	Di Iorio	2004	P
PHY-GCEM-0404b1	March 2004 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2004	P
PHY-GCEM-0404d1	March 2004 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2004	P
PHY-GCEM-0404a2	March 2004 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2004	P
PHY-GCEM-0404e2	March 2004 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2004	P
PHY-GCEM-0404c2	March 2004 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Inner Marsh transect	Di Iorio	2004	P
PHY-GCEM-0404b2	March 2004 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2004	P
PHY-GCEM-0404d2	March 2004 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2004	P
PHY-GCEM-0406a1	May 2004 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2004	P
PHY-GCEM-0406f1	May 2004 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2004	P
PHY-GCEM-0406c1	May 2004 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Duplin River transect	Di Iorio	2004	P

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Accession	Dataset Title	Lead PI	Period	Status
PHY-GCEM-0406d1	May 2004 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Inner Marsh transect	Di Iorio	2004	P
PHY-GCEM-0406b1	May 2004 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2004	P
PHY-GCEM-0406e1	May 2004 bin-averaged CTD profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2004	P
PHY-GCEM-0406a2	May 2004 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Altamaha River transect	Di Iorio	2004	P
PHY-GCEM-0406f2	May 2004 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Doboy Sound transect	Di Iorio	2004	P
PHY-GCEM-0406c2	May 2004 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Duplin River transect	Di Iorio	2004	P
PHY-GCEM-0406d2	May 2004 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Inner Marsh transect	Di Iorio	2004	P
PHY-GCEM-0406b2	May 2004 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Intracoastal Waterway transect	Di Iorio	2004	P
PHY-GCEM-0406e2	May 2004 CTD, PAR, oxygen and chlorophyll profiles for the Georgia Coastal Ecosystems Sapelo River transect	Di Iorio	2004	P
	Phytoplankton Productivity (LTER Core Area: Primary Production)			
PHP-GCEM-0302a	June 2001 surface water phytoplankton productivity for 10 Georgia Coastal Ecosystems LTER sampling sites	Hodson	2001	P
PHP-GCEM-0302c	November 2001 surface water phytoplankton productivity for 10 Georgia Coastal Ecosystems LTER sampling sites	Hodson	2001	P
PHP-GCEM-0302b	October 2001 surface water phytoplankton productivity for 10 Georgia Coastal Ecosystems LTER sampling sites	Hodson	2001	P
PHP-GCEM-0302e	December 2002 surface water phytoplankton productivity for 10 Georgia Coastal Ecosystems LTER sampling sites	Hodson	2002	P
PHP-GCEM-0211a	March 2002 surface water phytoplankton productivity for 10 Georgia Coastal Ecosystems LTER sampling sites	Hodson	2002	P

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Accession	*Dataset Title*	*Lead PI*	*Period*	*Status*
PHP-GCEM-0302d	September 2002 surface water phytoplankton productivity for 10 Georgia Coastal Ecosystems LTER sampling sites	Hodson	2002	P
PHP-GCEM-0511e	December 2003 surface water phytoplankton productivity for 10 Georgia Coastal Ecosystems LTER sampling sites	Hodson	2003	P
PHP-GCEM-0511a	June 2003 surface water phytoplankton productivity for 10 Georgia Coastal Ecosystems LTER sampling sites	Hodson	2003	P
PHP-GCEM-0305	March 2003 surface water phytoplankton productivity for 10 Georgia Coastal Ecosystems LTER sampling sites	Hodson	2003	P
PHP-GCEM-0511b	September 2003 surface water phytoplankton productivity for 10 Georgia Coastal Ecosystems LTER sampling sites	Hodson	2003	P
PHP-GCEM-0511c	March 2004 surface water phytoplankton productivity for 10 Georgia Coastal Ecosystems LTER sampling sites	Hodson	2004	P
PHP-GCEM-0511d	May 2004 surface water phytoplankton productivity for 10 Georgia Coastal Ecosystems LTER sampling sites	Hodson	2004	P
	Plant Ecology (LTER Core Area: Primary Production)			
PLT-GCED-0409	Plant community response to fertilization at Sapelo Island, Georgia	Pennings	1996-1997	P
PLT-GCEM-0303a	Fall 2000 plant monitoring survey -- biomass calculated from shoot height and flowering status of plants in permanent plots at GCE sampling sites 1-10	Pennings	2000	P
PLT-GCEM-0101	Fall 2000 plant monitoring survey -- shoot height and flowering status of plants in permanent plots at GCE sampling sites 1-10	Pennings	2000	P
PLT-GCEM-0303b	Fall 2001 plant monitoring survey -- biomass calculated from shoot height and flowering status of plants in permanent plots at GCE sampling sites 1-10	Pennings	2001	P
PLT-GCEM-0110	Fall 2001 plant monitoring survey -- shoot height and flowering status of plants in permanent plots at GCE sampling sites 1-10	Pennings	2001	P
PLT-GCEM-0303c	Fall 2002 plant monitoring survey -- biomass calculated from shoot height and flowering status of plants in permanent plots at GCE sampling sites 1-10	Pennings	2002	P
PLT-GCEM-0211	Fall 2002 plant monitoring survey -- shoot height and flowering status of plants in permanent plots at GCE sampling sites 1-10	Pennings	2002	P
PLT-GCEM-0211b	Plant allometry at GCE sampling sites 1-10 in October, 2002	Pennings	2002	P

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Accession	Dataset Title	Lead PI	Period	Status
PLT-GCEM-0311b	Fall 2003 plant monitoring survey -- biomass calculated from shoot height and flowering status of plants in permanent plots at GCE sampling sites 1-10	Pennings	2003	P
PLT-GCEM-0311a	Fall 2003 plant monitoring survey -- shoot height and flowering status of plants in permanent plots at GCE sampling sites 1-10	Pennings	2003	P
PLT-GCEM-0501b	Fall 2004 plant monitoring survey -- biomass calculated from shoot height and flowering status of plants in permanent plots at GCE sampling sites 1-10	Pennings	2004	P
PLT-GCEM-0501a	Fall 2004 plant monitoring survey -- shoot height and flowering status of plants in permanent plots at GCE sampling sites 1-10	Pennings	2004	P
PLT-GCEM-0511b	Fall 2005 plant monitoring survey -- biomass calculated from shoot height and flowering status of plants in permanent plots at GCE sampling sites 1-10	Pennings	2005	R
PLT-GCEM-0511a	Fall 2005 plant monitoring survey -- shoot height and flowering status of plants in permanent plots at GCE sampling sites 1-10	Pennings	2005	R
	Pore-water Chemistry (LTER Core Area: Movement of Inorganic Matter)			
POR-GCED-0210	Porewater nutrients, dissolved organics, redox species, and gasses in estuarine intertidal sediments at sites on Sapelo Island and near the Satilla River from Fall 2000 through Fall 2002	Joye	2000-2002	P
	Terrestrial Insect Ecology (LTER Core Area: Population Studies)			
INS-GCEM-0011	Fall 2000 grasshopper monitoring -- mid-marsh grasshopper abundance and species diversity at GCE LTER sampling sites 1, 3, 4, 5, and 6	Pennings	2000	P
INS-GCEM-0108	Fall 2001 grasshopper monitoring -- mid-marsh grasshopper abundance and species diversity at eight GCE LTER sampling sites	Pennings	2001	P
INS-GCEM-0208	Fall 2002 grasshopper monitoring -- mid-marsh grasshopper abundance and species diversity at eight GCE LTER sampling sites	Pennings	2002	P
INS-GCEM-0310	Fall 2003 grasshopper monitoring -- mid-marsh grasshopper abundance and species diversity at eight GCE LTER sampling sites	Pennings	2003	P
INS-GCEM-0409	Fall 2004 grasshopper monitoring -- mid-marsh grasshopper abundance and species diversity at eight GCE LTER sampling sites	Pennings	2004	P
INS-GCEM-0511	Fall 2005 grasshopper monitoring -- mid-marsh grasshopper abundance and species diversity at eight GCE LTER sampling sites	Pennings	2005	R

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Summary of data access by parties not affiliated with the GCE LTER project from 2001-2005

Year	User Affiliation	Research Theme	Downloads
2001	Academic Research Program	Meteorology	5
	Educational Program (Post-secondary)	Terrestrial Insect Ecology	4
	Government Agency	Meteorology	6
	Other LTER Site	Meteorology	1
		2001 Total:	**16**
2002	Academic Research Program	General Nutrient Chemistry	2
		Meteorology	5
		Organic Matter/Decomposition	2
		Plant Ecology	3
		Terrestrial Insect Ecology	3
	Educational Program (K-12)	General Nutrient Chemistry	1
		Meteorology	3
		Plant Ecology	3
	Educational Program (Post-secondary)	Meteorology	10
		Plant Ecology	1
		Terrestrial Insect Ecology	1
	Environmental Advocacy Group	Plant Ecology	1
	Government Agency	Fungal Productivity	1
	Other LTER Site	Meteorology	8
		Organic Matter/Decomposition	1
		Plant Ecology	3
	Other/Unspecified	Fungal Productivity	1
		General Nutrient Chemistry	4
		Meteorology	1
		Organic Matter/Decomposition	2
		Physical Oceanography	2
		Plant Ecology	2

		Terrestrial Insect Ecology	3
		2002 Total:	**63**
2003	Academic Research Program	Aquatic Invertebrate Ecology	1
		Bacterial Productivity	2
		Fungal Productivity	1
		General Nutrient Chemistry	2
		Meteorology	1
		Organic Matter/Decomposition	1
		Physical Oceanography	1
		Plant Ecology	4
		Terrestrial Insect Ecology	2
	Educational Program (K-12)	Physical Oceanography	1
		Plant Ecology	1
	Educational Program (Post-secondary)	Meteorology	1
	LTER Network Office (Metacat)	Aquatic Invertebrate Ecology	1
		Plant Ecology	1
	Other LTER Site	Aquatic Invertebrate Ecology	7
		Bacterial Productivity	2
		General Nutrient Chemistry	2
		Meteorology	1
		Phytoplankton Productivity	1
		Plant Ecology	3
	Other/Unspecified	Aquatic Invertebrate Ecology	3
		General Nutrient Chemistry	1
		Meteorology	5
		Terrestrial Insect Ecology	1
		2003 Total:	**46**
2004	Academic Research Program	Aquatic Invertebrate Ecology	12
		General Nutrient Chemistry	2
		Meteorology	9

	Organic Matter/Decomposition	1
	Physical Oceanography	11
	Phytoplankton Productivity	3
	Plant Ecology	3
	Pore-water Chemistry	2
	Terrestrial Insect Ecology	2
Educational Program (Post-secondary)	Aquatic Invertebrate Ecology	20
	Bacterial Productivity	3
	General Nutrient Chemistry	2
	Meteorology	3
	Organic Matter/Decomposition	1
	Physical Oceanography	8
	Phytoplankton Productivity	2
	Plant Ecology	6
	Terrestrial Insect Ecology	5
Government Agency	Fungal Productivity	1
	General Nutrient Chemistry	1
	Meteorology	4
	Physical Oceanography	3
	Plant Ecology	4
	Real-time Climate	4
	Terrestrial Insect Ecology	2
International LTER Site	Meteorology	1
	Physical Oceanography	1
LTER Network Office (Metacat)	Aquatic Invertebrate Ecology	101
	Bacterial Productivity	11
	General Nutrient Chemistry	3
	Meteorology	2
	Organic Matter/Decomposition	8
	Physical Oceanography	13

		Phytoplankton Productivity	7
		Terrestrial Insect Ecology	3
	Other LTER Site	Aquatic Invertebrate Ecology	1
		Organic Matter/Decomposition	1
		Physical Oceanography	5
		Plant Ecology	3
	Other/Unspecified	Aquatic Invertebrate Ecology	3
		Bacterial Productivity	1
		Meteorology	1
		Organic Matter/Decomposition	2
		Physical Oceanography	13
		Phytoplankton Productivity	5
		Plant Ecology	3
		2004 Total:	**302**
2005	Academic Research Program	Algal Productivity	1
		Aquatic Invertebrate Ecology	18
		Bacterial Productivity	14
		Chemistry	1
		Fungal Productivity	4
		General Nutrient Chemistry	2
		Hydrography	2
		Meteorology	4
		Organic Matter/Decomposition	9
		Physical Oceanography	38
		Phytoplankton Productivity	7
		Plant Ecology	17
		Pore-water Chemistry	1
		Real-time Climate	21
		Terrestrial Insect Ecology	7
	Educational Program (K-12)	Bacterial Productivity	1

	Organic Matter/Decomposition	1
	Physical Oceanography	26
	Plant Ecology	1
	Real-time Climate	5
	Terrestrial Insect Ecology	2
Educational Program (Post-secondary)	Aquatic Invertebrate Ecology	7
	Bacterial Productivity	14
	General Nutrient Chemistry	12
	Meteorology	1
	Physical Oceanography	12
	Phytoplankton Productivity	9
	Plant Ecology	28
	Pore-water Chemistry	1
	Real-time Climate	41
	Terrestrial Insect Ecology	4
Government Agency	Bacterial Productivity	1
	Chemistry	5
	General Nutrient Chemistry	10
	Hydrography	2
	Meteorology	3
	Physical Oceanography	172
	Phytoplankton Productivity	11
	Real-time Climate	5
	Terrestrial Insect Ecology	1
International LTER Site	Meteorology	1
LTER Network Office (Metacat)	Aquatic Invertebrate Ecology	84
	Bacterial Productivity	4
	Fungal Productivity	5
	General Nutrient Chemistry	3
	Organic Matter/Decomposition	4

	Physical Oceanography	7
	Phytoplankton Productivity	14
	Plant Ecology	43
	Pore-water Chemistry	1
	Terrestrial Insect Ecology	1
Other LTER Site	Fungal Productivity	1
	General Nutrient Chemistry	1
	Meteorology	11
	Physical Oceanography	3
	Plant Ecology	6
	Pore-water Chemistry	3
	Real-time Climate	3
	Various (custom file)	1
Other/Unspecified	Aquatic Invertebrate Ecology	1
	Bacterial Productivity	2
	Fungal Productivity	3
	General Nutrient Chemistry	3
	Meteorology	2
	Organic Matter/Decomposition	3
	Physical Oceanography	54
	Phytoplankton Productivity	1
	Plant Ecology	2
	Pore-water Chemistry	2
	Real-time Climate	3
	2005 Total:	**793**
	2001-2005 Total:	**1220**