MID-TERM REVIEW REPORT

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LONG-TERM ECOLOGICAL RESEARCH PROGRAM

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FCE LTER

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EXECUTIVE SUMMARY

This report presents the scientific, educational and organizational accomplishments of the Florida Coastal Everglades LTER Program (FCE), first funded in May 2000 (FCE I) and renewed in February 2007 (FCE II). Since our inception, we have grown from having 30 collaborators, students and staff, to over 140, representing 29 institutions/organizations. We have amassed 186 publications that directly cite FCE support, conferred 30 M.S. and 18 Ph.D. degrees and presented LTER findings in 765 conference presentations. We have received over $20,000,000 in external funding linked to FCE, which represents a leveraging ratio of 8.8. We have had continuity in staffing of our FCE LTER Program office, including our Program and Information Manager, who have catalogued over 383 datasets and provide a highly effective on-line platform that provides FCE resources to FCE scientists, the LTER network and the public. Our FCE Schoolyard program has a K-24 mission that involves teachers and students in research and public education, both locally and globally. FCE scientists, staff, educators and students have been very active in network-level research and governance. Our website statistics suggest the broad impact that FCE research can have, even remotely. The organization of our program solid and clear, and leadership and governance are both stable and functional.

FCE research is focused on the central idea that *in the coastal Everglades landscape, population and ecosystem-level dynamics are controlled by the relative importance of water source, water residence time, and local biotic processes. This phenomenon is best exemplified in the oligohaline ecotone, where these 3 factors interact most strongly and vary over many [temporal and spatial] scales.* Because freshwater resources are controlled in part by human activities, FCE provides an excellent laboratory for understanding how coastal ecosystem dynamics respond to, and influence, human activities. While we await large-scale restoration of freshwater flows into our ecosystem, or the "Grand Experiment", we have amassed decadal time series of observational data on primary production, soil dynamics, water quality, organic matter characteristics, consumer/trophic dynamics, and on key physical/environmental parameters, such as water levels, rain levels, and salinity, that improve our understanding of system variability and its drivers. We now have three carbon flux (eddy covariance) sampling towers in the mangroves (SRS-6), marl prairie marsh (TS/Ph-1) and slough (SRS-2) that allow us to directly quantify ecosystem-scale carbon fluxes and their drivers. We also have a number of experimental research activities that are focused on our central concept. We integrate these observational and experimental data in several ways, including our own synthesis activities and through several major integrated modeling efforts. In FCE II, we have developed a Human Dimensions theme that enables us to understand the interactions between society and ecosystem processes, and the politics of decision-making that drive the restoration process.

FCE has become an important driver of the science of Everglades Restoration, thanks to many agency scientists (ENP, NAS, SFWMD, USGS) and several NGOs who collaborate with the FCE LTER Program. Restoration will bring long-term changes that are key drivers in our central hypothesis. FCE scientists and students are involved in research efforts that are critical to determining how to best conduct this restoration, and if the products of restoration are ecologically successful. Thus, the FCE LTER Program has become a critical "hub" of Everglades science.

I. INTRODUCTION

A. Overview and History of the FCE LTER Program

The Florida Coastal Everglades (FCE) LTER Program was funded through a 1999 NSF initiative to add three new coastal sites to a then 21-site LTER Network. By re-allocating funding for the Land-Margin Ecosystems Research (LMER) Program to more permanent coastal ecological programs, three new LTER programs were supported: Georgia Coastal Ecosystems (GCE) LTER based at the University of Georgia, the Santa Barbara Coastal (SBC) LTER based at the University of California-Santa Barbara, and the FCE LTER Program based at Florida International University. Our funding began in May 2000 (FCE I) and was renewed in 2007 (FCE II); in this report we summarize our activities, findings, and accomplishments during FCE II, although the long-term perspective of our work and the trajectory of program building requires a blending of the boundaries between funding cycles to fully address the goals of our LTER program. This report provides an overview of findings by our working groups, directed at the central questions established in our FCE II proposal to guide working group research. During the site visit, we will expose you to the details of our science both during the field trip and at our evening poster session. We will integrate these findings relative to our central questions during the *Science Morning* session of presentations. This report is rich with hyperlinks to relevant data, publications and web pages, and we encourage you to read the document "interactively," while online.

The FCE LTER research program focuses on the landscape-scale connectivity of the freshwater to marine gradient that characterizes the south Florida Everglades. Our original proposal postulated that **Regional processes mediated by water flow control population and ecosystem level dynamics at any location within the coastal Everglades landscape**. **This phenomenon is best exemplified in the dynamics of the estuarine oligohaline zone where freshwater draining phosphorus-limited Everglades marshes mixes with water from the more nitrogen-limited coastal ocean**. We hypothesized that ecosystem productivity would be greatest where freshwater supplies, enriched (relative to coastal waters) in nitrogen and dissolved organic carbon, meet marine waters where phosphorus is more available. This is the opposite of most estuaries, where freshwater supplies of nutrients are plentiful and often result in the enrichment of coastal waters. The Everglades is a karstic wetland, on a limestone bedrock that sequesters phosphorus (P) and causes extreme oligotrophy, creating this "upside-down" gradient in nutrient supply. Where freshwater meets the coast, we hypothesize a low-salinity peak in productivity (in the oligohaline zone). Our experimental design follows this central hypothesis with two transects that track water flow, from canal inputs to the Gulf of Mexico (Fig. 1A.1 and maps and photos of the transects and sites). We hypothesized an oligohaline productivity peak in the Shark River Slough (SRS) transect, because the slough is directly connected with the Gulf of Mexico. Our Taylor River Slough/Panhandle (TS/Ph) transect, on the other hand, is in the southern Everglades and empties into the shallow, expansive Florida Bay estuary before reaching the Gulf. We hypothesized that this transect would not have an oligohaline peak because the shallow, carbonate-rich estuary supports subtidal seagrass communities adept at sequestering oceanic P before it can reach the oligohaline zone.

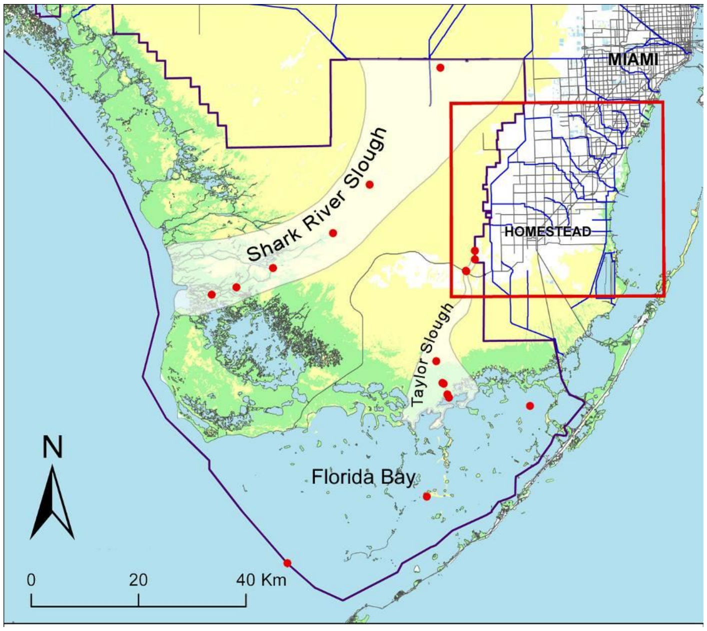


Figure IA.1 Map showing the location of FCE study sites (red dots) along Shark River and Taylor Sloughs and the Human Dimensions suburban study area (red box) in South Florida.

The questions generated by these FCE I hypotheses were addressed by working groups that closely parallel the core areas required of all LTER sites: primary production, consumer and trophic dynamics, soils and organic matter, nutrient dynamics and disturbance. Observational data and experimental studies generated by these groups during FCE I were integrated (see FCE I final report and Childers et al., 2006) and new hypotheses emerged to guide FCE II. Rather than finding a productivity peak in central Shark River Slough and an absence of one in Taylor Slough, our research showed that many ecosystem components showed enhanced productivity in the TS/Ph ecotone and a wedge of productivity toward the marine end of the SRS transect (Fig. IA.2). Rates of aboveground net primary production (ANPP) were greatest in the oligohaline ecotone along the TS/Ph transect (Ewe et al., 2006), co-located with unexpectedly high P concentrations during the dry season (Childers et al., 2006). By examining groundwater nutrients along this transect, we discovered that brackish-water is often discharged into the ecotone especially during dry periods, subsidizing P supply during the dry season (Price et al., 2006). Along the SRS transect, ANPP showed a “wedge” of increasing productivity toward the coast in the tall mangrove forest (Ewe et al., 2006), where tidal influences are greatest. This was similar to a marine-directed increase in seagrass ANPP that occurs in Florida Bay at the end of the TS/Ph transect (Fourqurean et al., 1992).

In addition, after devoting considerable effort to understand the dynamics of dissolved organic matter (DOM) in our ecosystem, we found that DOM is more refractory than originally hypothesized (Maie et al., 2006). We learned that much of the nutrient cycling may be controlled by particulate organic matter (POM) that forms a thick, flocculent detrital (“floc”) layer in the southern estuaries (Jaffé et al., 2001). While this floc layer was found to be mobile (Leonard et al., 2006), *in situ* accretion of soils reflects the balance of peat or marl production and oxidation or mineralization, soil subsidence and transport during storm events. Peat soil accretion rates are about 3 mm yr^{-1} in the fringing mangrove forests, which is about equal to the rate of eustatic sea level rise in south Florida. In contrast, marl soils accreted in shallow and unproductive regions of the southern Everglades are well below this rate and subject to rapid displacement by salt-water encroachment (average 1 mm yr^{-1}; Gaiser et al., 2006). However, storm events with high surge can deposit marl sediment that can make up for decades of accretion or subsidence in one event (Davis et al., 2004). Long-term projections of interacting effects of sea-level rise and water management on soil accretion rates are being examined by our modeling and synthesis group. This interdisciplinary and multi-institutional team works with more than a dozen models that have improved our understanding of the sources and fate of nutrients and organic matter in this system, and use FCE data to parameterize models that inform us of ecosystem consequences of interacting climate and disturbance changes.

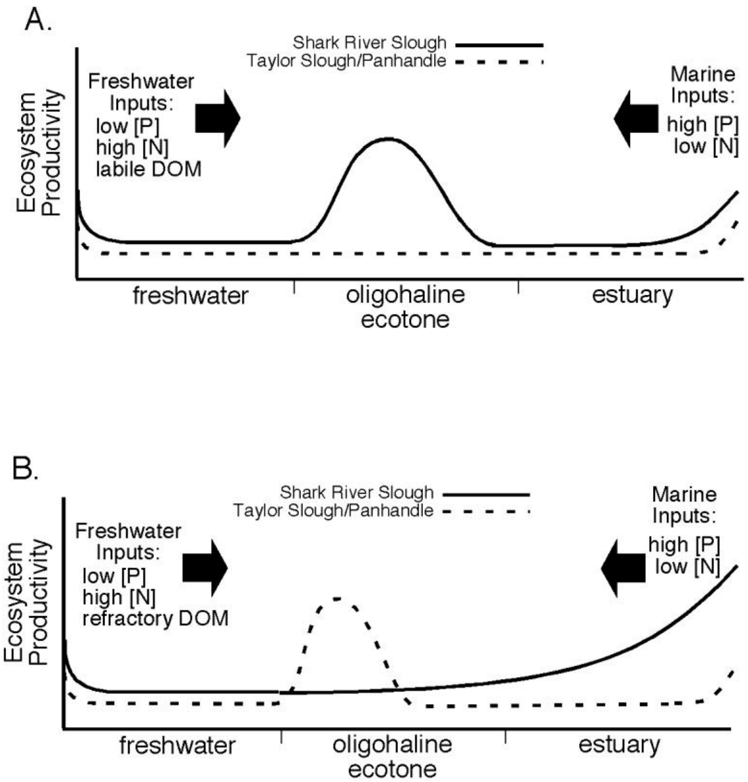


Figure IA.2. (A) Generalized landscape-scale patterns of our FCE I hypothesis about how ecosystem productivity would vary along the SRS (solid line) and southern Everglades (TS/Ph: dashed line) transects. (B) Generalized landscape-scale patterns of how ecosystem productivity actually varied along the Shark River Slough (solid line) and southern Everglades (TS/Ph; dashed line) transects, based on FCE I results.

During FCE I, it also became clear that FCE research is critical to the science of Everglades Restoration. With anticipated large-scale hydrologic restoration on the horizon for FCE, we formulated hypotheses that are testable on an unprecedented scale. Through direct collaborations with agency scientists (SFWMD, USGS, ENP), FCE collaborators and students conduct research that is critically important for determining how to best conduct this restoration. Our agency collaborators help in this integrative effort, typically without support from FCE; in fact, they often fund FCE-related research through their own positions. FCE has therefore become a critical "hub" for Everglades research that informs both science and restoration decision making.

Developments during FCE I helped us modify our central theme for FCE II to reflect our new understanding, described in our renewal proposal: **In the coastal Everglades landscape, population and ecosystem-level dynamics are controlled by the relative importance of water source, water residence time, and local biotic processes. This phenomenon is best exemplified in the oligohaline ecotone, where these 3 factors interact most strongly and vary over many [temporal and spatial] scales.** We expect to be able to test this theme through Everglades Restoration, which will directly affect both freshwater and groundwater inputs. We view this restoration as a "Grand Experiment" for our research, because of anticipated differences in the magnitude of projects affecting our two transects. Planned removal of portions of the Tamiami Trail canal levee (see Everglades Primer) should dramatically increase freshwater inputs to our SRS transect, while we do not expect our TS/Ph transect to change dramatically during this time (Fig. 1A.3). As such, we are prepared to use a long-term Before-After-Control-Intervention (BACI) design to answer the following focal hypotheses:

Hypothesis 1: Increasing inputs of freshwater will enhance oligotrophy in nutrient-poor coastal systems, as long as the inflowing water has low nutrient content; this dynamic will be most pronounced in the oligohaline ecotone. This hypothesis follows from our understanding that in this "upside-down" estuary, freshwater supplies are highly oligotrophic (Noe et al., 2001) and that activities that increase inflows would suppress the marine water supply along our SRS transect and shift groundwater intrusion along our TS/Ph transect toward the coast.

Hypothesis 2: An increase in freshwater inflow will increase the physical transport of detrital organic matter to the oligohaline ecotone, which will enhance estuarine productivity. The quality of these allochthonous detrital inputs will be controlled by upstream ecological processes. Having discovered that much of the detrital transport in our system happens in the flocculent detrital material, we hypothesized that increase freshwater inflows would increase floc transport to the ecotone and supplement the consumer food web in the estuary.

Hypothesis 3: Water residence time, groundwater inputs, and tidal energy interact with climate and disturbance regimes to modify ecological pattern and process in oligotrophic estuaries; this dynamic will be most pronounced in the oligohaline ecotone. Water residence time in the oligohaline ecotone is controlled by precipitation, freshwater inflow, tidal energy and storms; this focus on hydrology will enable us to understand the role that water source plays in controlling P availability in the ecotone and thus inform us of the mechanism of results obtained by the "Grand Experiment."

Below we describe the conceptual model that guides our FCE II research addressing these central questions. Each of our working groups focuses on a sub-component of these three questions, and these are addressed in the 8 working group summary chapters of this report. Finally, we present integrated synthesis of these questions in our Integration, Synthesis and Modeling section as well as in our *Science Morning* presentations.

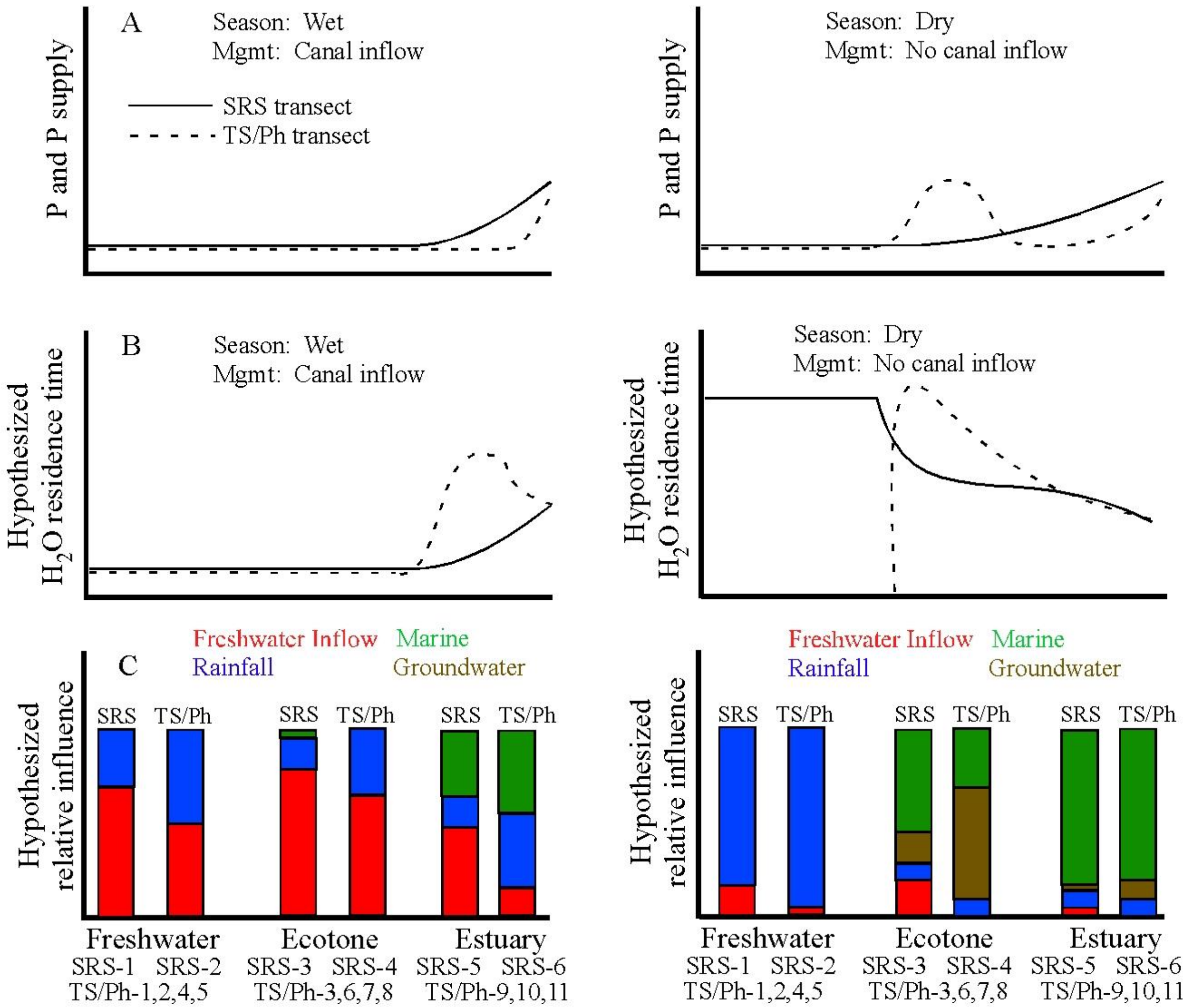


Figure IA.3. Note that the x-axis labels for A-C is shown in C. (A) Generalized landscape-scale patterns of water column P concentrations in the wet season (left panel) and dry season (right panel) along the SRS (solid line) and southern Everglades (TS/Ph; dashed line) transects (as in Fig. 1A.2; Childers et al., 2006). (B) Hypothesized landscape-scale patterns of water residence time in the wet season (left panel) and dry season (right panel) along the SRS (solid line) and TS/Ph (dashed line) transects. Dry season water residence time in the TS/Ph ecotone is long, when upstream marshes are dry (no freshwater inflow or tidal flushing). Resdience time in the freshwater SRS marshes is long, but is dramatically shorter in the ecotone because of regular tidal flushing. (C) The relative influence of four main water sources that we hypothesize are driving oligohaline ecotone dynamics. For each landscape component (freshwater marshes, estuarine ecotone, and estuary), the SRS and TS/Ph transects are shown with separate bars. Re = freshwater inflow, green = marine water, blue = precipitation, brown = groundwater. The major difference between the 2 transects is in the ecotone in the dry season, when we hypothesize that groundwater inputs to the TS/Ph transect are relatively large compared with the SRS transect.

B. FCE II Conceptual Framework

Our conceptual approach is a refinement of our earlier concept based on what we learned about the coastal Everglades during FCE I. Our conceptual emphasis is on: 1) oligohaline ecotone dynamics; 2) hydrologic, climatological, and human drivers that affect those dynamics, and; 3) processes that regulate biophysical inputs to the ecotone from upstream freshwater Everglades marshes and the estuary proper. Figure 1B.1 shows how we visualize the connections between working groups and cross-cutting themes in our program to address the central hypotheses described above. While we maintain our long-term observational studies along our two transects to address landscape-connectivity, we have a strong focus on the biophysical dynamics in the oligohaline ecotone, accomplished through research in four working groups: biogeochemical cycling, organic matter dynamics, primary production and trophic dynamics. These dynamics are influenced by water movement from the upstream freshwater end of our system as well as from marine and groundwater. This complexity caused us to develop a new hydrology initiative that integrates our research as a cross-cutting theme. Water sources and supplies are controlled by climate and storms, tides, sea level rise and water management. In addition, biophysical properties of our ecosystem are directly influenced by climate and disturbance. As such, we developed a second cross-cutting theme focused on climate and disturbance.

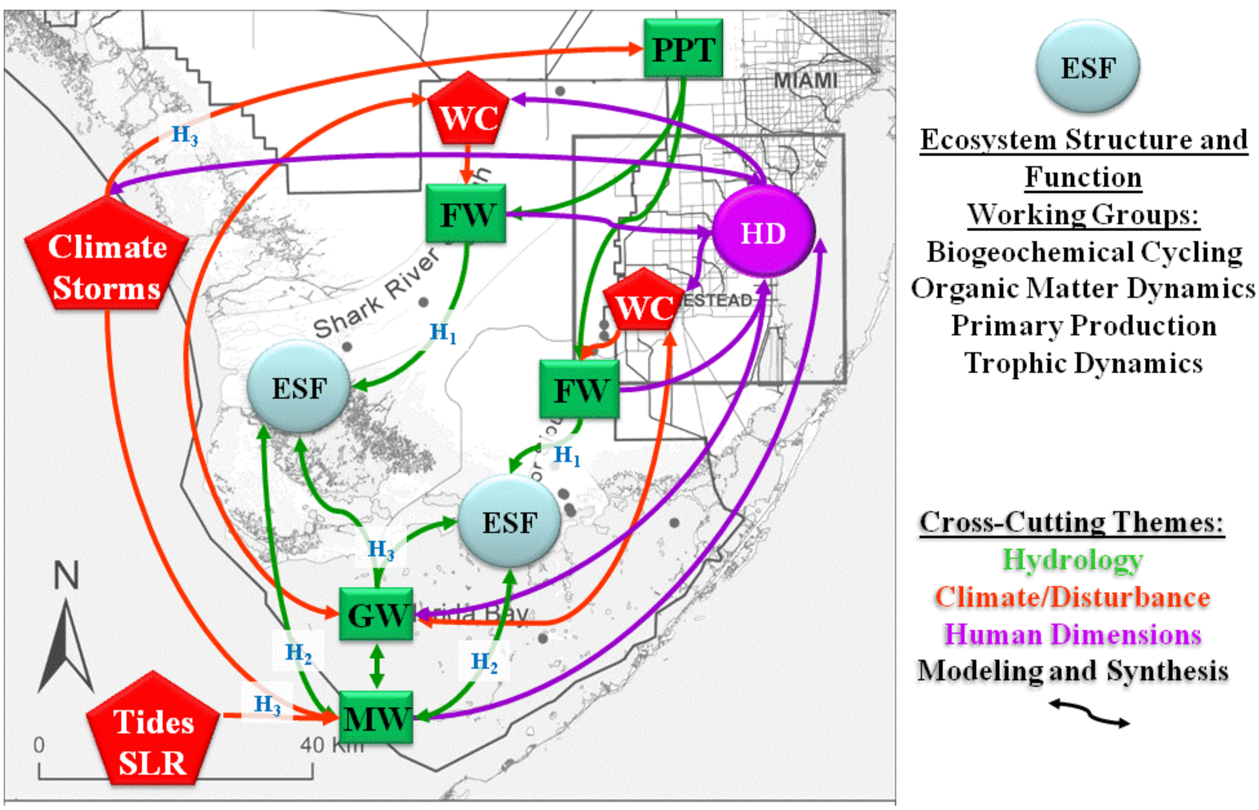


Figure 1B.2. Map of South Florida (see Figure 1A.1) showing our conceptual framework of linkages among our working groups and cross-cutting themes.

Our biophysical work occurs along our two central drainages, with a focus on the ecotone, where we study ecosystem structure and function (ESF) organized by four working groups. Our three hypotheses (H1-3, see above) are addressed by our cross-cutting themes of hydrology, climate-disturbance and human dimensions that interact with the biophysical dynamics of the ecosystem. Finally, we integrate these hypotheses by examining connections between key drivers and response variables through our modeling and synthesis cross-cutting theme (represented by the arrow connectors).

Because the greater Everglades is a human-dominated ecosystem, modifications to the landscape have influenced water quality, vegetative community structure and productivity, and hydrological patterns, among other things. Everglades Restoration may ameliorate some of these impacts; however, we believe it is critical that we understand the social, economic, and political processes that will continue to drive land use changes in south Florida. While always an implicit part of FCE science, we have developed a Human Dimensions (FCE HD) cross-cutting theme in FCE II in order to explicitly study human dimensions of environmental change in southern Florida and the socio-ecological causes and consequences of these changes.

Finally, integration and synthesis remains a top priority for our FCE II program. We facilitate this synthesis through a Modeling and Synthesis cross-cutting theme, which coordinates synthesis through a diversity of modeling strategies. Our FCE program shares empirical information and insights and works closely with new and existing models that operate at a variety of scales to make projections about system behavior relevant to our central hypotheses.

Waiting for the "Grand Experiment"

Early into FCE II, we realized that the completion of the "Grand Experiment" during the FCE II funding period was unlikely due to political delays stalling some projects in the Comprehensive Everglades Restoration Program (CERP). Through partnerships with our Everglades National Park (ENP) and South Florida Water Management District (SFWMD) collaborators, we continue to feel the pulse of Everglades restoration efforts by not only following the progress of specific projects but also providing scientific information to help guide their scope and timing. In 2007, we were disheartened to learn that the scope of the Tamiami Trail Modification Project had been substantially reduced from an 8-10-mile causeway to a 1-mile bridge to be constructed in the extreme eastern edge of Northeast Shark River Slough. We voiced this opinion at several public meetings and provided written scientific documentation supporting a reevaluation of plans for a more expansive bridge project. One direct result was support of a leveraged FCE project to evaluate the effectiveness of reinstating flow to SRS by creating swales on existing culverts along the Tamiami Trail, to be constructed in 2010. This enabled FCE to "acquire" four new observational sites in ENP along the Tamiami Trail, which will increase our ability to measure the effectiveness of the swales but also of future bridge creation, regardless of the selected location along the northern boundary of ENP. Also, in 2009, the Federal Appropriations Act required a re-evaluation of all restoration plans affecting ENP to ensure that they meet restoration goals. While funding for the eastern 1-mile bridge was appropriated by the Army Corps of Engineers on September 28, 2009 (with a completion deadline of 2013), 7 new options are on the table to expand the project to meet its original intent, and there is an accelerated timeline for implementation of the resultant recommended plan. In addition, while we await changes to the SRS watershed, projects potentially influencing our TS/Ph transect have accelerated. An expansion of detention ponds on the eastern boundary of ENP was initiated in order to reduce freshwater drainage to the east (and out of ENP). With leveraged support from ENP, FCE scientists are studying the influence of these detention basins on ground and surface water, nutrient fluxes and biotic communities at the upstream end of Taylor Slough. We also have re-initiated FCE observational research on the upper end of the C-111 basin, where similar detention projects should improve water delivery.

While we await large-scale modifications of water delivery to our ecosystem, we proceed to test FCE II hypotheses in three ways: 1) by using the very high seasonal and inter-annual variability in water delivery to our ecosystem as a surrogate for the experiment; 2) by testing their antithesis as restoration is delayed; and 3) by continuing to compare our two transects that have contrasting freshwater connectivity. We have learned that many of the natural patterns of ecosystem variability in our system are driven by decadal, or in some cases, multidecadal, oscillatory climate fluctuations (Childers et al., 2006; Briceno et al., 2009; Gaiser et al., 2009), which necessitate long data series to understand. We now have several datasets that illustrate the critical importance of long data series for correctly interpreting the effects of management activities (Trexler et al., 2009; Doren et al., 2009). In fact, FCE studies show that in some cases, at least decadal time series are necessary to extract natural from management-derived signals in ecological datasets, and without them, incorrect conclusions would be drawn that could result in inappropriate management decisions (Briceno et al., 2009). By understanding the influence of interannual hydrologic variability in our system on ecosystem attributes, we not only improve the probability of success for our BACI design once restoration begins, but also undertake a small-scale test of our central hypothesis, and facilitate its modification through improved understanding.

As restoration is prolonged, the Everglades continues to respond to multi-decadal alterations in water delivery, a point cautioned to the U.S. Congress by the National Academy of Sciences' 2nd Annual Biennial Review of Progress Toward Restorating the Everglades. We test the converse of H_1 by proposing the further delays in restoration will enhance productivity (rather than oligotrophy) in the ecotone, particularly along our TS/Ph transect, due to progressive groundwater intrusion of saltwater and entrained nutrients. Two new leveraged projects have enabled an expansion of work in the ecotone to not only examine the dynamics of intrusion but also, through controlled experiments, its influence on plant community composition and below-ground biomass. We propose that the converse of H_2 would be decreased physical transport of detritus to the ecotone and reduced access to these detrital resources by marine consumers. Results reported in the Consumer and Trophics Dynamics section already address this hypothesis, based on applying the above approach of using interannual variability to understand system dynamics under contrasting hydrologic regimes. Finally, H_3 requires no modification, as the interaction of natural and management-derived changes is a persistent and inherent property of our system that can only be understood through long-term studies.

Therefore, although it is frustrating to observe further delays in restoration of this fragile ecosystem, we continue to be able to validly test hypotheses that improve our ability to understand controls on ecosystem structure and function, while also improving our ability to guide the restoration process using sound science. Our Human Dimensions group is actively involved in researching the socio-political mechanisms that drive (or stall) the restoration process, and all FCE scientists are engaged in communication with policy makers in numerous ways (see Reaching Constituent Groups section) to encourage forward progress on projects. One established mechanism for this is the collaborations between FCE scientists and the South Florida Ecosystem Restoration Task Force, which co-produced a volume of the journal *Ecological Indicators* (2009; 9S) that illustrates our method of modeling ecological response to management projects (or delays in restoration) in order to communicate the state of the Everglades ecosystem in a way that can be understood by policy makers. This is an ongoing effort with a long-term vision for uniting FCE science with Everglades policy. One new instrument for this involvement is a collaborative effort between FCE scientists and Everglades National Park, funded by the NPS Cooperative Ecosystems Studies Initiative, to write a book that would synthesize decades of Everglades science in a way that may effectively communicate to policy makers the urgency of restoration.

C. FCE LTER Productivity

We monitor the productivity of our LTER in several ways, including our scientific impact through tracking publications and presentations, our collaboration-building capacity by tracking participants of different types and our graduate training by the theses and dissertations we produce. We also quantify our impact on K-12 and undergraduate education, reported in our Education and Outreach section, and our proposal writing efforts and leveraged funding, which is reported in the Budget section of this report. Each year at our FCE All Scientists Meeting (ASM) we discuss the trajectories of our productivity records, and set targets for the next year and for meeting our goals at renewal.

We view our publications to be the most important metric of scientific productivity of the FCE LTER, and we have divided ours into three categories: (1) Peer-reviewed journal articles, (2) Peer-reviewed book chapters and (3) books. Since its inception (2000) through August 2009, the FCE LTER has produced 171 peer-reviewed journal articles that acknowledge FCE support (Fig. IC.1). This number has grown steadily, with a spike in 2006 when we published a full issue of the journal *Hydrobiologia* (2006; 569) that synthesized our FCE I findings. A total of 84 peer-reviewed journal articles and book chapters have been published during FCE II, which, by the end of 2009 should exceed our target of producing 30 publications per year. Notable FCE II publications include a 2009 special issue of the journal *Ecological Indicators* (2009; 9S), which synthesized our approach to using long-term data series on sensitive indicator organisms to communicate the science of restoration to policy makers. We are planning a sequel to this issue that focuses on the application of this approach to ecosystem assessment. In the coming

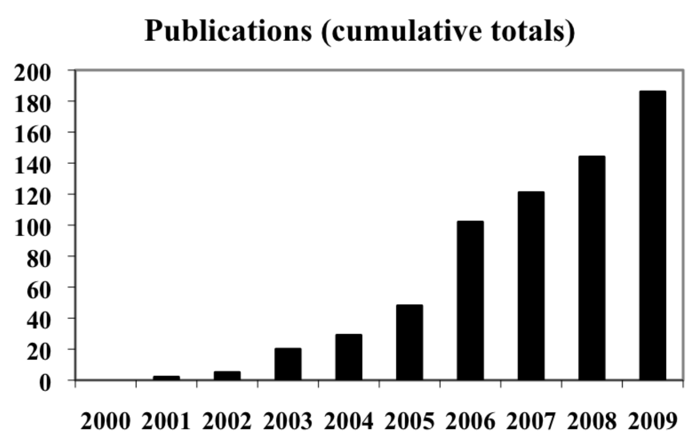


Figure IC.1. Cumulative number of publications acknowledging the FCE LTER year, we also plan to focus on a synthesis volume on hydrologic drivers of ecosystem change in FCE, and are discussing opportunities with several publishers. In addition to peer-reviewed publications, we have published 12 book chapters and 3 books. Seven of the chapters and two of the books were published during FCE II, denoting a shift toward increasing synthesis as our program matures. We have begun discussions about producing a book that synthesizes FCE science, and will be deciding a topical focus and target publishers and dates at our next FCE ASM.

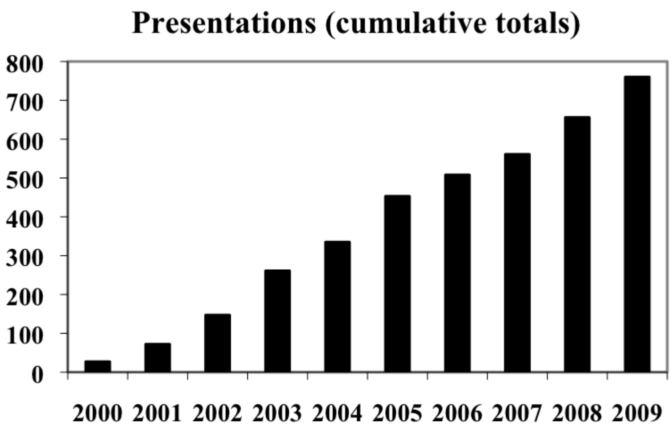


Figure IC.2. Cumulative number of presentations given by scientists, students and staff acknowledging the FCE LTER.

Presentations at scientific meetings or in departmental seminars are also an important form of research productivity (note that we typically classify other types of presentations as FCE outreach, which is covered in the Education/Outreach section of this report). Since 2000, FCE scientists and students have presented LTER results a total of 765 times (257 since the initiation of FCE II; Fig. IC.2).

Collaboration-building and network-support are also forms of productivity for LTER programs, and this is a particularly important measure of progress at FCE because of our central involvement with the Everglades restoration effort. The number of collaborating institutions increased from 8 to 20 during FCE I, and has stabilized near 30 during FCE II, a leveling that we anticipated as our program defines itself (Fig. IC.3). We continue productive and longstanding collaborations with a diversity of academic collaborators, students and staff at Louisiana State University, College of William & Mary and Texas A&M University, and have built new collaborations with scientists at the University of Florida, University of Alabama and 24 other academic institutions. We continue direct scientific collaborations with scientists at 7 Federal, State and local agencies and two non-governmental organizations. This institutional growth trajectory is reflected in the number of FCE personnel, which increased from 30 to 130 during FCE I and stabilized around 140 during FCE II (Fig. IC.4). These include 63 collaborators, 48 students and 28 staff members. Our graduate students continue to be a very important part of our program, and we have conferred 47 degrees since 2000 (14 so far in FCE

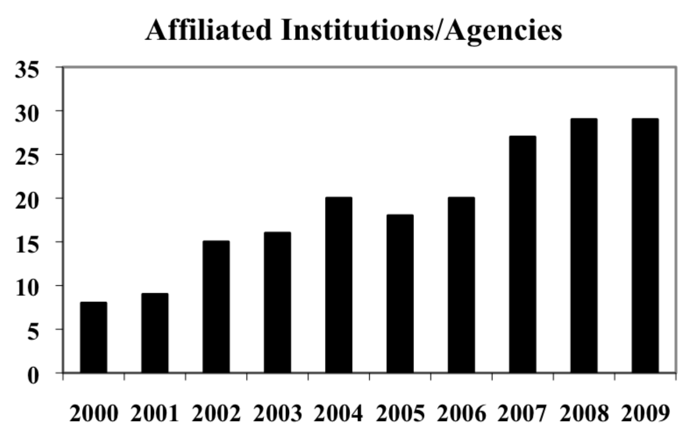


Figure IC.3. Number of affiliated institutions and agencies participating in FCE LTER.

II; Fig. IC.5). They have contributed 29 theses, 18 dissertations and 76 manuscripts. University incentives aimed at increasing the number of Ph.D. degrees conferred at many of our collaborating institutions has caused a shift in dominance of M.S. to Ph.D.-earning students in our program.

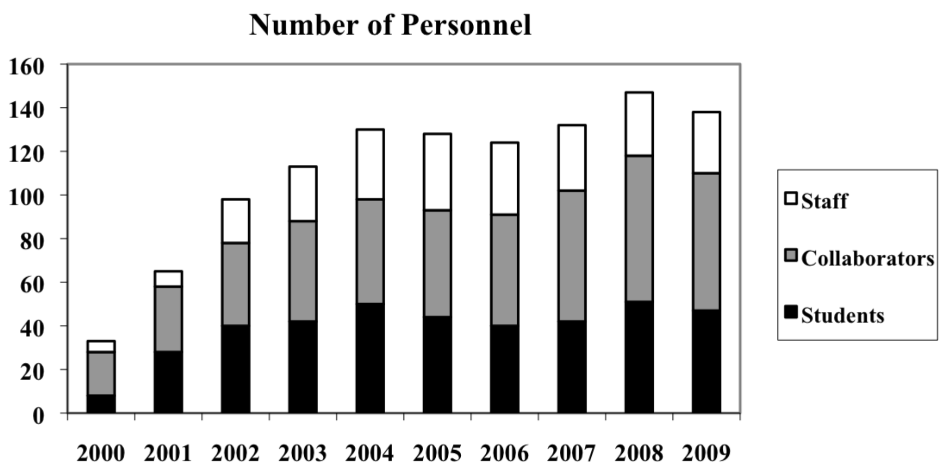


Figure IC.4. Number of collaborators, students and staff participating in FCE LTER.

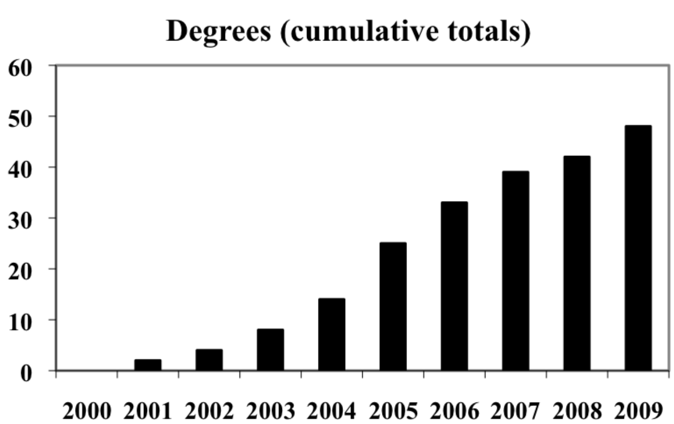


Figure IC.5. Cumulative number of M.S. and Ph.D. degrees conferred to FCE students.

The extent to which FCE science is highly dependent on multi-institutional and interdisciplinary collaborations is reflected in co-authorship patterns in our publication list. Using 186 publications and book chapters in our publication list (2000 – August 2009), we categorized authors as (co-) principal investigators, academic collaborators, students, non-FCE scientists (other), scientists from the USGS, National Park Service or non-governmental organizations, a Florida Water Management District or scientists from other LTER sites (x LTER). Figure IC.6 shows how all of these entities are actively involved in publishing FCE science and that all collaborating entities are connected through publication. It further shows how FCE strives to produce integrative science, by providing a platform through which multiple types of institutions can engage in publication. It also shows a progression toward increasing publication production from network-level and cross-LTER site collaborations, an explicit objective set at our 2007 ASM in commitment to the goals of the LTER Decadal Plan for Science.

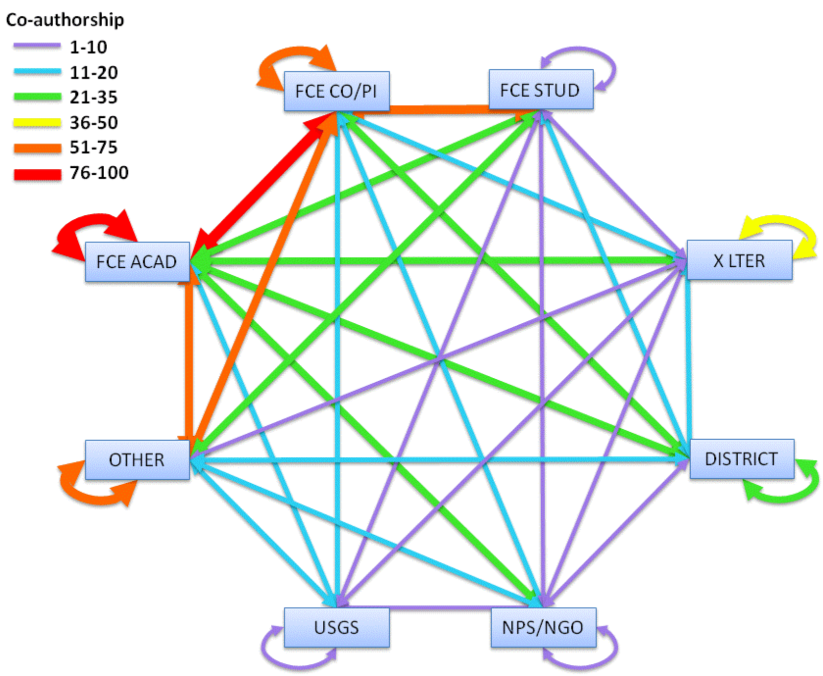


Figure IC.6. Number of shared authorship experiences across collaborator types in FCE (2000-August 2009; N=186), showing linkages between FCE collaborators in academic institutions (FCE ACAD), co-PIs of FCE I and II proposals (FCE CO/PI), FCE students (FCE STUD), other LTER sites (X LTER), Florida Water Management Districts (DISTRICT), the National Park Service and Non-Governmental Organizations (NPS/NGO), the United States Geological Survey (USGS) and non FCE collaborators or students at other institutions (OTHER).

II. RESEARCH

Here we describe the progress of our 4 Working Groups and 4 Cross-Cutting themes toward addressing the central FCE II questions. We begin each section with an overview of the topic, a brief history of studies on this topic in FCE, a description of goals and hypotheses guiding each group, an overview of guiding conceptual framework and models, a summary of research results pertaining to those goals and a discussion of future plans (both FCE II and longer-term). We begin with two Cross-Cutting themes, Climate and Disturbance and Hydrology, to set the hydroclimatological stage, progress through the 4 biophysical working group reports, and end with the Human Dimensions and Synthesis and Modeling Cross-Cutting themes that integrate our work.

A. Climate and Disturbance

The Hydroclimatological Setting of FCE

The FCE spatial domain is in a subtropical setting and is therefore exposed to high variability in precipitation and resultant runoff over both short and long time frames, and this sets the hydroclimatological stage for FCE science. Before describing the research of our climate and disturbance research, we present examples of the kinds of climatological and hydrologic histories we are using to provide context to our long-term datasets. In each figure, we show the 30 year means of monthly data (January 1979 – December 2008) with a 10^{th} and 90^{th} percentile envelope that depicts interannual variability during these 30 years for that month. Finally, we plot the monthly data for the first 9 full years of the FCE LTER Program (January 2000 – December 2008).

The long-term monthly precipitation data clearly show the bimodal wet season pattern that characterizes the Everglades (Fig. IIA.1). It is also notable that interannual variation in rainfall is often as great as the long-term mean rainfall. The plot shows years of relatively low wet season rainfall (2003, 2004) bounded by periods of high rainfall (2002 and the storm-rich year of 2005). Thus, our climatological environment is one with large intra-annual variability in rainfall (dry vs. wet seasons), large spatial variability on small scales of much of that rainfall (contrast the two transects), substantial inter-annual variability (that is highly driven by teleconnections, see below), and irregular major precipitation events associated with tropical weather systems (including hurricanes).

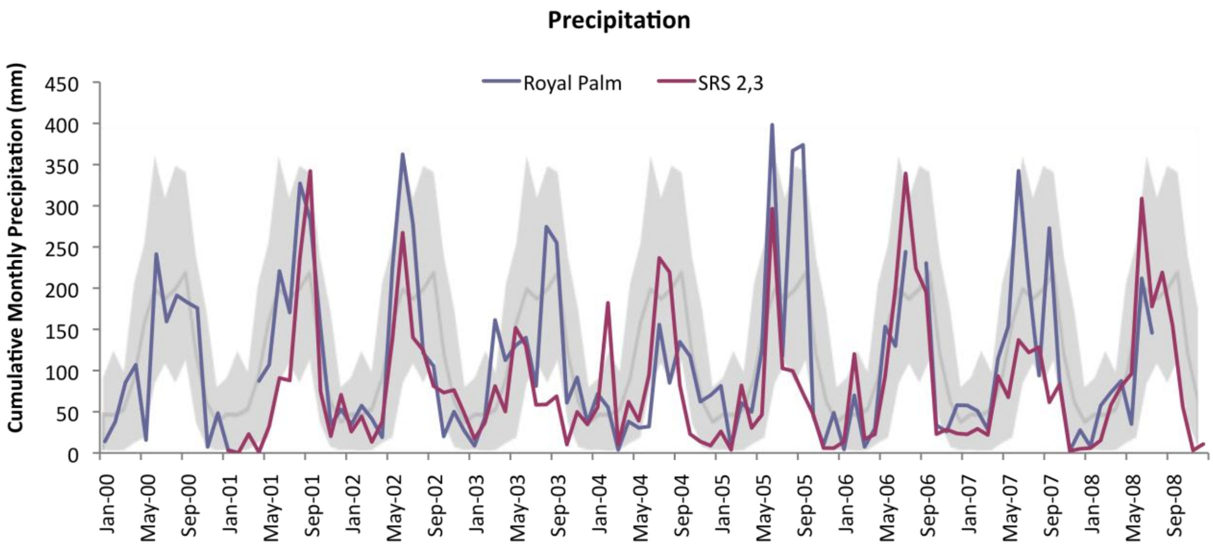


Figure IIA.1. Mean cumulative monthly rainfall from FCE sites SRS 2-3 (red lines) and Royal Palm (at the head of our TS/Ph transect, blue lines), plotted with the 30-year mean cumulative monthly rainfall (gray line), and the 10th and 90th percentile values about that mean (gray shading).

The hydrologic environment of the FCE study area is controlled by two factors: 1) the balance of rainfall and evaporation, and; 2) water management. Water management is carefully controlled by the SFWMD and USA COE water control structures. Shark River Slough receives freshwater inflows through the S-12 A, B, C and D gated structures along Tamiami Trail (Fig. 11A.2), and our SRS transect is anchored at site SRS-1d near the S-12 D pump structure. Water also enters the park from the L-31W canal via the S-332D pump structure (the anchor point for our TS/Ph transect at TS/Ph-1). There are many factors that influence the control of water inflows to ENP from year to year (and many of these factors are, to some degree, political). In some years like 2000 and 2007, some of the water that would normally be allowed into SRS was routed to the eastern margin of ENP, and entered through the Southern Everglades rather than at Tamiami Trail. This is why our discharge rates in these years fall below the 10th percentile of water inflows since 1978. Notably, most of SRS went dry for several months during the 2001 dry season (an event that has happened about every 10 years in the last 50-60 years, but that was probably very rare before 1900).

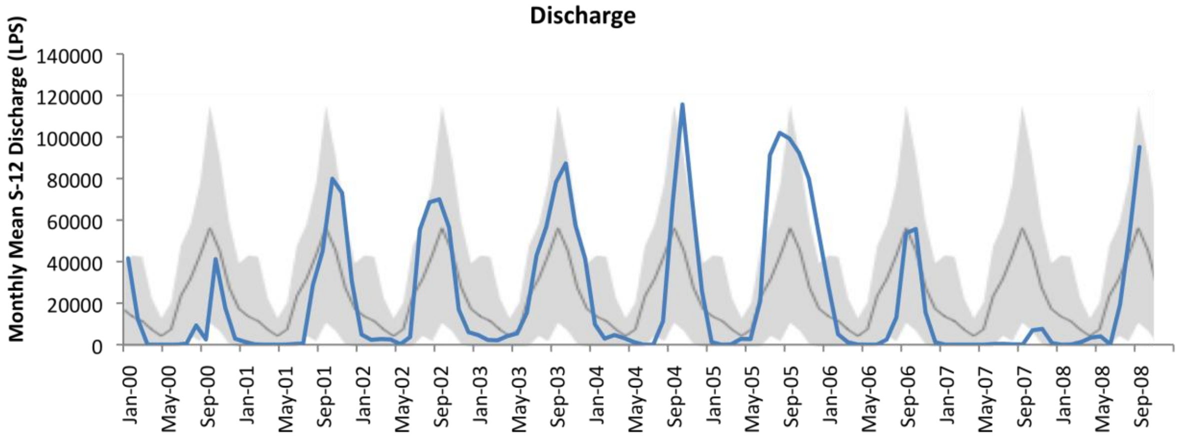


Figure IIA.2. Mean monthly dicharge rates for water entering Shark River Slough (ENP) through the four S-12 structures along Tamiami Trail for 2000-2008 (blue line), 30-year mean discharge rates (gray line) and the 10th and 90th percentile values about that mean (gray shading).

The Florida Bay estuary is directly downstream of our TS/Ph transects and is indirectly downstream of our SRS transect, as GOM water diluted by freshwater flows from SRS enters across the northwestern Florida Bay boundary. This region of the estuary becomes hypersaline for the last few months of the dry season in most years, but did not in Spring 2002 after two relatively wet years (Fig. IIA.3). Salinity in central Florida Bay (at a site near TS/Ph-10) shows some coherence with the precipitation patterns in Figure 11A.1, and may also be related to monthly freshwater inflow rates at the southern Everglades inflow points and groundwater discharge.

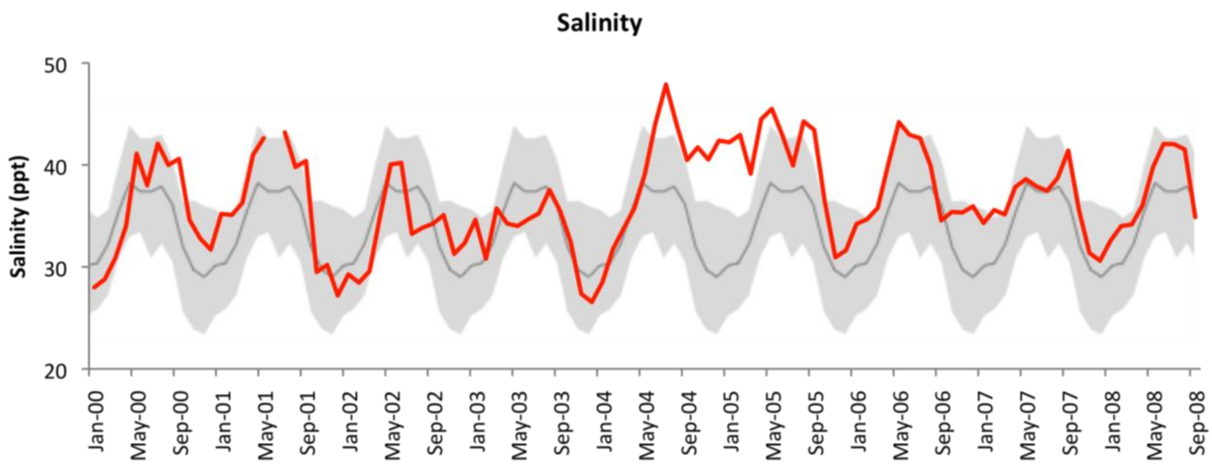


Figure IIA.3. Mean monthly salinity in central Florida Bay (near TS/Ph-10) for 2000-2008 (red line), 30-year mean salinities (gray line) and the 10th and 90th percentile values about that mean (gray shading).

History: FCE I research was based on the central concept that regional processes controlled by water flow affect population and ecosystem dynamics at any location within the coastal Everglades system. Short (i.e., seasonal) and long-term (i.e., teleconnections, sea-level rise) predictable or directional climate changes interplay with stochastic events (i.e., storms) of varying magnitude and type to influence dynamics in the coastal zone. In this way, FCE provides a prime example of a setting for which press and pulse attributes interact in a primary driver. For example, a long-term disturbance on the coastal system is sea-level rise, and this forcing alone will become one of the most important factors affecting our system in the future, but storms modify (in some cases enhance) the impact of sea-level rise on this ecosystem. Large-scale restoration can be viewed as another type of disturbance in our system, which will interact with climate change to affect the Everglades ecosystem (Fig. IIA.4). While climate and disturbance were studied implicitly in FCE I, a Climate and Disturbance Cross-Cutting Theme was established for FCE II to centralize our research on this theme. We formulated the following question to guide FCE II Climate and Disturbance research:

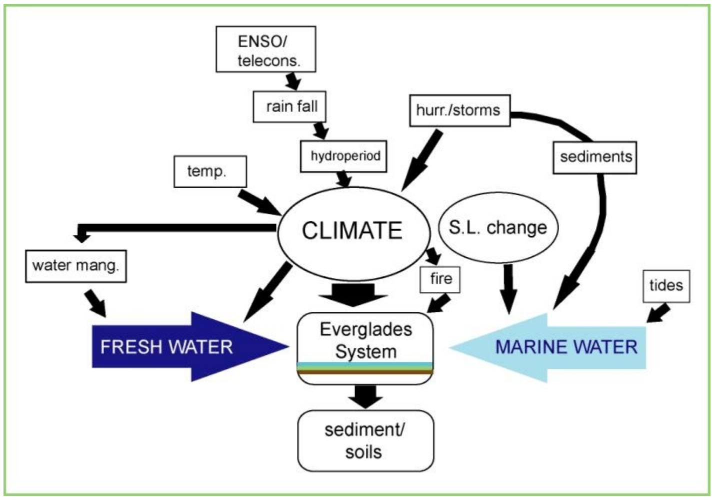


Fig. IIA.4. Conceptual diagram for the Climate and Disturbance Working Group showing how climate links all FCE working groups, and how disturbance events will have different impacts on the system and its sub-components depending on their magnitude and duration.

Question: ***How is the location and the spatial extent of the oligohaline ecotone controlled by changes in climate (precipitation, temperature, wet vs. dry years), freshwater inflow (management, restoration, and the "Grand Experiment"), and disturbance (sea level rise, hurricanes, fire)?***

Goals: Our group established the following goals in order to address the central hypothesis, above: 1) evaluate changes in ecotone vegetation relative to freshwater stages and flows; 2) document vertical soil dynamics by measuring soil elevation change and surficial accretion; 3) reconstruct historical changes in hydroperiod across the coastal Everglades using paleo-archives; and, 4) relate regional climate records to existing teleconnection indices (AMO, NAO, NAtl, ENSO and PNA) to investigate long-term relationships between global climatic drivers and biophysical dynamics at the FCE. Due to Hurricane Wilma's modification of the biogeochemistry and productivity of our SRS transect in 2005, we have also been studying how this ecosystem is responding to and recovering from that event.

Results:

<u>1. Changes in the Oligohaline Ecotone</u>

TS/Ph Transect-The oligohaline zone of Taylor River is controlled to a great extent by seasonal patterns of freshwater flow, storm events, and frontal passages. In order to assess the impacts of pending changes in water management (i.e., restoration) and long-term effects of sea-level rise, we have continuously tracked variations in water quality at a number of locations along the mangrove ecotone. As part of this work, we've conducted intensive seasonal samplings of water quality at locations upstream and downstream the mangrove ecotone in Taylor River. Six samplings were made over a one-week period of time, intended to capture the short-term hydrological and biogeochemical variability associated with wind and tide forcing and precipitation-driven runoff during these periods. August samplings were designed to capture early wet season conditions (low salinity, strong outflow from Everglades to Florida Bay) in the mangrove ecotone of Taylor River, January samplings were planned to capture the transition period between the wet season and the dry season, and the May samplings were designed to capture conditions that typify the peak of the dry season, when salinity levels and water residence times are high.

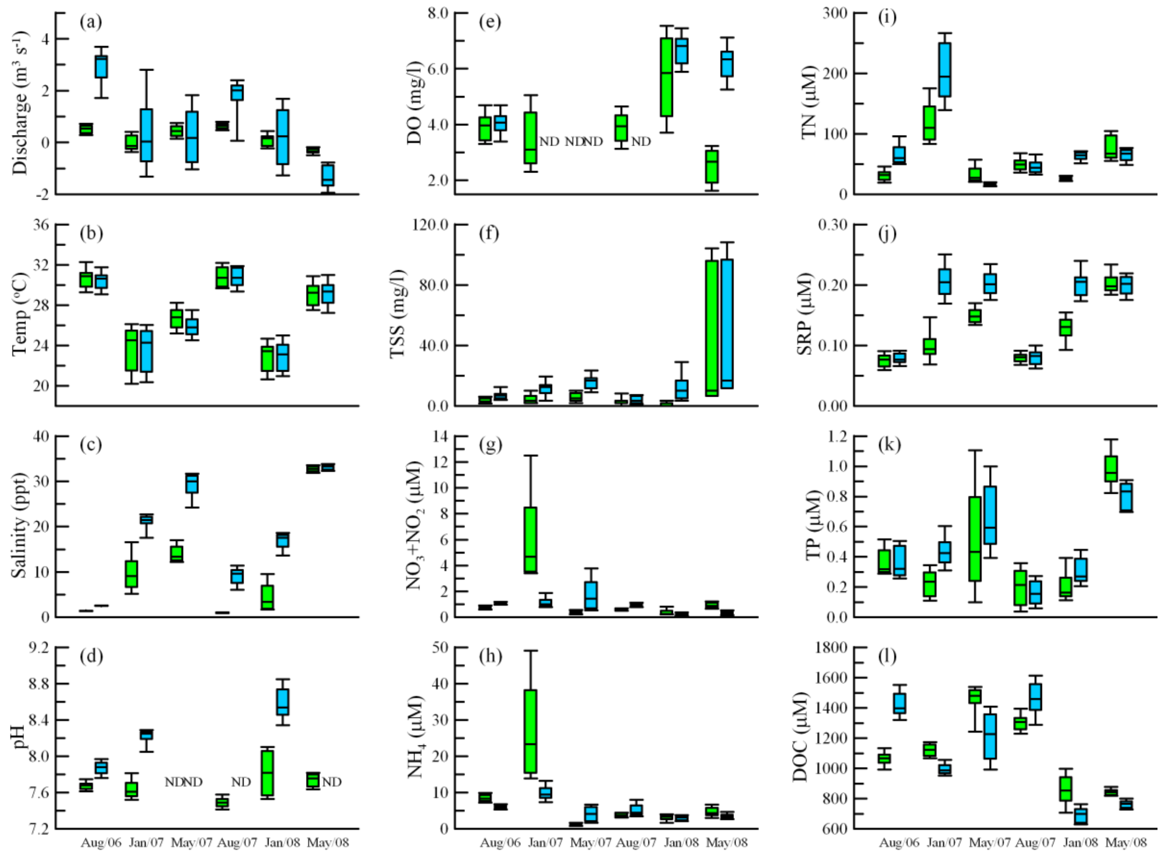


Figure IIA.5. Box-and-whisker plots illustrating the distributions in water quality and constituent concentration data collected in upstream (TS/PH-6a) and downstream (TS/Ph-7a) sampling sites in Taylor River. Each plot includes data from samplings conducted in Aug. 2006, Jan. May & Aug. 2007, and Jan. & May 2008.

Considerable differences in water quality and constituent concentrations were found between sampling sites and across samplings, indicating strong spatial and seasonal controls on water quality and materials exchange in this region (Fig. IIA.5). Data from the May sampling support the FCE II hypothesis that surface water P concentrations in the TS/Ph ecotone are typically highest during the dry season during times of high salinity, while inorganic N, TN, and DOC are quite low. In contrast, in the January sampling, SRP was quite high near the mouth of Taylor River, which is predicted by our FCE II hypothesis to be due to greater flows from the oligotrophic Everglades. Overall, TP, SRP, TSS, salinity, and pH were higher near the mouth of the river and seemingly highest during the dry season or the transition from the wet to the dry season.

SRS Transect - The SRS transect was greatly influenced by Hurricane Wilma, which brought winds that caused extreme defoliation and storm surge that transported sediment into the mangroves. We have studied impacts of this storm event on productivity, soil accretion and nutrient transport, much of which was published in the special issue of *Wetlands* (2009; 29) devoted to this topic. The mangrove forest was differentially impacted by the storm, partly due to the variability in wind fields, with the most extreme cases experiencing total defoliation (i.e., Harney River; Fig. IIA.6, 7). Defoliation patterns reflected previous canopy gaps, and the number of gaps per square kilometer increased from about 400~500 to 4000 after the storm.

Fig. IIA.6. Hurricane Wilma impact (October 2005) on forest canopy in Harney River (December 15, 2005), defoliation was almost 99% in this mangrove stand.

Fig. IIA.7. Fringe mangrove forest in Cape Sable close to Little Shark River (South western Florida) (February 23, 2008) impacted by hurricane Wilma on October 24, 2005. Notice re-sprouting of the black mangrove species, *Avicennia germinans*, in the forefront; although mangrove stands from this region have yet to recuperate from this climatic disturbance.

One extremely important component of our ecotone observations is the flux tower located at SRS-6, which has been monitoring net ecosystem exchange since June 2003. While the tower remained standing during Hurricane Wilma, it was damaged beyond repair. Reconstruction was completed in October 2006, and flux studies were commenced to evaluate post-hurricane ecosystem response and function. Initial results from the study reveal greatly reduced carbon dioxide assimilation rates throughout the day following the hurricane, likely a result of reduced canopy biomass (Fig. IIA.8).

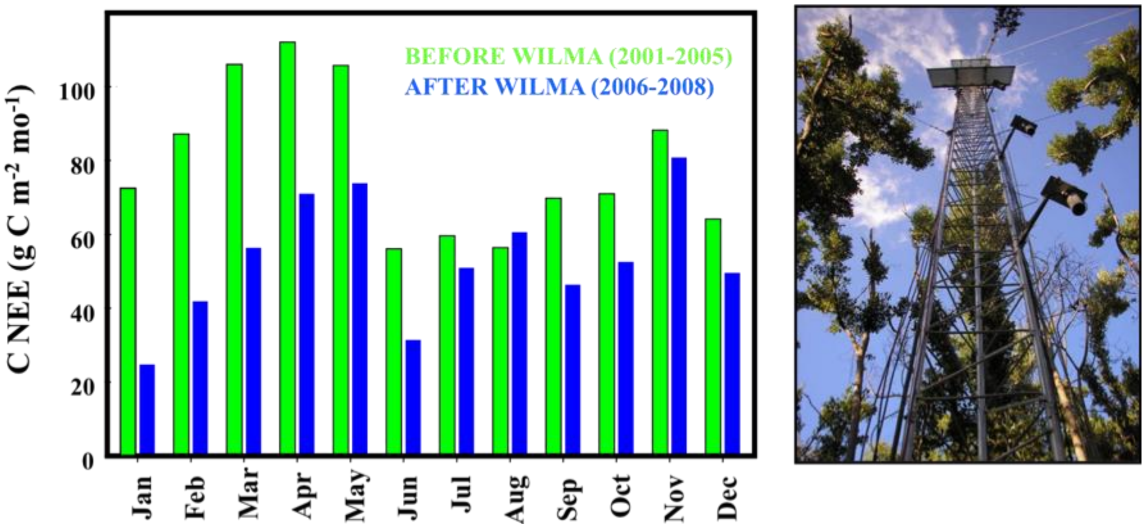


Figure IIA.8. Net Ecosystem Exchange measured at the SRS-6 eddy covariance tower (right) before (green) and after (blue) Hurricane Wilma.

2. Sediment Accretion

We are studying long-term patterns of sediment accretion with the Organic Matter Dynamics Working Group, and much of these dynamics are reported in that section of the report. Here we focus on the effects of the storm surge from Hurricane Wilma on our SRS transect. This surge event lasted approximately 7-8 h, based on data recorded by the instruments. Deposition of mineral sediments from the Gulf of Mexico (0.5 to 4.5 cm) varied spatially, with maximal deposition in areas adjacent to the water edge and lower deposition in the interior forest (Fig. 11A.9). Along Shark River, sediment deposition was maximal at SRS-6, close to the Gulf of Mexico, and decreased upstream as no deposition was evident in SRS-4 (18.2 km from the mouth of the estuary; Whelan et al., 2009; Smith et al., 2009; Fig. IIA.6). Mean TP concentrations in storm deposits differed significantly from mangrove soils, with higher TP in the storm layer (0.36 ± 0.02 mg cm^{-3}) compared to pre-existing mangrove soils (0.22 ± 0.02 mg cm^{-3}). The higher Ca-bound portion of TP in storm sediment deposits compared to surface mangrove soils suggests that allochthonous mineral inputs from adjacent coastal waters during the passage of Wilma is significant contribution to nutrient density of P. Moreover, vertical accretion resulting from this hurricane event was 8-17 times greater than the annual accretion rate (0.30 ± 0.03 cm yr^{-1}) averaged over the last 50 yrs for FCE mangroves. Accordingly, these mineral inputs from Hurricane Wilma represent a critical source of sediment that determines soil vertical accretion rates and nutrient resource gradients in mangroves of the southwestern Everglades. Patterns of P deposition to mangrove soils associated with this storm event are particularly significant to forest development due to the P-limited condition of this carbonate ecosystem. This source of P may be important for adaptation of Neotropical mangrove forests to projected sea-level rise.

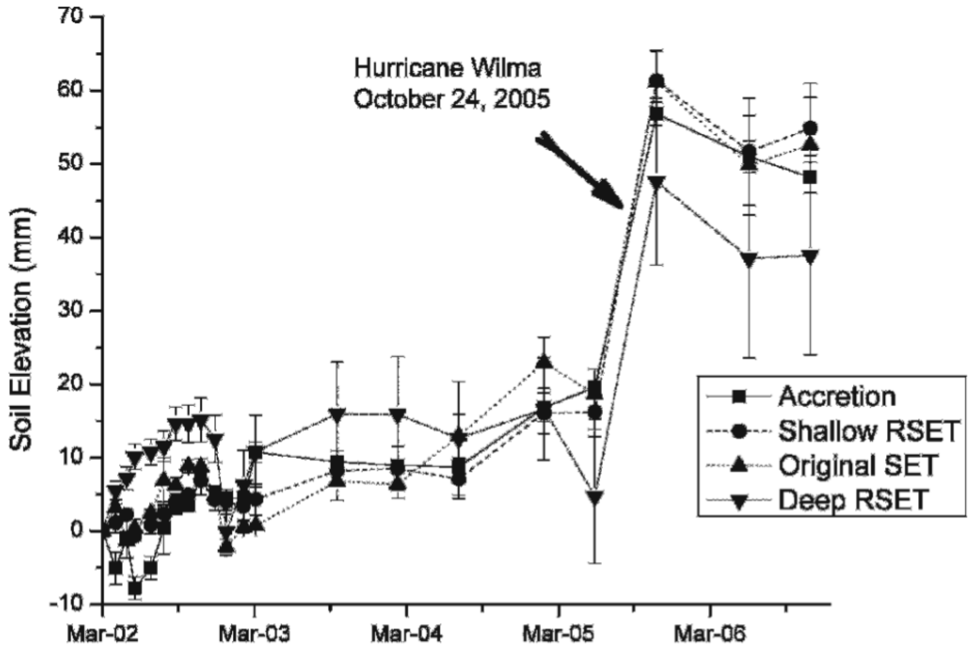


Figure IIA.9. Long term mean (+- 1SD) absolute soil surface elevations for Accretion, Shallow-RSET, Original-SET and Deep-RSET at a mangrove forest on the Shark River capturing the impact of Hurrricane Wilma. From Whelan et al., 2009.

3. Paleoecological Research

Taylor Slough - FCE collaborators have initiated a combined physiological and paleoecological study to examine past and current plant community and physiological changes along Taylor Slough coastal ecotone. Research activities in the past year have included collection of soil cores from five sites spanning TS/ph-3 (freshwater sawgrass marsh) to TS/Ph-7, three of which are co-located with TS/Ph-3, -6 and -7 and with existing sites where Sediment Elevation Tables (SETs) are being employed to quantify soil elevation changes. Cores are being radiometrically dated using ^{210}Pb and ^{137}Cs profiles and analysed for macrofossil profiles and macrofossil isotopic composition (e.g., sawgrass seeds, sawgrass leaf and root fragments). Vegetation changes inferred from macrofossil profiles and species-specific isotopic varation (downcore) will provide a means to understand past physiological responses to changes in hydrology and salinity encroachment. In addition to characterizing the pre-drainage system, these data will be important in calibrating the SCAT model, which will be used to hindcast decadal to centennial marsh vegetation and soil accretion changes along the coastal ecotone.

Shark River Slough - Cores from marsh transects (slough – ridge) in Shark Slough are being analyzed for macrofossils and radiometric dating to determine long-term changes in accretion and vegetation in relation to past climate changes. Research includes examining millennial changes (last 5KYBP to present) in the context of major paleo-climate proxies related to rainfall patternsand a focus on the past 200 years in the context of multiple proxies that include paleo-climate (NAO, ITCZ, etc.), climate records (mainly rainfall), and known water management events (e.g., Tamiami Trail construction). Soil cores analyzed to date show substantial vegetation change in historic Shark Slough over the past century or more. In general, they show increasing

Cladium and the reduction or disappearance of water lily sloughs, starting mostly in the early 20th Century and possibly reflecting drainage due to water use by humans and the completion of the Tamiami Trail by 1940. Some of the cores also indicate a return to wetter conditions, including increased water lily abundance, in the 1990s, consistent with higher rainfall and water stages observed in the 1990s relative to previous decades. We have found a general pattern of major changes in accretion over the past 5 KYBP, showing an initial fast rate of peat accretion (from ~4.5 KYBP to ~3.5 KYBP) followed by a slow phase that has lasted until the last few centuries. This change is most pronounced in the NE-SRS region (technically within the SRS-2 "oligotrophic" landscape) in which the slow accretion phase corresponds with the switch from a peat-substrate to marl-substrate and also corresponds with a switch from ridge-slough vegetation (water lily and sawgrass macrofossils) to one dominated by Charophytes (oospores) and Cyperaceae (seeds, species not yet determined).

Florida Bay - Analyses of fossil diatom records from four sediment cores collected along major environmental gradients in Florida Bay provided insight into the central question of our working group. Diatom-based reconstructions revealed that salinity and water quality conditions in Florida Bay have been strongly influenced by the last century's alterations of the quantity, quality and timing of freshwater deliveries related to the water management practices in South Florida. The anthropogenic-driven changes were superimposed and amplified by long-and short-term climate fluctuations that control the amount of precipitation in this region. Diatom-based reconstructions revealed that salinity and water quality were influenced by the changes in precipitation driven by the global teleconnection patterns and hurricanes. Additionally, analyses of older sediments (~4600 years old) showed that diatom communities shifted from fresh and brackish water taxa to marine communities, which reflects transformation of Florida Bay from an ecosystem that resembled today's Everglades to an estuarine system due to sea level rise (Wachnicka 2009).

4. Investigating the importance of teleconnection indices.

Because our FCE domain intersects two climate zones, we are studying teleconnections in the upper part of the watershed (to determine controls on downstream processes) and in the lower watershed of Florida Bay and the Florida Keys. We have been studying climate and disturbance patterns at a "reference" location at the headwaters of the Everglades watershed (Lake Annie) that is relatively immune from changes driven by water management but located at the head of the Everglades watershed and in the same climate regime as most of our system. Climatological signals reflected in long-term observational and paleolimnological records of Lake Annie can be used to inform similar records from more disturbed settings at FCE sites in the Everglades and Florida Bay. We are analyzing both observational (Gaiser et al., 2009 a, b) and paleolimnological records (Quillen, 2009) to extract climate signals. We found signals of cyclical dynamics driven by the same forces in the upper Everglades watershed (Gaiser et al., 2009a, b) as the Southern Everglades estuaries (Briceno et al., 2009). This led to a pending NSF DMUU collaborative FCE proposal with University of Central Florida to 1) compare climate signals throughout the Everglades watershed in order to 2) reduce uncertainty in interpreting water management influences in the southern Everglades. In addition, high frequency aquatic sensors have been deployed contemporaneously in Lake Annie (Gaiser, unpubl.) and lakes of the southern Everglades (Koch, unpubl.) as part of the Global Lake Ecological Observatory in order to detect system-scale influences of climatological variability in South Florida. Multi-billion dollar hydrologic restoration plans for South Florida have only just started to encompass recent entry into a warm phase of the Atlantic Multidecadal Oscillation (AMO), that has increased interannual variability in precipitation and that is projected to continue to bring more rainfall and storms through Florida. Perhaps because the AMO modulates climate in an opposite pattern to the rest of the continental United States, the majority of the South Florida restoration planning period in the 1980s and 1990s did not take the AMO into account. The critical discrimination of cyclical from directional climate controls on long-term changes observed in South Florida lakes, wetlands and estuaries will require commitment to long-term data collection programs.

Future Goals: Our research on climate drivers in the oligohaline ecotone will continue to document recovery in the system in response to Hurricane Wilma, and integrate with the Hydrology group to understand the influence of changes in freshwater flow (both deterministic and stochastic) on transport of nutrients to and from the system. Our long-term observations on sediment accretion will continue to inform broader regional models of effects of sea-level rise on coastal wetlands. We will be collaborating with the LTER Caribbean Hurricane Research Network by hosting a meeting in Miami in December to continue to build cross-site efforts to compare the impact of storms on subtropical and tropical ecosystems. To integrate our paleoecological findings, we are planning a special issue of a paleoecological journal that focuses on putting modern Everglades history in a long-term paleoecological framework. Regarding our work on teleconnections, we have hired a new post-doc, Chris Moses, with leveraged funding from the SFWMD. He will be comparing regional climate records to existing teleconnection indices (AMO, NAO, NAtl, ENSO, PNA, and PDO) to investigate long-term relationships between global climatic drivers and biophysical dynamics at the FCE. His initial work in collaboration with the SFWMD (Sklar) indicates that different periods of the AMO might be modulated by the PDO in the 1940s and 1950s (Fig. IIA.10), as the direction of correlation between the AMO and precipitation in South Florida may change as we cross into Region 5 in the Florida Bay estuary. Our findings continue to inform modeling efforts by our Modeling and Synthesis Cross-Cutting Theme to drive integration and projection of system properties under variable climate and water management (disturbance) scenarios.

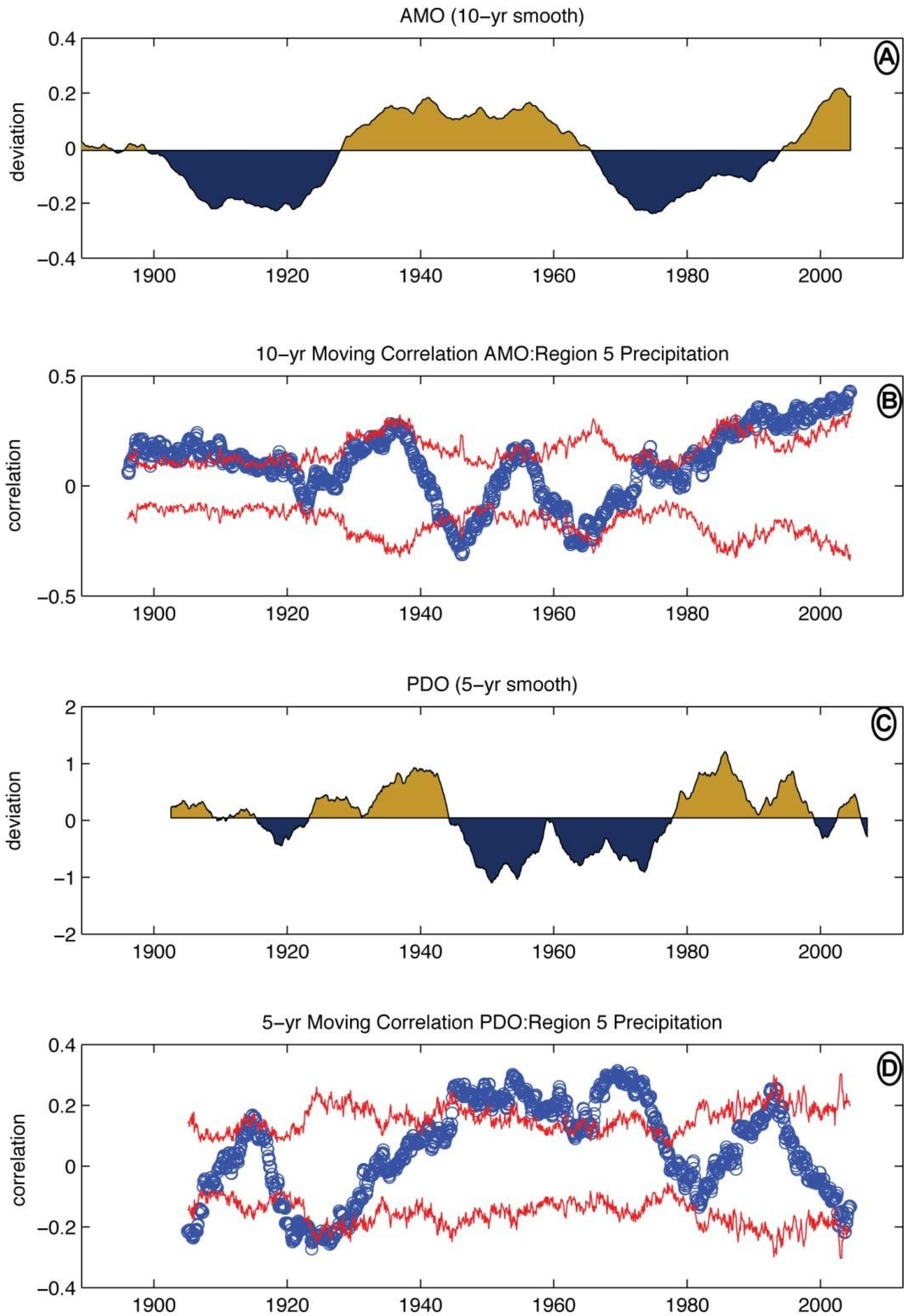


Fig. IIA.10 (A) 10-yr smoothed Atlantic Multidecadal Oscillation (after Enfield et al 2001); (B) Correlation between the AMO and Region 5 precipitation using a detrended 10-yr moving window; (C) 5-yr smoothed Pacific Decadal Oscillation (after Mantua et al 1997); (D) Correlation between the PDO and Region 5 precipitation using a detrended 5-yr moving window. The PDO is smoothed at 5-yrs because of the decadal, rather than multidecadal, nature of the index. Region 5 precipitation is a function of multiple climate controls and teleconnections as shown by the combined relationships of precipitation with both the AMO and PDO. Redlines indicate confidence level of 95%. From Chris Moses (FIU).

B. Hydrology

History: Our FCE I research hypothesized that surface water transport of nutrients exerts primary control on ecosystem processes in the ecotone, and that the relative source and magnitude of transport would determine ecotone dynamics. We discovered that groundwater is a much more important source of nutrients (and salinity) to our system than previously hypothesized, and in particular, learned that brackish groundwater was discharging to the oligohaline ecotone, particularly in the dry season (Price et al. 2006). This brackish groundwater was the result of seawater that intruded into the underlying surficial aquifer some 10-30 km inland from the coast in the TS/Ph and SRS drainages. The brackish groundwater contained excess concentrations of calcium and phosphorus, most likely due to water-rock interactions related to the high ionic strength seawater mixing with the fresh aquifer groundwater (Price et al. 2006). We expect that increased inflows from the "Grand Experiment" will: 1) shift the location of salinity mixing in the oligohaline ecotone towards the coast; 2) suppress brackish groundwater discharge to the oligohaline ecotone, thus changing the geochemical conditions in this area; and 3) reduce water residence times in the oligohaline ecotone. We formulated the following question to guide FCE II Hydrology research:

Questions:

1. **How will changing inflows from the upstream Everglades affect the position of the salinity mixing zone and alter geochemical conditions in the ecotone by suppressing brackish groundwater discharge?**
2. **How will changing freshwater inflows affect water residence times in the oligohaline ecotones of Taylor and Shark River Sloughs?**

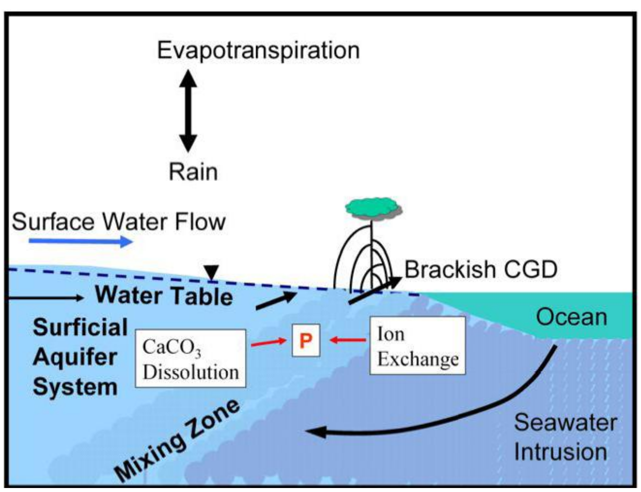


Figure IIB.1. Hydrodynamic model of the coastal Everglades. Brackish coastal groundwater discharge (CGD) contains excess phosphorus (P).

Conceptual Framework: The conceptual framework that guides our research involves the dynamic balance of fresh water and seawater in a coastal aquifer (**Fig. IIB.1**). As seawater intrudes into the surficial aquifer system beneath the Everglades, it mixes with fresh groundwater to form a brackish mixing zone that discharges as brackish coastal groundwater discharge (CGD) to the surface water of the Everglades. The geochemical reactions of $CaCO_3$ dissolution and ion exchange are believed to release P to the groundwater, increasing its P content relative to surface water (Price et al. 2006). The position of this surface water salinity mixing zone in the oligohaline ecotone is determined by the balance between freshwater inflow, groundwater discharge, and marine inputs. Evapotranspiration and rainfall affect surface and groundwater levels.

Goals: The goals of the Hydrology Cross-Cutting Theme include 1) quantifying the major water balance parameters (precipitation inputs, evapotranspiration, surface water flow rates, and groundwater discharge); 2) observing changes in the position of the groundwater mixing zone due to changes in water flow across Tamiami Trail; and 3) estimating the water residence times across the ecotones of Shark and Taylor Slough. These goals are being addressed by 1) collecting hydrologic data at each of the FCE sites; 2) utilizing longer-term hydrologic data from our collaborating agencies such as the Everglades National Park, the USGS, and the SFWMD; and 3) conducting hydrologic investigations at smaller temporal (wet and dry seasons) and spatial scales. The Hydrology Working Group is working closely with the Modeling and Synthesis Group to use hydrologic models to estimate each of the water balance parameters across the ecosystem. We are also working with the Climate and Disturbance Working Group to separate out man-induced water changes (such as the 'Grand Experiment') from teleconnections forcings such as the NAO, ENSO, and sea level rise.

Modeling: The Hydrology Working group is utilizing models developed by the Modeling and Synthesis Group and the USGS, as well as experimenting with new hydrodynamic models. Models that link the Hydrology Working Group with the Modeling and Synthesis Group include the Everglades Landscape Model (ELM) and Mangrove Hydrology (HYMAN) models. The ELM model is being used to provide estimates of water residences times across the FCE landscape. The HYMAN model, which balances both water and salt, is applied to individual sites within Shark River (Tsai et al. 2008). Models used by the Hydrology Working Group that were developed at the USGS include the Everglades Depth Estimation Network (EDEN) and Tides and Inflows of the Mangroves of the Everglades (TIME). EDEN (http://sofia.usgs.gov/eden) provides real-time water-level monitoring, ground-elevation modeling, and water-surface modeling that are used by Hydrology Working Group researches to estimate surface water flow direction and discharge in the freshwater portion of FCE. The TIME model (http://www.time.er.usgs.gov) bridges the gap of EDEN by including the mangrove ecotone region of the coastal Everglades. The model is a finite element, surface-groundwater and hydrodynamic model with a variable size grid that simulates all the components of the hydrologic cycle in the Everglades, including tidal inputs and density driven flow in the coastal zones. For the application to FCE II, the model will be used to calculate surface water residence times in relation to physiographic and boundary conditions for each of the LTER sites. Relationships between easily measured field parameters and hydrologic residence times will be sought and then used for the interpretation of nutrient biogeochemistry and trophic interactions along the LTER transects and salinity gradients. In other efforts, Vic Engel of ENP, and Dr. Marc Stieglitz of Georgia Tech University have developed a spatially-explicit hydrologic, nutrient and dynamic vegetation model, originally developed for analyzing pattern formation in arctic systems, to simulate ridge and slough formation. Collaborators at Louisiana State University, Victor Rivera-Monroy, B. Michot, Robert Twilley, and E. Meselhe, have also developed a hydrodynamic model for the Taylor River region including the FCE-LTER sites TSPh-6 and TSPh-7.

Results:

1. Quantifying major water budget components

We found that evapotranspriation exceeded precipitation in Shark Slough between 2002 and 2008 (Saha and Price, 2009). Furthermore during that time, surface water outflows from Shark Slough significantly exceeded surface water inflows. These results indicated that Shark Slough was loosing more water than it was recieving. In order to accommodate the loss of water from evapotranspiration and surface water runoff, a significant input of groundwater discharge to Shark Slough was needed. This groundwater discharge was most needed in the summer months of May through September.

A short-term study on the water budget of Taylor River was conducted by M.S. student Xavier Zapata, between January 2008 and June 2009. In that investigation, groundwater was found to be discharging to the surface water of Taylor River during the months of June and July 2008 and in May 2009 (Xavier and Price, 2009). The timing of the groundwater discharge was confirmed by measureable differences in water levels between the groundwater and overlying surface water, soil temperature fluctuations, and geochemical signatures between the groundwater and surface water.

We also found that Florida Bay was an evaporative basin with long-term (30-year) estimates of evaporation of 166 cm/yr as compared to the average rainfall amounts of 106 cm/yr (Price et al., 2007). On an annual basis evaporation from Florida Bay could vary from 148 to 181 cm/yr, while rainfall could vary widely from 62 to 152 cm/yr. Evaporation rates varied seasonally within Florida Bay with the highest rates in the late spring and summer (April through October), and the lowest rates in the late fall and winter (November through March). Evaporation was highest in May corresponding with the highest measured values of net radiation, and then decreased slightly during the rainy season months of June through October due to an increased presence of cloud cover.

Most of the groundwater beneath Florida Bay had a salinity of 36 and higher (Price et al. 2008). Therefore, little to no fresh groundwater from the mainland was expected to discharge into Florida Bay. Nutrient concentrations of phosphorus, nitrogen, and carbon were elevated in groundwater beneath Florida Bay. The phosphorus and nitrogen (ammonium) species in groundwater were most likely associated with the decomposition of organic matter as opposed to water-rock interactions.

The results of the HYMAN model reasonably matched the observed trends in pore water salinity at the three Shark River mangrove sites (SRS-4, 5 & 6) and was consistent with distance along the estuary to its mouth (Tsai, 2008). Precipitation, especially at the beginning of the rainy season, determined the seasonal timing of the pore water salinity peak. In addition, model results suggested that the most inland site, SRS-4, was more sensitive to groundwater inputs or upstream overland flow than the other two sites.

We also examined the effects of Hurricane Wilma (2005) on heat flux from the forest floor using our eddy covariance tower at SRS 6 (see Climate and Disturbance section). The largest impact of the storm was found in the sensible heat fluxes, which now represent a significantly lower percentage of the total available energy at the site (Fig. IIB.5). Dry leaves at the top of the canopy represent the primary source of sensible heat flux in this system. Sensible heat fluxes therefore declined with the defoliation caused by the storm. The lower leaf area and tree mortality following the storm also appear to have resulted in decreased transpiration. The relatively small changes in the total latent heat fluxes following the storm may have been caused by increased penetration of radiant energy to the substrate, which in turn resulted in increased direct evaporation, thereby compensating for the decrease in transpiration. Soil temperatures were found to be generally higher after the storm, supporting this hypothesis.

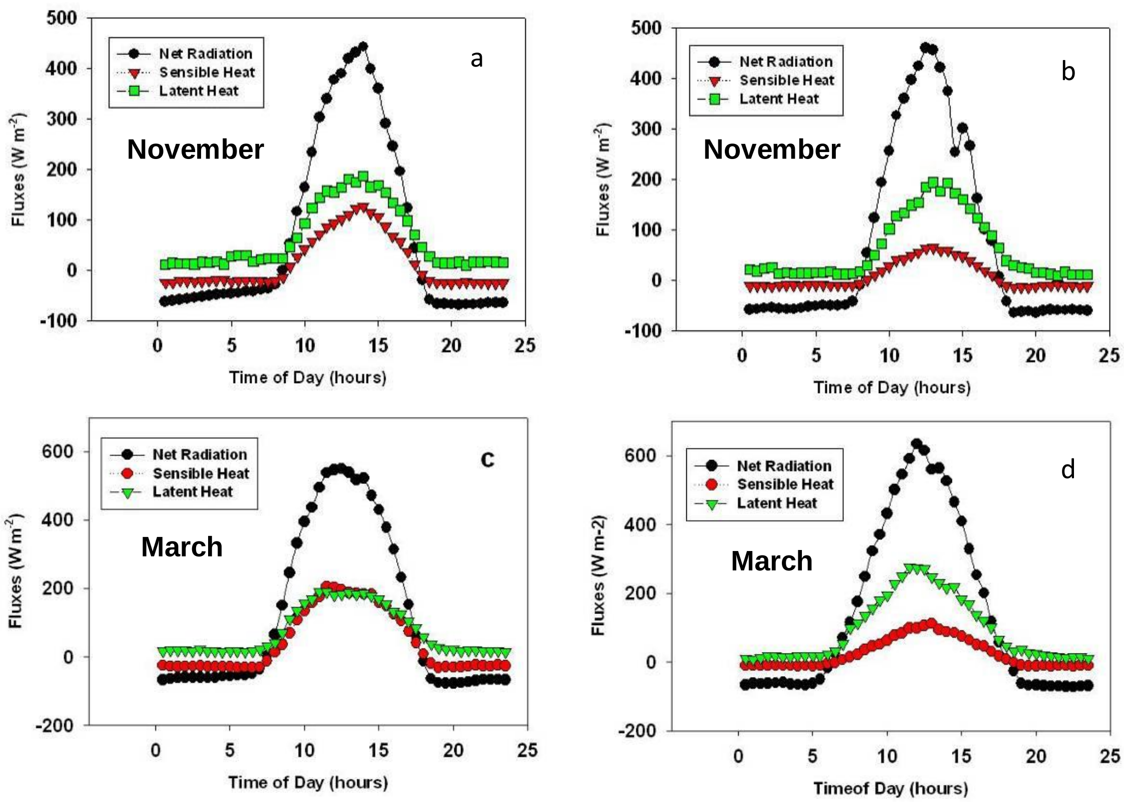


Figure IIB.5. Average diurnal trends for partitioning of energy into latent and sensible heat for (a) November, 2004 (pre-Wilma), (b) November, 2006 (post-Wilma), (c) March, 2004, and March, 2007. Given similar radiational loads before and after the hurricane, sensible heating is observed to be reduced following Wilma, while latent heating is slightly elevated, though comparable for the pre- and post-hurricane forest.

Surface water flow plays a role in shaping substrates, biogeochemical cycling, and ecosystem characteristics of the Everglades freshwater marshes. To improve understanding of the linkages between flow and vegetation patterning, automated velocimeters were deployed between July 2003 and December 2007 at five sites in Shark Slough. Flow speeds were very low (< 3 cm s^{-1}), and exhibited fluctuations which were correlated with seasonal changes in water depth but also showed distinctive deviations. Stepwise linear regression showed that upstream gate discharges, local stage gradients, and stage together explained 50% to 90% of the variance in flow speed at four of the five sites and only 10% at one site located close to a levee-canal combination. Two non-linear, semi-empirical expressions relating flow speeds to the local hydraulic gradient, water depths, and vegetative resistance accounted for 70% of the variance in our measured speed. The data suggest local-scale factors such as channel morphology, vegetation density, and groundwater exchanges must be considered along with landscape position and basin-scale geomorphology when examining the interactions between flow and community characteristics in low-gradient wetlands such as the Everglades (He et al. 2009). Earlier work by Leonard et al. (2006) at these same sites showed water velocity was affected more by the presence of submerged vegetation (e.g. *Utricularia* spp. and periphyton mats) than the emergent species. Flow rates were found to increase by as much as three times when the submerged vegetation was removed. Leonard et al. (2006) also found particulate accumulation rates and the thickness of sedimentary floc layers were greatest at the terminal ends of isolated sloughs. Infilling of sloughs by particulates and sawgrass expansion are frequently cited as factors causing the decline of the ridge-slough habitat. Together these studies indicate the importance of flow to the Everglades communities and also how management decisions regarding the timing, location, and amounts of surface water discharges into ENP directly affect landscape geomorphology and habitat quality.

In 2006 and 2007, surface water flow dynamics in the Everglades freshwater marshes were investigated using large-scale sulfur hexafluoride (SF_6) tracer releases. Several sites were studied, each characterized by different vegetation patterns and proximity to hydrologic control structures. In areas where the habitat was relatively well preserved, the predominant flow direction was aligned with the orientation of the vegetation patterning. This was the condition that characterized the pre-drainage Everglades. Unexpectedly, flow rates were found to differ significantly in adjacent sloughs, apparently as a function of differences in vegetation density and bathymetry. The results also suggested that basin-scale forcing from water management structures and operations could override the effects of local landscape features and vegetation patterning in guiding the flow. Management effects were particularly evident in two regions where the historic, natural landscape patterning was degraded. In these regions, the flow direction was found to be orthogonal to the remnant landscape patterning. The large spatial scale over which tracer data were collected allows advection and dispersion rates to be determined at unprecedented spatial scales. These measurements showed much larger dispersion coefficients than reported by previous experiments at smaller scales. This finding and a measurement of the drag due to vegetation were of interest to water resource managers in the Everglades concerned with the transport of sediment and biologically active solutes such as phosphorous. These experiments were summarized in Ho et al. (2009) and Variano et al. (2009).

Spatial and temporal heterogeneity of water and nutrient pools is closely associated with the existence of different plant communities in hydrologically-controlled ecosystems such as the Everglades. Saha et al 2009 (a) compared water source utilization in hammocks and pine rocklands on the Miami Rock Ridge using stable isotopes of water. Hammocks do not flood, while adjacent pinelands may flood between 2-3 months. In the wet season, hammocks were found to use phosphorus (P) rich soilwater, a local pool of water and nutrients while pineland plants primarily relied upon groundwater, the regional pool. Access to a rich pool of P in the oligotrophic Everglades was associated with higher community-level foliar P concentration in hammocks. In the dry season, however, hammocks utilized groundwater, which suggests sensitivity to extended droughts. Saha et al 2009 (b) compared the hammock (upland or head) and swamp forests (lowland or tail) on tree islands in the Shark River Slough. Uplands were associated with P-rich soilwater uptake in the wet season, with regional water uptake in the dry season. Accordingly, tree island heads are rich in foliar P and thereby P-hotspots in the Everglades. Foliar nutrient concentrations can thus indicate limiting nutrient availability in the

Everglades. Saha et al 2009 (c) looks at how leaf phenology patterns are tied to water and nutrient pools. Leaf fall in ridge hammocks is associated with high foliar carbon isotope values over the dry season, which is not the case for tree island hammocks. However, in some species, high levels of foliar nitrogen are also associated with high foliar C^{13} values indicating stomatal limitation of photosynthesis. Growing season for most hammock species is the wet season coinciding with high availability of P, as reflected in high foliar P in this season. Linking water sources to foliar nutrients elucidates roles of water and nutrient pools in leading to different plant communities within an ecosystem.

Observing the position of the groundwater mixing zone

The extent of seawater intrusion into the groundwater beneath Shark Slough was found to be dynamic, varying on a seasonal basis (Fig. IIB.2). Groundwater and surface water levels co-varied seasonally (Fig. IIB.2). Linear regression analysis of the surface and groundwater levels resulted in a slope of water levels with time to be not significantly different from zero. Salinity, however, was found to increase significantly (P<0.001) in both the groundwater and surface water at rates of 0.44 psu/yr and 0.47 psu/year, respectively (Fig. IIB.2).

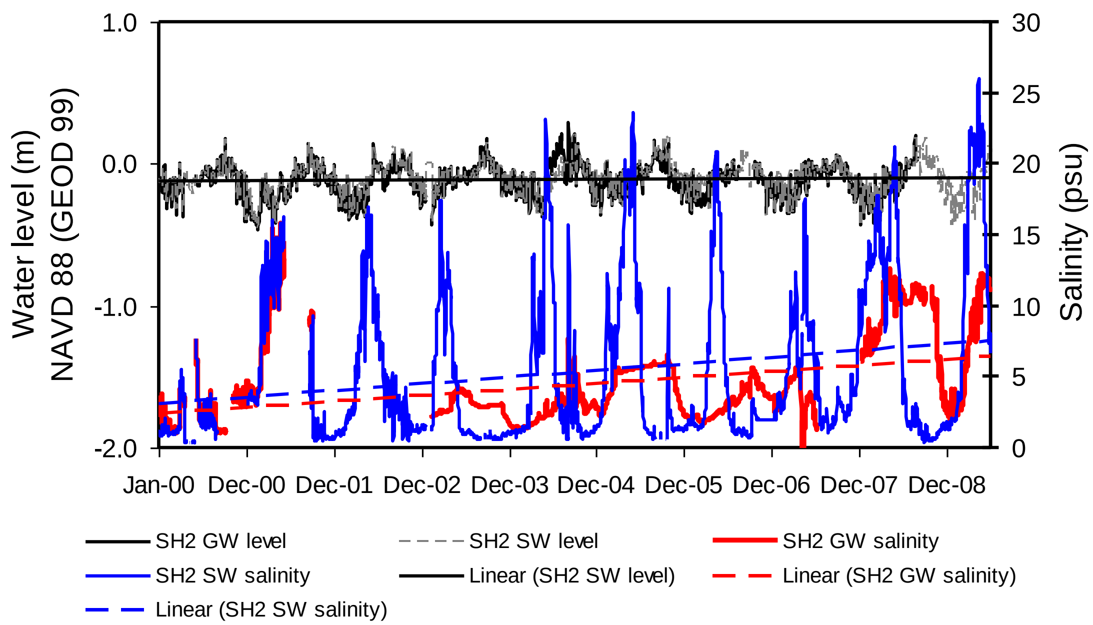


Figure. IIB.2. Variation in groundwater and surface water levels (left axis) and groundwater and surface water salinity (right axis) at USGS station SH-2, near SRS-4 (see Figure IIB.3 for location) from January 2000 through June 2009. Both surface water and groundwater salinity were found to increase with time.

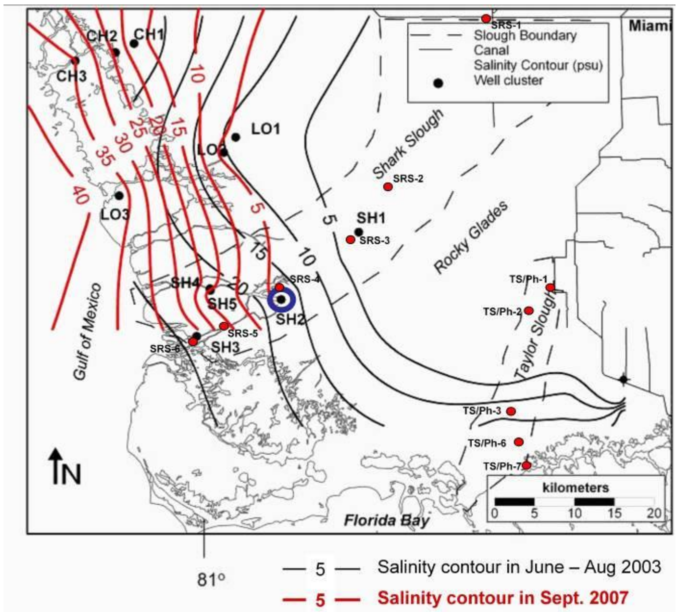


Figure IIB.3. Salinity contours in shallow groundwater (<25 m) as determined from synoptic sampling in the summer of 2003 (black contours) and September 2007 (red contours).

Groundwater nutrient concentrations of nitrogen, phosphorus and carbon were found to be higher in groundwater beneath Shark Slough as compared to the overlying surface water (Price et al. 2008). A positive relationship was observed between groundwater phosphorus concentration and salinity beneath Shark Slough. Phosphorus concentrations (total and soluble) in all of the waters (surface, porewater, and groundwater) seemed to be a function of mixing of three end-members waters: 1) fresh surface water; 2) Gulf of Mexico surface water; and 3) high salinity groundwater (Fig. IIB.4).

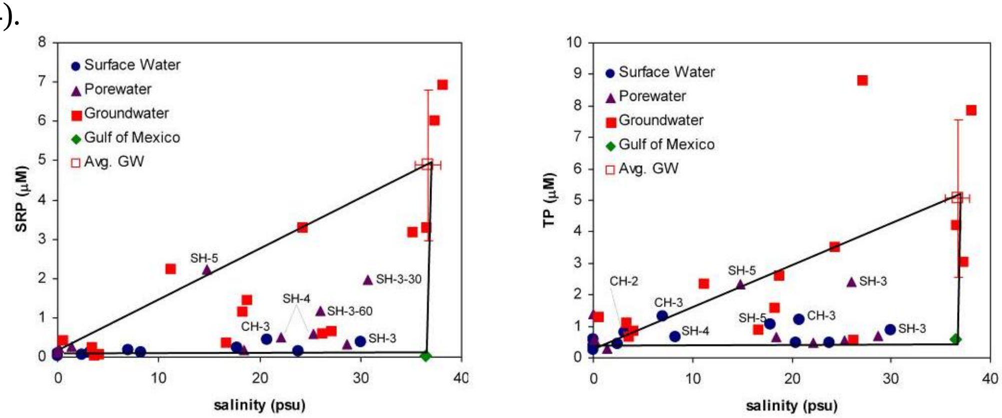


Figure IIB.4. Soluble reactive phosphorus (left graph) and TP (right graph) in surface waters, porewaters groundwater, and Gulf of Mexico surface water (Boyer et al., 1999) as compared with salinity in Shark Slough. Both SRP and TP were a function of mixing of three end-members waters: 1) fresh surface water; 2) Gulf of Mexico surface water; and 3) high salinity groundwater (Fig. IIB.4)

Limestone samples collected from the top of the Biscayne Aquifer beneath ENP were found to contain total phosphorus concentrations in the range of 30 to 50 µg of P/g of rock from the ground surface to 6 m depth (Marquez and Price 2009). The total P in the limestone rock remained at values less than 50 µg of P/g of rock to an approximate depth of 6 m. Between 6 m and 25 m, the total P concentration of the limestone increased dramatically to concentrations between 300 and 1500 µg of P/g of rock. These high concentrations at depth were most likely due to the presence of a phosphorite-bearing sand unit underlying the limestone bedrock. The results of this extraction study indicated the presence of a significant amount of P within the limestone bedrock that could account for the excess P observed in the brackish groundwater mixing zone.

The results of adsorption/desorption experiments on a limestone cube from the Biscayne Aquifer determined that the limestone had a high affinity to adsorb phosphorus in deionized water (Jolicoeur et al. 2008). Phosphate adsorption was significantly less in seawater, and more phosphorus was desorbed in the seawater compared to the deionized water. Dissolution of the carbonate minerals, calcite and aragonite, where found to release phosphorus at low salinities. At higher salinities, ion exchange reactions involving bicarbonate were most likely desorbed phosphorus. The results of this study suggest that as seawater intrudes into a fresh coastal aquifer, phosphorus would be expected to be released into the groundwater.

Estimating water residence times

The Hydrology Working Group in conjunction with the Modeling and Synthesis Group has hired a post-doc, Dr. Amartya Saha. During the last 6 months, Dr. Saha has made significant progress on addressing the our first objective of quantifying the major water budget parameters in Shark Slough. Dr Saha will begin to address the questions of water residence times in Shark Slough in the coming year. He is expected to combine the results of ELM and other hydrologic models to provide estimates of residence times. In addition, our collaborators are planning to conduct short-term tracer (i.e. radon, radium, SF_6) studies in both Shark and Taylor Rivers with the goal of estimating residence times.

Future goals: The future goals of the Hydrology Working Group include: 1) using additional tracer tests to determine water flow rates and directions; 2) identifying hydrologic changes expected with the “Grand Experiment”; 3) quantifying water residence times in Shark and Taylor Rivers; and 4) provide more detailed measurements and modeling linking hydrologic processes with teleconnections forcings. Tracer experiments using SF_6 and iron floc will be conducted in Shark and Taylor Rivers, respectively. These tests will be conducted along with *in situ* monitoring of dissolved inorganic and organic carbon to determine tidal exchange of these parameters in the oligohaline ecotone. Heat flux modeling will be applied to temperature data from thermocouple sensor arrays installed at various depths in the soil profile in the Shark and Taylor River to identify groundwater flow directions. Water level and flow will continue to be monitored in the upstream Shark River Slough region in an attempt to identify hydrologic changes with the “Grand Experiment”. These hydrologic changes will be combined with vegetation models of ridge and slough formation and persistence. ELM and other hydrologic models will be used to estimate water residence times in both Shark and Taylor Rivers. Finally, detailed measurements and modeling of climatic drivers impacting temporary to decadal-scale fluctuations in local sea level and saltwater intrusion will be conducted.

C. Biogeochemical Cycling

History: Understanding the sources, fate, and transport of dissolved organic matter (DOM) was a strong emphasis of our FCE I research, and we have learned a great deal about each. Notably, Everglades DOM is more refractory than originally hypothesized. During FCE I, we also began to understand the importance of detrital organic matter production and transport to ecotone dynamics. Much of this particulate organic matter (POM) is not suspended in the water column, but rather is found as a flocculent detrital layer above the soil surface (colloquially referred to as "floc"). As such, floc moves primarily as bedload, and we expect that increased freshwater inflows will cause more floc transport to oligohaline ecotone areas. Biomarker-based assessment of floc sources in the SRS and TS estuaries have been used to great effectiveness. Our conceptual model suggested different processes controlled POM mixing in these two systems and we found that simple end-member models do not work well in FCE estuaries. We also found that much of this floc was locally produced, which also complicates traditional 2-source allochthonous mixing models. The Everglades floc has relatively high metabolic rates, suggesting its importance to nutrient regeneration and biogeochemical cycling. Increased floc transport to the ecotone may increase P availability via this remineralization process. However, floc also is the base of our aquatic food webs - this detrital component is important to food web dynamics and ecosystem energetics. It is possible that floc inputs to FCE ecotone areas will be directly consumed, rather than decomposed, thus enhancing secondary production rather than P availability. We expect increased floc inputs will result in both responses.

Questions: Our research program is driven by two central questions:

1. **What are the mechanisms by which P availability acts to regulate N cycling rates?**
2. **How is the soil bacterial community influenced by temporal changes in water source in the oligohaline ecotone, and how are these community shifts reflected in ecosystem processes?**

Results:

1. <u>P Availability and N Cycling.</u>

P Availability – We continue to assess water quality, including temperature, salinity, dissolved oxygen, nitrate, nitrite, ammonium, total organic nitrogen, total phosphorus, soluble reactive phosphorus, silicate, total organic carbon, and chlorophyll *a* at all FCE sites. We are working with the Hydrology group to integrate these data with water flow and residence time estimates in order to determine fluxes. These data along with soil, floc, porewater and groundwater nutrient data are also being incorporated into models, particularly the Ribbon and MIKE-NUMAN models (see Modeling and Synthesis section), to understand connectivity in the system. Long-term trends in water quality are being examined by a suite of collaborators, particularly to extract climate from water management signals (Childers et al., 2006; Briceno et al., 2009; see Climate and Disturbance section). Trend analyses have revealed a connection between the 2005 hurricanes (Katrina and Wilma) to a persistent increase in water column phosphorus in the SRS ecotone, particularly at site SRS 6 where P-rich mineral sediment from the Gulf of Mexico was deposited during the Hurricane Wilma storm surge event. This event may have resulted in a significant subsidy of phosphorus to the SRS ecotone.

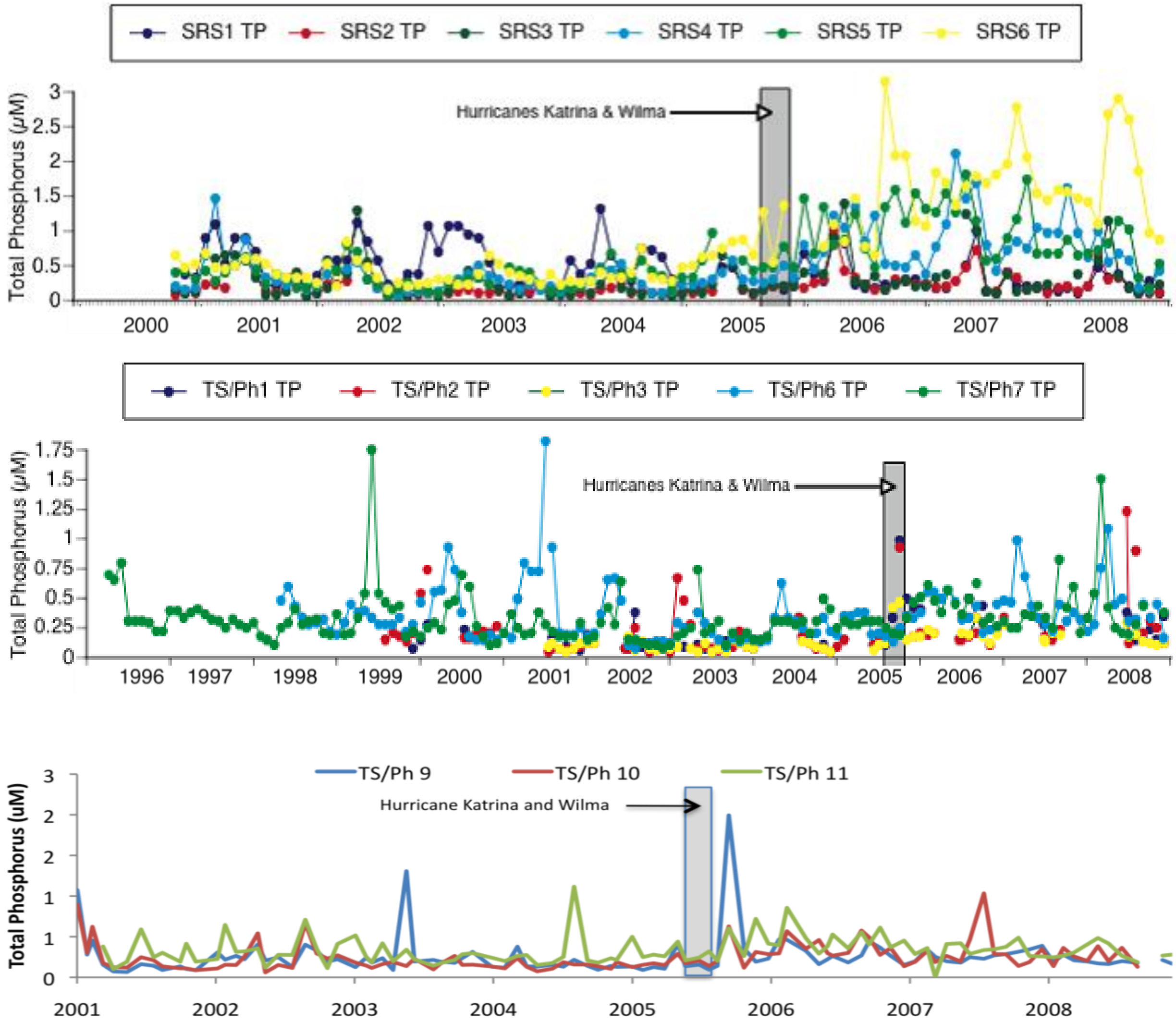


Figure IIC.1. Long-term trends in water column total phosphorus concentrations at SRS 1-6 (top panel), TS/Ph 1-7 (middle panel) and TS/Ph 9-11 (bottom panel). The timing of Hurricanes Katrina and Wilma is also denoted (shaded columns).

N-Cycling - We developed a core incubation study to evaluate the role of season and surface water quality in affecting benthic nutrient (N and P) exchange across lower Taylor Slough. The experiments to address this have included wet season, dry season, and wet-dry transition incubations in each year on cores collected at TS-7 and nearby locations. These other sites include: Taylor River Pond 1 (pond 1), West of Taylor River mouth in Little Madeira Bay, and East of Taylor River mouth in Little Madeira Bay. The latter two sites were selected as a way to consider the different bottom type and water chemistry found in each. In total, all sites represent the range of soils and sediments (peat soil, marl/floc, and carbonate mud) throughout the lower mangrove ecotone in Taylor Slough that may exhibit different patterns in benthic fluxes of nutrients.

Three sets of control batch-type experiments were run on soils/sediments from these sites in 2007 (January, May, and August) and in 2008 (January, May, and October). Beginning in May 2007, we began amending the water column (of half the incubations; n = 5) with 1 µM P (> 10X ambient concentrations) in order to understand the effects of limiting nutrient additions on benthic exchanges. Intact sediment cores (core dimension: 10 cm I.D. X 30 cm depth) were contained in the lower part of core tubes with overlying site water. Sediment cores were incubated in the water bath and overlying site water was replaced with filtered site water. We measured initial dissolved oxygen (DO) and took water samples for analysis of nutrients and DOC. At the conclusion, (approximately 4 hours), we measured the final DO concentration and took final samples for nutrients and DOC.

Significant DO removal occurred from the water column to sediment at both inland sites (TS-7 and Pond 1) indicating net heterotrophy in the peat-dominated soils and the marl sediment. Strong NO_3 + NO_2 uptake and NH_4 release from soil at both sites suggested denitrification via microbial activity in addition to ammonification of organic material contributing to release of reduced inorganic nitrogen. DOC consumption supported this. In ambient conditions, we observed weak, but significant PO_4 uptake at both sites between water column and sediment. In the bay sites, the less vegetated eastern bay site (East of Little Madeira Bay (LMB)) and vegetated western bay site (West of LMB), we saw similar uptake of PO_4 and release of NH_4, but fluxes of NO_3 + NO_2 were inconsistent. Significant DO uptake from sediments at both bay sites was also found.

Enhanced PO_4 uptake by sediments was found after the addition of 1 µM of PO_4 in the water column. Intensified PO_4 removal from water column may be due to the stronger gradient between the water column and sediment or may have contributed to microbial demand for this limiting element. In support of this, during some samplings, fluxes of NO_3 + NO_2 and DOC shifted direction or exhibited a greatly altered magnitude of flux with added P, indicating a P effect on microbial respiration and mineralization. In May 2008, the addition of P to the incubations did not seem to affect the fluxes of other elements. However, up to that point, we observed a gradual increase in the rate of P uptake in the P-addition treatment at each site over time - especially at TS7b and Eastern LMB. The cause of this is currently unknown, but we hypothesize that it may be a result of recent storm activity that affected soils and sediments in this region of the Everglades. Data from our final experiment in October 2008 showed that this trend ceased at all sites and reverted back to levels observed at the beginning of the study.

2. Bacterial Metagenomics.

Sediments - Community structure of sediment bacteria in the Everglades freshwater marsh, fringing mangrove forest and Florida Bay seagrass meadows were described based on PCR - denaturing gradient gel electrophoresis (DGGE) patterns of 16S rRNA gene fragments and by sequencing analysis of DGGE bands. The DGGE patterns were correlated with the environmental variables by means of Canonical Correspondence Analysis. There was no significant trend in the Shannon-Weiner index among the sediment samples along the salinity gradient. However, cluster analysis based on DGGE patterns revealed that the bacterial community structure differed according to sites. Not only were these salinity/vegetation regions distinct but the sediment bacteria communities were consistently different along the gradient from freshwater marsh, mangrove forest, eastern-central Florida Bay, and western Florida Bay (Fig. IIC.2). Actinobacteria- and Bacteroidetes/Chlorobi-like DNA sequences were amplified throughout all sampling sites. More Chloroflexi and members of candidate division WS3 were found in freshwater marsh and mangrove forest sites than in seagrass sites. The appearance of candidate division OP8-like DNA sequences in mangrove sites distinguished these communities from those of freshwater marsh. The seagrass sites were characterized by reduced presence of bands belonging to Chloroflexi with increased presence of those bands related to Cyanobacteria, γ-Proteobacteria, Spirochetes, and Planctomycetes. This included the sulfate-reducing bacteria, which are prevalent in marine environments. Clearly, bacterial communities in the sediment were different along the gradient, which can be explained mainly by the differences in salinity and total phosphorus.

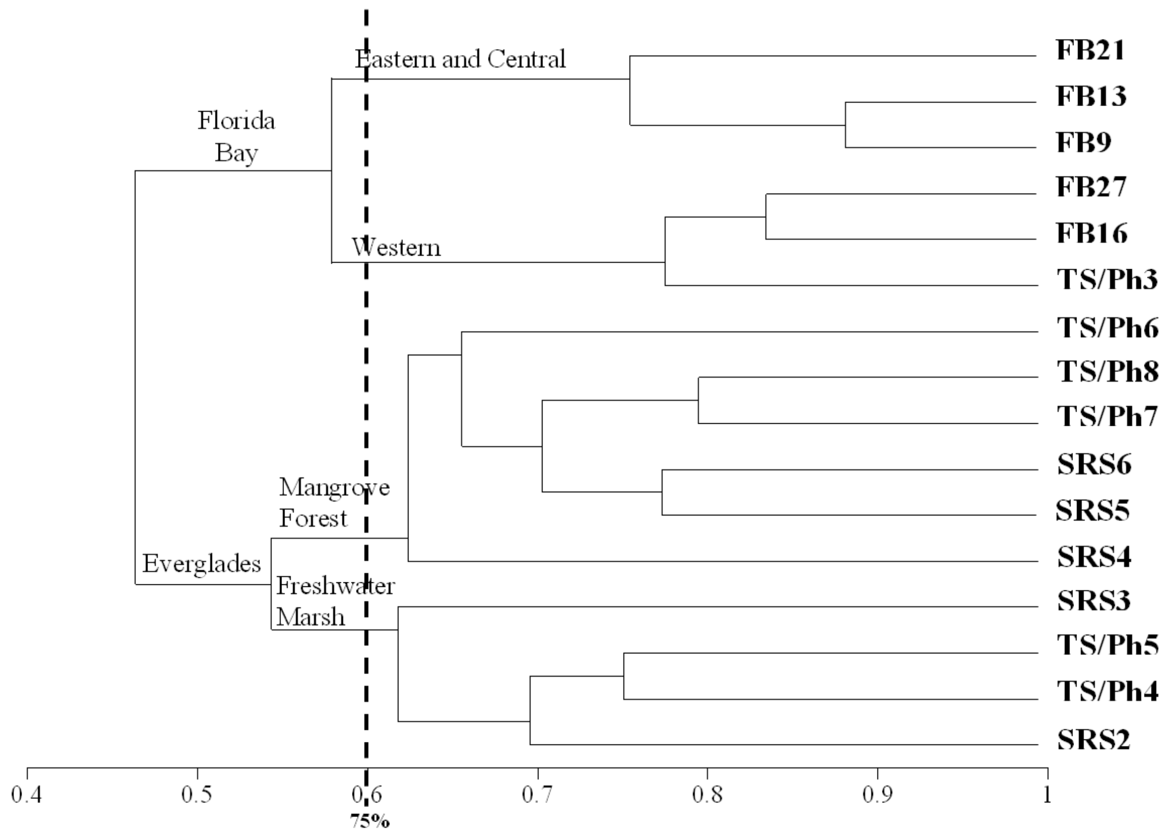


Figure IIC.2. UPGMA dendrogram constructed from the similarity matching data (Morisita's similarity index) obtained from the DGGE profiles of 16S rRNA gene partial sequences amplified from the sampling sites at Shark River Slough (SRS), Taylor Slough/C-111 canal basin (TS/Ph), and Florida Bay (FB). The cutoff similarity value is indicated by a dash line.

Bacterial Metagenomics of Floc - Floc samples have been collected for DNA analysis at 6 LTER sites: SRS-1, -2, and -6, and TS-1, -2, and -6. Thus far, samples have been collected in May and September 2007. DNA was extracted from the samples using a FastDNA SPIN kit (for soil) and the extracted DNA was then amplified by PCR and analyzed using T-RFLP (Fig. IIC.3).

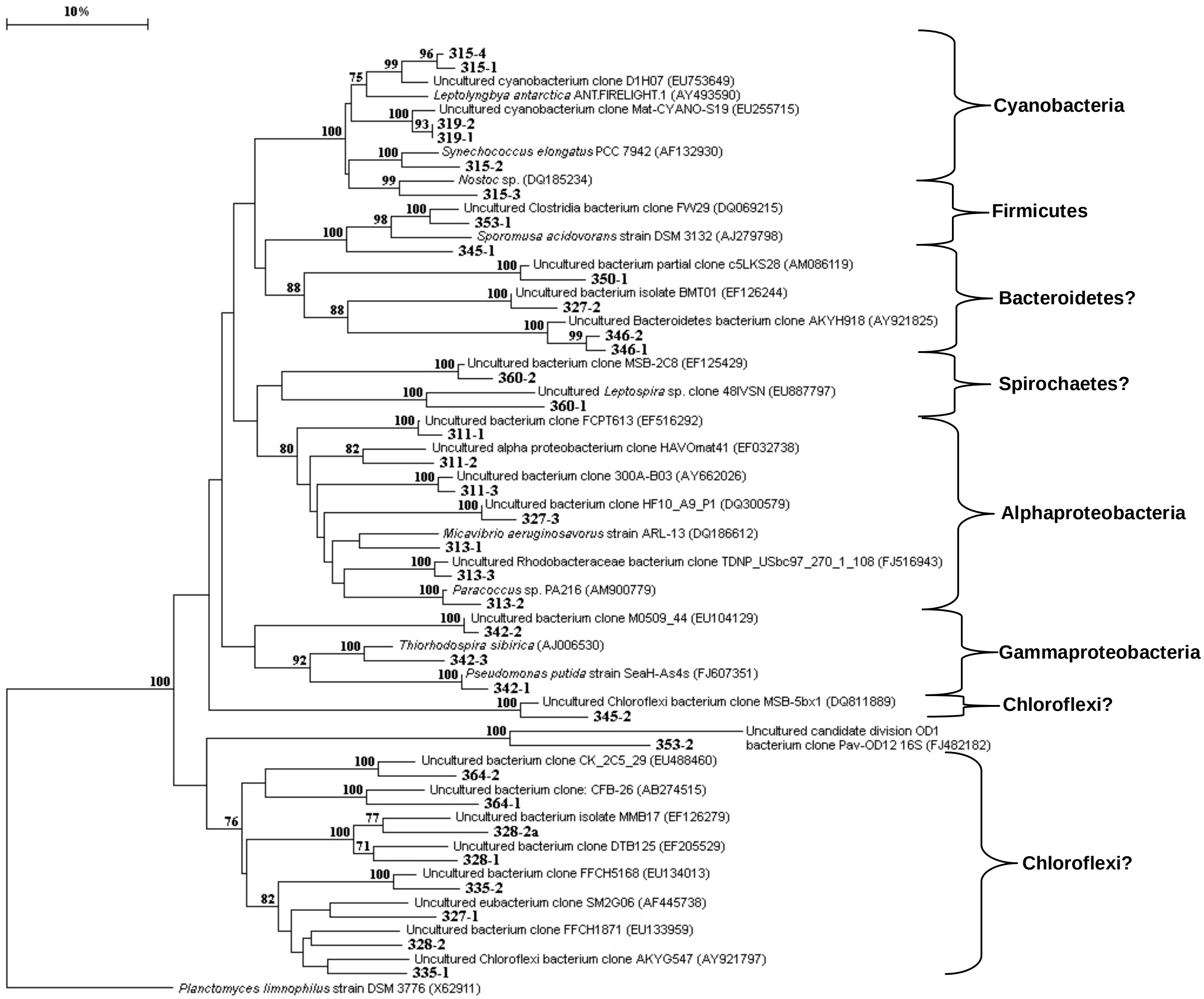


Figure IIC.3. Floc bacterial sequences tree constructed of 16S rRNA gene partial sequences amplified from the floc from wet season and dry season sampling of Shark River Slough sites (S1, S2, and S6) and Taylor Slough sites (T1, T2, and T6).

Microbial Ecological Processes - Three procedures were performed each month for all FCE II sites: bacterial production, bacterial enumeration, and the measurement of chlorophyll *a*, quantum yield, and excitation characteristics of phytoplankton using Phyto-PAM. Heterotrophic bacterial production is determined using ^{3}H-thymidine uptake within 24 hours of collection. Bacterial enumeration was determined through epifluorescence microscopy using DAPI. Algal dynamics were determined through PAM (pulse-amplitude modulation) fluorescence within 24 hours of collection. Algal energetics were analyzed by PAM fluormetry for CHLA and production irradiance curves.

Bacterial and Eukaryotic Metagenomics via Pyrosequencing **-** In collaboration with Dr. Linda Amaral-Zettler at International Census of Marine Microbiology, (ICoMM), we received NSF funding to support 454-based tag sequencing strategy that allows extensive sampling of marine microbial populations (PNAS 103: 32 p. 12115-12120). Strategy based on sequencing of hypervariable regions of the SSU rRNA gene allows measurement of both relative abundance and diversity of dominant and rare members of the microbial community thereby allowing efficient comparison of the structure of microbial populations in marine systems. This project sampled aquatic components at 4 sites in FCE during wet and dry season, in collaboration with Dr. Ryan Penton at Michigan State University to sample marine sediments in Florida Bay for bacterial metagenomic profile using 454-based pyrosequencing. Preliminary analysis suggests that TS-10 is drastically different from TS-9 and TS-11. It seems that TS-10 has much lower DOC and is a more refractory site. The proportion of observed OTUs and Chao1 ratios indicate that TS-9,-10, and -11 are all relatively phylum poor in contrast with the richest communities observed at barrow canyon (Alaskan maritime), Juan de Fuca (Pacific) and Cascadia basin (Pacific).

Future work: Future research in the Biogeochemical Cycling Working Group will focus on three broad topics: 1) developing hydrologic flows and loads of nutrients and DOM through the coastal Everglades ecosystem; 2) determining relative importance of exogenous climate drivers to internal processes such as primary production and nutrient export, and; 3) assessing factors affecting degradation and microbial community structure of floc. We are accomplishing the first through collaborations with the Hydrology group, particularly our new post-doc, Amartya Saha, who is developing water budget and flux models for the estuaries. The exploration of exogenous climate drivers is becoming a more exciting area of research as our program grows in duration, and we are now able to extract long climate cycles and persistent management signals from our datesets. We view this as a central area of expansion as we move toward FCE III. Finally, we are continuing multiple collaborations with the Organic Matter Dynamics Group to understand the importance of floc in our ecosystem, to which we should have compelling answers as our program moves toward renewal.

D. Primary Production

History: The first phase of Florida Coastal Everglades research (FCE I) focused on understanding how dissolved organic matter (DOM), and the N associated with that DOM, from upstream oligotrophic marshes interacts with a marine source of phosphorus, the limiting nutrient, to control productivity in the estuarine ecotone. We expected that productivity peaks would occur where communities are released from N or P limitation by the confluence of fresh and marine water. We found an increase in sawgrass and mangrove productivity in the oligohaline regions of Shark River Slough and two production peaks in the Taylor River Slough, one in the oligohaline zone and one at the terminal site close to the Gulf of Mexico. These productivity patterns conformed generally to our interpretation of water quality trends (Childers et al., 2006a), with the unexpected oligohaline peak in the TS transect likely being driven by a supply of nutrients from the groundwater (Childers, 2006). In FCE II, we are continuing to explore how spatially distinct supplies of N and P interact to control primary productivity, and we have added a focus on how the relative supply of nutrients from the surface and groundwater interact to control biomass allocation and production in the ecotone.

Questions: The Primary Productivity Working Group is organized around the central question: **How does seasonal and inter-annual variability in water source (surface water, groundwater, rainfall, and marine inputs) and associated P availability control primary productivity and biomass allocation in the oligohaline ecotone?** To investigate this question, we originally set out 2 specific research questions in the FCEII proposal:

1. **How does a surface water P source versus access to shallow groundwater P affect belowground production and biomass allocation in ecotone plants?**
2. **How does a surface water P source versus access to shallow groundwater P affect sawgrass and periphyton productivity at the freshwater-ecotone transition? How does increased hydroperiod and decreased water residence time (as a result of increased freshwater inflows) affect productivity in this transition zone?**

We expect that increased freshwater inflow to the oligohaline ecotone will affect salt budgets, water residence times, and the sources, availability, and flux of organic and inorganic nutrients. Marine and groundwater discharge are the dominant sources of P to the ecotone, and both are expected to decline with increased freshwater inflow. In this scenario, we expect that primary productivity and biomass allocation in the ecotone will reflect a long-term increase in oligotrophy (Childers et al. 2006a; Price et al. 2006). The Shark River Slough ecotone, with relatively high freshwater inflows and considerable tidal energy, receives most of its P via tidal inputs directly from the Gulf of Mexico (Chen & Twilley 1999; Childers et al. 2006a). The Taylor Slough ecotone, with negligible tidal energy and distinct seasonal variability in water source and quality (Davis et al. 2003; Sutula et al. 2001), appears to receive considerable P from shallow groundwater inputs (Price et al. 2006). We expect that this "vertical" difference in the dominant P source will be reflected in differences in both primary productivity and biomass allocation between the SRS and TS/Ph ecotones.

Goals: The Primary Productivity working group aims to quantify primary productivity across the spatial domain of FCE, and to relate spatial and temporal patterns in rates of primary productivity and plant community structure to patterns in nutrient and organic matter supply. We are accomplishing this goal by systematically monitoring ANPP and nutrient availability at the FCE II focal sites, as well as by conducting controlled experiments in which organic matter and nutrient availability are manipulated and the effects of these manipulations on primary productivity are assessed. From the inception of FCE I we have been assessing ANPP using measures of biomass accumulation of the dominant primary producers in the ecosystem (phytoplankton, periphyton, sawgrass, seagrass and mangroves); we have begun to collect whole-ecosystem estimates of production and respiration using gas flux enclosures and open atmosphere gas flux methods to get a more complete picture of ecosystem metabolism across the domain of the FCE.

Results: The primary productivity group has been very active, and has produced many published papers and book chapters describing the details of the spatial and temporal patterns in ANPP of various components of the FCE ecosystem since the inception of FCE II. Much, but by no means all, of this work address the central questions we posed in the FCE II proposal. Rather than give a too-short summary of each of the papers that have been published so far in FCE II, this section will concentrate on what we have learned about the two central questions posed in the proposal.

<u>Belowground production and biomass allocation</u>

We have found that the availability of P, as well as the source of P, controls biomass allocation and belowground primary productivity in the Coastal Everglades. The seagrass *Thalassia testudinum* is the dominant macrophyte primary producer in Florida Bay, the marine end point of the TS transect. This species dominates seagrass beds from the P-replete western margin of the FCE domain, in the severely P-limited stretches of central and eastern Florida Bay, as well as in the ecotone region adjacent to the mangrove shoreline. Biomass allocation to above and belowground structures is strongly controlled by the availability of P, with plants from low-P environments investing more heavily in below-ground structures than plants from high-P environments (Herbert and Fourqurean, 2009; Fig IID.1, top panel). The net primary productivity, as well as the relative growth rate, of seagrass in Florida Bay is also strongly controlled by P availability (Fig. IID.1, middle and bottom panels). Belowground production of seagrasses in Florida Bay accounts for 23% to 37% of total NPP (Herbert and Fourqurean 2009) The general pattern of a decrease in P availability for seagrasses from west to east across Florida Bay (Fourqurean and Zieman 2002) does not hold as one approaches the mangrove ecotone in northeast Florida Bay, where P availability, and consequently seagrass productivity, are elevated (Herbert and Fourqurean 2009). As water column P does not show increases in concentration in this region, and as this area has been shown to be an area of discharge of brackish groundwater with relatively high P availability (Price et al 2006), we hypothesize that this increase in productivity in the ecotone is driven by groundwater-derived P.

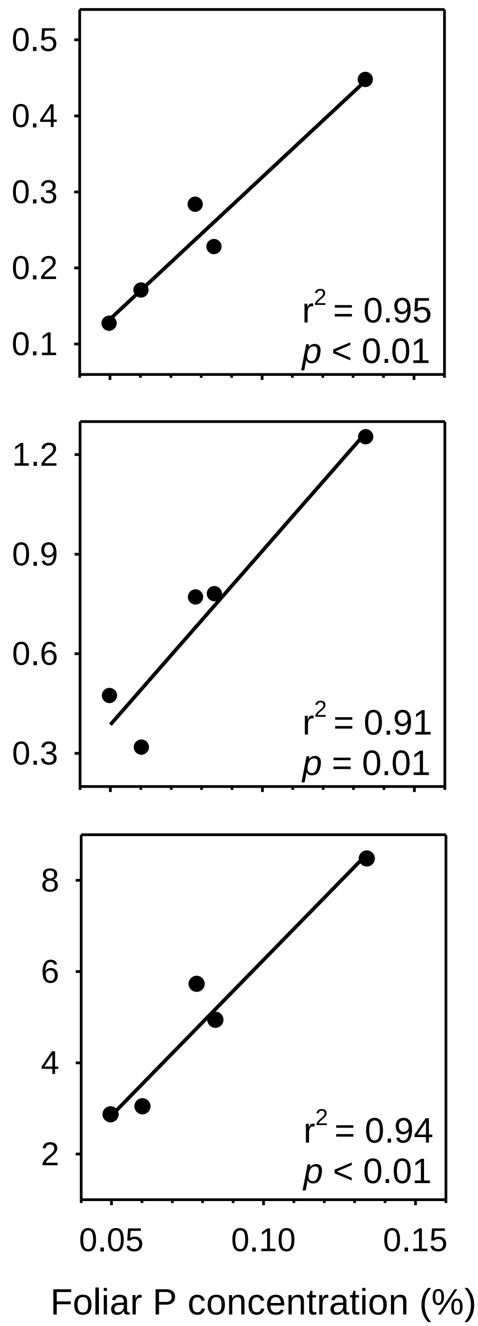


Figure IID.1. Biomass allocation (PBR, or the ratio of aboveground to total plant biomass), net primary productivity, and relative growth rate of seagrasses increase as P availability increase in Florida Bay (From Herbert and Fourqurean 2009).

Similarly, P availability exerts strong influence on the biomass allocation and root productivity of mangroves. Total mangrove root biomass was greater in the relatively low P availability the Taylor River region (3265 ± 531 g m^{-2}) compared to the high-P Shark River region (2477 ± 528 g m^{-2}). Further, within the Shark River, where there is a strong decrease in P availability for mangroves from the mouth to the head of the river (Chen and Twilley 1999), allocation of biomass to fine roots increased from the mouth to the head of the river. Root productivity, as assessed with root ingrowth bags, was higher in the relatively P-replete Shark River system (159 ± 11 g m^{-2} yr^{-1}) compared to Taylor River sites (56 ± 8 g m^{-2} yr^{-1}). We also found a significant relationship of fine root biomass and productivity with soil TP concentrations (Fig. IID.2), suggesting a strong control of nutrient availability on belowground root allocation. Our results support our hypothesis that sites with more limiting P conditions such as Taylor sites, have lower turnover rates of fine roots and longer root longevity (the inverse of root turnover) spans compared to Shark River. The relative increase in root life span in the Taylor River sites compared to Shark River could be an adaptation of mangroves to nutrient loss. This is particularly significant given that the P-limited condition and the likely greater expenditure of energy in foraging the limiting nutrient in the Taylor sites, at expenses of growth, could add a physiological cost in maintaining root growth and higher turnover rates.

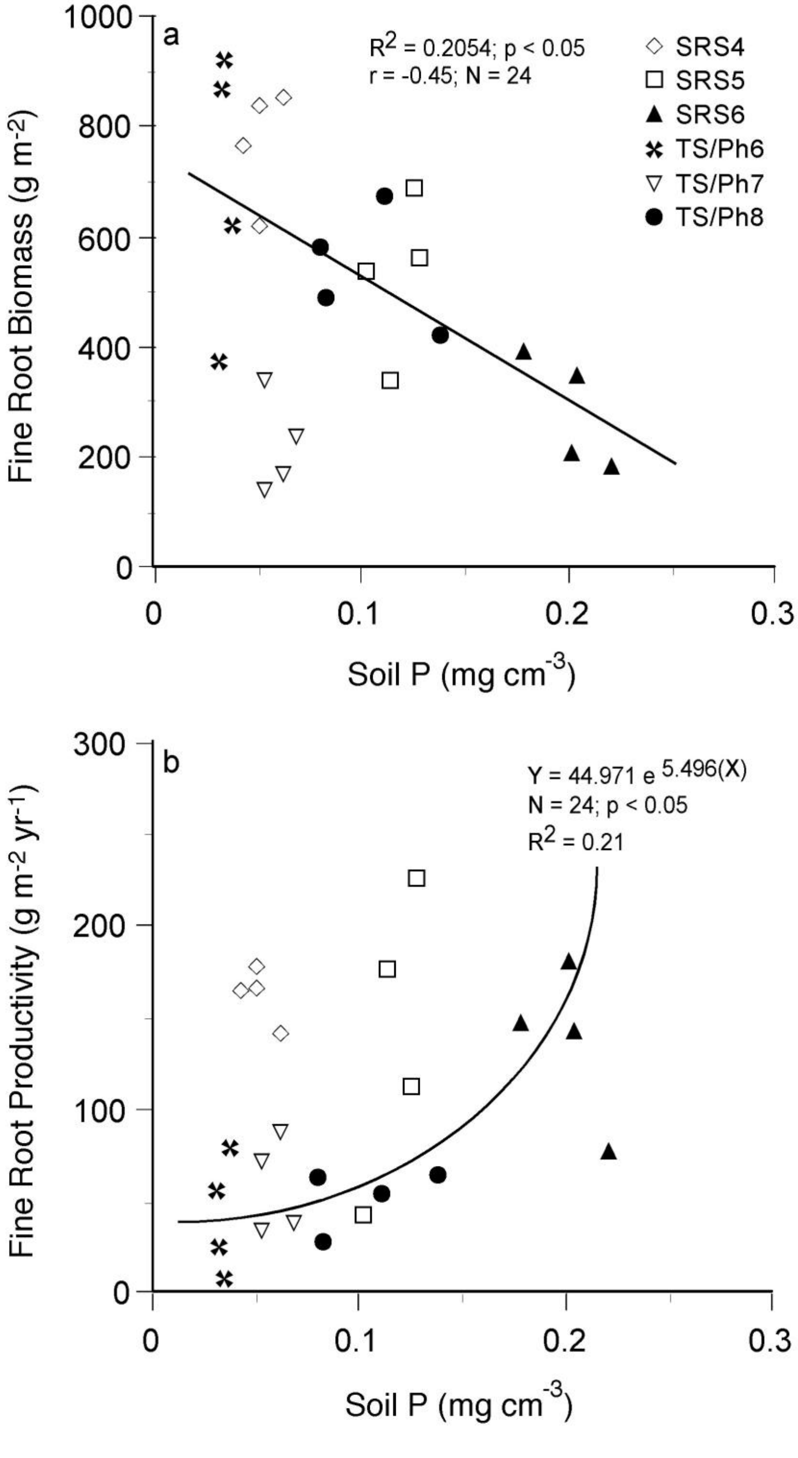


Figure IID.2. (a) Linear relationship between fine root biomass and soil P concentrations in mangrove forests of Everglades National Park. Standard parameters of the linear model are indicated. (b) Nonlinear relationship between fine root productivity and soil P concentrations in mangrove forests of Everglades National Park. Standard parameters of the exponential model are indicated

Effects of P source and hydrology on sawgrass and periphyton productivity

Phosphorus availability can have surprising influences over primary producers in the P-limited Everglades ecosystem. While sawgrass, seagrass and mangrove biomass and productivity are all positively correlated with P availability, the biomass and productivity of periphyton in much of the ecosystem are negatively correlated with P availability. High rates of periphyton productivity continue to be measured in the freshwater marsh that results in thick floating and epilithic mats that average 4800 ml m^{-2} in wet biovolume, 210 g m^{-2} in dry mass and 60 g m^{-2} ash-free dry mass. Rates of periphyton ANPP were lower in the predominantly floating mats of SRS than for the epilithic mats of TS (mean 2001-2004 = 21 g m^{-2} yr^{-1} vs. 1400 g m^{-2} yr^{-1}, respectively). There was a general negative relationship between periphyton production and phosphorus availability, as well as between periphyton abundance and P availability (Fig. IID.3), as has been observed spatially in larger surveys and experiments (Gaiser et al. 2006, 2009). In the subtidal seagrass beds of Florida Bay, periphyton is commonly referred to as epiphytes. Epiphyte accumulation rates in Florida Bay were lower than those for the freshwater marsh. Rates are significantly higher at TS/Ph-11 than TS/Ph-9 and 10 at all times of the year and these epiphytes contain a higher concentration of phosphorus than those at the two upstream sites. Compositional differences in the epiphytic diatom flora were also pronounced among the three Florida Bay sites and were related to gradients in salinity and phosphorus availability (Frankovich et al. 2006); experimental P additions confirm that P availability directly influences the composition of the epiphyte community (Frankovich et al. 2009; Wachnicka 2009).

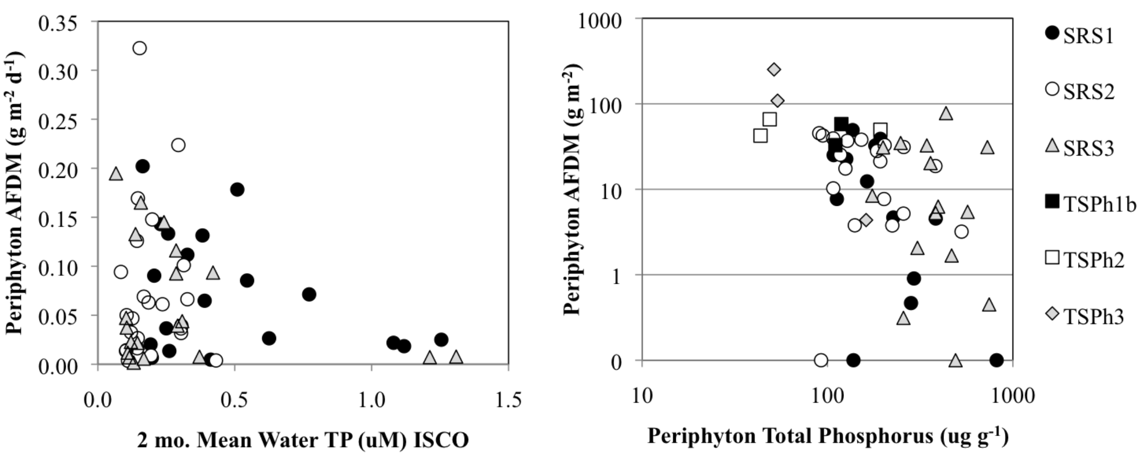


Figure IID.3. Negative relationships between biomass and production of periphyton with phosphorus concentrations in water and periphyton at FCE sites.

Hydroperiod has a strong influence on periphyton structure and productivity as well. Within the SRS transect, the highest rates of periphyton production occurred during the wet season of each year, with values being highest in the central slough (SRS 2, 3) and lowest at the SRS 1a and b, close to the Tamiami Canal. Periphyton production suggests a unimodal reponse to increasing water depth (Fig. IID.4), a trend which holds throughout the freshwater Everglades (Gaiser et al. 2006, 2009). Within the TS transect, periphyton production is highly variable, with highest rates occurring just after seasonal inundation of previously dry mat (Iwaniec et al. 2006).

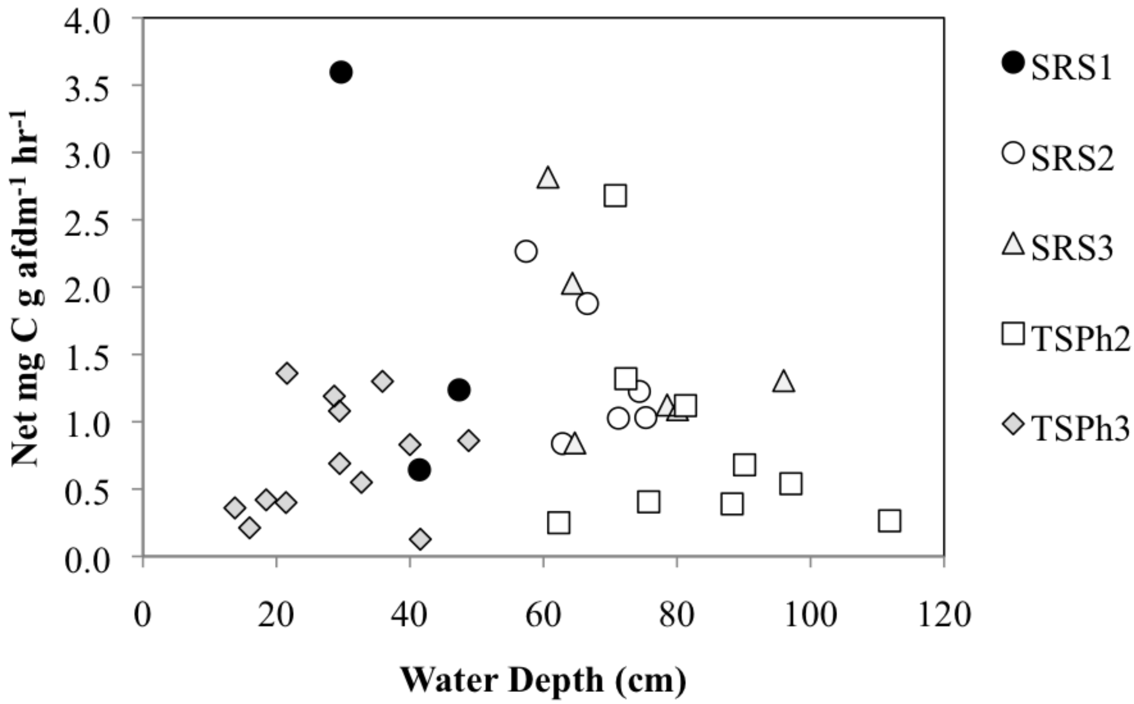


Figure IID.4. Periphyton tend to show a unimodal response to water depth across sites.

The productivity of sawgrass in the freshwater marsh is highly dependent on hydroperiod. Over the entire decadal record of sawgrass ANPP at FCE focal sites (Fig. IID.5), there were significant differences in mean ANPP rates across the sites (Fig. IID.6a) and in long hydroperiod (SRS sites) vs. short hydroperiod (TS/Ph sites) marshes (Fig. IID.6b). Interestingly, the southernmost site in the Taylor Slough transect (TS/Ph-3) more closely resembles a long hydroperiod marsh than the other short hydroperiod marshes in its basin. This is likely because this site is considerably wetter than the other TS/Ph sites. It is also notable that the overall ANPP mean at the northernmost SRS site (SRS-1), which is considerably drier than the other sites in this basin, most closely resembles the shorter hydroperiod TS/Ph marsh locations. Various measures of the hydrologic environment did explain significant portions of the interannual variation in sawgrass ANPP, and the best relationship was a curvilinear response of ANPP to depth-days with all sites and all years pooled together ($r^2=0.43$; intercept $p<0.001$; Depth-Days $p<0.0001$; $(\text{Depth-Days})^2$ $p=0.018$; Fig. IID.7). This relationship suggests a “wetness maximum” in either water depth, hydroperiod, or both, at which sawgrass is most productive. This result is not what we expected, based on Childers et al. (2006) where they found a negative relationship between Depth-Days and sawgrass ANPP. That analysis was based only on short hydroperiod sites, though, and only on data from 1998 – 2004. This more complete ANPP and hydrology dataset may, in fact, present a clearer picture of how sawgrass responds to inundation and is more in keeping with the autecology of the species. We are working to understand the interaction between hydroperiod and soil phosphorus availability in controlling the long-term trends in sawgrass production across our marsh sites.

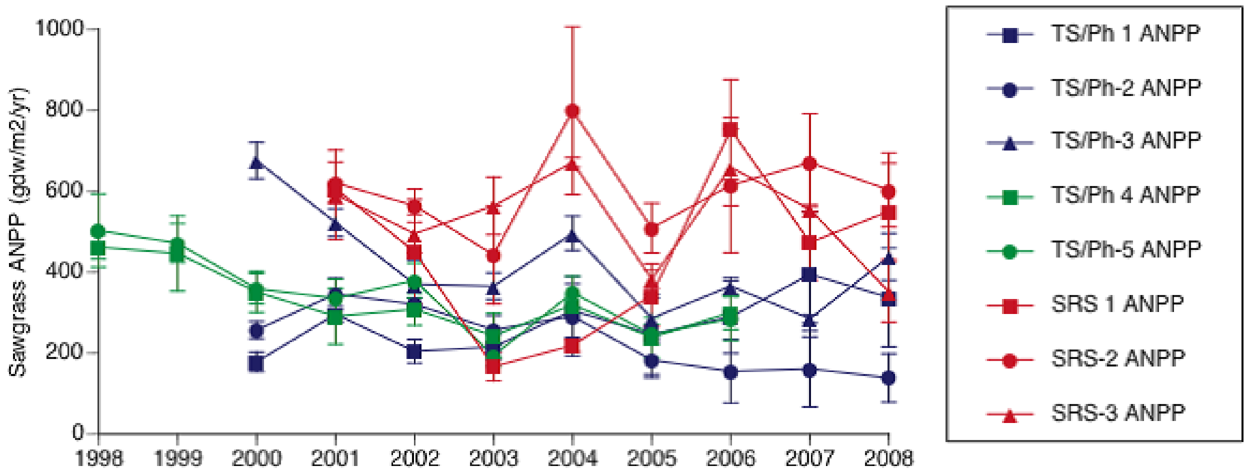


Figure IID.5. Time-series of ANPP by site and by basin (C-111 in green, Taylor Slough in blue; Shark River Slough in red).

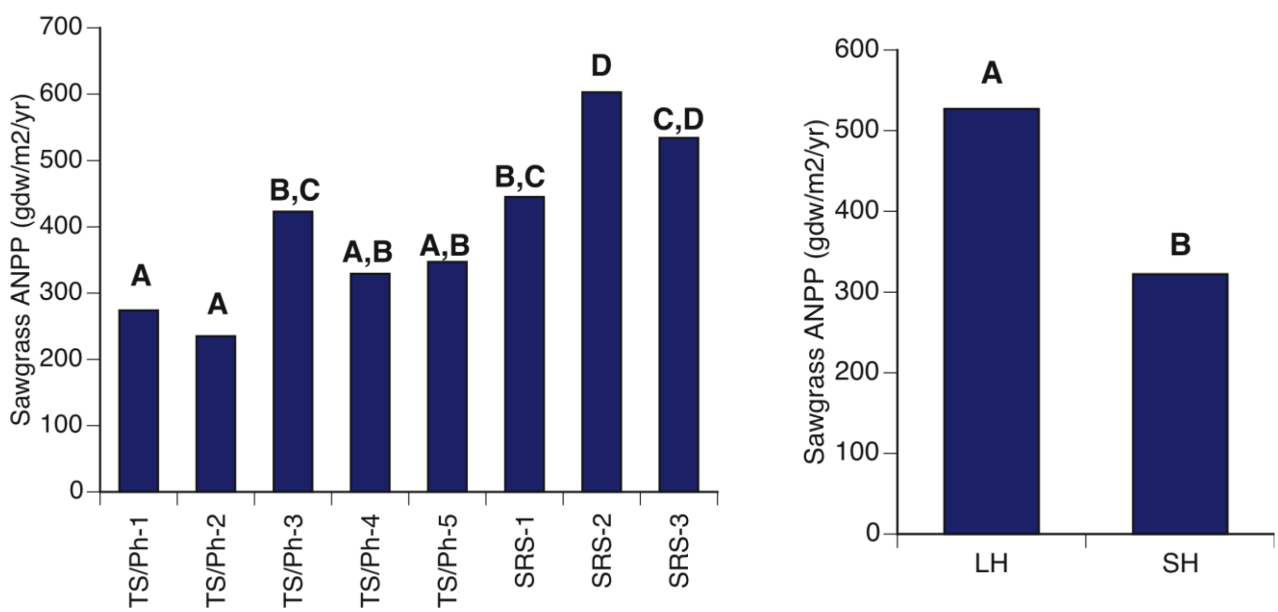


Figure IID.6. Overall time-series mean ANPP by site (A) and by hydroperiod (B; LH = long hydroperiod; SH = short hydroperiod). All differences are significant to p<0.0001.

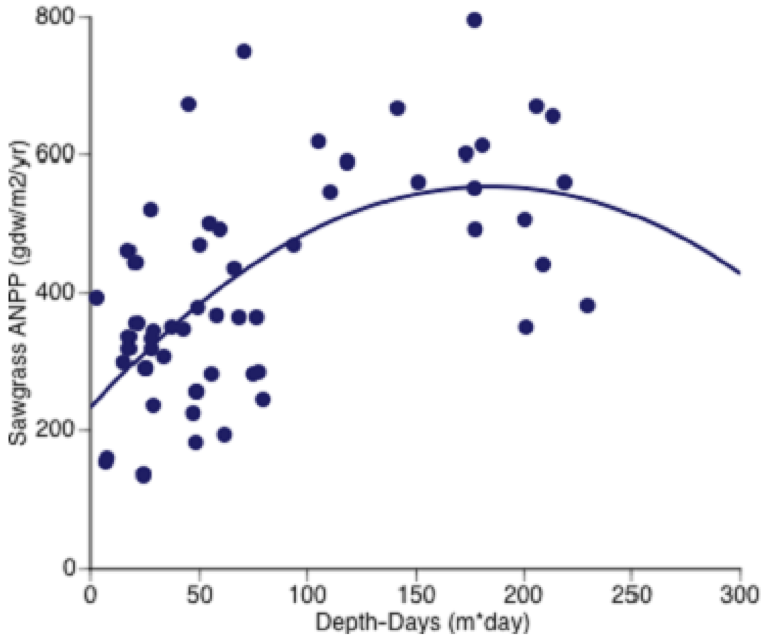


Figure IID.7. Relationship between ANPP and the hybrid hydrologic variable depth-days. Overall r^2=0.43 and p<0.0001. ANPP=2.1(Depth-Days)-0.011(Depth-Days)^2+282.

Future Goals: We have made progress in addressing how biomass apportionment and belowground productivity respond to P availability in 2 of the 3 focal macrophyte groups (seagrasses and mangroves); we intend to address how P availability affects belowground production and biomass of sawgrass in the coming years. As our hydrology group better defines the delivery of P via groundwater across the landscape of the FCE we will be able to further explore how groundwater-delivered P affects the primary production of FCE plant communities. We have also made great progress in measuring net ecosystem metabolism using flux chambers in freshwater marshes and seagrass beds, and flux towers in mangrove forests and sawgrass marshes. We are moving towards a synthesis, aiming to understand the relative contributions of ANPP of focal organisms, for which we have been collecting primary production data, to whole system metabolism. The importance of such a synthesis is being highlighted by the finding of net heterotrophy in some sawgrass marshes and some seagrass beds during certain times of the year.

E. Organic Matter Dynamics

History: Understanding the sources, fate, and transport of dissolved organic matter (DOM) was a strong emphasis of our FCE I research. FCE DOM is quite varied in composition and has both seasonal and spatial variability in its composition. It is also more bio-refractory than originally hypothesized. Still, not enough is known about DOM photo- and bio-reactivity, its sources and source strength, and exchange with groundwater. During FCE I, we also began to understand the importance of detrital organic matter production and transport to ecotone dynamics, where much of this particulate organic matter (POM) is not suspended in the water column, but rather is found as a flocculent detrital layer above the soil surface (colloquially referred to as "floc"). As such, "floc" moves primarily as bedload, and we expect that increased freshwater inflows will cause more floc transport to oligohaline ecotone areas. We reported that much of this "floc" seemed to be locally produced, and found relatively high metabolic rates for freshwater marsh "floc", suggesting its importance to nutrient regeneration and biogeochemical cycling. Increased "floc" transport to the ecotone may increase P availability via this re-mineralization process. However, "floc" also is the base of our aquatic food webs (Williams & Trexler 2006) and this detrital component is important to food web dynamics and ecosystem energetics. It is possible that "floc" inputs to FCE ecotone areas will be directly consumed, rather than decomposed, thus enhancing secondary production rather than P availability. We expect increased "floc" inputs will result in both responses. However, still little is known about the environmental dynamics of floc such as its reactivity, source variability on spatial and temporal scales and its contribution to OM in soils and the dissolved OM pool.

Questions: Research in FCE I led to the following central question that drives FCE II research: **How are organic matter dynamics (DOM, "floc" and soils) in the oligohaline ecotone controlled by local processes versus allochthonous freshwater, marine and groundwater sources?** We have three specific questions that help guide our research:

1. ***Does the [allochthonous and autochthonous] supply of DOM and "floc" to the oligohaline ecotone vary seasonally, and how do hydrological, ecological, and climatological processes interact to control this supply?*** The quality of the organic matter pool is quite variable across the Everglades landscape, due to differences in vegetation, geomorphology and seasonality of hydrology and primary productivity. Ecosystem energetics, including the structures of food webs and microbial loops, are influenced by DOM, "floc", and suspended POM (SPOM) dynamics particularly in oligohaline systems.
2. ***Are the chemical characteristics and quality of DOM leaching from soils discernible from groundwater DOM sources, and [if so] what is the relative contribution of each source to surface water in the oligohaline ecotone?*** Little is known about the contribution of soil-derived and groundwater derived DOM to overall DOM pools in our oligohaline ecotone regions. The increased focus on hydrology in FCE II (particularly groundwater-surface water interactions) will allow us to investigate the dynamics of groundwater DOM inputs to the ecotone using molecular characterizations of both high molecular weight (>1000 Dalton) and bulk UDOM. We expect that the characteristics and fate of groundwater DOM will be discernible and different from DOM in [either marine or fresh] surface waters.

3. ***How are soil dynamics (nutrient and OM content, peat accumulation, sedimentation) in the oligohaline ecotone controlled by water source and hydrologic residence time?*** Soil properties integrate biogeochemical, ecological, and physical processes over extended time scales, much in the same way that climate is the long-term aggregate of weather conditions for a region. In FCE II, we will continue to track long-term patterns in soil dynamics and how they respond to changes in hydrology, nutrient cycling, and ecological dynamics, with emphasis on the ecotone, through transect-based analysis of bulk soil properties, soil elevation change and radiometrically dated soil cores.

Goals: We organized our research to address the following goals: 1) Characterize DOM and 'floc' sources and dynamics on spatial and temporal scales throughout the FCE to better assess potential changes in the oligohaline zone induced by enhanced water delivery. This includes assessments of both quantity and quality of such OM. 2) Determine how soil dynamics (nutrient and organic matter content, peat accumulation, sedimentation) in the oligohaline ecotone vary with water source and hydrologic residence time in the context of shifts in dominant vegetation types. 3) Our paleoecological and accretion research contributes to the goals of CERP restoration projects. Paleoecological findings will significantly contribute to the development of pre-drainage targets for the hydrologic conditions required to support pre-drainage ridge-slough habitats, and in the ecotone sawgrass and mangrove community assemblages typical of the pre-drainage environment. Data compiled on soil accumulation and accretion contribute to CERP restoration goals by showing how soil accumulation rates have been altered by drainage (or impoundment) and what restoration targets should be to restore microtopographic variation in ridge-slough, to maintain tree islands, and to buffer coastal habitats from sea-level rise.

Models: Our data have been integrated with several FCE models, including the Ribbon model (integrating floc metabolism data), and current modeling efforts are increasingly integrated with our paleoecological and soil accretion data. In the Ribbon model, floc metabolism and transport were found to be highly sensitive factors underlying local P cycling in freshwater environments. With some refinement from additional data on floc dynamics, the freshwater FCE models such as the Ribbon model and ELM may be useful in scaling-up empirical studies of floc to assess the sensitivity of ecotone nutrient cycling to upstream processes. Paleoecological and soil accretion studies provide long-term (decadal to millennial) time series data on vegetation and soil dynamics. These data are important components in the calibration/validation of several FCE models, including ELM (whole landscape), SCAT (marshes), NUMAN (mangroves), and SEACOM (Florida Bay and mangrove ponds).

Results:

1. <u>Dissolved organic matter (DOM) dynamics.</u> In order to assess the environmental dynamics of DOM in the FCE on both spatial and temporal scales, we have continued our monthly monitoring of DOM, at all active FCE-LTER sites. The main objective is creating a long-term database on optical properties of DOM. We have included in this exercise the determination of excitation-emission-matrix fluorescence measurements (EEM) in combination with parallel factor analysis modeling (PARAFAC). We now have a database covering monthly samples at all FCE sites for the past four years which clearly demonstrates consistent differences in compositional patterns in DOM, and thus source heterogeneity, on both spatial and temporal

scales (Fig. IIE.1). Some of these changes seem driven by hydrological variations or primary productivity. However, diagenetic processing through photo- and bio-degradation also seem important drivers on DOM dynamics. With that in mind, we have performed detailed bio- and photo-reactivity studies with the objective of characterizing end-member DOM reactivity.

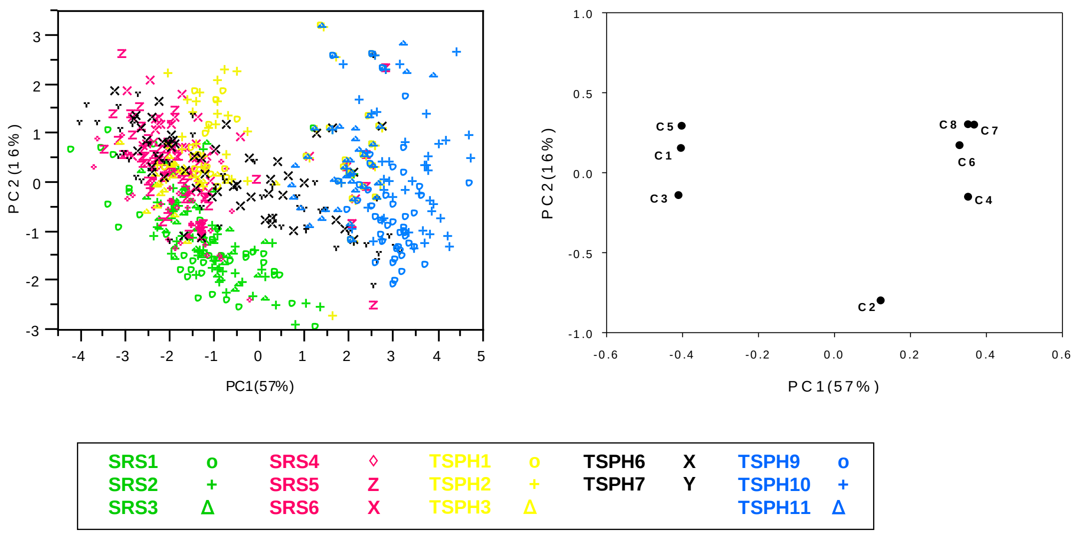


Figure IIE.1. PCA biplot of EEM-PARAFAC values from 14 stations over 51 monthly sampling events (n=568). Spatial variability in DOM composition is clearly observed

As such we have studied DOM reactivity in diverse biomass, soil leachates and surface waters. Both photo- and bio-reactivity were strongly related to OM source and composition. In addition to surface water DOM we studied the dynamics of DOM in ground water, with the objective to assess potential surface-to-groundwater exchange as a potential DOM source in this ecosystem. Preliminary findings suggest that there is active exchange between surface and groundwater associated DOM both in the freshwater marshes as well as the estuarine Florida Bay, and that environmental conditions such as red-ox differences and light availability seem to control the composition of DOM. Lastly, we determined the reactivity of FCE DOM towards trace metals, specifically Hg and Cu through a novel application using fluorescence quenching and EEM-PARAFAC. Differences in interactivity were determined both between soft and hard metals and between samples of different DOM quality.

2. Detrital Dynamics. The Everglades is an oligotrophic subtropical wetland characterized by very low quantities of planktonic particulate organic matter (POM). In this environment, POM occurs as a slow-moving, benthic layer of flocculent material (floc) relatively rich in organic matter. In contrast, OM associated with particulates (POM) is abundant in estuarine areas of the FCE and in Florida Bay. We have studied the characteristics and environmental dynamics of these materials over the past years. Although it is well known that floc represents an important component of the FCE food web, still little is known about its biogeochemical dynamics (i.e. sources and reactivity) in this ecosystem. We are investigating the seasonal and spatial variability of floc quality (sources and reactivity) along two transects of the FCE. Molecular characterization of floc (lipid biomarkers and pigment - chemotaxonomy) is being performed with the objective to identify and differentiate on spatial and temporal scales organic matter (OM) sources. Floc reactivity is also being investigated by assessing its bio- and photo-

reactivity. For this purpose we have measured floc respiration rates and DOM generation after solar exposure, respectively.

We have continued to make progress with regards to the characterization of OM sources in sediments and soils of the FCE in an attempt to determine biomass/source specific biomarkers. As such we have concluded studies regarding biomarkers from periphyton and mangroves, including some detailed mangrove biomarker photo-degradation studies. In addition, we have successfully used such biomarkers to assess the paleo-history of OM deposition in Florida Bay and as a means to determine historical hydroperiod changes in the FCE freshwater marshes.

In contrast to OM in POC, sediments and soils in the FCE, little is known about the sources and dynamics of floc. In our present efforts to assess the biogeochemistry of floc, we have found correlations between specific lipid biomarkers and pigment algal components that could aid in assessing the OM sources and transformations of this detrital pool. Progress in this area has been slow due to the complexity of the floc material and the fact that biomarker analyses are very labor intensive. Our data suggest that some lipid biomarkers such as the C20 highly branched isoprenoid seem to be produced by cyanobacteria (periphyton) and as such might be applicable as a marker for such organisms in floc when pigments are no longer usable for chemotaxonomic purposes. Similar results were obtained for a series of unusual botryococcanes which may be biomarkers for green algae. With regards to floc reactivity, both freshwater marsh and mangrove floc seemed to be highly reactive to UV-Visible irradiance resulting in significant photo-dissolution of this detrital matter (Fig. IIE.2). DOC levels after several days of exposure increased by about a factor of 10. As such, floc may be an important source of DOM in the Everglades ecosystem. This process is under further investigation!

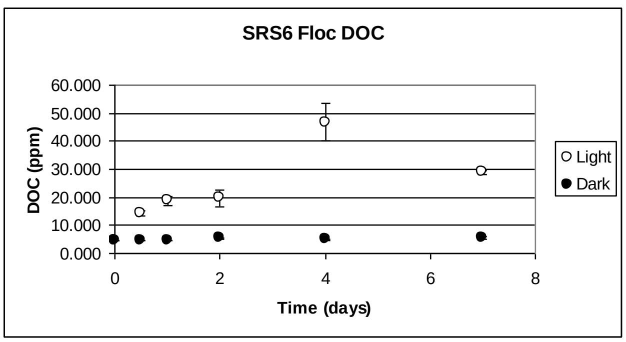


Figure IIE.2: Example of photo-induced dissolution of floc under solar simulation for samplescollected at a fringe mangrove site (SRS6).

To track the rate of floc transport in Taylor River, student Greg Koch initiated a pilot study using a synthetic tracer manufactured to mimic Everglades floc that is also para-magnetic (i.e. it can be captured with a magnet but the particles do not stick to themselves). This research is being conducted with the support of the South Florida Water Management District as well as ParTrac, the tracer manufacturer, in the United Kingdom. The pilot study showed that our tracer transport to the field and release methods were more than sufficient and also showed that floc transport at the spatial order of magnitude of interest (10s of meters) occurs at a temporal scale of several days to two weeks. We also identified problems with our initial plan for magnet capture and have since solved these problems.

<u>3. Soil nutrients and organic matter.</u> We continue our long-term collection and analysis of soil samples along Everglades and Florida Bay transects to document responses to both short- and long-term drivers of hydrologic change. Because identical sampling and analytical protocols are used at all transect locations at the same time each year, these data provide important baseline

information regarding spatial and temporal variation in sediment organic matter and nutrients. We documented 2-3 year changes in soil structure and nutrient availability related to a single, acute storm event (Hurricane Wilma in 2005) that redistributed sediments along the lower portion of the Shark River Slough (SRS) transect. Hydrologic changes driven by the upcoming, long-term press event (i.e., increased freshwater addition along the SRS transect), will alter the location and ecosystem function in the oligohaline ecotone. Our data will document changes in soil nutrients and organic matter related to the anticipated positional shift in the oligohaline ecotone. Finally, since these upstream changes may act as drivers for changes downstream in the estuarine mangrove and coastal ocean environments, our synoptic sampling should capture the long-term response in the pools of soil organic matter and nutrients.

Through 2008, the redistribution of sediments on the estuarine portion of the Shark River Slough transect that occurred with Hurricane Wilma in 2005 has been "assimilated", and soil organic matter and nutrients have returned to their pre-storm levels. Longer-term changes in nutrients and organic matter, however, may accrue with changes in differential seedling recruitment and plant success driven by storms, a landscape-level feature we observed in 2007 and again in 2008.

In 2002 we began a long-term experiment testing the addition of reactive iron to sediments in the freshwater Everglades, for comparison with seagrass ecosystems where iron additions stimulated plant growth. In reduced seagrass sediment, iron additions buffered toxic sulfides, retained sediment phosphorus and stimulated phosphorus uptake in plants. In the freshwater Everglades, however, sulfide concentrations are already low, so additional iron has not acted as a buffer. The sawgrass in iron-enriched plots is not as productive as in control plots, although the plants exhibit no obvious signs of iron toxicity other than reduced growth. This past year we tried unsuccessfully to assess plant condition in control and iron addition plots using a portable field photosynthesis meter (meter malfunction during extreme temperatures in August. We are working to refine the method. Finally, we completed a trip to the Taylor Slough dwarf mangroves to develop an experimental design to test the effects of iron and phosphorus additions on soil organic matter and plant production.

4. Mangrove research. The large contrast in hydroperiod regimes between the Shark River and Taylor FEC-LTER transects provides a unique opportunity to test the influence of environmental variables in mangrove forest development, species composition and spatial distribution. Our work in the mangrove ecotone has underlined the critical role of phosphorous (versus salinity) in controlling mangrove forest structure and productivity. The interaction among hydroperiod, resource, and regulator gradients along the FCE-LTER transects define the local importance of hydrology in controlling fine root decomposition and production as well as above ground productivity (wood, litterfall) and pore water chemistry. We have found that major differences in nitrogen and carbon isotopic composition of organic matter (leaves) among sites and species reflect the local importance of fertility gradients and influence the relative composition of organic matter exported to adjacent coastal waters.

5. Paleoecological and soil accretion studies. Soil profiles of biomarkers and macrofossils collected along ridge-to-slough transects throughout Shark Slough and WCA-3B have demonstrated deeper water conditions and habitats currently dominated by sawgrass and spikerush were previously dominated by water lily species. These studies demonstrate the utility

of using macrofossil (mainly seeds and plant fragments) to delineate past habitat boundary shifts and their potential impacts on soil formation.

The literature review of Everglades soil accretion studies, based on radiometric dating of soils, is in progress; however, preliminary results show that landscape variation in accretion rates show some correspondence with the landscape variation in soil loss based on repeated surveys over the 20th century (Fig. IIE.3). Soil accretion data compiled for Shark Slough thus far also indicates that in the SRS-3 conceptual landscape, accretion in deep sloughs has been outpacing sawgrass accretion, potentially reflecting a loss in microtopography in this region. Substantial amounts of fossil sawgrass plant tissues (leaf fragments and seeds) observed in an SRS-3 slough core also suggested allochthonous (upstream) sources of POM have been accumulating in these sloughs.

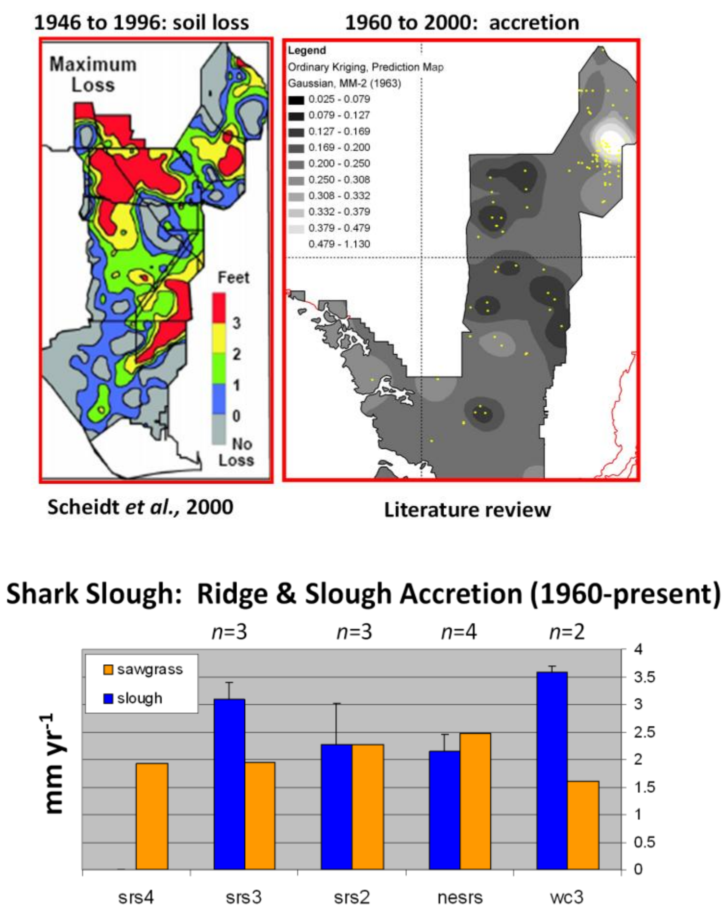


Figure IIE.3. (Top panels) Spatial variation in soil loss from 1946 to 1996 documented by Scheidt et al., 2000 compared with spatial variation in soil accretion based on radiometric dating (210Pb and 137Cs) of soil cores taken throughout the Everglades. (Bottom panel) Literature review data specific to ridge and slough accretion rates in Shark Slough, from upstream (WCA-3) down to SRS-4 (no slough accretion rates are measured at SRS-4).

Future goals:

1. We need to measure the reactivity of both DOM and floc, both with regards to bio- and photo-processing if we want to get a better handle on model predictions of the fate of this OM in the oligohaline ecotone. Such determinations are underway but need to be expanded. With this in mind we want to develop biogeochemical proxies for both photo- and bio-reactivity of DOM in the form of optical measurements. Such proxies will allow for a simplified, high sample throughput assessment of spatial and seasonal changes in DOM quality as restoration of this ecosystem proceeds. Last but not least, we need to quantify separately DOM sources from freshwater, estuarine and marine end members to better understand the oligohaline ecotone dynamics of DOM in the FCE.

2. The "dynamics" component with regards to soil OM to date has simply been the long-term variation in soil properties. The stated goal will require more collaboration with hydrology group to relate those hydro-metrics to soil variables. Since factors like soil redox are controlled in part by hydroperiod and organic matter, one future goal is to determine the interaction among electroactive species (iron, sulfur, carbon, nitrogen) in ecotone soils. This information will contribute to our current understanding of ecotone production along SRS and TS transects, and could be used in models to predict changes in production associated with water source and residence time.

3. The collective use of paleoecological and soil accretion studies will be an important building block for modeling and synthesis activities aimed at understanding habitat changes, soil dynamics and large-scale boundary shifts along the coastal ecotone regions.

F. Consumer/Trophic Dynamics

History: During FCE I we found that the dynamics of consumer communities were more complex than we had previously thought. Contrary to predictions, fish species richness and standing crops were higher in mangrove habitats of the oligotrophic Taylor River than in the more nutrient-rich Shark River (Green et al. 2006) likely because of differences in microtopography that affect the ability of freshwater taxa to access mangrove communities. We also found that detrital sources are very important to the consumer food webs but variation in trophic relationships was not consistent with simple seasonal or hydrological fluctuations (Williams and Trexler 2006) indicating that further investigations into the role of detritus in consumer community dynamics were warranted – especially in light of proposed changes to Everglades hydrology during restoration. Finally, the finding that there was no productivity peak in the ecotone region of the Shark River Slough and that nutrient availability declined continuously from the mouth of the river upstream combined with pilot studies of large consumers suggested that these mobile species might play an important role in the nutrient dynamics of the communities.

Questions: During the initial three years of FCEII we have begun addressing several of the key questions outlined in the proposal as well as several that have emerged since the initiation of FCE II. Our major working group questions include:

1. **Do large consumers (Florida gar, snook, bull sharks, alligators) transport nutrients from freshwater marshes and downstream marine sources (Florida Bay and the Gulf of Mexico) into the mangrove zone? What factors drive patterns of large predator habitat use and trophic interactions? What role does individual variation in foraging tactics and movements play in linking ecosystems?**
2. **What is the structure (standing crops and species composition) of fish communities in the mangrove zone of our two transects and how do they change in response to changing water delivery and marsh drydown events?**
3. **What is the structure of food webs in the mangrove zone and how are they changing in response to dynamic sources of water and nutrients?**
4. **Can we use marsh consumers as ecological indicators? Can we use responses of populations to natural variation in environmental conditions to create dynamic targets for these indicator species under different water management regimes?**

Goals and Conceptual Framework: The work during FCE II has been guided by the recognition that consumer movements, habitat use, populations and communities will be influenced by a diverse array of biotic and abiotic drivers, many of which interact (Fig. IIF.1). One of the primary goals of our group in FCE II has been to gain a functional understanding of the drivers of consumer movements (e.g. movement into drydown refugia by marsh taxa or shifts in home ranges by taxa using channels) and their trophic interactions that will allow us to develop predictive models for understanding the impacts of large-scale climate change or water management on the ecosystem.

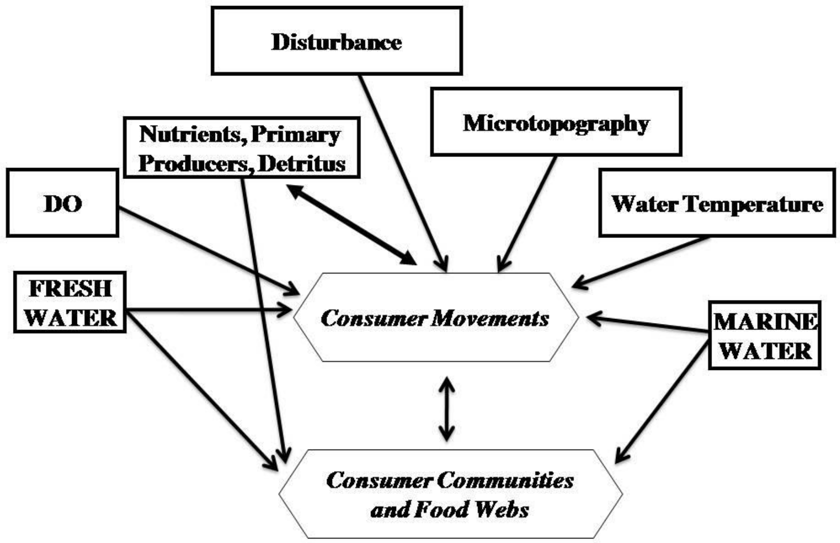


Figure IIF.1. Conceptual model of drivers of consumer communities. Note that interactions among many of the factors influencing consumers are not included in this diagram and are the foundation of investigations of other working groups, which highlights the importance of collaborations among working groups.

Modeling: Modeling efforts in our group are in their beginning stages. The Ribbon model has been particularly useful in gaining insights into the production and delivery of detritus into various regions of the coastal Everglades and will become more important as we move forward with markers to quantify detrital contributions to food webs. We have recently submitted a manuscript evaluating three models of dispersal in a simulated wetland landscape. A spatial model of fishes moving along hydrological gradients to match resource availability as predicted by an ideal free distribution was the most promising option. We plan to scale this model up to a more realistic spatial framework to determine if it predicts recolonization of wetlands following droughts. We are also conducting other modeling that seeks to forecast fish and macroinvertebrate dynamics based on targets for ecosystem restoration to be used in assessing the match of field data with management goals.

Results:

1. Marsh Communities. During FCE II, studies in marsh communities has focused on developing biological indicators for assessing the impacts of water management. Studies focused on four species – bluefin killifish, flagfish, eastern mosquitofish, and Everglades crayfish – that represent a gradient from slow recovery to rapid recovery in response to drying events. The goal was to detect effects of water management beyond typical variation in population dynamics of these species driven by natural rainfall and hydrological fluctuation. We have found that these species do provide good indicators of water management success, but that applying dynamic targets is critical to disentangling the effects of natural fluctuations and anthropogenic impacts (Fig. IIF.2).

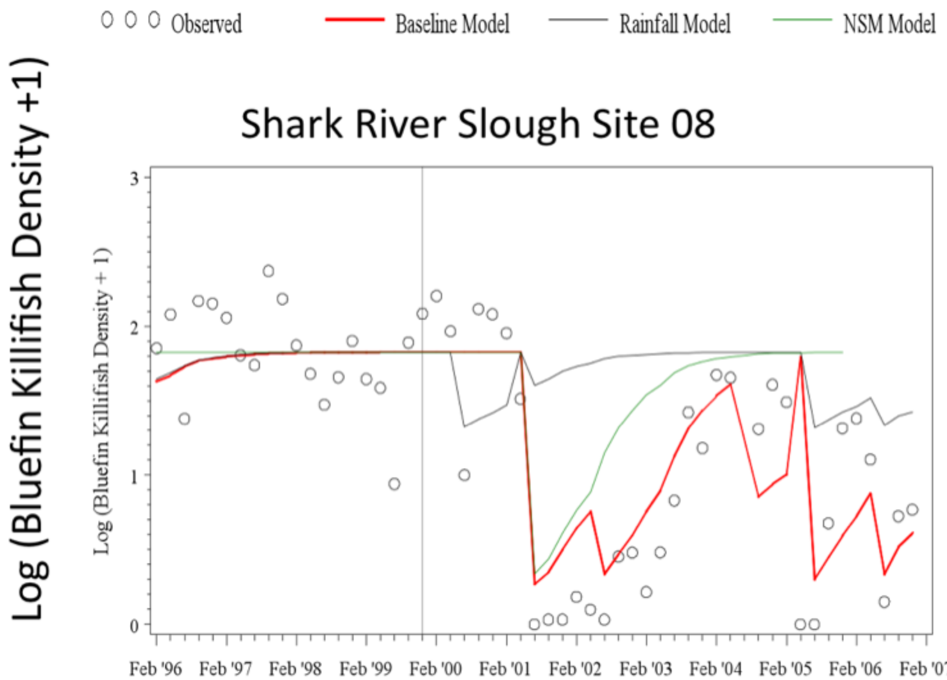


Figure IIF.2. Bluefin killifish densities at one study site in the Shark River Slough before and after changes in water management (denoted by vertical line). Circles are the observed density of fish and the red line indicates the best fit of the observed data. The black line indicates the target densities based on goals for hydrological management set by Everglades National Park personnel, and the green line is the density of fishes expected if hydrology matched our best guess of historical water levels given observed rainfall (NSM = natural system model).

2. Ecotone Communities. Our five years of sampling show that the upper Shark River estuary is inhabited by a diverse and dynamic fish community composed of transient marsh species, resident estuarine species, and transient marine taxa (e.g., 37 fish species were collected via electrofishing since 2004). Patterns of fish abundance vary markedly yearly and seasonally, and are closely tied to marsh hydrology upstream, as well as to local abiotic conditions in the estuary, particularly salinity and dissolved oxygen.

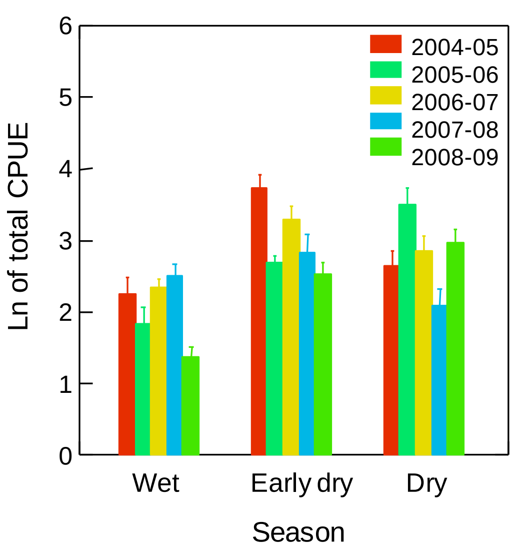


Figure IIF.3. Total catch per unit effort (CPUE) in electrofishing data platted as a function of season and sampling year.

Catch per unit effort (CPUE) generally peaked in the drier months of sampling, reflecting a pulse of freshwater taxa into creeks as marshes upstream dry (Fig. IIF.3). These marsh species that move into the estuary remain in the uppermost sites, perhaps limited in distribution by the higher salinity of the estuary in the dry season. Along with the increases in freshwater fish taxa (both predators and prey) in the upper estuary, we also detect increases in the abundance of marine predators (i.e., snook, tarpon and redfish) that are synchronous. The timing of these increases in fish abundance is closely tied to the pattern of water recession in upstream marshes, and may have important implications for marsh prey availability and thus to wading bird foraging and nesting success. Fish abundance generally peaked early in the dry season in years where marshes wet season levels were lower and they dried earlier (2004-05, 2006-07, and 2007-08); whereas in years with rather wet seasons (i.e., 2005-06 and 2008-09; shown in shades of green in Fig. IIF.3) catches peaked later.

In these dry years, high catches seen early in the dry season are typically followed by decreases in fish abundance, suggesting that some of that fish biomass that moves intro creeks in response to early marsh dry-down may be readily consumed by piscine predators, instead of remaining on the marsh surface where it may be available to wading bird predators. This is of critical importance to Everglades restoration since a major performance measure for restoration is wading bird nesting success, particularly in the historical coastal mainland rookeries in the vicinity of our SRS sites.

Our minnow trapping throughout the estuary showed that five palaemonid shrimp species occur throughout, and their distribution and abundance varies seasonally. CPUE was dominated by *P. paludosus,* and the distribution of this common marsh species expanded significantly downstream at low salinities in the wet season. At the downstream end of the estuary, composition was dominated by *Palaemon floridanus,* while multiple species co-occurred in the mid-estuary (i.e., Tarpon Bay). Salinity and other physiochemical variables had little explanatory power when examining variation in CPUE. We suspect this is due to their broad broad salinity tolerances. Stable isotope analyses suggest that these shrimp species have similar functional roles, but have varying food resources throughout the estuary particularly in the dry season. Patterns of N and C enrichment match those detected by previous studies, which are thought to result from variation in freshwater input and primary production across the estuary.

In summary, our data suggest that the seasonal hydrology of the Everglades ecosystem is altering functional diversity both temporally and spatially in the Shark River Estuary, as well as the strength and magnitude of predator-prey interactions among fishes in the upper estuary. The effects of this variability on ecosystem function are not fully understood and deserve further study.

<u>3. Habitat use, movements and trophic interactions of large predators.</u> We have discovered several surprises in our investigations of the trophic position of large predators. First, alligators appear to occupy a lower trophic position that we had originally thought and feed at a trophic level considerably below those occupied by the smaller-bodied snook, Florida gar, and bull sharks (Fig. IIF.4). Both bull sharks and alligators show a considerable degree of individual specialization in their diets. Analysis of isotopic signatures of slow-turnover tissues reveals that individual bull sharks may specialize in feeding in marine food webs, estuarine/freshwater food webs, or a mix of the two (Fig. IIF.5). All three foraging tactics are found throughout the SRS – up to 25+km upstream (Fig. IIF.6). Analysis of rapid-turnover tissues suggests that these specializations are stable through time. Analysis of bull shark movements (n = 40 transmitters deployed to date) suggests that there is considerable individual and inter-annual variation in residence times and short-term movements. At the population level, however, the presence of bull sharks is driven by interactions of biotic and abiotic factors (Heithaus et al. 2009). The

juvenile sharks that are found in the Shark River Slough are most abundant upstream, most likely to avoid large predatory sharks at the mouth of the river, but the probability of capturing sharks is most strongly influenced by dissolved oxygen levels. Because of the diverse array of larger predators (and prey) in the system that vary in their susceptibility to low DO levels it is possible that this physical factor plays an important role in shaping trophic interactions and the spatiotemporal patterns in consumer community structure.

For alligators, trophic interactions appear to be related to movement tactics. Individual alligators appear to adopt either a residential or "commuting" movement tactic. Residential alligators remain in the same basic region (either upstream or mid-estuary) throughout the year while commuters will remain upstream during the dry season but during the wet season make numerous trips to the mouth of the river. Over a three day period, they commute from upstream areas (~18km from the mouth of the river) to the Gulf of Mexico and back and then repeat the movement several days later. Isotopic signatures of commuting individuals suggest a greater reliance on marine food webs than those that remain resident upstream.

Movements of gar and snook are less dramatic than those of bull sharks and alligators, and stable isotopic analyses suggest much less specialization in feeding with an almost exclusive reliance on freshwater and estuarine food webs (Fig. IIF.4).

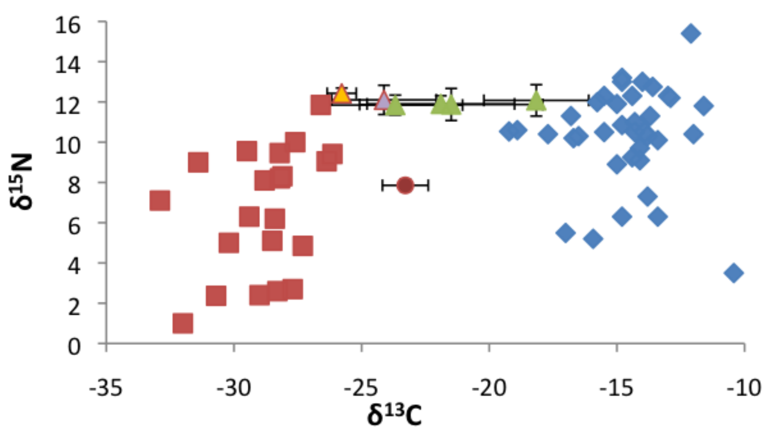


Figure IIF.4. Isotopic signatures of representative freshwater and estuarine taxa (red) and marine taxa (blue) relative to bull sharks captured from the river mouth to upstream (green triangles), Florida gar (orange triangle), snook (purple triangle) and alligators (red circle).

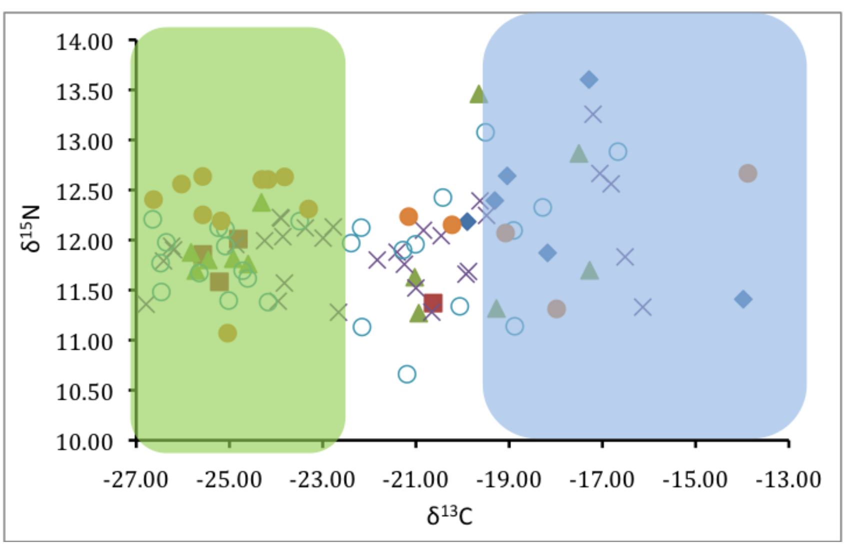


Figure IIF.5. Individual variation in isotopic signatures of juvenile bull sharks. Sharks show relatively marine (blue-shaded area) and freshwater/estuarine (green-shaded areas) signatures regardless of capture location. Different symbols represent sharks captured near the river mouth in dry (diamond) and wet (squares) seasons, at SRS5 (triangles), in Tarpon Bay (X), Otter Creek (open circles) and Rookery Branch (closed circles).

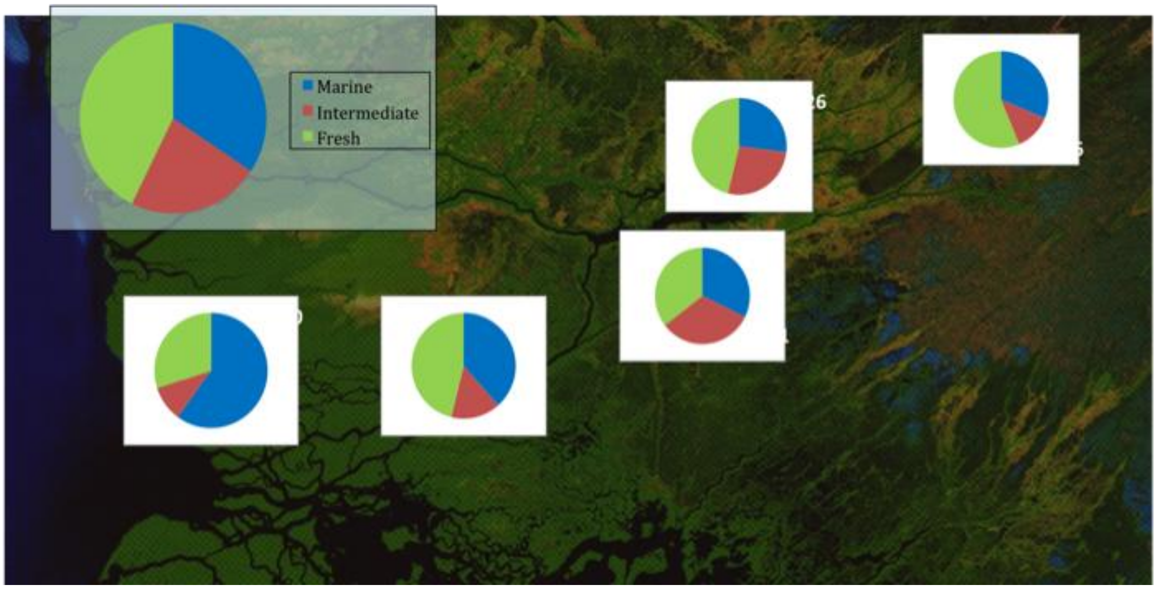


Figure IIF.6. Distribution of bull shark foraging patterns within the Shark River Estuary.

4. Community dynamics of Florida Bay.
At a eutrophic site, nutrient addition did not strongly affect food web structure, but at a nutrient-poor site, enrichment increased the abundances of crustacean epiphyte grazers, and the diets of these grazers became more varied. Benthic grazers did not change in abundance, but shifted their diet away from green macroalgae + associated epiphytes and towards an opportunistic seagrass (*Halodule wrightii*) that occurred only in nutrient addition treatments. Benthic predators did not change in abundance, but their diets were more varied in enriched plots. Food chain length was short and unaffected by site or nutrient treatment, but increased food web complexity in enriched plots was suggested by increasingly mixed diets. Strong bottom-up modifications of food web structure in the nutrient-limited site and the limited top-down influences of grazers on seagrass epiphyte biomass suggest that in this system, the bottom-up role of nutrient enrichment can have substantial impacts on community structure, trophic relationships, and, ultimately, the productivity values of the ecosystem.

Future goals: Although we have made substantial progress in the first three years of FCE II, we have many questions remaining. Our studies of the drivers of community structure and trophic dynamics at the marsh-mangrove ecotone will continue and will be expanded to include a greater focus on the importance of biotic factors (e.g. predation risk/rates and food availability) and only recently recognized important physical factors (e.g. dissolved oxygen levels). Also, we plan to expand our detailed studies into Taylor River to more fully explore how microtopography affects the dynamics of consumer communities in the ecotone region. Most importantly, we will begin work developing biomarkers that will help us quantify the importance of detritus in consumers throughout the food web to understand how changes in the timing, quantity, and quality of detrital inputs influence food webs. Using new technology (DIDSON) and trapping, we will greatly expand the spatial scope of our studies of consumer communities to document spatial and temporal variation in invertebrate and fish communities along a transect from the mouth of the Shark River Slough to upstream ecotone sites where current sampling is occurring. In addition to these studies, we will continue and extend our studies of large consumer movements and the potential role of individual variation in foraging tactics in consumer-mediated nutrient transport from coastal waters into the ecotone region. These studies all will take advantage of seasonal and interannual variation in environmental conditions to create predictive models of community structure and dynamics (in collaboration with other working groups) that ultimately can be tested when the hydrology of the Everglades is modified by ecosystem restoration.

G. Human Dimensions

History: The greater Everglades is a human-dominated ecosystem which has experienced a dramatic population growth. Associated land use change continues to have significant ecological effects on the Everglades, including (but not limited to) changes in water quality, vegetative community structure and productivity, and hydrological patterns. Everglades Restoration may ameliorate some of these impacts; however, we believe it is critical that we understand the social, economic, and political processes that will continue to drive land use changes in south Florida. While always an implicit part of FCE science, we have developed our Human Dimensions (FCE HD) research in FCE II in order to explicitly study human dimensions of environmental change in southern Florida and the socio-ecological causes and consequences of these changes.

Question: **What social and economic processes drive land use change in areas adjacent to FCE and how do these changes affect the quantity and quality of water flowing along FCE transects?**

Conceptual Model: The overarching FCE conceptual model identifies several complex socio-ecological drivers of environmental change including alterations in climate patterns and changes to water and nutrient flows related to Everglades restoration (particularly modifications to the Tamiami Trail). We apply two interrelated approaches to our understanding of how and why land and water use in southern Florida has changed, as well as the implications of these changes to both quality of life and ecosystem health. Broadly, these approaches are *Everglades Political Ecology* and *Land Use/Cover Change Science*. As described below, our research relies on both qualitative and quantitative methodologies including archival, ethnographic, GIS based spatial analyses, and analyses of high resolution satellite imagery.

Figure IIG.1. People have lived in southern Florida for nearly 10,000 years, pre-dating the emergence of Everglades environment as we now know it. Above Don Edwards and Glen Simmons pole glade skiffs across an Everglades marsh, demonstrating a form of transportation that was common prior to the adoption of motorized airboats in the 1950s.

Results:

Everglades Political Ecology. Political ecology draws attention to how environments and access to resources are shaped by relations of power at multiple scales, and how in turn, environmental change has differentiated social impacts. In the past century, the Florida Everglades has been radically transformed by social and economic concerns at multiple scales – from federal flood control policy to county planning initiatives. When Florida gained statehood in 1845, much of the southern portion of the state was under water for periods of the year and, according to federal law, these wetlands remained under the control of the U.S. government. At that time, wetlands were considered impediments to the developmental interests of the nation, with agriculture production considered a national security interest. "Reclaiming" wetlands for agricultural production allowed states to gain ownership of these wetlands. In southern Florida, drainage schemes gained momentum in 1881 when Florida Governor William Bloxham sold Philadelphia millionaire Hamilton Disston four million acres (over 1.6 million hectares) of Everglades land. So began the process that ultimately led to the development of two-thirds of the historic Everglades.

Figure IIG.2. Harvesting sugarcane for the U.S. Sugar Corporation, Clewiston, Florida. Photo courtesy of the U.S. Library of Congress, Florida Photograph Gallery.

The environmental history of the Everglades reveals a convergence of federal, state and local politics that resulted in the conversion of wetlands for agricultural purposes. FCE HD researcher Gail Hollander examines the sugar industry's role in this transformation. Using archival and ethnographic research, Hollander demonstrates how "the sugar question"—a label nineteenth-century economists coined for intense international debates on sugar production and trade—became a touchstone for local, state and federal debates about livelihoods, national identities and environmental values.

Ongoing debates about the future sustainability of the Everglades often neglect the long-term history of human settlement in the region. FCE HD research seeks to understand how the Everglades landscape is co-produced by social and ecological processes. Laura Ogden's longterm ethnographic project offers a theoretical framework for understanding nature's humanity that draws from social and ecological theory. Currently she is examining the intersecting histories of mangrove forests, alligators, snakes, and outlaws in the real and mythic Everglades. Expanding upon this research, Ogden and Daniel Childers document the co-evolution of tree islands and people in the Everglades. In this project they show that in the past 5000 years people have not only adapted to a changing south Florida climate and environment by living on tree islands, but that prehistoric and contemporary peoples have actively created these tree islands. Their work builds upon archaeological, anthropological, paleobotanical, soil and climate research.

Water delivery into ENP and the FCE study site is largely determined by Central and Southern Florida Project ("C & SF Project") operations. Constructed by the U.S. Army Corps of Engineers, the C & SF Project includes one thousand miles of levees and canals, fifteen square miles of interconnected water reservoirs, 150 water control structures, and sixteen major pumping stations. Much of southern Florida's residential, industrial and agricultural development would not have been feasible without the C & SF Project. To provide adequate flood control for the region, each day water managers divert an average of 1.7 billion gallons of freshwater to the oceans and bays, causing repeated water shortages and saltwater intrusion to the aquifer.

In response to the ecological problems caused by this reengineering, the U.S. Congress authorized the Comprehensive Everglades Restoration Plan (CERP) in 2000. Spanning 18,000 square miles, with costs estimated to rise beyond current projections of $19.7 billion, the Everglades restoration program is certainly one of the most costly environmental restoration projects ever attempted. Implementation of CERP and other restoration programs have been slow, due, in part, to ongoing negotiations and disagreements among environmental organizations, agricultural and other commercial interests, as well as tribal, federal, state and local agencies. A central focus of FCE II has been to collect and analyze long-term data to gain a better understanding of system responses to future restoration-related changes in water deliveries. Even after two decades of planning, the outcome of some restoration components key to water deliveries into ENP and the FCE study site remain uncertain.

FCE HD research had sought to understand the role of science and the public in restoration decision-making. Laura Ogden has conducted interviews with scientists and policy makers to understand the ways in which restoration goals (scientific and other) have changed over time and have been shaped by the competing agendas of resource agencies. As Ogden documents, while CERP began as a plan for creating a sustainable south Florida, it was transformed into a highly complex water engineering plan designed to convey ecological benefits, reflecting the expertise and financial stakes of the lead agencies.

Like the other FCE working groups, the FCE HD is interested in understanding the role of disturbance, particularly hurricanes, in environmental change. Our Hurricane Andrew project examines the role of hurricanes in land use/cover change in southern Miami-Dade County. For this project, we are examining how Hurricane Andrew, in 1992, acted as a “pulse” event that reconfigured the landscape in heterogeneous ways. This heterogeneity, we hypothesize, stems from ongoing press processes that produces uneven resilience to pulse events among different communities. Preliminary findings for our research suggest that Hurricane Andrew exacerbated pre-existing historically constituted social inequalities. More specifically, communities and neighborhoods with higher percentages of African-American residents were less resilient to Hurricane Andrew. African-American households were characterized as being underinsured for the disaster, less likely to be homeowners, and were less able to rebuild after the pulse event. However, in contrast to ecological models in which resilience is a property of a given ecosystem and place, the consequence of variation in resilience in response to Hurricane Andrew is that less resilient (largely African American) victims were unable to relocate, whereas more resilient (largely white) victims retained the capacity (via higher rates and quality of insurance) to relocate to other areas. Coincident with this change in the demographics of the resident populations of our study region was a significant change in land use. The broader implication of this research is that understanding responses of socio-ecological systems to disturbance requires attention to both social processes and their ecological consequences.

<u>Land Use/Land Cover Change</u>. Our study site, southern Miami-Dade County, has traditionally served as a rural, agricultural buffer between urban Miami and the Everglades. The conversion of agricultural and forested lands to residential use represents the greatest contemporary source of habitat fragmentation and ecosystem decline in the United States—a transformation that is well

underway in our study site. Historically, land use in our study site has concentrated on row crop agriculture (beans, tomatoes and other crops), groves (avocado, mango and other tropical fruits), commercial plant nurseries and rural residences. In past decades, the site and region have experienced rapid suburbanization.

Figure IIG.3. Beans growing in the backyard. As this photo demonstrates, land conversion in the FCE study site often entails the development of agricultural parcels. This property is adjacent to Everglades National Park.

We refer to our land conversion research as the "lawn project," reflecting the predominance of this type of land cover in our study site. Our research seeks to understand the social and ecological implications of lawn production at multiple scales. Our overarching goal is threefold: (1) to understand the complexity of the interactions, drivers and feedbacks that produce lawns (and "lawn people," as Paul Robbins (2007) terms it), (2) to develop spatially-explicit theories and models of these patterns and processes, and (3) adopt a methodology that facilitates cross-LTER site comparisons.

For this work our research team is collaborating with Miami-Dade County Dept. of Planning and Zoning to understand the role of zoning in the transformation of agricultural lands in our study site. Strategies to slow suburbanization at local and regional scales include growth management policies and zoning regulations. In particular, zoning ordinances serve as the primary method for lessening and preventing the conversion of agricultural and forested lands—though zoning has also been implicated in increased landscape fragmentation. To understand the role of zoning in shaping (or not) the conversion of agricultural lands into residential lands in southern Dade we have been engaged in the following activities:

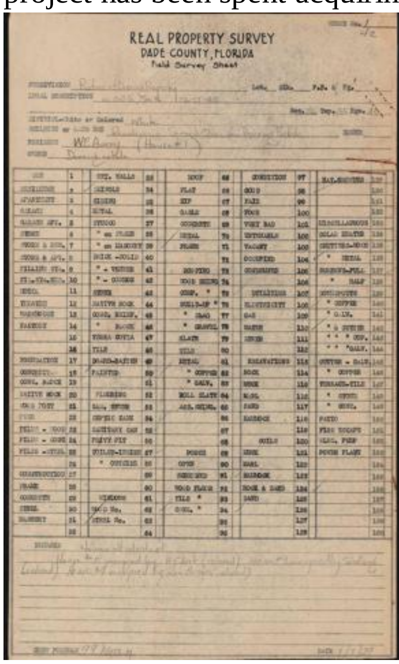
- Collaborating with Miami-Dade County's Department of Planning and Zoning to develop a methodology to incorporate historic zoning data into a GIS platform
- Acquiring and processing zoning data for southern Dade-County. The period we are analyzing is from 1992 through 2008. All zoning data is being geo-referenced to the parcel.
- Incorporating other data into our GIS parcel-level analyses. These include parcel boundaries (and changing boundaries), assessment and sale amounts over time, comprehensive plan classification, land use zoning, and census-derived socioeconomic data.
- Acquiring high-resolution remotely-sensed imagery to help us quantify green vegetation, classify prevailing land use/covers (including lawns) and derive indices of landscape structure for the study site.

FCE HD members are working with other LTER sites to employ common approaches to analyze these data (e.g., using object-oriented classification approaches for high-resolution land cover characterization).

Preliminary analyses suggest several phenomena. First, simply zoning a parcel of land as "agriculture" does not guarantee that parcel can remain an economically viable farm, as nearby landscapes and land uses, along with economic opportunities and disincentives, can strongly outweigh the effects of zoning alone. Second, the rezoning of lands from agriculture to residential, commercial, or some other form of development hastens the conversion (and the prerequisite zoning change) of nearby lands still zoned for agriculture. Third, the greater number of edges an area of agriculturally zoned land has with land zoned for development affects how quickly that land will also be rezoned for development. Lastly, allowing subdivision of agriculturally zoned lands into five acre lots discourages agricultural food production and encourages instead nurseries or non-productive "ranchettes"

Figure IIG.4. 2004 aerial photograph with parcel boundaries zoned for residential uses outlined in red. Parcels may be zoned residential yet the land use is agricultural, suggesting a high probability of future conversion.

This project has required the acquisition and analysis of an immense data set using GIS as well as new approaches to analyzing high-resolution land cover data. The first two years of this project has been spent acquiring and cleaning up parcel-scale zoning data. Jeff Onsted, Rinku Roy Chowdhury and Hugh Gladwin are producing the first sets of papers in this research. In addition, we are participating in a cross-site research project that compares the processes and patterns of lawn production with three other LTER research sites (BES, CAP and PIE). Based on our collaboration, we are finalizing an article that examines the importance of scale in our understanding of suburbanization.



REAL PROPERTY SURVEY
DADE COUNTY, FLORIDA
Field Survey Sheet

Figure IIG.5. WPA property survey, an important archive for understanding the social history of land use in our study site.

FCE HD researchers have also acquired and scanned historic U.S. Works Projects Administration (WPA) land use surveys of Miami Dade County from the 1930s (Fig. IIG.5). The WPA was a federal program under the New Deal. This archive includes hand-written surveys for each property in Miami-Dade County and describes land use, property characteristics, soil information, and demographic information for home and landowners. We completed scanning this archive so that it can be geo-referenced into our GIS parcel layers. We anticipate this archive will provide a critical baseline for our understandings of land use change and an important contribution to our overall understandings of the region's history and growth.

Figure IIG.6. GIS parcel-scale analyses of the relationship between zoning and land conversion. Red lands are already developed; red cross-hatching over white backgrounds are undeveloped lands that are zoned for future development; green land in the center of the maps is agricultural land. From 1992 to 2006 much of this land was developed and/or its zoning was changed to developed uses. Those areas that are green background with a red cross-hatched foreground are areas where zoning changed from agricultural to developed uses between 2001 and 2009. Those parcels with a black outline changed their zoning at the direct request of the landowners.

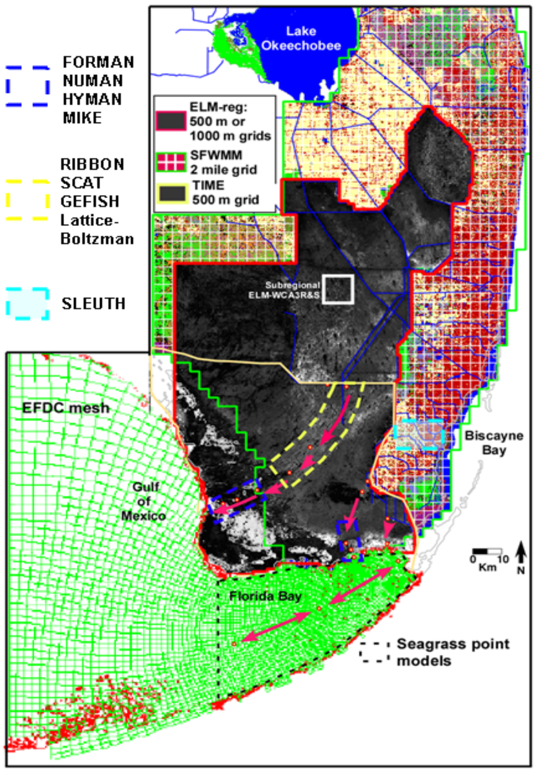
H. Integration, Synthesis and Modeling

History: In FCE II, we have continued collaborations with ongoing modeling projects associated with restoration of the greater Everglades and with FCE-specific research efforts. Large-scale hydrologic models such as the South Florida Water Management Model (SFWMM) and the Tides and Inflows in the Mangrove Ecotone (TIME) model and the Everglades Landscape Model (ELM), all initiated prior to the FCE, provide simulations of landscape dynamics across the greater Everglades. These models continue to provide hydrologic boundary conditions and inputs for other models and, in the case of ELM, address FCE research questions directly. In FCE I, several modeling efforts were focused on local habitats or subregions of ENP.

While we continue refining these models, in FCE II we have also begun a shift toward understanding the importance of linkages in biogeochemistry and population dynamics among habitats or sub-regions. A new FCE post-doc was brought in to synthesize existing hydrology data, which will enable standardization of inputs and boundary conditions for all models as well as synthesize new findings and insights from the hydrology working group. We have initiated the Soil Carbon Accumulation and Transport (SCAT) modeling effort to better understand feedbacks between ridge-slough vegetation and the accumulation and transport of particulate matter in soil and downstream (addressing FCE II hypothesis 2). In the Taylor River mangrove ecotone, a modeling effort is underway to understand spatially explicit hydrology and water quality model (MIKE11 and MIKE12 models) and potential impacts on nutrient accumulation using the mangrove nutrient accumulation model (NUMAN). The mangrove hydrology model (HYMAN) is being used for hydrology and water quality modeling in the Shark River estuary.

The various models of freshwater, mangrove and estuarine habitats supporting FCE projects have been developed independently, and therefore were not effectively linked. Our recent workshop in June 2009 generated an integrated, multi-model plan to create a synthesis of models that work together to address FCE hypotheses. As one example, we have initiated a project linking ELM and the Seagrass Ecosystem Assessment and Community Organization Model (SEACOM) to understand the ramifications of nutrient deliveries from upstream, freshwater processes on the structure and function of downstream estuarine habitats (addressing FCE II hypothesis 1 and 3). Additional future plans include a more holisitic integration of ELM, SCAT, Ribbon, the mangrove models (HYMAN, NUMAN, MIKE), and the SEACOM model, along with multiple sources of data (FCE and related) to address ecosystem dynamics specific to the ecotone. In particular, this project will enable us to understand boundary shifts within the oligohaline ecotone region (FCE general question 6), as well as facets of FCE II general questions 1 (position of the salinity mixing zone), 2 (spatial variation in primary production and vegetation change), and 5 (controls on the quantity and quality of organic matter transport and accumulation).

Questions: A total of 18 modeling and synthesis projects (Fig. IIH.1) are currently addressing FCE II research questions. These projects cover a wide range of spatio-temporal scales, objectives, and different agency mandates (e.g., ENP, SFWMD, USGS). In June, 2009 we held a workshop (Key Largo, FL) to improve integration among these projects; workshop objectives included (1) summarizing the current status of modeling and synthesis in addressing the FCE II research questions; (2) highlighting potential synergies among modeling and synthesis activities; and (3) drafting an outline for a review paper on FCE modeling/synthesis and applications to restoration. An important outcome from the first objective was a matrix rating each activity in addressing the 6 general FCE II research questions. This effort helps show that while some research questions are the focus of multiple, fully calibrated, and completed modeling or synthesis projects (questions 1, 2, 4 and 5), other research questions are only partly addressed or in the planning stage. This exercise helped clarify the need for greater focus on general research questions 3 (consumer impacts in the ecotone), 6 (ecotone boundary shifts) and 7 (socioeconomic impacts on Everglades hydrology).



Model Name(s) or Synthesis Project	Spatial Domain & Resolution	Temporal Domain & Resolution	Principal Outputs
SFWMM	Regional, South Florida (km)	decades (daily)	managed water depths, "grand experiment" hydrology
ELM	Subregional to all Everglades (m to km)	decades to centuries (daily)	hydrology, bio-geochemistry, biology, salinity, groundwater
TIME (ASICS)	Subregional (m to km)	years (daily)	groundwater and surface water hydrology, salinity
RIBBON, SCAT, Lattice-Boltzman	Subregional, Ridge-Slough (m to km)	days to millennia (hr - month)	biogeochemistry; vegetation & peat dynamics; surface water flow
FORMAN, NUMAN, HYMAN, MIKE	Mangroves (m)	century (daily - yearly)	biogeochemistry, succession, water quality
SEACOM (+ TIME EFDC, FATHOM)	Florida Bay (m to basin)	years (hr - daily)	seagrass and phytoplankton biological responses
ODFISH, GEFISH	theoretical landscape (m)	years (daily)	fish community responses to seasonal wetting & drying, elevation gradients
SLEUTH	Urban landscape (property units)	years (monthly)	urban growth, zoning laws, land use change
Hydrology FCE data and literature review	Subregional (m to km)	years (hr - daily)	subregional and landscape variation in hydrology
Soil accretion literature review	All Everglades (m to km)	decades to millennia (yr – decadal)	subregional and landscape variation in accretion

Fig. IIH.1. Overview of the geographic domains and objectives of FCE modeling and synthesis activities

Goals: Our group set the following goals for FCE II: (1) increasing the linkages among modeling/synthesis activities, (2) developing fine-scale hydrologic models for specific habitats, (3) continuing development of dynamic soil and nutrient accumulation models for marsh (ELM, SCAT) and mangrove (NUMAN) habitats with an aim toward linking these models and (4) developing a land-use change/socioecological model (SLEUTH). We are also working on (1) a review paper of how FCE modeling/synthesis is being applied to Everglades restoration and (2) refinement and implementation of our long-term goals, including multi-modeling approaches.

Results:

SFWMM and TIME Models. The South Florida Water Management Model (SFWMM) is a regional-scale simulation model of hydrology and management of the south Florida region

(SFWMD 2005). Widely accepted as the best tool for evaluating future changes to regional water management, SFWMM helped set Everglades restoration goals and continues to provide boundary conditions for models, including FCE models. The Tides and Inflows in the Mangrove Ecotone (TIME) model, a landscape-scale hydrologic model developed by USGS researchers, simulates the duration, timing and extent of inundation and salinities along the freshwater-saltwater interface in Everglades National Park (ENP). TIME is currently being used to simulate hydrology under different scenarios of sea level rise and changes to upstream inflows. These results will add to standardized boundary conditions, driving variables and consistency checks for FCE models in evaluating system responses to restoration scenarios.

ELM Model. During FCE II, an Independent Expert Panel completed a 6-month review of the regional application of the Everglades Landscape Model (ELM) (Fitz et al. 2004) and concluded that the ELM v2.5 should be used for applications involving Everglades restoration projects (Mitsch et al., 2007). Since then, development and documentation of a finer-scale (500 m grid resolution) application has been completed for ELM (v2.8 http://ecolandmod.ifas.ufl.edu/publications), with the regional domain extending from the northern freshwater Everglades to the border of Florida Bay and Gulf of Mexico. The output variables include water depths and flows, water column and soil phosphorus, water column chloride, soil accretion, and periphyton and macrophyte distributions. Performance of ELM v2.8 improved over that of ELM v2.5 in terms of stage, chloride tracer (an indicator of gradients of surface water flows) and water phosphorus (P) concentrations. This calibrated and validated model is available to provide boundary condition ecological data to other FCE models, and to directly explore scenarios associated with FCE general research questions 1, 2, 4, 5 and 6.

Ribbon Model. The Ribbon model had been used in FCE II to integrate data from all FCE working groups to highlight the ecosystem sensitivities of P cycling in freshwater Shark Slough to hydrologic drivers, internal ecosystem processes, and habitat exchanges of P, including downstream floc transport. The model highlights P transport and exchanges in regulating P cycling and simulating realistic water TP and floc-P. The Ribbon model is unique in quantifying overland floc transport; thus model output provides a point of comparison for FCE II studies examining the quantity of floc dynamics, including transport to the ecotone (research question 5-1).

SCAT Model. The Sediment Carbon Accumulation and Transport model (SCAT) simulates vegetation and soil accretion in Shark Slough marsh habitats to understand the long-term dynamics of ridges and sloughs under altered hydrologic conditions. Based on previous 1-D soil accretion models (Rybczyk et al., 1998; Saunders, 2003), SCAT uses FCE data on primary production, decomposition, hydrology, soil accretion and paleo-vegetation. A simplified version of the model was recently developed to simulate downcore profiles of fossil sawgrass seeds based on empirical relationships between water depth, sawgrass biomass and seed production provided by a synthesis of FCE LTER data and pre-drainage water levels hindcasted by the SFWMM. Model runs (Fig. IIH.2) matched observed seed profiles reasonably well at both sites. Model improvements for the SRS-3 slough were achieved only by including an advection term, depositing seeds from marshes upstream into the slough. These results highlight consistency among several lines of FCE data, historic climate and stage records, and SFWMM simulations of pre-drainage water stages. Future plans include adapting the model to marshes within the oligohaline ecotones.

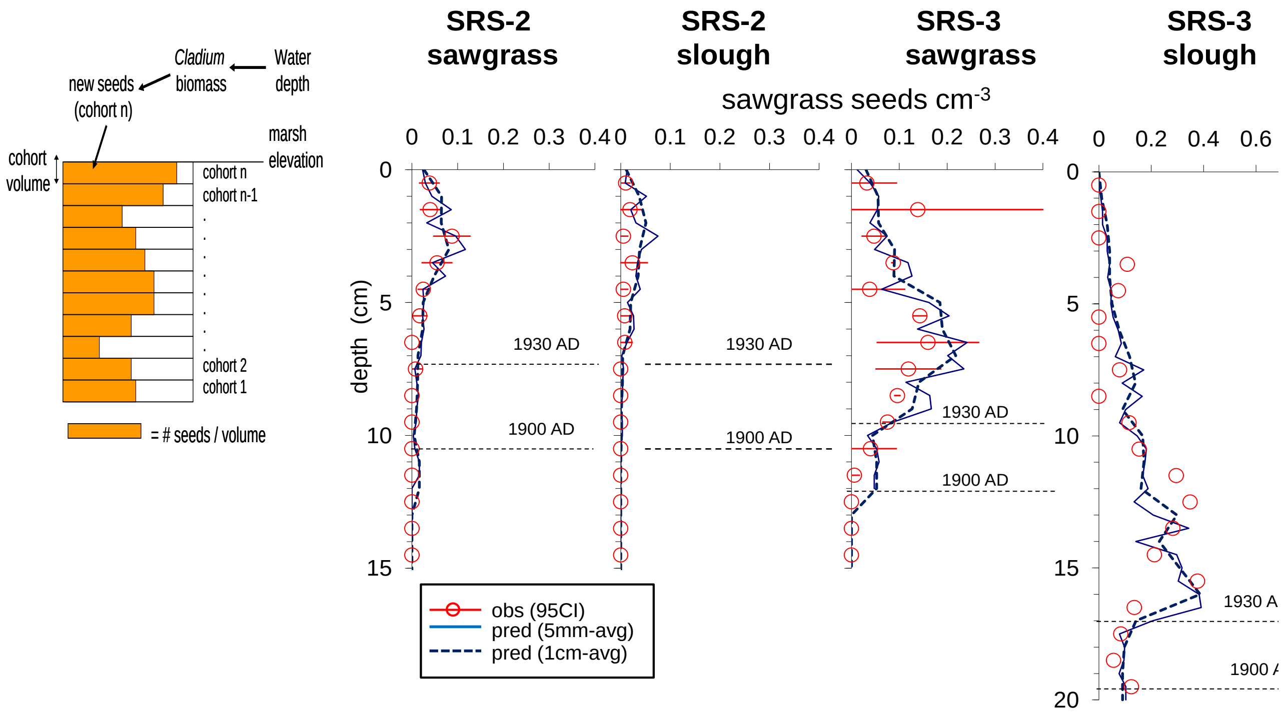


Figure IIH.2. Left: Conceptual model for hindcasting sawgrass seed profiles. Right: Predicted and observed seed profiles for SRS-2 and SRS-3 sawgrass and slough cores. SRS-3 slough model assumes horizontal advection of sawgrass seeds (produced upstream) into the slough (downstream).

LBM (Lattice-Boltzman) Models. Understanding the interactive effects of vegetation and water management on sheet flow patterns is necessary to restore the Everglades plant communities, biogeochemical cycles, and carbon budgets. Simulations of flow vectors in and around landscape features using highly-parameterized finite element models are computationally expensive. Lattice Boltzmann models of sheet flow, developed thru collaboration between FCE Hydrology co-lead Vic Engel (ENP) and Drs. Michael Sukop and Shadab Anwar (FIU) provide an alternative to simulate hydrodynamics in this complex landscape.. In this application, high resolution aerial imagery is pixilated to generate the model domain. Flow vectors are derived as a function of the input boundary head gradients and the vegetation resistance. A parameter optimization scheme (PEST) calibrates the model using results from several large-scale surface water tracer releases (Ho et. al. 2009 and Variano et al. 2009). A partial proposal for this work was funded by SFWMD in 2008. A full proposal was funded by ENP in 2009. This work will be useful for analyzing nutrient fluxes and water residence times in the freshwater marshes along the SRS transect and will also occur in parallel with additional tracer releases in 2009-2010.

HYMAN Model. Mangroves play an important role in the maintenance and sustainability of coastal wetlands due to their ability to adapt and survive in a wide range of saline and tidal conditions. Hydrologic processes (e.g., inundation frequency) and salinity are important regulators controlling the growth and productivity of mangrove forests. To quantify how changes in landscape-level hydrology will influence these regulators in mangrove forests, the mangrove hydrology model (HYMAN) is being applied to FCE-LTER sites SRS-4, -5 and -6 along the Shark River estuary. The HYMAN model determine daily water and salt budgets using mass balance equations, statistical relations of water depths versus channel water elevations, inputs of evapo-transpiration and seepage. Simulated pore water salinity reasonably matches observed trends with distance to the estuary mouth. Best-fit parameters were determined for each site and most of the simulated results fell within a reasonable range compared to the discrete measured values. Most of the observed discrepancies can be correlated to corresponding hydrologic signals.

<u>MIKE-NUMAN Model</u>. Restoration planning requires understanding how water flow through the mangrove ecotone influences salinity and nutrient loading to Florida Bay. The ecotone can be a sink, source, and transformer of nutrients and substantially impacts N and C outputs to Florida Bay. A hydrologic/water quality model (MIKE 21) is being applied to ecotone system dynamics along lower Taylor River (TS/Ph-6 to TS/Ph-7) to evaluate how water flow and management alter the salinity, biogeochemistry and water balance in this area and to Florida Bay. The model's spatial domain is established based on pond bathymetry, creek channel cross sections and wetland elevations in Taylor Slough and includes wetland surface, groundwater and creek flows. Boundary conditions are established at TS/Ph-6 and TS/Ph-7 downstream and driven by USGS gauge data and TIME model outputs. The MIKE21 and MIKE11 models are in the process of calibration; already they have demonstrated the capability to predict observed salinity throughout the domain during wet and dry seasons. A salinity calibration example (Pond 3, an area midway between the two boundary sites) is provided in Fig. IIH.3. The largest uncertainties in the model arise from unknown overland flow in the wet season, and bathymetry errors in the dry season.

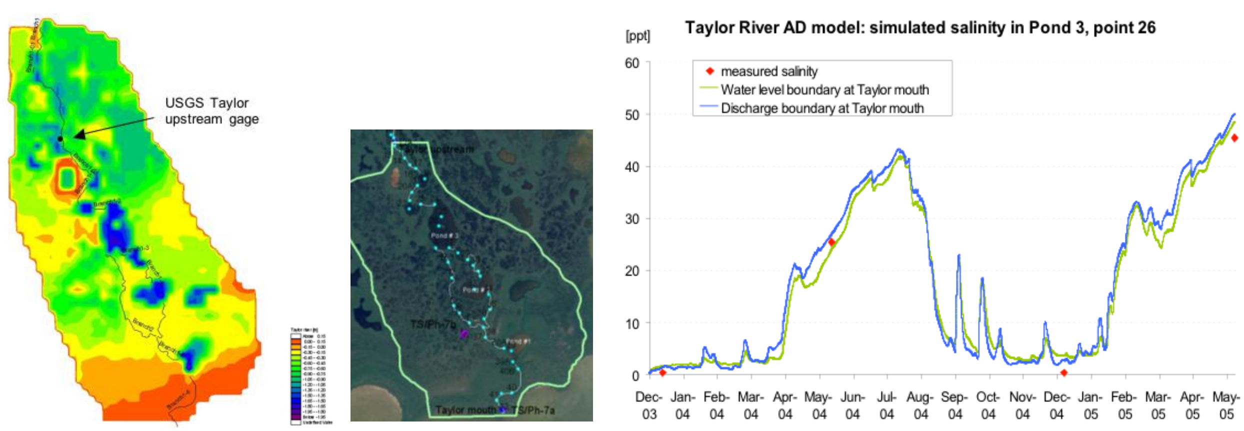


Figure IIH.3. Left: bathymetry setups including the original (50 x 50 m) MIKE21 grid with connected MIKE11 channel); Center: Location of salinity measurements; Right: Simulated salinity in Pond #3.

<u>GEFISH and Consumer Models</u>. Using information theoretic framework, FCE researchers are employing model selection methods on time series data to understand long-term dynamics of consumer populations. Ongoing projects include assessment models (Trexler and Goss, 2009); analysis of dragonfly naiad dynamics (Urgelles, MS); aquatic fauna population and community dynamics incorporating disturbance and migration. Complementary to the statistical modeling, the Greater Everglades Fish model (GEFISH, developed by Don DeAngelis, Joel Trexler, Fred Jopp, and Doug Donalson) has been developed to simulate spatio-temporal dynamics of small

fish biomass in a landscape conceptually similar to elevation patterns in Taylor Slough. Model drivers include seasonal water level changes, and model structure includes primary producers, detritus, detritivores, fish, and recycling of a limiting nutrient. Fish functional types move seasonally along hydrologic gradients with flooding and dry-downs. The model currently simulates patterns of biomass change for six food web species through a year across an elevational gradient. Future plans are to apply model different scenarios of water pattenrs and also including: (1) a canal containing piscivorous fish and bordering a marsh landscape; (2) new piscivorous fish introductions and movements from canal to marsh areas; (3) spreader swales that form permanent refuges for small fish, but increase habitat for piscivorous fish.

SEACOM and Integrated SEACOM-ELM Models**.** Development of a mechanistic simulation model of seagrass-water column interactions for Florida Bay has continued with the goal of understanding effects of hydrologic and salinity restoration via managed freshwater discharge on submersed aquatic vegetation (SAV) and phytoplankton communities. The Seagrass Ecosystem Assessment and Community Organization Model (SEACOM), calibrated for nine basins in the bay, describes biological and nutrient dynamics and is parameterized from experimental data in the field, mesocosms, bioassays, and monitoring. Recent updates include incorporation of the growth dynamics and recruitment of *Ruppia,* a low-salinity species, and calibration for two mangrove ponds of Taylor River, an important step in linking SEACOM with other FCE models and to address FCE II hypotheses on coastal ecotone dynamics. A preliminary but fully functional phytoplankton module has been integrated into the core SAV model. Other improvements include linkages with the SICS (Southern Inland and Coastal Systems) model for water and salinity boundary conditions, EFDC (Environmental Fluid Dynamics Code) for internal circulation, and the FATHOM model for coarse-scale water transport and salinity determination.

SEACOM is being used to simulate the phytoplankton bloom that occurred in the eastern bay from 2005-2008. The model demonstrates that a single pulse of phosphorus, similar in magnitude, timing and duration to that observed in late summer 2005, is sufficient to sustain phytoplankton blooms for months to years from internal recycling. SEACOM is also evaluating system responses to pulsed nutrient inputs such as from tropical storm runoff and to climate change scenarios of increased temperature and water levels. SEACOM scenarios of changing nutrient cycling rates and basin residence times reveal ecosystem thresholds or “tipping points” in which longer water residence times, efficient nutrient retention, and pulsed nutrient inputs can push the ecosystem toward algal dominance over SAV-dominance.

This year a project was initiated to link FCE models ELM and SEACOM to understand impacts of freshwater hydro-ecological processes on the Florida Bay estuarine system. P loads from ELM into Florida Bay were simulated in two scenarios: a 36-yr future baseline case and a scenario with tripled inflows into the southern Everglades through one structure (S-332D) upstream of Taylor River. The ELM high-inflow scenario with increased upstream inflow resulted in increased P outflows from freshwater Everglades into Florida Bay. SEACOM was run for ten years using ELM output of TP from the Taylor Slough site as direct file inputs for the Little Madeira Model Basin (Fig. IIH.4), with no model feedbacks on cross-boundary flows. TP was run at the ELM baseline level, 2X and 3X. SAV responded by generally lower biomass, although nonlinearities are apparent in seagrass responses (e.g. year 7-8).

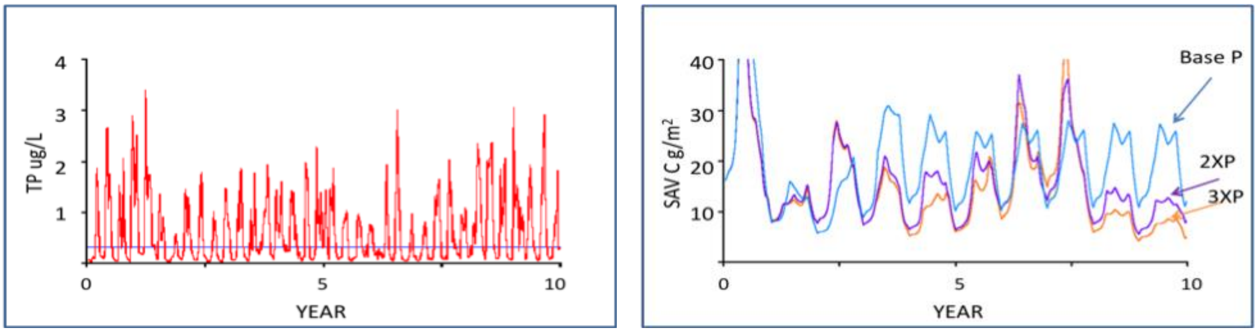


Figure IIH.4. Left: ELM water TP for the high water inflow scenario (red line) and static water TP concentration used in the unlinked SEACOM model (blue line). Right: SEACOM output of SAV response to three P scenarios: Baseline ELM output, 2X and 3X water inflow.

SLEUTH Model. The Human Dimensions working group is developing the cellular automata SLEUTH model (developed by Keith Clarke, UCSB) to simulate urban growth and land use change in South Florida. In the model, each cell's future state is affected by the current state (land-use type or land zoning) of nearby cells and by slope and proximity to roads, which may cause state changes—e.g., land use. Empirical investigations on land zoning changes and residential lawns will be integrated so the model may both use zoning in forecasting land use change as well as forecast zoning changes themselves. Forecasts of built environments and agricultural change will allow for the forecasting of impervious surfaces and water draw, i.e., the groundwork for incorporating socioeconomic drivers into existing FCE ecohydrological models.

Hydrologic Budgets and Paleoecological Studies. The joint Hydrology/Modeling post-doc (Amartya Saha) has developed annual water budgets of Shark Slough for 2002-2008, integral components for standardizing boundary conditions and drivers for other FCE models and for comparing with other hydrologic models. Synthesis of water flow data will also permit calculation of water residence times across the FCE, useful for models predicting particulate and nutrient transport, water and nutrient availability for productivity and salinity fluctuations in the ecotone and Florida Bay.

Paleoecological investigations are used to reconstruct past changes in vegetation, hydrology, salinity, water quality, soil accretion and soil nutrient accumulation.. Long-term (decadal to millennial) time series obtained from these studies provide calibrationdata for several FCE models: ELM, SCAT, NUMAN, and SEACOM. These investigations include salinity and water quality reconstructions in Florida Bay; vegetation and hydrology reconstruction of Shark Slough; plant community and physiological changes in the Taylor Slough ecotone; and a literature review of Everglades-wide accretion (including FCE sites).

Future Goals: Our future research goals stem from regular meetings and our workshop in June, 2009, in which we highlighted remaining priorities for modeling/synthesis, potential synergies, and generated a draft outline for a review manuscript. We constructed a matrix of potential synergies among FCE modeling and synthesis as a means to address current research gaps; as an example, we developed a plan for using a multi-modeling approach (Fig. IIH.5) to help address FCE General Question 6 (ecotone boundary shifts). The review manuscript, "A strategy for integrating ecohydrological models of the Florida Everglades: Advances and limitations in the context of the restoration," will serve as a road-map for long-term goals and objectives of FCE modeling/synthesis.

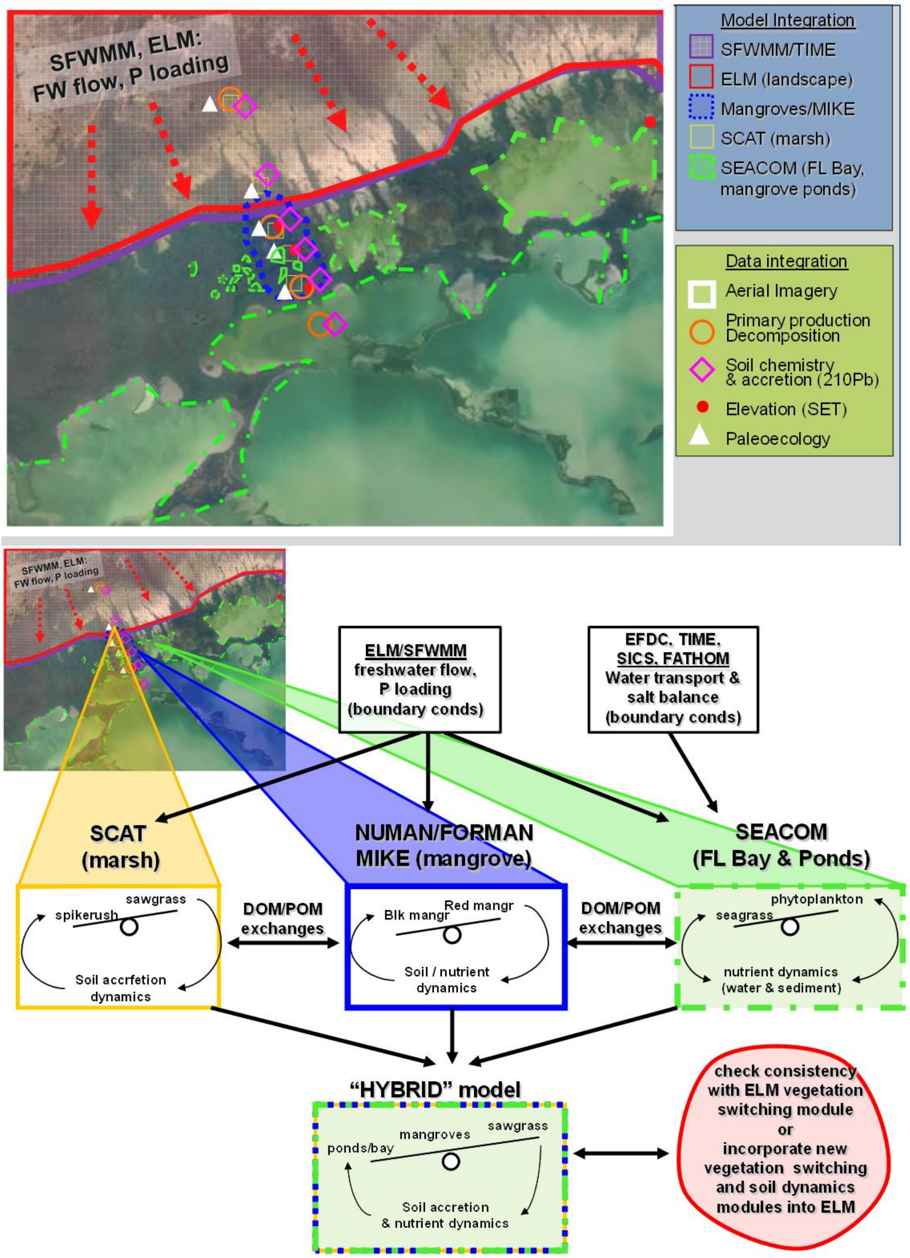


Fig. IIH.5. Conceptual work plan for a multi-modeling approach to address the extent and magnitude of ecotone boundary shifts (FCE II General Question 6). SFWMM, TIME and ELM models provide boundary conditions to smaller-scale ecosystem models which may be linked with each other. Selected parts of each model will build "hybrid" models of ecotone habitat change, which can refine vegetation change algorithms in ELM. Integration and synthesis of data, including potentially new studies, will be required for calibration/validation.

III. INFORMATION MANAGEMENT

A. Objectives

The Florida Coastal Everglades LTER Information Management System (IMS) provides a centralized network of information and data related to the coastal Everglades ecosystem. Given the potentially important role that the FCE LTER program may play in Everglades Restoration, an important objective is to increase public and private awareness of our Everglades research activities. The FCE Information Management Group has established IMS level protocols and services for data collection, quality assurance, data organization, data archive, data access, and data distribution to facilitate our scientific work and to ensure the integrity of the information and databases resulting from the research. A detailed accounting of the FCE IMS scope, system design and its support for science is found online under our research tab at http://fcelter.fiu.edu/research/information_management/ and the formal FCE Data Management Policy is posted at http://fcelter.fiu.edu/data/DataMgmt.pdf.

B. Resources

The FCE LTER Office has three Windows servers and two Linux servers with a total storage capacity of 1.9 Gigabytes and an additional 400 Gigabytes of storage between two desktop workstations. Connectivity within the FCE LTER Office is a gigabit switched Ethernet Network (Florida International University Computer Science Network). The FCE Information Management Group consists of one full-time Information Manager, Linda Powell, and one full-time Project Manager, Mike Rugge. Linda Powell's station location is now in Tallahassee, Florida, where she is able to remotely perform her information management duties via the FIU VPN. She also visits the FCE LTER Office at quarterly intervals and is in constant contact with the group via telephone, emails, and conference calls. Overlap between the IMS group's critical tasks allows collaboration on computer system administration issues and with the FCE webserver and Oracle10g Database design issues, content and implementations.

C. Data Management Procedures

FCE Data: All of the FCE LTER core data and metadata files from individual research studies are stored in a hierarchical flat file directory system. FCE project information and minimal research data metadata are stored in an Oracle10g database that drives the FCE Web site. This hybrid system (flat file and database) gives FCE researchers, network scientists and the general public an option to download complete original data files submitted by individual FCE scientists in addition to downloading queried data from the Oracle10g database. Core data are made available to the public within two years of data collection and are accessible online in accordance with the FCE Data Management Policy.

Because we feel that it is extremely important that published online data be accessible at all times, the FCE IMS has implemented a versioning system where all previously published data are unchanged. Changes in data values or newly appended data will result in the creation of a 'new' version of the dataset as described under the 'Data Organization' section of the data management policy. Currently, the FCE archive contains 383 FCE datasets, of which, a total of 357 are publically available online (Fig. III.1).

FCE publications are updated frequently and are searchable online by querying on any combination of date, author, keyword, and publication type. Presentations are listed on the FCE website, and in some cases, users may view a presentation via a document link. Limited GIS and raster data are available for download via our Everglades interactive map application.

Current Status	Archived Datasets
Public	357
FCE Only	4
Locked	12
Offline	10
TOTAL	383

Public Dataset Type	Online
Climate	72
Primary Production	65
Physical	75
Nutrients & DOM	98
Soils & Sediments	25
Trophic Dynamics & Community Structure	22
TOTAL	357

Fig. III.1. FCE Dataset Archive thru August 15, 2009

FCE General Data Procedures: The FCE project and information managers have divided the FCE information flow (Fig. III.2) into two information categories: 1) Data related or 2) general project related. Data, metadata and information management documents are handled by the information manager whereas general project details like personnel information, FCE project and sub-project information and research documents are organized and archived by the project manager.

Data and information are contributed to the FCE IMS by eight designated working groups. Workgroup researchers are responsible for quality assurance, data entry, validation, and analysis for their respective projects. The Information Manager schedules quarterly data collection dates (Jan 1, April 1, July 1, & October 1) throughout the year by sending email reminders, with the appropriate data submittal information, to all participating researchers. The Oracle relational database has been designed to accommodate diverse spatial and temporal heterogeneous data submitted by the FCE researchers. Minimal data submission requirements described in the FCE Data Submission Information Document allow individual FCE scientists to maintain their own specific research procedures and protocols that were established prior to the start of the FCE LTER program.

Data submitted to the Information Manager undergo IMS quality assurance and quality control procedures whereby the data and metadata are thoroughly examined to ensure that the data fields and values are correctly described by the metadata. These data are then converted into ASCII text (if not already submitted as ASCII) and loaded into the Oracle10g database. Metadata and data values are then combined into one ASCII text file for archival purposes. A full schematic of the FCE IMS Data Procedures is discussed in the FCE Information Management System (IMS) Overview .

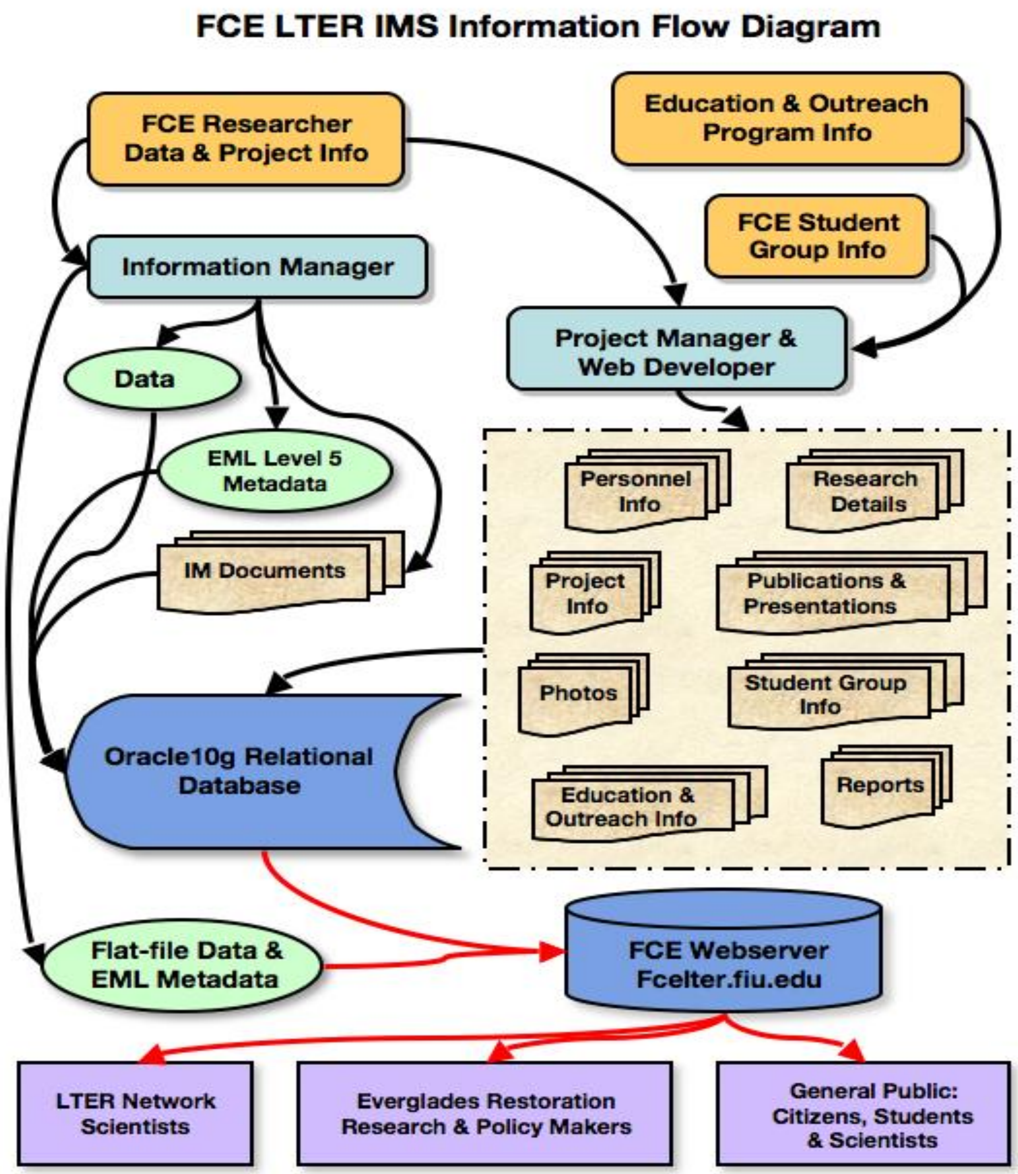


Fig. III.2. FCE IMS Information Flow

D. Data and Information Accessibility

FCE LTER Program researchers have first priority for use of their data in publications but they are encouraged to make their data publicly available as soon as possible to enhance collaborations and synthesis. The FCE Information Management distribution protocol is thoroughly described in the FCE Data Distribution Policy.

Public access to the FCE LTER data and information for the scientific community at large is provided through the FCE LTER web site on the internet at the following URL: http://fcelter.fiu.edu/. Our web site has been active since March 2000 and consists of a variety of information including the FCE LTER Program overview, personnel, maps, data, publications, education and outreach, job announcements and Everglades related links.

The FCE website ''Data' Section is unique to most other LTER sites in that it acts as a portal to three major data categories: 1) FCE Data Products, 2) LTER Network Data and 3) Outside Agency Related Everglades Data. Users can easily select a data category of interest and are taken to a new page containing pertinent links found under that category. The FCE Data Products page has 7 major subcategories such as core data, signature datasets and climate data. Users are given a 'FCE Sampling Attribute' subcategory where they can search by a sampling attribute and the return results will include sites, datasets and projects associated with that sampling attribute. A series of FCE data statistics tracks the project's data submissions and data downloads, categorized by type and purpose.

All FCE LTER personnel have access to our password protected Intranet site. Researchers can easily compile their personal FCE information by selecting the menu choice 'Your Information' whereby all pertinent contact information, publication, presentation, leveraged funding, dataset and project description results are reported online. Users can also browse the intranet site for downloadables like the FCE project information form and important FCE documents such at the ENP Sampling Permits, the FCE II proposal and the LTER network Planning Grant and Strategic Planning Process presentation. The FCE intranet 'Resources' section provides links to mailing lists, a FCE LTER office resource list of available equipment and FTP server information.

E.   FCE IMS Server/Workstation Security & Data Protection

All FCE servers and workstations undergo continual updates and patches to their operating systems. All FCE computers have dynamic firewalls. Database and flat file integrity are maintained through access passwords and user privileges and roles. The servers housing the development and production versions of the FCE Oracle10g database and the FCE Website structure documents and website related files are equipped with RAID5 technology (Redundant Array of Independent Disks). The FCE IMS implements 2 levels of data protection: 1) nightly incremental backups to external drives, 2) daily incremental (Web), and weekly full backups to external hard drives with one set being stored offsite.

F.   Future Initiatives

A web-based query interface tool, which is linked to FCE physical and chemical research results stored in the FCE Oracle10g database, is finished and currently being vetted by the FCE Information Management Advisory Committee (IMAC) and its internal executive board (IEC). The new web interface will simplify data discovery and data access for FCE and LTER network scientists as signature FCE chemical and physical data, togther with over 4 million physical and chemical data values from outside agencies (Everglades National Park, South Florida Water Management District and the USGS) have been added to the FCE Oracle10g database. We anticipate adding analysis and synthesis tools to the website whereby queried FCE physical and chemical data could easily be manipulated in real-time.

In the near future, the IMS group will be working with the FCE Human Dimensions group in expanding our current GIS data archive and finding innovative ways to present his group's intriguing research. Additionally, the FCE LTER has a very active Modeling and Synthesis working group which plans to work with the FCE IMS in developing an interface where a select model would be made available online allowing users to manipulate the model parameters and then view and download results based on their manipulations.

IV. EDUCATION AND OUTREACH

The primary objective for FCE II Education and Outreach is to address the strategic initiatives and goals of The Decadal Plan for LTER. Our approach is to expand the scope of our existing programs to include other LTER sites, establish international relationships, enhance and expand our community partnerships, and to continue to support educational programs that promote scientific literacy. This report summarizes our results since December 2006 and begins with FCE's individual contributions to address Initiatives II & III before concluding with our efforts in support of the LTER network goals of Initiative I.

A. Conduct Research, Develop Environmental Literacy and Inclusion: *Developing learning progressions leading towards environmental science literacy*

FCE Research Experience programs work towards developing environmental literacy by including students from Kindergarten through graduate school (K-20) in our research. While we continue to offer traditional graduate and undergraduate research training, we also offer complementary programs that allow pre-college students to work side by side with our RETs, REUs, and other FCE researchers. These programs target specific learning groups for pre college students and are modeled after our current REU and RET programs.

1. Pre-College Programs

Research Experience for Secondary Students

The FCE Research Program for pre-college students began in 2002 with a single high school student enrolled in our Research Experience for Secondary Students (RESSt) program. Since then FCE researchers have worked with over 33 students on an individual basis and an additional 30 in small group settings. Through FCE II we increased our number of student internships from 18 to 66 RESSt students working with FCE researchers.

In 2006-2007, first year RESSt interns Nia Brisbane and Sebastian Diaz worked with Dr. Colin Saunders studying seed morphology within soil profiles found along the Everglades estuarine ecotone. Brisbane and Diaz presented their results at the South Florida Regional Science and Engineering Fair (SFRSEF) held in Miami where both received a superior rating for their work and advanced to the state level. Brisbane was the first FCE RESSt student to advance to the Intel International Science and Engineering Fair (ISEF) in Albuquerque, NM, and was nominated by her high school for the Silver Knight Award in community service.

Diaz's poster entitled "*The use of Cladium jamaicense seeds as indicators of historical changes in the Everglades estuarine ecotone*" was one of the top scoring posters in the Environmental Division at the Regional Fair and received an additional Outstanding Project award presented by the Sierra Club, and an award from US Army.

In her third year working with Dr. Jeff Wozniak, Magaly Dacosta presented their poster "*Isotopic values for southern Everglades marshes: C and N natural abundance"* at the 2007 FCE-ASM meeting.

During year two of FCE II, Ben Giraldo presented the results from two years of work with Dr. Tiffany Troxler in a poster entitled "*Bacterial diversity indicies, enzyme activity, and soil* CO_2

flux along a soil P gradient in a coastal peatland, Panama" at the 54th Annual SFRSEF. Ben earned a "superior" rating in the Environmental Division and is the first intern to earn a "perfect" score. Ben advanced to the 54th Annual State of Florida Science and Engineering Fair (SFSEF) where he received Third Place in Botany.

Additional successes of FCE II year two include first year intern Michael Fins and second year Bryan Aguilar. In January, Michael presented the results from his work with Dr. Michael Heithaus and Megan Dunphy-Daly in a poster entitled "*The influence of predation risk on habitat use of the red eared slider (Trachemys scripa elegans)*". Michael earned a "superior" rating in the Zoology division and is the first FCE intern to receive a unanimous decision by the judges to advance to the State competition. Although Bryan Aguilar graduated before being able to present his work at the science fair, he will be the first RESSt student to be listed as co-author with his mentor, Dr. Colin Saunders, in a book chapter entitled "*Seed production versus biomass relationships of Cladium jamaicense and Nymphaea odorata"*.

The success of our RESSt program continued into 2008-2009 when Christopher Sanchez received international recognition for his research. In his third year working with Drs. Evelyn Gaiser and Colin Saunders, Chris received many awards and Second Place in Plant Science at the 2009 ISEF for his poster entitled "*Interpreting the hydrologic history of an Everglades wetland through microscopic characterization of phytoliths*." Chris also received Superior in the Botany division at the 54th SFRSEF where he was awarded Best Biological project and received the George Avery Award by the Florida Native Plant Society.

In February 2009, Erikamarie Gil became the first RESSt intern to submit a proposal and receive grant funds. In her second year as an RESSt intern, Erikamarie Gil was one of thirty students to receive Planet Connect Grants in January 2009 from the National Environmental Education Foundation. Erikamarie was the only Florida recipient.

Over the first three years of FCE II More than 30 undergraduates have gained experience sampling bull sharks, alligators, snook, and gar. Three high school students worked on LTER-related projects in the consumer dynamics group and one of them conducted independent research and won several awards for his Science Fair presentations based on this work.

Research Experience for Middle Schools

In 2007, we launched Research Experience for Middle Schools (REMS). As we move into our third year, REMS continues to expand and is largely supported through the financial support of our community partner and aggregate mining conglomerate, CEMEX. Since 2007, FCE has worked with CEMEX to create a habitat restoration area at one of their inactive limestone quarries that is adjacent to the Everglades. In 2007-2008, we planted over 7500 native grasses, trees and shrubs provided by CEMEX at the 0.63 acre restoration area. Since its construction, we have worked with over 372 students in hands on ecology lessons at the site. In 2008-2009, our RESSt students conducted short FCE Everglades ecology lessons with over 150 middle school students and worked with FVSHS Stagecraft students in construction and assembly of 40 bird nesting boxes using materials provided by CEMEX.

We also supported a visit by Lisa Giles and her 7th grade class from Key Largo Elementary School. Ms. Giles created the Everglades, Keys, and Ocean (EKO) dropout prevention program to identify at-risk students early in their careers and provide them with a year-long environmental research project aimed at rekindling their love of learning. The curriculum involves hands-on oceanography and marine ecology activities and outdoor expeditions educate students about their local environment while helping them excel in school. Students share the data they collect with a national science database, which also helps boost their self-esteem. The program culminates with a special Science Night during which students present the results of their studies to members of the scientific community. Ms. Giles, has received the DCAT "*Making a Difference Award*", which was presented by the National Science Teacher Association. During their time at FIU, they visited the Nutrient Analysis Lab, Microbial Ecology Lab, and Seagrass Lab where they received research instrument demonstrations and hands-on training.

2. Pre-Service and Professional Service Teacher Education

FCE is working to improve learning progressions that lead towards environmental science literacy by working with pre-service teachers through our partnerships with teacher education programs and by providing RETs to professional service classroom teachers.

<u>Pre-service Teachers:</u> FCE has worked with the Miami Dade College Department of Biology, Health and Wellness (MDC-DBHW) since FCE I and has continued to broaden that relationship throughout FCE II. This year, in addition to our annual presentations within the MDC-DBHW, RET Teresa Casal has begun to introduce FCE lessons and FCE datasets to pre-service Math and Science teachers enrolled in the Miami Dade College School of Education (MDC-SE).

In 2009, our relationship with MDC-SE has grown to include our partner, Everglades National Park (ENP). As collaborators in ENP's Parks as Resources for Knowledge (PARK) project, FCE is providing support as their scientific advisor. Through the Everglades PARK program, pre-service teachers will work with Everglades and FCE staff in developing hands on, laboratory activities while studying Everglades fire ecology in relation to soil and water characteristics.

<u>Professional Service Teachers:</u> Our RET program provides a unique opportunity for teachers to work directly with FCE researchers in developing hands on activities for use in the classroom. In 2006-2007 Teresa Casal worked closely with our Data Manager, to develop a series of investigative modules that direct students through the development and execution of a science fair project. The modules incorporate the downloading, use, and analysis of FCE datasets and are used by our RESSt interns.

Along with FCE Education and Outreach Staff, our RETs have also worked as authors for the new Florida Sunshine State Standards in K-12 science curriculum. They have also served as Content Area Experts in authoring questions and designing the new teacher certification exams in the State of Florida for Middle School Science, Earth Space Science, Biology, and Chemistry subject exams.

RETs have also participated in field research within the Everglades' Taylor and Shark River Sloughs with FCE and Mex LTER scientist Victor Monroy and on a large predator study on bull sharks Phillip Matich.

Nicholas Oehm, our Education and Outreach Coordinator, is also a professional service teacher and presented information about FCE and the Everglades to his biology students. Together, Nick, Teresa, and our Catherine have given FCE presentations to an additional 527 students at FVSHS and an additional 483 at MDC.

3. Including and learning from diverse people and perspectives

In our efforts to promote scientific literacy beyond the classroom, we have focused our efforts on producing short LTER videos, the internet, and translating FCE materials for an international community.

LTER Videos: In 2008, we completed the first of our FCE data education movies entitled "*FCE FILES*". The initial debut and release of "*Part I: Aboveground Net Primary Production (ANPP) of Sawgrass*" took place at our All Scientists Meeting in March 2008. Since then the film has been evaluated by both teachers and students in Miami Dade County Public Schools and Newton County, GA. In response to evaluations of the film we have added more information to simplify the information. We also have adapted the movie to include two activities and a short quiz. We have also submitted a proposal to NSF for funding under the Communicating Research to Public Audiences Program that would fund the creation of a permanent kiosk at the Ft. Lauderdale Museum of Discover and Science that would feature a 20-min documentary on our work and an interactive computer program that would allow visitors to see animations – of animals and time periods of their choosing – of the movements of consumers we have tracked along with the physical data during that time period. Along with this project we would create video-enhanced lessons for middle school and high school students.

Internet: In October 2007, 50 Miami Dade County Public High School students participated in a live, interactive broadcast with FCE's Patrick Gibson from the Aquarius underwater habitat. Students were given the opportunity to ask Patrick questions about his research and interact with a diver with a helmet camera that was positioned outside of the underwater research station.

Translation for Bilingual Citizens & ILTER: In June 2008, FCE released the En Español feature of our webpage and "*Foreverglades"* classroom presentation and script. Both the website and presentation were translated by English teacher and native Spanish speaker Carlos Escobar. Carlos made a great effort in consulting resources from the University of Spain to insure an accurate translation.

Children's Book: We have been preparing a FCE volume of the LTER Schoolyard Book Series entitled "*One Night in the Everglades*" dealing with an overnight field experience in the FCE of two scientists studying the dynamics of DOM. The text of the book has been completed and approved by the book committee. We are presently in the phase of preparing the illustrations and have hired a professional illustrator for this purpose. The book should be completed by early 2010 and we hope to find funding to produce an edition in Spanish once the English version is completed.

International Programs: We have begun developing a curriculum in marine sciences, offered jointly Universidad Nacional Autónoma de México and FIU. Courses include undergraduate and graduate level offerings in Marine Protected Areas and Monitoring in Coastal Wetlands, co-taught by FCE collaborators Ligia Collado, Joel Trexler and Jim Fourqurean. We have begun discussions with Dr. Victor Rivera Monroy (FCE and MexLTER) about establishing a sister Education & Outreach program with the MEX LTER. Our hope is to begin connecting

American students with our Mexican counterparts with interactive curriculum and research experiences for teachers and students.

In a recent visit to Asia, our Education & Outreach Coordinator contacted schools in Taiwan and China in order to begin establishing a network of English language schools to partner with FCE. Our goal is to develop and share lessons with these schools by including the Taiwan Ecological Research Network (TERN) and the Chinese Ecological Research Network (CERN) in order to allow students from around the globe to collect, share, and discuss the reasons for differences among common forms of data.

B. **Developing programs for working with specific constituent groups**

1. Work at undergraduate and graduate levels to improve training

Undergraduate Education:

FCE has an active undergraduate program through support from the LTER REU program and FCE-associated projects. FCE undergraduates regularly present their work at scientific conferences and occasionally publish. Some recent highlights include:

Perea, Jean P. (FIU; Mentor: Jennifer Rehage) . 2008-2009. Variation in parasite load among Palaemonid shrimp species along a salinity gradient.

Metzger, Edward (FIU; Mentor: Evelyn Gaiser). 2008-2009. Periphyton dynamics across nutrient and hydrologic gradients in the Florida Everglades.

Lewis, L. David (Texas A&M University; Mentor: Steve Davis). 2009. Studies of the Everglades mangrove ecotone.

Perry, Regina (Texas A&M University; Mentor: Steve Davis). 2007. REU. Influence of light and biological processes in governing the transformation of nutrients and lignin leached from red mangrove leaves. Presented at the 2008 FCE-LTER ASM.

Aguilera, Rene (University of New Mexico; Mentor: Steve Davis). 2006. REU. Importance of labile organic carbon in governing early mangrove leaf decay. Presented at the 2007 FCE-LTER ASM; 2007 Society of Wetland Scientists Meeting; 2007 Estuarine Research Federation Meeting.

Sandoval, Estefania (FIU; Mentor: René Price). 2009. Cation and anion composition of Everglades surface and ground water.

Marquez, Tatiana (FIU; Mentor: René Price). 2007-2008. Phosphorus content of the Biscayne Aquifer Limestone. Presented at the 2008 FCE-LTER ASM; 2009 FCE-LTER ASM.

Vanconselos, G. (FIU; Mentor: Rudolf Jaffé). 2009. Organic matter in soils: Characterization of humic and fluvic acids using fluorescence spectroscopy. 2009 LTER Network ASM.

Graduate Education:

The FCE LTER has a very active graduate student organization with over 48 participants. A total of 14 theses and dissertations have been produced during FCE II, and students publish regularly and present their findings at scientific conferences (see student presentations). A total of 8 students will be attending the 2009 Network All Scientists Meeting, where they will be presenting 8 posters and co-leading a cross-site working group. The group is highly active at the local and network levels. They meet monthly to discuss FCE LTER science, review FCE student presentations, and to maintain social and professional communication. The FCE student group has also been active in forming and participating in primary literature reading groups as well as collaborative research working groups. The leadership of the student group is structured as an executive committee headed by a President and assisted by several other offices. The exact structure of the executive committee has changed annually to reflect the needs of the larger group and its connections to other organizations for that year. Notable examples of this dynamic leadership were the creation of offices to integrate with Florida International University's graduate student organization as well as the creation of a Biscayne Bay Campus representative to help coordinate communication between FCE LTER student researchers positioned across two geographically disparate FIU campuses. The FCE student group executive committee is chosen by student election annually at the FCE All Scientists Meeting.

FCE LTER graduate education is facilitated through mentoring, but also through formal coursework taught by FCE PIs. Co-PI Ogden pioneered the first formal cross-site LTER course, "*From Yardsticks to Gyroscopes: Interdisciplinary Methods for Socio-ecological Research*," which she co-teaches with Ted Gragson (CWT LTER) and Morgan Grove (BES LTER). This is a video-assisted course using a live interactive video-feed. In 2008, this course reached 8 students participated in this course from 18 different universities and three countries. All materials from the course (readings, video presentations, power point slides) are archived and available through a course website. PI Gaiser also teaches a graduate course at FIU entitled "*Readings in LTER Science*" which exposes students of all FCE disciplines to science published by FCE and the LTER Network. Recent themes have included "*How to Review Manuscripts for Publication*," "*LTER Network Graduate Student Publications*" and "*FCE II Science and Planning*."

2. Work with K-12 schools to promote environmental literacy

FCE continues to promote environmental literacy in K-12 schools through our Research Experience programs and our partnerships. In 2007, we began working with Science Approach (SA), LLC of Tucson, Arizona and Alison Whitmer (SBC & MCR). Working with SA, through an NSF Information Technologies for Students and Teachers (iTEST) grant (award # 0737706), we provided professional development and instruction to support teachers in using LTER data and GIS in their classrooms.

Coastlines Summer Institute (CSI) is being offered over the course of three consecutive summers and FCE was the first of four LTER sites (FCE, BES, SBC, MCR) to participate. Through Coastlines we provided 50 teachers with professional development and instruction in LTER science and GIS technology. In all, 28 local teachers and 6 others completed the program. The group included 24 high school and 10 middle school teachers, and each participant received 24 hours of online training; 80 hours of face-to-face professional development; and 16 hours of implementation support.

In 2008-2009, we continued to support our partnership with SA by providing Webinar presentations on LTER science and through RET participation in the Coastlines II Summer Institute in Washington DC, with BES. Second year participants and FCE RETs, Teresa Casal and Catherine Laroche, provided input with an FCE perspective while receiving an additional 24 hours of online training; 80 hours of face-to-face professional development; and 16 hours of implementation support. Using their experience with Coastlines, Teresa and Catherine are developing new FCE curriculum through their 2009-2010 RETs.

3. Engage citizens and leaders with LTER research

Citizens

FCE II continues to improve citizen engagement in our research through outreach with community groups and our community partners. In March 2008, Nick Oehm presented "*The role of mangroves in the Everglades estuarine ecotone*" to 34 visitors from across North America at Dagny Johnson Key Largo Hammock Botanical State Park. Our RESSt interns have also been invited to present their research to the South Florida Chapter of the Florida Native Plant Society in 2007 and 2009.

FCE has also begun to increase our visibility in the community through our partnership the Ft. Lauderdale Museum of Discovery & Science (FLL MODS). As FLL MODS' research partner in their Communicating Climate Change (C3) project, FCE scientists act as scientific advisors and plans are underway for FCE staff to give guest lectures during special climate programs.

Community Leaders

The inclusion of community leaders and agency scientists is an intrinsic component to our research program and has played a major role in FCE since inception. Our research collaborators include governmental organizations such as the South Florida Water Management District, Everglades National Park, National Park Service South Florida Caribbean Network, United States Geologic Survey Florida Integrated Science Center and National Research Program. In addition, we interact and collaborate with researchers from NGOs including Harbor Branch Oceanographic Institute, National Audubon Society Tavernier Science Center, and the private firm Ecology and Environment, Inc.

One formal way we have communicated our science to other scientists and policy makers is through publication of a 2009 special issue of the journal *Ecological Indicators*, devoted to a novel, statistically rigorous way of extracting management signals from long-term datasets in order to inform the restoration decision-making process. This special issue was co-sponsored by the Federal Task Force on Everglades Restoration and the FCE LTER, and led by FCE collaborators Robert Doren (South Florida Ecosystem Restoration Task Force), Joel Trexler (FIU) and Andrew Gottlieb (SFWMD). This same FCE-affiliated collaborative group worked with personnel from the National Park Service, US Army Corps of Engineers, US Fish and Wildlife Service, and other universities to produce a report to the U.S. Congress (Doren et al. 2008) that will be repeated bi-annually in order to convey our findings directly to Federal policy-makers. One new instrument for this involvement is a collaborative effort between FCE scientists and Everglades National Park, funded by the NPS Cooperative Ecosystems Studies Initiative, to write a book that would synthesize decades of Everglades science in a way that may effectively communicate to policy makers the urgency of restoration.

Another way that we regularly communicate with policy-makers is via participation in public meetings regarding restoration projects. In particular, FCE provided detailed written comments to the Army Corp of Engineers proposed design of the bridge along Tamiami Trail "The Grand Experiment". We objected to the installation of a smaller bridge located along the eastern boundary of ENP. We felt that this design would limit the effects of additional water deliveries to ENP to only a small portion of eastern Shark Slough. We proposed that the bridge be placed more toward the west, near the center of Shark Slough to maximize the region influenced by the additional water deliveries.

Several FCE scientists are collaborators or advisors to the SFWMD Comprehensive Ecosystem Restoration Program Monitoring and Assessment Program (CERP MAP) Team. Data collected by these investigators help expand the spatial coverage and landscape ecology investigated by FCE, and FCE data are used to inform long-term trajectories of change elsewhere in the ecosystem. Investigators contribute integrated results to the annual Everglades System Status Report to the U.S. Congress and present their findings at frequent meetings of the CERP MAP team. In addition, FCE collaborators are training representatives of State and Federal agencies in the use and application of the Everglades Landscape Model through the Interagency Modeling Center at SFWMD.

While FCE scientists frequently participate in formal collaborations and informal science workshops geared toward improving integration of science and water management, new FCE collaborations with climate scientists from a number of agencies are improving integration of the science of climate change with water management policies. On September 25th, 2009 the Climate and Disturbance Working Group will host a Climate Workshop at FIU for FCEII researchers (collaborators and graduate students) and representatives from the SFMWD. The goal of this workshop is to facilitate communication on the state of climate research affect the Greater Everglades system between our university research community and managers from SFWMD. A great deal of climate research is being conducted by both groups, and this forum will bring these two communities together. At the end of the workshop, it is our ultimate goal to state what future directions climate research should take regarding the sustainability of the Everglades ecosystem.

C. Goals to address Leadership, Coordination, and Cyberinfrastructure in Education

1. Develop LTER Network Education Leadership - Establish Education Site Coordinators

Our current Education & Outreach Coordinator has had a formal role since 2006. In 2007, he began to coordinate Education & Outreach efforts across sites (FCE, SBC, MCR, BES) though our work with Ali Whitmer (SBC & MCR) in the Coastlines project. In 2009 he and Ali served as Education Representatives on the ASM Planning Committee and presented Coastlines results at the 2009 ASM. In addition, he was also a co-presenter with Marcia Nation from the Global Institute of Sustainability at Arizona State University on the use of social networking.

2. Develop LTER Education Cyberinfrastructure

In 2007 we began working with the Everglades Digital Library (EDL) in an effort to restructure the "*Ask a Scientist*" feature on our webpage. Together we are working to find funding and continue developing a searchable database that would combine EDL's *Ask an Everglades Librarian* with FCE's *Ask a Scientist* into a single, joint *Ask an Everglades Expert* program. The ultimate goal of this project is to expand the feature to create Ask an LTER Expert.

V. CROSS-SITE AND NETWORK LEVEL ACTIVITIES

A. Cross-Site Activities

In response to the LTER Decadal Plan for Science, FCE has been increasingly involved in several types of cross-site activities including: 1) science projects coordinated by FCE that involve other LTER sites; 2) workshops organized or attended by FCE scientists to coordinate cross-site science, write proposals or papers; 3) education and information management activities coordinated or attended by FCE students, collaborators or staff; and, 4) activities coordinated by FCE researchers at sites not involved in the LTER network. These are catalogued on our cross-site and network activities page, but we have had a particular focus on cross –site activities in four areas: 1) research in Mexico and the Caribbean with other LTER and ILTER collaborators and students; 2) characterization of dissolved organic carbon across the LTER network; 3) cross-site investigations of urban land use (described in the Human Dimensions section of this report); and, 4) cross-site education programs (i.e., *Coastlines*, described above). Below, we highlight our research in the Caribbean, because it is a culmination of the Caribbean Initiative planned during FCE I and addresses many of the goals set forth in the resultant collaborative Bioscience manuscript (Rivera-Monroy et al., 2004).

Cross-Site Research in Mexico and Greater Caribbean

FCE research is founded on the premise that the Everglades operates differently from other coastal ecosystems, having estuaries that are "upside-down", with seawater supplying limiting nutrients landward in surface and groundwater, rather than the other way around (Childers et al., 2006). Wetland organisms also contradict conventional theories in their response to their environment, with producer communities that disintegrate with exposure to nutrient runoff (Gaiser et al., 2006) and consumer communities that are much less abundant than they should be, given the ample resources available to them (Turner et al. 1999). While our research continues to improve our characterization and mechanistic understanding of the seemingly unique features of this ecosystem, as with all place-based science, our understanding would be improved by comparative work in analogous systems. Through collaborations with Caribbean scientists, particularly researchers associated with Mexican LTER programs (MexLTER), we have learned about analogous karstic wetlands with characteristics similar to those in the Everglades, occurring throughout the Caribbean basin, particularly in the Yucatan peninsula and northern Belize. There is a paucity of published work from these wetlands, so FCE scientists have begun extensive cross-disciplinary science with collaborators in these countries to determine if the unusual biophysical features of the Everglades gradients are present in other upside-down estuaries in the Caribbean. We are also working with Mexican colleagues to develop plans for monitoring human-driven changes in coastal ecosystems of the Yucatan region and to educate local scientists and the public about conservation and restoration practices.

Freshwater Wetlands: FCE scientists Joel Trexler, Evelyn Gaiser and Bill Loftus and students Josette LaHee, and Cliff Ruehl have been working since 2006 in karstic marshes of the Sian Ka'an Bioreserve in Quintana Roo, Mexico, and in the New River Lagoon, near Orange Walk, Belize (Fig. VA.1). The goal of this research is to determine whether these wetlands are like the

Everglades in exhibiting high levels of primary productivity and biomass of algal producers, yet very low biomass of aquatic consumers. By sampling from freshwater wetlands to the coastal ecotone, we have discovered the same inverted response of periphyton to nutrient available as observed in the Everglades, and indication that anthropogenic nutrient enrichment erases the unusual Eltonian pyramid of biomass by decreasing standing crops of algae and increasing those of aquatic consumers. This research is being completed in the dissertation research of students LaHee and Ruehl.

Mangroves and Estuaries: FCE researchers René Price (FIU) and Victor Rivera-Monroy (LSU) and their graduate students Jeremy Stalker and Edward Castaneda have been collaborating Dr. Jorge Herrera-Silveira of CINVESTAV in Merida Mexico, and his graduate student Sara Morrales, in a project that compares mangrove productivity patterns, water sources and movement and biogeochemical cycling between the coastal Everglades and estuaries of the Celestun lagoon on the northwest Yucatan coastline (Fig. VA.1). During wet and dry season visits in 2008 and 2009, water samples were collected and analyzed for the stable isotopes of hydrogen and oxygen, major cations, and anions at FIU, and for total and dissolved concentrations of nitrogen, phosphorus, carbon and silica at CINVESTAV. A mass balance mixing model was developed to determine the dominant sources of water (seawater, fresh groundwater, and brackish groundwater) to the estuary. Three dominant sources of water were identified as contributing to water in the Celestún estuary during the Spring 2008. These source waters included : 1) seawater (SW) from the Gulf of Mexico; 2) Upper Celestún surface water (UCSW) that discharges to the headwaters of the estuary, and 3) fresh groundwater (GW). The UCSW was brackish with salinities varying between 19 and 20 psu and was characterized as a mixture of fresh groundwater and seawater that discharged to the upper reaches of Celestún. Seawater from the Gulf of Mexico had salinity values close to 36 psu while the fresh groundwater had a mean salinity value of 3 psu. Using a 3 component mixing model of strontium and salinity, seawater was determined to be the largest contributor of water to the Celestún estuary was seawater (50%). The remaining 50% was divided between the UCSW (31 %) and fresh groundwater (20%). Nutrient concentrations of nitrate and total phosphorus were found to be highest in the fresh groundwater, and may be responsible for elevated concentrations of these nutrients within the estuary, in keeping with our dry-season findings in the Everglades.

FCE collaborator Christopher Madden (SFWMD) is extending this research into the shallow marine environment at ECOPEY to quantify relationships between water residence time, the nutrient and light climates of coastal waters and the degree, allocation and type of benthic versus pelagic of primary production. In collaboration with scientists at CINVESTAV, he is comparing seagrass and phytoplankton community processes to develop cross-site ecological simulation models that will predict impacts of human development, natural perturbations and climate change. FCE collaborators Ligia Collado and Jim Fourqurean are also starting comparative work in benthic marine communities, collaborating with scientists at Universidad Nacional Autonoma de Mexico (UNAM) to determine relative importance of top-down and bottom-up processes in controlling seagrass abundance in several sites on the Yucatan coastline, including Sisal, Puerto Morelos and Akumal (Fig. VA.1).

FCE collaborator Mark Rains (USF) is focusing on groundwater interactions to determine sources of salinity and nutrients at the terrestrial-marine interface at FCE, ECOPEY and the Ecosistemas Arrecifales del Pacifico MEX-LTER on the Pacific coast of Mexico, where he

Figure VA.1. Sites in the Yucatan peninsula where FCE is conducting collaborative research. Image from Google Earth.

works with Drs. Francisco de Asís Silva Bátiz and Enrique Godínez Domínguez (Universidad de Guadalajara). Surface-water and ground-water were sampled from lagoons and associated mangroves habitats located at La Manzanilla, Barra de Navidad and La Veina in the summer of 2008 (Fig. VA.1). Samples were analyzed for dissolved constituents and stable isotopes. These data were combined with previously-collected data and used to better constrain mass-balance mixing models that quantify the proportional contributions of ocean water and fresh water to the mangroves and lagoons. This collaboration led to an NSF Integrative Graduate Education and Research Traineeship (IGERT) pre-proposal now under development, the focus of which is the development of strategies for balancing limited water resources in coupled human-natural systems in the US, Latin America, and the Caribbean Basin. A key finding of the Mexico Pacific study was that the contribution of fresh water to each of the lagoons and mangrove regions varied with geomorphology. The proportion of freshwater contribution to the lagoon was highest (>80 %) for a closed-mouth lagoon, and lowest for an open-mouth bay. Surface water in a spring-fed river was made up of about equal contributions of ocean water and fresh water. The results of this research indicated that fresh groundwater, which is increasingly used for local and regional water-supply purposes, could be quite a large contributor of water to some coastal mangrove and lagoons.

Human Dimensions: FCE collaborator Rinku Roy Chowdhury (IU) is developing research comparing the social-ecological dynamics of urbanization in southern Florida with the Yucatan peninsula, where she has been conducting social and ecological fieldwork for over a decade. She combines remote sensing with GIS data on socioeconomic, policy and environmental drivers of land use decision-making to develop spatially explicit, empirical models of landscape change.

Education and Outreach: Formal cooperative education programs between Florida and Mexico have been facilitated by the Florida-Mexico Institute (FMI), created by the Florida State Legislature to promote educational and other linkages between Florida and Mexico. FCE collaborator Ligia Collado, appointed as a UNAM ambassador to Florida International University (FIU) in 2005, established two courses taught and offered jointly between the universities; one in Marine Protected Areas and another in Marine Botany at Puerto Morelos (see Education and Outreach section). She and Rudolf Jaffé are also coordinating workshops with UNAM and FCE faculty to be taught at the Unidad Multidisiplinaria de Docencia e

Investigación, Sisal, Yucatan on techniques for measuring primary and secondary production, water quality and geochemistry. Through collaborations with the Mexican LTER Network, FCE is providing a conceptual framework to Mexico for developing mangrove monitoring programs and to establish restoration activities in areas most affected by human activities in the Yucatan.

Information Management: Data from collaborations initiated at FCE are being integrated into the information management system at FCE. FCE information manager Linda Powell has been offering assistance to the MEXLTER in developing an information management system.

Caribbean Hurricane Network: FCE collaborators Gaiser, Davis and Rivera-Monroy participated in the LTER Hurricane Research Coordination Network meeting in Merida, Yucatan supported by the 2008 supplement award to the Luquillo LTER. This meeting initiated a cooperative approach among US LTER and Mexico ILTER sites to the study of the effects of hurricanes on tropical forests. The meeting established a strong core group of researchers committed to establishing a network of sites and scientists to expand, improve, and synthesize research on hurricanes and their effects (see workshop report). Moreover, meeting participants agreed to develop two manuscripts, established working groups to prepare a proposal to the NSF Research Coordination Network program, initiated a bibliography of research on Caribbean hurricanes, and began development of a web page that describes these achievements and the sites that will be involved in the new network. Using 2009 NSF LTER supplemental funding to FCE and LUQ, FCE will be hosting the second meeting of the network in Miami in December 2009, with the goal of: 1) completing the manuscripts under development, 2) expanding the working group to include additional ecologists and social scientists from the Greater Caribbean Basin, and 3) maintaining the momentum that the first meeting provided until we obtain longer-term funding.

B. Network Level Activities

FCE scientists, students, and staff have been particularly active at the network-level, including governance, program development, and research enhancement (Cross-Site & Network Activities). FCE participation in Network governance includes Linda Powell, who just completed a two year term on the Network Information Systems Advisory Committee (NISAC), and is a member of the Information Management Committee. She has participated in *ClimDB* data enhancement, facilitates our *Ecotrends* involvement and was co-editor and now contributes regularly to the Network-wide Information Management newsletter "*Databits*." Other Network-level activities include participation by PI Gaiser and a second FCE representative in all Science CC meetings, regular contributions to the Network LTER Newsletter, and participation on the 2009 Network All-Scientist Meeting (ASM) Program Committee (Nick Oehm, Evelyn Gaiser). A total of 28 FCE collaborators, staff and students will be participating in the 2009 Network LTER ASM, where 16 FCE posters will be presented. Leadership in ASM working groups includes our student group who co-organized an urban ecology student workshop, FCE collaborator Tiffany Troxler, who organized a workshop entitled "*A unified framework to quantify biogeochemical complexity of large-scale ecological systems*," and Gaiser, who organized a working group on the influence of sea-level rise on coastal wetland ecosystems. The latter is a continuation of efforts to build a proposal for integrative, continental-scale cross-site research on this topic, coordinated with Hopkinson (PIE), McGlathery (VCR) and Alber (GCE).

VI. PROGRAM ADMINISTRATION AND GOVERNANCE

A. Program Organization

As with all aspects of FCE LTER Program administration and governance, FCE program organization is set by the Guidelines for Program Administration & Management. FCE science is accomplished through four working groups (WG) and four cross-cutting themes (CCT) that each address a central question from the FCE II proposal. We view the WG as conduits for addressing research questions that are integrated by the CCT (see our working group diagram). The four WG are Primary Production, Consumer/Trophic Dynamics, Biogeochemical Cycling and Organic Matter Dynamics while the four CCT are Hydrology, Climate and Disturbance, Human Dimensions and Modeling and Synthesis. [On a minor note, we departed from the proposal design slightly in moving the Hydrology working group to a cross-cutting theme during our 2007 ASM, when it was realized that FCE hydrological studies are highly integrative). We view our Education and Outreach Program as an additional WG. All FCE collaborators and students are asked to align themselves with at least one WG or CCT, and much of the daily communications, field logistical coordination, and data analytical discussions occur within these groups. Each WG/CCT has a direct link to program administration and governance through its leaders (see below), following a democratic style of representation. Each WG/CCT also has access to resources through both the group leaders and through the FCE LTER Office itself. In addition to WG/CCT-specific communications, program-wide communication occurs very regularly, and is facilitated by list-serve e-mail distribution lists for all FCE personnel, collaborators, students and technical staff.

We facilitate WG/CCT interactions, data synthesis, and idea incubation with our annual FCE All Scientist Meeting. These meetings are held in Miami, where many (but certainly not all) FCE scientists, students and staff are based, and we facilitate accommodations for our out-of-town collaborators, students and external advisors. We usually hold these meetings over 2-days at Fairchild Tropical Gardens, and include formal presentations, discussion time, poster session and administrative meetings. The themes of our 2007, 2008 and 2009 ASM were *Launching FCE II*, *Synthesis!*, and *Planning our 3rd Year Review*, respectively.

B. Program Administration and Governance

Early in FCE I, we established a programmatic “constitution” called the Guidelines for Program Administration & Management. These guidelines stipulate that all major programmatic decisions will be made or overseen by an Internal Executive Committee (IEC). This committee has served us well over the years, and only a few minor changes have been made since FCE I, all with unanimous approval by the committee. The first change was to increase the voting membership from 7 to 9 people to accommodate a representative from the two additional working groups established in FCE II. These currently include Jim Fourqurean (Primary Production), Mike Heithaus (Consumer/Trophic Dynamics), Joe Boyer (Biogeochemical Cycling), Rudolf Jaffe’ (Organic Matter Dynamics), Rene’ Price (Hydrology), Bill Anderson (Climate and Disturbance), Laura Ogden (Human Dimensions), Colin Saunders (Modeling and Synthesis) and Nick Oehm (Education). The IEC also includes two non-voting external members, to provide objective guidance and leadership (currently held by Karen McGlathery, lead PI of VCR LTER, University of Virginia and Chuck Hopkinson, former lead PI of PIE LTER, Director Georgia Sea Grant Program), a non-voting representative of Everglades National Park (currently Vic Engle, Senior Scientist) and the South Florida Water Management District (new FCE II, currently Fred Sklar) and a non-voting student representative (currently Greg Koch, FCE student representative to the Network student group). The FCE Information Manager and Project Manager serve as non-voting *ex officio* members of the IEC. In 2007, we also created a new rule to allow former FCE Lead PIs to serve as *ex-officio* non-voting members on the IEC if elected by majority vote. IEC membership is non-term for voting members, but members may rotate on or off the committee at the behest of their Working Group (who elect them). The IEC is responsible for such responsibilities as: 1) approving the addition of new collaborators to the FCE Program, 2) approving support for related proposals via a formal Letter of Collaboration, written by the Lead PI; 3) approving substantive changes in fiscal resource allocations; 4) approving changes in the Data Management Policy and Administrative Guidelines, and; 5) approving substantive changes in programmatic direction, among others. Votes are either majority or two-thirds majority, depending on the gravity of the decision (see Guidelines for Program Administration & Management for details). The IEC meets bi-monthly or when necessary.

The Lead PI is contractually responsible for the FCE LTER Program to NSF and to the FIU administration, and is thus the *defacto* leader of the FCE LTER Program. The Lead PI is the sole site contact for communications with NSF Program Officers and contracting personnel and the LTER Network Office, and is by definition the FCE representative to the Network Coordinating Committee. However, all major decisions are made by the IEC (although generally at the request of the Lead PI, who notably does not have a vote on the IEC). The Lead PI serves at the behest of the IEC and the Lead PI may be replaced by the IEC. The transition in PI leadership experienced during FCE II was effectuated by the IEC. When FCE I and FCE II proposal PI Dan Childers took a leave of absence from FIU to become an NSF Program Officer, Evelyn Gaiser, already a member of the IEC, was asked to lead the program. A year later, when Childers left FIU for a new position at Arizona State University, he nominated Gaiser to take the lead role, after approval by the IEC. The IEC also elected Laura Ogden, the lead of our Human Dimensions cross-cutting theme, to fill the fifth co-PI role left vacant.

At FCE, we fully recognize the extreme importance of strength, consistency, and stability in programmatic leadership and governance. The Guidelines for Program Administration & Management and the IEC provide these for governance, and the Lead PI provides these for leadership. While we value the importance of long-term stability in leadership, we recognize that this requires a plan for inevitable turnover of the Lead PI position again at some point. We accomplish this by striving to bring junior level faculty into governance and leadership roles so as to provide ample options for future changes in the Lead PI position. Our approach to distributed decision-making and governance responsibilities assures that, when the time comes, we will have a number of viable and qualified candidates to take over leadership of the FCE LTER Program.

C. Infrastructure and Office

The FCE LTER Program is run through an independent office housed on the campus of FIU. The office is the home of the Program Manager (Mike Rugge), the Education and Outreach Coordinator (Nick Oehm) and the off-site home of the Information Manager (Linda Powell) who conducts her work at her home office in Tallahassee, FL (see Information Management Resources section of this report). The office is responsible for all primary administrative duties of the program, and is run with funds in an Infrastructure budget, subsidized by matching funds from FIU (see below). In addition to the website and database support already discussed, the FCE LTER Office provides a number of services to FCE personnel, including: 1) ENP sampling permit administration; 2) travel funding logistics; 3) communications coordination; 4) outreach support; 5) subcontract administration; 6) budget and accounting assistance to PIs, and 7) assistance for off-site scientists and staff, among others. The office maintains key equipment and supplies that are available to all FCE personnel, including a field cell phone, a field satellite phone, field first aid/safety kits, a computer projector, a slide projector, laptops and desktop computers, and a fire-proof safe.

D. Budget and Institutional Support

The annual NSF FCE LTER base budget is divided into 9 subaccounts at FIU. An Infrastructure account is used to run the FCE LTER Office, and includes funding for: 1) staff salaries; 2) conference and meeting travel; 3) equipment replacements and upgrades (primarily for data storage and web servers); 4) supplies, including funds for poster printing and software upgrades/purchases; 5) maintenance of field support equipment (i.e., the cell and satellite phones) and helicopter time; 6) funds for the annual FCE ASM; 7) all subcontracts, and 8) all infrastructure-related supplemental funds received from NSF. The 8 subaccounts are to Bill Anderson, Joe Boyer, Jim Fourqurean, Evelyn Gaiser, Mike Heithaus, Rudolf Jaffe', Laura Ogden and Rene' Price, each of whom is lead on a working group or cross-cutting theme. One additional subaccount accommodates supplemental funding for REU, RET, RESSt support and another accommodates supplemental funding for participant support costs for network science meetings. Each is the sole signatory on their own FCE research subaccount, although the Lead PI is ultimately responsible to the FIU administration and to NSF for the entire budget. The Lead PI is signatory on the Infrastructure account. Additionally, we manage four subcontracts to Randy Chambers (College of William and Mary), Robert Twilley (Louisiana State University), Mark Rains (University of South Florida) and Steve Davis (Texas A & M University).

The FIU administration, through the Office of Sponsored Research and the College of Arts & Sciences, has always been very supportive of the FCE LTER Program. FIU is returning indirect costs to FCE through the Southeast Environmental Research Center (SERC) in the form of: 1) the salary of the FCE Program Manager (including fringe benefits); 2) $5K per year in travel funds for FCE students; 3) tuition waivers for 3 FCE graduate students; 4) partial funding for undergraduate hourly office help in the SERC office, and 5) some support for general operations of program management and core facilities (i.e., SERC Field Operations Center and Water Quality Analysis Laboratory).

Leveraged Funding

An important characteristic of the FCE LTER Program is that it builds on a number of pre-existing and ongoing research and observational studies by many FCE scientists. We keep track of proposals and projects that integrate address FCE hypotheses by collecting this information from existing and new potential collaborators during the proposal submission phase (which for new collaborators requires a Letter of Collaboration from the Lead PI) and from existing collaborators during the annual reporting period. We currently have catalogued 62 projects affiliated with FCE II, that amount to $21,642,264 of leveraged funding. Our ratio to NSF base funding ($820,000 per year, or $2,460,000 cumulative to date) is 8.8, roughly double that at our last mid-term review. Not included in this tally is the funding supporting the numerous collaborative modeling projects (see Modeling and Synthesis section) that are considered a part of FCE, but are difficult to track because they are multi-institution projects supported by many different agencies to a diversity of FCE collaborators as well as non-FCE scientists, but to fulfill a similar purpose. Our leveraged funding comes from a diversity of sources, including the National Park Service (Everglades National Park), the South Florida Water Management District, the U.S. Army Corps of Engineers, NASA, the Everglades Foundation and other NSF programs (Fig. VIC.1). The SERC endowment also supports FCE in numerous ways, including through competitive undergraduate, graduate, visiting scientist and faculty scholarships, supplying meals and often venue costs for FCE events, publication of our children's book, and enhancing our program office infrastructure at FIU. Information on individual leveraged projects, their PIs, title, funding source, period and amounts can be found on our leveraged funding page on our protected intranet site.

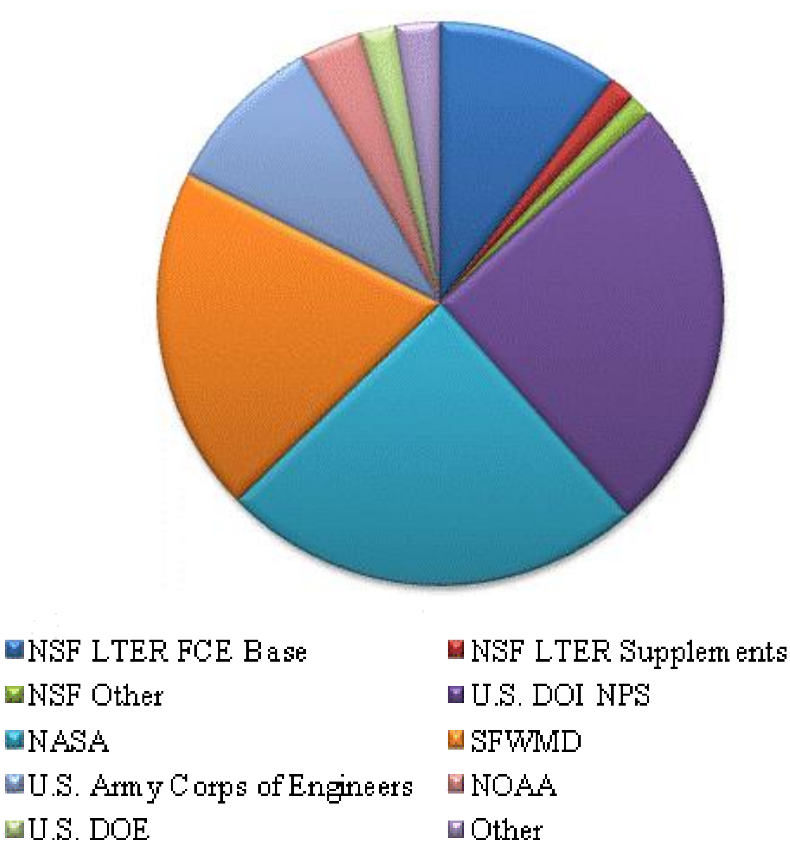


Figure VIC.1. Pie chart showing the proportion of leveraged funding for FCE research coming from a diversity of sources. Total FCE funding (NSF LTER plus leverage) amounts to $24,102,264 (a 8.8 ratio of leverage to base funding).

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