PROJECT DESCRIPTION

1. RESULTS OF PRIOR LTER SUPPORT

History and Growth of the FCE LTER Program: The Florida Coastal Everglades (FCE) LTER Program is dedicated to long-term studies of how changing patterns of freshwater availability interact with climate variability to affect ecosystem structure and processes in the estuarine ecotone regions of the coastal Everglades. Our research domain is the remnant of a once-larger Everglades ecosystem, the majority of which has been profoundly transformed through regional water management practices and altered patterns of land use, providing an excellent laboratory for studying how coastal ecosystem dynamics respond to, and influence, human activities. By emphasizing long-term studies in the context of a landscape-level experiment (Everglades restoration), our research continues to inform key issues, test general theory, and develop new frameworks for discoveries in coastal ecosystem and restoration science. FCE research is highly trans-disciplinary, and has grown to include 86 Ph.D.-level scientists, 58 students, and 21 technical staff from the fields of anthropology, climatology, ecology, hydrology, geochemistry, political science, and modeling, from its base at Florida International University (FIU) and 34 other universities, key state and federal agencies, and NGOs (http://fcelter.fiu.edu/about_us/personnel/).

FCE research began in 2000 with a focus on providing an understanding key ecosystem processes while also developing a platform for and linkages to related work in the wider Everglades research community. Our primary research objective was to determine how freshwater from oligotrophic marshes interacts with a marine source of the limiting nutrient, phosphorus (P), to control productivity in the oligohaline ecotone – the zone where freshwater and marine supplies meet in the coastal Everglades. We hypothesized that ecosystem productivity would be greatest where freshwater supplies, higher in nitrogen and dissolved organic matter (DOM) (relative to coastal waters), meet marine waters where P is more available. A Lagrangian sampling design was established to allow us to track water flow and ecosystem properties along the main Everglades drainages, Taylor Slough-Panhandle (TS/Ph) and Shark River Slough (SRS), from freshwater canal inputs to the Gulf of Mexico. Our research showed the existence of a productivity peak in the oligohaline ecotone of the TS/Ph transect, due to brackish groundwater delivery of P to ecotone plant communities (Price et al. 2006). In contrast, the SRS transect exhibited a wedge of increasing productivity toward the coast (Ewe et al. 2006), where tidal influences were greatest. This work demonstrated how the Everglades are functionally "upside-down" relative to the classic estuary model, with seawater supplying limiting nutrients landward, rather than the other way around (Childers et al. 2006a; comprehensive review in Trexler et al. 2006) (Fig. 1.1). These findings led us to further expand our trans-disciplinary research examining how freshwater flow restoration interacts with climate variability to influence the shape of this productivity gradient.

Results from FCE II: Since 2007, FCE produced 226 publications, including 178 refereed journal articles, 2 books, 16 book chapters, 3 thematic issues of journals, and 30 dissertations and theses (see http://fcelter.fiu.edu/publications/ for a full list). Extramural funding leveraged for FCE II research was $33.5M (~14-fold greater than the NSF budget for core activities). Here, we summarize results from FCE II, highlighting 10 key papers (cited in **bold**) in the context of describing our past and planned research.

FCE II Research Findings: In our 2006 proposal, we framed hypotheses that could be tested through restoration projects aimed at enhancing freshwater inflow to SRS but not to TS/Ph during this period. This landscape-scale manipulation provided a "*Grand Experiment*" to test three core hypotheses:

H_1) Increasing inputs of freshwater will enhance oligotrophy in nutrient poor coastal systems, as long as the inflowing water has low nutrient content;

H_2) Increasing freshwater inputs will increase physical transport of detrital OM to the oligohaline ecotone, which will enhance estuarine productivity; and

H_3) Water residence time, groundwater inputs, and tidal energy interact with climate and disturbance regimes to modify ecological patterns at the oligohaline ecotone.

Although these hypotheses remain central to FCE, restoration plans did not proceed as expected: anticipated projects were stalled and reduced in scope, and new projects were considered. In lieu of a

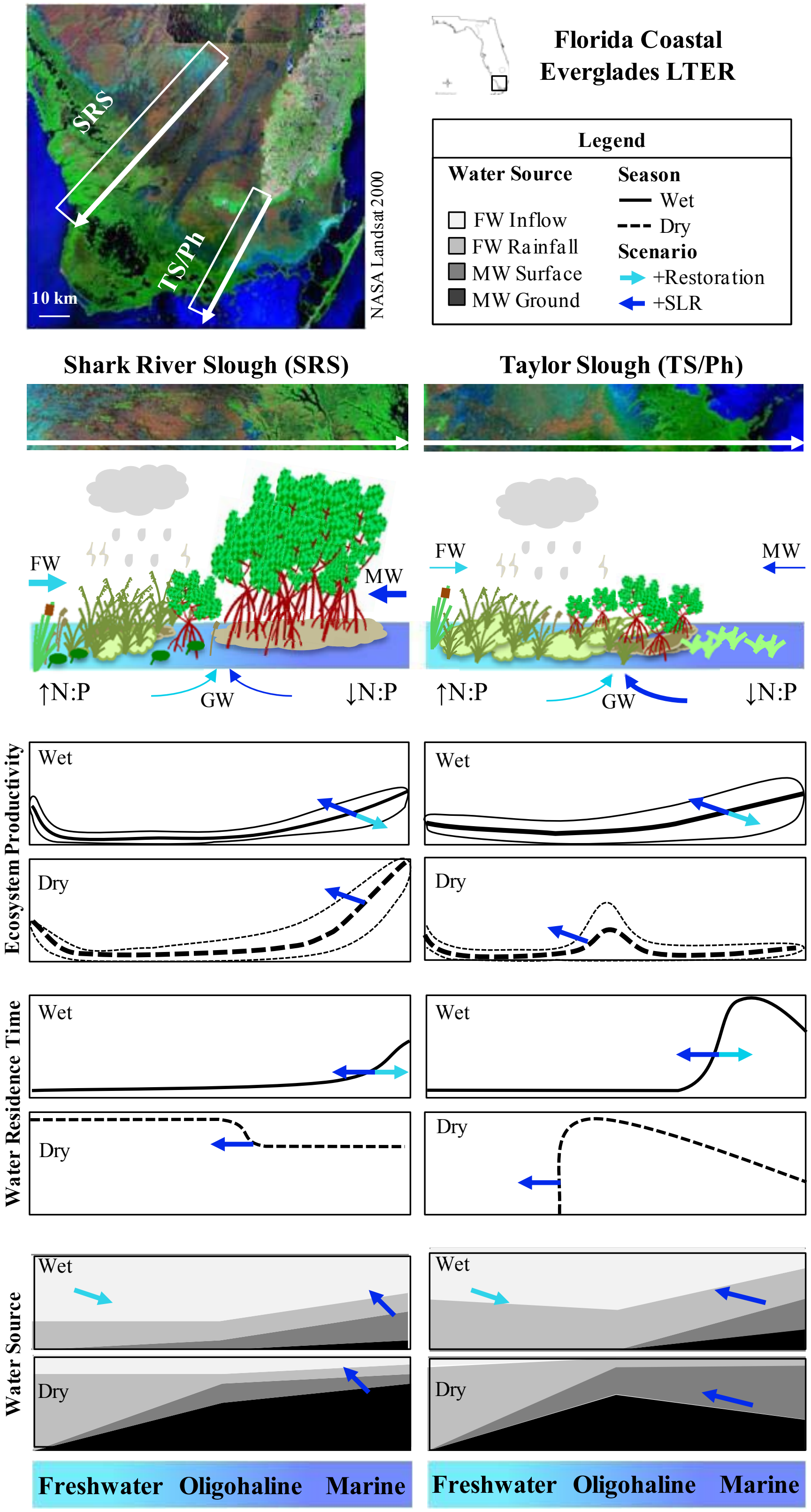


Fig. 1.1. Satellite image (*above*) of Shark River Slough (SRS, *left panels*) and Taylor Slough (TS/Ph, *right panels*) drainages in South Florida with illustration of water sources and distribution of primary producers along the freshwater-oligohaline-marine gradient. In FCE II, we hypothesized that freshwater (FW) inflows resulting from freshwater restoration (*light blue arrows, productivity panels*) would shift the productive coastal zone toward the marine water (MW) of the Gulf of Mexico along the SRS transect during the wet season (*solid lines*), relative to its position in the dry season (*dashed lines*), due to a coastward movement of the severity of P-limitation. In TS/Ph, landward groundwater (GW) discharge of P during the dry season causes a productivity peak in the oligohaline ecotone that also shifts coastward when counteracted by seasonal or restored freshwater inflow. We showed how in the absence of restoration, there is significant variability in productivity (*halos around lines)* due to high inter-annual variance in wet and dry season freshwater flows and marine pulses, driven by tides and storm surge. In FCE III, we will explore how changes in freshwater inflows resulting from management decisions interact with coastal pressures of SLR and storms (*dark blue arrows*) to control the location of the productivity peak. Water residence time (WRT, *middle panels*), a key driver of landscape pattern, reflects seasonal inflows in the SRS freshwater marsh and tidal flushing in the ecotone. In TS/Ph, WRT is long when upstream marshes are dry, and tides have minimal impact on the ecotone. The relative influence of four main water sources driving oligohaline ecotone dynamics varies in the wet and dry seasons (*bottom panels*), which may be enhanced by the opposing scenarios of freshwater restoration and SLR, respectively. The major difference between the two transects is in the ecotone, where groundwater has a substantial impact in the TS/Ph compared with the SRS transect.

"*Grand Experiment"* during the FCE II time frame, we examined our hypotheses in alternate ways: 1) by using high seasonal and inter-annual variability in freshwater delivery to our ecosystem as a short-term proxy for restoration; 2) by examining whether delays in freshwater restoration cause the converse patterns (i.e., reduced oligotrophy in and detrital transport to the ecotone); and 3) by comparing ecosystem dynamics between our two transects of contrasting freshwater connectivity. Restoration delays enhanced our appreciation of the value of long-term datasets for correctly interpreting the effects of management activities on a backdrop of high underlying variability in hydrodynamics and ecosystem function (e.g., Trexler & Goss 2009; Briceño & Boyer 2010). By extending the period of measurement before restoration, our LTER improved the probability of successfully employing our paired transect experimental framework now that restoration projects have begun. We summarize these findings below, organized by our 4 working group topics that provide the foundation for long-term FCE science, and 4 cross-cutting themes that drive integrative synthesis (topics are highlighted in **bold**).

In the absence of restored freshwater flows during FCE II, our **Biogeochemical Cycling** and **Primary Productivity** research addressing H_1 showed that variability in delivery of marine supplies of saltwater and nutrients, and their interaction with water residence time, primarily control production patterns across the coastal gradient. In upstream freshwater marshes, short inundation periods and severe P-limitation reduce sawgrass (*Cladium*) production in TS/Ph relative to SRS, resulting in low net ecosystem-atmosphere CO_2 exchange rates indicative of oligotrophy (Schedlbauer et al. 2010). In the ecotone, *Cladium* production is declining with increased landward brackish groundwater intrusion (Price et al. 2006; Troxler 2010), while commensurate delivery of P is stimulating mangrove root production (**Castañeda-Moya et al. 2011**), benthic algal P uptake and microbial release of ammonium (Gaiser et al. 2011; Twilley & Rivera-Monroy 2009), and metabolism rates in the adjacent open water (Koch et al. 2011). Our long-term research revealed that groundwater supply of P is important throughout the coastal gradient, controlling biomass allocation in Florida Bay seagrass communities, where historic P subsidies leave a permanent legacy (**Herbert & Fourqurean 2008**, 2009). The SRS ecotone is also susceptible to increasing brackish groundwater discharge (**Saha et al. 2011a**), in addition to surface water pulses driven by tides and storms. Hurricane Wilma (October 2005) delivered 3-4 cm of P-rich marine sediment into the fringing mangrove forest in SRS (Castañeda-Moya et al. 2010), which increased soil elevation relative to sea level rise (SLR), stimulated mangrove belowground production (Whelan et al. 2009), and eventually leached into the river water column (Fig. 1.2) to cause phytoplankton blooms across Florida Bay (Briceño & Boyer 2010). Data from our mangrove eddy covariance tower enabled us to document recovery of this nearly completely defoliated forest (Smith et al. 2009), to one that sequesters CO_2 at rates exceeding temperate and many tropical forests (**Barr et al. 2011**). In summary, the delays in rehabilitating freshwater flows to the Everglades have created a system where biogeochemistry and productivity in the coastal transition zone are largely driven by marine water supplies to the ecotone, *confirming extraordinary sensitivity to saltwater encroachment associated with SLR and storm activity*.

In addition to understanding how variability in freshwater and marine water supplies controls primary production, we also have a long-standing interest in their effect on **Organic Matter Dynamics** (H_2). **Yamashita et al. (2010)** showed how the ecotone receives OM subsidies from considerable distance upstream, particularly during large runoff events (Xu & Jaffe 2007), supporting our hypothesis that increased freshwater inflows influence OM delivery to estuaries. Although biodegradation of particulate OM generated by freshwater Everglades marshes is P-limited and slow, photo-degradation is an important source of humic DOM and nutrients to the ecotone (Pisani et al. 2011; Shank et al. 2011). We also found that marine-derived DOM from seagrass communities arrives to the ecotone during tides and storms (Maie et al. 2005, 2006), and from landward groundwater delivery during the dry season (Chen et al. 2010). Our **Trophic Dynamics** research used biomarkers to explore the fate of OM in the food web, and determined its transport by mobile consumers using acoustic tracking arrays. Analysis of the fatty acid composition of primary benthic consumers showed detritus, rather than primary production, to be a strong, direct contributor to diets (Belicka et al. 2012). Consumer and prey distribution studies showed how availability of detritivores, along with the patterns of water distribution and salinity on the landscape, regulate the distribution of secondary consumers (Rehage & Loftus 2007; Jopp et al. 2010;

Obaza et al. 2011; Rehage & Boucek, in review). We found that many large estuarine consumers, such as alligators and bull sharks, spend much of their time in the low-salinity ecotone while traveling to marine waters to feed (**Rosenblatt & Heithaus 2011**; Matich et al. 2011), thereby transporting marine energy upstream (Heithaus et al. 2009). Our research on detrital and consumer transport converges with our biogeochemical and productivity findings in the way that it *illustrates how connectivity to marine habitats influences the dynamics in the estuarine ecotone in the absence of significant freshwater flows*.

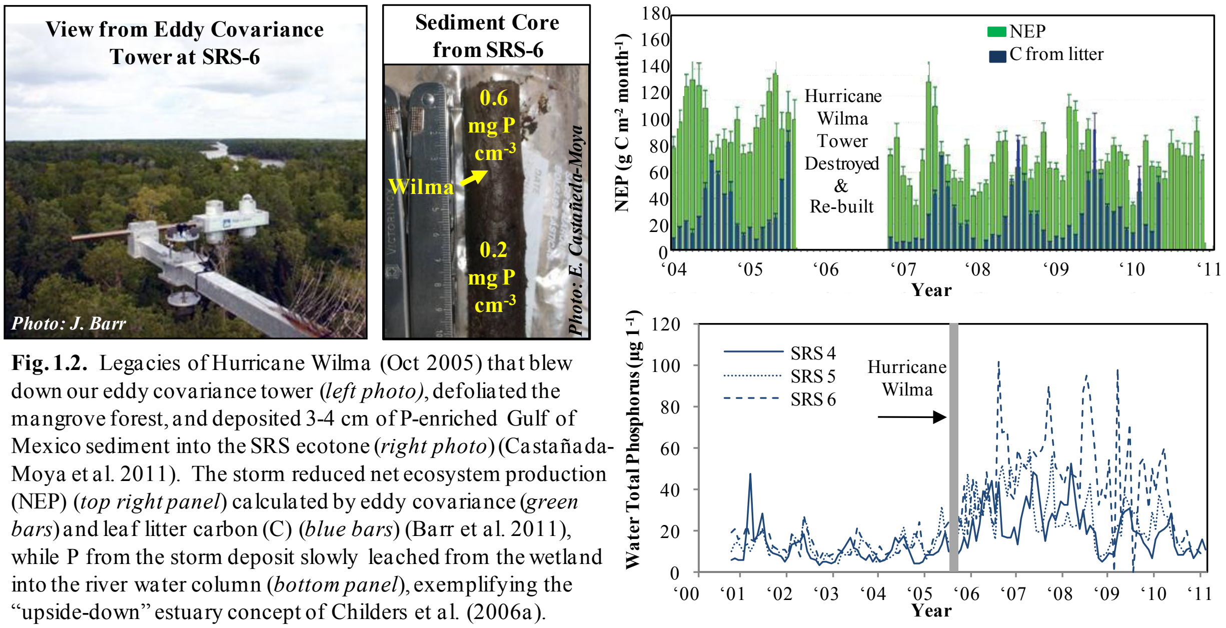


Fig. 1.2. Legacies of Hurricane Wilma (Oct 2005) that blew down our eddy covariance tower (*left photo)*, defoliated the mangrove forest, and deposited 3-4 cm of P-enriched Gulf of Mexico sediment into the SRS ecotone (*right photo*) (Castañada-Moya et al. 2011). The storm reduced net ecosystem production (NEP) (*top right panel*) calculated by eddy covariance (*green bars*) and leaf litter carbon (C) (*blue bars*) (Barr et al. 2011), while P from the storm deposit slowly leached from the wetland into the river water column (*bottom panel*), exemplifying the "upside-down" estuary concept of Childers et al. (2006a).

Realizing that effects of restored freshwater flows through the Everglades would eventually be experienced on a template of high natural variability in water supply, our **Climate and Disturbance** and **Hydrology** cross-cutting research addressed (H_3) to determine the temporal dynamics of water delivery to the ecotone and its impact on ecosystem processes. Temporal variability in water delivery is both periodic (e.g., tides, subtropical seasonal weather patterns, and ocean-atmospheric teleconnections) and pulsed (e.g., cyclones and associated storm surge). The pulses punctuate the directional pressure of saltwater encroachment driven by SLR and the continued diversion of freshwater away from the Everglades drainages. To characterize the variation in water source, we developed the first water balance for the two Everglades drainages, finding that while precipitation and evapo-transpiration control the annual water budget in both sloughs, 20-30% of inputs come from groundwater (Zapata-Rios 2009; **Saha et al. 2011a**; Zapata-Rios & Price, in review), and <20% from upstream freshwater sources (He et al. 2010). Landward discharge of brackish groundwater causes a dry-season increase in salinity in both transects (Barr et al. 2009; Zapata-Rios & Price, in review), and the position of this groundwater mixing zone is moving inland (Saha et al. 2011a,b). Highly variable water residence times reflect seasonal precipitation patterns, which are partly driven by long-term cycles that regulate winter rainfall in South Florida (Moses et al. 2012). Cyclical patterns in water delivery to the upstream watershed (Gaiser et al. 2009) appear to correlate with trends in the paleosalinity in Florida Bay (Wachnicka et al. 2012a), suggesting that local climate patterns control, to some degree, the high sensitivity of southeastern Florida coastal marshes to past and ongoing management. *In 11+ years of FCE research, we have shown pronounced and persistent sensitivity of the flat South Florida landscape to SLR and storms, exacerbated by continued diversion of freshwater delivery away from the Everglades ecosystem.*

The delays and changes in scope of Everglades restoration experienced during FCE II underscored the importance of understanding the role of water in the sociopolitical environment, so we instituted a **Human Dimensions** theme to address how and why land and water use in South Florida has changed (Roy Chowdhury et al. 2011). Anthropological research is providing a better understanding of how past decisions about Everglades land and resource allocations shape contemporary stakeholder conflicts related to restoration (Ogden 2008). Research in political ecology exposed the role of the sugar industry in transforming wetlands (Hollander 2008), while **Ogden's (2011)** research on human activities in the Everglades interior revealed the great extent to which human and environmental histories are intertwined. *We now have a solid foundation for building a greater capacity in human dimensions research to explore how legacies of resource use decisions shape both the existing environment as well as future socio-ecological response to rapid climate and land-use change in this highly vulnerable landscape*. Our mid-term review team encouraged this expansion, noting that the FCE trans-disciplinary framework should generate "*textbook examples of research integrating natural and social sciences*."

Throughout its history, FCE has emphasized integrative **Synthesis and Modeling** efforts, becoming a clearinghouse for hydrodynamic, socio-ecological, and ecosystem models that have helped sythesize our empirical findings and formulate new hypotheses. Specific developments include the creation of dynamic water budgets linking key meteorological drivers to hydrodynamics (Saha et al. 2011a), and models linking hydrodynamics to nutrient cycling and vegetation dynamics (Rivera-Monroy et al. 2011) and consumer distribution, movement, and feeding (**DeAngelis et al. 2010**). We also calibrated a land-use change model to forecast the consequences of urban growth in South Florida (Onsted & Roy Chowdhury, in review). A major contribution of FCE modelers to the South Florida research community is a synthesis of the diverse modeling tools available for this ecosystem (Onsted et al., in review), *providing a blueprint for addressing holistic questions about how the South Florida socio-ecological system responds to change across multiple spatio-temporal scales*.

Broader Impacts and Synthesis Activities:

FCE Education, Outreach and Diversity: Our Education & Outreach program communicates our research findings to K-12 students, teachers in the South Florida community (which is over 60% Hispanic), and more broadly through a variety of programs that educate the public about the ecology and importance of the Everglades (http://fcelter.fiu.edu/education_outreach/). These include a children's book, quarterly site newsletters, museum exhibits, television segments, a website, videoconference presentations, a high school student internship program, and classroom presentations. The FCE II program included 26 formal Research Experience for Undergraduates (REUs), and over 46 informal undergraduate internships in 11 labs, at seven institutions. The FCE graduate student association is extremely active in LTER research and programmatic development, undergraduate and high school student mentoring, and has spearheaded LTER Network science initiatives (including organizing two symposia at the 2009 LTER Network All Scientists Meeting). In addition to public outreach, FCE has been a leader in the "co-production" of research with agency scientists and decision-makers since its inception, and these direct collaborations and partnerships with federal, state and local government agencies, and NGOs have helped FCE become a critical "hub" for Everglades restoration science and a global example for the successful conveyance of science into restoration policy (Doren et al. 2009a). The research findings described above resulted from this co-production and their policy implications and outcomes are studied as a core component of our research.

Synthesis, Cross-Site and Network-Level Activities: FCE scientists are committed to synthesis activities, and have produced a number of documents in FCE II that integrate our research in ways that speak to general ecological theory as well as set the stage for FCE III research. These include book chapters providing the conceptual framework presented here (**Gaiser et al. 2012**) and a context for comparative research on wetland conservation (Rivera-Monroy et al. 2012a), and three special journal issues presenting our developing perspectives on communicating restoration science to policy makers (Doren et al. 2009a, *Ecological Indicators*), ecology and management of wetlands and estuaries (Fourqurean et al., in review (a), *Marine and Freshwater Research*), and South Florida paleoclimatology (Anderson & Gaiser, in review, *Journal of Paleolimnology*). In addition, our comparative, trans-disciplinary research on mangrove forests has transformed the perspective of the importance of subtropical coastal wetlands to the global carbon (C) budget (**Bouillon et al. 2008a**), and accentuated the global significance of quantifying C losses through lateral transport in estuary ecosystems (Barr et al. 2010).

FCE scientists, students, and staff have been active in LTER Network leadership and research (http://fcelter.fiu.edu/research/cross-site_network/) including serving on 22 Network committees as participants and leaders (e.g., Social Science, Communications, Education, ILTER, All Scientist Meeting planning, and heavily on the Network Information Systems Advisory Committee). FCE II collaborators have participated in or led over 20 cross-site scientific workshops, catalyzing comparative science within the LTER Network and internationally. We helped coordinate meetings with other coastal sites that led to the comparative research framework presented here, spearheaded the establishment of an LTER Caribbean Hurricane Research Network (Calderon-Aguilera et al. 2012; Rivera-Monroy et al., in review), and led studies of patterns and consequences of land-use change in neighborhoods in the context of other residential landscapes in America (Roy Chowdhury et al. 2011). These activities have resulted in 16 funded cross-site research projects, including expanding international partnerships with the MexLTER for comparative studies in karstic wetlands of the Yucatan, Mexico (Gondwe et al. 2010; La Hée et al. 2012), and with collaborators in Shark Bay, Australia (Fourqurean et al., in review (a)), where we have discovered similar "upside-down" estuaries.

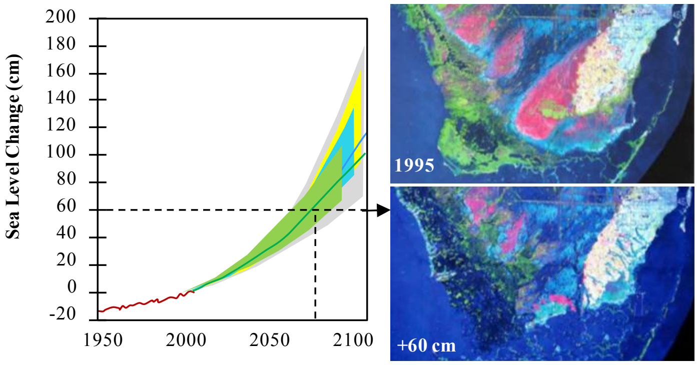
FCE II Supplemental Support: In addition to supporting educational, outreach, cross-site, and international activities, we have used supplemental support to enhance our site infrastructure, including updating our data servers, and maintaining weather stations, eddy covariance towers (one mangrove and two marsh), aquatic sensors, and acoustic tracking arrays. We also used 2011 supplemental funds to establish a sensor information management system to obtain, organize, and analyze high resolution automated data from our growing suite of sensors, which will support FCE research as well as be disseminated to the wider community through coordinated LTER sensor network workshops.

2. PROPOSED RESEARCH

A. Introduction and Background

Climate change poses an unprecedented threat to coastlines by exposing >50% of the human population and vulnerable coastal ecosystems to changes in temperature, rainfall, storm activity, and sea level rise (SLR), which are already having devastating impacts on coastal systems around the globe (Nicholls et al. 2007). Direct effects of climate change on coastal ecosystems are manifest in losses in wetland extent and function as rates of SLR exceed their natural capacity to adapt (Gedan et al. 2011), while human communities are affected through loss of life and livelihood, increased costs of disaster mitigation and recovery, salinization of drinking water supplies, and intensified social vulnerabilities (Crate & Nuttall 2009; Oliver-Smith 2009). Possibly even more important are the effects of climate change on the interactions between humans and natural ecosystems, as growing coastal human populations further 'squeeze' coastal ecosystems by converting wetlands to agriculture and diverting freshwater for human use, diminishing the capacity for coastal wetlands to re-hydrate increasingly saline aquifers with clean water, sequester CO_2, buffer storms, and provide other services upon which humans depend (Doody 2001). Despite these threats to coastal communities, pressures are largely unmitigated, partly attributable to misunderstandings of human-resource dependencies, political agendas, nonlinearities in driver-response relationships, and uncertainties about sources of change and future prognoses (Jasanoff 2004; Hobbs & Suding 2009). We need to understand how coupled human-natural systems at this land-sea interface are jointly vulnerable to climate change through deliberate integration of long-term socio-ecological research. Persistent investigations of hydrologic, biogeochemical, sedimentary, and biotic cycles in the coastal zone are critical as they reveal ways in which coastal communities are vulnerable to, and mediate, pressures and disturbances operating at local, regional, and global scales. Resultant improved understanding of these vulnerabilities and feedbacks must also be used to assist coastal resource management through reliable forecasting of ecological and human systems.

The FCE LTER program is located on the South Florida peninsula, in a shallow-sloping (3-6 cm km^{-1}) basin underlain by a highly transmissive limestone aquifer that is exceptionally exposed to SLR, storm surges, and changes in freshwater inflows (Titus & Richman 2001; Price et al. 2010) (Fig. 2.1). This basin contains Everglades National Park (ENP), the third largest wilderness area in the continental U.S. (6110 km^2), as well as six million residents, generating complex socio-ecological dependencies and joint vulnerabilities. The Everglades has lost nearly half of its original extent due to land conversion and diversion of freshwater into 2500 km of canals (Davis & Ogden 1994). Changes in freshwater distribution threaten the persistence of the features for which the Everglades is characterized, including endemic species, distinctive habitats and functions (Jopp & DeAngelis 2011), and key interactions with humans both inside and outside wetland boundaries (Ogden 2011). Reduced freshwater delivery to the coastal zone and SLR are accelerating coastal transgression (Ross et al. 2000, 2002; Krauss et al. 2011; Saha et al. 2011b) (Fig. 2.2), and adjacent urban areas are experiencing residential water use restrictions. The Comprehensive Everglades Restoration Plan, approved in 2000, was intended to reverse some of these trends, but has stalled due to considerable technical, economic, and political challenges. At the same time, South Florida is ill prepared to mitigate effects of, or adapt to, SLR, threatening the future of sustainable water resources for both expanding populations and this distinctive wetland ecosystem (Noss 2011). *As a result, South Florida may provide one of the best examples of the sensitive balance between the pressures of SLR and increasing human demand for an increasingly limited freshwater supply, which will eventually confront coastal ecosystems worldwide.*



Sea Level Rise Projections for the FCE

Fig. 2.1. Observed and projected SLR scenarios (*left panel*), redrawn from Vermeer & Rahmstorf (2009), and a comparison of South Florida in 1995 (*top image*) with a preconstruction of the same area in ~100 years (*bottom image*) with a 60 cm SLR and no elevation change (from Wanless & Vlaswinkel 2005). The rate of SLR measured at Key West averaged over the last 100 years is 1.87 mm yr^{-1}, with a projected rise of 0.75-1.9 m expected by 2100 (Zhang et al. 2011).

Recognizing this opportunity to provide scientific guidance toward a more sustainable future for South Florida, the FCE program engages in investigations addressing a persistent theme: **In the coastal Everglades landscape, climate change and resource management decisions interact to influence freshwater availability, ecosystem dynamics, and the value and utilization of ecosystem services by people. Because they are highly sensitive to the balance of freshwater and marine influences, coastal wetlands of the Florida Everglades provide an ideal system to examine how socio-ecological systems respond to and mitigate the effects of climate change and freshwater allocation decisions.** Key discoveries since our program's inception have guided the evolution of our research approach, the development of our hypotheses, and the disciplinary breadth of our program. In FCE I, our biophysically-oriented research along the Shark River Slough (SRS) and Taylor Slough/Panhandle (TS/Ph) drainages of ENP showed how hydrodynamics, nutrient supply, and salinity are regulated by the balance of inflows from the upstream Everglades and Gulf of Mexico to create an "upside-down" productivity gradient across the landscape (Childers et al. 2006a) (Fig. 1.1). In FCE II, we expanded our hydrodynamics research to determine how the oligohaline ecotone – the zone where fresh and marine water supplies meet – would respond to restoration of freshwater flows to SRS but not to TS/Ph, in a landscape-scale experiment. We reacted to delays in restoration by refocusing on how the high seasonal and inter-annual variability in freshwater inflows interact with marine pressures (i.e., tides, storms, continued SLR) to influence dynamics in the coastal gradient (Fig. 2.2). We discovered that hydrodynamics, nutrient cycling, primary production, organic matter (OM) transport, and animal behavior are highly sensitive to this balance (see Gaiser et al. 2012 for a review), partly due to the unusual biogeochemistry of this karstic landscape that is highly oligotrophic and therefore susceptible to exogenous nutrient inputs from anthropogenic freshwater and natural marine sources (Childers et al. 2006a; Gaiser et al. 2006a). With this heightened understanding of underlying variability enabled by long-term data collection, we move into FCE III with an increased capacity to detect the influence of restoration projects that are now underway. We also recognize the critical importance of understanding the socio-hydrological underpinnings of restoration, in the context of added risks of SLR and resource demands of demotechnic growth, by expanding the Human Dimensions research developed in FCE II across all elements of our program in a socio-ecological framework. Notably, this framework will also help us to understand the dynamics and properties of emergent ecosystems under these conditions of change.

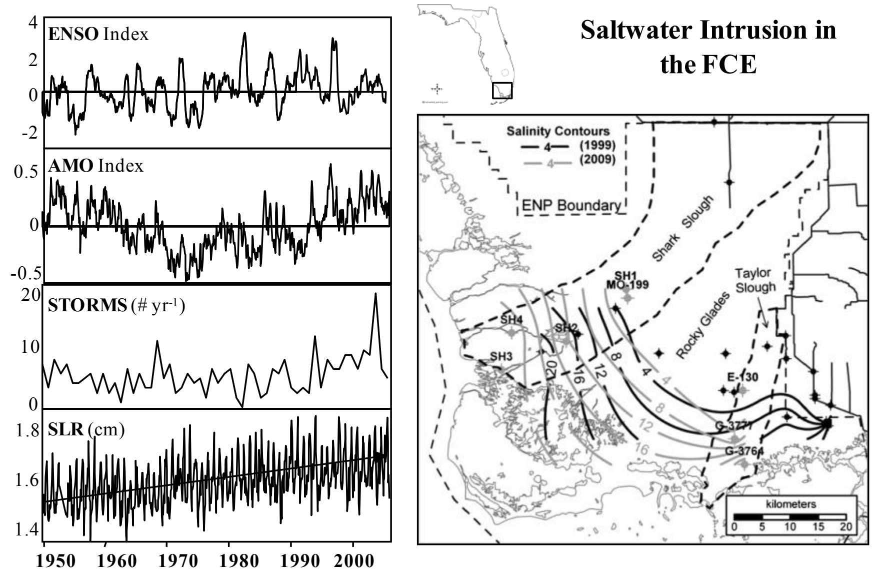


Fig. 2.2. Drivers of long-term variability in fresh and marine water sources in FCE (*left panel*) including cyclical teleconnections (El Niño Southern Oscillation (ENSO)) and the Atlantic Multidecadal Oscillation (AMO) that control rainfall patterns across South Florida (Moses et al. 2012), tropical storm activity, and SLR. Reductions in freshwater inflows and SLR are increasing saltwater intrusion in SRS and TS/Ph (*right panel),* with this example comparing LTER data from June 1999 (*black contours)* with June 2009 (*grey contours).* The contours are in increments of 4‰ and represent groundwater salinity at depth of less than 4 m. [From Saha et al. (2011b).]

We developed this new framework recognizing both the challenges and potentially transformative outcomes of integrating theory and action in complex systems (Berkes et al. 2003). This approach requires a combined understanding of how ecosystems function *and* how they are connected to social structures, decisions, and institutions across spatio-temporal scales (Carpenter et al. 2009). A key feature of socio-ecological systems is that they are continually transforming in response to changing pressures and internal feedbacks operating at local to global scales (Gunderson & Holling 2002). Resultant nonlinearities, uncertainties, and emergent properties in both pressures and internal feedbacks reduce predictability in socio-ecological systems (Norberg & Cumming 2008). This complexity can confound restoration goals unless social and ecological systems are analyzed and managed simultaneously (Seastedt et al. 2008), appreciating that connections at different spatial scales have different feedback relationships (Groffman et al. 2006), and histories that influence resilience or reorganization (Foster et al. 2003).

In South Florida, ideas that the Everglades ecosystem has been altered to one with emergent properties having no past analog (i.e., a "novel" landscape *sensu* Seastedt et al. 2008) conflict with aims to restore the ecosystem to a past target (Zweig & Kitchens 2009). Changes exhibiting positive feedbacks indicative of emergence include the loss of wetland extent and topographic patterning (Sklar et al. 2002; Watts et al. 2010), reduced cultural dependencies (Ogden 2011), and increased populations of non-native species at the expense of endemics (Doren et al. 2009b; Dorcas et al. 2012). However, while FCE research has helped identify some of these emergent properties, our comparative studies have also enabled us to recognize an expansive remnant habitat mosaic exemplary of Caribbean karstic wetlands, with distinctive species, functions, and human dependencies (Gondwe et al. 2010; La Heé et al. 2012; Gaiser et al. 2012), as well as a sensitivity to variable freshwater delivery, indicating a susceptibility to restorative action (e.g., Childers et al. 2003, 2006b; Trexler & Goss 2009). Conflicts over Everglades restoration can be attributed to reduced connectivity between scientists and managers (Folke et al. 2002) and barriers to public involvement in restoration decision making (Ogden 2006, 2008). Perhaps more critically, lack of scientific and stakeholder consensus is driven by biases associated with *uncertainty* (Loucks & van Beek 2005). Our long-term data have provided us with unique insights into the emergent dynamics of a changing system. Our future emphasis on scenarios and modeling will both contribute to theories of uncertainty in socio-ecological systems as well as provide empirically-grounded frameworks to help resource managers make better decisions for a more sustainable future.

B. Conceptual Framework: Multi-Scaled Socio-Ecology of the Everglades

We proceed into FCE III using a conceptual framework that mechanistically links "human" and "biophysical" domains (*sensu* the *Press Pulse Dynamics Model* of Collins et al. 2011) across spatial and temporal scales. Such integrated conceptual ecological models help define patterns and relationships in complex, dynamic systems while providing a means of formulating testable hypotheses at disciplinary levels to promote discoveries that reduce uncertainty (Carpenter et al. 2009). The conceptual model guiding FCE research was developed with the recognition that humans and biophysical processes are intertwined at global to local scales, and therefore retains them in the same "box" in order to understand joint vulnerabilities and relational dynamics (Fig. 2.3). Spatial scales are connected through hydrodynamics (the relative supply of fresh and marine water to South Florida), the central focus of our research. The model also can be applied in three temporal contexts (past, present, future), allowing examination of the effects of legacies on modern trends and future predictions (Chapin et al. 2001).

External Drivers: Global, regional, and local processes having "press" and "pulse" attributes control the balance of fresh and marine supplies of water to South Florida. Regionally, water balance components are highly variable, driven partly by subtropical seasonality, peninsular effects, and inter-annual patterns connected to climate oscillations (Enfield et al. 2001; Moses et al. 2012) (Fig. 2.2). This climate variability interacts with freshwater distribution decisions to determine availability on the landscape. Water distribution is controlled by complex, constantly changing federal, state, and local legislation, which can result in unseasonal flooding or droughts in both the Everglades and urban areas. Future projections for the South Florida climate include reduced rainfall and increased drought severity (although highly uncertain (Held & Soden 2006)), increased evaporation, especially near urban areas (Misra et al. 2011), reduced transpirational water losses (Lammertsma et al. 2011), and increased autumn tropical storm severity (Bender et al. 2010). Future distribution decisions will react to both climatic influences on water availability and the increasing freshwater demand from a growing Florida human population that already exceeds domestic water availability and environmental flow requirements (Ahmad & Prashar 2010), especially in coastal areas (Misra et al. 2011).

Marine influences in South Florida are controlled by proximity to and periodicity of tidal exchange, storm surge, and groundwater discharge. In addition, the shallow topographic relief exposes much of the landscape to SLR, which, combined with surface freshwater diversion into canals, has accelerated saltwater intrusion into well-fields and the Everglades (Ross et al. 2002; Gaiser et al. 2006b; Saha et al. 2010b; Krauss et al. 2011) (Fig. 2.2). Decades of encroachment are punctuated by dry season freshwater crises, and high tides and storm events that can erode low lying areas and flood them with saltwater (Noss 2011). Predictions of a SLR of 75-190 cm for 1990-2100 under the temperature range projected by the Intergovernmental Panel on Climate Change (Vermeer & Rahmstorf 2009) would inundate most of the Everglades with sea water (Zhang et al. 2011) (Fig. 2.1). This rate does not take into account nonlinearities that are challenging to predict, including catastrophic collapse of the Greenland or West Antarctic Ice sheets, either of which could cause a SLR of 6-7 m in a relatively short period of time (Allison et al. 2009). With expectations for a population growth to 15 million people in the next 30 years, Miami has been ranked as the world's most vulnerable urban region in terms of assets exposed to coastal flooding and fourth in the world in terms of population exposed to SLR (Hanson et al. 2011).

Local Processes and Feedbacks: FCE biophysical research is dedicated to ENP where the balance of fresh and marine water supplies determine salinity, water residence time, and nutrient delivery, and through their interaction, the dynamics of OM and nutrient cycling, and the productivity, composition and distribution patterns of plants and animals. Shifts in fresh or marine water supply thereby determine C storage and loss patterns, which feed back to influence elevation above sea level and resultant ecosystem dynamics (McKee et al. 2007). These feedbacks and the legacies of past environmental change can cause major shifts in the availability of ecosystem services, such as groundwater recharge and freshwater supply, flood and storm protection, C sequestration, and cultural uses. In turn, these changes may alter social dynamics in ways that intensify ecosystem change and increase social vulnerabilities to reduced services. These societal dynamics include changes in environmental perceptions, resource decision-making, land-use and stewardship, and water demand, quality, and distributional patterns.

Within the framework of our conceptual model, we developed 4 new research goals to explore the drivers of socio-hydrological complexity and biophysical feedbacks in the coastal Everglades, in a temporal context that connects long-term socio-ecological legacies to plausible alternative futures.

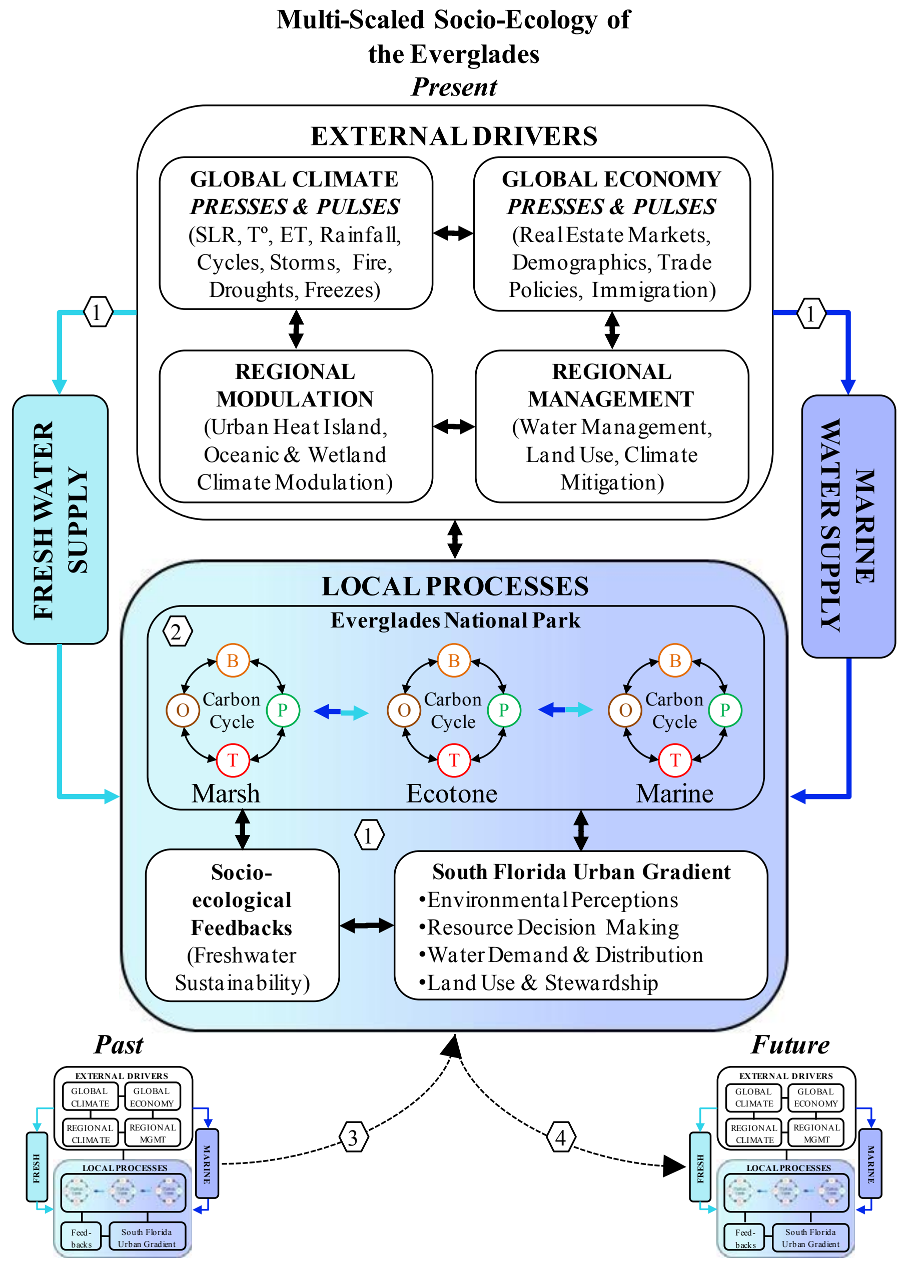


Fig. 2.3. Level 1 conceptual model guiding FCE research, showing how changes in the global climate and economy drive local processes through regional filters. FCE III research will address 4 goals (*numbered in diagram*) about how changes in climate and resource management (each with press and pulse attributes) interact to determine fresh and marine water supply (*light & dark blue lines and shading*) to ENP and the South Florida Urban Gradient. ***Goal 1 (Water):*** Explore how water management decisions are informed by and influence the impacts of climate change (especially SLR) on freshwater resource distribution. ***Goal 2 (Carbon):*** Determine how the balance of fresh and marine water supplies regulate C uptake, storage, and fluxes by influencing water residence time, nutrient availability, and salinity. ***Goal 3 (Legacies):*** Examine long-term datasets to determine how historic variability in the relative supply of fresh and marine water modify ecosystem sensitivity to further change. ***Goal 4 (Scenarios):*** Use modeling tools to envision socio-ecological futures under alternative climate change and water management scenarios. FCE Working Groups contribute to these goals through dedicated studies of biogeochemical cycling (*B*), primary production (*P*), organic matter (*O*) and trophic dynamics (*T*) guided by Level 2 conceptual models.

GOAL I (*Water*): Evaluate the source of sociopolitical conflicts over freshwater distribution, and how solutions that improve inflows to the Everglades mediate the effects of climate change (especially SLR) on freshwater sustainability in the coastal zone. This goal explores the role of uncertainty as both a feedback and driver of change within emergent ecosystems (Hobbs et al. 2006). The complexities of planning in the context of climate change, increasing water demand, and environmental needs are challenging water-vulnerable communities throughout the world (e.g., Swyngedouw 2004; Gober et al. 2010; Campbell & Meletis 2011). For the Everglades, recognition of the potential impacts of climate change has increased uncertainties in the likelihood of natural system restoration and future water distribution scenarios. This proposed research will provide guidance regarding the management of emergent ecosystems (Seasted et al. 2008; Jackson & Hobbs 2009), using approaches from science and technology studies (e.g., Clark & Dickson 2001; Fortun 2001; Jasanoff 2004; Peterson & Broad 2009) that examine the ways social actors and communities approach risk and scientific uncertainty.

GOAL II (*Carbon*): Determine how the balance of fresh and marine water supplies to the oligohaline ecotone, by influencing P availability, water residence time, and salinity will control the rates and pathways of C sequestration, storage, and export. This new focus on C cycling is an exciting direction for FCE, as understanding the mechanisms of how global, regional, and local processes interact with CO_2 uptake, storage, and export is paramount to anticipating how coastal ecosystems will respond to SLR and, possibly, the counteracting influence of freshwater restoration. Until recently, little was known about the C cycling, or mechanisms controlling its variability, in coastal ecosystems (Mcleod et al. 2011). Building on our recent findings that mangrove forests sequester globally-relevant quantities of CO_2 at rates that are sensitive to climate change and disturbance (Bouillon et al. 2008a; Barr et al. 2011) (Fig. 2.4), we will place a special focus of FCE III biophysical research on how the balance of fresh and marine water supplies influence CO_2 uptake, storage, and export, by modifying biological response to three key interacting drivers: P availability, salinity, and water residence time.

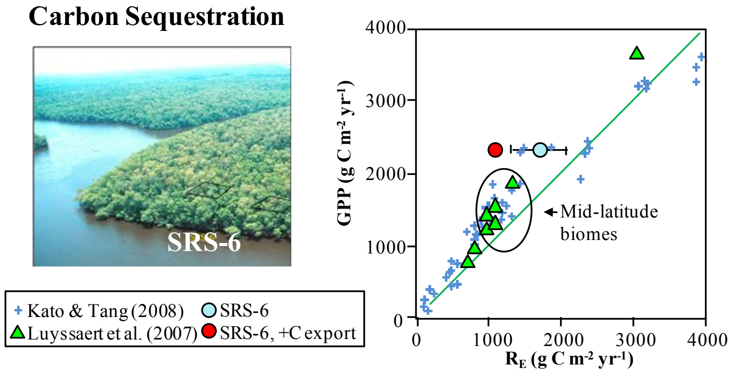


Fig. 2.4. Photo of the fringing mangrove forest at SRS-6 (*left*), and figure (*right*) comparing mangrove annual gross primary production (GPP) and ecosystem respiration (R_E) calculated from eddy covariance measurements at this site *(red circle)* with those reported for other forested ecosystems. NEP for this forest was unusually high (~1170 g C m^{-2} yr^{-1}) due to low decomposition rates in tidally flooded soils and advection into the estuary (R_E corrected using estimates for lateral transport shown in *blue circle*) (Barr et al. 2010). FCE III research will constrain these estimates of C loss to the estuary.

GOAL III (*Legacies*): Characterize spatio-temporal patterns in ecosystem sensitivity to *and* legacies of modifications of freshwater delivery to the Everglades that are driven by climate variability and land-use change. Patterns of species distributions and ecological functions in landscapes are conditioned by disturbance histories, the drivers and pathways of which must be unraveled to assess sensitivity patterns and improve predictions of change (Foster 2003). We expand our program in a spatio-temporal context to associate climate and land-use changes, and their effect on the balance of fresh and marine water supplies, to legacies of change in the FCE system. By identifying patterns of response diversity to freshwater delivery (*sensu* Elmqvist et al. 2003) at a landscape scale, this research will assume a critical role in establishing realistic goals for Everglades restoration in the face of SLR, as well as appropriate tools and approaches to achieve those ends (Chapin et al. 2009, 2011).

GOAL IV (*Scenarios*): Determine scenarios of freshwater use and distribution that maximize sustainability of the FCE in the face of global climate change, particularly SLR. Because the FCE is faced with uncontrollable uncertainty in the future of climate change, water management, and socio-ecological feedbacks, we will engage in scenario planning to identify key uncertainties and envision plausible outcomes that can increase resilience to surprise (Peterson et al. 2003; Carpenter et al. 2006) (Fig. 2.5). We will continue exploiting our diverse academic and agency collaborations to utilize more than a decade of FCE research and modeling tools to quantify ecosystem properties for the FCE under a manageable suite of alternative freshwater distribution decisions and climate change scenarios, and focus outreach communications on the implications of these alternative futures not only for a sustainable Everglades but also a sustainable South Florida habitation.

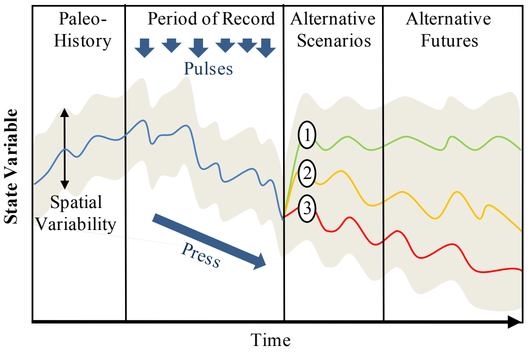


Fig. 2.5. Illustration of FCE III research approach to identify past and current connections between long-term changes (press) and disturbances (pulses) in the balance of fresh and marine water delivery and ecosystem state variables. This research will determine spatio-temporal patterns of variability in ecosystem sensitivity that can be used to inform predictive models to project future ecosystem condition under alternative water management and climate change scenarios.

C. Ongoing and Proposed Research

We will continue to conduct our biophysical research along the SRS and TS/Ph transects in ENP with a focus on dynamics in the oligohaline ecotone, while we expand our socio-hydrological research to extend beyond the boundaries of ENP (Fig. 2.6). During FCE III we expect to finally see an increase in freshwater inputs to our SRS transect: a 1.6 km stretch of the Tamiami Trail canal levee will be removed by 2013 and a second 8.9 km is approved and awaiting construction funding. Projects are also planned to enhance water delivery to the TS/Ph basin, including a new spreader canal and improved water inflow management. These projects provide a landscape-scale experiment in a before-after-control-intervention-paired-series study design. We have analyzed our paired transect data following the recommendations for this design (Schmitt & Osenberg 1996), showing that the transects do track each other in "before impact" time-series, and that our sampling effort provides appropriate effect sizes to be able to detect an impact of appreciable magnitude (Fig. 2.7). If both transects are simultaneously manipulated, our long-term observations and mechanistic studies have improved our potential to compare observed impacts to modeled predictions in the absence of restoration. We use continuous measurements, experiments, models, and comparative studies throughout our research to address our questions. Routine measurements and experiments are generally described below (see http://fcelter.fiu.edu/data/protocols/ for further detail), while modeling and comparative research efforts are integrated throughout.

Continuous Measurements: We remain dedicated to our core long-term datasets using an existing design that optimizes the number of sites and the sampling frequency necessary to support our experimental design by measuring key variables through highly coordinated, cross-disciplinary field efforts, and automated data collection (Table 2.1). Notable new features of our sampling design includes expanding our cross-system eddy covariance measures in the fringing mangrove forest (SRS-6) and short- and long-hydroperiod marsh (TS/Ph-1 and SRS-2, respectively), with two new systems in the dwarf mangrove forest (TS/Ph-7) and seagrass ecosystem of Florida Bay (TS/Ph-9). We will balance long-term continuity with new ideas by continuing to leverage other funding support for observational and experimental research. As examples, our water quality and vegetation sampling along the TS/Ph transect share support from NSF, ENP and the South Florida Water Management District (see R. Johnson and F. Sklar, Letters of Support (LOS)), and, together with the US Geological Survey, these agency partners maintain a robust network of hydrologic, meteorological, and sediment elevation monitoring stations throughout the Everglades. Another relevant project was initiated in 2011 to determine the impacts of the Tamiami Trail bridge on northern SRS, adding 10 persistent sites to capture the effects of restoration at the headwaters (see R. Johnson, LOS). State-wide budget cuts have threatened some important Everglades programs, further increasing the value of FCE long-term datasets, but we anticipate stability in these particular non-NSF funding sources and monitoring programs because all are closely tied to the adaptive management monitoring for the multi-decadal Everglades restoration program (http://www.evergladesplan.org/).

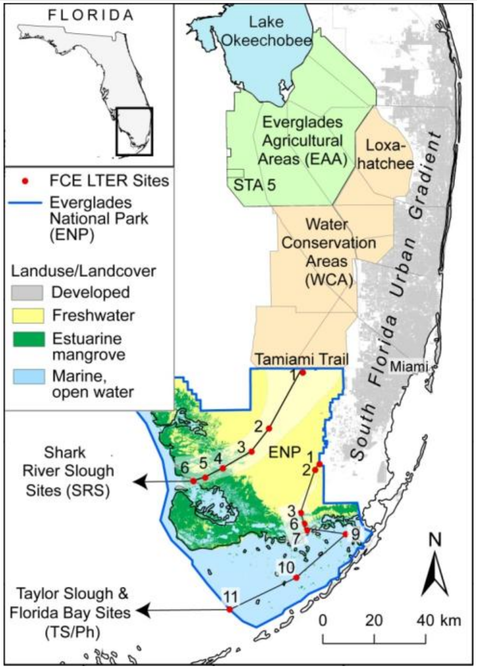


Fig. 2.6. FCE III site map, including locations of our 14 biophysical research sites (*red dots*) along transects through Shark River Slough and Taylor Slough into Florida Bay within Everglades National Park (ENP). Our cross-cutting research will extend beyond these into the South Florida Urban Gradient to examine socio-hydrological underpinnings of current, past and future conditions in the oligohaline ecotone.

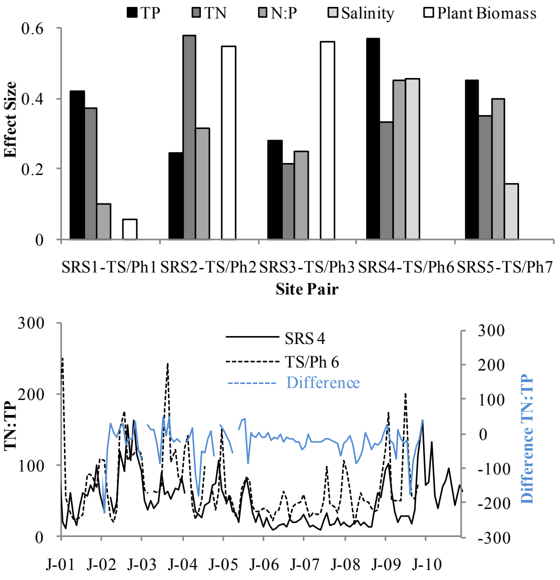


Fig. 2.7. Effect sizes (*upper panel*) for several key variables estimated from 10 years of FCE "before" freshwater restoration differences in water total phosphorus (TP), total nitrogen (TN), the N:P ratio, and plant biomass (sawgrass and periphyton) at paired sites along the TS/Ph and SRS transects from marsh to marine sites, providing an estimate of the magnitude of difference necessary to detect a significant effect changes in freshwater delivery driven by restoration projects. Example of differences in a paired set of ecotone sites (SRS-4 and TS/Ph-6) (*bottom panel*) showing the level of concordance (*left axis*) and difference (*right axis*) for the surface water molar N:P ratio.

Table 2.1. Evolution of core variables measured in FCE long-term studies.

Working Group or Theme	Core Area Variable	Frequency	FCE I	FCE II	FCE III
Water:	Meteorology, water depth	Minute	All but Florida Bay	All but Florida Bay	All but Florida Bay
	Surface, groundwater T°, O_2 & salinity	Minute	All sites	All sites	All sites
	Groundwater discharge	Monthly	None	Ecotone sites	Ecotone sites
	Surface water flow	Minute	Prelim Expts	Select marsh sites	Select wetl. Sites
Biogeochemical Cycling:	Water quality	Daily, monthly	All sites	All sites	All sites
	P & N cycling rates	Monthly	Prelim Expts	Ecotone sites	Ecotone sites
	Pore & groundwater nutrients	Monthly	All sites	All sites	All sites
	Bacterial biomass, production	Monthly	Ecotone sites	Ecotone sites	Ecotone sites
	Flocculent detrital (POM) characterization	Monthly	Prelim Expts	Select ecotone sites	SRS-2, -6, TS/Ph-2, -7
	Soil structure and nutrients	Annually	All sites	All sites	All sites
Primary Production:	Aboveground production	Monthly	All sites	All sites	All sites
	Belowground production	Monthly	Prelim Expts	Ecotone sites	Ecotone sites
	Composition, tissue C, N, P	Monthly	All sites	All sites	All sites
Organic Matter Dynamics:	DOM characteristics	Monthly	All sites	All sites	All sites
	DOM flux rates	Monthly	Prelim Expts	Prelim Expts	Ecotone sites
	DIC and soil CO_2 efflux	Monthly	None	Prelim Expts	Ecotone sites
Trophic Dynamics:	Consumer abundance & diet	Monthly	All but Florida Bay	All but Florida Bay	All sites
	Consumer movements	Monthly	None	Ecotone sites	Ecotone sites
Carbon Cycling:	Net ecosystem metabolism	Minute	SRS-6	SRS-2, -6, TS/Ph-1	SRS-2, -6, TS/Ph-1, -7, -9
	Carbon storage	Annually	All sites	All sites	All sites
	Soil elevation change	Annually	Ecotone sites	Cross-system	Cross-system
Legacies:	Tax, land use, zoning	Annually	None	All parcels	All parcels
	Paleoecology	Decadal res.	Florida Bay	Marsh & Ecotone	Ecotone
	Landscape ecotone change	Annually	None	Ecotone sites	Ecotone sites

Mechanistic Experiments**:** While we maintain an emphasis on persistent core data collection, we also recognize the importance of coordinated mechanistic studies linking key drivers to ecosystem responses. Much of our leveraged support is directed toward such experiments. In FCE III, we propose a new manipulative experiment to identify the mechanisms underlying observed patterns of ecosystem response to the balance of marine and fresh water supplies to the oligohaline ecotone, a central goal of FCE research. This experiment will be conducted at the mesocosm facility at the Florida Bay Interagency Science Center in Key Largo, FL (see F. Sklar, LOS, for details), which we renovated for a pilot study in preparation for this proposal using NSF 2011 supplemental funding matched by the Everglades Foundation (see T. Van Lent, LOS) (Fig. 2.8). These mesocosms are ideal for this research, enabling us to control key regulatory variables including water source, tidal cycles, water residence time, P concentration, and salinity, and examine responses on spatio-temporal scales that can guide interpretation of responses to the landscape-level experiment provided by Everglades restoration (for more details see http://fcelter.fiu.edu/research/projects/projects.htm?pid=62). Treatment effects on biogeochemical cycling, production and decomposition dynamics, and OM accretion and transformation will be examined in a coordinated way, providing necessary quantitative data to address our integrative project goals.

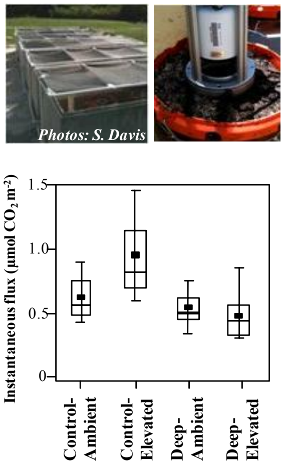


Fig. 2.8. Photos of the mesocosms at the Florida Bay Interagency Science Center showing soils incubating under shade cloth (*left*), and measuring instantaneous soil CO$_2$ efflux (*right*). Box plot distributions (*below*) of CO$_2$ efflux from mangrove peat soils from SRS-6, stabilized for two weeks at ambient salinity (15-20 ppt) and tidal range (25 cm), and subjected to a one-week period of elevated salinity (30-35 ppt) and inundation (7.6 cm deeper than mid-tide mark).

Working Group and Cross-Cutting Theme Research

FCE III will maintain our past Working Group (WG) and Cross-Cutting Theme (CCT) organization (described in detail in Section 4), retaining the four existing WGs: **Biogeochemical Cycling, Primary Productivity, Organic Matter** and **Trophic Dynamics**, that provide the long-term, spatio-temporally resolved datasets and mechanistic understanding of biophysical dynamics, and propose four reorganized CCTs: **Hydrology: *Water* Policy and Practices, *Carbon* Cycling, Climate and Disturbance *Legacies***, and ***Scenarios* and Modeling**, that will integrate WG products to address the four research goals.

1. Biogeochemical Cycling WG (co-leads - J. Boyer & S. Davis)

GENERAL QUESTION 1: How does the balance of fresh and marine water supply to the oligohaline ecotone influence microbially-mediated C and nutrient cycling in soils and water?

RATIONALE –The stability of organic C in detritus, soils and water in wetlands and estuaries is largely mediated by microbial communities that control the rate of OM transformation from particulate (POM) to dissolved (DOM) forms, and fluxes of CO$_2$ and CH$_4$ across air-land-water boundaries. The controls on the wide spatio-temporal variability in these rates need to be identified in order to create dynamic C budgets and forecasts at local to global scales. Substrate (OM) quality, nutrient availability, salinity, and water residence time can influence rates of microbially-mediated transformation and nutrient cycling, but in coastal wetlands, these influences are often highly correlated in space and time, complicating attempts at

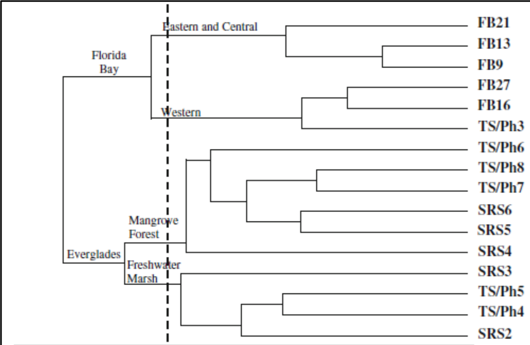


Fig. 2.9. Dendrogram constructed from the similarity of DGGE profiles of 16S rRNA of soils from the FCE study sites, including Shark River Slough (SRS), Taylor Slough (TS/Ph), and Florida Bay (FB). [From Ikenaga et al. (2010)].

balancing C budgets (Gutknecht et al. 2006; Weston et al. 2011). In the FCE, we have found that hydrologic differences between TS/Ph and SRS ecotones result in distinctly different residence times, tide ranges, seasonal flows and salinity patterns, and limiting nutrient (P) availability, which influence microbial community structure (Ikenaga et al. 2010) (Fig. 2.9). Variability between the transects and over time provides a comparative template to examine relationships between driving variables and microbial processing rates, which will be enhanced by process experiments that will disentangle these important ecological drivers of wetland biogeochemistry and C cycling (Fig. 2.10). These determinations will improve our mechanistic understanding of legacy peat loss across the ecosystem (McVoy et al. 2011) as well as constrain projections for peat accretion under contrasting SLR and water management scenarios.

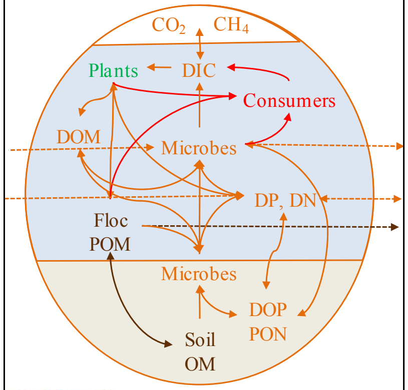


Fig. 2.10. Level 2 conceptual model guiding FCE III **Biogeochemical Cycling** research. The circle highlights processes in the ecotone (*see Fig. 2.3*), but connectivity to upstream marsh and downstream marine habitats will be studied relative to the balance of fresh and marine water supplies (*dashed arrows*). We will continue long-term measurements of organic and inorganic C, N, and P cycling along our transects, complemented by experiments to understand the effects of salinity, P, and inundation time on microbial mineralization of OM and organic nutrients (*orange arrows*).

Hypothesis 1.1: The balance of fresh and marine water supplies influences microbially-mediated C and nutrient cycling in wetland soils through interacting effects on P availability, salinity, and water residence time, culminating in gains or losses in C storage. Recent experiments have demonstrated how saltwater intrusion can stimulate microbial decomposition in coastal wetland soils, accelerating organic C loss (Weston et al. 2011). We manipulated both salinity and inundation in a pilot mesocosm study and similarly found that salinity increased the rate of CO_2 efflux from mangrove peat soils, but not when inundation depth was also increased (Fig. 2.8). Our eddy covariance data from the mangrove forest and marsh also show a suppression of CO_2 efflux during high tides (Barr et al. 2010) and extended inundation periods (Schedlbauer et al. 2010), respectively, but we don't understand the microbial controls over these rates, or their interaction with salinity and P availability. *We expect that factors that increase salinity and P supply from marine sources will increase microbially-mediated rates of C efflux and transport, but only if water depth and residence time remain unchanged.*

Approach – We propose a suite of controlled six-month experiments in the mesocosm facility to understand how P, salinity, and water residence time and depth affect microbially-mediated C and nutrient cycling along the TS/Ph and SRS transects. Briefly, in year 1, we will establish a plant-soil system representative of the SRS mangrove ecotone. Tidal cycles of the field site will be recreated by controlling the input of fresh and marine source water, and inundation manipulated within each mesocosm by adjusting soil depth relative to mid-tidal height. Four treatments will be assigned across 12 mesocosms, including salinity and P controls, and salinity-enhanced, P-enhanced, and combined salinity and P treatments. Similar experiments will follow annually for the TS/Ph ecotone and TS/Ph and SRS marsh ecosystems, adjusting treatments to represent the conditions of adjacent downstream ecosystems. We will measure effects on soil CO_2 and CH_4 efflux (continuous), bacterial production, redox conditions, total and dissolved nitrogen (N), P, organic C concentrations, and the optical properties of water (weekly), soil bulk density, total C, N and P concentrations, microbial activity and composition (by molecular fingerprinting) (initial and final soils), and leaf and root decomposition rates (using litterbag techniques).

Hypothesis 1.2: The balance of marine and freshwater supplies of dissolved organic carbon (DOC) to Everglades estuaries will determine bioavailability for bacterioplankton and the microbial loop. The microbial loop is an important pathway of energy and C flow in oligotrophic ecosystems, converting DOC to biomass through uptake by bacterial production and by metabolism to CO_2 by respiration. The magnitude of DOC consumption and extent to which it is partitioned into biomass or is respired has major implications for C storage and loss. Bacterial growth efficiency, or the fraction of DOC used for growth, exhibits a wide range in estuarine and marine ecosystems (0.01 – 0.6), which has been ascribed to variability in DOC and nutrient (bio) availability and salinity (del Giorgio & Cole 1998). DOC bioavailability is highly variable in space and time depending on source, age, and environmental conditions (Chen 2011). We do not know the rates at which different DOC sources are used by bacteria and transferred to higher trophic levels. Dissolved organic P (DOP) can regulate use of DOC (Lennon & Pfaff 2005), and since most P is found in the DOP pool in the FCE, the relationship between DOC and P stimulation of bacterial production are confounded by overall magnitude and source of DOC. Finally, salinity influences microbial use of DOC by altering its bioavailability (Stepanauskas et al. 1999) and incurring metabolic stress to the bacterial cell (Langenheder et al. 2003). Therefore, we will use bacterial growth efficiency as a dynamic indicator of ecosystem function, *expecting that it will: 1) increase with bioavailability of DOC determined by its source; 2) increase with additions of inorganic P relative to DOP; and 3) be related to changes in salinity, independent of changes in DOC source.*

Approach – Assays will be performed with and without nutrient additions to quantify the coupling of bacterial production and respiration to phytoplankton, seagrass, and microphytobenthos primary production. We will expose producers to ^{13}C-bicarbonate and quantify primary production on filtered samples or tissue, while filtrate will be incubated in the dark to quantify bacterial respiration. Bacterial production will also be measured using ^{3}H-thymidine uptake. Lability of allochthonous C in the ecotone and estuary will be quantified by measuring changes in [DOC] over one-month incubations. Bacterial growth efficiency will be compared across FCE transects relative to biogeochemical drivers.

2. Primary Production WG (co-leads – V. Rivera-Monroy & T. Troxler)

GENERAL QUESTION 2: How does the balance of fresh and marine water supply to the oligohaline ecotone influence the composition, distribution, and productivity of primary producers?

RATIONALE – Effects of SLR on coastal wetland productivity depend partly on local factors such as the rates and history of exposure to saltwater encroachment, and ability of species to adapt to changing inundation, salinity, and nutrient availability. A summary of Net Primary Productivity (NPP) patterns across our transects showed that within the SRS basin, sawgrass, and periphyton NPP did not differ significantly among sites, but mangrove NPP was highest at sites nearest to the Gulf of Mexico. In TS/Ph basin, there was a productivity peak in sawgrass and periphyton in the upper estuarine ecotone, but no trends were observed in the lower basin for either producer (Ewe et al. 2006). We attribute these striking differences in patterns of NPP not only to the stress of P-limitation, but also to variation in inundation times and salinity across FCE freshwater marsh and mangrove communities (Childers et al. 2006b; Schedlbauer et al. 2010; Castañeda-Moya et al. 2011) (Fig. 2.11). In the lower freshwater ecotone, our long-term data suggest an increasing effect of salinity as a primary driver of productivity and a strong correlation between the variability in freshwater discharge and lower ecotone salinity (Troxler 2010), illustrating how upstream water diversion can amplify the effect of SLR (Michot et al. 2011). In FCE III, we will apply a new, integrated approach to investigate how changes in environmental drivers that determine these gradients shape patterns of production, composition and biomass allocation (Fig. 2.12).

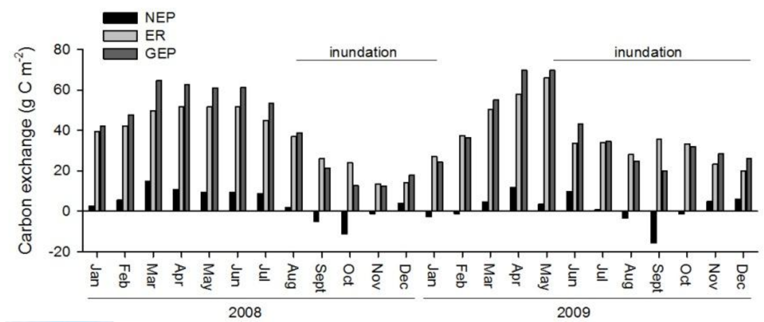


Fig. 2.11. Monthly carbon exchange across two inundation (wet/dry season) cycles from the eddy covariance tower at the TS/Ph marsh (*photo, left*), broken down into net ecosystem production (NEP), ecosystem respiration (ER), and gross ecosystem production (GEP). [Updated from Schedlbauer et al. (2010).]

Hypothesis 2.1: The balance of fresh and marine water supplies regulates primary producer composition and productivity through interacting effects on P availability, salinity, and

water residence time. While FCE research has revealed important connections between primary productivity and P availability, salinity, and water residence time, their interactive effect is magnified in the oligohaline ecotone. As sawgrass, mangrove, and periphyton productivity have been shown to increase with increasing P availability up to a threshold (Daoust & Childers 2004; Lovelock et al. 2004; Castañeda-Moya 2010), increased P associated with marine water delivery may alleviate the effects of extended residence time and salinity on primary productivity or water-use efficiency (Childers et al. 2006b; Ewe et al. 2007a; Mancera-Pineda et al. 2009; Lovelock et al. 2011). While salinity is clearly an important driver of ecosystem productivity and composition across the FCE coastal landscape (Troxler 2010; Barr et al. 2010), the relative influence of salinity along gradients of P availability and water residence time has not been examined (Cardona-Olarte et al. 2006). *We expect that marine delivery of P and salinity will be amplified under scenarios where freshwater delivery is not restored, resulting in mangrove transgression and decline in sawgrass aboveground NPP in the oligohaline ecotone.*

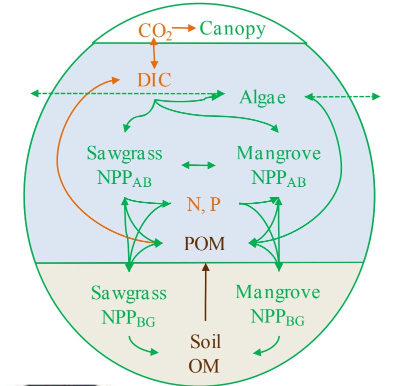


Fig. 2.12. Level 2 conceptual model guiding FCE III **Primary Production** research. The circle highlights processes in the ecotone (*see Fig. 2.3*), but connectivity to upstream marsh and downstream marine habitats will be studied relative to the balance of fresh and marine water supplies (*dashed arrows*). We will continue long-term measures of above- (AB) and belowground (BG) Net Primary Productivity (NPP) (*shown in green*). We will experimentally manipulate P, salinity, and inundation time to determine causes for long-term changes observed in the field.

<u>Approach</u> - We will assess the effects of salinity, water residence time, and P availability on productivity of sawgrass, mangrove saplings, and periphyton in collaboration with biogeochemical cycling studies in the mesocosm experiment described above. We will quantify changes in aboveground and belowground biomass and NPP of sawgrass and mangroves using an allometric approach (e.g., Coronado-Molina et al. 2004) and root in-growth cores (Castañeda-Moya et al. 2011), respectively, and of periphyton NPP using artificial subtrates (Gaiser et al. 2006a). Changes in abiotic drivers including leaf and periphyton P, N and C, porewater salinity, hydrogen sulfide, and soil redox potential will be assessed.

Hypothesis 2.2: Landscape patterns of plant composition and production express legacies of fresh and marine water supplies to the ecotone. Since OM accumulation and turnover are the primary processes controlling soil formation and accretion in mangrove forests and sawgrass in the oligohaline ecotone, biomass dynamics (and their legacies) can control how vegetation will respond to future impacts of SLR. This dynamic is dramatically observed in the southeastern sawgrass-mangrove ecotone, which has shifted in its distribution during the last 50 years, coincident with the expansion of a low productivity zone ("white zone") (Ross et al. 2000, 2002; Rivera-Monroy et al. 2011) resulting from diminished freshwater flows and rapid saltwater encroachment. Legacies of tropical storms are also evident in the mangrove forest, providing a tool for understanding how increased saltwater inundation and nutrient delivery influence short- and long-term recovery of the forest (Fig. 1.2). *By examining large-scale patterns of plant community composition and production in light of large-scale changes in hydro-dynamics, we hope to reveal the relevance of the results of mechanistic studies to interpreting and predicting long-term and landscape-scale dynamics in the Everglades ecotone.*

<u>Approach</u> - We will continue to measure sawgrass and periphyton NPP at marsh sites, mangrove productivity and biomass allocation in the ecotone, and seagrass, macroalgal, epiphyte, and phytoplankton production in Florida Bay using established methods (Ewe et al. 2006; Juszli 2006; Gaiser et al. 2006a; Collado-Vides et al. 2007; Castañeda-Moya et al. 2011; http://fcelter.fiu.edu/data/protocols/). We will refine methods for estimating NPP in the TS/Ph dwarf red mangrove (*Rhizophora mangle* L.) community based on measurements of leaf turnover, stem elongation, and prop root growth on tree clusters. We will also estimate aboveground biomass with annual measurements of crown area and prop root number from 16 randomly selected tree clusters using allometric equations (Coronado-Molina et al. 2004), and quantify belowground NPP using coring and root in-growth techniques. Calculations of community NPP and

Gross PP from biometric data will be provided to the *Carbon* CCT for integration with ecosystem C exchange data to compare C dynamics at plot and ecosystem scales across the two transects. We will explore how spatial patterns of ecosystem C sequestration and community structure have responded to changes in fresh and marine water supply by up-scaling activities described in the *Legacies* CCT.

3. Organic Matter Dynamics WG (co-leads – R. Jaffe & W. Anderson)

GENERAL QUESTION 3: How do surface water residence times, P availability, and salinity interact to affect OM quality, abiotic and biotic processing, and exchange between freshwater, ecotone, and marine environments?

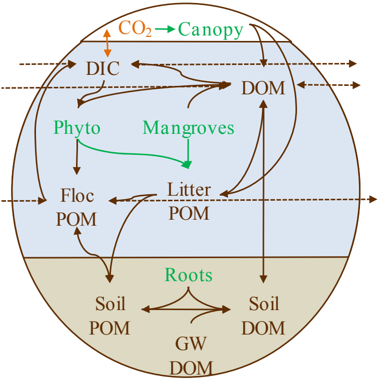


Fig. 2.13. Level 2 conceptual model guiding FCE III **Organic Matter Dynamics** research. The circle highlights processes in the ecotone (*see Fig. 2.3*), but connectivity to upstream marsh and downstream marine habitats will be studied relative to the balance of fresh and marine water supplies (*dashed arrows*). We will continue long-term source characterization of OM and add new observational and experimental research to measure the flux and transformation rates of OM and DIC across atmosphere-land-water boundaries (*brown arrows*).

RATIONALE - FCE research characterizing OM in coastal ecosystems has improved our ability to track the source and fate of C across system boundaries, but the rates of exchange and transformations need to be quantified to complete a C budget for the FCE estuaries, and determine how these processes are influenced by changes in the balance of water sources. In addition, the fluxes of dissolved inorganic carbon (DIC) are poorly understood relative to their recently recognized importance in estuarine C budgets (Bouillon et al. 2008b). The primary objectives of this WG will be to quantify OM and DIC fluxes in FCE marshes and estuaries so that these can be combined with terrestrial surface-atmosphere and surface-groundwater C fluxes to complete our C budget (Fig. 2.13). We will combine experimental manipulations with continuous field observations to understand how the biological and physiochemical mechanisms regulating OM dynamics – including C transformations between labile and recalcitrant forms – may vary across salinity and nutrient gradients. This information is needed to predict the changes in C dynamics that may accompany altered freshwater discharges and SLR in this system.

Hypothesis 3.1: Water source and residence time influence the relative contribution and quality of OM from marshes, mangroves, and the marine system to FCE estuaries. FCE II studies identified autochthonous and allochthonous OM sources in FCE marshes (Lu et al. 2003; Neto et al. 2006; Yamashita et al. 2010) and estuaries (Jaffé et al. 2004; Maie et al. 2005; Mead et al. 2005), distinguishing between fresh water marsh-, mangrove-, and marine-derived DOM and POM using 3D fluorescence techniques and biomarkers (Jaffé et al. 2001; Jaffé et al. 2006; Xu et al. 2006). These studies identified differences in OM mixing dynamics based on source and reactivity, but a complete C mass balance requires OM flux rates across all system boundaries. *We expect an increased importance of marine supplies of OM to the ecotone, particularly from the groundwater, when freshwater delivery is depressed, and increased processing to more refractory forms when water residence time is extended.*

Approach - We will assess estuarine OM inputs, mixing, and transport dynamics along salinity transects in each estuary in the wet and dry season (including sampling throughout tidal cycles). In conjunction with the *Water* CCT, we will determine DOC quality and exchange dynamics between ground and surface water in Shark River, Taylor River, and Florida Bay (Chen et al. 2010). In addition to molecular-level characterizations, stable C isotope determinations of DOC, DIC, and particulate organic carbon (POC) will provide C source identification and degradation dynamics (Miyajima et al. 2009).

Hypothesis 3.2: Variability in water source and residence time control the rates of DOC, POC, and DIC transport in and export from water and soils. FCE research has contributed one of the longest and most comprehensive evaluations of the drivers of C dynamics in mangrove estuaries, but attempts to balance C budgets in the Everglades and other mangrove forests throughout the globe have been compromised by a lack of data on C export rates, particularly the inorganic component, which could be 3-5 times greater than organic C losses (Bouillon et al. 2008a). OM degradation rates influence transport distance and heterotrophic metabolism, but, while we can distinguish source dynamics through OM characterization, we need to understand degradation processes to predict how changes in delivery influence supply over time. *We expect that C fluxes from water and soils will be determined by the magnitude of hydrodynamic pulses (tides, freshwater flows, storms) and the rates of OM degradation driven by longer-term changes in the balance of water sources.*

Approach - OM degradation rates will be measured in laboratory photo- and biodegradation incubations of samples from estuarine transects taken during the wet and dry season at high and low tides. DOC reactivity proxies (Chen 2011) will be used to assess quality and degradation processes throughout the estuaries, calibrated using laboratory simulations. DOM composition will be examined molecularly to determine effects of molecular weight and recalcitrant components (such as black C) on reactivity. We will determine rates of photo-degradation and metabolic CO_2 production, and perform in-depth molecular characterizations of all C components in DOM using advanced analytical techniques such as ultra-high resolution mass spectrometry (FT-ICR/MS; e.g., Gonsior et al. 2011) and NMR (Abdulla et al. 2010; Maie et al. 2006). We also will continue to document POC (flocculent detrital) dynamics using ^{13}C to track the fate of POC in DOC (in the mesocosm experiments) and rates of DOC generation through photo-dissolution (Pisani et al. 2011; Shank et al. 2011) during the wet-dry season cycle in the ecotone. We will compare associated reactivity and composition between photo-derived and biogenic DOC. Watershed influences on OM dynamics will be compared with other LTER sites (e.g., Jaffé et al. 2008; Balcarczyk et al. 2009; Yamashita et al. 2011; Jaffé et al., in review) (Fig. 2.14) and in the context of our international research in the Okavango Delta (Botswana), Pantanal (Brazil), and Shark Bay (Australia) using a model developed for the FCE (Cawley et al. 2012). We will calculate aquatic C export by coupling our measurements of DOC, POC, and DIC concentrations with discharge rates measured at the mouths of TS/Ph and SRS. CO_2 efflux to the atmosphere from water, sediments/soils, and vegetation will be determined at estuary sites during the wet and dry season. Measurements of pCO_2 ($CO_{2\,(aq)}$) and DIC (dissociation constants determined with continuous pH measurements) will determine soil-water column C flux to reduce error estimates associated with values of hydrologic export of C. Continued measurements of soil, root, and course woody debris CO_2 fluxes will disaggregate components of below-canopy CO_2 flux, constrain relationships between soil CO_2 flux and environmental drivers (i.e., salinity, inundation, temperature), and validate C budget estimates made using alternative methods.

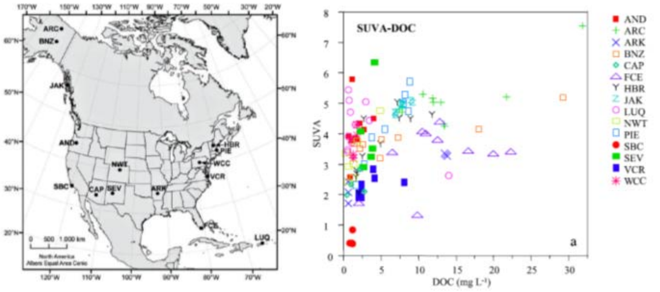


Fig. 2.14. FCE scientists are interested in determining the controls of patterns of organic matter quantity and quality in aquatic ecosystems across the continent (*left map*). Crossplots of dissolved organic carbon (DOC) concentrations (quantity) and specific UV absorbance (SUVA) (quality) across 11 LTER and three non-LTER sites (*right figure*), show how FCE (*purple triangles*) expresses very high variability in both DOM quantity and quality. [From Jaffé et al. (2008)].

4. Trophic Dynamics WG (co-leads - M. Heithaus & J. Trexler)

GENERAL QUESTION 4: How will SLR interact with changes in freshwater inflows to modify detrital food webs and the spatial scale of consumer-mediated habitat linkages?

RATIONALE - Wetland and estuarine food webs can be complex because of large spatio-temporal variability in the biophysical environment and the high mobility of many upper trophic level consumers and their prey that can create spatially disjointed patterns of predation, excretion, and mortality impacts (Garman & Macko 1998; McCann et al. 2005). Our food web research has shown that: 1) movements of top predators in the ecotone can be tracked and related to their feeding habitats and ecological role

(Matich et al. 2011; Rosenblatt & Heithaus 2011); 2) detrital linkages are quantifiable and important in metazoan food webs (Belicka et al. 2012); and 3) water flow and distribution on the landscape determines consumer abundance and movement (Rehage & Loftus 2007; Heithaus et al. 2009; Jopp et al. 2010; Rosenblatt & Heithaus 2011; Rehage & Boucek, in review). In FCE III, we will expand this research by adding experiments to quantify the importance of microconsumers in the microbial loop, observational studies to determine factors controlling predator impacts, and enhanced top predator movement and diet tracking to map changes in consumer-mediated dynamics driven by water supply (Fig. 2.15).

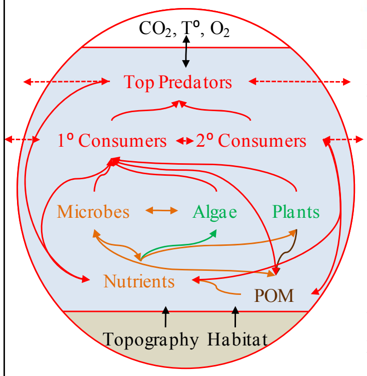


Fig. 2.15. Level 2 conceptual model guiding FCE III **Trophic Dynamics** research. The circle highlights processes in the ecotone (*see Fig. 2.3*), but connectivity to upstream marsh and downstream marine habitats will be studied relative to the balance of fresh and marine water supplies (*dashed arrows*). Research will address how feeding habits (*solid red arrows*) and movement patterns of consumers (*dashed red arrows*) are influenced by availability and quality of primary and detrital food resources (particulate organic matter, POM) and access to quality habitat (*black arrows*).

Hypothesis 4.1: Freshwater delivery influences the importance of detritus to freshwater marsh and mangrove estuary food webs. The degree to which detrital and associated benthic microbial food webs support metazoan productivity in wetlands and coastal estuaries is still highly debated (Lemke et al. 2007), partly due to complex dynamics in the source, quality, and abundance of OM supplies (Grimaldo et al. 2009). Prior work characterizing the source and lability of C to estuary food webs has enabled us to understand these dynamics at unprecedented spatial and temporal scales (Xu & Jaffe 2007; Yamashita et al. 2011). FCE food web research has laid the ground work for establishing microbial links between detritus and metazoan food webs in the Everglades through analysis of stable isotopes (Williams & Trexler 2006; Sargeant et al. 2010) and fatty acid profiles of key consumers (Belicka et al. 2012). In FCE III, we will examine how water source influences consumer-resource dependencies by determining the factors that drive shifts from autochthonous to allocthonous pathways in metazoan foodwebs. *We expect that the freshwater inputs will enhance the importance of microbial loops and detritus in the food webs of Everglades freshwater marshes and mangrove estuarie, as long as inputs are not enriched in P.*

<u>*Approach*</u> – We propose to address this question in two ways. First, we will conduct experiments in Everglades wetlands to determine how energy-flow pathways are changed by freshwater delivery, particularly if the delivery is associated with P-enrichment. We will manipulate nutrients and key consumers using established *in-situ* field enclosures (Dorn et al. 2006) to test how freshwater sources and predator behaviors control markers of food assimilation (stable isotopes of C and N, fatty acids), delineating predictions based on the presence of key microbial energy-flow routes in oligotrophic Everglades wetlands that are changed when P is enriched. We will focus particularly on microinvertebrates, as our preliminary work has shown that rotifers and protozoan grazers may be key consumers in a currently undocumented microbial loop. The relevance of our experimental results will be explored in the context of our ongoing spatial studies documenting metazoan abundance along hydrological gradients and across seasons in the Everglades (i.e., Sargeant et al. 2011). Our second line of work will evaluate microbial energy flow into estuarine food webs, relying on movement studies to identify wide ranging estuarine consumers that travel between marshes, the ecotone, and downstream marine areas. After identifying foraging and "refuging" sites where consumers feed and travel to, we will evaluate isotopic and fatty acid signatures of detritus, algae, microinvertebrates, and mesoconsumers in an effort to delineate linkages to the wide-ranging top predators (i.e., alligators and large fish).

Hypothesis 4.2: Variability in freshwater inflows will interact with SLR to modify the spatial scale of consumer-mediated habitat links. Because of their large size and high mobility, top predators may be important in cross-boundary nutrient flow and in coupling and stabilizing food webs (e.g., Polis et al. 1997; McCann et al. 2005; Rooney et al. 2006). In FCE II, we began research to document the extent to which mobile consumers connect freshwater and marine habitats through material and energy transport by initiating studies of movements by two representative top predators using passive

acoustic telemetry and bulk stable isotopic compositions. We found that American alligators (*Alligator mississippiensis*) and juvenile bull sharks (*Carcharhinus leucas*) were potential nutrient vectors from marshes and the Gulf of Mexico into the mangrove ecotone (Rosenblatt & Heithaus 2011; Matich et al. 2011) (Fig. 2.16). However, both species exhibited a high degree of seasonality and individual specialization in feeding and movement, stressing the importance of persistent behavioral studies to document the extent of these linkages. *This behavioral sensitivity to seasonal changes in habitat access and suitability cause us to expect that the strength and direction of consumer subsidies to the ecotone will shift with changes in the balance of freshwater and marine water supplies to the ecotone.*

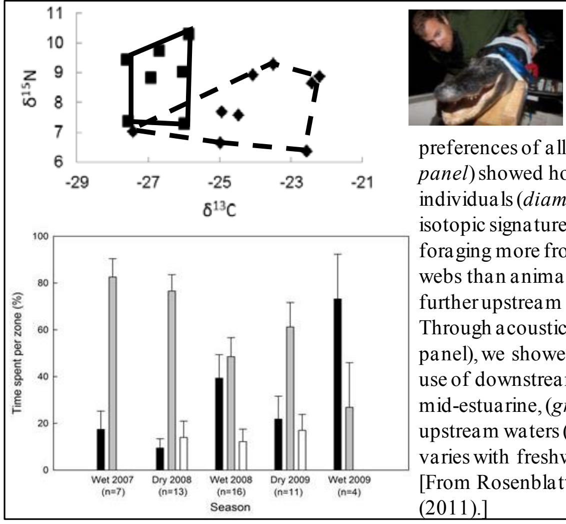


Fig. 2.16. FCE II research to identify the feeding preferences of alligators (*upper panel*) showed how commuting individuals (*diamonds*) have stable isotopic signatures indicative of foraging more from marine food webs than animals remaining further upstream (*squares*). Through acoustic tracking (bottom panel), we showed how alligator use of downstream (*black bars*), mid-estuarine, (*gray bars*), and upstream waters (*white bars*) varies with freshwater flow. [From Rosenblatt & Heithaus (2011).]

<u>Approach</u> –To quantify the precise extent of animal movements and foraging behavior relative to environmental fluctuations, we will deploy satellite tags and animal-borne cameras. To determine variability in potential contributions of top predators to community dynamics and nutrient cycling, we will maintain quarterly sampling of bull shark abundance and bi-annual sampling of alligator abundance, diets, and body condition in the ecotone region in relation to freshwater flow, salinity, dissolved oxygen and nutrient concentrations, and other continuous FCE data. We will connect top predator abundance, foraging, and movement to mesoconsumer community dynamics by maintaining our seasonal electrofishing (wet, dry, and transition seasons), and determine connectivity between top and meso-consumers by complementing our abundance and tracking research with analyses of stomach contents, stable isotopes, and fatty acids. Resultant linkages will be interpreted relative to temporal variability in hydrologically-controlled environmental variables and in the context of microconsumer abundance and diets, described above. By conducting parallel research in a similarly oligotrophic mangrove estuary in Shark Bay, Australia, we will continue to improve our ability to generalize our findings about the importance of top predators in determining estuarine habitat connectivity in subtropical habitats (e.g., Heithaus et al. 2008, 2011). We will expand this comparative approach to include temperate estuaries through our coastal site collaborations in FCE III, particularly by synthesizing our findings with those of food web and consumer movement research conducted in parallel at the Plum Island Ecosystems LTER.

5. <u>Hydrology: Water Policy & Practices CCT (co-leads - R. Price & L. Ogden)</u>

GENERAL QUESTION 5: How do climate change and SLR interact with water management practices to control hydrologic conditions in the oligohaline ecotone?

RATIONALE - The *Water* CCT will address Everglades hydrology from a variety of disciplinary perspectives to advance an integrated understanding of the processes that shape the Everglades as a eco-socio-hydrological system. For at least the past century, water management decisions, rather than natural processes, have controlled the distribution of sheet flow from Lake Okeechobee to the southern Everglades (Meindl 2005; McVoy et al. 2011). As a result, we need to understand how water/restoration management practices and perceptions interact with longer-term trends in climate variability and SLR to produce the contemporary Everglades. The *Water* CCT will work with the *Scenarios* CCT to explore future paths for water management decisions and estimate their impact on surface and groundwater availability and quality in the oligohaline ecotone, and with the *Legacies* CCT to link climate-hydrologic interactions with historical and evolving land-water system dynamics.

Hypothesis 5.1: Variable inflows from upstream sources, SLR, and storm surge interact to alter surface water residence time, salinity, and groundwater intrusion in the oligohaline ecotone. Our research indicates that over the last several decades (10-40 yr) groundwater salinity and surface water levels in the oligohaline ecotone were most strongly influenced by SLR, as inputs of upstream freshwater were insufficient to counteract the marine transgression (Saha et al. 2011a,b; Fig. 2.2). The extent to which future restored freshwater inputs counteract SLR and climate change remains to be seen, and will continue to be a focal point of our research. *We expect that climate processes of rainfall and evapotranspiration (ET) along with SLR will continue to be the dominant drivers of water availability across the Everglades landscape, but that the balance between regional water demand and restoration efforts will fine tune the position of the oligohaline ecotone, and its surface and groundwater quality.*

Approach – This hypothesis will be addressed using a combination of field measurements, hydrologic modeling, and satellite observations. We will maintain continuous measurements of groundwater and surface water levels, temperature, salinity, and chemistry in the oligohaline ecotone of both sloughs. Rainfall and ET from meteorological stations will be combined with surface water inflows, outflows, and water levels measured across ENP into a water balance. Water balance parameters and residence times (the quotient of inputs to volume of surface water) will be compared before, during, and after construction of the Tamiami bridge. Field data will be input to two hydrodynamic models. Expanding upon modeling efforts by Spence (2011), the variable-density groundwater flow model SUTRA-MS (Hughes & Sanford 2005) will not only be used to quantify groundwater discharge but also coupled with P concentrations in the shallow groundwater to provide a better understanding of the roles that groundwater discharge plays in the water and nutrient budgets (Michot et al. 2011). We will develop a reach-scale particle-tracking model to track the fate and transport pathways of water and dissolved constituents (i.e., DOC, nutrients) from the slough to the integrated mangrove-surface water-groundwater system and back to the slough over tidal and seasonal cycles, with water and chemical residence times being expressed in terms of probability density functions (e.g., Banas & Hickey 2005). Wetland Interferometric Synthetic Aperture Radar will be used to provide high spatial-resolution (1-5 m pixels) water level change maps over a greater region of the oligohaline ecotone of SRS by comparing pixel-by-pixel observations over time (Wdowinski et al. 2004, 2008; Hong et al. 2010a,b; Gondwe et al. 2010). Water level changes in the mangrove marshes will be used to constrain the particle-tracking model. Findings will be compared to other coastal ecosystems in the Caribbean, particularly through ongoing FCE hydrological and ecological investigations in coastal mangrove communities in Celestun and Sian Ka'an, of the Yucatan Peninsula, Mexico, which are geologically and ecologically similar to FCE and at risk of future urban development and SLR (Gondwe et al. 2010).

Hypothesis 5.2: Stakeholder uncertainties over SLR will increase conflicts over Everglades restoration implementation and will affect freshwater delivery to the oligohaline ecotone. Water demand by urban and agricultural users competes with the need for additional water to sustain ecosystems (and the services they provide) in ENP (Kirsch 2005; Ogden 2008). The extremely flat landscape and porous nature of the underlying limestone aquifer as well as fragmentation of this once interconnected watershed by levees, roads, and canals makes deliveries of additional water to ENP an engineering challenge. Future water demands by urban and agricultural users, concerns of flooding with SLR, and future economic and climate-related uncertainties are all concerns for water managers and a source of friction shaping hydrologic conditions in the oligohaline ecotone. *We will examine the social, institutional, and economic processes that have produced current hydrologic disconnections within the broader watershed and its ultimate impact on the oligohaline ecotone.*

Approach - We will examine the production of uncertainties and conflict by focusing our research on two key sites where these processes are particularly visible: Stormwater Treatment Area 5 (STA5) and the S-12 structures (along the Tamiami Trail that control the flow of water into northwestern SRS). Located within the Everglades Agricultural Area (EAA), STA 5 is a constructed wetland designed to improve input water quality to the Everglades by removing P (Fig. 2.6). The establishment of nesting snail kites (an endangered species) has affected STA 5 operations. New uses of STA 5 and surrounding areas – e.g., for birding, duck hunting, cultural heritage claims – reveal the social complexity of water management infrastructure. We need to understand how the conflicts in this region may be overcome, in order to release more water through the Tamiami Trail (currently a barrier to sheet flow), and ultimately to the oligohaline ecotone. Operations of the S-12 structures, and plans for water flow under the newly constructed bridge, are governed by a complex array of federal and state regulatory agencies, which often must balance competing water delivery and flood control needs with endangered species impacts. In addition, water quality concerns have further hampered S-12 operations and restoration planning. Using a multi-methodological approach, we will interview local residents, recreationalists, and resource managers, as well as analyze archival data and restoration planning documents to understand the management (institutional) and local perspectives that create connections and disconnections of water in STA 5 and the S-12 structures and eventually to the oligohaline ecotone. We will also determine from water managers and engineers responsible for site design whether climate change has been considered in the design and operations of both of these sites in order to understand long-term influences on the oligohaline ecotone.

6. Carbon Cycling CCT (co-leads – V. Engel & J. Fourqurean)

GENERAL QUESTION 6: How do changing freshwater inflows, tidal and storm cycles, and climate patterns affect the magnitude, rates, and pathways of C sequestration, loss, storage, and transport across the land-water continuum?

RATIONALE - Recent studies show that vegetated coastal systems can bury "blue carbon" at rates up to 50 times higher than tropical forests (Mcleod et al. 2011; Bouillon et al. 2011), suggesting that continued coastal development and exposure to SLR and storms will have global biogeochemical consequences (Donato et al. 2011). The FCE transect approach is designed to examine long-term spatio-temporal patterns in ecosystem response to changing coastal pressures, and we have been gradually building our infrastructure to express change in terms of the C balance using multiple cross-validating tools. A central feature of this infrastructure are eddy covariance towers that measure net ecosystem-atmosphere CO_2 exchange (NEE) and energy balance at three sites along our transects. Comparisons between NEE-derived estimates of net ecosystem productivity (NEP) and direct measurements of NPP provide important insights into the C balance, including the magnitude of C burial and transport. In FCE II, we determined that in short-hydroperiod freshwater marshes, low rates of CO_2 exchange (Schedlbauer et al. 2010) (Fig. 2.10) align with low NPP values indicative of oligotrophy (Ewe et al. 2006). However, in the full-stature SRS mangrove forest, marine-derived P, year-round growth, low respiration rates, and intensive C burial and tidal export promote NEE levels (~1100 g C m^{-2} yr^{-1}) that exceed forest records of NEP (Bouillon et al. 2008a; Barr et al. 2010) (Fig. 2.4). In the seagrass ecosystem, we are just beginning to understand rates of C burial. In Florida Bay, ~37% of NPP is channeled into belowground biomass (Herbert & Fourqurean 2009), and eventually the sediments (Orem et al. 1999). New results suggest that C storage in seagrass sediments rivals that of tropical forests, and that Florida Bay sediments are C-rich compared to seagrass systems worldwide (Fourqurean et al., in review (b,c)). By examining ecosystem metabolism from freshwater wetlands to the sea, using gas exchange, ground sampling, landscape analyses, and experiments, FCE is uniquely poised to address how C cycling is regulated across wide spatio-temporal scales to unravel, and improve predictions of subtropical wetland responses to SLR. We will synthesize WG results to create dynamic, spatially-explicit, and mechanistically-supported C budgets for the marsh-mangrove-seagrass ecosystem that can be used to drive simulation models to quantify how the C balance, and associated services (e.g., storm buffering, C sequestration) respond to, and mitigate, changes in water delivery, nutrient fluxes, and pressures of SLR in a highly vulnerable coastal ecosystem.

Hypothesis 6.1: Temporal variability in C uptake, storage, and transport in the mangrove ecotone reflects the pulsed dynamics of marine water, nutrient, and sediment supplies driven by tides and storms, and freshwater supply driven by seasonal rainfall and water management. Our 11+ years of eddy covariance, ground sampling, and landscape data suggest that inter-annual variability in the coastal C balance is largely associated with pulse dynamics of storm disturbance (including cold-fronts), tidal cycles, and groundwater dynamics (Zhang et al. 2008; Whelan et al. 2009; Barr et al. 2011;

Castañeda-Moya et al. 2011) (Fig. 1.2) that influence nutrients, salinity, and inundation – the three features defining the “production envelope” for mangrove wetlands (Twilley & Rivera-Monroy 2009). Attempts to balance C budgets find that a significant fraction of the atmospheric CO_2 uptake is not accounted for in the measurements of plant primary productivity (Barr et al. 2010, 2011) and there are large uncertainties in the transport and losses by tidal advection of organic and inorganic C into adjacent estuarine waters, downstream mineralization, and air-water CO_2 efflux (Duarte et al. 2005; Bouillon et al. 2007, 2008a; Miyajima et al. 2009). Once we integrate C transport and loss processes fully into FCE C budgets*, we expect to find that the temporal variability in the C balance along the FCE transect will reflect the seasonally-adjusted plant eco-physiological and ecosystem respiratory responses to the variable influences of marine and freshwater supplies defined by changes in surface and pore-water conductivity, water residence time, and tidal energy.*

Approach - We will integrate our C cycle measurements following the analytical approaches and field methods of Chapin et al. (2006), Engel et al. (2011), and Rivera-Monroy et al. (2012b) (Fig. 2.16) utilizing continuous estimates of NEE from our flux towers, regular above and belowground NPP values, OM accretion from sediment elevation and paleoecological studies, DIC and CO_2 fluxes across the land-water-air continuum, and measurements of dissolved and particulate C tidal fluxes (including riverine fluxes using Lagrangian tracer techniques). This framework will be newly applied in the dwarf mangrove system in TS/Ph, and comparisons between the SRS and TS/Ph datasets will enable rigorous tests of this hypothesis. Integration will be accomplished through a dedicated post-doc and subannual workshops of contributing working groups. We will collaborate with the *Scenarios* CCT to further refine biospheric-hydrodynamic models needed to quantify and predict C dynamics and ecosystem function.

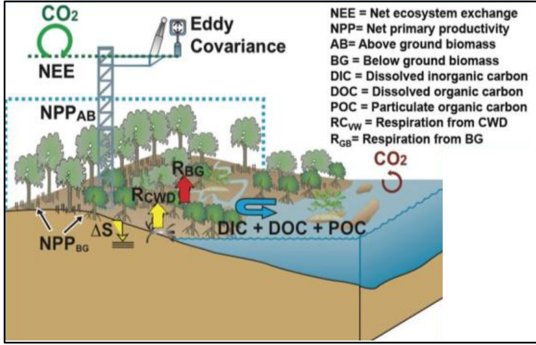


Fig. 2.17. Schematic showing CO_2 uptake, transport, and storage (S) components and land-water-atmospheric fluxes that will be used to balance the FCE C budget. Existing eddy covariance towers in the SRS marsh and mangroves and TS/Ph marsh will be supplemented by new towers in the TS/Ph dwarf mangroves and Florida Bay. Aboveground and belowground NPP and ecosystem R are measured at all sites, and C flux research is being expanded to quantify lateral transport of DIC, DOC, and POC in Taylor and Shark Rivers. Storage is estimated using sediment elevation tables and dated sediment cores. By quantifying these parameters across a spatio-temporally variable template of fresh and marine water delivery, we can create dynamic C budgets to determine how changes in water supply influence the balance of C uptake, storage, and transport.

Hypothesis 6.2: Landscape patterns in C fluxes reveal legacies of exposure of the marsh, mangrove, and seagrass ecosystems to long-term changes in the balance of fresh and marine water supplies. While our dedicated C cycling research in the SRS mangrove ecotone has moved us closer to balancing the C budget there, we are only just beginning to understand controls on C dynamics in the TS/Ph dwarf mangrove forest and our marsh and seagrass end-members. In the marsh, seasonal and spatial differences in NPP and ecosystem respiration appear to be connected to water residence time and P availability (Childers et al. 2003; Schedlbauer et al. 2010). Longer-term patterns accessible from preliminary soil cores in the TS/Ph ecotone associate mid-20th Century drainage of the Everglades to reduced OM accumulation rates in the marsh, and increased rates in the mangroves consistent with greater groundwater P delivery associated with saltwater intrusion (C. Saunders, unpublished data) (Fig. 2.18). In the seagrass ecosystem, we have found production dynamics to be linked primarily to variations in P supply and salinity (Herbert & Fourqurean 2009), which are functions of freshwater supply and SLR in Florida Bay. *We expect that landscape-scale patterns of change in the C balance will be determined by the mitigating or magnifying effects of water management and rainfall variability on the impacts of SLR.*

Approach – We will coordinate a large-scale initiative to determine landscape variability in the patterns and controls on C budget components, including the expansion of our eddy flux network to include a tower in the dwarf mangrove forest of TS/Ph-7 and underwater O_2-based gas flux (Hume et al.

2011) in Florida Bay. We will use the framework described above to calculate and cross-validate C cycling measurements from plot-based and tower-based methods. We will work with the *Legacies* CCT to extend our site-based measures to the landscape using satellite imagery. By coordinating cross-site and international meetings we will enable this comprehensive C budget to be used to increase our understanding of the future of coastal C dynamics in a global context. This includes integration with other Atlantic coastal LTER sites, ongoing and expanding international research projects in coastal Panama (Troxler 2007; Troxler et al., in review), Shark Bay, Australia (Cawley et al., in review; Fourqurean et al., in review (b,c); Price et al., in review), and locations throughout Central America (Rivera-Monroy et al. 2007; Rivera-Monroy et al., in review) to assess vulnerability of C budgets in a variety of coastal wetlands to climate change and human impacts.

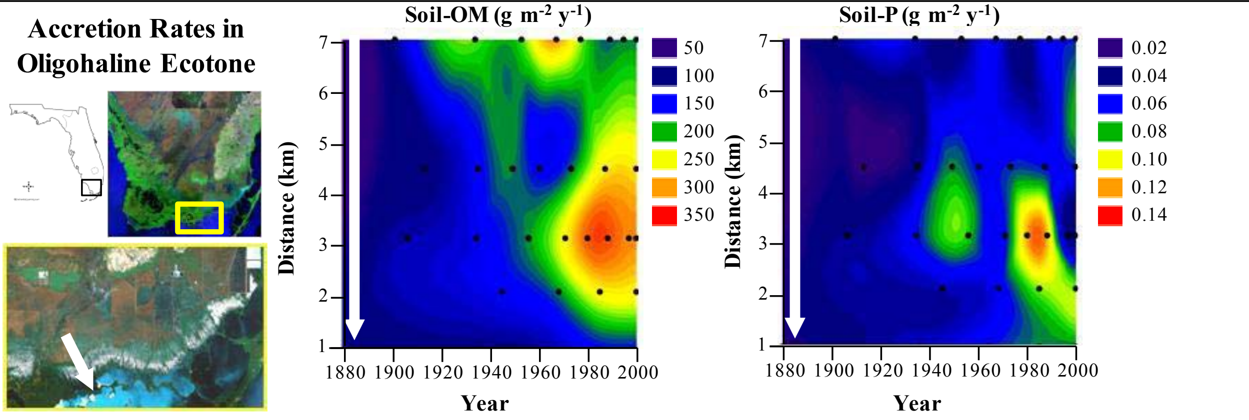


Fig. 2.18. Heat maps showing spatio-temporal patterns in organic matter (OM, *left panel*) and phosphorus (P, *right panel*) accretion rates calculated from a series of radiometrically dated sediment cores taken along a 7 km transect in the TS/Ph drainage. High OM and P accumulation rates in the marsh correspond to periods of high freshwater delivery, while in the mangroves, the opposite is observed – high P accumulation rates occur during periods of low freshwater deliveries. The latter observation is consistent with greater seawater intrusion, resulting in groundwater discharges of P into the ecotone (C. Saunders, unpublished data).

7. Climate & Disturbance Legacies CCT (co-leads –R. Roy Chowdhury & H. Briceño)

GENERAL QUESTION 7: How have the legacies of wetland conversion to urban and agricultural land uses and resulting shifts in water demand/management across the Everglades watershed changed the sensitivity of the coastal zone to freshwater restoration in the face of SLR?

RATIONALE - The goal of the *Legacies* CCT is to understand the legacies of regional climate and land-use change on the eco-hydrodynamics of the oligohaline ecotone. We seek to understand the temporal and spatial scales, as well as the nonlinear relationships, by which these global and regional drivers produce change in the ecotone. To advance an integrated understanding of the FCE socio-hydrologic system across broad spatial and temporal scales, this CCT will build on data and insights from FCE II's Human Dimensions and Climate and Disturbance CCTs. Specifically, it will link landscape structure, connectedness, and boundaries with land-water management dynamics to assess the sensitivity of the socio-ecological system within the framework of global and regional drivers. The FCE III *Legacies* CCT will collaborate with the *Water* CCT to investigate legacies of water policy regimes, with the *Carbon* CCT to explore their consequences at the landscape scale, and generate empirical input for the *Scenarios* CCT to explore possible futures of land-water use decisions and impacts.

Hypothesis 7.1: Changes in land-use and water allocation decisions in the South Florida Urban Gradient have hydrodynamic consequences in the Everglades landscape that explain observed changes in the oligohaline ecotone. In South Florida, landscape patterns reflect biophysical legacies of continuous SLR since the end of the last glacial period, and of climate, hydrological, and land-use disturbances since the mid 1800s (Walker et al. 1997; Walker 2001; McVoy et al. 2011). Today, the location of the brackish groundwater mixing zone varies spatially and temporally (Saha et al. 2011a), but we do not know the extent to which this variability is connected to changes in water management. Complementing the *Water* CCT's study of the impacts of water use policies on freshwater flow and ecotone hydrodynamics, the *Legacies* CCT will conduct retrospective analyses to examine the interplay of climate and land-use change in changing saltwater intrusion rates, which feed back to determine both Everglades function in the natural landscape and the trends and vulnerability of resource utilization and distribution in the urban-agricultural gradient. *We will test the hypothesis that periods and locations of land-use and/or climate-driven changes in available freshwater correlate (perhaps with lags, step-functions or nonlinearities) with the migration of the oligohaline ecotone along the TS and SRS transects.*

Approach – In FCE II, we quantified the spatial patterns of land use in (sub) urbanizing southern Miami-Dade Co. using satellite imagery to resolve land cover to the parcel scale, and connected land cover to neighborhood social composition at the census block group scale (Roy Chowdhury et al. 2011; Onsted & Roy Chowdhury, in review; Aladwaik et al., in review). In FCE III, we will extend our land-use change work to the full Everglades watershed, analyzing the past four decades of landscape change across the urban, suburban, and exurban/agricultural gradients using aerial photographs and multi-resolution satellite platforms (GeoEye, Landsat, MODIS). These analyses will provide spatially-explicit assessments of regional water flow patterns and connect them with land cover changes through time. We will further quantify urban and agricultural water demand by developing empirically calibrated water budgets (pilot budgets for southern Miami-Dade are currently being evaluated) for urban, suburban, agricultural, and other land covers within the Everglades watershed. To validate and refine our water demand and land-use analyses, we will collaborate with the *Water* CCT to survey urban and agricultural land managers (e.g., farmers, residential homeowners), ascertain their water use and land management practices, and elicit their experiences and perceptions of vulnerability to climate change. These land-use, water demand, and survey data will characterize the sensitivity of land users and the regional land-use system as it is exposed to hydrological changes due to climate variation and saltwater intrusion. We will also profile the adaptive capacity of the terrestrial-hydrological system in terms of water policy regimes, and thematically link past land-use changes with estimates of the relative SLR, climate cycles, and precipitation patterns from remote sensing and meteorological datasets tailored to our FCE land cover and hydrology databases (Adler et al. 2003; Curtis & Adler 2003) to interpret sources of long-term variability in groundwater salinity in the Biscayne aquifer. These analyses of linked landscape-water-human system dynamics and the exposure, sensitivity, and adaptive capacity of the greater Everglades to climate variability and change will help us assemble a picture of system vulnerability to climate change.

Hypothesis 7.2: Legacies of changing freshwater inflows to the oligohaline ecotone have influenced sensitivity to the balance of fresh and marine water supplies across the landscape. FCE has been collecting long-term observational and paleoecological data to address how continually changing, nonlinear exogenous drivers (i.e., climate change, economic policies) interact with internal dynamics to produce existing social, hydrological, and biological patterns. For example, diatom-based salinity reconstructions show how long-term changes driven by SLR and water management are expressed on shorter-term variability driven by regional weather patterns that regulate ecosystem sensitivity to changes in water management (Wachnicka et al. 2012b), improving our ability to detect restoration-driven change. Observational datasets similarly show how spatio-temporal patterns of nutrient fluxes and productivity track both long-term climate cycles and shorter-term disturbances due to water management and storms (Briceño & Boyer 2010; Castañeda-Moya et al. 2010; Barr et al. 2011) (Fig. 2.10). In FCE III, we will integrate our legacy datasets with new geospatial data and modeling tools to reveal how land-use and climate change interact to control past and future ecosystem dynamics.

Approach – In addition to the datasets on land-use change and climate variability noted above, we will generate remote-sensing based vegetation indices to explore drivers of directional, cyclical, and stochastic change on salinity, nutrient concentrations, and C storage. Datasets include 20-50 yr salinity and nutrient concentrations at the mouth of the SRS and TS/Ph transects, 11+ yr of C flux data, and a suite of long-term (>150 yr) paleoecological datasets that have generated spatially-explicit C and nutrient accumulation or loss rates in or near the ecotone (C. Saunders, unpublished data). In coordination with the Primary Production WG, we will derive and use vegetation indices from past and current multi-resolution remote sensing data (AVHRR, MODIS, Landsat) to evaluate whether vegetation indices can be combined with C flux data for gross primary production modeling (e.g., in estimating ecosystem light use efficiency—see Goerner et al. 2011), allowing us to scale up C dynamics from the plot to the landscape.

We plan to examine connections between socio-hydrological (hypothesis 7.1) and ecological (hypothesis 7.2) processes using time-series analyses to identify and characterize their components (trend, cycles, breaks, seasonality), including the use of standardized cumulative sum charts (Z-cusum; Manly & MacKenzie 2000; Briceño & Boyer 2010) to identify probable driver-response relationships of interest, confirm the significance of shifts with appropriate statistical tests (Rodionov 2004; Taylor 2000), and assess commonalities using time-series approaches. Statistical analyses and modeling (e.g., spatial regression, factorial ANOVA designs, multi-level modeling) will test relationships among indices of land cover, landscape structure, and climate-hydrological indicators at varied spatial scales to investigate boundary dynamics and neighborhood effects. These explorations of land-climate change legacies will position us to investigate additional, complex ecosystem science and policy questions in the future by identifying the critical pathways of change in the Everglades land-hydrologic system, and the critical feedbacks to the coupled system from ecosystem changes. In so doing, they will yield insights into the implications of land/water management dynamics for the sustainability of the integrated system, addressing the sensitivity of the Everglades system to climate change and further anthropogenic alteration. This work will also benefit from ongoing, cross-site research projects, including a newly funded study (Co-PIs: Simard, Roy Chowdhury, Rivera-Monroy) assessing the vulnerability of coastal mangroves in the Americas (including in the Everglades) to climate and anthropogenic change.

8. Scenarios & Modeling CCT (co-leads - M. Rains and C. Fitz)

GENERAL QUESTION 8: What scenario of water distribution and climate change will maximize socio-economic and environmental sustainability of a future FCE?

RATIONALE - Modeling is a key tool for the FCE program for understanding outcomes where drivers are expected to change at all scales. In conjunction with an LTER Network-wide initiative, we will implement a scenario study framework to envision multiple plausible outcomes of alternative changes in a select set of climate and water-use management drivers (Fig. 2.19). In scenario studies, common storylines are adopted, with the degree to which modeling efforts are linked to these storylines helping to define the ways in which the modeling efforts proceed and interact (Biggs et al. 2007). This approach is well suited to LTER programs, where complex multi-scale research reaches across disciplines and scales, and from academia to society (Thompson et al. 2011). We adopt this approach and combine it with "bottom-up" decision scaling (Brown et al. 2012) that includes an initial extraction of signals of climate and land-use change from long-term socio-ecological datasets (*Legacies* CCT) and obtaining stakeholder feedback on the outcomes of climate extremes and water management decisions. This allows sensitive ecosystem attributes and thresholds for undesirable impacts to be identified at the outset, constraining the modeling efforts to drivers and response variables that are likely to provide the most meaningful outcomes. Planning for climate change can then build on an understanding of ways in which ecosystem and societal risks are enhanced or mitigated by ecosystem feedbacks or social infrastructure and influence decisions in a way that facilitates investments that maximize chances for a sustainable future.

Hypothesis 8.1: Scenarios that maximize freshwater inflow to the Everglades will sustain distinctive biophysical features and dynamics of the oligohaline ecotone in the face of climate change. Our LTER is identifying trajectories of change, and their underlying mechanistic controls, in the response of the oligohaline ecotone to the balance of fresh and marine water delivery. We have developed tools for assessing these trajectories to guide adaptive restoration (Doren et al. 2009a). In FCE III, we will use modeling tools developed from our long-term datasets and experiments to predict future trajectories for the FCE under a distinct set of water management and climate scenarios, and employ existing assessment frameworks to guide interpretations of resultant trajectories.

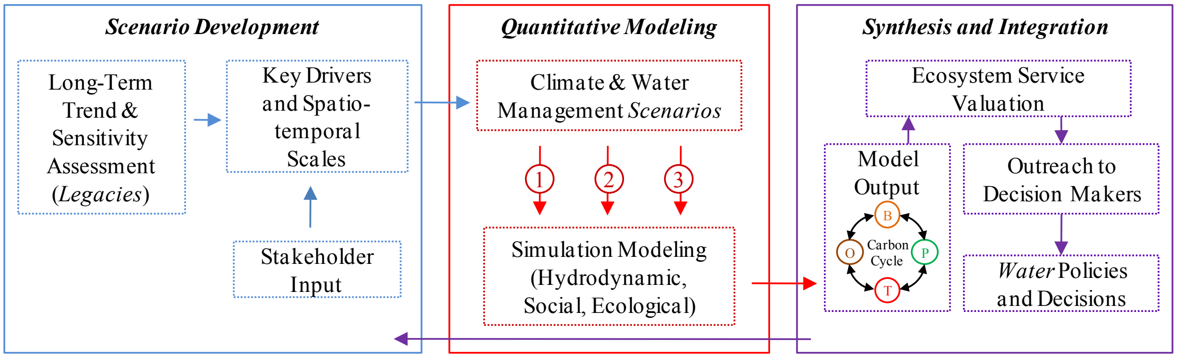


Fig. 2.19. Proposed three-step framework for developing scenarios for FCE III futures. ***Scenario Development:*** The Climate and Disturbance *Legacies* Cross-Cutting Theme (CCT) will use FCE datasets to determine important socio-hydrological drivers and relevant time scales of change for sensitive response parameters. These results and input from restoration stakeholders will be used to refine and select an appropriate suite of coupled hydrodynamic and ecological empirical simulation models and time scales for model runs. ***Quantitative Modeling:*** The *Scenarios* & Modeling CCT will employ these models to project outcomes in the four core Working Group areas under alternative climate and water management scenarios. ***Synthesis and Integration:*** Evaluations of outcomes, including implications for ecosystem services, will be conducted through our partnership with Everglades Foundation, and used to further refine models. Communication of outcomes with decision-makers is a vital component of FCE outreach, and their impact on political decisions regarding restoration will be examined by our *Water* CCT.

Approach - *Scenario Development:* In the first two years of FCE III, we will coordinate meetings of science experts and stakeholders to balance the interplay between tightly- and loosely- linked scenarios, creating common (trans-disciplinary) storylines while allowing full independence to discipline-specific modelers, and formulating bridges to encourage cross-discipline or cross-scale comparisons. These efforts will build upon climate-change scenarios being developed by FCE collaborators in the State University System Climate Change Task Force (Misra et al. 2011; Stephanova et al. 2012) and Everglades restoration scenarios developed by a partner project, "*Synthesis of Everglades Research and Ecosystem Services*" (SERES) (Borkhataria et al. 2011; T. Van Lent, LOS). We will identify a manageable number of plausible timelines and climatic and water management conditions to drive interactive socio-ecological models. These model domains range from site-specific (points) to spatially extensive models (>10,000 km^2) with temporal domains ranging from weeks to decades.

Quantitative Modeling: In years 3-6, we will focus on refining our multi-modeling framework to both continue model-data synthesis and extrapolate findings spatio-temporally to explore future scenarios, with the model-development flexibility to accommodate newly identified needs for scenario assessment. We will begin with the South Florida Water Management Model (SFWMM) (MacVicar et al. 1984; SFWMD 2005), the primary tool used in water management planning (USACE & SFWMD 1999; Van Lent et al. 1999), to examine how regional climate changes and tradeoffs in water delivery influence water levels and flows within ENP and the South Florida Urban Gradient. Output will drive the Everglades Landscape Model (ELM) (Fitz 2009; Fitz et al. 2011) to evaluate consequences tied to hydro-ecological dynamics within the Everglades (focusing on the ecotone), ranging from salinity and nutrient fluxes, to soil accretion, and succession of vegetation communities. We will analyze results of the SFWMM and ELM models but also use them as boundary conditions for FCE ecosystem models, enabling more detailed relative comparisons of the hydrologic, ecological, and social responses to changes in the balance of fresh and marine water supplies. Simple water-budget models (Zapata-Rios 2009; Saha et al. 2011b) and more complex reach- and landscape-scale hydrodynamic models (Anwar & Sukop 2009; Ho et al. 2009; Michot et al. 2011; Spence 2011) developed by the *Water* CCT will link field data and model results to better constrain the estimates of groundwater to surface water contributions to FCE, and can feed back to models that examine how land-use zoning influences Everglades hydrology relative to changing regional water resources (Onsted & Roy Chowdhury, in review). A suite of linked hydrologic, biogeochemical, and community models will provide expectations for producer and C processes in the marsh (Noe & Childers 2007; Onsted et al., in review), soil and mangrove dynamics in the ecotone (Twilley & Rivera-Monroy 2005, 2009), and seagrass and phytoplankton dynamics in the Florida Bay ecosystem (Madden et al. 2007; Madden 2011). To understand consequences of contrasting hydrologic regimes to aquatic consumers, we will couple movement models (Jopp et al. 2010; Obaza et al. 2011) with statistical models that predict consumer densities (Trexler & Goss 2009). Results from these local-scale models can further refine the ELM, with the ELM being subsequently used to extrapolate that improved understanding across the broader spatio-temporal scales of the Everglades.

Hypothesis 8.2: Scenarios that maximize the sustainability of ecosystem services provided by the marsh-mangrove ecotone will also improve freshwater sustainability in the South Florida Urban Gradient. Our *Scenarios* approach also seeks to better understand how the nearby human-dominated environment interfaces with Everglades dynamics, primarily through socio-ecological feedbacks to climate change and water management decisions. We will focus on freshwater supply, but also evaluate other local-scale feedbacks identified by prior FCE science, including flood and storm protection (Zhang et al. 2012) and recreational value (largely linked to wildlife abundances) (Mather Economic Study 2010).

<u>Approach</u> - *Synthesis and Integration:* Model outcomes will be visualized using GIS-based mapping tools (including video) developed through our partnership with the SERES program and will be used to evaluate the economic consequences of scenario options to ecosystem services, including freshwater supply, flood protection, and fish and wading bird abundances (as they apply to recreational use). The SERES program is conducting the extensive economic analysis necessary to generate comparisons based on monetary metrics. Further, because many of our modeled ecosystem components are already "ecological indicators" used in regular system-wide assessment, we can employ this methodology carefully developed during FCE II for continuous observational datasets (Doren et al. 2009a) to both evaluate and communicate future outcomes of contrasting scenarios to policy-makers.

D. Synthesis and Integration (co-leads - E. Gaiser & D. Childers)

The FCE program is deliberately structured in a way that promotes synthesis, by having a conceptual framework that helps generate integrative hypotheses that can be tested through coordinated WG research that is integrated by CCT activities. In FCE III, our *Water*, *Carbon*, *Legacies,* and *Scenarios* CCTs will address our goal of understanding how the legacies of freshwater use and distribution decisions influence socio-ecological vulnerability to SLR. We also are devoted to understanding emergent properties of the Everglades in the context of other ecosystems, including similarly vulnerable coupled human-ecological systems, other "upside-down" estuaries and other large wetland restoration programs, details about which are woven throughout this proposal. A specific integrative effort planned for this renewal is to meet with the other three Atlantic Coast wetland sites (PIE, VCR, GCE) on an annual basis to advance cross-site synthesis and collaborations. Meetings will rotate among the sites, and will be held in conjunction with site annual meetings. Visitors will attend the annual meeting of the host site, and then meet on the following day(s) to address topics ripe for cross-site work. Likely initial topics of cross-site synthesis include: 1) drivers of wetland accretion; 2) role of lateral flux in the C budget of coastal wetlands; and 3) controls of coastal plant productivity, which are key components of FCE *Carbon* CCT research.

We pay particular attention to synthesis in our third phase by planning a book to communicate our integrative research findings. Any long-term program gains from periodic retrospective, and introspective, analysis of the scientific legacies and lessons learned from the past. The LTER Network has a tradition of focusing such retrospective synthesis activities around published books known as "LTER Site Synthesis Volumes." After 12 years of FCE research, it seems appropriate to approach our central research questions in a broad, synthetic way, with the goal of a product that goes well beyond simply producing additional, more refined research questions. The product will be more than a review of past findings or a question-specific list of research products. Our retrospective synthesis effort will represent the best of our collective knowledge, effectively answering the question: "*How has FCE science and research led to the re-writing of textbooks and the re-thinking of theory?*" By definition, our synthesis exercise will include the active participation of all FCE researchers—past and present and will allow us to critically examine: 1) the overall state of our knowledge; 2) the accomplishments and value of this knowledge to both science and society; and 3) what changes we may want to consider for future FCE research. Our progression from our original proposal (FCE I) and through FCE II to III has involved several "step functions" in our research as we continually build on past knowledge to refine our thinking and expand our program to include exciting new directions (e.g., our socio-ecological and urban work). We are cognizant that the research results, expertise, and enthusiasm of all FCE researchers are needed for a successful synthesis, and we will nurture these with a series of workshops early in FCE III that will first define the broad themes that will guide our synthesis, then increasingly focus our retrospective synthesis on key legacies. This activity will be led by D. Childers (Lead PI from 2000-2008), working closely with Lead PI E. Gaiser and Co-PI L. Ogden. Childers' experience with FCE I and FCE II, his current experience with a similar synthesis exercise at CAP LTER (where he is now Lead PI), and his holistic and integrative approach to science lend confidence in our synthesis effort. Our timeline for this effort is to produce our first FCE Synthesis Volume in time for our FCE III mid-term review in 2015.

3. EDUCATION & OUTREACH

The FCE III Education and Outreach (EO) program (http://fcelter.fiu.edu/education_outreach/) will address the goals and objectives for *Education, Communication, and Coordination with Other Networks* described in the *2011 Strategic Implementation Plan (SIP)* for the *Long Term Ecological Research Network: Research and Education*. In the *SIP,* several new Network-wide challenges for Education, Communication, and Coordination with Other Networks are identified and are being used to guide the structure and coordination of our EO programs. FCE EO is currently addressing and will continue to address all six of the *Challenges* for *Education* listed in the *2011 SIP*. Our approach divides these challenges into two categories: Site-level challenges and Network-level challenges.

Addressing Site Level Challenges: The geographic location of the FCE LTER provides us with the opportunity to work with a large number of individuals that are traditionally underrepresented in science. The majority of our "end users", within our K-20 constituency, are from Miami Dade County Public Schools (MDCPS) and Florida International University (FIU). MDCPS and FIU are both minority-serving institutions that enroll >80% and >70%, respectively, Hispanic and African American students.

FCE's Research Experience Program (REP) is the foundation of our educational programs and includes students in grades K-20, pre- and professional service teachers, community college, and university faculty. Throughout FCE II, we have worked closely mentoring MDCPS teachers, Teresa Casal and Catherine Laroche. Both are bilingual, National Board Certified Teachers with over 30 years of combined teaching experience ranging from middle school through undergraduates in the US, Mexico, and Haiti. Their wealth of experience has been invaluable in working with our two largest immigrant communities in South Florida and in addressing differences across demographics and educational standards. The results of their Research Experience for Teacher (RET) experiences are also used (by Casal) in undergraduate courses for pre-service teachers at Miami Dade [Community] College (MDC) and to provide ongoing professional development to MDCPS teachers (by both Casal and Laroche). In addition, Casal continues to collaborate with ENP and MDC through the *Parks As Resources for Knowledge (PARK) Program* by presenting hands-on Everglades fire ecology lessons to over 130 pre-service teachers. In FCE III, we will expand our RET activities. One specific activity will be to develop a curriculum based on the process and outcomes of our *Scenario* CCT research. Students will learn the function of models in predictive science and visualize and interpret FCE futures using hands-on exercises.

In FCE III, we also propose to continue working with K-12 students in the classroom and our research laboratories. Since 2000, FCE has worked directly with over 65 high school students outside of the classroom in formal internships and workshops. FCE scientists have provided in-depth mentoring to 13 underrepresented high school students that have presented their research at Regional, State, and International competitions—they have received 57 awards (44 in FCE II) and $59,200 ($42,850 in FCE II) in prizes and scholarships. One student placed 2nd at the Intel International Science and Engineering Fair for his research to unravel Everglades paleohydrology, and received a minor planet named in his honor by the MIT Lincoln Laboratory (http://en.wikipedia.org/wiki/25793_Chrisanchez). He also produced a published article for our special issue of the *Journal of Paleolimnology* (Sanchez et al. 2012). The FCE REP programs bridge the K-20 spectrum through our extensive use of *near peer mentoring (NPM)*. FCE faculty, graduate, and undergraduate students have always served as mentors to our K-12 students, and our high school students have mentored middle and elementary students. Recently we have begun to formalize *NPM* in our REPs by requesting that REUs mentor high school or middle school students in science fair projects related to their research.

In FCE III, we propose to expand our REU program by increasing the participation of students from a wider range of institutions. We will also work with the LTER Executive Board for EO to develop a standard, formalized mechanism to promote REU exchanges between sites. This process will likely begin during the spring semester for the upcoming summer and will include the expectation to mentor a K-12 student and a presentation of results at our annual All Scientists Meeting (ASM).

Founded in 2001, the FCE Student Group (FCE SG) continues to actively cultivate academic collaboration and community-building among FCE graduate students. Each academic year, its Executive Board (EB) coordinates social and scholarly events including meetings, socials, academic talks, and conference preparation workshops (http://fcelter.fiu.edu/students/). In 2011, the FCE SG pioneered the *Everglades Hour*, a seminar designed to introduce graduate students to key FCE documents and to foster a deeper understanding of our research program, and this will continue through FCE III. In 2007, FIU began a special topics course for graduate students at FIU to engage the SG in reading, interpreting, writing and proposing FCE and LTER science with guidance from the Lead PI. In FCE III, this special topics course will include instruction in time-series analysis led by H. Briceño to support goals of the *Legacies* CCT. In Fall 2011, the FCE SG launched a conference travel grant award program and a Facebook page. The FCE SG is devoted to organizing science communication activities at national and international venues including an *Everglades Symposium* at the *GEER/INTECOL 2012 International Wetlands Conference*. The SG has been one of the most active in the LTER Network, sponsoring workshops at the LTER ASM, leading national proposal activities and workshops, and developing proposals for socio-ecological science synthesis for the LTER Network (http://fcelter.fiu.edu/research/cross-site_network/), which will continue in FCE III.

Addressing Network Level Challenges: FCE LTER is an active participant and leader in many committees aimed at addressing the coordination of EO activities across the LTER Network and we will continue to foster these roles in FCE III. FCE is currently represented by EO Coordinator, Nicholas Oehm, and Asst. Coordinator, Susan Dailey on eight committees and subcommittees including the Education EB, Communication, and ASM 2012 Planning Committees. FCE EO is also a member of the E-newsletter, Education Website, Network Website, Science Journalism, and Transformational Science Publication/Future Scenarios Subcommittees. The EO Coordinator is also working with the Everglades Foundation and the Everglades Digital Library (EDL) to improve the cyber-infrastructure of Everglades research and resources. Together we are working with the EDL to develop a central repository and "building a discovery system for everything Everglades." We have also recently partnered with the Deering Estate [Museum] to improve our citizen science programs.

FCE III will introduce a new, interdisciplinary, cross site, graduate course with the other Atlantic Coastal wetland sites (PIE, VCR, GCE). The objective of the course is to expose graduate students to the breadth of coastal research, and provide tools that will improve their ability to function in a highly interdisciplinary research environment. Taught by video conferencing, each course will feature readings and lectures from PIs at each site and will analyze both LTER natural and social science datasets. The first course will be coordinated by GCE and will occur during years 3 and 6 of our proposal cycles.

Challenges to Communication: FCE is addressing the *2011 SIP* communication challenges by making results tangible and visible to our diverse constituents through our agency partnerships and EO programs. FCE is a diverse research group that currently consists of 34 collaborating institutions. One third of our collaborators are researchers imbedded within our constituencies including state (1) and federal agencies

(5), Non-Governmental Organizations (3), and a private consulting firm. In FCE III, these collaborative partnerships will continue to imbed FCE researchers and results in the reports used in policy-making decisions (e.g., Doren et al. 2009; SFERTF 2010).

Through the coordination of our Research Experience Programs, our teachers, undergraduate, and high school fellows work directly with FCE scientists to make our research findings tangible and visible to diverse educational groups and establish a consistent dialogue with our end users. Our EO Coordinator and RETs are our primary points of contact for MDC, MDCPS, and Monroe County Public Schools. FCE III EO will continue to broaden the diversity of our audience through our newsletter and social networking sites for communicating with both internal and external groups. FCE researchers and educators contribute regularly to FCE's Facebook to provide announcements of research findings and publications. We currently have 91 Facebook friends and 47 followers on Twitter and continue to work towards increasing our audience. Throughout FCE III, Susan Dailey will continue to contribute to the LTER Network Newsletter and produce/distribute our new FCE E-newsletter.

4. MID-TERM EVALUATION

The FCE II Program appreciated constructive feedback from a positive mid-term evaluation and incorporated suggestions into our subsequent research and this proposal, including the following:

- We were encouraged to develop a comprehensive heuristic model that integrates all of the factors and processes relevant to FCE science. We used the resultant conceptual framework (Fig. 2.3) to reconstruct our CCT research to examine socio-ecological response and feedbacks to changes in water resource allocation and distribution at extended spatio-temporal scales, enabling us to directly address socio-hydrological connectivity beyond the ENP boundaries.
- Between 2007-Feb 2012, FCE produced 178 refereed journal articles, 2 books, 16 book chapters that acknowledge the FCE II NSF grant. With 20+ publications currently in review and 9 mo. remaining in our funding cycle, we anticipate well-exceeding our goal of 200 publications for our funding period (double that of FCE I). This list includes eco-hydrological modeling papers (i.e., He et al. 2010; Saha et al. 2011a; Onsted et al., in review) that guide proposed research and reflects the broad network of FCE scientists and their productivity, with the reminder that many of our agency collaborators generate products other than publications that are critical to the FCE mission (i.e., advancements in policy communications, restoration science support, and feedback). We also produced three special issues of journals during FCE II highlighting our discoveries in restoration science communication (Doren et al. 2009a), paleoecology (Anderson & Gaiser, in review), and coastal ecosystem management (Fourqurean et al., in review (a)) (see C. Hadley and T. Welschot, LOS, for descriptions of forthcoming special issues).
- In response to specific research concerns, our Trophic Dynamics studies have been expanded to include microconsumer linkages (e.g., Sargeant et al. 2010, 2011), our extensive invasive species research continues through many leveraged projects (e.g., Ewe et al. 2007b; Doren et al. 2009b; Rehage et al. 2009; Sih et al. 2010), and, although we do focus on P as the dominant driver in this unusual P-limited estuary, we continue to improve our understanding of the importance of N through dedicated research integrated in our central framework (e.g.,Williams et al. 2009; Inglett et al. 2011; Wozniak et al. 2012).
- FCE advances freshwater and coastal wetland restoration science by spearheading trans-disciplinary regional, national, and international comparative research in threatened wetlands and coastal ecosystems elsewhere (e.g., Rivera-Monroy et al. 2004, 2007, 2012b; Calderon-Aguilera et al. 2012; La Hée et al. 2012; Fourqurean et al., in review (a)). Our co-production of science through broad agency representation enables our research to be informed by and guide policy decisions at local, state and Federal levels (see http://fcelter.fiu.edu/research/key_findings/index.htm?ts=communication). In this way, the FCE LTER has provided a model for integrating science for society and the environment since its inception.

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*****References in **bold** are the "key findings" identified in Section1 (*Results of Prior Support*)