# GCE-IV Annual Report – Year One (2020)

## What are the major goals of the project?

The Georgia Coastal Ecosystems (GCE) LTER program focuses on estuarine and intertidal wetland ecosystems and how they respond to long-term change. The research proposed for GCE-IV is designed to characterize perturbation patterns and their relationships to external drivers, to develop an understanding of disturbance responses, and to evaluate the consequences of these responses at the landscape scale. We divide our research into 4 inter-related programmatic areas: External Drivers of Change (Area 1); Long-term Patterns within the Domain (Area 2); Marsh Response to Disturbance (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 external drivers such as climate change, sea level rise, and human alterations of the landscape and to statistically characterize these external drivers in terms of long-term trends, spatio-temporal variability, and occurrence of extreme events (e.g., storms, droughts) so that we can investigate the links between external drivers, domain perturbations, and ecosystem responses.

Area 2: to follow spatial and temporal variability in physical (estuarine salt intrusion length, residence time, and inundation), chemical (salinity, nutrient concentration and speciation, dissolved inorganic C, and pH), geological (accretion) and biological (organism distribution, abundance, and productivity) characteristics so that we can understand the biophysical template of the GCE domain in relation to external drivers and evaluate responses to domain perturbations.

Area 3: to characterize the ecological responses of our three key marsh habitats—*S. alterniflora*-dominated salt marsh, fresh/brackish marsh, and high marsh—to disturbance so that we can track trajectories of response and recovery from disturbance and characterize transitions to new states.

Area 4: to evaluate ecosystem properties at the landscape level (habitat distribution, net and gross primary production, C budgets) and to assess the cumulative effects of disturbance on these properties so that we can produce synoptic estimates of ecosystem properties in the GCE domain and develop driver-response relationships for marsh ecosystems.

## What was accomplished under these goals?

The GCE works in four main areas. The specific objectives associated with each of these are listed below, along with initials of the primary PIs involved in each activity: AB: Burd, AS: Spivak, AW: Wilson, BS: Silliman, CA: Alexander, CC: Craft, CH: Hladik, CHA: Angelini, CM: Meile, DD: Di Iorio, DM: Mishra; JB: Byers, JS: Schalles, MA: Alber, NH: Heynen, CO: Osenberg, PM: Medeiros, RC: Castelao, RP: Peterson, RV: Viso, SP: Pennings, VT: Thompson, WC: Cai.

Below we summarize our major activities and significant results for each of the objectives targeted for yr 1.

## Area 1: External Drivers of Change

We collect long-term measurements associated with both A) environmental and B) human drivers that influence conditions in the GCE domain.

Area 1A Objectives

1. Collect ongoing information on climate and oceanographic conditions, sea level, and river discharge - DD, MA

Year One 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. We now also generate 15-minute summaries from our eddy covariance flux tower. Referenced sea level data, offshore wind forcing, and river discharge are also tracked.

Significant Results: An analysis of sea level rise rates at NOAA buoys near GCE shows that rates were 2x higher from 1999-2019 than from 1940-1999. A manuscript with these observations is currently under review at PNAS (Crotty et al. subm.).

2. Maintain an eddy covariance tower in the Duplin River - DM, DD, MA

Year One Activities: The GCE eddy covariance flux tower on the Duplin River measures $CO_2$, $H_2O$, weather conditions, radiation, water levels, and soil temperature. This past year we registered the tower with the Ameriflux network, installed additional radiation sensors and a second soil temperature gauge, standardized the processing of raw eddy covariance fluxes, and developed methodologies for integrating fluxes and exploring uncertainty in the data.

Significant Results: Eddy covariance data collected in 2019 have been processed to the levels of 30-minute net ecosystem exchange (NEE), gap-filled, and partitioned into gross primary production and ecosystem respiration. Feagin et al. (in press) included GCE data in a larger effort that used eddy covariance data to create a MODIS-based blue carbon model to estimate GPP of tidal wetlands.

3. Monitor Altamaha River water entering the GCE domain - MA, PM, WC

Year One Activities: We collect monthly samples of river water entering via the Altamaha River for analysis of dissolved inorganic nutrients, DIC, alkalinity, and pH. We also completed a directed study to evaluate the DOM signatures of water entering the system.

Significant Results: Letourneau and Medeiros (2019) found increased biodegradation of DOC when the discharge of the Altamaha River was high, and the DOM composition was more terrigenous in character. This paper, in JGR Biogeosciences, was featured as an EOS research spotlight.

4. Measure exchange between the Duplin River and Doboy Sound - DD

Year One Activities: We run a horizontal looking acoustic Doppler current profiler (HADCP) to measure along-channel current flow at the mouth of the Duplin River.

Significant Results: Tidally averaged currents measured by the HADCP show a residual along-channel flow that is predominately outwards (Fig. 1). This may correspond to connectivity with surrounding waters of Sapelo Sound to the north and Teakettle Creek to the west during periods of high inundation (spring high tides, sea surface heights > 0).

Area 1B Objectives

1. Evaluate how human activity relates to impervious surface and shoreline structures - NH, CA, VT, MA

Year One Activities: We are developing a detailed land use history of the Hog Hammock Community on Sapelo Island. We have also deployed data loggers in drainage ditches to evaluate salt water incursion into populated areas.

Significant Results: Turck et. al. (in review) and Thompson (2019) have documented resilience and possible sustainable management practices among Native American communities.

2. Assess human modifications of oyster reefs - VT, CA

Year One Activities: We measured 37,805 oysters from Late Archaic and Mississippian period sites and are currently compiling radiocarbon dates and climate data for these samples. We have also mapped all oyster reefs in the GCE domain.

Significant Results: Thompson et al. (in review) demonstrated significant spatio-temporal variability in oyster size, with larger oysters in the lowest, and hence earliest, deposits at some sites and a non-random pattern that often clustered by island, which they ascribe to processes related to territoriality, fishing rights, and coastal environmental variability.

## 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, B) repeat photography, and C) modeling.

Area 2A Objectives

1. Continue the GCE core monitoring program in the water column - DD, MA, WC, PM

Year One Activities: We maintain sondes that collect continuous measurements at 10 sites, and we obtain quarterly or monthly CTD profiles and measurements of nutrients, dissolved organic matter, chlorophyll and suspended sediment at 12 sites (Table 1, Fig. 2).

Significant Results: We observed increased salinity in the tidal forest (GCE11) in conjunction with Hurricane Irma, and a more recent increase that corresponded to a combination of high sea surface heights and low river flow (Fig 2). We also observed large changes in DOM composition (analyzed by FT-ICR MS) and high microbial utilization of DOC in association with hurricane Matthew (Letourneau and Medeiros 2019) and are currently processing samples from hurricanes Irma, Michael, and Dorian.

2. Continue the core monitoring program in the marsh and tidal fresh water - SP, CC, CHA, CO

Year One Activities: We monitor plants, invertebrates, and soils in 2 zones at each of our 10 marsh sites (Table 1, Fig. 2). In the tidal forest we measure litterfall, basal area increment, and sediment elevation, and have begun assessing vegetation cover. We are also testing biomimics to evaluate the thermal regimes experienced by macrofauna.

Significant Results: Liu and Pennings (2019) used the long-term plant monitoring data to evaluate whether the “self-thinning” law applies to *Spartina* (see Accomplishments). We are also working on a dynamical systems analysis of *Spartina* biomass in response to external drivers. Preliminary results indicate the spring and preceding fall conditions are causally related to plant production.

3. Characterize groundwater flow - AW, CM, CA, RP

Year One Activities: We monitor groundwater levels and salinities at a series of wells associated with the high marsh manipulation (see 3C.2). In 2019 we installed additional wells across the upland marsh transition at Marsh Landing where we have long-term observations of vegetation shifts (Fig. 3).

Area 2B Objectives

1. Continue the GCESapelo Phenocam and add a second site - SP, MA

Year One Activities: The GCESapelo Phenocam, which is focused on a *Spartina* marsh, contributes data to the national phenocam network every 30 min. We are scouting locations for a second camera with both *Spartina* and *Juncus* in its field of view.

Significant Results: O’Connell et al. (2019) analyzed Phenocam imagery to develop a spring warm-up model for *Spartina* that suggests long-term changes in the date of green-up onset (Fig. 3, see also Accomplishments).

2. Continue regular aerial photographs of the GCE domain - CA, CH, CHA

Year One Activities: Aerial photography was taken in 2017 and 2018 with funds from a RAPID grant related to Hurricane Irma.

Area 2C Objectives

1. Upgrade hydrodynamic models (Delft3D) - RC, DD

Year One Activities: We have recently switched to Delft3D (from FVCOM) because of the added flexibility and additional functions available.

2. Enhance soil models - CM

Year One Activities: Our soil model (Miklesh & Meile 2018) predicts porewater salinity based on hydrology and evapotranspiration, and we are working to incorporate soil temperature.

3. Enhance *Spartina* models - AB, MA, DM

Year One Activities: We are gathering data on soil temperature, above- and below-ground biomass, and NPP that can be used to enhance *Spartina* models.

## Area 3: Marsh Response to Disturbance

We work in each of our key marsh habitats to understand ecosystem response to major perturbations. A) In the *Spartina* marsh, we are assessing changes in inundation and top-down control. B) In the upstream areas of brackish/fresh marsh and tidal forest, we are evaluating the effect of increases in salinity that occur as the result of droughts, storm surge, or upstream sea level intrusion. C) In the high marsh, we are assessing changes in runoff at the upland/marsh border.

Area 3A Objectives

1. Evaluate drivers of *Spartina alterniflora* production - SP, MA, AB, CHA, CM

    Year One Activities: We deployed soil temperature sensors at the core marsh sites to evaluate its relationship to *Spartina* green-up. We are also planning to manipulate temperature in a greenhouse experiment.

    Significant Results: Hawman et al. used general additive models to evaluate the annual cycle of GPP and light use efficiency measured at the flux tower (Fig. 4), and found that the cloudiness index and daily maximum tide height are the primary factors that explain deviation in *Spartina* light use efficiency. This work was presented at multiple conferences and is being written up for publication.

2. Continue our predator removal manipulation - BS, CHA, JB, AS, SP, CC, CO

    Year One Activities: We continue sampling the predator exclusion experiment initiated in summer 2016. In 2019 we began sampling pore water and decomposition, conducted tethering experiments with fiddler crabs and *Littoraria*, and completed a literature search to identify which species are likely being excluded by the treatment.

    Significant Results: The results from the PredEx manipulation indicate that nekton are exerting top-down control of marsh invertebrates, with evidence for a short-lived release that may be compensated for by mesopredators such as mud crabs (Fig. 5). Initial results suggest that pore water salinity and pH do not vary with treatment. However, decomposition in predator exclusion plots was significantly greater than controls, presumably due to greater oxygenation by crab burrows. Soil bulk density (0-5 cm) was also lower, although not significantly, while there was no difference in soil C and N.

3. Quantify ecosystem effects of marsh perturbations - CHA, SP, AS, MA

    Year One Activities: We conducted a study of marsh perturbation and recovery at headward-eroding creeks that are subject to Sesarma herbivory (Fig. 4). We also developed a protocol for field monitoring the impacts of wrack and drought disturbance.

    Significant Results: We have evidence that grazed creeks have become increasingly prevalent over the past few decades and are causing a significant increase in drainage density by accelerating creek incision, which has implications for invertebrate communities and predator-prey interactions on the marsh platform (Crotty et al., in review).

4. Conduct standardized disturbance manipulations - SP, CHA, MA

    Year One Activities: We are participating in a distributed "DragNet" experiment aimed at understanding how grasslands recover from disturbances under different nutrient regimes. We also plan to initiate a standardized disturbance experiment across the GCE domain based on observations of natural marsh perturbations. We continue to monitor recovery from a wrack disturbance experiment conducted in 2011.

5. Investigate marsh fauna interactions - BS, CHA, JB, CO

Year One Activities: We began field measurements to evaluate how interactions between cordgrass and ribbed mussels influence tide water chemistry and the net import/export of materials from marshes.

Significant Results: Tethering experiments with *Littoraria* show that the probability of survival increases with body size: for every millimeter increase in shell height, the log odds of survival increases by 0.16048.

Area 3B Objectives

1. Assess upstream habitat transitions - MA, CC, CH, JS

Year One Activities: We conduct an annual survey of bankside vegetation and sample plots with mixed vegetation to document transitions along the Altamaha River salinity gradient. In 2018 we added an annual photo survey of trees in the tidal fresh forest and observations on Broughton Island, which has a dynamic mix of oligohaline and mesohaline species. We have also sampled bald cypress deposits for a longer dendrochronology analysis (Fig. 5, Napora et al. 2019).

Significant Results: Herbert et al. (in press) found that long-term addition of N and P to a tidal freshwater marsh in the Altamaha increased above-ground biomass, microbial biomass and N cycling, and N, P, and C assimilation and burial more than either nutrient alone (Fig. 6), and suggest that the ability of these habitats to mitigate eutrophication will depend on the quantity and relative proportion of N versus P entering the system.

2. Track recovery from our salt water intrusion manipulation - CC, SP, CHA, JS

Year One Activities: We sampled porewater, greenhouse gases, vegetation, invertebrates, and soil biomarkers in the SALTEx experiment to track recovery following cessation of dosing in December 2017.

Significant Results: Widney et al. (2019) published a synthesis of the biochemical effects of the SALTEx experiment showing that three years of saltwater intrusion increased porewater $Cl^-$, $SO_4$, HS and inorganic N ($NH_4$ and $NO_3$) and decreased plant N storage (see Accomplishments). Manuscripts regarding the changes in soil elevation and the vegetation response are both in review.

Area 3C Objectives

1. Assess habitat dynamics at vegetation borders - SP, MA, CA

Year One Activities: We monitor vegetation dynamics in 9 high marsh mixtures and have begun annual drone flights to scale up to the surrounding landscape. We also operate two web applications where citizen scientists align and extract data from photographs taken along transects that begin in the high marsh.

2. Continue our upland manipulation - SP, AW, RV

Year One Activities: The high marsh experiment has had little effect on water flow, and hence there have been no effects on plants or invertebrates. However, data from the wells are being analyzed to calculate hydraulic gradients for groundwater flow models (Fig. 3).

## Area 4: Integration and Forecasting

We use the information collected in Areas 1-3, along with modeling and remote sensing, to A) produce synoptic descriptions of ecosystem properties, B) create a scaled-up disturbance-scape that tracks the temporal and spatial patterns of perturbations and their cumulative effects, and C) investigate relationships between drivers and ecosystem responses.

Area 4A Objectives

1. Produce synoptic habitat maps of the GCE domain - CH, JS, MA

Year One Activities: Aerial photographs (Obj 2B.2) were analyzed using random forest to generate classified maps of habitat distributions for 2017 and 2018.

Significant Results: Habitat maps delineating 11 tidal habitats were generated with overall classification accuracies ranging from 0.83 (2017) to 0.88 (2018). These are being used for change detection analyses.

2. Assess scaled-up biomass patterns - DM, JS, CH

Year One Activities: We extended our studies of *Spartina* biomass (O'Donnell & Schalles 2016) by applying our algorithm to Landsat 8 data and expanding our analysis to the Georgia coast. We are also optimizing our algorithm to generate estimates of below-ground biomass, and continue to collect monthly samples of *Spartina* above- and below-ground biomass for groundtruthing.

Significant Results: Our expanded analysis of long-term trends in *Spartina* biomass was applied to 7 USGS HUCs along the Georgia coast and showed declines in all but the Altamaha HUC (which has the most freshwater input). These data were presented at several meetings and are being included in a cross-coastal LTER climate synthesis manuscript. A manuscript describing below-ground biomass trends is also in prep.

3. Evaluate C stocks and transport from tidal wetlands to the coastal ocean - WC, AS

Year One Activities: As part of an ROA supplement awarded in 2019, we sampled 33 stations during successive neap and spring tides to obtain high-temporal-resolution analysis of carbonate chemistry. We also continued processing cores from all 11 GCE sites for C content and radioisotope dates.

Significant Results: High-frequency monitoring conducted with an ROA supplement showed evidence for DIC export during spring tides due to flushing of tidal nodes, which may explain the net export observed from the Duplin River (Obj.1A4). Spivak et al. (2019) wrote a synthesis paper highlighting the importance of understanding the key biogeochemical mechanisms within the marsh that control decomposition of soil organic matter when evaluating the effects of climate change on coastal wetland C storage.

Area 4B Objectives

1. Use drones to track disturbances over time - MA, DM, JS, CA, SP

Year One Activities: We launched a large-scale effort to track disturbances via regular drone flights. We acquired a Matrice 200 drone with a Micasense RedEdge Altum camera, obtained appropriate permits and FAA licenses, performed tests to optimize flight conditions, began monthly flights over an initial test site, and obtained ground-truth data for field validation of disturbances. We have developed a work flow for processing imagery and are optimizing our algorithm to detect disturbances.

Significant Results: Our initial drone imagery is already yielding important insights into patch dynamics in the salt marsh, with evidence of shifting areas of wrack from month to month that leave residual signals on the landscape (Fig. 7).

2. Construct a scaled-up disturbance-scape - DM, MA, JS, CHA

Year One Activities: We used *Spartina* biomass from clip plots to calibrate a biomass algorithm based on drone reflectance, and we are now working to pair these high-resolution observations with satellite imagery (WorldView, Sentinel, Landsat, MODIS).

Significant Results: *Spartina* biomass maps were successfully produced from the drone imagery flown at the Airport Marsh test site (Fig. 8). *Spartina* biomass estimates were barely affected (<1.3%) when scaled up using MODIS. This will be presented at the first NOAA-SECOORA Drones in the Coastal Zone Workshop in March, 2020.

Area 4C Objectives

1. Characterize driver-response relationships in GCE data - MA, AB, CC, SP

Year One Activities: We have analyzed our long-term salinity data from the Altamaha River estuary to evaluate the conditions under which high salinity events occur (Fig. 6).

Significant Results: We identified 79 high salinity events, ranging from 1 to 51 days, in the Altamaha River estuary over the last 16 years. These events could be explained by river flow that was objectively low based on the historical record, strong up-estuary winds, or (to a lesser extent) unusually high tides (Sheldon & Alber 2019).

2. Develop simple mechanistic models to explore disturbance - AB, MA, CM

Year One Activities: We plan to use the results from the SALTEx experiments (Obj. 3B.2) as a test case for characterizing ecological responses from field data with a known perturbation (i.e. saltwater intrusion).

3. Investigate disturbance patterns through model simulations - RC, DD, CM, AB

Year One Activities: The hydrologic monitoring data from groundwater wells will be used to investigate links between major disturbances (high rainfall events, very high tides), and vegetation changes.

## GCE Activities 2020

### Area 1: External Drivers of Change

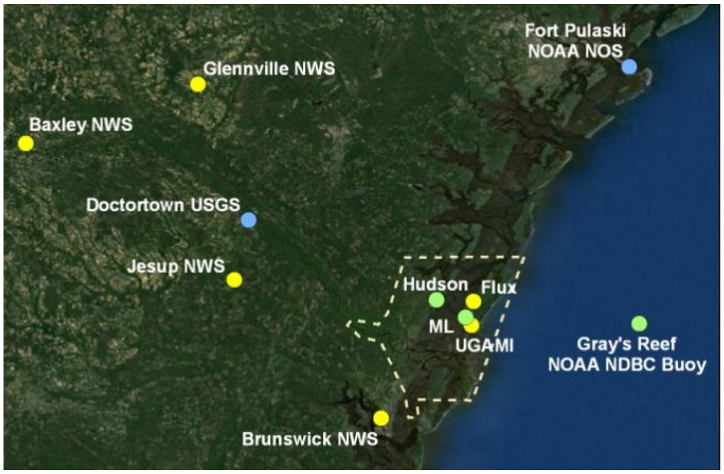



Fig. 1. Locations of observing stations used for boundary conditions (ML is Marsh Landing; UGAMI is UGA Marine Institute). Corresponds to Objective 1A.1: Collect ongoing information on climate and oceanographic conditions, sea level, and river discharge.

### Area 2: Patterns within the Domain

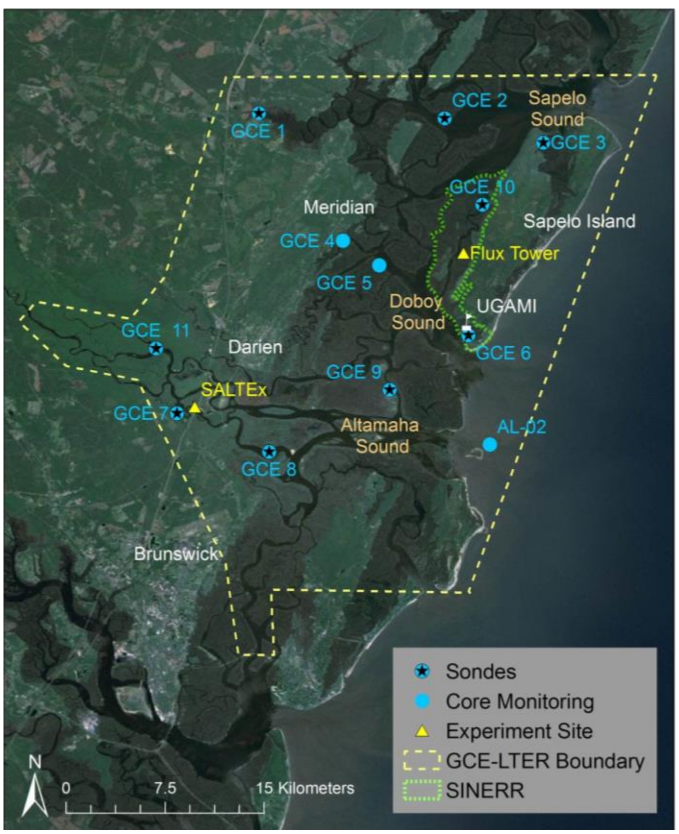



Fig. 2. GCE domain showing core monitoring stations. Corresponds to Objective 2A.1: Continue the GCE core monitoring program in the water column and 2A.2: Continue the core monitoring program in the marsh and tidal fresh water.

Table 1. Monitoring program for GCE-IV. 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. PI initials are CC: Craft, CHA: Angelini, CM: Meile, DD: Di Iorio, DM: Mishra; MA: Alber, JO: Jessica O'Connell, PM: Medeiros, SP: Pennings, WC: Cai. Corresponds to Objectives 2A.1: Continue the GCE core monitoring program in the water column and 2A.2: Continue the core monitoring program in the marsh and tidal fresh water.

| Type | Location | Frequency | Core Area & Variables Measured |
|---|---|---|---|
| **Area 1** | | | |
| Weather stations, with SINERR, USGS (DD) | Sites 4, 6, flux tower | 15 min | 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 $CO_2$, humidity and heat fluxes |
| Altamaha River chemistry (MA, WC) | Head of tide | Monthly | 3, 4. Dissolved inorganic nutrients ($NO_x$, $NH_4^+$, $HPO_4^{2-}$, $H_2SiO_4^{2-}$) and organics (DOC, TDN, DON, TDP, DOP), particulate CN, DIC, alkalinity, pH |
| **Area 2 Water** | | | |
| Sound chemistry (MA, WC, PM) | Sites 1-5, 8-11, AL-2 | Quarterly | 1, 3, 4. Dissolved inorganic nutrients ($NO_x$, $HPO_4^{2-}$) and organics (DOC, TDN, DON), particulate CN, DIC, alkalinity, pH, chlorophyll *a* |
| | Sites 6-7 | Monthly | 1, 3, 4. Dissolved inorganic nutrients ($NO_2^-$, $NO_3^-$, $NH_4^+$, $HPO_4^{2-}$, $H_2SiO_4^{2-}$) and organics (DOC, TDN, DON, TDP, DOP), particulate CN, DIC, alkalinity, pH, chlorophyll *a*, total suspended sediment |
| | Sites 7, AL-2 | Quarterly | 3. DOM composition |
| Sound hydrography (DD) | Sites 1-4, 6-11 | 30 min | 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. | 15 min | Abiotic driver of 1-5. Horizontal ADCP measurements of water flux |
| **Area 2 Marshes** | | | |
| Soil accretion (CC) | Sites 1-11 | Annual | 3. Sediment accretion, elevation, compaction |
| Soil temperature (JO, CM) | Sites 1-11 | 15 min | Abiotic driver of 1-4. Loggers in root zone (10 cm deep), in 2 marsh zones adjacent to vegetation plots. |
| Plant productivity (SP, CC, DM, JO) | Sites 1-10 | Annual | 1. Stem density, height, flowering status, calculated biomass, in 2 marsh zones |
| | Site 11 | Annual | 1. Litterfall traps and stem wood growth of tupelo gum and bald cypress |
| | Flux tower | 5 min | 1. Net ecosystem exchange |
| | Flux tower | Monthly | 1. Above- and belowground biomass in short, medium, tall *Spartina* |
| | Flux tower, site 4 | 30 min | 1. Phenocam estimates of aboveground biomass in short, medium, tall *Spartina* |
| Disturbance (SP) | Sites 1-10 | Annual | 5. Disturbance in permanent vegetation plots |
| Plant composition (SP, MA, CC) | Sites 6, 10 | Annual | 2. Community composition in 4 types of salt marsh, 2 types of high marsh vegetation mixtures |
| | Altamaha | Annual | 2. Community composition in 2 types of low-salinity marsh vegetation (3 sites). Distribution of Altamaha marsh types (~50 stations), health and survival of tidal fresh forest trees (~50 stations). |
| Marsh Invertebrates (CHA, SP) | Sites 1-11 | Annual | 2. Density and size of benthic macroinvertebrates (mollusks, crab burrows) in 2 marsh zones. |
| Insects (SP) | Sites 1-6, 9, 10 | Annual | 2. Density of grasshoppers in salt marsh transects |
| Recruitment (CHA) | Sites 1-11 | Annual | 2. Recruitment of barnacles to standard substrates |

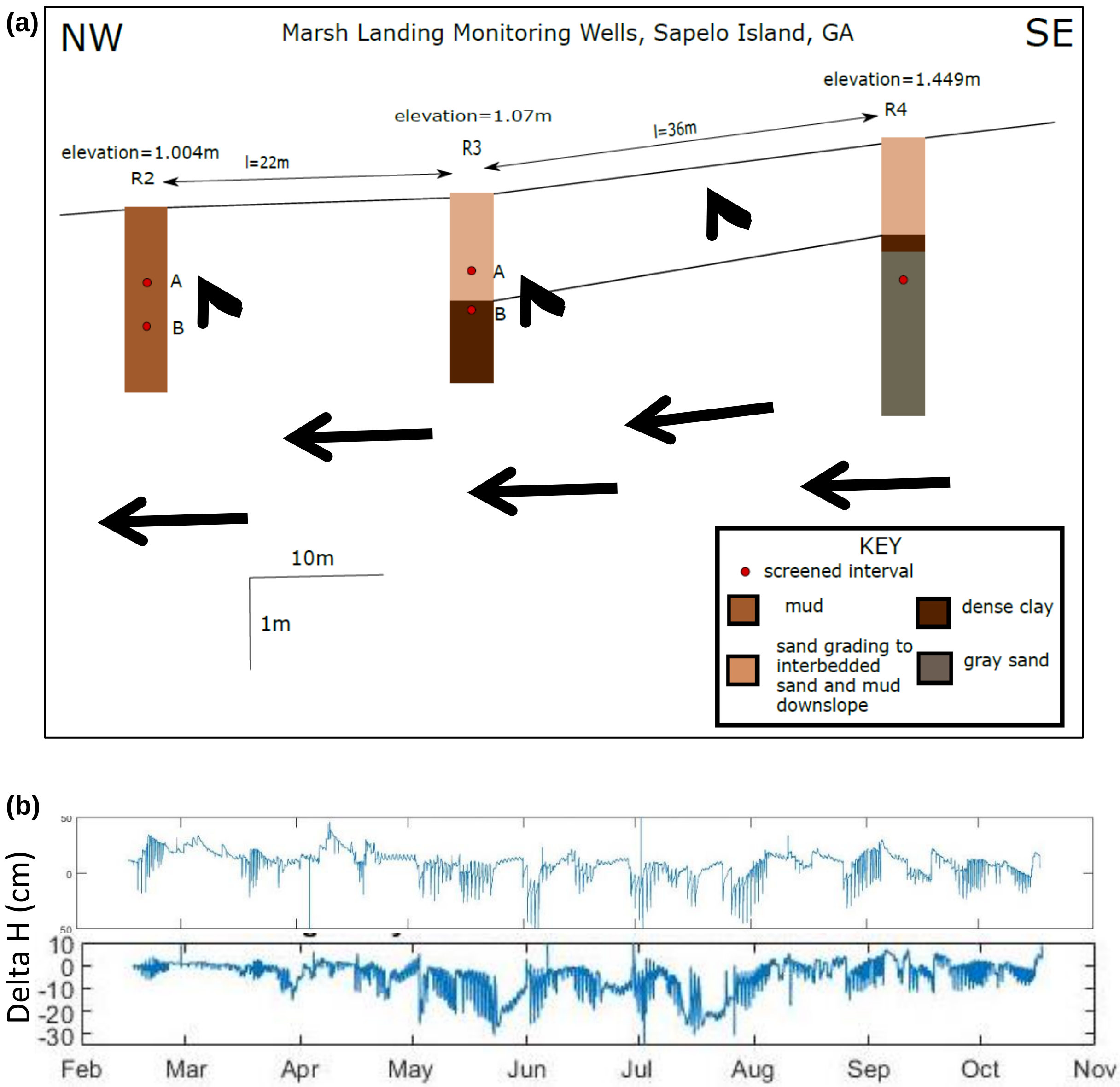



Fig. 3. Groundwater wells were installed in Feb. 2019 in an area of vegetation transition at Marsh Landing. (a) stratigraphy and overall flow patterns, (b) the difference in hydraulic head (top) between well R4 and R3B, which is net positive (landward) and (bottom) between well R3B and R2B, which is net negative (creekward). Source: Alicia Wilson and Sophia Sanders. Corresponds to Objective 2A.3: Characterize groundwater flow.

**GCE Activities 2020**

**Area 3: Marsh Response to Disturbance**

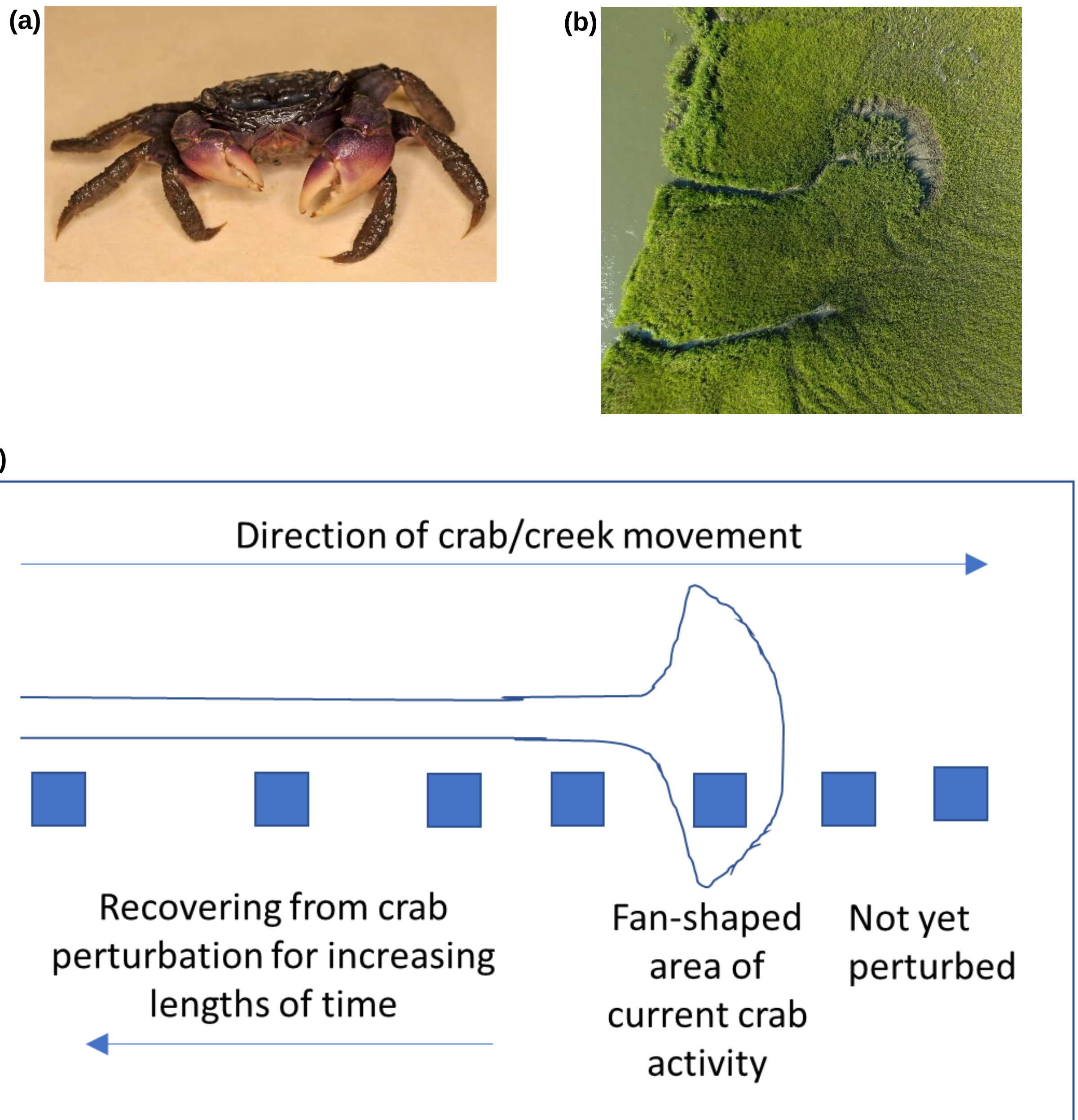



Fig. 4. The mud crab, *Sesarma reticulatum* (a), can cause headward erosion of a tidal creeks (b) at a rate of 1-2 m/yr. We sampled quadrats along transects that went through areas of crab activity as a space-for-time substitution to evaluate the effects of this perturbation (c). Blue squares indicate quadrats. Source: Steve Pennings. Corresponds to Objective 3A.3: Quantify ecosystem effects of marsh perturbations.

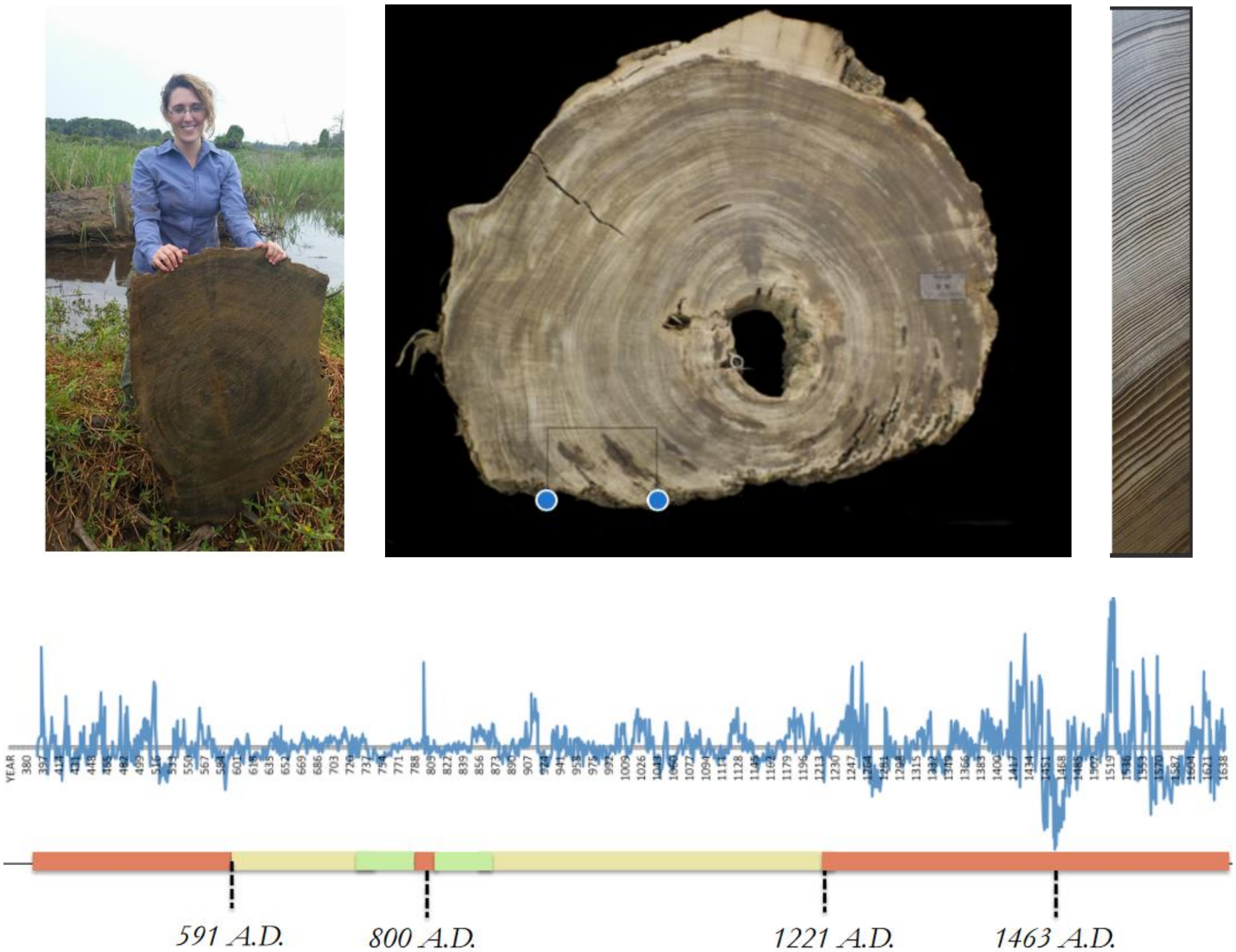



Fig. 5. Dendrochronology from bald cypress tree cookies collected on the Georgia coast showing changes in annual tree rings from 393 – 1642. Periods of fluctuations are indicated in orange. Source: Kat Napora and Victor Thompson. Corresponds to Objective 3B.1: Assess upstream habitat transitions.

## Area 4: Integration and Forecasting

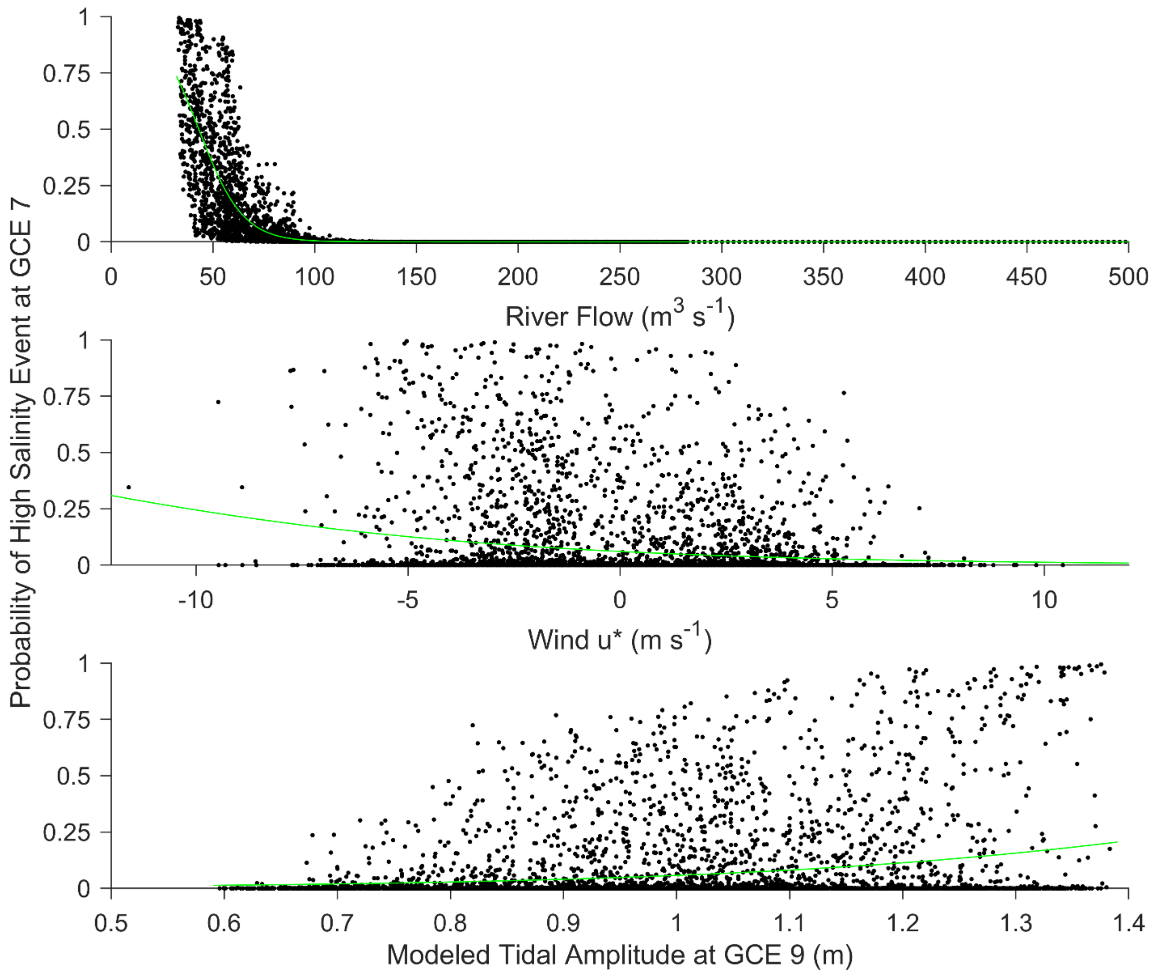



Fig. 6 Estimated probability of a high salinity event at GCE 7 as a function of the combined effects of river flow, along-estuary wind, and tidal amplitude (black dots) and as a function of each driver alone (green lines). Combined-effects probabilities for the conditions of each day in the study period are plotted against individual driver variables, so the vertical scatter at any given driver value is due to the effects of the other two drivers. River flows >500 $m^3$ $s^{-1}$ not shown because event probabilities are zero. Source: Sheldon and Alber 2019. Corresponds to Objective 4C.1: Characterize driver-response relationships in GCE data.

**GCE Significant Results 2020**

**Area 1: External Drivers of Change**

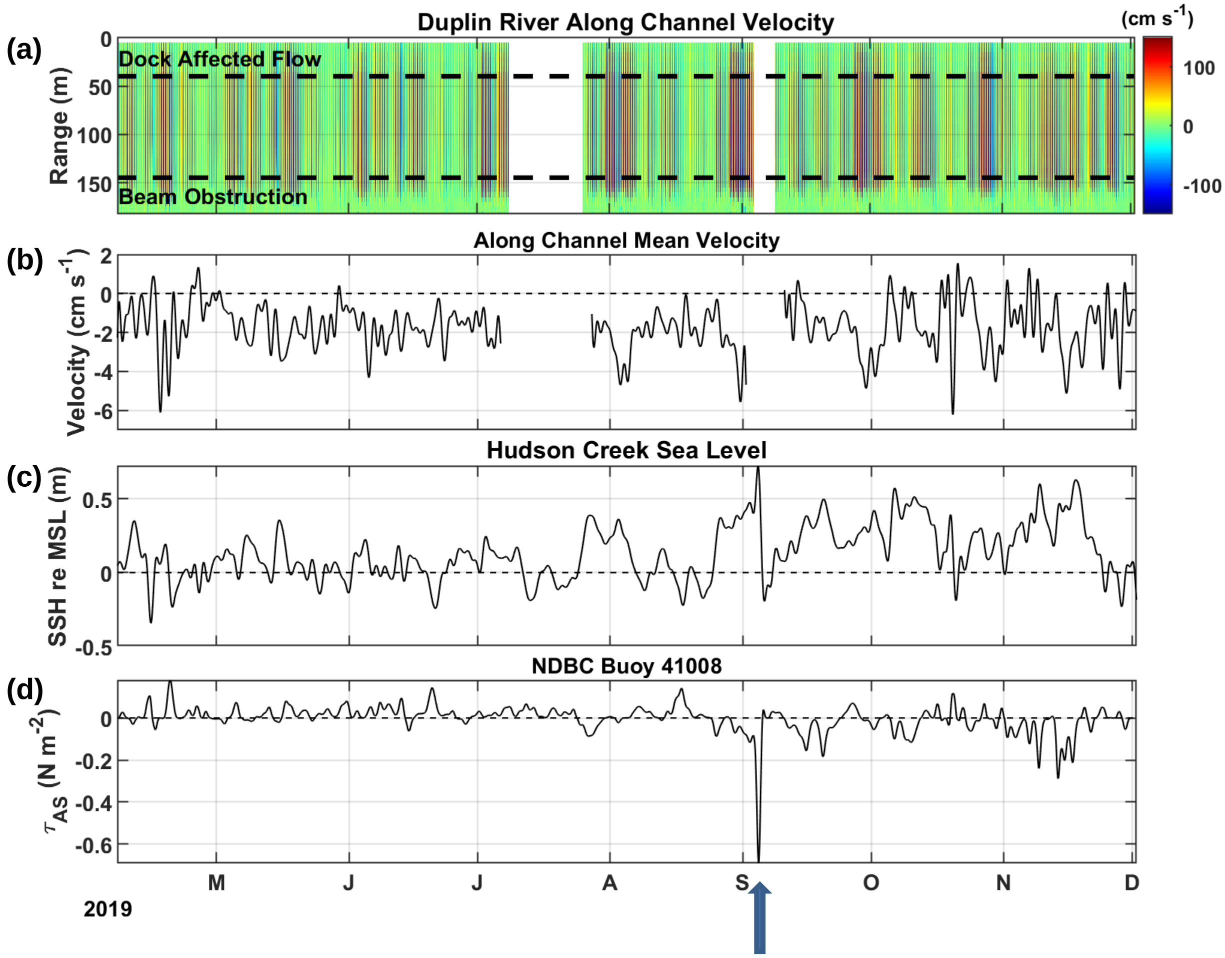



Fig. 1. a) Channel velocity measured by the horizontal looking acoustic Doppler current profiler (HADCP) moored at Marsh Landing showing tidal variations with strong spring/neap modulations. b) Tidally averaged currents show a residual along channel flow that is predominately outwards with an average flow of -2 cm/s. c) The sea surface height measured at Hudson Creek, Meridian shows that significant inundation of up to 0.5 m occurred starting in August 2019 and resulted in greater outflow speeds. d) Winds at the Gray's Reef Buoy NDBC41008. Hurricane Dorian passed Georgia Sept 4, 2019 (blue arrow) with strong southerly winds, which caused the mean SSH to go above 0.6 m. Source: Daniela Di Iorio. Corresponds to Objective 1A.4: Measure exchange between the Duplin River and Doboy Sound.

## Area 2: Patterns within the Domain

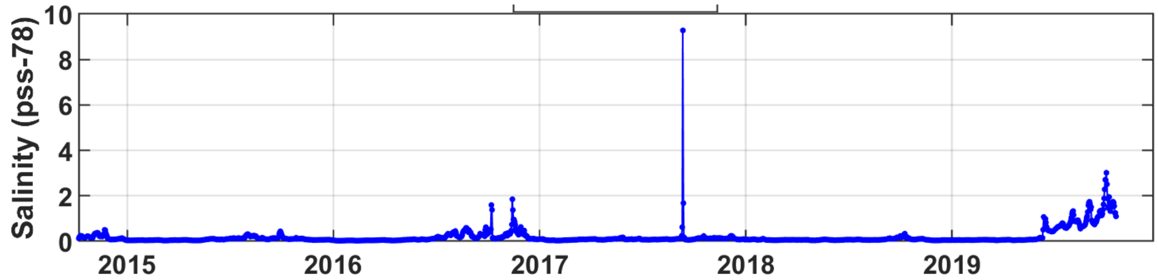



Fig. 2. Salinity measured over the period of record at site GCE11 in the tidal fresh forest. Note large increase due to Hurricane Irma in 2017 as well as increases starting in August 2019, which is likely the result of high sea surface heights (see Fig. 1) in combination with low river flow. Source: Daniela Di Iorio. Corresponds to Objective 2A.1: Continue the GCE core monitoring program in the water column.

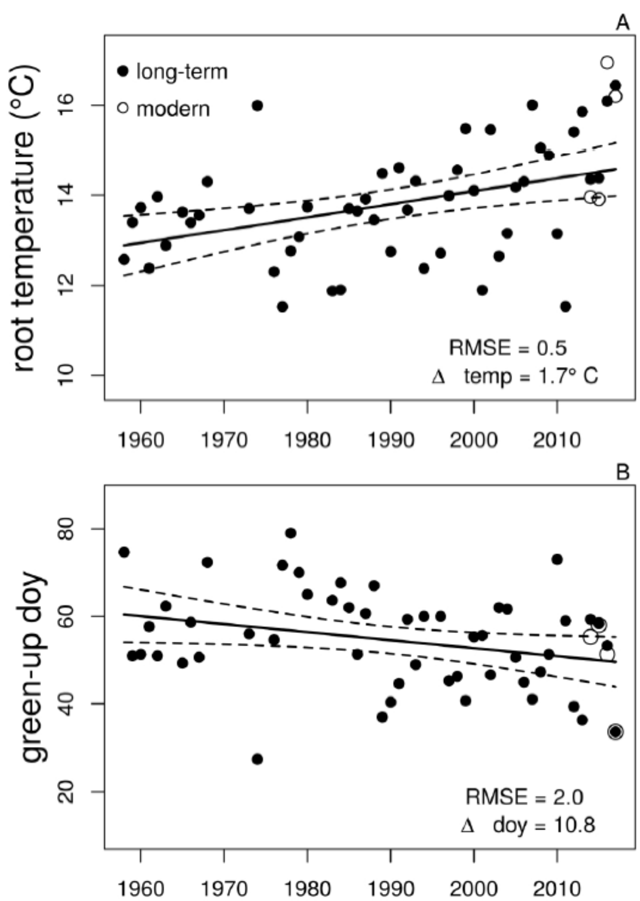
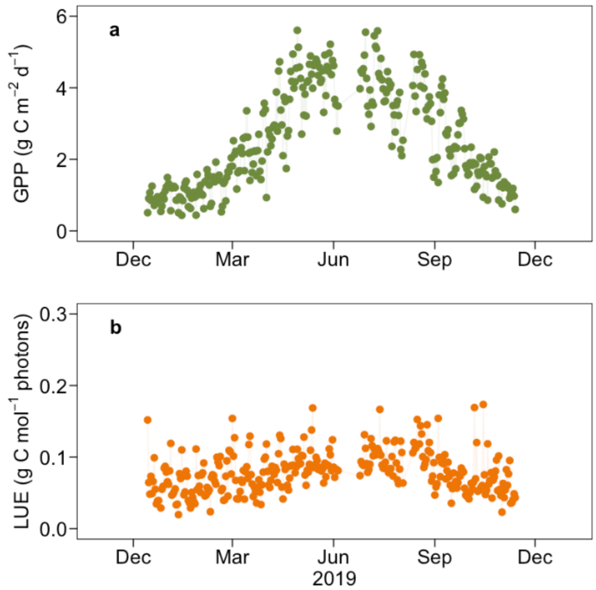


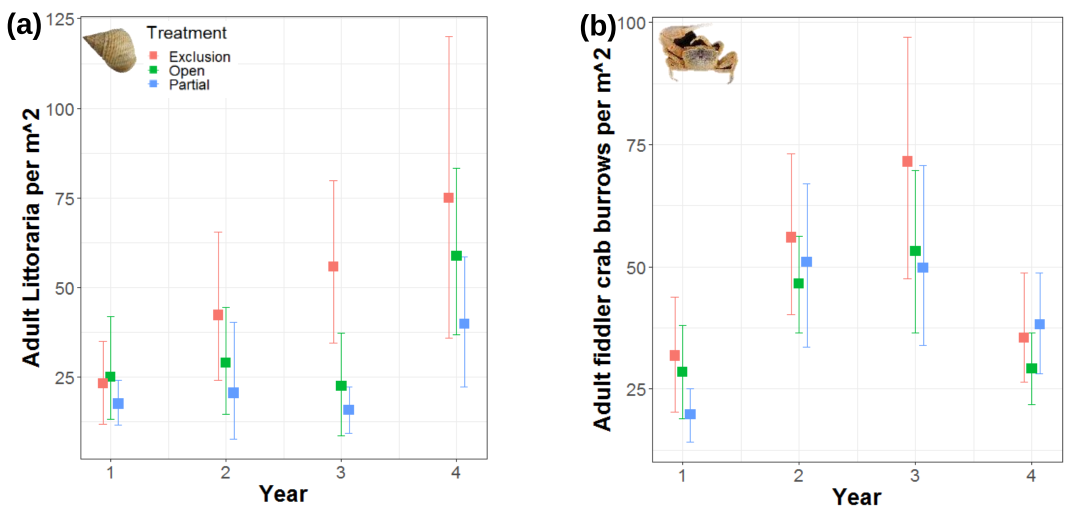

Fig. 3. A) Long-term record of change in estimated mean winter soil temperatures from the gap-filled and site-calibrated 60-year climate data, estimated as the mean of all marsh zones during December and January. Modern data estimated from the flux tower are also superimposed and RMSE is provided for the difference between modern and long-term estimates for overlapping years. The best fit line (solid line) estimating the increase in temperature with time is presented ($P < 0.001$) where the dashed lines represent the 95% CI for the fit. B) Long-term change in green-up day of year (doy) predicted from the climate record in panel A through the use of the spring warming model. The best fit line (solid line) for change in green-up doy with respect to year also is indicated ($P < 0.001$). The dashed lines represent the 95% CI for the fit. Modern green-up dates from the PhenoCam (mean of all zones) also are superimposed and RMSE is provided for the difference between modern and long-term estimates for overlapping years. Source: O'Connell et al. 2019. Corresponds to Objective 2B.1: Continue GCESapelo Phenocam and add a second site.

## GCE Significant Results 2020

### Area 3: Marsh Response to Disturbance

Fig. 4. Annual cycle of Gross Primary Production, GPP (a) and Light Use Efficiency, LUE (b) calculated from the GCE flux tower. LUE is GPP/PAR. Source: Peter Hawman et al., in prep. Corresponds to Objective 3A.1: Evaluate drivers of *Spartina alterniflora* production.



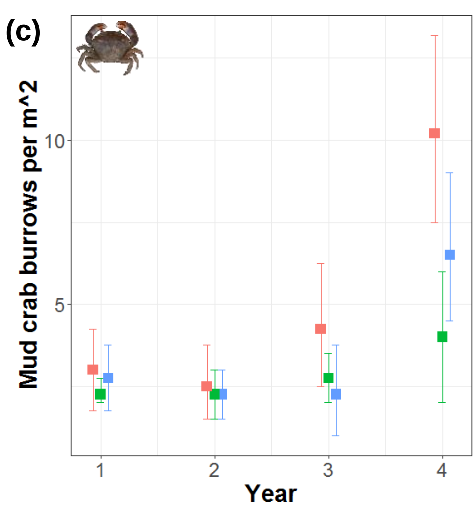




Fig. 5. Densities of a) *Littoraria* b) fiddler crab burrows and c) mud crab burrows observed in the predator exclusion experiment. By year 3 both *Littoraria* and fiddler crabs exhibited an apparent release from predation when nekton was excluded, but this effect disappeared in year 4 when the abundance of mud snails (mesopredators) increased inside the treatments. Source: Joe Morton and Brian Silliman. Corresponds to Objective 3A.2: Continue our predator removal manipulation.

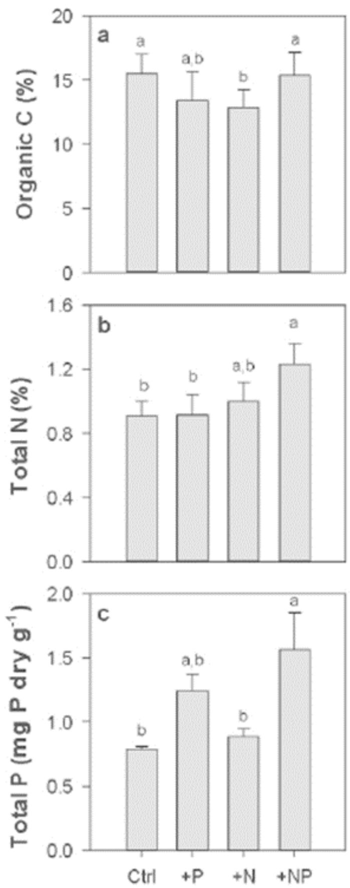



Fig. 6. Total (a) C (%), (b) N (%), and (c) P (µg P dry g-1) in the top 20 cm of soils in a tidal freshwater marsh in the Altamaha River that was fertilized for a period of 10 years with N and P, alone or in combination, as indicated. Source: Herbert et al. in press. Corresponds to Objective 3B.1: Assess upstream habitat transitions.

**GCE Significant Results 2020**

**Area 4: Integration and Forecasting**

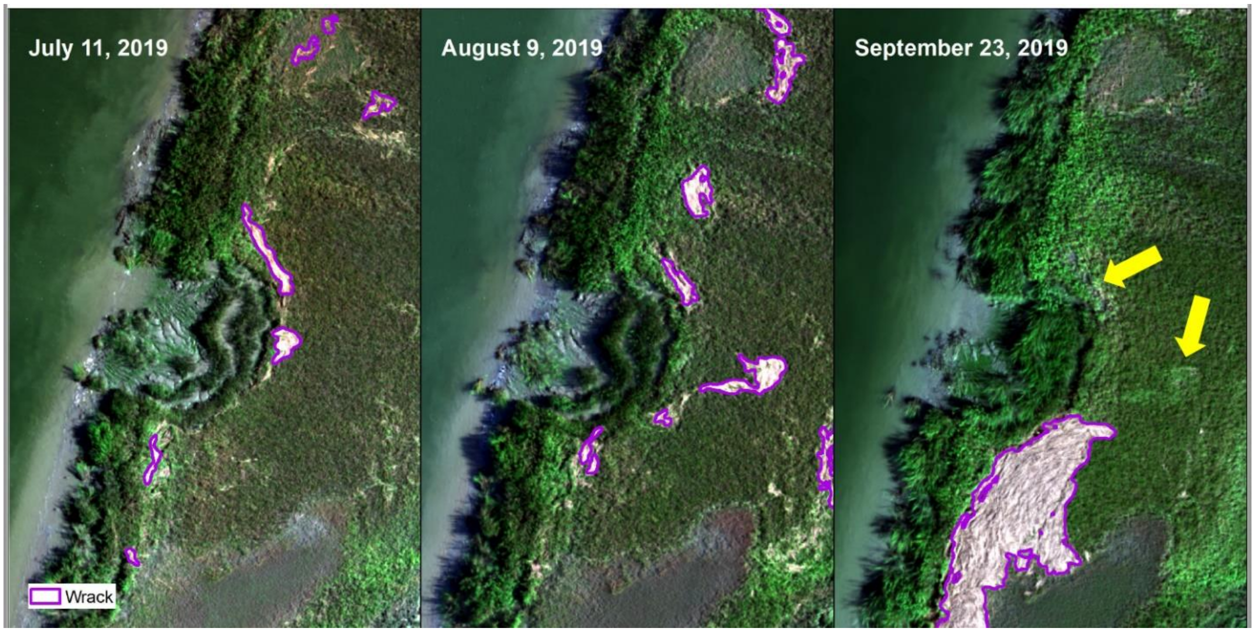
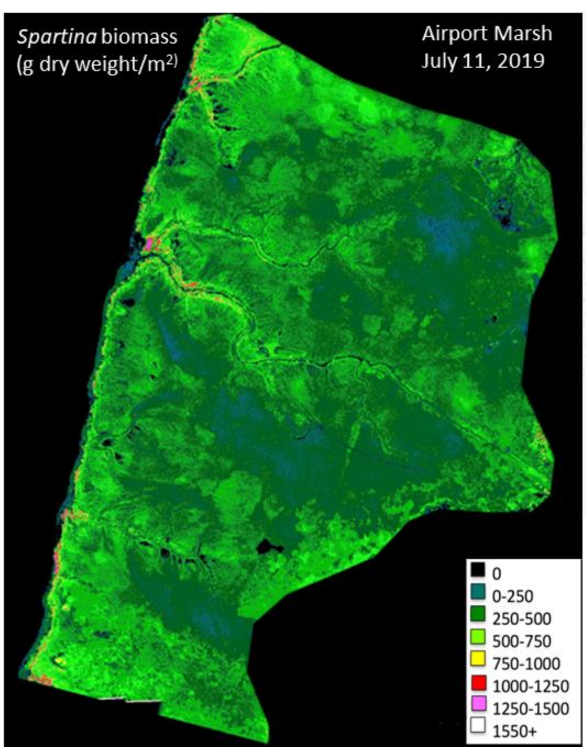



Fig. 7. Comparison of wrack disturbance patches (outlined in purple) identified from monthly drone flights of the airport marsh. Yellow arrows in the September image indicate areas where wrack packets were no longer present. Source: Tyler Lynn. Corresponds to Objective 4B.1: Use drones to track disturbances over time.



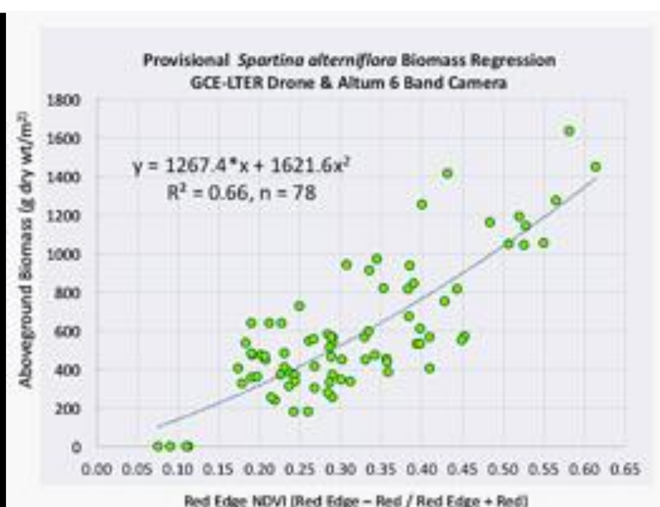




Fig. 8. Patterns of above-ground *Spartina alterniflora* biomass at the Airport Marsh site on Sapelo Island (left) based on relationship between NDVI from the GCE drone camera and ground-truthed clip plot data (above). Source: John Schalles. Corresponds to Objective 4B.2: Construct a scaled-up disturbance-scape.

## WHAT WERE THE KEY OUTCOMES AND ACCOMPLISHMENTS?

Key accomplishments this past year include research on allometric relationships in *Spartina* alterniflora, elevation gradients in salt marsh temperature, and the biogeochemical effects of saltwater intrusion in freshwater marshes.

### Allometric rules describe variation in salt marsh plant size and flowering

Allometry is the study of how an organism's shape changes as it grows. The best known allometric rule for plants is the -3/2 self-thinning law, which describes a well-known trade-off between size and density. Plants also trade off investment into growth vs. sexual reproduction, as described by life-history theory. Liu and Pennings (2019) took advantage of 16 years of GCE monitoring data to examine relationships between *Spartina alterniflora* height, shoot density, and flowering. Although plants in different landscape positions and years varied tremendously in size and shoot density, all this variation could be explained by a single allometric relationship consistent with the self-thinning law, but with a lower slope (Fig. 1a). The size at which plants had a 50% probability of flowering also differed among habitats, sites, and years, but was consistently smaller under conditions in which average plant size was smaller (Fig. 1b). Finally, reproductive biomass and the proportion of shoots flowering increased with increasing vegetative size (plant height or shoot biomass). Combining these two patterns, *S. alterniflora* plants growing at high density are small and reproduce at a smaller size than large plants growing at low density. Historically, ecologists have dealt with variation in size of marsh plants like *S. alterniflora* by dividing the marsh into different habitat types. This work shows that it may be possible to understand differences in growth across the marsh as simply different parts of the same allometric relationships, and thus provides a more synthetic understanding of salt marsh ecology. Moreover, because saltmarsh plants often occur in monospecific stands, they may serve as simple, model systems for studies of plant life history.

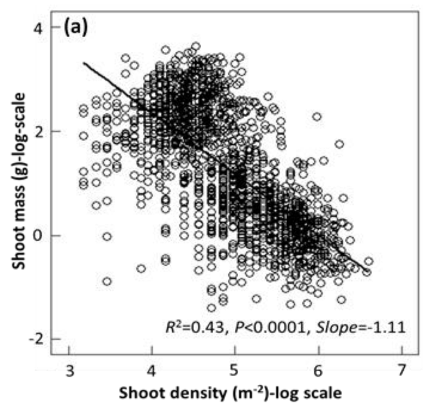
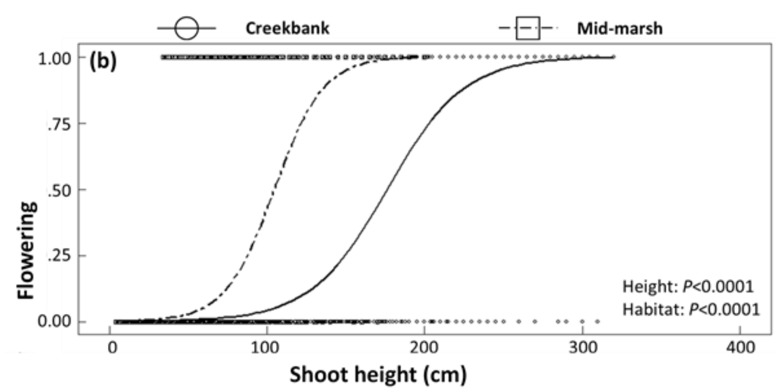



Fig. 1. (a) Relationships between shoot mass and shoot density, and (b) binomial regression models predicting the probability that an individual shoot of *Spartina alterniflora* will flower based on shoot height in creekbank versus mid-marsh habitats for all sites and years combined. Source: Liu and Pennings 2019. Corresponds to Year One Accomplishment: Allometric rules describe variation in salt marsh plant size and flowering.



**Elevation gradients drive microspatial differences in marsh temperature and spring green-up**

Subtle elevation differences in salt marshes are known to cause variation in tidal flooding, with numerous consequences for plant growth, salinity, and other properties. Alber and O'Connell (2019) discovered that elevation differences are also negatively correlated with soil temperature on the marsh platform, irrespective of tidal flooding. Field observations of soil temperature at 10 cm depth demonstrated that elevation increases of 0.5 m corresponded to decreases in average soil temperature of 0.9–1.7°C (Fig. 2). This was corroborated by satellite-based estimates of surface temperatures, which also decreased with increasing elevation. Similar satellite-based findings were also evident in a test marsh in Virginia, suggesting that this phenomenon occurs at broad scales. Biological reactions are temperature-dependent, and these observations indicate that metabolic processes will vary over short distances. This was borne out by our analyses of *Spartina alterniflora* phenology: O'Connell et al. (2019) found that fine-scale differences in elevation (and hence soil temperature) resulted in green-up onset 1.5–3 weeks earlier in the marsh interior, where elevations were lower than in the mid-marsh or at the channel edge. They suggested that the key driver of plant green-up was winter soil temperature, which has been increasing over the last 60 years. We are following up on these findings by measuring soil temperatures at all of the GCE core sites and planning a controlled experiment in which we will grow *Spartina* in treatments with different temperatures. These findings have broad implications for accurately estimating marsh metabolism and predicting how changes in temperature will affect future productivity and marsh sustainability.

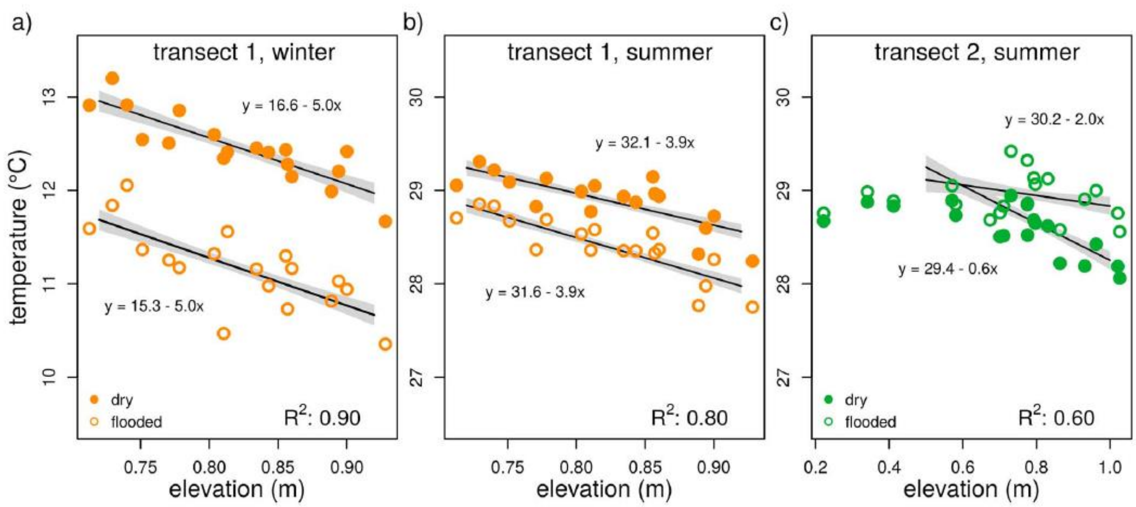



Fig. 2. Mean soil temperature versus elevation measured at 10-cm depth along (a) transect 1 during winter, (b) transect 1 during summer, and (c) transect 2 during summer in the GA study area. Dry (closed circles) and flooded (open circles) conditions are plotted separately. Linear models for flooded and dry observations >0.5 m are shown (solid lines) along with confidence intervals (dotted lines) and line equations. The $R^2$ for linear models of the form temperature = elevation * flood status is shown for each deployment. Source: Alber and O'Connell 2019. Corresponds to Year One Accomplishment: Elevation gradients drive microspatial differences in marsh temperature and spring green-up.

**Saltwater intrusion releases N from freshwater marshes**

Freshwater marshes process and store N. But what happens when they are inundated with salt water, as is expected as a result of sea level rise? Widney et al. (2019) synthesized the results of biogeochemical studies done as part of the GCE SALTEx experiment to assess the response of a tidal freshwater marsh to saltwater intrusion. They found that continuous additions of dilute seawater resulted in increased porewater chloride, sulfate, and sulfide concentrations and lower soil oxidation-reduction potential relative to untreated plots. The concentrations of inorganic N increased dramatically, with a 50-fold increase in porewater $NH_4$ and a 2-fold increase in $NO_3$ relative to untreated plots. At the same time, plant biomass decreased by 50–90%, with almost complete loss of above-ground macrophytes and a concurrent decrease in plant N storage (from 27 to 11 g N/m$^2$). These results, which are consistent with our original hypotheses (Fig. 3), suggest that sea level rise is likely to shift tidal freshwater marshes from a sink to a source of N by releasing ammonium-N from sorption sites, increasing nitrification and severely reducing N storage in macrophyte biomass. The SALTEx experimental manipulation is now complete and we are beginning to observe recovery of the system. However, these results suggest that one of the effects of sea level rise will be to release N and potentially exacerbate eutrophication of coastal waters.

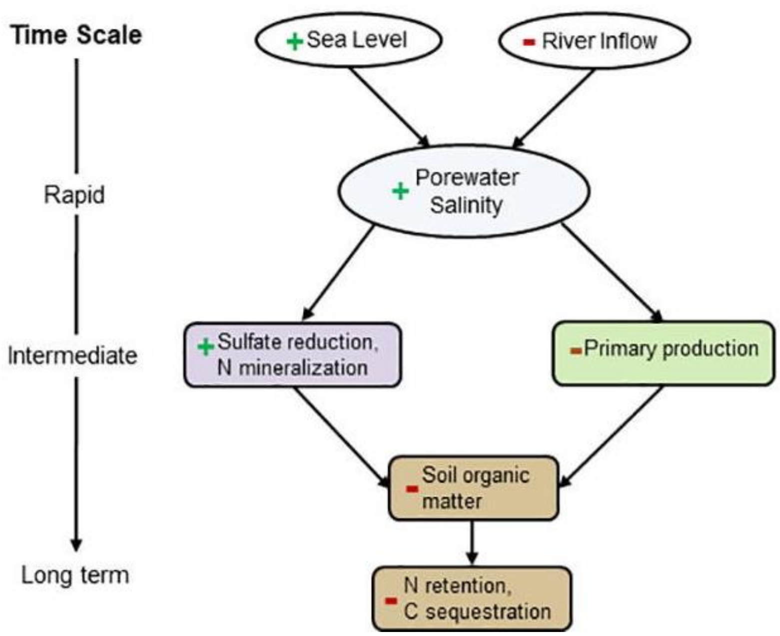



Fig. 3. Hypothesized responses of a tidal freshwater marsh to saltwater intrusion. Predicted changes are indicated as positive (+) or negative (-). Source: Widney et al. 2019. Corresponds to Year One Accomplishment: Saltwater intrusion releases N from freshwater marshes.

## 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. We used this year's Schoolyard workshop to conduct a retrospective analysis of the program and identify opportunities for improvement. Co-PD's M. Alber and S. Pennings worked with V. Butler (GCE Schoolyard Coordinator) and 14 teachers who had participated in the workshop at least once before (and most on multiple occasions) for half of each day, with the remaining time spent in the field. We performed a SWAT analysis, summarized all previous evaluations from both teachers and researchers, and discussed ways to facilitate the use of GCE data in the classroom. We found overwhelming evidence in the evaluations that working with scientists is a successful program model: participants identified the opportunity for hands-on immersive experiences in the field alongside the scientists as unique and the program's most valuable asset, with 96% of participant expressing a desire to return. Scientists working with educators found the time well-spent, and reported reflecting more deeply on the relevance and communication of their research as a result of the experience. We have subsequently revised the GCE Education and Outreach website to reflect the teacher's suggestions, and are planning to implement several additional tweaks this coming year (i.e. assigning returning teachers a task; producing "meet the scientist" videos for our website; better integrating our efforts with the Sapelo Island National Estuarine Research Reserve).

Undergraduate Education

14 undergraduate students from 8 institutions worked with GCE LTER scientists on projects this past year:

- Several student interns worked at the field site on Sapelo Island over the summer: 2 students from GA Southern worked with C. Hladik collecting GPS data on disturbances; 2 students from Creighton and 1 from Elon worked with J. Schalles on drone imagery and groundtruthing; 1 UH student worked with S. Pennings on creek disturbances; 1 from Savannah State worked with C. Hintz to sample DIC; 1 from GA Tech worked with C. Angelini on the disturbance project.
- 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: 2 students from IU worked in C. Craft's lab analyzing samples collected at SALTEX; 1 UGA student worked on the soil model with C. Meile; 1 UGA student worked with A. Spivak sampling pore water; 1 UGA student worked with C. Osenberg assembling biomimetic sensors.
- J. Schalles (Environmental Remote Sensing; Marine and Freshwater Ecology) and P. Medeiros (Introduction to the Marine Environment) use GCE data in their undergraduate courses.

Graduate Education

Graduate students are an integral part of the research at the GCE LTER. There are currently 26 students from 8 institutions engaged in LTER activities. Graduate students have also been authors on numerous publications that have resulted from this work. Other graduate activities include:

- S. Williams (UF student, Angelini) and J. Schalles organized a weekly brown bag seminar series for all GCE-LTER personnel at the UGA Marine Institute during summer 2019. Speakers included faculty, visiting scientists, GCE graduate students, and undergraduates. The seminar is an excellent mechanism for promoting awareness among the students of the full scope of the GCE program.
- Pennings ran a distributed graduate course in the fall of 2019. Taught live on the internet, this course focused on disturbance in coastal habitats. Lectures rotated among national experts and reached graduate students, faculty and resources managers from around the country.
- C. Hladik uses GCE data in her graduate course (Geospatial Techniques and Applications).

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.

- M. Alber attended the LTER Science Council Meeting in Puerto Rico in May 2019.
- GCE flux data was included in a cross-site effort to estimate GPP of tidal wetlands (Feagin et al., in press).
- M. Alber and C. Alexander are PIs on a cross-site coastal SEES grant to evaluate the vulnerability of salt marshes to rising sea levels being conducted at GCE, VCR, and PIE.
- C. Meile is involved in several cross-site efforts organized by the Pacific Northwest National Lab as part of the Worldwide Hydrobiogeochemistry Observation Network for Dynamic River Systems.
- S. Pennings and two undergraduates collected data for NutNet, which is a global synthesis of how nutrients affect plant biomass and diversity in more than 130 (mostly terrestrial) grassland sites. In addition to contributing to the network, the data will provide a better understanding of plant community ecology in tidal, brackish and fresh marshes at the GCE site. C. Angelini is representing GCE in the “Dragnet” effort, which is a similarly distributed experiment focused on the crossed effects of disturbance and nutrient fertilization.
- A. Spivak is part of the coastal carbon research coordination network (RCN) and participates in the soil carbon working group.
- The high-resolution digital camera on the GCE flux tower is part of the Phenocam network.
- The GCE flux tower is now part of the Ameriflux network.
- GCE actively contributes content to the LTER Network Office for inclusion on the LTER website and newsletters.

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:

- Continued to collaborate with BCO-DMO personnel to refine cross-listing of relevant GCE data sets to enhance discovery
- Continued to assist the CWT LTER 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 support and training on using the GCE Data Toolbox for MATLAB for processing and quality controlling sensor data at other LTER sites
- Continued to work with the EDI/LTER working group on transitioning the LTER Climate/Hydrography Database (ClimDE/HydroDB) to modern cyber infrastructure
- Continued to host 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 general public via our website; we work with coastal managers through the Georgia Coastal Research Council; we reach schoolchildren through our children's book and our comic book; we host two citizen scientist web applications; 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. We maintain restricted email lists and file exchange services to facilitate collaboration on several large projects (SALTEx, Flux Tower, High Marsh, PredEx, Modeling), and publish a weekly newsletter for GCE participants and other interested parties.

We hold training sessions on data and metadata submission at annual meetings and provide downloadable versions of presentation and sample data submission forms on-line as well as one-on-one consultation for participants. We also operate a Subversion (SVN) software code repository server for both IM and researcher-led software development projects.

We have developed dashboard displays for the eddy covariance flux tower, the HADCP, and our new tide gauge that enable researchers to identify potential problems with their instrumentation and view data plots in near real-time. GCE research activities have been generating drone imagery in increasingly higher volumes, and we have been developing procedures for downloading, backing-up, and distributing these data to researchers. This past year we joined a working group commissioned by the LTER IMC to develop best practices for archiving drone data in the LTER Data Portal.

Data and Metadata

We operate an integrated information management system 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 2017 we finished synthesizing annual data from our core plant, invertebrate, salinity and climate monitoring programs to generate long-term data sets covering the full period of record at our site, and in 2019 we updated these data sets to extend the record (i.e. 16-18 years). Data are standardized for comparison, and include basic gap-filling as practical 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 new data are available for release. As of Dec 2019, 604 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 612 catalog data sets are currently online, representing 19.1 million tabular data records in 921 files, plus 30 GB of raster GIS data. An additional 818 public data sets are also available through the GCE Data Portal. Collectively, we provide online access to over 29 million tabular data records from GCE research and affiliated monitoring programs as well as over 100 GB of GIS data, with an additional 18 million records being finalized for inclusion.

GCE data are downloaded by a diverse group of web visitors, including academic researchers, educators, and personnel from other LTER programs (Table 1). Data downloads increased dramatically in 2013 after synchronizing public data to the LTER Data Portal, and this trend continued in 2019. We also actively collaborate with staff of the Biological and Chemical Oceanography Data Management Office (BCO-DMO) in Woods Hole to include dynamic data links on the GCE project page at BCO-DMO, and we will continue to refine this approach to enhance discovery. 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 including publications, reports, research data, photographs and remote sensing imagery. Use of the GCE website has increased steadily since 2001, with over 1.2 million page views from 144,093 visitors between Sept 2018 and Dec 2019. Over 7.3 million page views from 1.7 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. This past year we migrated the GCE Schoolyard website to a WordPress platform while maintaining the functionality of the custom lesson pages and supplemental material. We will use this as a test case for migrating the GCE public facing website to a more generic platform in the coming year.

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 (over 4,000 public downloads to date). This software is broadly used at other LTER sites and was identified as a high priority for support by the Environmental Data Initiative.

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 143 affiliates from 19 universities, 6 federal agencies, and 7 state/regional organizations). The GCRC website (www.gcrc.uga.edu) has member biographies, project summaries, and research needs, and serves an important role as a conduit of coastal research information.

The GCRC completed several technical synthesis documents at the request of Georgia DNR over the past year, including a report evaluating high salinity events in the Altamaha River and a compilation of information regarding oil spill clean-up in salt marshes (in response to the Golden Ray incident).

Additional Activities

- We published a comic book, “The Adventures of Jacob the Technician”, written by S. Pennings.
- We continue to distribute the GCE children’s book, “And the Tide Comes In“ to environmental educators throughout the southeast.
- The GCE now hosts two citizen science web sites developed by S. Pennings and M. Garvey: "Scaling Up Marsh Science" and "Marsh Explorer” to align and identify marsh features in photo transects.
- M. Alber received the 2019 Margaret A. Davidson award for stewardship from the Coastal and Estuarine Research Federation in recognition of the GCRC and other science/management efforts.
- GCE continues to provide web hosting for the Georgia Coastal Research Council, as well as a searchable bibliographic database for the UGA Marine Institute.
- GCE scientists regularly give seminars and public presentations, contribute articles to newsletters and other popular publications, and talk to the media about coastal issues.

**GCE Dissemination of Results 2019**

Table 1. Public data file downloads for 2012-2019 and 2001-2019 by data set theme and user affiliation, excluding downloads by GCE participants and GCE-to-LNO/EDI file transfers.

| **Downloads by Theme** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2001-2019** |
|---|---|---|---|---|---|---|---|---|---|
| Algal Productivity | 3 | 49 | 430 | 329 | 232 | 74 | 71 | 40 | 1266 |
| Anthropology | 0 | 60 | 492 | 268 | 257 | 41 | 24 | 29 | 1171 |
| Aquatic Invertebrate Ecology | 74 | 445 | 9164 | 5212 | 4750 | 1379 | 1202 | 909 | 23881 |
| Bacterial Productivity | 1 | 293 | 4269 | 2094 | 2073 | 505 | 216 | 225 | 9914 |
| Botany | 0 | 0 | 0 | 49 | 69 | 31 | 15 | 5 | 178 |
| Chemistry | 0 | 33 | 444 | 425 | 277 | 90 | 70 | 60 | 1424 |
| Fungal Productivity | 0 | 49 | 748 | 351 | 351 | 101 | 32 | 47 | 1708 |
| General Nutrient Chemistry | 17 | 77 | 487 | 366 | 251 | 115 | 125 | 65 | 1689 |
| Geology | 3 | 32 | 440 | 396 | 273 | 181 | 491 | 87 | 1953 |
| Geospatial Analysis | 0 | 47 | 1064 | 632 | 646 | 206 | 173 | 94 | 2874 |
| Groundwater Hydrology | 0 | 0 | 0 | 0 | 0 | 26 | 32 | 29 | 87 |
| Hydrography/Hydrology | 1 | 27 | 221 | 502 | 154 | 121 | 87 | 50 | 1199 |
| Marsh Ecology | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 45 | 45 |
| Meteorology | 12 | 157 | 1499 | 1315 | 888 | 194 | 179 | 157 | 4594 |
| Microbiology | 0 | 0 | 0 | 0 | 0 | 25 | 34 | 16 | 75 |
| Multi-Disciplinary Study | 29 | 41 | 764 | 563 | 459 | 107 | 74 | 52 | 2097 |
| Organic Matter/Decomposition | 0 | 201 | 1707 | 1238 | 877 | 321 | 207 | 143 | 4865 |
| Physical Oceanography | 66 | 1631 | 18972 | 18906 | 11481 | 2468 | 2961 | 1794 | 59444 |
| Phytoplankton Productivity | 0 | 107 | 2297 | 1081 | 1014 | 310 | 152 | 128 | 5256 |
| Plant Ecology | 54 | 348 | 7117 | 5269 | 4297 | 1446 | 803 | 694 | 20403 |
| Population Ecology | 0 | 8 | 186 | 198 | 1322 | 427 | 288 | 133 | 2562 |
| Pore-water Chemistry | 11 | 44 | 518 | 499 | 341 | 308 | 109 | 72 | 1930 |
| Real-time Climate | 142 | 79 | 125 | 110 | 223 | 832 | 116 | 190 | 2260 |
| Terrestrial Insect Ecology | 63 | 155 | 2498 | 1252 | 1277 | 472 | 163 | 171 | 6396 |

| **Downloads by Affiliation** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** | **2001-2019** |
|---|---|---|---|---|---|---|---|---|---|
| Academic Research Program | 151 | 42 | 185 | 112 | 264 | 1018 | 110 | 296 | 3600 |
| Educational (K-12) | 4 | 7 | 10 | 26 | 41 | 5 | 1 | 14 | 200 |
| Educational (Post-secondary) | 126 | 26 | 78 | 44 | 8 | 34 | 81 | 76 | 1065 |
| Environmental Advocacy Group | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| Government Agency | 4 | 3 | 1 | 14 | 3 | 21 | 1 | 9 | 445 |
| International LTER Site | 11 | 1 | 2 | 0 | 0 | 1 | 0 | 0 | 47 |
| LTER Network Office (Metacat) | 51 | 9 | 4 | 38 | 1 | 0 | 884 | 126 | 2246 |
| LTER NIS | 0 | 3641 | 53045 | 40714 | 31073 | 8475 | 6453 | 4691 | 148192 |
| Other LTER Site | 29 | 29 | 3 | 4 | 4 | 134 | 5 | 5 | 407 |
| Other/Unspecified | 102 | 132 | 114 | 103 | 118 | 92 | 89 | 18 | 1119 |

| **Total Data Downloads** | **479** | **3890** | **53442** | **41055** | **31512** | **9780** | **7624** | **5235** | **157329** |
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### WHAT IS THE IMPACT ON THE DEVELOPMENT OF THE PRINCIPAL DISCIPLINE(S) OF THE PROJECT?

GCE scientists have published 24 journal articles and other one-time publications this past year. Papers cover a broad range of ecological topics, including disturbance (e.g. Sharp and Angelini 2019), habitat restoration (e.g. Li et al. 2019), plant ecology (Li and Pennings 2019), carbon dynamics (Spivak et al. 2019), and invasive species (e.g. Kinney et al. 2019). We have also made contributions in anthropology (e.g. Turck and Thompson 2019), organic chemistry (e.g. Letourneau and Medeiros 2019), remote sensing (e.g. Zhang et al. 2019), and economics (e.g. Vinent et al. 2019). A complete list of publications can be found at http://gce-lter.marsci.uga.edu/public/app/biblio_query.asp. Key accomplishments this past year include research on plant allometry, microspatial gradients in salt marshes, and nutrient release due to saltwater intrusion.

### 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 13 undergraduate students, 28 graduate students and 2 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 Brazil (Sao Paulo State University), the Netherlands (Radbound University), China (East China Normal University, Fudan University, Xiamen University, Fujian University), and the United Kingdom (Swansea University).

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

The GCE has installed an extensive boardwalk system that provide 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 20 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 Doboy Sound, 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 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, four Kawasaki mules and one truck 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. In 2019 we continued to maintain and operate these systems, updating software and expanding storage to accommodate new data collection activities and for hosting more imagery for leveraged citizen science web applications (Scaling Up Marsh Science and Marsh Explorer).

### 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 4200 registered users (565 since 2016) and is actively used at 9 other LTER sites for sensor data harvesting, data analysis or general data processing tasks. 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 2019 we completed implementation of a web-based metadata and data submission applications to replace legacy spreadsheet data submission templates and MS Access management forms. We have deployed web-based data entry forms to facilitate the speed and efficiency at which sampling data is reported for several high-frequency core monitoring efforts (e.g. monthly water quality and vegetation sampling). These forms allow us to automate initial QA/QC of the data when it is entered, and ensures the data are in consistent formats for further processing and archiving. We plan to expand this to include additional high-frequency core monitoring efforts.

### 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 1.7 million distinct web visits have been recorded since 2001, with over 1.2 million page views from 144,093 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), which works to promote science-based management of Georgia coastal resources by facilitating information transfer between scientists and managers.

## Products and Publications

Book Chapters

Turck, J.A. and Thompson, V.D. 2019. Human-Environmental Dynamics of the Georgia Coast. In: Reeder-Myers, L., Turck, J. and Rick, T. (editors). The Archaeology of Human-Environmental Dynamics on the North American Atlantic Coast. University Press of Florida, Gainesville, GL.

Conference Papers and Presentations

Alber, M. 2018. Presentation: Sustainability of salt marshes: still a realistic goal? NSF LTER Science Symposium, Alexandria, VA.

Hawman, P., Mishra, D., Cotten, D.L., O'Connell, J., Mao, L. and Narron, C. 2019. Poster: Salt marsh light use efficiency and gross primary production in response to environmental conditions. Coastal and Estuarine Research Federation (CERF), 2019, Mobile, Alabama.

Hawman, P., Mishra, D., Cotten, D.L., O'Connell, J., Narron, C. and Mao, L. 2019. Presentation: Salt marsh light use efficiency and gross primary productivity in response to environmental conditions. Disturbance Impacts on Ecological and Biogeochemical Processes in Coastal Wetlands I. American Geophysical Union Fall Meeting 2019, December 12, 2019, San Francisco, California.

Hawman, P., Mishra, D., O'Connell, J., Cotten, D.L., Narron, C. and Mao, L. 2019. Presentation: Salt marsh light use efficiency and gross primary production in response to environmental conditions. Carbon fluxes in coastal systems. CERF Biennial Conference 2019, November 5, 2019, Mobile, Alabama.

Letourneau, M.L., Schaefer, S.C., Alber, M. and Medeiros, P.M. 2019. Poster: Spatio-temporal changes in dissolved organic matter composition and biodegradation throughout the GCE-LTER domain. 25th Coastal and Estuarine Research Federation (CERF) Conference, November 2019, Mobile, AL.

Mao, L., Mishra, D., Cotten, D.L., O'Connell, J., Narron, C. and Hawman, P. 2019. Poster: Analyzing chlorophyll fluorescence in Juncus roemerianus by Pulse Amplitude Modulated (PAM) fluorometer at different plant heights. International Geoscience and Remote Sensing Society, 2019, Yokohama, Japan.

Martineac, R.P., Craft, C.B. and Medeiros, P.M. 2019. Poster: Effects of simulated seawater intrusion on soil biomarkers distribution in a tidal freshwater marsh wetland. 25th Coastal and Estuarine Research Federation (CERF) Conference, November 2019, Mobile, AL.

Medeiros, P.M. 2019. Presentation: What controls dissolved organic matter composition in marsh-dominated estuaries? Southeastern Regional Meeting of the American Chemical Society (SERMACS), October 2019, Savannah, GA.

Medeiros, P.M. and Letourneau, M.L. 2019. Poster: Seasonal changes in dissolved organic matter composition in the Altamaha River, Georgia, USA. ASLO 2019 Aquatic Sciences Meeting, February 2019, San Juan, PR.

Meile, C. 2019. Presentation: The breathing coastal zone: dynamics in Southeast US mars. Mini-Symposium, 22. November 2019, Zuerich, Switzerland.

Meile, C., Schalles, J.F., Peterson, R.N., O'Donnell, J., Bice, K., Medeiros, P.M., Di Iorio, D., Hopkinson, C.S., Joye, S.B., Stegen, J., Goldman, A., Thomle, J. and Danczak, R. 2019. Presentation: Flow and short-

and long-term carbon dynamics at tidally impacted coastal interfaces in the SE USA. Goldschmidt Conference, August 18-23, 2019, Barcelona.

Mishra, D., Cotten, D.L., O'Connell, J., Mao, L., Narron, C. and Hawman, P. 2019. Poster: Salt marsh light use efficiency and gross primary productivity in response to environmental conditions. American Geophysical Union (AGU), 2019, San Francisco, CA.

O'Connell, J. 2019. Presentation: Patterns of Spartina alterniflora phenology and belowground biomass. Departmental Seminar, 2019, Athens, GA.

O'Connell, J. 2019. Presentation: Patterns of Spartina alterniflora phenology and belowground biomass. Departmental Seminar, 2019, Lafayette, LA.

O'Connell, J. and Alber, M. 2019. Poster: Elevation drives gradients in surface soil temperature within salt marshes. Coastal and Estuarine Research Federation (CERF), 2019, Mobile, Alabama.

O'Connell, J., Alber, M., Mishra, D. and Byrd, K.B. 2018. Presentation: Landsat models of Spartina alterniflora belowground biomass in coastal marshes. Ecological Society of America, New Orleans, LA.

Schalles, J.F., O'Donnell, J., Nealy, N., Mizoguchi, T. and Hladik, C.M. 2018. Presentation: Multidecadal biomass declines and controlling variables for the keystone salt marsh species, Spartina alterniflora, in coastal Georgia . SS86: Connecting the Dots – Signals of Global Change Effects in Freshwater and Marine Ecosystems. ASLO 2018 Summer Meeting, June 15, 2018, Victoria, British Columbia, BC.

Sheldon, W.M. Jr. 2019. Presentation: Using the GCE Data Toolbox to automate environmental data processing and produce EML-described data packages for the EDI repository. Environmental Data Initiative Webinar Series, 08-Jan-2019, Madison, Wisconsin.

<u>Journals</u>

Alber, M. and O'Connell, J. 2019. Elevation drives gradients in surface soil temperature within salt marshes. Geophysical Research Letters. 46:5313-5322. (DOI: https://doi.org/10.1029/2019GL082374)

Chalifour, B., Hoogveld, J., Derksen-Hooijberg, M., Harris, K., Uruena, J., Sawyer, W., van der Heide, T. and Angelini, C. 2019. Drought alters the spatial distribution, grazing patterns, and radula morphology of a fungal-farming salt marsh snail. Marine Ecology Progress Series. 620:1-13. (DOI: 10.3354/meps12976)

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Dugan, J., Emery, K., Alber, M., Alexander, C.R. Jr., Byers, J., Gehman, A., McLenaghan, N.A. and Sojka, S. 2018. Generalizing Ecological Effects of Shoreline Armoring Across Soft Sediment Environments. Estuaries and Coasts. 41(1):180-196. (DOI: 10.1007/s12237-017-0254-x)

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Noormets, A., Mitra, B., Jaimes, A., Hinson, A.L., Bergamaschi, B. and King, J.S. 2020. Tidal wetland Gross Primary Production across the continental United States, 2000-2019. Global Biogeochemical Cycles (in press)

Fischmann, H., Crotty, S.M. and Angelini, C. 2019. Optimizing coastal restoration with the stress gradient hypothesis. Proceedings of the Royal Society B. 286(1917):10. (DOI: 10.1098/rspb.2019.1978)

He, Q. and Silliman, B.R. 2019. Climate Change, Human Impacts, and Coastal Ecosystems in the Anthropocene. Current Biology. 29(19):1021-1035. (DOI: 10.1016/j.cub.2019.08.042)

Herbert, E., Schubauer-Berigan, J.P. and Craft, C.B. 2020. Effects of ten years of nitrogen and phosphorus fertilization on carbon and nutrient cycling in a tidal freshwater marsh. Limnology and Oceanography. (in press)

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Letourneau, M.L. and Medeiros, P.M. 2019. Dissolved organic matter composition in a marsh-dominated estuary: Response to seasonal forcing and to the passage of a hurricane. Journal of Geophysical Research: Biogeosciences. 124:1545-1559. (DOI: 10.1029/2018JG004982)

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<u>Websites</u>

*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.