

## **GCE-III Annual Report – Year Six (2018)**

### **WHAT ARE THE MAJOR GOALS OF THE PROJECT?**

The primary goal of GCE-III is to understand how variation in salinity and inundation, driven by climate change and anthropogenic factors, affect biotic and ecosystem responses at different spatial and temporal scales, and to predict the consequences of these changes for habitat provisioning and C sequestration across the coastal landscape. We divide our research into 4 inter-related programmatic areas: Climate and Human Drivers of Change (Area 1); Long-term Patterns within the Domain (Area 2); Response of Marsh Habitats to Changes in Salinity and Inundation (Area 3); and Integration and Forecasting (Area 4). Our major goals within these areas are as follows:

Area 1: To track long-term changes in climate (average conditions and extreme events like storms) and human actions (in the watershed and adjacent uplands), and to evaluate the effects of climate and human drivers on domain boundary conditions (riverine input, runoff and infiltration from adjacent uplands, sea surface height).

Area 2: To describe temporal and spatial variability in physical (stratification strength, estuarine salt intrusion length, residence time), chemical (salinity, nutrient concentration and speciation, organic matter lability), geological (accretion) and biological (organism abundance and productivity, microbial processes) properties within the domain and to evaluate how they are affected by variations in river inflow and other boundary conditions.

Area 3: To characterize the responses of the marsh habitats in the domain (Spartina marsh, fresh/brackish marsh, high marsh) to pulses and presses in salinity and inundation that might be expected in the coming decades.

Area 4: To describe current patterns of habitat provisioning and C sequestration and export in the GCE domain, and to evaluate how these might be affected by changes in salinity and inundation.

### **WHAT WAS ACCOMPLISHED UNDER THESE GOALS?**

The GCE works in 4 main areas. The specific objectives associated with each of these are listed below, along with the years over the 6-year course of the project during which we plan to address them. The initials of the primary PIs involved in each activity are also listed. AB: Burd, BS: Silliman, CA: Alexander, CC: Craft, CH: Hopkinson, CM: Meile, DD: Di Iorio, JB: Byers, JH: Hollibaugh, JS: Schalles, MA: Alber, MG: Garbey, ML: Leclerc, PM: Medeiros, RC: Castelao, RP: Peterson, RV: Viso, SJ: Joye, SP: Pennings, VT: Thompson, WC: Cai, WS: Sheldon.

Below we summarize our major activities and significant results for each of the objectives targeted for yr 6.

#### **Area 1: Drivers of Change**

We collect long-term measurements of A) climate, water chemistry, oceanic exchange, and B) human activities on the landscape in order to document how boundary conditions that affect the domain vary over time.

## Area 1A Objectives

1. Install and maintain an eddy covariance flux tower in the Duplin River (yr 1-6) DD, ML, WS

Year Six Activities: The sonic anemometers and IR gas analyzers used for eddy covariance measurements failed this past year due to damage sustained during Tropical Storm Irma and the harsh conditions of the marine environment. After a lengthy outage the anemometers and one IRGA have now been repaired and are being redeployed. We also recently added a total solar radiometer and a second set of soil temperature probes to support our marsh heat flux and phenology studies.

2. Collect ongoing information on climate and oceanographic conditions, sea level, and river discharge (yr 1-6) WS, DD, MA, ML

Year Six Activities: A series of meteorological stations are used to characterize the GCE domain (Fig. 1). The station at Marsh Landing serves as our primary station for ClimDB. In September 2017 Hurricane Irma passed through Georgia, causing salt water intrusion far up the Altamaha River estuary (Fig. 2).

Significant Results: We analyzed sea level variation at Meridian and the wind stress at the NDBC41008 offshore buoy and at Marsh Landing and computed daily climatologies over the period 2003 to 2017 (Fig. 1).

3. Collect samples of Altamaha River water entering the GCE domain, and analyze it for dissolved inorganic nutrients, DIC, alkalinity and pH (yr 1-6) MA, WC, SJ

Year Six Activities: We collect monthly samples of the river water entering the GCE domain via the Altamaha River for analysis of dissolved inorganic nutrients, and semimonthly samples for DIC and alkalinity.

Significant Results: We found a decrease in the quantity of DIC measured in Altamaha River samples over the past two decades. This will be included in a synthesis of Georgia coastal waters (in prep).

4. Measure exchange between the mouths of the estuaries and the coastal ocean (yr 2-4) DD, RC

Completed yr. 5.

Significant Results: Richards (2018) found that Ekman dynamics are most apparent offshore at the 20 m isobath as the primary mode of variability driving flow dynamics and that the secondary mode of variability is related to buoyancy driven flows that enhance offshore transport. Alongshore currents are most apparent near shore within the inner shelf 10 m isobath and are directly related to alongshore wind stress.

5. Measure exchange between the Duplin River and Doboy Sound (yr 1-6) DD

Year Six Activities: We have been analyzing the horizontal acoustic Doppler current profiler (HADCP) for transport measurements at Marsh Landing. The HADCP failed during Hurricane Irma due to a power loss; we are looking into a permanent power back up source for the instrument.

Significant Results: HADCP estimates of transport from the Duplin River to Doboy Sound shows

that there is a persistent net outflow throughout the year. The data also reveal an annual cycle of sea surface height, with low water in spring and higher water in fall. Hurricane Irma created a large surge in sea surface height as a direct result of the large cross-shore wind stress to the west (Fig. 2).

### Area 1B Objectives

1. Conduct structured interviews of McIntosh County residents about environmental change (yr 1) MA

Completed yr 1.

2. Evaluate market and nonmarket values of natural resources in McIntosh County (yr 1) MA

Completed yr 1.

3. Incorporate information on human activities in the GCE database (yr 1-6) CA, VT, WS

Year Six Activities: We are continuing to build on our tree ring, oyster measurements, and radiocarbon database. We have collected samples from over 100 bald cypress trees for radiocarbon dating to create a 7000 year dendrological sequence for the GA coast. We are also working to examine obvious cultural features identified in aerial imagery.

Significant Results: Examination of aerial imagery has revealed the presence of a large oyster ring that is now below sea level, but which may have pre-European cultural significance. This will be presented at the fall AGU meeting.

4. Assess changes in Native American economic systems over time and their impact on the coastal Georgia landscape (yr 1-4) VT

Year Six Activities: We are using oyster samples to evaluate fishery changes, and we are also tracking shifts in habitations of archaeological sites over the past 4000 years.

Significant Results: Lulewicz et al. 2017 identified a size reduction in oysters over time, especially beginning about 3800 years ago. This follows up on Turck and Thompson 2016, which examined how radiocarbon dates and sites tracked with populations of Native American groups.

### **Area 2: Patterns within the Domain**

We collect data documenting key ecosystem variables within the GCE domain. Major activities in this area consist of A) field monitoring of water and marsh attributes at our core monitoring sites, B) remote sensing of productivity and habitat shifts, and C) hydrodynamic modeling of water and salt transport.

### Area 2A Objectives

1. Continue the GCE core monitoring program in the water column, which consists of continuous measurements of salinity, temperature and pressure at 10 sites, and quarterly or monthly CTD profiles and measurements of nutrients, chlorophyll and suspended sediment at 11 sites (see Major Activities Table 1) (yr 1-6) WS, DD, MA, SJ

Year Six Activities: We continue to maintain sondes at 10 GCE sites (Fig. 3). We also take CTD measurements and water samples according to the schedule in Table 1. We increased nutrient sampling to monthly at all GCE sites and added 10 additional sites from March 2017 to February

2018 as part of a GA Environmental Protection Division project to inform the process of establishing numeric nutrient criteria for Georgia coastal waters.

2. Continue the core monitoring program in the marsh, which consists of annual measurements of soil accretion, accumulation, compaction and decomposition; disturbance to plant communities; and plant and animal biomass, densities, and community composition in the marsh associated with each core site (yr 1-6). This will be augmented to include monitoring mixed plant communities; brackish/salt plant distributions; and barnacle recruitment (starting yr 1) SP, CC, BS

Year Six Activities: We continue to monitor plants, invertebrates, and sediment elevation at each core site (Fig. 3) as well as plant mixtures and barnacle recruitment at sites established in 2006, and continue to monitor recovery from a wrack disturbance experiment.

Significant Results: Li et al. (2018) found that *Zizaniopsis* production varies among years as a function of temperature and river discharge (Fig. 3). Herbert et al. (in review), studying in a nearby site, evaluated the effects of long-term (10 yr) fertilization of a tidal freshwater marsh and found that N, not P, is the primary limiting nutrient in these systems. However, N additions reduced C storage, which could have negative consequences for maintaining elevation.

3. Add a core monitoring station in tidal fresh water (yr 1-2) CC

Year Six Activities: We continue to measure plant productivity at the core monitoring tidal forest site using dendrometer bands and litterfall traps.

Significant Results: Stahl et al. (2018) found that soil accretion in the interior forest is far below the current rate of sea level rise.

4. Characterize groundwater flow into the Duplin River (yr 1-3) RP, RV, CM

Completed yr 5.

Significant Results: Analysis of the multi-year Rn time series taken at stations along the main axis of the Duplin River allowed us to delineate groundwater input and model subsurface flow (Fig. 4, Peterson et al., submitted).

5. Assess seasonal dynamics of ammonium oxidizing archaea (yr 1-2) JH

Completed yr 3.

Significant Results: Damashek et al. (in press) evaluated the contribution of organic N to ammonia oxidation in the South Atlantic Bight. They found limited oxidation of polyamine N, which was strongly correlated with ammonia oxidation rates.

6. Assess seasonal dynamics of blue crabs (yr 3-6) SP, BS

Year Six Activities: We ended the blue crab monitoring in the marsh in 2015 because it was too labor intensive to justify the limited data collected. However, we have obtained data from GA Department of Natural Resources that we are using in conjunction with our field monitoring to evaluate how blue crab densities vary with estuarine salinity.

7. Characterize DOM composition and predominant sources of estuarine water (yr 1-3) PM

Year Six Activities: Analyses of bulk (DOC), optics (CDOM) and molecular (FT-ICR MS) measurements on DOM samples collected in the Altamaha River and Sapelo Sound from Sep. 2015 to Sep. 2016 were finalized this past year (Fig. 4).

Significant Results: Roebuck et al. (2018), in a collaboration between GCE and FCE, documented the seasonal contents and composition of particulate and dissolved black carbon in the Altamaha River over an annual cycle.

### Area 2B Objectives

1. Create high resolution maps of site bathymetry and habitat distribution (yr 1-6) CA, MA, RV, DD

Year Six Activities: We have mapped the bathymetry of Sapelo Sound with interferometric side scan sonar, which will provide improved bathymetric data for modeling efforts. We have continued regular annual high-resolution aerial flights of the domain.

Significant Results: The first new bathymetry for Sapelo Sound since 1933 is now available to support modeling and benthic habitat assessments.

2. Assess patterns of marsh productivity using satellite imagery (yr 1-6) JS, SP, MA, WS

Year Six Activities: We developed an algorithm for generating estimates of belowground biomass of *Spartina alterniflora* based largely on information that can be obtained via remote sensing, including aboveground biomass, leaf chlorophyll concentration, phenology and elevation. We are also adapting our Tidal Marsh Inundation Index (TMII), which we developed for use with MODIS images, so that it can also be used with Landsat imagery to identify flooded pixels in tidal marshes.

Significant Results: We have successfully developed a model for predicting belowground biomass of *Spartina alterniflora* from remote sensing data. The model explains 77% of the variance in belowground biomass and reveals interesting spatial and temporal dynamics (Fig. 5). This was presented at ASLO and is being written up for publication.

### Area 2C Objectives

1. Implement FVCOM in the Duplin River (yr 1-6) DD, RC

Completed yr 5.

2. Implement FVCOM in the larger GCE domain (yr 1-6) RC, DD

Year Six Activities: An updated topography has been implemented for FVCOM, which will allow for more accurate representation of inundation patterns. We are also working to couple the model to a water quality module.

### **Area 3: Responses to Salinity and Inundation**

We work in each of our key marsh habitats to assess how they will respond to changes in salinity and inundation. A) In the *Spartina* marsh we will assess marsh-atmosphere and marsh-creek exchange; monitor and model *Spartina* primary production; assess organism interactions; and evaluate ecosystem metabolism. B) In the fresh/brackish marsh our work involves long-term observations along the transect

of the Altamaha River, and a large-scale field manipulation to evaluate how pulses and presses of salt water affect a tidal freshwater marsh. C) In the high marsh our work involves a field survey of high marsh areas, an experimental manipulation of runoff to the high marsh, and modeling of plant communities.

### Area 3A Objectives

1. Characterize temporal variability in marsh-atmosphere exchange of CO<sub>2</sub> (yr 2-6) ML, DD, CH, WS

Year Six Activities: We are using flux tower data to parameterize a MODIS-based Gross Primary Production model for *Spartina alterniflora*.

Significant Results: Forbrich (PIE) used GCE data as part of a study to predict salt marsh GPP across a latitudinal gradient on the US Atlantic coast. She found that a general light use efficiency model explained 80% of the variation in GPP at most of the sites. This was presented at CERF and AGU.

2. Evaluate *Spartina* plant phenology (yr 1-6) MA, JS, WS and above- and below-ground production (yr 1-4) SP

Year Six Activities: The phenocam camera contributes data to the national phenocam network every 30 min. We continue to sample plants in permanent plots near the flux tower on a monthly basis, timed to correspond with Landsat overpasses.

Significant Results: We used imagery from the “GCE Sapelo” Phenocam to detect spatial and interannual differences in *Spartina alterniflora* phenology (Fig. 6). We used this information to develop a spring warm-up model that uses elevation-related differences in soil temperature to predict the date of green-up onset (O’Connell et al., in prep).

3. Quantify lateral C exchange through a small tidal creek (yr 1-3) CH, WC, DD, RC, MA

Completed yr 4.

4. Evaluate net ecosystem metabolism and quantify net C exchange in the Duplin R (yr 1-4) CH, WC, MA

Completed yr 4.

5. Conduct a predator removal manipulation (yr 4-6) BS, SP

Year Six Activities: The predator exclusion experiment initiated in summer 2016 was sampled twice during this past year.

Significant Results: Silliman et al. (2018) explored the importance of shifting baselines when evaluating predator diversity. In our predator exclusion experiment snail and fiddler crab densities are increasing, but only moderately, which may be due to increases in predatory mud crabs.

6. Monitor headward erosion in tidal creeks (yr 1-4) SP

Completed yr 3.

7. Develop a *Spartina* physiological model (yr 1-3) AB

Completed yr 5.

Significant Results: Yung (2018) developed model parameters for the three *Spartina* height forms using data from the flux tower site. The model reproduced the timing of the seasonal cycles in above- and below-ground biomass, but not the amplitude of the cycles. Translocation of resources from above to below ground was small suggesting that, in GA, these plants are able to obtain their required resources from photosynthesis alone.

8. Develop a model to predict porewater salinity (yr 13) CM

Completed yr 5.

Area 3B Objectives

1. Assess changes in community composition along the salinity gradient of the Altamaha (yr 1-6) MA, CC

Year Six Activities: We continued our annual survey to document the transition in bankside vegetation from *S. cynosuroides* to *S. alterniflora* along the salinity gradient of the Altamaha River. We also conducted a Landsat analysis of swamp forest stands over 35 years of Landsat5 and 8 imagery.

Significant Results: Our remote sensing analysis of vegetation indices in swamp forest stands revealed no serious declines or notable changes over 35 years of Landsat imagery.

2. Conduct field manipulation of salt water intrusion in a low-salinity tidal marsh (yr 1-6) CC, SP, BS

Year Six Activities: Dosing of the SALTE<sub>x</sub> plots ended at the beginning of 2018 and the experiment is now in the "recovery" phase. We continue to monitor porewater, soil characteristics, plants and animals. We also reanalyzed soil samples collected in 2014 and 2015 to evaluate specific individual compounds as opposed to major chemical classes. This past year we continued a "phytometer" experiment in which we transplanted three species of brackish marsh plants into the plots to assess whether they could invade if dispersal limitation was removed.

Significant Results: Herbert et al. (2018) summarized the major biogeochemical findings of the SALTE<sub>x</sub> manipulation: press plots had increases in porewater nutrients and decreases in respiration and ecosystem production (Fig. 7). Li et al (in review) described the vegetation responses: plants were strongly affected by the saline press treatment and only mildly by the saline pulse treatment.

3. Apply SLAMM to the GCE domain (yr 1-3) CC, CA, MA

Completed yr 4.

Area 3C Objectives

1. Continue to monitor groundwater salinity, temperature and pressure on instrumented hammocks (yr 1-2) CA, CM, WS

Completed yr 3.

2. Survey high marsh characteristics in sites with different land-use categories (yr 1-2) MA, JB, CA, SP

Completed yr 4. We are further exploring the data to evaluate snail demographics and crab parasites.

3. Conduct upland manipulation of water flow to high marsh areas (yr 3-6) SP, MA, JB, CA

Year Six Activities: We sampled plants and invertebrates in treatment plots, and track groundwater pressure continuously at wells in the plots (Fig. 5). In 2018 we installed additional wells at Marsh Landing where we have monitored high marsh vegetation for over 20 years.

Significant Results: Resistivity profiles at the high marsh site suggest a shallow, fully saline layer of marsh sediments and a deeper, brackish to fresher layer (Fig. 8). Monitoring of hydraulic gradients indicates creekward flow in most but not all plots and suggests that the treatments were not successful in strongly altering groundwater flow.

4. Develop a clonal plant model to explore vegetation dynamics (yr 3-5) MG

Year Six Activities: We have suspended model development and shifted our emphasis to documenting vegetation patterns in photographs collected in annual surveys of a high marsh to inform the upland manipulation and future work on the clonal plant model. The web sites that allow citizen scientists to contribute data towards this project have been migrated to servers at UGA.

#### **Area 4: Integration and Forecasting**

We use a combination of integrative modeling, empirical observations, and remote sensing to produce an integrated picture of habitat provisioning and carbon flow across the landscape, and evaluate how changes in salinity and inundation may change these services in the future. Major activities include A) develop an integrative model that uses a hydrodynamic model (FVCOM), a soil model, and 3 different semi-empirical plant models to predict salinity and inundation patterns, porewater salinities, and plant responses over different time scales, and B) use combined model output to evaluate habitat provisioning and C) flow under different scenarios.

##### Area 4A Objectives

1. Run FVCOM to predict salinity and inundation (yr 3-4) DD, RC

Year Six Activities: The GCE hydrodynamic model is currently being implemented for 2017, which will allow us to produce high-resolution predictions of salinity and inundation throughout the domain, including during the passage of Hurricane Irma.

2. Run the soil model to predict porewater salinity (yr 4-5) CM

Year Six Activities: The porewater model is being used to determine if predicted historical patterns of porewater salinity explain changes in plant community composition in long-term monitoring plots in the Duplin River.

Significant Results: Miklesh and Meile (in press) found that porewater salinity is sensitive to the composition of the creek water in the low marsh and to evapotranspiration in the high marsh. They also found evidence for substantial interannual variability (Fig. 9).

3. Run the plant models to predict vegetation response yr (2-6) AB, MG

Year Six Activities: The *Spartina* plant model was run at three different latitudes to assess the sensitivity of plant production to day length and temperature.

Significant Results: We are using the soil model to see if predictions of historical patterns of porewater salinity explain changes in plant community composition in long-term monitoring plots.

#### Area 4B Objectives

1. Develop scenarios (yr 3) MA, AB, CA, VT

Completed yr 4.

2. Evaluate C flow (yr 3-6) WC, CH, ML, MA, CC

Year Six Activities: Sediment cores have been collected at all GCE sites for accumulation rate determination and to calculate carbon burial along the salinity gradient. We are also using data from a series of cruises in the South Atlantic Bight to evaluate the mixing of marsh-derived C across the shelf.

Significant Results: Analysis of sediment cores revealed that accumulation rates peak near the channel margins and near the mean high water line. This unusual result may be due to sandy upland sediment reaching the marsh.

3. Evaluate habitat provisioning (yr 3-6) MA, RC, DD, CA

Year Six Activities: We completed an analysis of a 35-yr series of Landsat5 and 8 images to document dynamics of *Spartina alterniflora* seasonal phenology and interannual variation for the GA coast.

Significant Results: Our long-term analyses of Landsat imagery for the GA coast revealed that six of seven USGS drainage areas (HUCs) showed net declines in biomass over time (Table 1). The exception was the Altamaha River HUC, which showed a net increase, demonstrating the importance of freshwater flow to marsh health. This was presented at the ASLO meeting.

# GCE Activities 2018

## Area 1: Drivers of Change

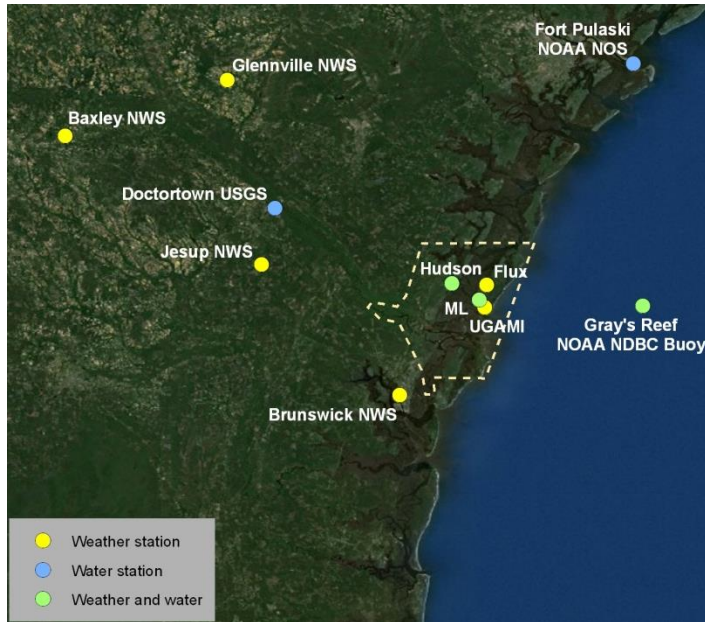


Fig. 1. Locations of observing stations used for boundary conditions (ML is Marsh Landing; UGAMI is UGA Marine Institute). Corresponds to Objective 1A.2: Collect ongoing information on climate and oceanographic conditions, sea level, and river discharge.

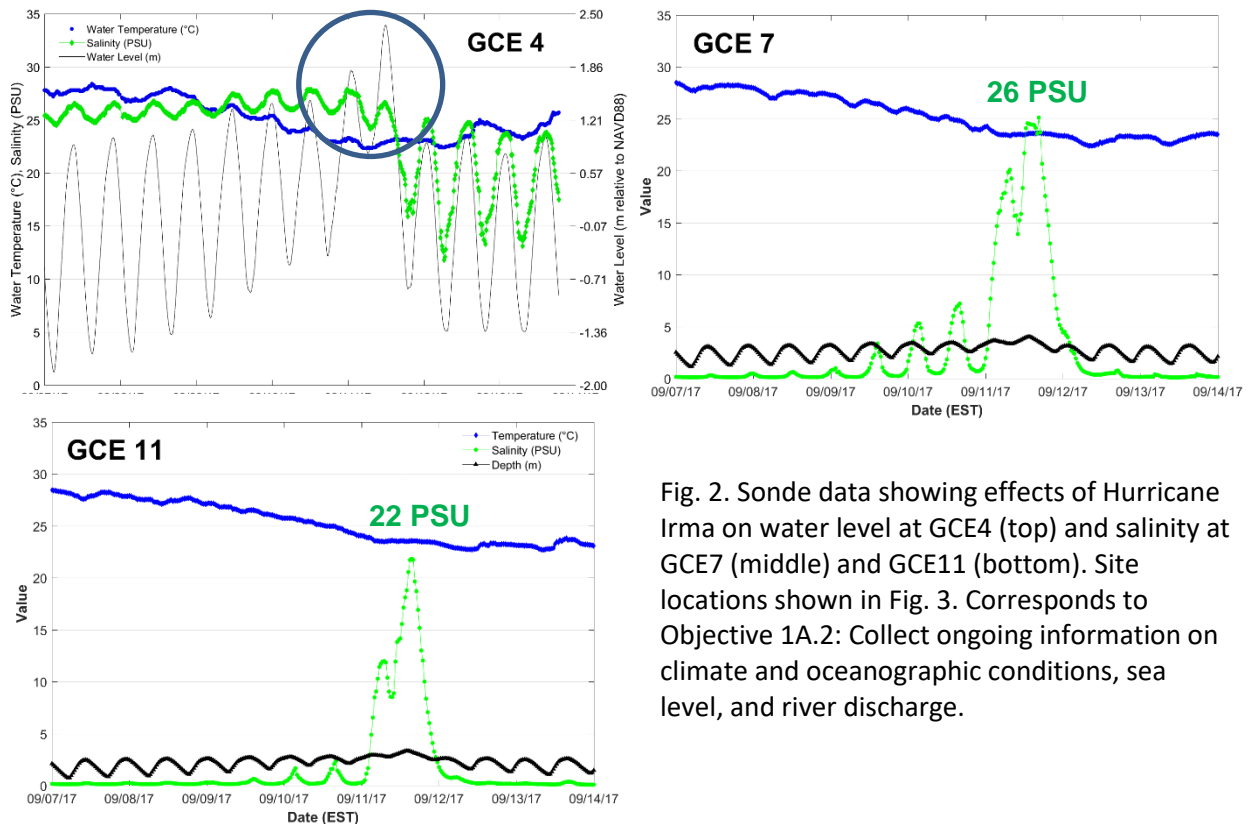


Fig. 2. Sonde data showing effects of Hurricane Irma on water level at GCE4 (top) and salinity at GCE7 (middle) and GCE11 (bottom). Site locations shown in Fig. 3. Corresponds to Objective 1A.2: Collect ongoing information on climate and oceanographic conditions, sea level, and river discharge.

## GCE Activities 2018

### Area 2: Patterns within the Domain



Fig. 3. GCE domain showing core monitoring stations. Corresponds to Objective 2A.1: Continue the GCE core monitoring program in the water column and Objective 2A.2: Continue the core monitoring program in the marsh.

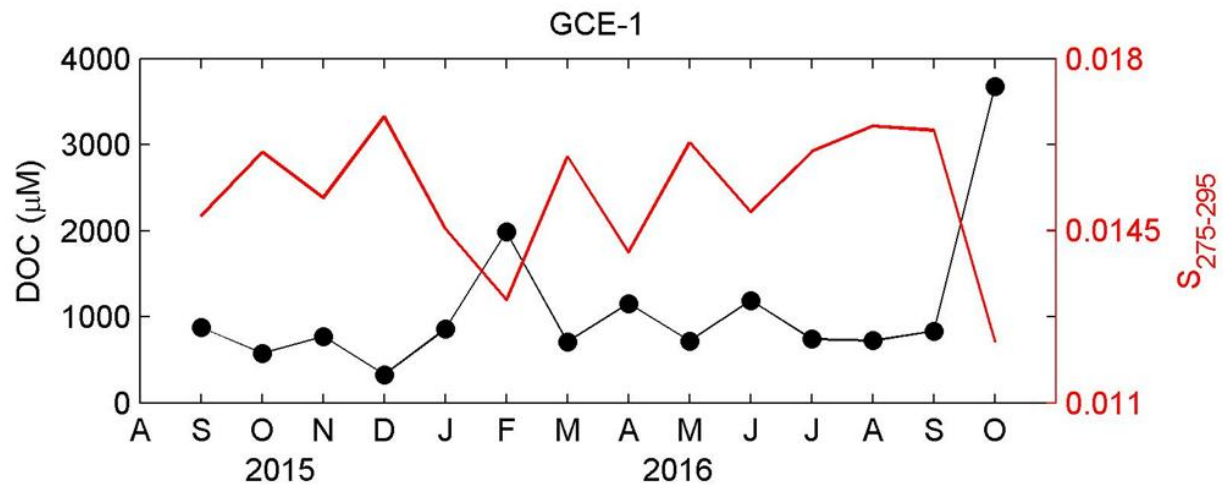


Fig. 4. DOC concentration and spectral slope ( $S_{275-295}$ ; a proxy for terrigenous organic matter) at Sapelo Sound (GCE1) from September 2015 to October 2016. The highest DOC and lowest spectral slope values (highest terrigenous inputs) were observed in October 2016, 3 days after Hurricane Matthew hit the Georgia coast. Corresponds to Objective 2A.7: Characterize DOM composition and predominant sources of estuarine water.

## GCE Activities 2018

Table 1. Monitoring program for GCE-III. Initials of 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. GCE PIs: AB: Burd, BS: Silliman, CA: Alexander, CC: Craft, CH: Hopkinson, CM: Meile, DD: Di Iorio, JB: Byers, JH: Hollibaugh, JS: Schalles, MA: Alber, MG: Garbey, ML: Leclerc, PM: Medeiros, RC: Castelao, RP: Peterson, RV: Viso, SJ: Joye, SP: Pennings, VT: Thompson, WC: Cai, WS: Sheldon. Corresponds to Objectives 2A.1 and 2A.2: Continue the GCE core monitoring programs.

Type	Location	Frequency	Core Area & Variables Measured
<b>Area 1 Atmospheric</b>			
Weather stations, with SINERR, USGS (DD)	Sites 4, 6, flux tower	Every 15 min	Abiotic driver of 1-5. > level 2 stations: PAR, temp, rH, precip, wind speed and direction, barometric pressure, total solar and long wave radiation; flux tower also measures CO <sub>2</sub> , humidity and heat fluxes
Wet deposition, with SINERR, NADP (MA)	Site 6	Weekly	4. Hydrogen (acidity as pH), sulfate, nitrate, ammonium, chloride, base cations (such as calcium, magnesium, potassium, sodium)
<b>Area 1 Water</b>			
Altamaha River chemistry (MA, WC)	Head of tide	Monthly	3, 4. Dissolved inorganic nutrients (NO <sub>x</sub> , NH <sub>4</sub> <sup>+</sup> , HPO <sub>4</sub> <sup>2-</sup> , H <sub>2</sub> SiO <sub>4</sub> <sup>2-</sup> ) and organics (DOC, TDN, DON, TDP, DOP), particulate CN, DIC, alkalinity, pH
<b>Area 2 Water</b>			
Sound chemistry (MA, WC)	Sites 1-5; 8-11, AL-2	Quarterly	1, 3, 4. Dissolved inorganic nutrients (NO <sub>x</sub> , HPO <sub>4</sub> <sup>2-</sup> ) and organics (DOC, TDN, DON), particulate CN, DIC, alkalinity, pH, chlorophyll <i>a</i>
	Sites 6-7	Monthly	1, 3, 4. Dissolved inorganic nutrients (NO <sub>2</sub> <sup>-</sup> , NO <sub>3</sub> <sup>-</sup> , NH <sub>4</sub> <sup>+</sup> , HPO <sub>4</sub> <sup>2-</sup> , H <sub>2</sub> SiO <sub>4</sub> <sup>2-</sup> ) and organics (DOC, TDN, DON, TDP, DOP), particulate CN, DIC, alkalinity, pH, chlorophyll <i>a</i> , total suspended sediment
Sound hydrography (DD)	Sites 1-4, 6-11	Every 30 min	Abiotic driver of 1-5. Salinity, temperature, pressure at moorings; CTD profiles at all stations in conjunction with sound chemistry; sea level station at GCE4
Duplin-domain exchange (DD)	Mouth of Duplin R.	Every 15 min	Abiotic driver of 1-5. Continuous horizontal ADCP measurements of water flux
<b>Area 2 Marshes</b>			
Soil accretion (CC)	Sites 1-11	Annual	3. Sediment accretion, elevation, compaction
Plant productivity (SP)	Sites 1-11, 2 zones	Annual	1. Stem density, height, flowering status, calculated biomass, in 2 marsh zones
	Flux tower	Monthly	1. Monthly measurements of biomass in short, med, tall <i>Spartina</i> using allometric relationships between height and mass
Disturbance (SP)	Sites 1-11	Annual	5. Wrack and biotic disturbance in permanent vegetation plots
Plant composition (SP)	Site 3, 6, 7, 8, Altamaha	Annual	2. Community composition in 4 types of salt marsh, 2 types of low-salinity and 2 types of high marsh vegetation mixtures
Marsh Invertebrates (SP BS)	Sites 1-11, 2 zones	Annual	2. Density and size of benthic macroinvertebrates in 2 marsh zones
Recruitment (BS)	Sites 1-11	Quarterly	2. Recruitment of barnacles to standard substrates
Insects (SP)	Sites 1-6, 9, 10	Annual	2. Density of grasshoppers in salt marsh transects

## GCE Activities 2018

### Area 3: Responses to Salinity and Inundation

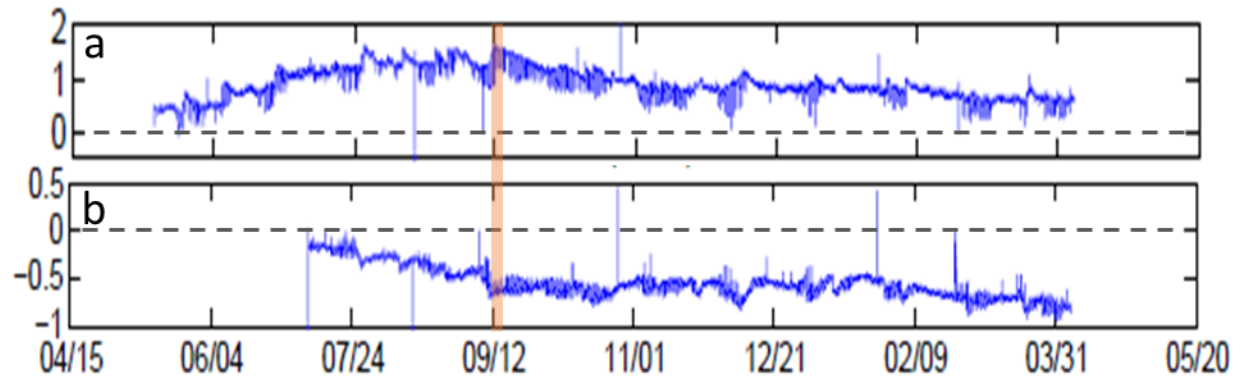


Fig. 5. Hydraulic gradients at Plot 3 in the High Marsh Experiment from May 2017 to April 2018. (a) Horizontal gradient, where positive numbers indicate creekward flow. Seasonal highs occur in late summer. (b) Vertical gradient, where negative numbers indicate increasing downward flow (recharge) during the observation period. Orange bar indicates the passage of Hurricane Irma. Corresponds to Objective 3C.3: Conduct upland manipulation of water flow to high marsh areas.

# GCE Significant Results 2018

## Area 1: Drivers of Change

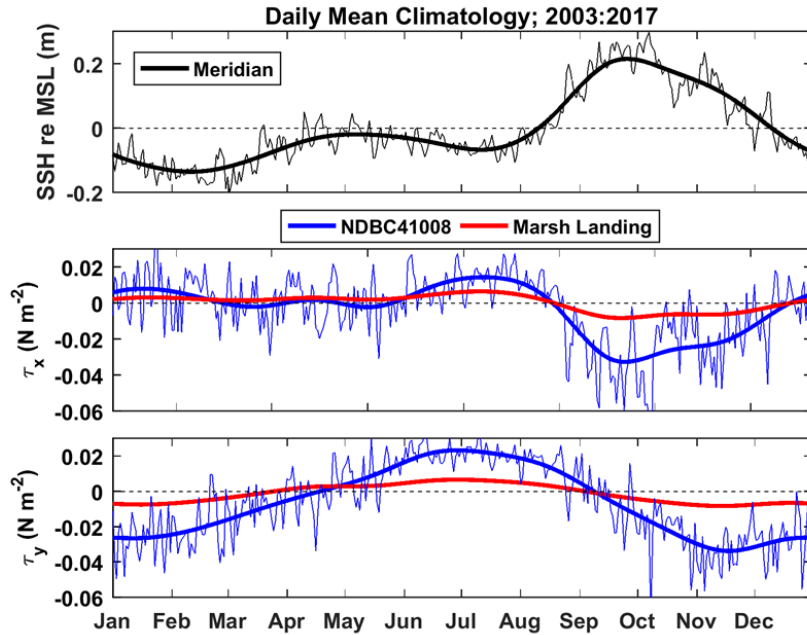


Fig. 1. Sea surface height (SSH) at Meridian Landing (top) increases when winds (Gray's Reef Buoy NDBC41008 and Marsh Landing) are toward the west and decreases when they are toward the east (middle). Longshore winds (bottom) are primarily to the north in summer and to the south in winter. Corresponds to Objective 1A.2 Collect ongoing information on climate and oceanographic conditions.

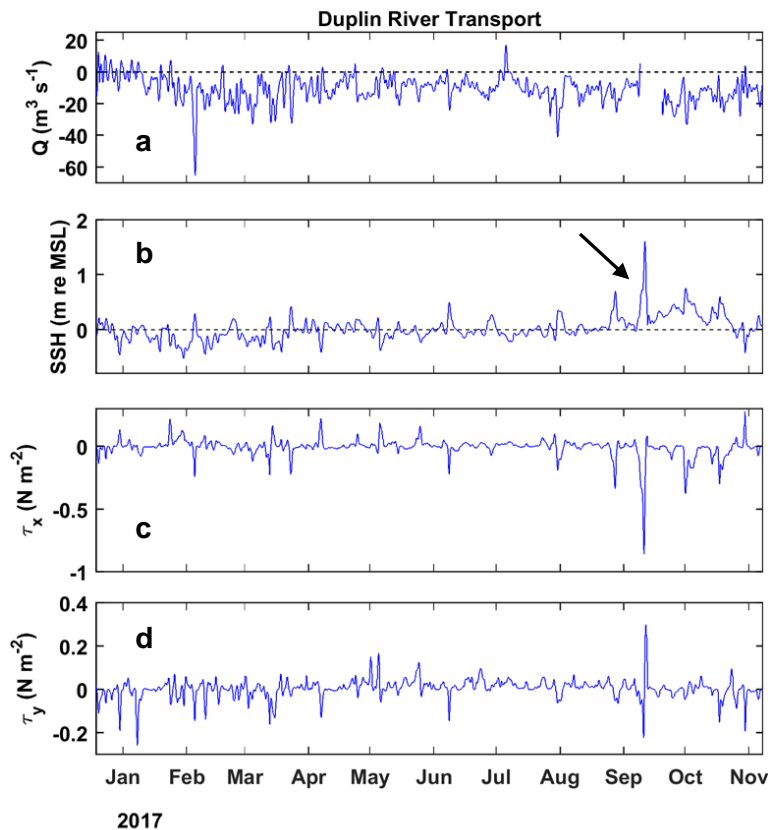


Fig. 2. (a) HADCP estimates of the transport from the Duplin River to Doboy Sound shows a persistent net outflow throughout the year. (b) Sea surface height has an annual cycle with low water in spring and higher water in fall. Hurricane Irma made landfall in Sept. 2017, creating a large surge in sea surface height (arrow) which was well correlated with (c) large cross-shore wind stress to the west to a greater extent than (d) north-south wind stress. Corresponds to Objective 1A.5 Measure exchange between the Duplin River and Doboy Sound.

## GCE Significant Results 2018

### Area 2: Patterns within the Domain

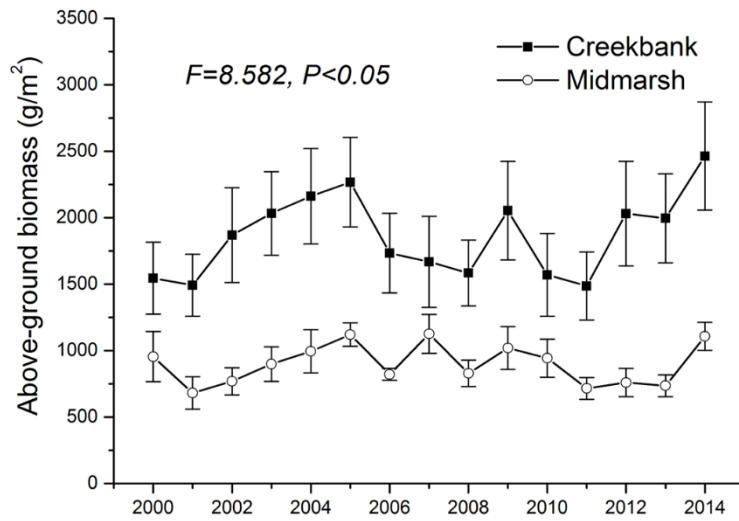


Fig. 3. Aboveground biomass of *Zizaniopsis miliacea* varies among years in both creekbank and midmarsh habitats as a function of abiotic conditions. In particular, biomass is positively correlated with river discharge and negatively correlated with temperature. From Li et al. 2018. Corresponds to Objective 2A.2 Continue the core monitoring program in the marsh.

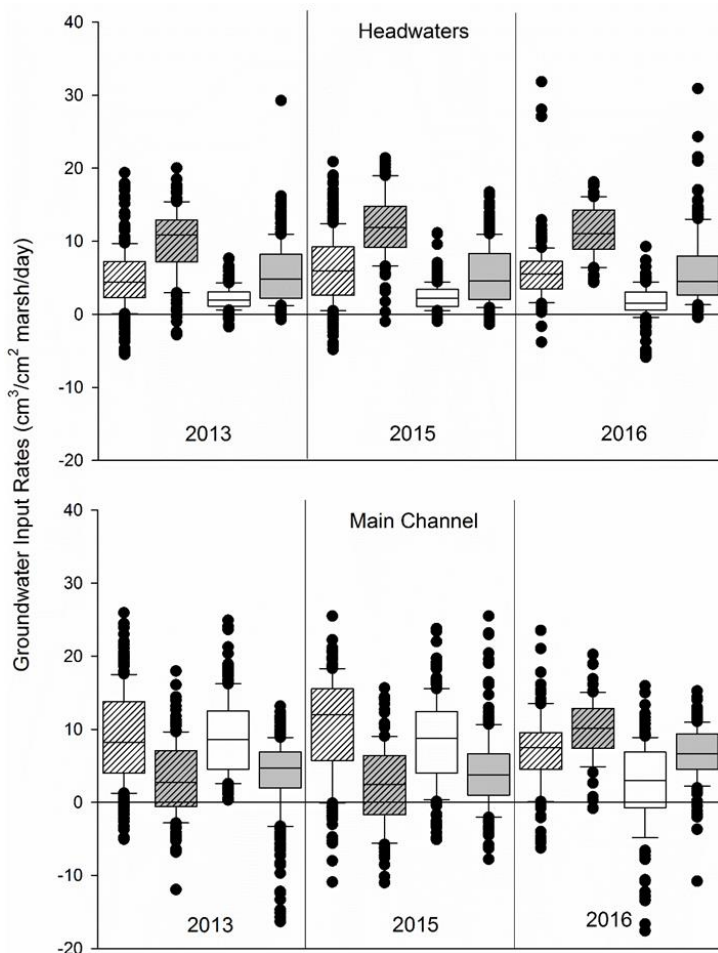


Fig. 4. Box plots of groundwater input to the Duplin River observed over three sampling years. Groundwater input rates have been normalized to flooded surface area and are shown for the headwaters (top) and the main channel (bottom) of the estuary. Data are separated based on when the marsh was inundated (hatched boxes) versus not inundated (not hatched) and further by flood (white) and ebb (gray) tide. From Peterson et al., submitted. Corresponds to Objective 2A.4 Characterize groundwater flow into the Duplin R.

## GCE Significant Results 2018

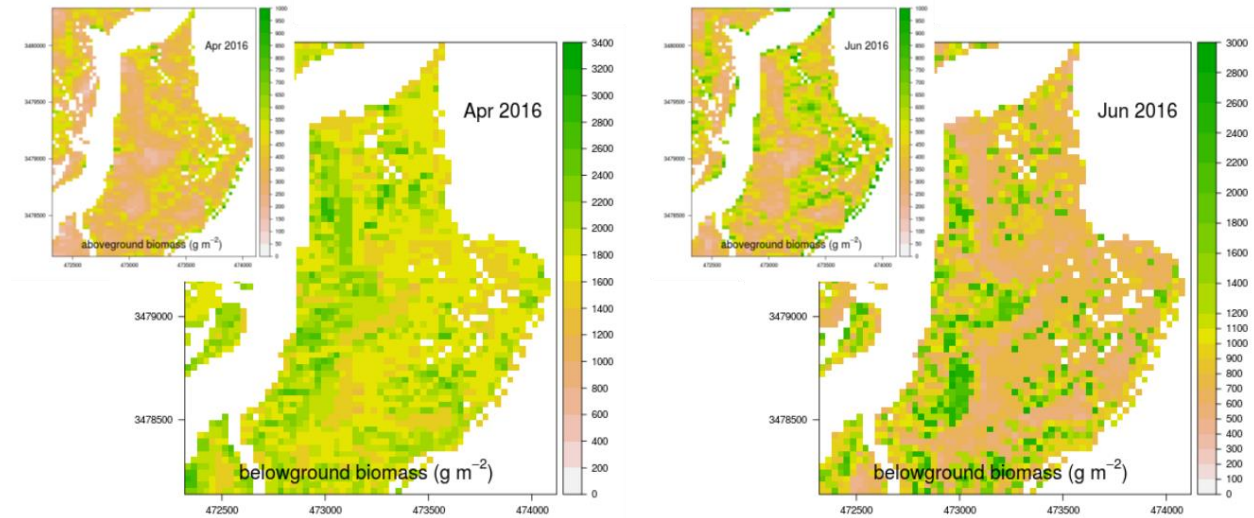


Fig. 5. Estimates of aboveground and belowground biomass derived from satellite imagery. Between April and June 2016, aboveground development (insets) gradually depleted belowground resources. From O'Connell et al., in prep. Corresponds to Objective 2B.2 Assess patterns of marsh productivity using satellite imagery.

### Area 3: Responses to Salinity and Inundation

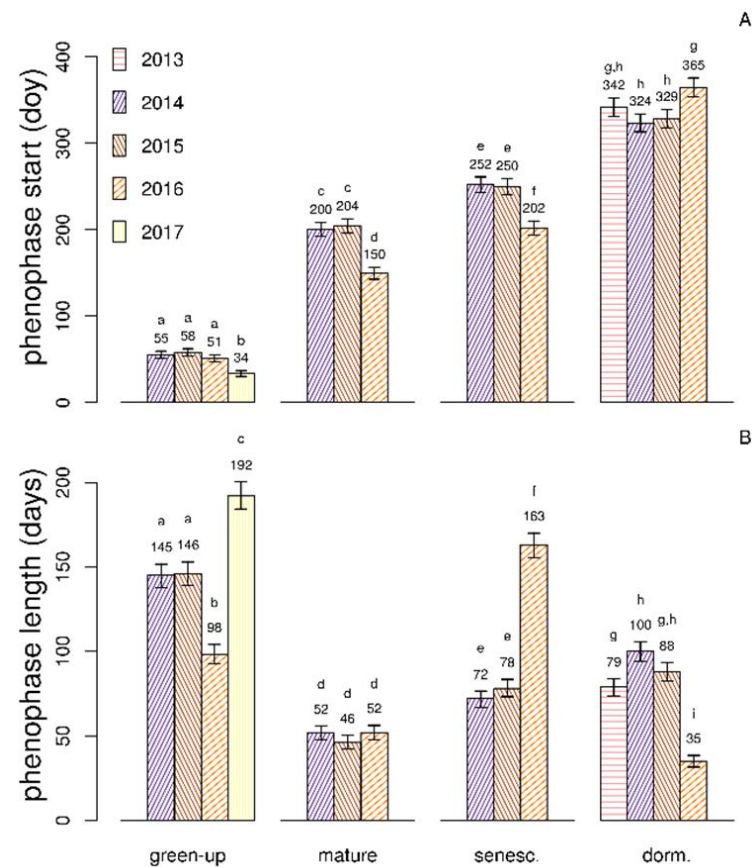


Fig. 6. Interannual variation in phenophase start dates (top) and lengths (bottom) of *Spartina alterniflora* estimated from PhenoCam imagery. Plants entered maturity and senescence earlier in 2016 than other years (likely due to a strong drought). Plants had a short dormancy period in 2016 and entered green-up early in 2017 (likely due to a warm winter). From O'Connell et al., in prep. Corresponds to Objective 3A.2 Evaluate *Spartina* plant phenology.

## GCE Significant Results 2018

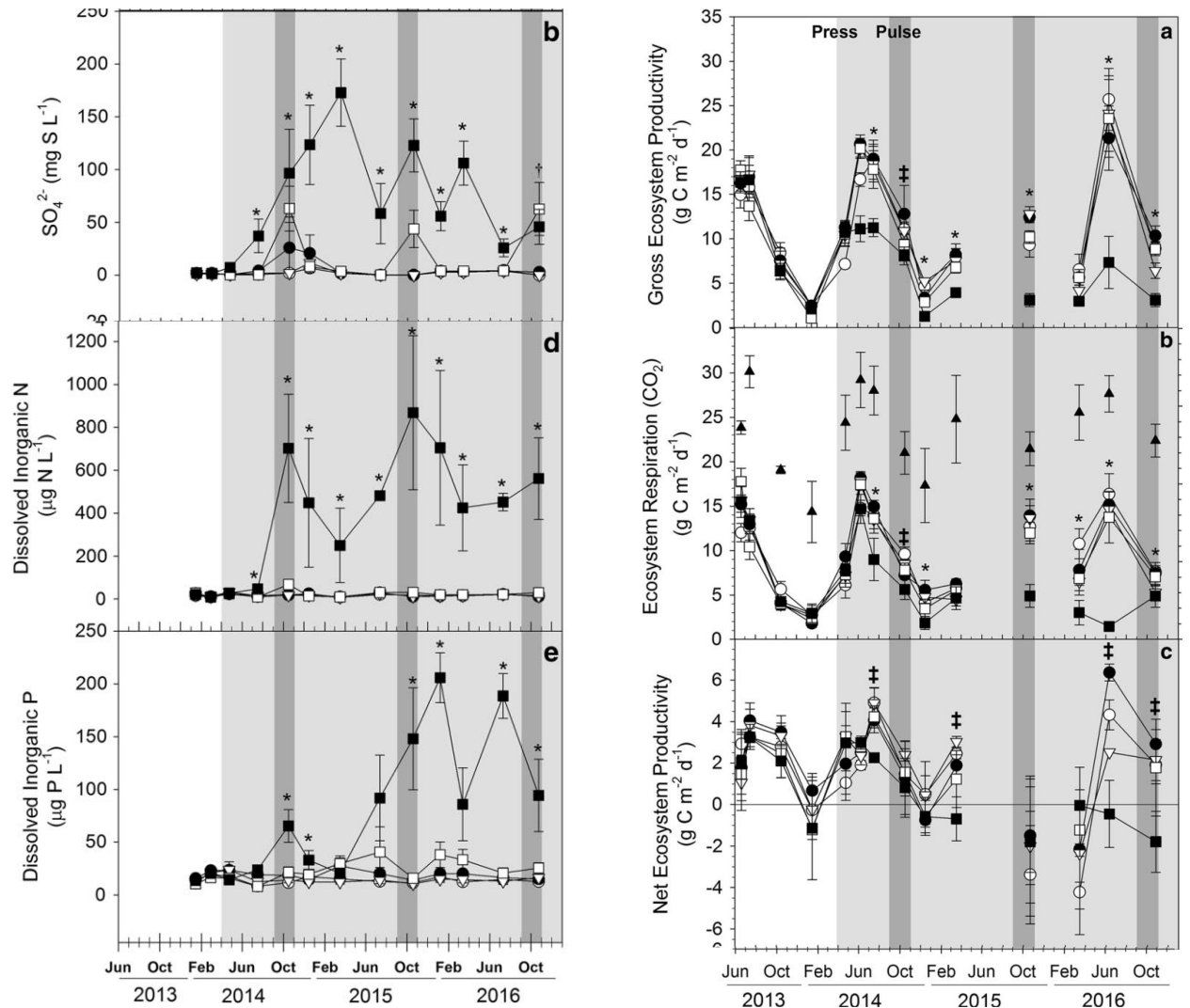


Fig. 7. (left) Mean porewater concentrations ( $\pm$  SE) of (top) sulfate, (middle) DIN and (bottom) phosphate of SALTEX treatments over time. (right) Mean modeled daily rates of (top) gross ecosystem production, (middle) respiration, and (bottom) net ecosystem production ( $\pm$  SE) in  $\text{g C m}^{-2} \text{d}^{-1}$  calculated from field gas flux rates measured seasonally in all treatments. Solid triangles in (middle) are mean daily air temperature ( $\pm$  SE). The white portion of the graph represents pre-treatment salinity, the light grey shading the press seawater addition, and the dark grey shading the simultaneous pulse and press seawater addition. From Herbert et al. 2018. Corresponds to Objective 3B.2 Conduct field manipulation of salt water intrusion in a low-salinity tidal marsh.

## GCE Significant Results 2018

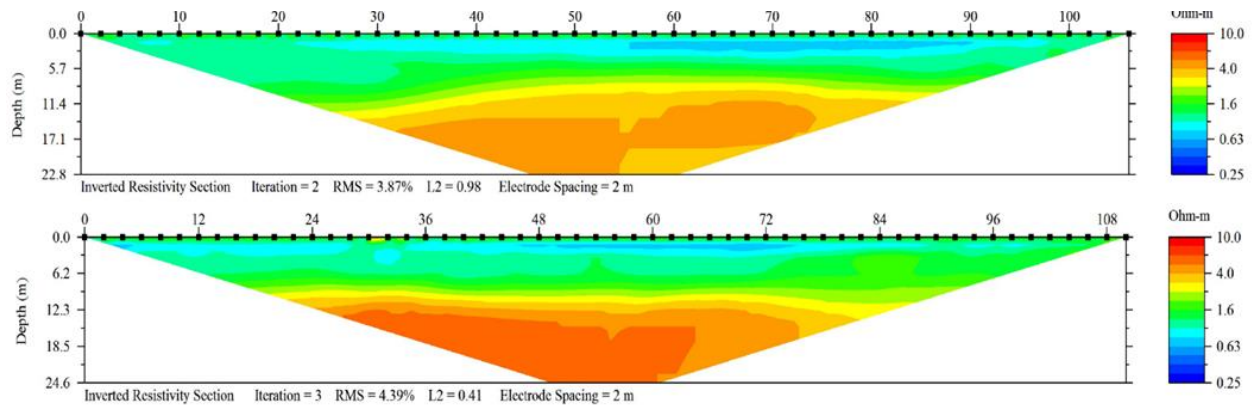


Fig. 8. Electrical resistivity profiles of the southern (top) and northern (bottom) portion of the marsh platform at the high marsh experimental site, oriented perpendicular to the Duplin River. Low electrode numbers are the riverward (west) end of the profiles, with the first few electrodes located on the riverbank. The profiles suggest a shallow (0-3 m deep) salt water saturated layer underlain by a deeper (> 8 m) fresh/brackish water saturated aquifer. Corresponds to Objective 3C.3 Conduct upland manipulation of water flow to high marsh areas.

## Area 4: Integration and Forecasting

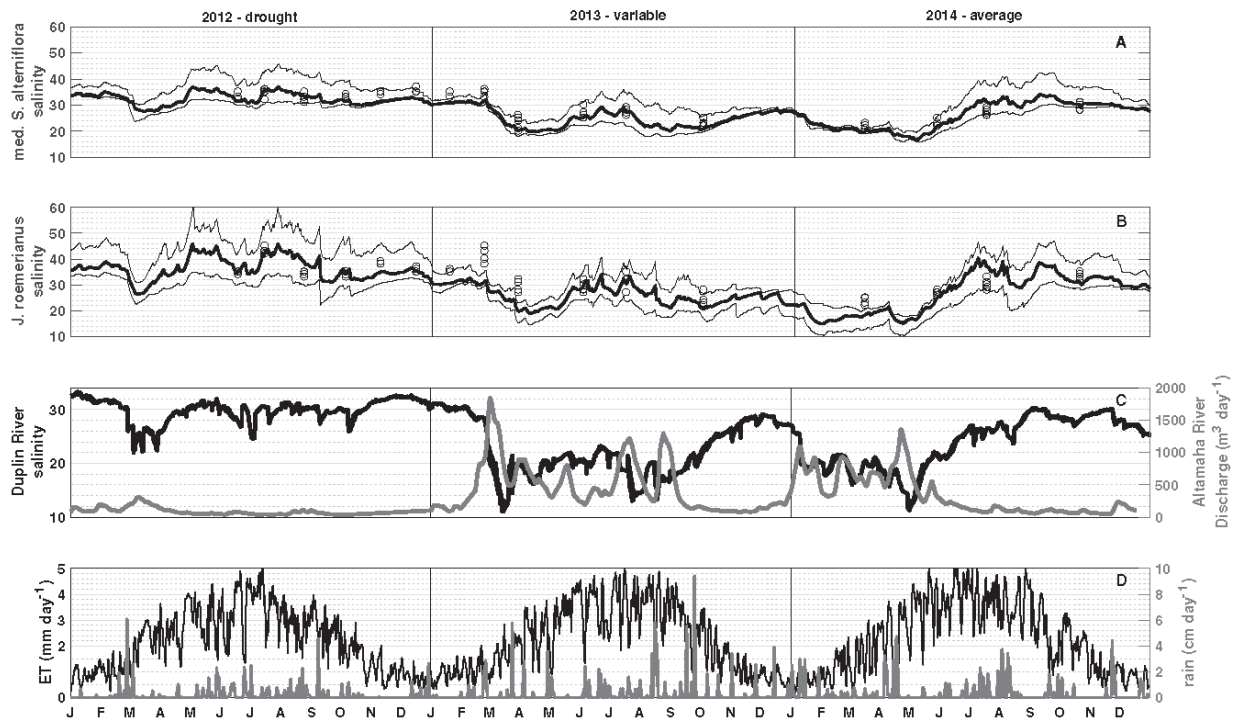


Fig. 9. Model predictions of median (bold line), and the 10th and 90th percentiles (thin lines) porewater salinity in the Duplin River during 2012 (drought), 2013 (hydrologically variable), and 2014 (hydrologically average). Black circles in (A) (low marsh) and (B) (high marsh) denote the measured porewater salinities. (C) shows tidal salinity and Altamaha discharge, and (D) shows daily precipitation and evapotranspiration for medium *S. alterniflora* and *J. roemerianus* used to force the model. From Miklesh and Meile, in press. Corresponds to Objective 4A.2 Run the soil model to predict porewater salinity.

## GCE Significant Results 2018

Table 1. Changes in Landsat-derived estimates of biomass in coastal drainage basins along the central Georgia coast over the period 1984-2018. All areas experienced net losses except the Altamaha, which receives freshwater from the Altamaha River. There was an overall net loss of 16.4% over the 613 km<sup>2</sup> study area. Corresponds to Objective 4B.3 Evaluate habitat provisioning.

Drainage Area	Watershed Size (ha)	% Biomass Change
Altamaha	4,082	+9.5
Doboy	7,891	-17.9
Ossabaw	11,123	-8.5
Sapelo	12,141	-26.5
St. Catherines	15,293	-24.5
St. Simons	7,680	-11.0
Wassaw	3,075	-28.5

## WHAT WERE THE KEY OUTCOMES AND ACCOMPLISHMENTS?

Key accomplishments this past year include research on comparisons with Chinese wetlands, foundation species, and the role of Archaea in nitrogen cycling.

**Comparisons with Chinese Wetlands** - *Spartina alterniflora*, the dominant plant in salt marshes in the U.S. Atlantic and Gulf coasts, was introduced into China in 1979 and now covers almost all of the Chinese coastline (He et al. 2014, Pennings and He in review, Li et al. 2018). This invasion presents powerful opportunities for comparative research, and in 2011 S. Pennings and C. Craft made an initial visit to China with funding from an NSF LTER supplement. They have both returned to China several times since then and have also hosted Chinese faculty members and graduate students in their laboratories. These collaborations have focused on three topics. **1) Soil development.** We have shown that *S. alterniflora* traps prodigious amounts of sediment in both China and the US, building wetlands and changing soil biogeochemistry (Li et al. 2013, He et al. 2016). These gains, however, may be offset in both countries by conversion of marshes to aquaculture and other land uses (Li et al. 2018). **2) Plant-plant interactions.** In both China and the US, salt marsh plants can either facilitate or compete with mangroves, depending on levels of abiotic stress and mangrove size (Zhang et al. 2012, Guo et al. 2013, Peng et al. 2018, Zhang et al. in prep). Exotic mangroves, *Sonneratia apetala*, that have also been introduced to China are likely to suppress *S. alterniflora*, replacing one exotic species with another (Peng et al. 2018). **3) Latitudinal clines.** In both China and the US, *S. alterniflora* displays strong latitudinal clines in plant height and biomass. In China, however, these clines are largely due to phenotypic plasticity, whereas in the US they are largely genetically based (Liu et al. 2016, 2017, in review). The one exception is a striking latitudinal cline in seed set in China that is genetically based and is absent in the native range, likely reflecting selection for seed set as *S. alterniflora* spreads at high latitudes in China (Fig. 1). Zhang et al. (in review) found that the invasion of *S. alterniflora* has homogenized latitudinal patterns in wetland soil nematode communities in China. These collaborations are ongoing. For example, the Pennings lab sampled nematodes in domestic sites in 2018 to compare the patterns observed in China with those in the US.

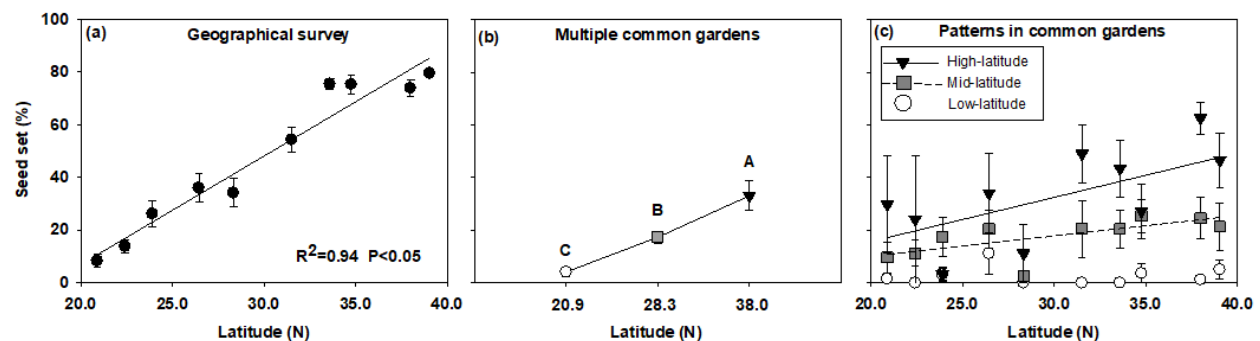


Fig. 1. (a) In China, *Spartina alterniflora* displays striking latitudinal variation in seed set, which ranges from ~10% at low latitudes to >80% at high latitudes. (b) In three common gardens, seed set increased with latitude of the garden, indicating an environmental effect on seed set. (c) Within the high- and mid-latitude gardens, seed set also increased with the latitude from which the plants were collected, indicating genetic control of seed set. From Liu et al. 2017.

**Foundation species** - Foundation species (FS) play important roles in many ecological systems, enhancing biodiversity, stability and multi-functionality. FS are generally habitat-formers such as trees and corals. In many cases FS facilitate the presence of secondary foundation species, which are habitat formers in their own right and may further modify the ecosystem. In southeastern salt marshes, *Spartina alterniflora* is the primary foundation species and the ribbed mussel, *Geukensia demissa*, acts as a secondary foundation species. The Angelini lab conducted a 6-month field experiment in which they added standard densities of mussels to evaluate whether patch configuration mediates their ecological effects. As reported in Crotty et al. (2018), they found that over 67% of response variables increased with clustering of mussels, responses that were driven by changes in patch characteristics (area-perimeter ratio, perimeter, and patch size). Thus, mussel configuration - by controlling the relative distribution of multidimensional patch interior and edge niche space - critically modulates this foundation species' effects on ecosystem structure, stability and function. In a separate study, Thomsen et al. (2018) conducted a meta-analysis of secondary FS to evaluate their effects on habitat-associated organisms (i.e. inhabitants). They found that secondary FS significantly enhanced the abundance and richness of inhabitants compared to primary FS alone. Finally, Borst et al. (2018) analyzed data from 58 food webs from seven terrestrial, freshwater and coastal systems and found that foundation species consistently enhanced food web complexity across the entire trophic network as compared to bare areas (Fig. 2). They suggest that the structure and stability of food webs often depends critically on non-trophic facilitation by foundation species. We helped organize a workshop on FS at the all-scientists meeting, and are helping to facilitate a cross-site comparison of FS across the LTER network.

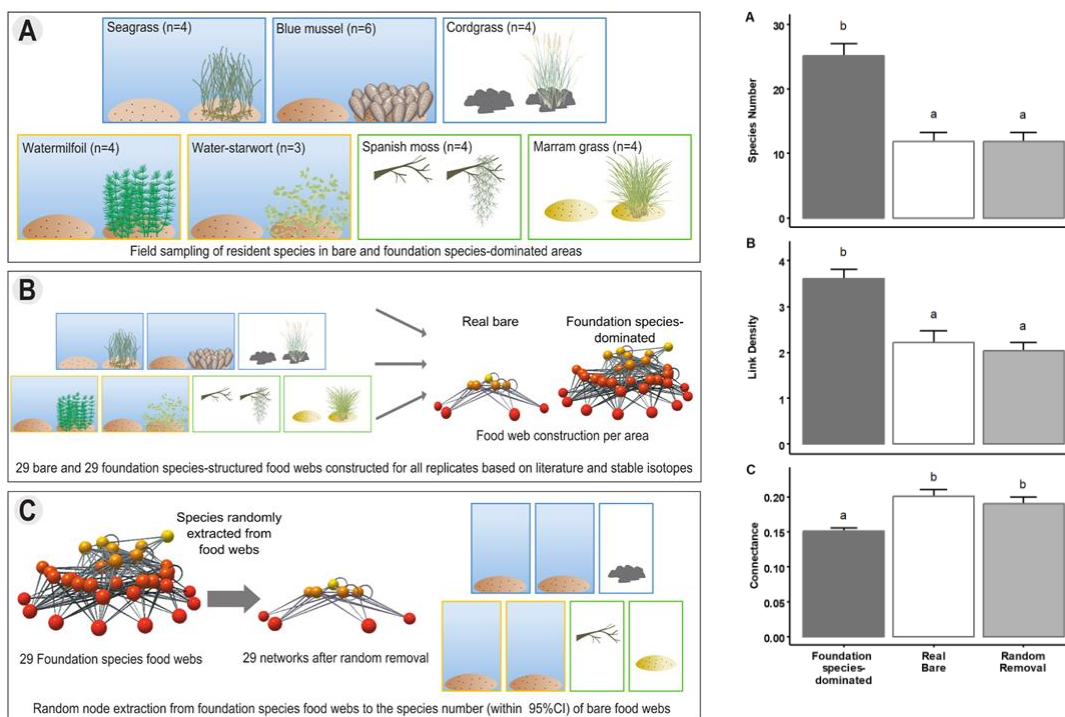


Fig. 2. (left) (A) Seven ecosystems were included in the study. (B) In each case, food webs were constructed for both bare and foundation species-dominated areas. (C) Nodes (i.e. species) were randomly removed until the species number matched the species number of the bare food webs. (right) The presence of foundation species consistently changed food web properties (mean  $\pm$  SE) across ecosystems, including (A) species richness, (B) link density, and (C) connectance. The random removal of nodes created networks that corresponded well with the properties of real bare food webs. From Borst et al. 2018.

**Archaea and Nitrogen Cycling** - Ammonia oxidizing Archaea (AOA) are members of the guild of microbes that convert ammonia to nitrite. A combination of molecular and ecological measurements suggested that these organisms can be locally abundant, but when we began this research little was known about their spatial or temporal dynamics or their relationship to environmental factors. In recent years the Hollibaugh lab has conducted multiple studies of ammonia oxidizers at the GCE site as well as in polar (PAL-LTER) and other habitats. Tolar et al. (2016) found pronounced mid-summer blooms of AOA at the GCE site that coincided with a peak in nitrite concentration. Analyses of the distribution of both AOA and ammonia-oxidizing betaproteobacteria (AOB) during six cruises in the South Atlantic Bight (Liu et al. 2018) revealed that ammonia oxidation rates were highest in inshore stations, where gene sequences serving as markers for ammonia oxidizers were dominated by Thaumarchaeota (AOA), with both members of the guild peaking in summer months. They concluded that the summer bloom was confined to inshore waters. Schaefer and Hollibaugh (2017) reported experiments that showed that the two steps of nitrification (ammonia- and nitrite-oxidation) become uncoupled between 20 and 30°C, leading to nitrite accumulation, and suggested that the observed nitrite peaks in GA coastal waters may be explained by differences in the responses of these two assemblages to increased summer water temperatures. Although time series of ammonia oxidation rates and AOA populations are rare, field data from 29 temperate and subtropical estuaries and lagoons showed evidence of transient accumulation of nitrite, which suggests that this is a widespread phenomenon. Moreover, the summer accumulation of nitrite was related to water temperature (Fig. 3). At the PAL-LTER site, Tolar et al. (2016) found that ammonia oxidation in Antarctic waters was ~10-fold greater than previously reported, and that previous global estimates of oceanic nitrification may be underestimates. These insights demonstrate the extent to which the discovery of AOAs has profoundly affected our understanding of nitrogen cycling in aquatic systems.

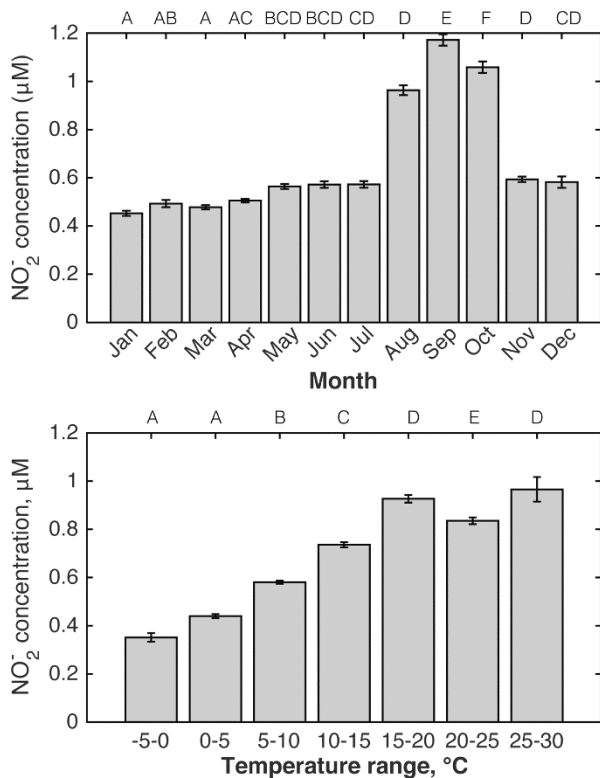


Fig. 3. Nitrite concentrations compiled from 270 stations in 29 tropical and subtropical estuaries and lagoons, binned by month (top) and temperature (bottom). Nitrite concentrations are highest during summer months when temperatures exceed 15 C. From Schaefer and Hollibaugh 2018.

## **WHAT OPPORTUNITIES FOR TRAINING AND PROFESSIONAL DEVELOPMENT HAS THE PROJECT PROVIDED?**

The GCE provides training and professional opportunities to K-12 educators, to undergraduate students, and to graduate students. GCE personnel are also involved in LTER network activities.

### GCE Schoolyard Program

The GCE Schoolyard immerses science and math teachers (K-12) in hands-on research activities alongside GCE scientists and graduate students. Teachers participate in field research, attend lectures, and develop ways to use this experience in the classroom. In July 2018, V. Butler (GCE Schoolyard Coordinator) and J. Crawford (UGA Marine Extension Service) ran our summer workshop, which included 8 new and 8 returning participants, at the GCE field site on Sapelo Island. The teachers worked on projects ranging from sampling the high marsh experiment, to water quality monitoring, to collecting samples, to surveying the tidal fresh forest. Participants reported an increase in their knowledge of both coastal systems and the scientific process. One of the participants wrote in their evaluation, *“As I gain more knowledge with each visit, I am able to demonstrate & explain to my students that science takes time.”* and another said, *“We were engaged in the process of science every day. I learned by doing and asking questions.”* We also solicited feedback from the GCE researchers who worked with teachers. They were highly satisfied with their interactions with the teachers and found their assistance valuable. One wrote, *“By having to teach them [teachers] the research, I gained better teaching and leading skills.”* and another said, *“I loved that the teachers asked follow-up questions on last year’s experiments.”*

### Undergraduate Education

17 undergraduate students worked with GCE-LTER scientists on projects this past year:

- A total of 12 student interns were in residence at the field site on Sapelo Island over the summer: 3 students from Creighton and 1 from Elon worked with J. Schalles on groundtruthing and analysis of Landsat imagery; 1 student from Brown and 1 from UGA worked with C. Angelini and B. Silliman on salt marsh community experiments; 3 students from GA Southern worked with C. Hladik on collecting and processing ground control points for orthoimagery; 1 student from GA Southern, 1 from Univ. of Houston and 1 from UGA worked with S. Pennings assisting with plant community ecology and data analysis.
- A student from UGA worked as a summer intern with the GCE field crew, helping in both the field and the lab with water quality and other sampling.
- Undergraduates also worked in the labs of GCE investigators: A student from GA Southern worked in C. Alexander’s lab analyzing sediment cores; a student from UGA worked with C. Meile developing the basis for a soil heat model; a student from UGA worked with P. Medeiros processing CDOM samples; a student from Univ. of South Carolina worked with A. Wilson analyzing data from the upland manipulation.
- R. Peterson used GCE data in his Hydrogeology course; P. Medeiros used GCE information in her Introduction to Marine Science course.

### Graduate Education

Graduate students are an integral part of the research at the GCE-LTER. There are currently 33 students from 7 institutions engaged in LTER activities. Graduate students have also been authors on numerous publications that have resulted from this work. Other graduate activities include:

- Former GCE graduate student Alyssa Gehman (UGA student, Byers) published a paper from her dissertation for which long-term temperature data from GCE-LTER was critical information. For her work on this paper, Alyssa was awarded the 2018 Thomas M. Frost Award from the Ecological Society of America's Aquatic Section for Excellence in Graduate Research 2018.
- Multiple investigators use GCE data in their graduate courses: C. Angelini (Coastal Systems; Advanced Environmental Planning and Design; Ecological Engineering), R. Peterson (Applications of Isotope Geochemistry), C. Alexander (Geology of the Georgia Coast), A. Burd (Quantitative Methods in Marine Science), R. Castelao (Estuarine and Coastal Oceanography), and C. Craft (Wetlands Ecology).

### International Education

GCE investigators worked with students and scientists from several institutions this past year:

- R. Peterson (CCU) is hosting a visiting scholar from East China Normal Univ.; C. Angelini (UF) hosted a PhD student from Swansea University (UK); Pennings hosted two visiting graduate students from China (Xiamen University; Fudan University) in his laboratory during the academic year and at Sapelo Island over the summer.
- C. Craft taught a Wetlands Ecology class at East China Normal University.
- We also have active collaborations with international students and scientists in the Netherlands (Radboud University Nijmegen), China (East China Normal University, Xiamen University), the Czech Republic (Czech University of Life Sciences), and the United Kingdom (University of Liverpool, Swansea University).
- The GCE has graduate students and post-doctoral associates from a variety of countries, including Turkey, China, Vietnam, South Korea, Malaysia, and Moldova.

### Network Activities

As detailed below, GCE scientists are actively collaborating on cross-site comparisons and are involved in network planning and governance, both within the LTER and with other groups:

- S. Pennings completed a three-year term on the LTER Network Executive Board. M. Alber serves on the children's book editorial committee.
- M. Alber and S. Pennings attended the LTER Science Council Meeting in Madison, WI in May 2018.
- M. Alber and C. Alexander are PIs on a cross-site coastal SEES grant being conducted at GCE, VCR, and PIE to evaluate the vulnerability of salt marshes to rising sea levels.
- P. Medeiros is working in collaboration with R. Jaffé (FCE) at FIU in analyses of DOM composition and black carbon content.
- M. Alber gave a talk on the sustainability of salt marshes at the NSF Symposium in April 2018.
- GCE flux tower investigators provided information for two conference presentations comparing C fluxes along the U.S. East Coast.
- The high-resolution digital camera on the GCE flux tower is part of the Phenocam network.
- $p\text{CO}_2$  data from 2014 GCE shelf cruises are available on the Surface Ocean Carbon Atlas website.

We also have a strong network presence in terms of information management, through the activities of W. Sheldon and A. Sapp (UGA). Over the past year, GCE IM staff served the network in the following capacities:

- W. Sheldon served on the Information Management Executive Committee and Executive Board as representative for the IM Committee.
- Continued to collaborate with BCO-DMO personnel to refine cross-listing of relevant GCE data sets in BCO-DMO to enhance discovery.
- Continued to assist the CWT in leveraging GCE-IMS technology to generate EML metadata, publish data in the LTER Data Portal, manage publications, process and display real-time data and provided web hosting for some dynamic web applications.
- Continued to leverage GCE-IMS components and protocols to operate a data catalog and bibliographic, taxonomic and geographic databases for the Savannah River Ecology Laboratory.
- Provided user support and training on using the GCE Data Toolbox for MATLAB for processing and quality controlling sensor data at other LTER sites.
- Joined a new EDI/LTER working group on transitioning the LTER Climate/Hydrography Database (ClimDB/HydroDB) to modern cyber infrastructure.
- Continued hosting the USGS Data Harvesting Service for HydroDB, in which data from 85 USGS stream flow gauging stations are automatically harvested on a weekly basis for 12 LTER sites (AND, BES, CAP, CWT, FCE, GCE, KBS, KNZ, LUQ, NTL, PIE, SBC) and 1 USFS site.
- Prototyped a new NCEI Data Harvesting Service for ClimDB to automatically harvest and contribute climate data on a weekly basis for 2 sites (FCE, GCE), which will be extended to other sites pending outcome of the EDI/LTER working group findings.

## **HOW HAVE THE RESULTS BEEN DISSEMINATED TO COMMUNITIES OF INTEREST?**

The GCE disseminates information to multiple audiences: we share information within the project itself; we distribute data and metadata; we provide information to the public via our website; we reach schoolchildren through our children's book; we work with coastal managers through the Georgia Coastal Research Council; and we conduct various specialized activities.

### Project Personnel

We use a wide variety of approaches for disseminating information internally. We maintain multiple email lists and a password-protected project website that provides GCE participants with role-based access to provisional data and private documents as well as web forms for submitting metadata, data files, announcements, calendar events and other content for archiving or sharing online. We maintain email lists and file exchange services to facilitate collaboration on our large research projects and publish a weekly newsletter and RSS feed for GCE participants and other interested parties. We also operate a Subversion (SVN) software code repository server for both IM and researcher-led software development projects.

This past year we leveraged data discovery and visualization tools introduced in 2017 to help GCE personnel explore trends in long-term data. We also used the data set linking tool we developed for the GCE Bibliography in 2017 to relate data set DOIs to publication DOIs and added data set links to accompany citations in the GCE Project Bibliography (Fig.1).

We require all new GCE personnel to attend training on data and metadata submission. Training is conducted in association with annual project meetings and is also available on-line and through one-on-one consultation.

### Data and Metadata

We operate an integrated information management system (GCE-IMS) at UGA based on relational database and dynamic web application technology to manage, archive and distribute data, metadata and other research products. We provide GIS support to GCE researchers and students, including ArcGIS licenses and software, and maintain an archive of GIS reference data as file geodatabases.

In 2018 we updated long-term data sets for all core monitoring and long-term research studies to cover the full period of record (i.e. 15-17 yrs) for addition to the GCE Data Portal and GCE Data Catalog. Data are standardized and include basic gap filling to provide monotonic time series for analyses. We archived these data along with value-added summary products as new "signature" data sets that are linked to the primary data sets and will be updated annually. As of Oct. 2018, 579 public data sets have been uploaded to the LTER Data Portal, and new and updated data sets are uploaded monthly as they reach their public access date (i.e. within 2 years of collection). We also continue to provide online access to both public and private GCE data sets through the GCE Data Catalog. A total of 587 catalog data sets are currently online, representing 16.5 million tabular data records in 884 files, plus 30 GB of raster GIS data. An additional 793 public data sets are also available through the GCE Data Portal. Collectively, we provide online access to over 27 million tabular data records from GCE research and affiliated monitoring programs as well as over 100 GB of GIS data, with an additional 15 million records being finalized for inclusion.

GCE data are downloaded by a diverse group of web visitors, including researchers and educators (Table 1). Data downloads increased dramatically in 2013 after synchronizing public data to the LTER Data Portal, and this trend continued in 2018. We also actively collaborate with staff of the Biological and Chemical Oceanography Data Management Office (BCO-DMO) to include dynamic data links on the GCE project page at BCO-DMO. Over 150,000 data files have been downloaded by the public since our data catalog was put online in 2001.

### General Public

We continue to maintain a GCE program website and public data portal for disseminating information and products from GCE research including publications, reports, research data, photographs and remote sensing imagery. We also actively contribute content to the LTER Communications Office for inclusion on the LTER network website and newsletters. Use of the GCE website has increased steadily since 2001, with over 1.4 million page views from 117,895 visitors between Sept. 2017 and 2018. Over 6.4 million page views from 1.6 million distinct web visits have been recorded since 2001.

We maintain a dedicated education program website, providing information on the GCE Schoolyard program, children's book ("And the Tide Comes In..." by M. Alber) and other GCE education activities, with content geared towards K-12 educators and students. This website includes supplemental material and lessons from the children's book that can be searched by grade level, subject, or book page.

We continue to host a support website for the GCE Data Toolbox for MATLAB software, an open source data management tool developed by W. Sheldon used for data processing and analysis at GCE and many other LTER sites (4,108 public downloads to date). This software is broadly used at other LTER sites and was identified as a high priority by the Environmental Data Initiative. We will pursue new opportunities to provide training and disseminate information in the coming year (e.g. depositing source code in the new EDI GitHub Repository).

### Children's Book

The GCE children's book, "And the Tide Comes In..." continues to be distributed to environmental educators and school teachers.

### Georgia Coastal Research Council

The GCE provides outreach to coastal managers through partial support of the Georgia Coastal Research Council (GCRC). Core activities of the GCRC include communicating via the GCRC listserv to affiliated members interested in coastal Georgia (the GCRC currently has 168 affiliates from 19 universities, 10 federal agencies, and 7 state/regional organizations). The GCRC website has member biographies, project summaries, and research needs, and serves an important role as a conduit of coastal research information.

The GCRC hosted the 7<sup>th</sup> Biennial Coastal Georgia Colloquium in Sept. 2018 in Savannah, Georgia. There were 60 coastal managers and scientists in attendance, representing 18 academic institutions, state and federal government agencies, and non-profit organizations with presentations on research projects and program overviews. Feedback from the Colloquium was very positive: 90% of respondents agreed that the meeting provided a beneficial exchange of information, and 90% found the content of the meeting relevant to their work or interests. The GCRC also hosted a roundtable discussion of resource issues on

the GA coast this past year. Topics included coastal community disaster resilience in light of recent extreme weather and climate change, aquaculture, and recent toxic algal blooms.

#### Additional Activities

- GCE response to Hurricane Irma was featured in an article in *Nature*, *Hurricanes Harvey and Irma send scientists scrambling for data*, (which was picked up by Scientific American) and on the NSF twitter account. The NSF twitter account also featured M. Alber's talk at the LTER Science Symposium as well as talks presented by GCE scientists at the ESA meeting.
- C. Alexander gave eight invited talks on sea level rise and its impacts on salt marsh ecosystems to civic and community groups and college classes.
- V. Thompson held a public archaeology day on the Georgia Coast and described how archaeology fits into the GCE-LTER project.
- The GCE field crew presented their research to multiple groups visiting Sapelo Island.
- The GCE now hosts two citizen science web sites: "Scaling Up Marsh Science" and "Marsh Explorer" to align and identify marsh features in photo transects.
- GCE continues to provide web hosting for the Georgia Coastal Research Council, as well as a searchable bibliographic database for the UGA Marine Institute.

### **WHAT IS THE IMPACT ON THE DEVELOPMENT OF THE PRINCIPAL DISCIPLINE(S) OF THE PROJECT?**

GCE scientists have published 40 journal articles and other one-time publications in 2017-18. Papers published this past year cover a broad range of ecological topics including biodiversity (Thomsen et al. 2018), trophic feedbacks (e.g. Silliman and He in press), predator-prey interactions (Lin and Pennings 2018), and biogeochemistry (Herbert et al. 2018). We have also made contributions in modeling (e.g. Miklesh and Meile in press), remote sensing (Cao et al. 2018), hydrogeology (Evans and Wilson 2017), and anthropology (e.g. Thompson et al. 2018). A complete list of publications can be found at [http://gce-Iter.marsci.uga.edu/public/app/biblio\\_query.asp](http://gce-Iter.marsci.uga.edu/public/app/biblio_query.asp). Key accomplishments this past year include comparisons with Chinese wetlands, research on foundation species, and Archaea and nitrogen cycling.

### **WHAT IS THE IMPACT ON OTHER DISCIPLINES?**

The GCE is an interdisciplinary program with biologists, geologists, chemists, physicists, and anthropologists engaged as PIs on the project.

### **WHAT IS THE IMPACT ON THE DEVELOPMENT OF HUMAN RESOURCES?**

There are currently 17 undergraduate students, 33 graduate students and 5 post-doctoral scientists associated with the project. We had 2 REU participants this past year. We also have active collaborations with international students and scientists in the Netherlands (Radboud University Nijmegen), China (East China Normal University, Xiamen University), the Czech Republic (Czech University of Life Sciences), and the United Kingdom (University of Liverpool, Swansea University).

### **WHAT IS THE IMPACT ON PHYSICAL RESOURCES THAT FORM INFRASTRUCTURE?**

The GCE has installed an extensive boardwalk system that provides access to plots associated with our long-term salinity addition experiment (SALTEX). We also installed boardwalks and photovoltaic cells in support of our eddy covariance flux tower, which is a 30 foot tall tower located in a salt marsh adjacent to Sapelo Island. We maintain sondes that continuously measure conductivity, temperature and salinity at 10 water quality monitoring sites in Altamaha, Sapelo, and Dobby Sounds, and in the adjacent marshes we have RSETs that measure sediment elevation (there are also RSETs in the SALTEX plots). We have groundwater wells installed to measure flow in support of our upland manipulation. We partner with the Sapelo Island National Estuarine Research Reserve to run our weather station and to provide support for a USGS water quality monitoring station. We operate a wireless, outdoor data server on Sapelo Island to acquire, store and relay real-time data from the flux tower and other field instruments to servers at UGA.

### **WHAT IS THE IMPACT ON INSTITUTIONAL RESOURCES THAT FORM INFRASTRUCTURE?**

The UGA Marine Institute (UGAMI) on Sapelo Island provides the base of field operations for the GCE-LTER. The project has 3.5 technicians who work at UGAMI, and all of our scientists use the facility while in the field. Two GCE labs (Pennings, Alber) maintain year-round housing and operations at UGAMI and at any given time there are students, technicians and other personnel at the facility. We maintain two 22' small boats, two Kawasaki mules and two trucks at the field station to access sampling sites. We also operate a GIS lab at UGAMI in collaboration with the Sapelo Island National Estuarine Research Reserve.

## **WHAT IS THE IMPACT ON INFORMATION RESOURCES THAT FORM INFRASTRUCTURE?**

The GCE Information System currently includes three dedicated, fault-tolerant servers collectively providing 14 TB of secure hard disk storage and a 24 TB LTO-5 tape library for near-line and off site backups. Raw data, processed data, version-controlled distributable data products and other digital resources are organized in a data file management system that is mirrored between servers and backed up daily. Backup files are mirrored to redundant hard disks in multiple buildings at UGA and are copied to magnetic tape weekly and stored off-site to protect against data loss. We also operate an ArcGIS license server and provide GIS software and support to affiliated researchers and students, and operate a Subversion (SVN) repository for management of software code developed by GCE personnel.

## **WHAT IS THE IMPACT ON TECHNOLOGY TRANSFER?**

The GCE Information Management program has developed a number of software products, database systems and web applications that have been released as open source software. These tools, including the GCE Data Toolbox for MATLAB, our Metabase Metadata Management System, our bibliographic database, our file archive and our geospatial library, are widely used across the LTER Network and in other environmental informatics programs. The GCE Data Toolbox software has been downloaded by over 4100 registered users (254 since 2016) and is actively used at 9 other LTER sites for sensor data harvesting, data analysis or general data processing tasks. This past year we updated the API Guide and QA/QC Flagging Reference on the toolbox support website, and we are currently collaborating with the Environmental Data Initiative to register the GCE Data Toolbox and training materials in their new IM Code Repository co-hosted with Earth Science Information Partners (ESIP). Our Metabase metadata management system was adopted by 3 other LTER sites (CWT, MCR and SBC) and the Savannah River Ecology Lab. In 2018 we deployed web-based metadata and data submission applications to replace legacy spreadsheet data submission templates and MS Access management forms. The application is now in use on the GCE website.

## **WHAT IS THE IMPACT ON SOCIETY BEYOND SCIENCE AND TECHNOLOGY?**

The GCE website and public data portal are used to disseminate publications, reports, research data, photographs and remote sensing imagery. Over 1.6 million distinct web visits have been recorded since 2001, with over 1.4 million page views from 117,895 visitors this past year. In addition, GCE scientists regularly give seminars and public presentations, contribute articles to newsletters and other popular publications, and talk to the media about coastal issues. Our Schoolyard program brings K-12 teachers to the field site, and our children's book and accompanying lesson plans are widely distributed to grade school teachers and environmental educators. GCE outreach is served by partial support of the Georgia Coastal Research Council (GCRC, [www.gcrc.uga.edu](http://www.gcrc.uga.edu)), which works to promote science-based management of Georgia coastal resources by facilitating information transfer between scientists and managers.

## Products and Publications

### Book Chapters

Thompson, Victor D. (2018). Collective Action and Village Life during the Late Archaic on the Georgia Coast. *The Archaeology of Villages in Eastern North America* Thompson, Victor D.. University Press of Florida. Gainesville. 20-35. Status = PUBLISHED; Acknowledgement of Federal Support = No ; Peer Reviewed = Yes

### Conference Papers and Presentations

Liu, Wenwen and Pennings, Steven C. (2018). *Allometric variation of the salt marsh grass Spartina alterniflora across space and time*. 103<sup>rd</sup> Annual meeting of the Ecological Society of America. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Miklesh, David Michael and O'Donnell, J.P. and Schalles, John F. and Meile, Christof (2018). *Analysis of decadal scale patterns of Spartina biomass in Georgia marshes using soil modeling and satellite imagery*. Ocean Sciences Meeting. Portland OR. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Pennings, Steven C. (2018). *Effects of Hurricanes Matthew and Irma on coastal wetlands in Georgia*. 103<sup>rd</sup> Annual meeting of the Ecological Society of America. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Burns, Christine and Alber, Merryl and Alexander, Jr., Clark R. (). *Historical analysis of marsh extent at three LTER site along the US Atlantic coast*. Coastal and Estuarine Research Federation Biennial Meeting. Status = ACCEPTED; Acknowledgement of Federal Support = Yes

Roebuck, J.A. and Medeiros, Patricia M. and Letourneau, Maria L. and Jaffe, R. (2018). *Hydrological controls on the seasonal variability of dissolved and particulate black carbon in the Altamaha River, GA*. Ocean Sciences Meeting. Portland, OR. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Zhang, Yihui and Pennings, Steven C. (2018). *Latitudinal patterns of insect folivory of mangrove forest in southern coast of China*. 103<sup>rd</sup> Annual meeting of the Ecological Society of America. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Adams, Tianjiao and Pennings, Steven C. (2018). *Long-term saltmarsh katydid (Orchelimum fidicinium) dynamics on Sapelo Island*. 103<sup>rd</sup> Annual meeting of the Ecological Society of America. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Schalles, John F. and O'Donnell, John and Nealy, Nicholas and Mizoguchi, Trek and Hladik, Christine M. (2018). *Multidecadal biomass declines and controlling variables for the keystone salt marsh species, Spartina alterniflora, in coastal Georgia*. ASLO 2018 Summer Meeting. Victoria, British Columbia, BC. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

O'Donnell, J.P. and Schalles, John F. and Hladik, Christine M. (2017). *Serious declines in Georgia salt marsh plant biomass are linked to climate variables*. Coastal and Estuarine Federation Biennial Meeting. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

O'Donnell, J.P. and Schalles, John F. and Hladik, Christine M. (2017). *Serious declines in a large area of Georgia Salt marsh plant biomass are linked to climate variables*. Coastal and Estuarine Research

Federation Biennial Meeting. Providence, Rhode Island. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Schalles, John F. (2018). *Spatial and temporal perspectives on multiple stressor impacts spanning inland to coastal ecosystems*. GLOBOLakes and GEO Aquawatch Joint Workshop. University of Stirling, Stirling, Scotland, UK. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Letourneau, Maria L. and Schaefer, Sylvia C. and Medeiros, Patricia M. (2018). *Temporal and spatial assessments of dissolved organic matter composition and biodegradation throughout the Georgia Coastal Ecosystem LTER domain*. Gordon Research Conference - Organic Geochemistry. Holderness, NH. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Schalles, John F. and O'Donnell, J.P. and Hladik, Christine M. and Ponzi, Sonya and Cao, Fang and Miller, William (2018). *The dynamic littoral fringe \_ Spatial and temporal patterns in community structure and productivity in North American coastal ecosystems*. GLOBOLakes and GEO Aquawatch Joint Workshop. University of Stirling, Stirling, Scotland, UK. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Bell, Tom and Castorani, Max and Schalles, John F. (2018). *Using drones for high spatial and temporal resolution - Long term observations*. NSF LTER All Scientists Meeting. Asilomar Conference Center, Pacific Grove, CA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

#### Journals

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### Thesis/Dissertations

Richards, Trevor. *A spatial and temporal investigation of estuarine and shelf flows on the Georgia Coast*. (2018). University of Georgia. Acknowledgement of Federal Support = Yes

Pannill, V.R. *Assessing the export of terrigenous dissolved organic matter in the South Atlantic Bight using CDOM analysis: 2014 and 2016 cruises*. (2018). University of Georgia. Acknowledgement of Federal Support = Yes

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Wang, Shiyu. *Inorganic carbon and oxygen dynamics in a marsh-dominated estuary*. (2017). University of Georgia. Acknowledgement of Federal Support = No

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#### Websites

*Marsh Explorer*

<http://marshexplorer.marsci.uga.edu/>

Marsh Explorer is a citizen science page that allows volunteers to identify some common plants and animals in over 6000 photographs of a salt marsh.