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FCE III Year Four Annual Report for NSF Award DBE- 1237517 (2016)

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FLORIDA COASTAL EVERGLADES LTER
FCE III YEAR FOUR ANNUAL REPORT
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Accomplishments

Major goals of the project

The goal of the Florida Coastal Everglades Long Term Ecological Research (FCE LTER) program is to conduct long-term studies to understand how climate change and resource management decisions interact with biological processes to modify coastal landscapes. Our focus is on the oligohaline ecotone of the Florida Everglades, integrating marine and freshwater influences. Long-term data show that the ecotone is highly sensitive to increasing marine pressures, driven over longer-time scales by sea level rise (SLR) and over shorter-time scales by storms and tidal exchanges. Freshwater flow, controlled by climate variation and upstream allocation decisions, interacts with marine pressures to affect water supplies to the ecotone. FCE is in its third phase of research (FCE III), focused on linking long-term dynamics in freshwater and marine water supplies to transformations in the ecotones of two major drainages, Shark River Slough (SRS) and the TS/Ph/Panhandle (TS/Ph).

The overarching goals of this reporting year included: (1) continue to constrain the sources of variance in the short and long-term dynamics of water supply to the ecotone, and socioecological and hydrological politics of freshwater restoration in the face of SLR, (2) continued collection of long-term data across the five core areas and integration with results from mechanistic experiments and spatial scaling studies to address the causes and consequences of long-term dynamics of the oligohaline ecotone relative to changes in fresh and marine water supplies, (3) continue studies of the legacies of climate and disturbance as drivers of change through alterations in ecotone salinity, phosphorus (P) supplies and inundation, (4) conduct data-model synthesis linking climate and disturbance legacies to future projections, (5) complete FCE synthesis book chapters for submission to publisher and initiate new data-model synthesis activities, (6) continue updates of FCE data to the Network Information System (PASTA), (7) integrate core findings through LTER network-wide collaborations, (8) advance education (FCE Schoolyard) and outreach activities through expanded partnerships directed toward goals of the Strategic Implementation Plan for LTER.

FCE III research is conducted within the context of four major working groups (WG): Biogeochemical Cycling, Primary Production, Organic Matter (OM) Dynamics, and Trophic Dynamics. Integration is accomplished through four Cross-Cutting Themes (CCT): Hydrology and Water Policy, Carbon (C) Dynamics, Climate and Disturbance Legacies, and Modeling and Scenarios. Further synthesis is being driven by our contributions to a holistic synthesis book to be completed in the coming months. Here, we report progress integrating across each of these categories relative to the themes set in our proposal using data from long-term studies and experiments, and addressing the feedback from our mid-term review team.

Major Activities

Hydrology and Water Policy: Our activities address how climate change and sea level rise (SLR) interact with water management practices to control hydrologic conditions in the oligohaline ecotone through two hypotheses: (1) variable inflows from upstream sources, SLR, and storm surge interact to alter surface water residence time, salinity, and groundwater intrusion in the oligohaline ecotone, and (2) stakeholder uncertainties over SLR will increase conflicts over Everglades restoration implementation and will affect freshwater delivery to the oligohaline ecotone. Activities addressing the first hypothesis included analysis of long-term (15 years) ground-based and satellite observations of hydrology and geochemistry to determine how SLR has influenced water levels and water chemistry of the oligohaline ecotone. We also addressed this hypothesis using the variable density groundwater flow model SUTRA to simulate seawater intrusion in TS/Ph, and via creation of water and chemical budgets for two brackish drainages of the southern Everglades. Activities addressing the second hypothesis included ethnographic field research in the Glades towns, northern Lake Okeechobee Watershed, and St. Lucie Estuary (March and May 2016), 65 semi-structured interviews conducted over the summers of 2014 and 2016 with key stakeholders (farmers, state and federal officials, and agricultural researchers) involved in Everglades water quality restoration, and finally by using hydrodynamic models to determine water flow patterns related to urban growth and climate change scenarios.

Carbon Dynamics: We addressed how changing freshwater inflows, tidal and storm cycles, and climate patterns influence the magnitude, rates, and pathways of C sequestration, loss, storage and transport across the land-water continuum through two hypotheses: (1) temporal variability in C cycling reflects the presses and pulses of the balance of marine and freshwater supplies, and (2) landscape patterns of C reveal legacies of this balance. We continue to address the first by coupling long-term data with field and laboratory experiments to address mechanisms, and the second through scaling plot-based long term measurements using remote imagery (an approach reaffirmed by our mid-term review feedback).

Long-term data collection and synthesis. Following the advice of our mid-term review team, we are driving synthesis of our long-term data through the production of 10 papers that synthesize 15 years of FCE biogeochemical, primary production, organic matter and consumer research. The biogeochemical syntheses test the hypothesis that surface water, porewater, plant, and soil C, nitrogen (N), and P dynamics along freshwater-ecotone-marine gradients in SRS and TS/Ph express the balance of freshwater and marine supplies (through surface and groundwater) in space and time. The synthesis of our primary production data builds on the biogeochemical analyses, integrating long-term hydrological and biogeochemical data to determine how water balance regulates plant composition and primary productivity. In addition, we are examining the interaction of a changing water balance on the quality and fate of C through synthesis of long-term organic matter quality and quality data (in water and soils), and continued measurements of C dioxide efflux to surface water along known gradients of soil P availability. Finally, we are examining the importance of this balance to the dependency of aquatic consumers on detrital resources, and on the spatiotemporal patterns of consumer movement and community structure through continued data collection, production of a special issue in the journal *Ecosphere* on the interacting effect of cold spells on these dynamics, and another synthesis paper on consequences to movement. In response to reviewer comments we enhanced efforts to document linkages in food webs of the estuary and expanded our long term studies of consumer dynamics in TS/Ph.

Experiments. To understand the mechanisms of how the balance of fresh and marine water supplies influence the C balance through interacting effects on P availability, salinity and water residence time we have continued several scales of experiments: (a) a mesocosm experiment manipulating P and mangrove leaf loss to quantify above- and belowground changes in C storage; (b) field experiments manipulating surface and porewater salinity in brackish and freshwater marshes to mimic saltwater intrusion and nitrogen and P additions in seagrass beds; (c) mesocosm experiments manipulating surface and porewater salinity, inundation level, and P loading on plant-soil and periphyton C loss from freshwater and brackish marshes; (d) a mesocosm experiment testing subsidy-stress gradients in salinity and P concentrations on freshwater peat soil C loss; (e) experiments to understand the impacts of increased freshwater flow on food webs. Through these experiments we are evaluating the role of microbially-mediated C and nutrient cycling on wetland soil and plant communities in a subsidy-stress theoretical framework. We also planned a special session at the International LTER meeting to integrate discoveries about the ecosystem consequences of saltwater intrusion across manipulative experiments along the U.S. Atlantic coast.

Landscape scaling. In addition to the aforementioned syntheses of spatio-temporal patterns of biophysical change at our long term research sites arrayed along long landscape gradients, we also completed a first landscape-scale map of coastal ecotone vegetation to determine how plant composition and primary productivity express legacies of fresh and marine water supplies. In response to mid-term review feedback, we also began an assessment of spatial representativeness of sites along our transects using these remotely sensed data. These data are being utilized in a global blue C assessment (NASA funding).

Climate and Disturbance Legacies: We hypothesize that changes in land-use and water allocation in the FCE have hydrodynamic consequences in the Everglades landscape that explain changes in the oligohaline ecotone. We investigated these legacies broadly using biophysical and integrated socio-ecological approaches including: (1) long term response of marl prairie vegetation to the climate-driven and management-induced hydrologic changes along the marl prairie-slough gradient that have different hydrologic histories; (2) biogeochemical and productivity legacies of SLR and tropical storms in in a press-pulse framework; (3) the legacies of extreme cold episodes on the responses of temperate and tropical species to changing fresh and marine water supplies, and (4) ongoing evaluation of the economic legacies of restoration decisions in retrospective and scenario analyses of the effects of decisions on ecosystem services.

Modeling and Scenarios: Modeling efforts are ongoing throughout all FCE LTER working groups and themes. An integrative goal is to determine the scenario of water distribution and climate change that will maximize socio-economic and environmental sustainability of the Everglades by developing a framework of plausible climate scenarios for use in FCE modeling efforts, to facilitate cross-disciplinary and cross-scale comparisons. To accomplish this, we have collaborated with experts with explicit expertise in land- and water-use and climate-change trends in South Florida. In addition we have advanced three classes of models: geochemical, hydrodynamic, and landscape. We made progress on geochemical and hydrodynamic modeling efforts to better understand the geochemistry, transport, and fate of dissolved constituents, with a focus on P and C, in the mangrove ecotone of the Everglades. Such efforts allowed us to undertake preliminary simulations using the Everglades Landscape Model (ELM v2.8.6) with a focus on Everglades National Park in 2060. Current models are used to identify data-gaps in long-term datasets, which we then take steps to fill.

Specific Objectives

Hydrology and Water Policy: Specific objectives of this past year were directly related to the hypotheses and included: 1) understanding how climate change and SLR interact with water management practices to control hydrologic conditions in the oligohaline ecotone, and 2) understanding how stakeholder uncertainties over SLR will increase conflicts over Everglades restoration implementation and will affect freshwater delivery to the oligohaline ecotone. We planned to analyze long-term ground-based and satellite observations of hydrology and geochemistry to understand change in the oligohaline ecotone, improve our ability to track and understand implications for hydrologic change in the TS/Ph ecotone, and complete our ethnographic and stakeholder surveys. An integrative goal included using hydrodynamic models to determine water flow patterns related to urban growth and climate change scenarios.

Carbon Dynamics: Specific objectives of our C Dynamics theme were directed toward two hypotheses: (1) temporal variability in C cycling reflects the presses and pulses of the balance of marine and freshwater supplies, and (2) landscape patterns of C reveal legacies of this balance. We planned continued long term data collection and coupled with field experiments to address the patterns and causes for change, and analysis of our ability to detect change at different scales by combining interpretations from long term measurements with those provided via remote imagery.

Long-term data collection and synthesis. We continue to collect and synthesize over 15 years of FCE biogeochemical, primary production, organic matter and consumer data to determine how the balance of fresh and marine water supplies influence components of the C cycle. We are finishing several collaborative synthesis papers to this end. A specific objective of our primary production group was to identify salinity threshold responses in long-term primary production along our transects (SRS, TS/Ph). We explicitly focused synoptic sampling to align with developing datasets that link variability in hydrology and salinity with vegetation structure and aboveground biomass. We also intended to use a similar approach to untangle the interconnected environmental drivers that control DOC export and C dioxide efflux at monthly and annual scales. We also planned to complete our paleoecological work to measure 100-year rates of organic C burial along this gradient on the SRS in addition to our synoptic surveys of bulk soil properties to evaluate connections between long-term vegetation patterns (above-and belowground), soil C storage, and soil C burial rates in mangrove sites along the SRS and TS/Ph transects. Our consumer research focused on synthesizing the legacies of extreme events on consumer populations, movements, and trophic interactions, extending long-term datasets to determine the importance of freshwater delivery to connectivity between marsh and estuarine systems through movements and trophic relationships of fish and other large consumer, synthesizing datasets to determine patterns of niche overlap and separation among the top predator guild, and extending long-term datasets on the movements and trophic interactions of large estuarine predators to predict impacts of freshwater delivery and SLR on their role in connecting ecosystems.

Experiments. To understand the mechanisms of how the balance of fresh and marine water supplies influence the C balance through interacting effects on P availability, salinity and water residence time we planned to continue our experiments, including evaluation of how pulses of salinity and P associated with storm surges affect C losses from freshwater wetlands. We also planned to complete mesocosm (salinity x inundation and salinity x P) and field (salinity) experiments with freshwater and brackish plant-soil peats. We finished synthesis of experiments completed in 2013 and REU components in 2015 and 2016. A special emphasis this year was on synthesizing results from our field and outdoor laboratory mesocosm experiments on the response of *Cladium* aboveground biomass and net ecosystem exchange to salinity, P and hydrology in freshwater and brackish water peat marshes. We will continue experimentally evaluating the impact of freshwater releases on the role of detritus in Everglades food webs, including effects on top predators in marsh habitats where freshwater flow is being experimentally manipulated.

Landscape scaling. In addition to the aforementioned syntheses of spatio-temporal patterns of biophysical change at our long term research sites arrayed along long landscape gradients, we planned to complete a first generation landscape-scale map of coastal ecotone vegetation to determine how plant composition and primary productivity express legacies of fresh and marine water supplies. In response to mid-term review feedback, we also planned an assessment of spatial representativeness of sites along our transects using these remotely sensed data. We planned to submit several proposals to increase our landscape scaling research to address these questions about transect representativeness.

Climate and Disturbance Legacies: Specific focus was on establishing the relationship between land-use change and ecosystem variability at the landscape scale. To create a baseline from which to better link landscape structure, connectedness, and boundaries with land-water management dynamics, we planned to evaluate paleoclimatological data. Lastly, we aimed to achieve a better understanding of human dimensions of the ecosystem by examining: a) institutions of landscape change; b) institutions of water management; and c) geographic patterns of environmental attitudes among the South Florida population.

Scenarios and Modeling: We had four main objectives for the preceding year: 1) arrive at a framework of climate scenarios suitable for a range of FCE modeling efforts; 2) acquire data necessary as input for models (i.e., by conducting laboratory experiments, bathymetric and remote sensing surveys, and a range of other data dependent on the multiple model requirements); 3) construct/refine geochemical, hydrodynamic, and ecological models that will in turn be quantitatively evaluated for model skill, with publishing plans in the coming year; and finally 4) use the multi-models to explore hypotheses of hydro-ecological dynamics in the ecotone.

Significant results

Hydrology and Water Policy: Long-term data show that the rate of SLR has increased in South Florida from an average rate of 3 to 9 mm/yr since 2006, increasing the frequency of coastal flooding (Wdowinski et al., 2016). At the same time, our long term studies of hydrology and geochemistry in the ecotone are showing that despite recent efforts to add fresh water to TS/Ph, the availability of surface water, its residence time and chemistry is still dominated by rainfall and evapotranspiration (Sandoval et al., 2016). In SRS, tidal inundation of the mangrove forest was found to result in a large exchange of constituents (CO_2, radon) between the mangrove peat and the overlying surface water and that the release of constituents, at least for radon, was greater in the dry season (Smith et al., 2016; Troxler et al., 2015) (Figure 1). The transfer of gases from SRS to the atmosphere was estimated at 3.3 ± 0.2 cm h^{-1} using a He/SF_6 dual tracer technique, with a water residence time of 16.5 ± 2.0 days (Ho et al., 2016).

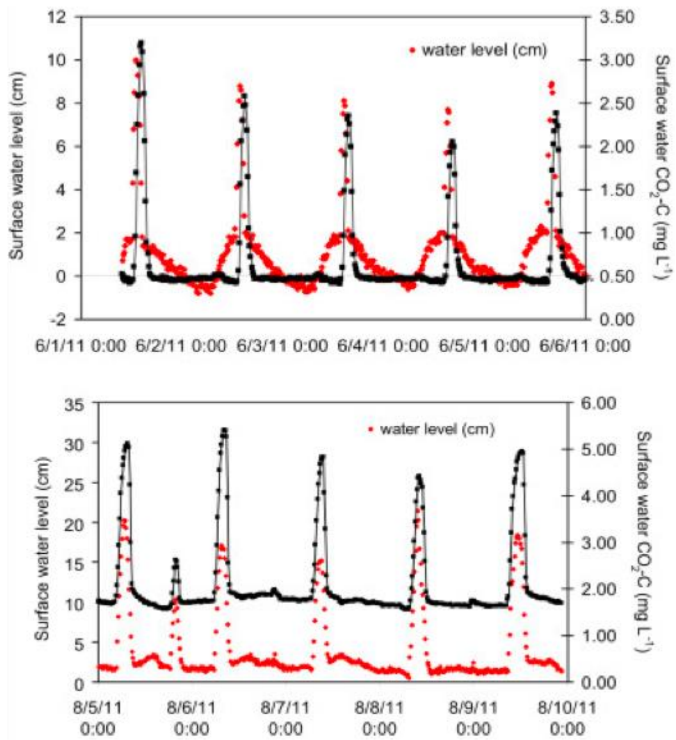

Figure 1. Dissolved CO_2 over tidal flood waters at SRS-6 during two periods: June 1-6, 2011 and Aug. 5-10, 2011 (Troxler et al., 2015).

Our studies of stakeholder engagement in Everglades restoration indicate that farm-level water quality monitoring is key to effective implementation of best management practices (BMPs) across the Everglades Agricultural Area (EAA), which is necessary for restoring clean freshwater flows. While the prospect of penalties affects BMP awareness, collaboration and exchanges among stakeholder groups has stabilized BMP implementation, which feeds into the state's regulatory approach. Remarkably, a majority of interviewed farmers perceived regulations as a benefit rather than (solely) a burden to farm production. Initial analysis of 2001-2016 data showed that 139 and 34 of the EAA basins were net reducers and contributors of P loads, respectively. Despite improvements in water quality, environmental groups continue to litigate and advocate for more stringent regulation of P "hot spots." Our interviews point to substantial interaction among farmers, regulators, and researchers, but very little interaction between farmers and environmentalists, with deep and continuing differences regarding appropriate land use practices in the EAA, and fundamentally opposed sensitivities to the (restoration) benefits vs. (social and livelihood) costs of additional farmland to wetland conversions.

Carbon Dynamics: *Long-term data collection and synthesis.* To understand the role of P in driving C dynamics, we synthesized long-term biogeochemical trends across our FCE domain, finding surface water P has dramatically increased at brackish water sites along SRS (Figure 2) and has steadily increased at freshwater sites along TS/Ph from 2000 to 2015 (Figure 3).

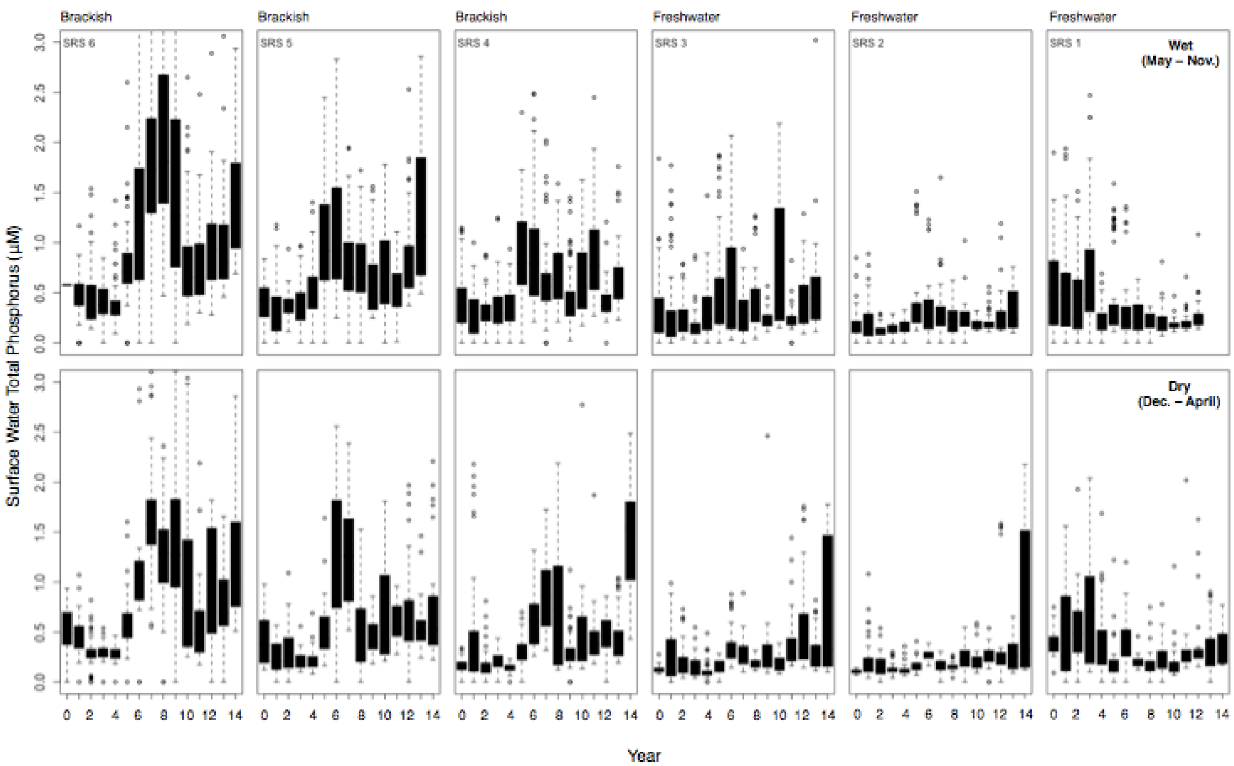

Figure 2. Long-term patterns of total phosphorus in surface water during along brackish and freshwater gradients of Shark River Slough of the Florida Coastal Everglades LTER, Everglades National Park, Florida. Histograms represent seasonal (wet and dry) means and variances (95% CIs) from 2000-2014.

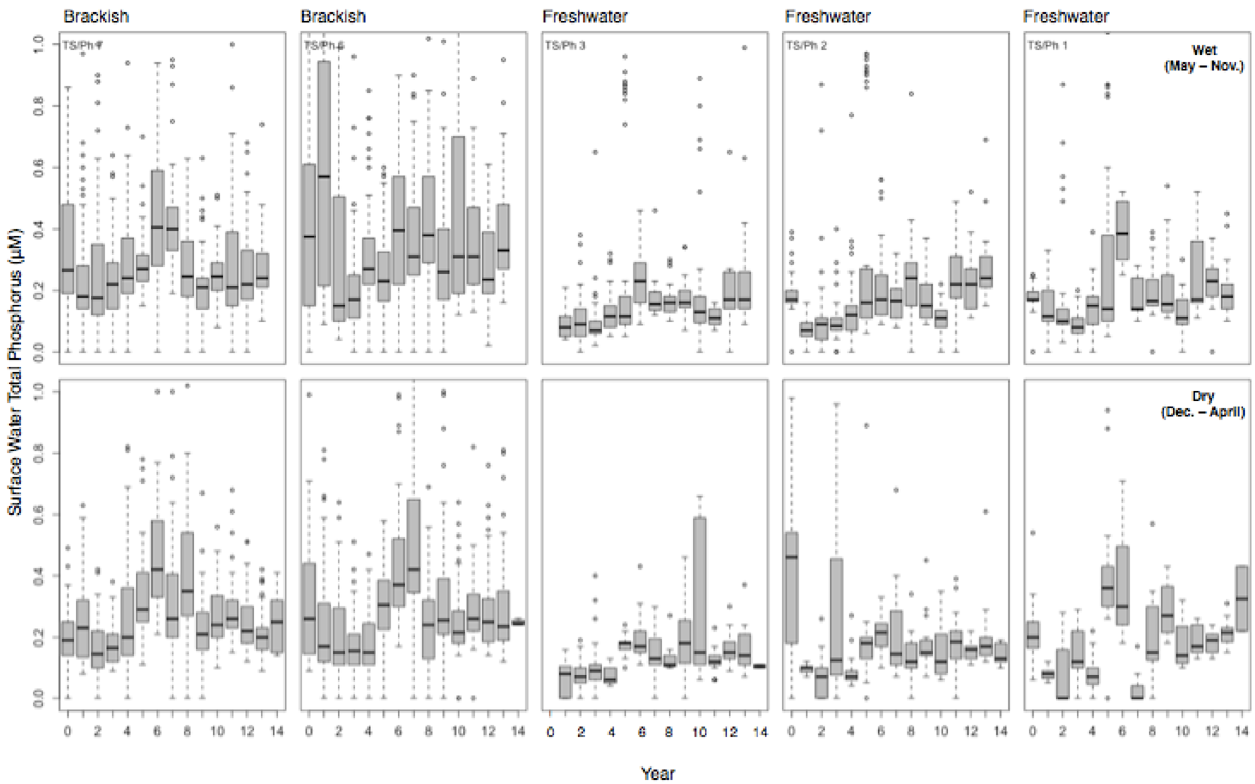

Figure 3. Long-term patterns of total phosphorus in surface water during along brackish and freshwater gradients of Taylor Slough/Panhandle of the Florida Coastal Everglades LTER, Everglades National Park, Florida. Histograms represent seasonal (wet and dry) means and variances (95% CIs) from 2000-2014.

In addition to reflecting legacies of storm events and tidal pulsing, P availability in surface water of freshwater and ecotone marshes varies as a function of rain-driven surface water volume and P adsorption-desorption of in cation-rich groundwater (Flower et al. 2016, Sandoval et al. 2016). Along the SRS ecotone, we have well-constrained the contributions of below-canopy components to C efflux at SRS (Troxler et al., 2015), and we will continue to measure CO_2 efflux to surface water. The synoptic survey of bulk soil properties are helping to describe the relationship between hydroperiod and soil oxidation state (Julian et al. 2016) and the projected "sink or swim" response of coastal wetlands to accelerated SLR (Morris et al. 2016). Mean mangrove C storage was 3.9 times higher in SRS than in TS/Ph (72.9 vs. 18.7 Mg C ha^{-1}, respectively), with greater C allocation to belowground in scrub mangroves (75%) relative to riverine mangroves (20%). Mean total ecosystem C storage ranged from 142.2 to 254.8 Mg C ha^{-1}: the vegetation C pool accounted for 29 and. 16% and soil C pools represented the larger fraction of C storage in each basin (84 vs 71%, SRS and TS/Ph, respectively). Long-term (^{137}Cs) soil annual accretion rates were twice higher in SRS than TS/Ph (0.29 vs. 0.16 cm yr^{-1}), thus controlling a wide range of soil C burial rates ranging from 1.31 to 0.62 Mg ha yr^{-1} (SRS, TS/Ph, respectively). In general, the lowest rates occur at the oligohaline ecotone (e.g. SRS-4) and near the Gulf of Mexico (Breithaupt et al., 2012). DOC fluxes were determined to be primarily controlled by hydrology but also by seasonality and long-term climate patterns and episodic weather events (Table 1; Regier et al., 2016).

Scenario	RF	Inflow	Salinity	% Change*
+RF+ET	+10%	+22%	0	+7%
+RF+ET+1	+10%	+22%	+1	-5%
+RF+ET+3	+10%	+22%	+5	-42%
+RF+ET+5	+10%	+22%	+10	-77%
-RF+ET	-10%	-58%	0	-13%
-RF+ET+1	-10%	-58%	+1	-24%
-RF+ET+3	-10%	-58%	+5	-61%
-RF+ET+5	-10%	-58%	+10	-96%

+RF+ET: 10% increased RF; *-RF+ET*: 10% decreased RF

Table 1. Changes in predictor variables for modeling DOC flux response to climate change scenarios

Experiments. Manipulations of salinity and P concentrations in fresh and brackish water wetlands suggest that elevated salinity is a stress to soil and plant communities which can be offset by the addition of P (Chambers et al., 2015 and Figure 4). In brackish water mangrove peat soils, saltwater inundation reduces C fluxes, microbial enzyme activities, and bacteria abundances (Chambers et al. 2015, 2016). In seagrass beds, P enrichment increases seagrass biomass (aboveground and belowground), and soil C storage despite nutrient limitation (Armitage and Fourqueran 2016, Howard et al. 2016). We also tested whether increasing freshwater flow would change the quantity and quality of food and increase the contribution of autotrophic production to food webs. Autotrophic production increased with experimental freshwater inputs, increasing P input and quantity of palatable algae, although we are still determining the impact on diet quality and consumer growth.

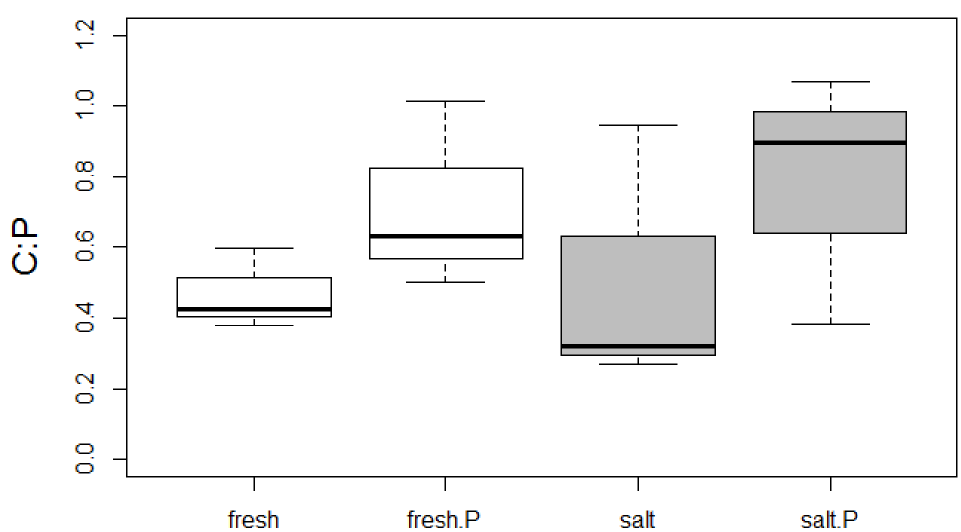

Figure 4. Carbon (C) and phosphorus (P) soil microbial extracellular enzyme activities represented as the C:P ratio of enzymes associated with C and P acquisition in freshwater sawgrass peat soils exposed to elevated salinity and P (2 × 2 factorial design). Addition of P increases C:P ratio of enzymes towards the global average of 1.

Landscape scaling. Our first generation coastal ecotone vegetation map leverages recent work by Gann et al., (2015) by applying fine-scale mapping and LiDAR data to identify fine-scale vegetation features that can be used for change detection to evaluate how landscape patterns express legacies in marine and freshwater supplies. We received two new NASA awards to expand this research.

Climate and Disturbance Legacies: In addition to changes driven by long-term changes in the balance of marine and freshwater supplies, legacies of cold snap events were evident across ecosystem components. Malone and colleagues (under review) discovered that cold events enhanced photosynthetic capacity in freshwater marshes while it declined in mangrove forests. Our consumer research has shown that cold spells drive predictable community change in the subtropics by altering ratios of coexisting tropical and temperate species (Boucek et al. 2016; Rehage et al. 2016, Rehage and Blanchard 2016, Stevens et al. 2016; Figure 5), restructuring recreational fisheries (Santos et al. 2016), and impacting top predators (Matich and Heithaus 2014).

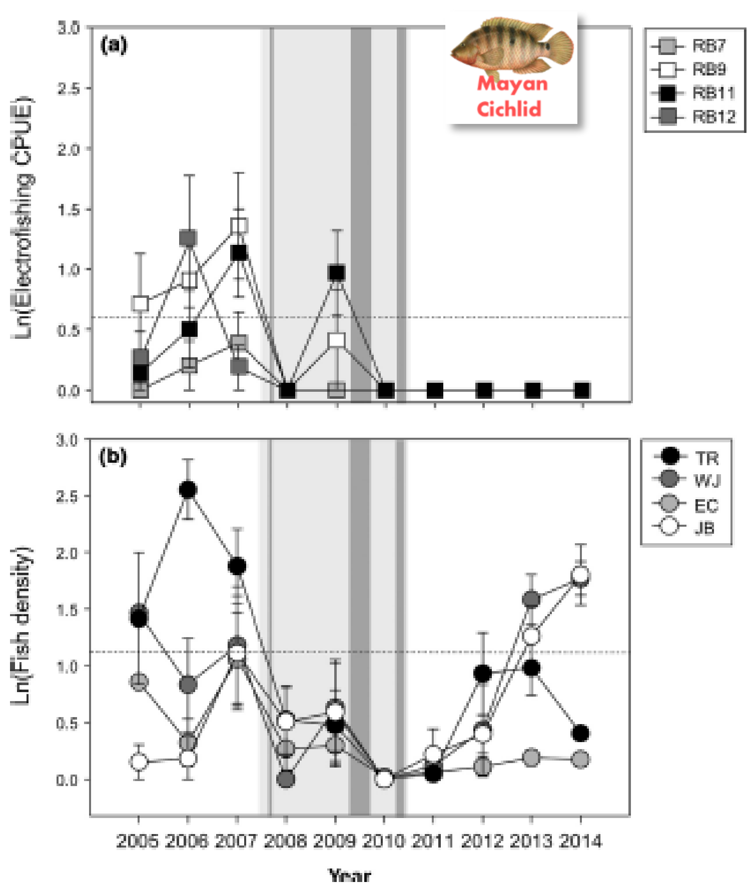

Figure 5. Mean yearly abundances (±SEs) for nonnative Mayan cichlids across the pre-and post-cold events years in the (a) Shark River and (b) Taylor Slough drainages. Symbols indicate four different populations in each drainage. Light shading indicates the disturbance period while the darker lines indicate the timing and severity of the three cold spells (including the extreme 2010 cold spell). For reference, the average pre-disturbance abundance across all populations is indicated by the horizontal dotted line. Resilience varies spatially, with higher resilience in Taylor Slough, particularly for certain populations closer to canals (EC and JB).

Modeling and Scenarios: We worked with stakeholders to derive a suite of climate scenarios to guide integrative FCE modeling efforts (Table 2), and used these to drive ELM predictions of hydrology, peat accretion, P availability, salinity, and vegetation dynamics.

Scenario name	Temperature change	Rainfall change	Sea level rise
Baseline	No change	No change	No change
-RF	No change	-10 %	No change
+RF	No change	+10 %	No change
+ET	+1.5°C	No change	+0.46 m
-RF +ET	+1.5°C	-10 %	+0.46 m
+RF +ET	+1.5°C	+10 %	+0.46 m

Table 2. Modeling scenarios based on temperature, temperature-driven evapotranspiration (ET), rainfall (RF), and sea level rise projections; all are SFWMM water management simulations that respond to the various climate and sea level attributes (Obeysekera et al. 2015).

P accumulation is consistently greater than rates simulated by FCE models (Figure 6) - the difference can be partially accounted for (10-66%) by recent estimates of GWD-P (Onsted et al., under review). A hydrodynamic model the coastal SRS was developed using bathymetric data, digital elevation and terrain models and related long-term FCE water depth data (Figure 7; Feliciano et al. 2014, Brisco et al. 2015a, Brisco et al. 2015b, Feliciano et al. 2016, Hong et al. 2015, Wdowinski and Hong 2015). Laboratory experiments on P sorption behavior (Flower et al. 2016; Flower in review-a; Flower in review-b) are being used in a geochemical models to investigate seawater-induced P desorption from soils and bedrock. Regier et al. (2016) were able to predict DOC fluxes with an R2 of 0.84 using a 4 component model. Using Hedonic price models, Asadi (2016) discovered that recreational fishing, which is reliant upon sound ecosystems, adds over $150M yearly to the Florida economy. Sikder (2016) found that Florida residents' preferences for restoration, as well as the different ecosystem services Everglades restoration would restore, varies significantly across the state.

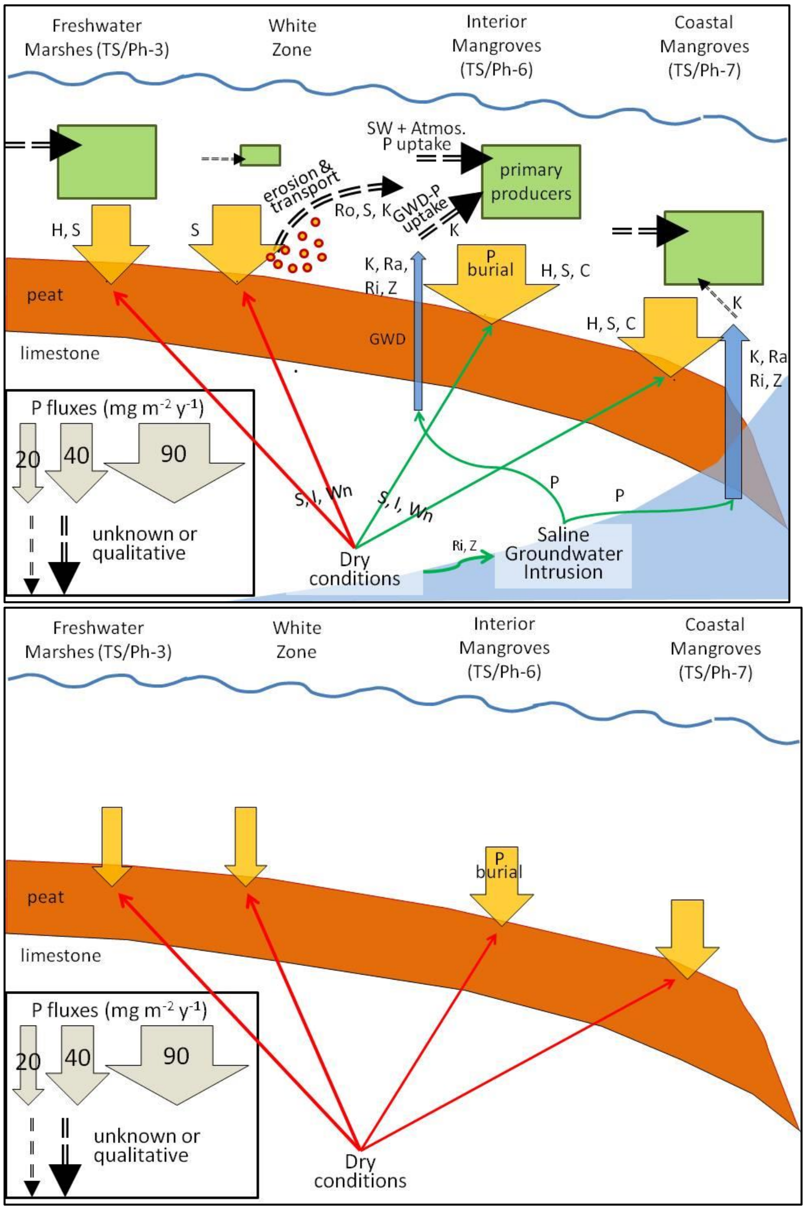

Figure 6. New hydrodynamic conceptual model developed in this synthesis, linking hydrology with new FCE studies estimating the magnitudes and drivers of P fluxes along the ecotone. (Top) Average groundwater discharge of P (GWD) and soil P burial fluxes inferred from radiometric cores (1960-2000), water budgets (2004, 2008, 2009), and other P fluxes across the Taylor Slough freshwater-to-mangrove ecotone. Positive relationships between hydrologic drivers (dry conditions and salinity intrusion) and specific fluxes are shown as green arrows, and negative relationships as red arrows. Individual studies supporting flux magnitudes or relationships between drivers (salinity or drying conditions) and fluxes are abbreviated as follows: C = Castaneda et al. (2009) and Castaneda, unpubl. data; H = C. Holmes and W. Orem, as sited in Sutula et al. (2001); I = Ishman et al. (online report); K = Koch et al. 2011, 2013; P = Price et al., 2006; Ra = Rains, unpubl. data; Ri = Rivera-Monroy et al. (2010); Ro = Ross et al. (2000); S = Saunders and Craft, unpubl. data; Z = Zapato-Rios et al. (2009); Wn = Wingard et al. (1999). (Bottom figure) ELM-simulated soil P burial rates and relationships between hydrologic drivers (dry conditions) and burial rates (color coded same as top figure). Note: ELM simulations are used to demonstrate the effect of omitting groundwater discharge, thereby highlighting its importance in reconciling differences between observed and modeled P burial rates.

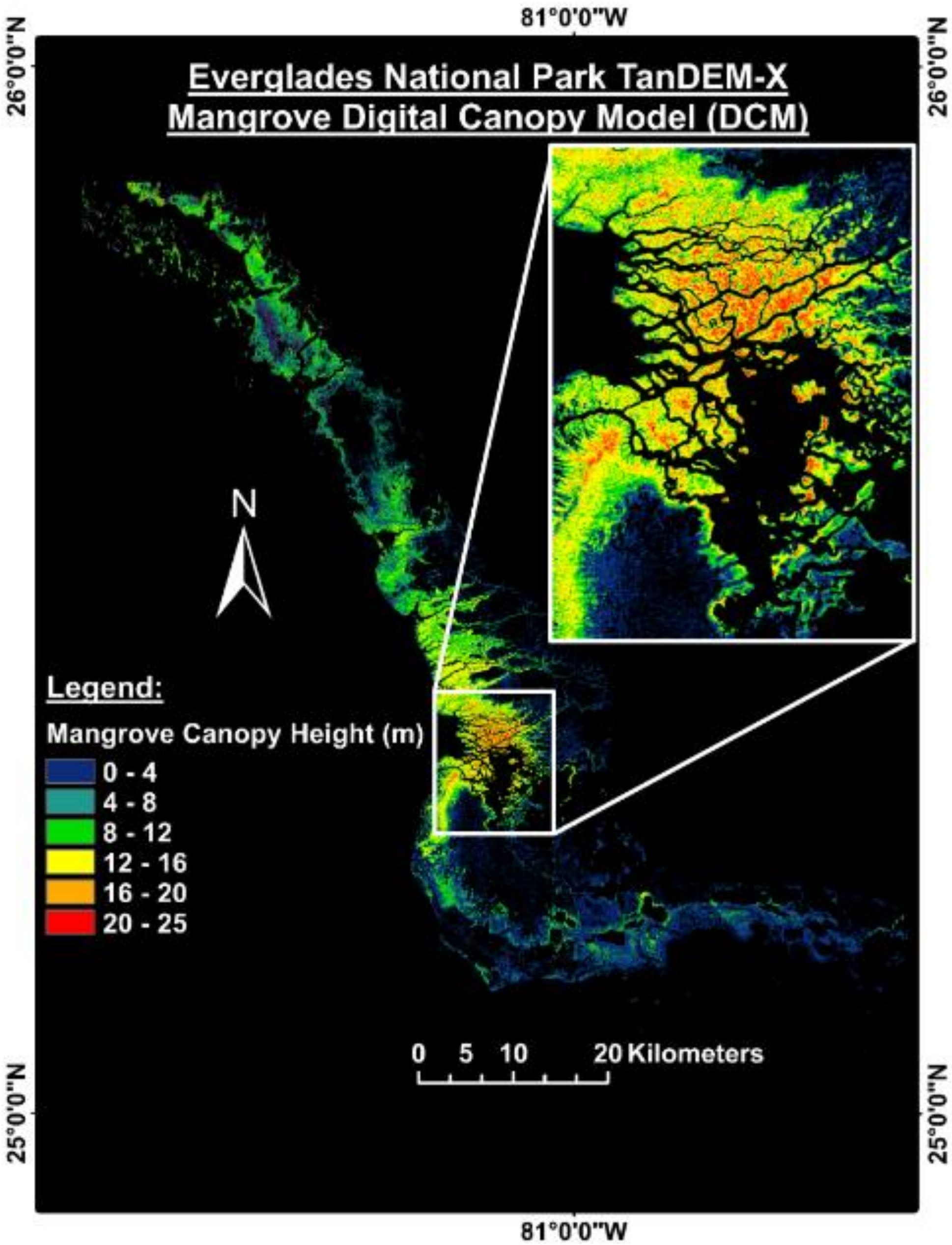

Figure 7. Everglades National Park TanDEM-X-based mangrove Digital Canopy Model (DCM) with a zoomed area in the SRS region.

Key outcomes or Other achievements

Here we provide a bulleted list of major outcomes and achievements organized across our cross-cutting themes:

Hydrology and Water Policy:

- We have refined the sea level rise rate from long term data, and found that it is rising 3 times faster than the historical average since 2006.
- Our hydro-political research is revealing how and why farm-level water quality monitoring and stakeholder interaction are necessary to achieve water quality standards to restore freshwater flows to the Everglades – we found substantial reductions in P levels (139 basins are net reducers vs. 34 net contributors over 2001-2016). Conflicts between farmers and environmentalists, however, continue to influence land use and water management dynamics.

Carbon Dynamics:

Synthesis of FCE long-term data suggests that:

- Enhanced marine connectivity with sea-level rise and water management is increasing P availability in brackish and freshwater wetlands of the FCE, particularly through the effects of high bicarbonate content of groundwater on P availability (Flower et al. 2016). Despite being a universally P-limited landscape, Everglades wetlands respond differentially to P addition based on availability of oxygen (higher in brackish and ecotone regions of the freshwater-marine gradient).
- Sawgrass responds strongly to continued salinity exposure that was approximately twice ambient of that found in brackish peat marshes (formerly freshwater peat marshes exposed to saltwater), or about 14 psu. This is the first report of a salinity threshold for sawgrass and the response corresponded with low relative aboveground biomass and annual net primary productivity of plants exposed to higher salinity (Figure 8).
- Riverine mangroves in the FCE store and sequester more C relative to scrub mangrove forests, which are P limited and influenced by long flooded hydroperiods. Further, regardless of forest ecotype, a large proportion of mangrove C production is stored in the soil. Our findings underscore the relative contribution of structurally distinct neotropical forested wetlands to mangrove C budgets. This finding is relevant given the need to quantitatively differentiate the actual regional and latitudinal contribution of each mangrove ecotype when assessing the economic value of C storage and sequestration (i.e., ecosystem services) for the establishment of global C markets to offset rising greenhouse gas emissions. C burial efficiency at the SRS ecotone was 22% of annual organic C production, thus exceeding the global average of 12% (Figure 9, Bouillon et al., 2008). The general relationship between bulk density and soil organic matter from a large sampling of tidal wetlands nationwide can be used to predict what rates of SLR would be too high for FCE wetland accretion to "keep up".
- Sympatric populations of upper trophic level predators in the SRS estuary exhibit niche partitioning both inter- and intras-pecifically through variation in spatiotemporal patterns of movement and foraging behavior.

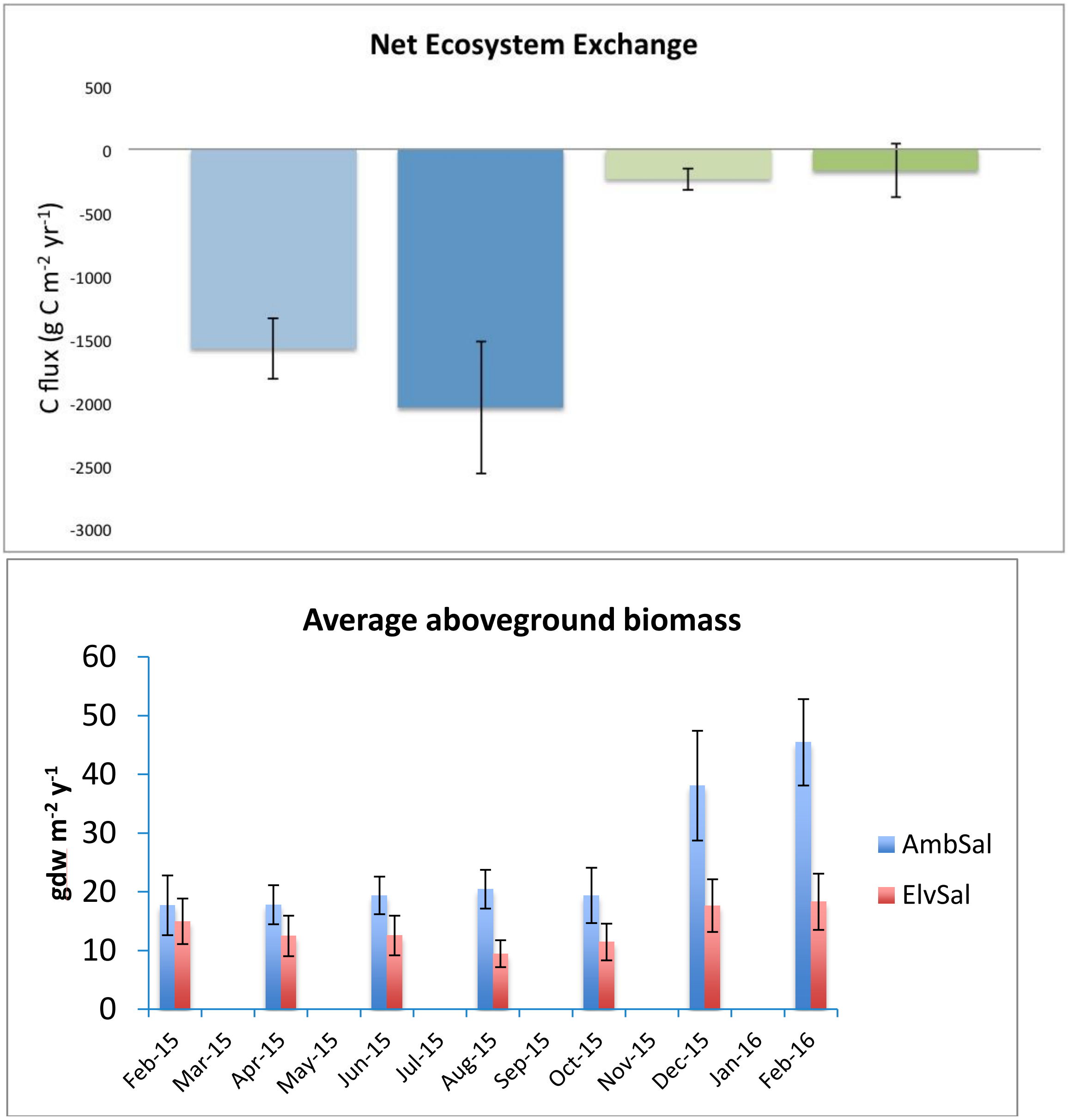

Figure 8. Net ecosystem exchange and average biomonthly aboveground biomass in experimental outdoor mesocosms with brackish water peat marsh "monoliths" exposed to twice ambient salinity.

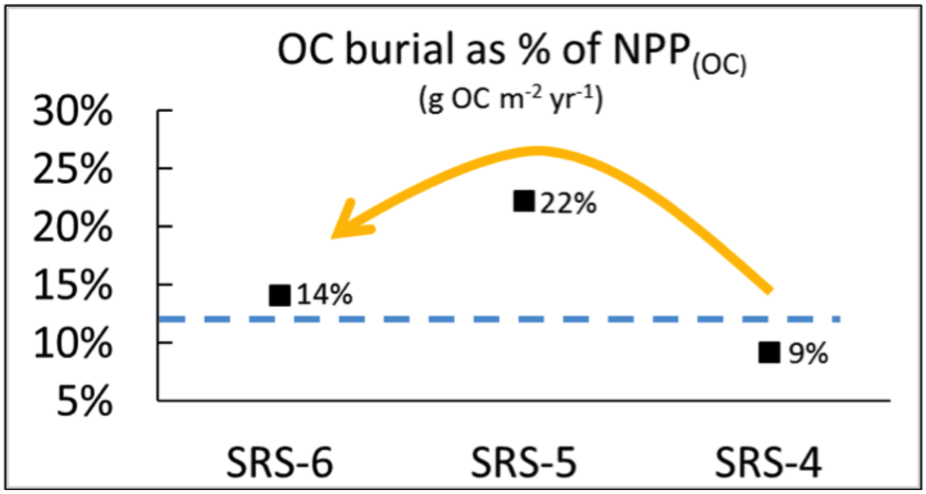

Figure 9. Organic Carbon burial as a percentage of Net Primary Productivity (Organic Carbon) (Castaneda-Moya et al., 2013). The blue dashed line indicates the global average of 12% (Bouillon et al., 2008).

Integration of mechanistic data suggests that:

- Reduced environments, such as coastal wetlands, can continue to store C despite additions of nutrients (N + P). P supply may alleviate the osmotic stress brought by saltwater exposure (Figure 10). P desorption from bedrock occurs with as little as 0.4% seawater, so incursions of seawater would be expected to increase P availability (Figure 11, Flower in review-b).
- Increased freshwater can alter the relative contribution of detritus to food webs. Although increased flow can lead to a greater contribution of autotrophic production, it is unclear if food quality to consumers will be increased.

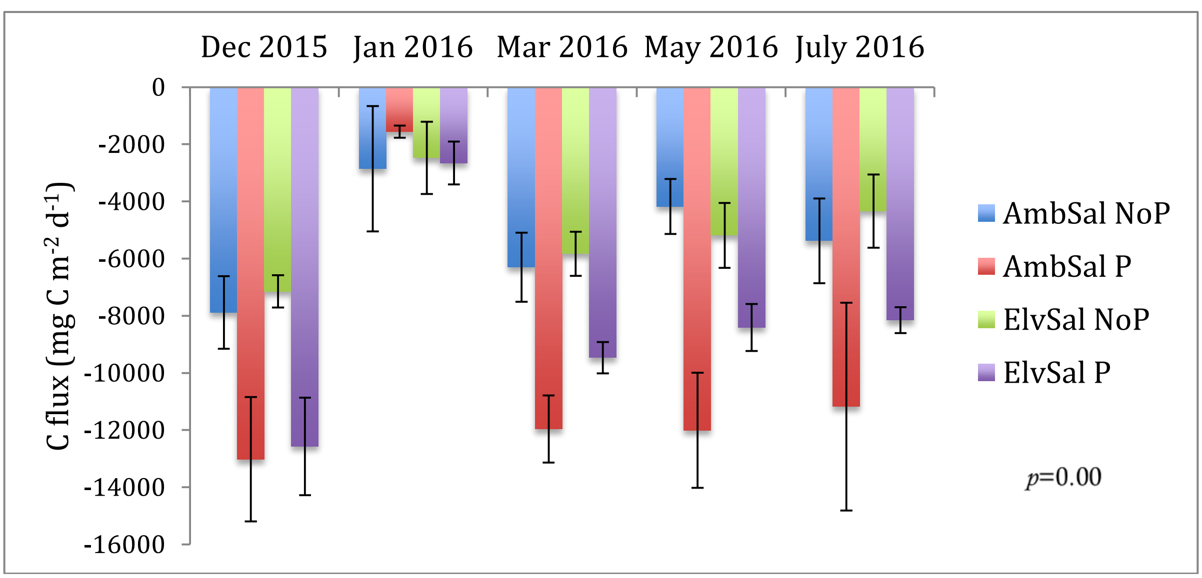

Figure 10. Net ecosystem exchange of freshwater peat marsh with atmosphere in “monoliths” exposed to low level salinity and phosphorus.

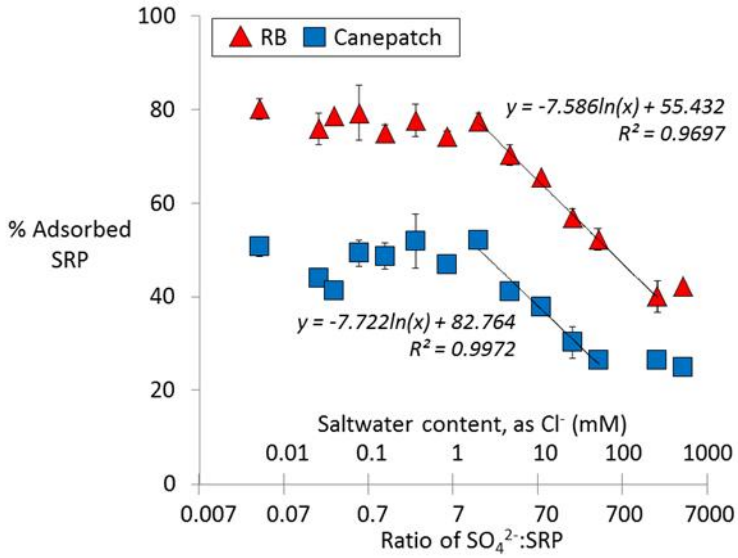

Figure 11. Percent adsorption of added SRP in mixtures of freshwater with varying amounts of saltwater (indicated by both increasing Cl^- concentration and ratio of SO_4^{2-}: SRP), by RB rock (red triangles) and Canepatch rock (blue squares). The logarithmic function equations with respect to Cl^- concentration are provided.

Landscape scaling efforts show that:

- Worldview 2 mapping tools can be used to identify 8 key community classifications that have strong east-west spatial structure roughly paralleling the coast, and therefore can be used to track ecotone change (Figure 12). Sawgrass and sparse graminoid marsh dominate in the north, while the mangrove classes dominate in the south; these areas are separated by sparse graminoid marsh (white zone) interspersed with dwarf mangrove.

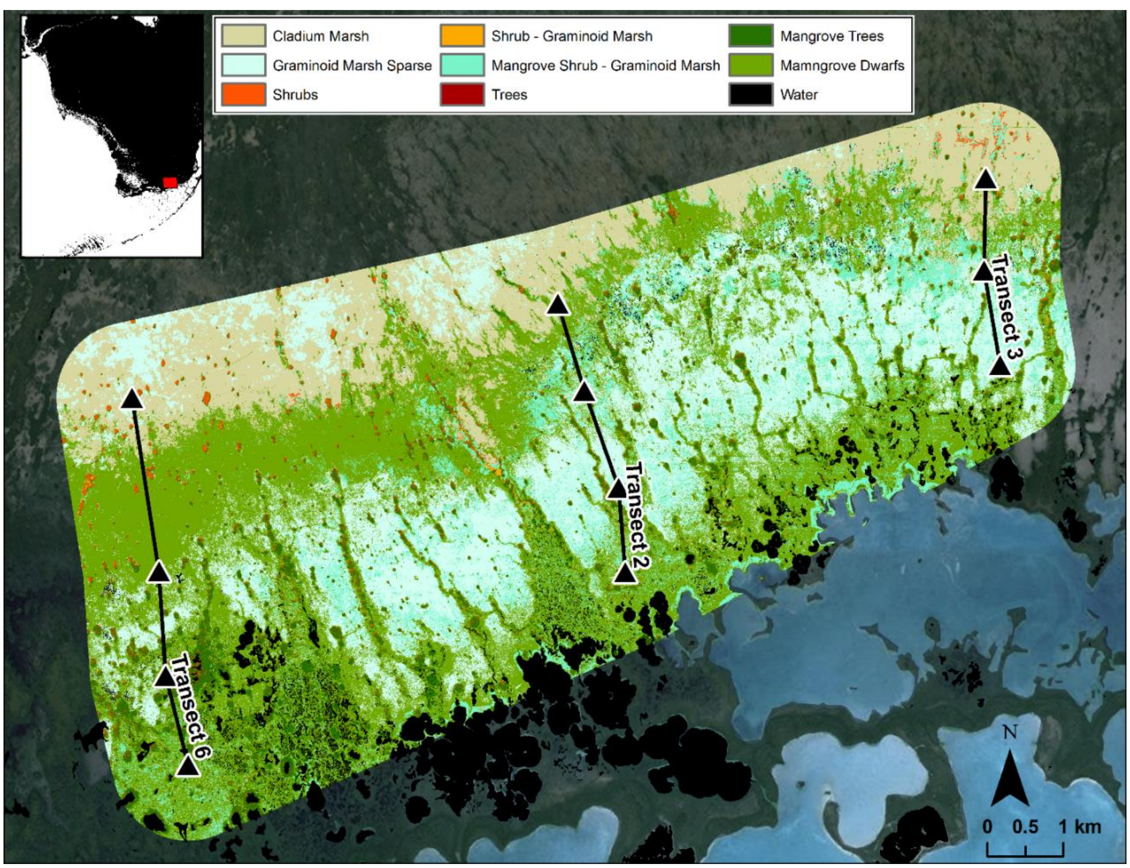

Figure 12. Vegetation map derived from 2012 multi-spectral WorldView2 and 2009 LiDAR data

Climate and Disturbance Legacies:

- Extreme climate events, like droughts and cold snaps, play an important role in both community dynamics and population densities and structures of top predators. These impacts may be particularly large on invasive species in the Everglades. Recovery from disturbances may take multiple years. For some top predators, like bull sharks, population structure has still not converged on that present before the event after 5 years. Low temperatures increase photosynthesis in freshwater marshes while lowering it in mangroves (Malone et al., in review).
- FCE completed two special issues of the journal Ecosphere, highlighting the effects of cold snaps on subtropical ecosystems (Boucek et al. 2016) and the importance of ILTER collaborations in interpreting results from place-based LTER science (Gaiser et al. 2015).

Modeling and Scenarios:

- Scenarios modeling indicates that decreased rainfall and increased sea levels result in inland encroachment of mangroves of 7-15 km (Figure 13), while increased rainfall and SLR result in both increased mangrove and open water habitats. (For more, see: http://www.ecolandmod.com/projects/ELM_FCE/.)
- Preliminary results from our hydrodynamic model suggest that the mean particle residence time on the lower 8-km of SRS is ~12 hrs (Figure 14), though some have indefinite residence times because they become trapped in hydrodynamic dead zones, a finding consistent with tracer experiments (Ho et al. 2009).
- Remote sensing indicates that mangrove forests in the Everglades National Park have grown over the past decade and a half despite destructive weather events, including the 2005 Wilma Hurricane and the 2010 long lasting winter freeze (Figure 7).
- The majority of scenario runs indicated that DOC export from the Everglades is expected to decrease due to future changes in rainfall, water management and salinity.
- FCE models consistently underpredict P and this discrepancy may be somewhat addressed by more recent estimates of groundwater-derived P (Onsted et al., under review).

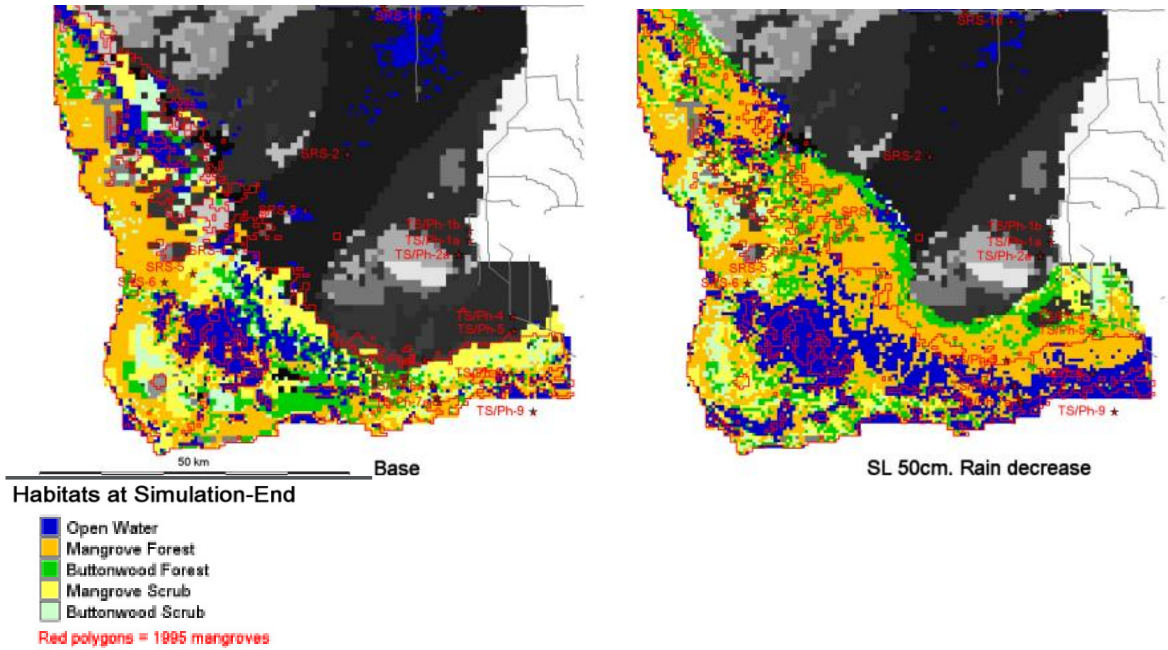

Figure 13. Habitat suitability map for the baseline scenario (left map), and the climate scenario featuring a 10% decrease of rainfall, +7% ET (1.5 C warming), and 50-cm sea-level rise (right map).

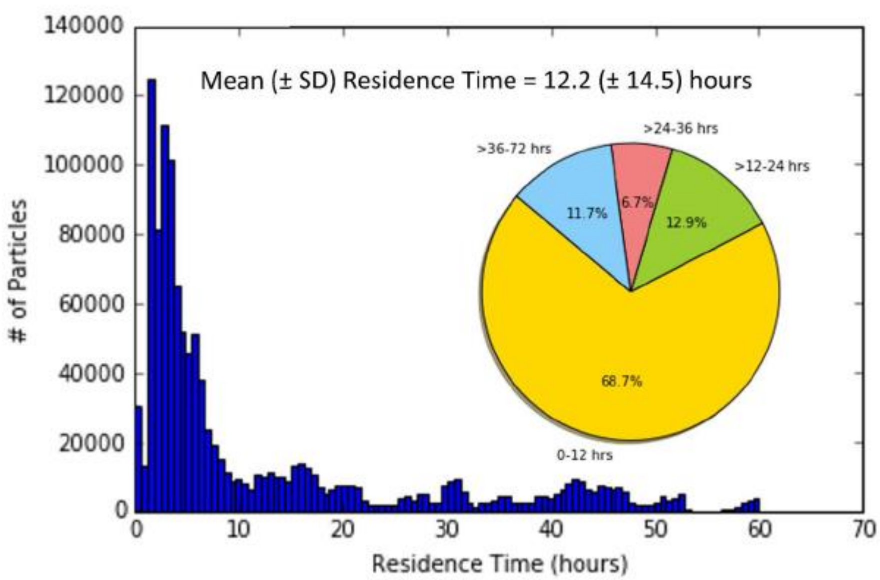

Figure 14. Histogram showing the distribution of modeled particle residence times. For this simulation, approximately 1.2 million particles were released near the center of the model domain from January 1st to 3rd, 2016. These results are only preliminary, and should not be used for any research purposes.

Opportunities for training and professional development

FCE graduate students, Shelby Servais and Jennifer Sweatman, participated in the *2015 Patricia and Phillip Frost Museum of Science's Communication Fellows Program* (*SCFP*). As Frost Fellows, they received training from the museum staff for improving their science communication skills and assistance in delivering their research results to non-scientists. The development of these skills is essential for bridging the gap between the general public and scientists, and has resulted in several important outcomes for FCE.

The first outcome of the *SCFP* was the development of two, hands-on, interactive exhibits that can be used by the Museum and can be adapted for use at FCE community outreach events. Shelby's exhibit was designed as a game in which participants explore microbial enzymatic activity. The enzymes are balls covered in Velcro and are used to collect pieces of felt "food". Through the activity, participants learn that some enzymes are better adapted (more Velcro) to environmental conditions, making them more efficient at collecting food, and thus improving their rate of survival.

Jennifer's exhibit simulates the effects of prop scars in the seagrass beds. In her activity, participants "drive" a boat through a seagrass bed made of pipe cleaners with a removable strip to represent the effects of a propeller scar. When removed, the seagrasses on either side of the strip have red colored bottoms to illustrate nutrient depletion in the adjacent seagrasses.

The SCFP has improved Shelby and Jennifer's ability to communicate their research through developing activities that provide the context and relevance of their work to broader communities. These same skills were applied in mock news interviews and town hall meetings for practice with communicating science to the media. Both have continued to practice science communication skills at other museum events and have improved their ability to engage a broader community in FCE research.

FCE continues to provide a range of opportunities for research, teaching and mentoring in science. Over the last year, FCE scientists have provided 48 semester units (SU) of undergraduate mentoring to 27 undergraduates and 2 postbaccalaureates, in 12 FCE labs, at 6 different institutions, in the US, Mexico, and Brazil. The majority (83%; n=24/29) of students mentored are traditionally underrepresented in STEM; 58% are female (n=17) and 83% (n=24) are considered ethnic minorities.

Communicating results to communities of interest

Our scientists continue to shape policy by reporting their research results to decision makers and working with many of them as FCE collaborators. On March 8, 2016, Dr. Mike Heithaus, provided testimony on "Research Innovations from Our Nations Agricultural Colleges and Universities" to the US House of Representatives Agriculture Committee; House Subcommittee on Biotechnology, Horticulture and Research. Our collaborators are also directly reporting back to their agencies as scientists at: the US Environmental Protection Agency; US Geological

Survey; United States Department of Agriculture-US Forest Service; Florida Department of Environmental Protection; National Park Service (NPS) Everglades National Park; NPS South Florida/Caribbean Network Inventory and Monitoring Program; and the South Florida Water Management District.

FCE research has been highlighted in the news by *CBS Miami, NPR Weekend Edition, Canadian Broadcasting Corporation, Atlantic Monthly, Science Daily, The Miami Herald, Tampa Bay Times, Weather Channel, Washington Post, and the Miami New Times.* Dr. Mike Heithaus' work was also featured on the Discovery Channel's 2016 Shark Week - *Sharks vs. Dolphins: Face Off*.

Our graduate students and scientists have maintained an active social media presence through Facebook, blogs, and YouTube. While our Facebook page remains the primary means of internal social networking, the FCE page has made 66 new posts that have been displayed 14,210 times through organic impressions, and has increased our outreach to 6,766 unique users through our news feed, ticker, or timeline and has resulted in over 8,650 "likes" to our posts.

The FCE *Wading Through the Research* (http://floridacoastaleverglades.blogspot.com) blog, continues to be maintained by our graduate student group and Post Doctoral Associate, Dr. Luca Marazzi. Over the last year, they added 11 new posts (90 total), including several contributions by Dr. Marazzi's "Diatom of the month" series. This series hopes to raise awareness about how diatoms are used to reconstruct, understand, and predict environmental changes in the Everglades. Since November 2015, this series reached ~1,100 people, generated over 7,200 impressions, and 180 engagements such as retweets, likes, and replies.

The Heithaus Lab also has an active social media presence through the *Heithaus Lab* blog (http://heithauslab.blogspot.com) and its YouTube channel. The blog has made 5 new posts (40 total) over the last year and The *Heithaus Lab Marine Biology and Science Adventures* YouTube channel has posted 8 new FCE and related videos (21 total).

Our scientists continue to engage with our community through wide range of outreach activities. More than 20 researchers have engaged with our stakeholders at over 48 different community events, where our scientists have given a reported 32 presentations to over 585 members of our community. We have also participated on 15 panel discussions, tabled 11 events at venues with over 17,000 visitors, collaborated with artists to display work at 9 art exhibitions, 4 workshops, and hosted 5 large group visits that included the 2015 Hispanic Association of Colleges and Universities Youth Leadership Development Forum.

FCE and the Humanities: The Tropical Botanic Artists (TBA) have remained active FCE Outreach partners. Since our last report, the *In Deep with Diatoms* exhibit has been on display at six new venues and is on display through August 2016 at The Anne Kolb Nature Center. This collection of 33 diatom portraits is the result of a collaboration with Dr. Gaiser's Lab and has been displayed at eight exhibits since 2014. This year, Pauline Goldsmith's portrait of *Amorphea proteus* is on loan to the National Park Service Headquarters in Atlanta and was on display at Hartsfield-Jackson Atlanta International Airport to celebrate the NPS centennial.

A second TBA exhibit, *Tamiami Trail: In the beginning portraits of plants found along the historic Tamiami Trail*, is on display with our partners at the Deering Estate through September 2016. The group artistically depicts various plants, many of which are still there today, but now bordering on the rare or endangered, or their predominant locations have shifted due to a change in water flow and man's intervention. The exhibition features 20+ portraits of plants found in the five vegetation zones across South Florida at the time the Tamiami Trail documentation was signed on May 15^{th} 1915.

Eco Artist Xavier Cortada continues to collaborate with Dr. Evelyn Gaiser as Artist In Residence for FIU's School of Environment, Arts, and Society. In 2015, Cortada's exhibit "*CLIMA*", he featured new and earlier works inspired by his collaboration with Dr. Gaiser. The exhibition coincided with the COP21 Paris Talks and included several panel discussions with FCE researchers Drs. Evelyn Gaiser, Rene Price, Tiffany Troxler and FCE Education and Outreach Coordinator Nicholas Oehm. Cortada used these panel discussions as inspiration to paint images on solar panels as depictions of the Earth's "original solar panels". *CLIMA* was on display at the Milander Center for Arts and Entertainment from November 30th, 2015 through January 29th, 2016 and *CLIMA 2.0* will return in December 2016.

On February 16, 2016, Cortada hosted *Exploring the Environment & Art: STEAM Workshop* at the Frost Art Museum for Miami Dade County Public School teachers. The workshop explored different "perspectives on the value of a STEAM focused education, especially as we need to educate a generation of students who will need to think creatively and innovate solutions to the complex problems facing our world." Drs. Evelyn Gaiser and Tiffany Troxler discussed their current research projects and described how art strengthens and enhances their work. Nicholas Oehm gave a brief presentation on how teachers could engage with FCE scientists to connect with their students and schools.

Cortada also hosted a *Native Flags* participatory, eco-art, Earth Day event, April 21-22, 2016 for Brucie Ball Education Center, Palm Lakes Elementary, Ruth Owens Krusé Education Center, and Dr. Rolando Espinosa K-8 Center. In the planting event, Cortada talked about the importance of re-growing native tree canopies in urban areas and introduced students to the permanent exhibit of *Native Flags* at our Education & Outreach partner site at the Deering Estate.

Outreach for Enhancing Public Understanding: FCE scientists share research results through the educational materials they use in their courses. Over the last year, 17 scientists report discussing FCE research in 30 courses, at 9 institutions, where they directly impacted the classroom instruction for over 900 undergraduate and 111 graduate students.

In July 2016, FCE donated 52 copies each of *One Night in the Everglades* and *Una Noche En Los Everglades* to the Miami Dade Public Library System (MDPLS). Servicing nearly 2.5 million residents, *One Night/Una Noche* is accessible to over 8 million annual library visitors and available to over 1 million registered borrowers, at 50 libraries distributed across Miami Dade County and two bookmobiles.

One Night in the Everglades/Una Noche En Los Everglades will be featured during MDPLS 2017 Earth Day events and will include special readings by FCE scientists and Everglades learning activities led by FIUteach students. We are also working with MDPLS to develop Everglades related STEM programming
for the two regional branches.

FCE continued to attend large events hosted by our Education & Outreach partners. In March 2016, over 9,000 local residents are estimated to have attended the Seafood Festival, where FCE staff presented educational activities such as the *Marine Macroalgae Mobile Lab* and the *Coastal Angler Science Team* mark and recapture "Fishing Tournament". FCE also participated in ZooMiami's, two-day, *Party for the Planet* Earth Day celebration, with 8,022 visiting guests.

Plans to accomplish goals during the next reporting period

Hydrology and Water Policy: We will continue long-term hydrological and geochemical ground-based measurements. Density-dependent flow modeling will continue to determine restoration efforts on the water delivery to and the water quality in the mangrove ecotone. Detailed statistical analysis will be used to assess how water level and chemistry in the oligohaline ecotone responds to the competing drivers of freshwater inputs and SLR. This year we will focus on the empirical relationships of farmer best management practices (BMP) to farm biophysical and economic characteristics, institutional factors and social-professional networks. We will also map and conduct a spatially-explicit analysis of the spatial distribution of water quality linked to the basin-specific BMP data.

Carbon Dynamics: *Synthesis of Long-Term Data:* We will analyze high-frequency fDOM and salinity data obtained using probes to better understand variables affecting DOC flux on short time-scales and validate the upstream-downstream C-burial pattern using several distinctly different methods. We will expand our research to evaluate C dioxide fluxes at TS/Ph, including C dioxide efflux in surface and soil porewater. We will complete our estimates of soil accretion rate specific for mangrove wetlands along the Everglades fringe. Long-term datasets in the marsh, ecotone, and estuary will be extended and we will complete syntheses of how movement decisions of large consumers influence ecosystem dynamics. New studies in the TS/Ph transect will enhance our understanding of the drivers of community dynamics and consumer behavior, and more studies of consumer diets will help us enhance our understanding of potential interaction strengths in the estuary. We will employ high-resolution sonar to better understand dynamics of mesoconsumers in the estuarine zone. *Integrated Experiments:* We will submit a manuscript to a peer-reviewed journal for the P addition and mangrove leaf loss experiment, finalize data analyses for field (salinity manipulation in freshwater and brackish water marshes) and mesocosm (salinity ´ inundation and salinity ´ P) experiments. We will continue to mentor a REU student and two RETs, analyze data, and generate products from the 2015 and 2016 REU, and 2016 RET projects. We will present results at the 2017 FIU Biology Research Symposium, 2017 FCE All-Scientists Meeting, 2017 Greater Everglades Ecosystem Restoration Meeting, and 2017 Ecological Society of America Meeting. We will focus on expanding our experimental work to determine the effect of a drought event on brackish peat marsh exposed to increased salinity and begin synthesizing results from integrated experiments to being work toward parameterizing a soil C mass balance model. We will expand our experimental research on consumers to evaluate how important top predators (alligators) and their behavior patterns are to the spatial pattern of detrital contributions to food webs. *Landscape Synthesis:* We will complete the mapping of the mangrove ecotone area in the saline southeastern Everglades and derive landscape level estimates of sawgrass and mangrove biomass using data from the maps combined with modeled community-specific estimates of biomass on an area basis. This work will allow us to link salinity thresholds to not only vegetation composition and primary production but also to integrated responses as expressed through spatial variation in coastal C stocks. We will further this work to develop elevation benchmarks to improve our capacity to understand how SLR is and will continue to influence the FCE and evaluate long-term changes in vegetation C pools in response to Hurricane Wilma's impacts to understand trajectories of recovery and resilience capacity.

Climate and Disturbance Legacies: In 2016–17 we will develop increasingly accurate land use change forecasts (incorporating policy optioned scenarios) that can also be coupled with and water demand, quality and quantity of effluent, and hydrologic flow. We will reparametrize SFWMM to identify boundary conditions for ELM as well as use outputs from SFWMM to constrain other FCE models, allowing for cascading modeling impacts. Taking the analysis we have already completed, we intend to publish a series of papers connecting a) salinity with rainfall; b) salinity with nutrients; and c) groundwater with nutrients. We will also submit our synthesis paper for review to Critical Reviews in Environmental Science and Technology (CREST) after it finishes internal review at SFWMD. We will continue to work on building a bridge across disciplines in order to better understand the complex connections and feedbacks among land use, water use, and ecosystem patterns and processes.

Modeling and Scenarios: We will complete a geochemical model that successfully captures seawater-induced P desorption (Figure 11). Once completed, this geochemical model can be adapted to examine changes to P sorption behavior that could be expected from our climate scenarios. We will complete our hydrodynamic model of coastal SRS, to track the flow of particles released within the model domain and to estimate particle residence time (Figure 14). Once completed, this model can be for any particle (e.g., DOC, mangrove propagules, or fish eggs). We will continue to update the ELM using long term FCE and experimental data, resulting in a unique, large-scale, spatio-temporal, process-based integration of a range of FCE research projects. We will then finalize ELM model simulations of the effects of climate change on a large suite of ecologically important variables from peat accretion to habitat suitability. Results will be the basis for a synthesis paper and potentially an additional set of synthesis papers across several disciplines. We will infill data gaps, including (1) additional bathymetric and remote sensing data collection, facilitating the expansion the hydrodynamic model and (2) georeferencing hydrologic monitoring stations at SRS 5 and SRS 6, enhancing the value of these long-term water level data.

Products

Publications

Journal Articles

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Santos, R.O. and J.S. Rehage, 2016. Spatiotemporal patterns in the catch rates of two important recreational species in Florida Bay: Bonefish and Atlantic tarpon. 36th Annual Meeting of the Florida Chapter of the American Fisheries Society, Haines City, Florida, March 02, 2016.

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Sklar, F.H., C. Coronado-Molina, T. Troxler, J. Stachelek, S.P. Kelly, and J. Kominoski, 2016. Coastal subsidence as a function of salinity intrusion and peat decomposition in a karst environment. Ecological Society of America Annual Meeting 2016, Fort Lauderdale, Florida, August 10, 2016.

Stachelek, J., C.J. Madden, S.P. Kelly, and M. Blaha, 2016. Fine-scale spatial patterning of phytoplankton abundance in a coastal estuary. Ecological Society of America Annual Meeting 2016, Fort Lauderdale, Florida, August 9, 2016.

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Trexler, J.C. 2016. Restoring an iconic ecosystem? Non-native fish and everglades restoration. Ecological Society of America Annual Meeting 2016, Fort Lauderdale, Florida, August 8, 2016.

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Venkatesan, A., G. Starr, S. Oberbauer, S.L. Malone, and C.L. Staudhammer, 2016. Understanding greenhouse carbon balance between long- and short-hydroperiod marshes in the Florida Everglades. Ecological Society of America Annual Meeting 2016, Fort Lauderdale, Florida, August 9, 2016.

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Wendelberger, K.S., D. Gann, and J.H. Richards, 2016. Using remote sensing to detect long-term coastal plant community changes due to sea level rise and ecosystem drying, Everglades National Park. Ecological Society of America Annual Meeting 2016, Fort Lauderdale, Florida, August 9, 2016.

Whitman, D., T.A. Frankovich, and R.M. Price, 2016. Electromagnetic surveying in the Mangrove Lakes region of Everglades National Park. National Conference on Ecosystem Restoration 2016, Coral Springs, Florida, April 18-22, 2016.

Wilson, B.J., S. Servais, V. Mazzei, F.H. Sklar, T. Troxler, J. Kominoski, E.E. Gaiser, and C. Coronado-Molina, 2016. Biogeochemical and Physiological Effects of Simulated Sea Level Rise in the Coastal Everglades. American Society for Limnology and Oceanography 2016 Summer Meeting, Santa Fe, New Mexico, June 07, 2016.

Wilson, B.J., S. Servais, S.P. Charles, T. Troxler, J. Kominoski, E.E. Gaiser, and F.H. Sklar, 2016. Simulated saltwater intrusion decreases net ecosystem exchange in coastal marshes, dampening their capacity to store carbon. Ecological Society of America Annual Meeting 2016, Fort Lauderdale, Florida, August 10, 2016.

Dissertations and Theses

Ph.D. Dissertations

Boucek, Ross . 2016. Investigating sub-tropical community resistance and resilience to climate disturbance. Ph.D. dissertation, Florida International University.

Sweatman, Jennifer Lynn. 2016. Gammaridean amphipods as bioindicators in subtropical seagrass ecosystems. Ph.D. dissertation, Florida International University.

Wendelberger, Kristie S.. 2016. Evaluating Plant Community Response to Sea Level Rise and Anthropogenic Drying: Can Life Stage and Competitive Ability be Used as Indicators in Guiding Conservation Actions?. Ph.D. dissertation, Florida International University.

Master’s Theses

Asadi, Mehrnoosh . 2016. Evaluating the Economic Impact of Recreational Charter Fishing in Florida Using Hedonic Price and Economic Impact Analysis. Master's thesis, Florida International University.

Bornhoeft, Sarah C.. 2016. Influence of Experimental Sheet Flow on Aquatic Food Webs of the Central Everglades. Master's thesis, Florida International University.

Kroloff, Emily . 2016. Where Are All the Bonefish? Using Angler Perceptions to Estimate Trends of Bonefish (Albula vulpes) Decline in South Florida. Master's thesis, Florida International University.

Prieto Estrada, Andres E.. 2016. Water-Rock Interactions and Seasonal Hydrologic Processes in Constructed Everglades Tree Islands. Master's thesis, Florida International University.

Schulte, Nicholas O.. 2016. Controls on benthic microbial community structure and assembly in a karstic coastal wetland. Master's thesis, Florida International University.

Sikder, Abu Hena Mustafa Kamal . 2016. Analyzing Spatial Variability of Social Preference for the Everglades Restoration in the Face of Climate Change. Master's thesis, Florida International University.

Websites

Florida Coastal Everglades LTER Program Website
http://fcelter.fiu.edu/
The Florida Coastal Everglades LTER Program Website provides information about FCE research, data, publications, personnel, education & outreach activities, and the FCE Student Organization.

Coastal Angler Science Team (CAST) Website
http://cast.fiu.edu/
The Coastal Angler Science Team (CAST) Website, created by FCE graduate student Jessica Lee, provides information about how researchers and anglers are working together to collect data on important recreational fish species in Rookery Branch and Tarpon Bay in the Everglades and invites anglers to participate in this project.

Predator Tracker
http://tracking.fiu.edu/
The Predator Tracker website has information about the Predator Tracker application and a link to download the application. Predator Tracker is a stand alone application based on a kiosk at the Museum of Discovery and Science in Ft. Lauderdale. The application allows one to learn how researchers at Florida International University track and study big predators in the Shark River Estuary in Everglades National Park and explore their predator tracking data.

Wading Through Research
http://floridacoastaleverglades.blogspot.com/
A blog created by FCE graduate students which focuses on the experiences of graduate students conducting research in the Everglades.

Other products

Databases

The FCE Information Management System contains 173 datasets, of which a total of 151 are also publicly available online at http://fcelter.fiu.edu/data/FCE/. Datasets include climate, consumer, primary production, water quality, soils, and microbial data as well as other types of data.

Data from eddy covariance towers near SRS-2 and TS/Ph-1 were added to the AmeriFlux website.

> Oberbauer, S. F, and **G. Starr**. 2016. "AmeriFlux US-Elm Everglades (long Hydroperiod Marsh)". United States. *doi:10.17190/AMF/1246118.* http://www.osti.gov/scitech/servlets/purl/1246118.
>
> Oberbauer, S. F., and **G. Starr**. 2016. "AmeriFlux US-Esm Everglades (short Hydroperiod Marsh)". United States. *doi:10.17190/AMF/1246119.* http://www.osti.gov/dataexplorer/servlets/purl/1246119

Audio or Video Products

The video "Florida Bay on the Brink," produced by The Everglades Foundation, features FCE scientist Dr. Jim Fourqurean talking about seagrass in Florida Bay. The video is available at http://www.evergladesfoundation.org/floridabay/ .

The video "Regaining Ground" features FCE scientists Dr. Victor Rivera-Monroy and Asher Williams discussing their mangrove research. The video is available at https://www.youtube.com/watch?v=fyVdaWrPqLQ.

Educational aids or Curricula

Dr. Victor Rivera-Monroy is an instructor for "Managing for a Changing Climate," a free online course available at https://janux.ou.edu/course.tag-nextthought-com-2011-10-nti-courseinfo-fall2016-geogmetr-3523.html.

Other publications

Davis, S.E. (2016). *Florida Bay: A Unique Everglades Estuary*. Blog post on The Everglades Foundation web site. http://www.evergladesfoundation.org/2016/08/26/florida-bay-a-unique-everglades-estuary/.

Davis, S.E. (2016). *Florida Bay: Devastation Goes Unrecognized by Most South Floridians*. Blog post on The Everglades Foundation web site. http://www.evergladesfoundation.org/2016/09/06/florida-bay-devastation-goes-unrecognized-by-most-south-floridians/.

Davis, S.E. (2016). *Florida Bay: What is The Solution?*. Blog post on The Everglades Foundation web site. http://www.evergladesfoundation.org/2016/08/26/florida-bay-what-is-the-solution/.

Participants & Other Collaborating Organizations

Group photo from the 2016 FCE LTER All Scientists Meeting

Participants*

*People who worked at least 1 person month on the project

Name	Most Senior Project Role
Gaiser, Evelyn	PD/PI
Heithaus, Michael	Co PD/PI
Jaffe, Rudolf	Co PD/PI
Kominoski, John	Co PD/PI
Price, Rene	Co PD/PI
Briceno, Henry	Faculty
Childers, Daniel	Faculty
Collado-Vides, Ligia	Faculty
Oberbauer, Steven	Faculty
Oehm, Nick	Faculty
Onsted, Jeff	Faculty

Name	**Most Senior Project Role**
Rains, Mark	Faculty
Rehage, Jennifer	Faculty
Rivera-Monroy, Victor	Faculty
Roy Chowdhury, Rinku	Faculty
Schwartz, Katrina	Faculty
Smoak, Joseph	Faculty
Starr, Gregory	Faculty
Staudhammer, Christina	Faculty
Troxler, Tiffany	Faculty
Wdowinski, Shimon	Faculty
Casal, Teresa	K-12 Teacher
Laroche, Catherine	K-12 Teacher
Flower, Hilary	Postdoctoral (scholar, fellow or other postdoctoral position)
Marazzi, Luca	Postdoctoral (scholar, fellow or other postdoctoral position)
Santos, Rolando	Postdoctoral (scholar, fellow or other postdoctoral position)
Fitz, Carl	Other Professional
Powell, Linda	Other Professional

Name	Most Senior Project Role
Rugge, Michael	Other Professional
Serna, Alexandra	Other Professional
Vanderbilt, Kristin	Other Professional
Absten, Michael	Technician
Duquesnel, Jim	Technician
Eggenberger, Cody	Technician
Gastrich, Kirk	Technician
Hines, Adam	Technician
Stumpf, Sandro	Technician
Tobias, Franco	Technician
Travieso, Rafael	Technician
Viadero, Natasha	Technician
Castaneda, Edward	Staff Scientist (doctoral level)
Davis, Stephen	Staff Scientist (doctoral level)
Frankovich, Tom	Staff Scientist (doctoral level)
Kiszka, Jeremy	Staff Scientist (doctoral level)
Malone, Sparkle	Staff Scientist (doctoral level)

Name	Most Senior Project Role
Allen, Joshua	Graduate Student (research assistant)
Boucek, Ross	Graduate Student (research assistant)
Charles, Sean	Graduate Student (research assistant)
Clasen, Hunter	Graduate Student (research assistant)
Danielson, Tess	Graduate Student (research assistant)
He, Ding	Graduate Student (research assistant)
Huang, Wenxi	Graduate Student (research assistant)
Kroloff, Emily	Graduate Student (research assistant)
Kunwor, Sujit	Graduate Student (research assistant)
May, Jeremy	Graduate Student (research assistant)
Mazzei, Viviana	Graduate Student (research assistant)
Paz, Valeria	Graduate Student (research assistant)
Prieto, Andres	Graduate Student (research assistant)
Regier, Peter	Graduate Student (research assistant)
Reio, Dillon	Graduate Student (research assistant)
Schulte, Nicholas	Graduate Student (research assistant)
Servais, Shelby	Graduate Student (research assistant)

Name	Most Senior Project Role
Strickland, Bradley	Graduate Student (research assistant)
Unthank, Kalli	Graduate Student (research assistant)
Venketasan, Anjana	Graduate Student (research assistant)
Garcia Estiu, Claudia	Undergraduate Student
Maxberry, Imani	Undergraduate Student
Simon, Matthew	Undergraduate Student
Unger, Steven	Undergraduate Student
Adair, Kenneth	Research Experience for Undergraduates (REU) Participant
Castrillon, Katherine	Research Experience for Undergraduates (REU) Participant
Fernandez, Marco	Research Experience for Undergraduates (REU) Participant
Fuentes, Andrew	Research Experience for Undergraduates (REU) Participant
Morales, Kristina	Research Experience for Undergraduates (REU) Participant
Nanez, Steven	Research Experience for Undergraduates (REU) Participant
Sola, Andres	Research Experience for Undergraduates (REU) Participant

Partner Organizations

Name	Location
Clark University	Worcester, Massachusetts
College of William & Mary	Williamsburg, Virginia
Dartmouth College	Hanover, New Hampshire
Encounters in Excellence, Inc.	Miami, Florida
Everglades Foundation	Palmetto Bay, Florida
Everglades National Park	Homestead, Florida
Florida Atlantic University	Boca Raton, Florida
Florida Gulf Coast University	Fort Meyers, Florida
Florida State University	Tallahassee, Florida
Indiana University	Bloomington, Indiana
Louisiana State University	Baton Rouge, Louisiana
Miami-Dade County Public Schools	Miami-Dade County, Florida
National Aeronautics and Space Administration	Pasadena, California
National Audubon Society - Tavernier Science Center	Tavernier, Florida
National Oceanic and Atmospheric Administration - AOML	Miami, Florida
National Park Service - South Florida/Caribbean Network	Palmetto Bay, Florida
Pacific Northwest National Laboratory	Richland, Washington
Plymouth State University	Plymouth, New Hampshire
Sam Houston State University	Huntsville, Texas

Name	Location
South Florida Water Management District	West Palm Beach, Florida
The Deering Estate	Miami, Florida
The Pennsylvania State University	University Park, Pennsylvania
University of Alabama	Tuscaloosa, Alabama
University of California, Berkeley	Berkeley, California
University of California, Los Angeles	Los Angeles, California
University of Central Florida	Orlando, Florida
University of Florida	Gainesville, Florida
University of Georgia	Athens, Georgia
University of Hawaii at Manoa	Honolulu, Hawaii
University of Miami	Coral Gables, Florida
University of South Florida	Tampa, Florida
University of South Florida St. Petersburg	St. Petersburg, Florida
USGS	Reston, Virginia
Yale University	New Haven, Connecticut
Zoological Society of Florida	Miami, Florida

Impacts

Impact on the development of the principal disciplines

FCE science is integral to understanding the long-term dynamics of coastal estuaries, and we have particularly advanced comparative coastal ecosystem studies through research in the tropics. Through a leveraged grant from NASA, we are contributing the global blue carbon assessment, and studies of organic matter processing in FCE have especially advanced these estimates because of our more thorough understanding of the relative importance of nutrients in controlling net carbon storage in reduced and oxidized environments in the face of sea level rise. In addition, our intensive work in the FCE mangrove ecotone has emphasized the importance of long-term research to understand complex functional and structural processes influence by natural and human disturbances not only in the neotropics, but also in other tropical and subtropical latitudes around the world. Mangrove restoration is currently one of the most active management strategies to recuperate mangrove areas around the world. Our current work in the FCE has been used in the design and operation of mangrove restoration projects currently underway in the Yucatan Peninsula, Mexico and has informed currently work in a NSF funded project in Tanzania to assess poverty traps as a mechanism influencing mangrove ecosystem services.

Impact on other disciplines

FCE science is informing socio-ecological solutions to global challenges, such as sea level rise and current interdisciplinary research of urban resilience to extreme events. FCE researchers are working closely with architects, designers, communications specialists, and computer scientists to develop user-friendly tools for the resource managers and the general public to use to visualize the outcomes of decisions under different future scenarios. FCE hydro-ecological models are being translated into video game platforms to provide an augmented reality experience with the goal of aiding in decision-making to create a more resilient South Florida. Social scientists will be studying the impact of these next generation tools on policy decisions.

Impact on the development of human resources

Professional and Pre-Service Teachers

FCE researchers are also working with the FIUteach program to provide professional development to K-12 teachers in Miami Dade County Public Schools (MDCPS). In June 2016, FCE teamed up with The National Tropical Botanical Garden (NTBG) to offer the *Kampong's Science Teachers Enrichment Program (K-STEP)* at NTBG's mainland garden, The Kampong. Similar in design to the *2015 Advanced Placement Summer Institute (APSI)*, the 2016 *K-STEP* program was offered to 16 middle and high school science teachers representing 13 local schools.

During the the week-long K-STEP program, participants were led on three field trips and had the opportunity to work with botanical experts in conservation biology, ethnobotany, and economic botany. On one of the field trips, NTBG scientists introduced teachers to the local resources

available at the Kampong and led a tour at *The Preston B. Bird & Mary Heinlein Fruit & Spice Park* where they explored some of the locally important agricultural crops and the history of agriculture in South Florida. After returning to the Kampong, Dr. John Kominoski gave an overview of FCE research and examined some of the key FCE datasets. The next day, participants met Dr. Kominoski at the Ernest Coe Visitor Center, where they boarded a bus for a guided tour of Everglades National Park. The tour made several stops along the salinity transition zone of the southern Everglades where they made observations, discussed Everglades ecology, FCE research, and many of the issues facing the Everglades ecosystem.
After returning to The Kampong, the teachers used the remainder of the week to work with the FCE Education & Outreach Coordinator to develop inquiry-based, environmental science lessons to use in their classrooms. The week concluded with an airboat tour of the upper Shark River Slough and participants received a $500 stipend upon submission of a completed lesson plan.

K-12 Students

FCE scientists are also mentoring exceptional K-12 students through the Research Experience for Secondary Students (RESSt) program. Over the last year, five of our scientists have formally mentored six students, from four public schools, in Miami Dade and Indian River Counties, totaling 15 semester units (SU) of mentoring. Dr. Thomas Frankovich mentored Gustavo Brugger of Sebastian River Middle School, who was 2nd Place Winner, in the Junior Division of the Earth and Environmental Sciences category at the 61st State Science and Engineering Fair of Florida for his project entitled *The Effects of the Sebastian River on Phytoplankton Growth in the Indian River Lagoon*.
Many of our other scientists continue to volunteer with the Miami Dade County Public Schools STEAM initiatives—four have served as judges in the South Florida Regional Science and Engineering Fair and six were members of the MDCPS Intel International Science and Engineering Fair selection committee.

REU

In 2015, Dr. John Kominoski mentored Kristina Morales, in a research project studying the effects of elevated salinity and phosphorus on organic carbon dynamics in freshwater marsh soils. As part of the project, Kristina developed a mesocosm experiment to manipulate nutrient concentrations across salinity and phosphorus gradients. The soils were incubated for 5 weeks, with repeated measures to detect changes in microbial respiration, microbial biomass, microbial extracellular enzyme activities, and soil C:nutrient (N and P) ratios. Kristina presented her results at the Department of Biological Sciences' Biology Student Symposium where she was awarded an undergraduate research scholarship from the Society of Wetland Scientists (SWS) Multicultural Mentoring Program.

In 2016, Dr. Jennifer Rehage mentored two REU students. REU Virginia Fourqurean compared seasonal space use among top and mesoconsumers in the Shark River (Common snook vs. American alligator). She used data collected by the USGS on space use of alligators and compared it to long term LTER data on snook. Her project found some correspondence on the seasonal distribution of these consumers. Virginia presented the results of her study at the 2015 ASM meeting, and her work has jump started a collaboration between LTER and the USGS on consumer dynamics.

Kenneth Adair used his REU opportunity to study stable isotopes in an examination of how a coastal recreational fishery species (Common snook) uses resources across space, and out of spawning habitats. Kenneth analyzed fin clips from snook for C, N and S isotopes to examine trophic placement, energy sources and marine contribution to diets across space. Kenneth and Dr. Rehage are planning to continue sampling through next year and working together on submission of a manuscript.

Improving Retention of Underrepresented Groups
In an effort to recruit and retain Hispanic students into STEM careers, FIU hosted the 2016 Hispanic Association of Colleges and Universities (HACU) Youth Leadership Development Forum (YLDF). Nearly 500 MDCPS students from nine high schools attended the HACU-YLDF on October 9, 2015. The annual event is designed to encourage students to consider STEM careers by engaging them in active, hands-on learning experiences and were led on tours of three FCE labs where they had the opportunity to learn about FCE research from Drs. Evelyn Gaiser, John Kominoski, and Jennifer Rehage.

Development of New Educational Materials
FCE scientist, Joseph Stachelek developed a new R package that enables scripted access to the South Florida Water Management District's (SFWMD) DBHYDRO database. The package is able to pull water quality and hydro data directly from DBHYDRO into R with a fast, reproducible, and scalable design. The package can be viewed at https://github.com/SFWMD/dbhydro. The landing page README describes the installation process and basic package usage with more detailed instructions available in the built-in package documentation or vignette (https://cdn.rawgit.com/SFWMD/dbhydro/master/inst/doc/dbhydroR.pdf).

Citizen Science
The FCE Citizen Science program continues to consist of two major initiatives: Predator Tracker and CAST. Introduced as part of the Living in the Everglades exhibit at the Ft. Lauderdale Museum of Discovery and Science. Predator Tracker allows museum patrons and website visitors to track Everglades predators such as alligators and bull sharks over the internet through Predator Tracker (http://tracking.fiu.edu). The research is also discussed in the episode *Coastal Carnivores* (26 min) as part of the PBS series *Changing Seas*.

FCE's CAST: Coastal Anglers Science Team remains a central theme for our outreach tabling events. The CAST activity models the mark and recapture technique used to estimate population size and is used to discuss how changes in the Everglades impact coastal fisheries.

Network Activities
Evelyn Gaiser and John Kominoski attended the 2015 Science Council meeting in Santa Barbara, California. Kominoski led working group activities centered around cross-site synthesis. Gaiser and Kominoski are hosting a distributed graduate seminar in Fall 2016 to advance ecological theory through LTER. They also hosted a blog-developer from the LTER NCO. In 2015, Nicholas Oehm completed his three-year term as Co-Chair of the LTER Education and Outreach Committee (EOC). As the FCE Education & Outreach Coordinator, he continues to participate in monthly, online Zoom meetings with the EOC. In the absence of his responsibilities as EOC

Co-Chair, he has increased participation in the Communication Committee, Diversity Committee, and has been working on cross site initiatives through LTER RET Information Share meetings.

Impact on information resources that form infrastructure

There was a change in membership on the FCE Information Management (IM) team this year for the first time since the project's inception in 2000. FCE Information Manager Linda Powell retired in April 2016, and Kristin Vanderbilt was hired to replace her. Kristin brings diverse LTER experience to her new role at the FCE. She was the IM for the Sevilleta LTER for sixteen years, and prior to that conducted research at the H.J. Andrews LTER while earning her Ph.D.

The IM team (K. Vanderbilt and M. Rugge) continue to support site and network level science by making high quality FCE data and metadata accessible through the FCE LTER website and the LTER Network Data Portal. Updates to long-term data sets are regularly published in both locations in compliance with the FCE Data Management Policy and LTER Data Access Policy. FCE LTER now has 156 data packages in PASTA. The FCE IM also contributes to cross-site LTER databases ClimDB, HydroDB, PersonnelDB, and SiteDB to keep them current. The FCE IM team lends its expertise to researchers by providing assistance with metadata development, data submissions, individual project database design, collaborations on GIS work and research graphics.

IT Infrastructure

The FCE information management system (IMS) Web server, Oracle 12C database and FTP server are loaded on four (4) virtual servers housed on Florida International University Division of Information Technology's (UTS) equipment. The FCE III Disaster Recovery Plan calls for data to be backed up offsite at the Northwest Florida Regional Data Center (NWRDC) located on the campus of Florida State University in Tallahassee, Florida. This allows the FCE website and Oracle 12c database to be continually available throughout disaster events such as hardware failures and hurricanes.

Two significant changes occurred in FCE LTER Infrastructure this year. Linda Powell migrated the Oracle database from version 11g to 12c in February 2016. In addition, some of the returned F&A from the 2016 LTER equipment supplement was used to purchase two Synology NAS devices, which increase local FCE backup storage from 2TB to 27TB.

FCE III Website and Data Archives

The FCE web site provides outstanding support for site and network science. FCE project information and minimal research data metadata are stored in an Oracle12c database that drives the FCE website. The site's homepage (http://fcelter.fiu.edu) design provides a simple, user-friendly gateway to a wealth of information ranging from the FCE LTER project overview to a searchable database of FCE publications to links to the quarterly FCE LTER newsletter "News from the Sloughs." Scientists seeking data may select from FCE LTER Data Products, LTER Network Data, and Outside Agency Data, where links are available to multiple external databases. FCE Core Research Data are searchable through a sophisticated interface. The FCE Data Summary Table for each data set displays a link to complete metadata and a link to download the data. The data set citation, including the DOI as generated by PASTA, is also displayed. This summary table also links to a web-based data visualization tool that allows researchers to rapidly visualize complex data streams and to efficiently process and annotate data.

Goals

1) Add related publications and data sets to the summary table for each FCE data set.
2) Work with FCE researchers to quantify uncertainty/error in existing data sets and include this information in the data abstracts and dataset metadata
3) When FCE data sets are updated in PASTA, use PASTA web services to auto-populate some fields in the local Oracle database

Impact on society beyond science and technology

FCE science is informing social-ecological solutions to global challenges, such as sea level rise as well as current interdisciplinary research of urban resilience to extreme events. Jeff Onsted and Rene Price participated in the panel discussion for the American Institute of Architect's Collaborative Design for Sea Level Rise discussion on February 24, 2016 in Miami, Florida. Evelyn Gaiser helped lead the planning and implementation of the Sea Level Solutions Center at FIU through weekly planning meetings and workshops. She also engaged municipalities in scenario development for building resilience to sea level rise and fostered partnerships with the City of Miami Beach and Southeast Florida Climate Compact through teach-ins, engagement workshops and planning meetings. Henry Briceno and others have contributed FCE science to understanding the human health consequences of runoff into pristine coastal waters from urban Miami-Dade County.

FCE scientists are contributing data to assess the status of the Comprehensive Everglades Restoration Plan, attending science meetings with resource managers on a regular basis. Evelyn Gaiser led the Service to Activism workshop focused on Everglades Restoration for the FCE LTER with co-host Senator Bob Graham in the fall of 2015. Stephen Davis gave Congressional Staff tours and extended educational briefings on the health of the Everglades and status of Everglades restoration, which involved FCE Scientists and discussion of FCE Science on March 30-April 1, 2016. He also gave an educational briefing and tour of Florida Bay with Monroe County Mayor Heather Carruthers and Islamorada Mayor Deb Gillis (June 20, 2016) and Florida State Senator Anitere Flores (August 23, 2016).

We have used the knowledge and conceptual framework of the FCE to guide and implement large-scale wetlands restoration projects elsewhere, particularly the Gulf of Mexico deltas. For example, Victor Rivera-Monroy (collaborator) is currently participating in the CNH: Coupled Natural-Human Dynamics in a Vulnerable Coastal System (NSF-1212112) project. In addition, FCE work has also informed funding priorities regarding climate change research needs as defined by the South Central Climate Science Center. Victor Rivera-Monroy is currently a collaborator in this initiative in the Gulf of Mexico coastal region.