

9-1-2010

FCE II Year Four Annual Report for NSF Award DBI-0620409 (2010)

Evelyn Gaiser

Mike Heithaus

Rudolf Jaffe

Rene Price

Follow this and additional works at: http://digitalcommons.fiu.edu/fce_lter_proposals_reports

Recommended Citation

Gaiser, Evelyn; Heithaus, Mike; Jaffe, Rudolf; and Price, Rene, "FCE II Year Four Annual Report for NSF Award DBI-0620409 (2010)" (2010). *FCE Annual Reports and Proposals*. Paper 2.
http://digitalcommons.fiu.edu/fce_lter_proposals_reports/2

This work is brought to you for free and open access by the FCE LTER at FIU Digital Commons. It has been accepted for inclusion in FCE Annual Reports and Proposals by an authorized administrator of FIU Digital Commons. For more information, please contact dcc@fiu.edu.



FCE II YEAR FOUR
ANNUAL REPORT FOR NSF AWARD DBI-0620409

FLORIDA COASTAL EVERGLADES LTER
Florida International University

Submitted September 2010

Principal Investigators

Evelyn Gaiser
Mike Heithaus
Rudolf Jaffé
Laura Ogden
René Price

CONTENTS

I. PARTICIPANTS	3
A. Participant Individuals	3
B. Partner Organizations	4
C. Other collaborators	5
II. ACTIVITIES AND FINDINGS	6
A. Research Activities	6
1. Working Group Reports	6
a. Primary Production	6
b. Organic Matter Dynamics	8
c. Biogeochemical Cycling	10
d. Trophic Dynamics and Community Structure	11
e. Hydrology	12
f. Human Dimensions	19
g. Climate and Disturbance	23
h. Modeling and Synthesis	24
i. Information Management	29
2. Science Planning: 2010 ASM Break Out Group Reports	32
a. An Analytic Framework (Trexler & Gaiser)	33
b. The Comprehensive Heuristic Model (CHM) (Saunders and Saha)	34
c. Hydrological Connections Between Social and Ecological Systems in South Florida (Ogden and Price)	41
d. Community Ecology/Stoichiometry (Jaffé, Heithaus, Rivera-Monroy)	42
B. Findings	43
1. Primary Production	43
2. Organic Matter Dynamics	53
3. Biogeochemical Cycling	64
4. Trophic Dynamics and Community Structure	66
5. Hydrology	69
6. Human Dimensions	79
7. Climate and Disturbance	84
8. Modeling and Synthesis	89
C. Training and Development	96
D. Outreach Activities	100
E. Project Outcomes	103
III. PUBLICATIONS AND OTHER SPECIFIC PRODUCTS	105
A. Publications	105
B. Other Specific Products	110
C. Internet Dissemination	111
IV. CONTRIBUTIONS	112
A. Contributions within Discipline	112
B. Contributions to Other Disciplines	113
C. Contributions to Human Resource Development	115
D. Contributions to Resources for Research and Education	115
E. Contributions Beyond Science and Engineering	116
V. REFERENCES	117

I. PARTICIPANTS

A. Participant Individuals

Principal Investigators:

Evelyn Gaiser

Co Principal Investigators:

Mike Heithaus, Rudolf Jaffé, Laura Ogden, René Price

Senior personnel:

William Anderson, Anna Armitage, Jordan Barr, Mahadev Bhat, Joseph Boyer, Andrew Bramburger, Henry Briceno, Randolph Chambers, Daniel Childers, Ligia Collado-Vides, Tim Collins, Carlos Coronado, Susan Dailey, Stephen Davis, Bob Doren, Vic Engel, Sharon Ewe, Jack Fell, Carl Fitz, James Fourqurean, Jose Fuentes, Jennifer Gebelein, Hugh Gladwin, James Heffernan, Darrell Herbert, Gail Hollander, Krish Jayachandaran, Lynn Leonard, William Loftus, Jerome Lorenz, Christopher Madden, Melissa Memory, Fernando Miralles-Wilhelm, Vasubandhu Misra, Christopher Moses, Pallab Mozumder, Greg Noe, Steve Oberbauer, Laura Ogden, Jeff Onsted, Mark Rains, Jennifer Rehage, Jenny Richards, Victor H. Rivera-Monroy, Rosanna Rivero, Mike Robblee, Michael Ross, Rinku Roy Chowdhury, Dave Rudnick, Jay Sah, Colin Saunders, Margo Schwadron, Len Scinto, Norm Scully, Marc Simard, Fred Sklar, Christopher Smith, Ned Smith, Tom Smith, Helena Solo-Gabriele, Gregory Starr, Serge Thomas, Joel Trexler, Tiffany Troxler, Robert Twilley, Kevin Whelan, Keqi Zhang, Joseph Zieman

Post-docs:

Tom Frankovich, Robinson Fulweiler, Rafael Guevara, Amartya Saha, Jessica Schedlbauer, Jeremy Stalker, Anna Wachnicka, Jeff Wozniak, Youhei Yamashita

Graduate students:

Robin Bennett, Rebecca Bernard, Ross Boucek, Justin Campbell, Edward Castaneda, Meilian Chen, Yan Ding, Katherine Dunlop, Brett Gallagher, Dave Gandy, Brett Gallagher, Lisa Gardner, Rebecca Garvoille, Patrick Gibson, Daniel Gomez, Zayda Halun, Elizabeth Harrison, Kelly Henry, Monica Isola, Kristine Jimenez, Michael Kline, Greg Koch, Josette La Hee, David Lagomasino, Sylvia Lee, Kung-Jen Liu, Diana Lopez, Vivian Maccachero, Philip Matich, Lauren McCarthy, Jay Munyon, Emily Nodine, Adam Obaza, Danielle Ogurcak, Annie Palya, Pamela Parker, Oliva Pisani, Carrie Rebenack, Adam Rosenblatt, Clifton Ruehl, Robin Sarabia, Katherine Segarra, Victoria Spence, Christina Stringer, Suresh Subedi, Pamela Sullivan, Travis Thyberg, Xavier Zapata

Undergraduate students:

Melissa Anderson, Allison Cornell, Clarence Henry, Greg Losada, Alex Perez, Glauco Puig-Santana, Estefania Sandoval, Rachel Tennant, James Wilson

Pre-college teachers:

Nick Oehm, Teresa Casal, Catherine Laroche

High school students:

Vanessa Castellanos, Erikamarie Gil, Vanessa Novoa, Jonathan Prendergast, Christopher Sanchez

Technicians, programmers:

Robin Bennett, Daniel Bond, Alex Croft, Kevin Cunniff, Jeana Drake, Brett Gallagher, Chuck Goss, Imrul Hack, Steve Kelly, Mark Kershaw, Andrew Jungman, Greg Losada, Amanda McDonald, Jennifer Mellein, Alaina Owens, Christina Pisani, Linda Powell, Mike Rugge, Pablo Ruiz, Timothy Russell, Olga Sanchez, Brooke Shamblin, Adele Tallman, Franco Tobias, Rafael Travieso, Josh Walters, Matthew Wilson

B. Partner Organizations

- College of William & Mary: Collaborative Research; Personnel Exchanges
- Ecology and Environment, Inc.: Collaborative Research; Personnel Exchanges
- Everglades Foundation: Collaborative Research; Personnel Exchanges
- Everglades National Park: Collaborative Research; Personnel Exchanges
- Florida Gulf Coast University: Collaborative Research; Personnel Exchanges
- Florida State University: Collaborative Research; Personnel Exchanges
- Harbor Branch Oceanographic Institute: Collaborative Research
- Indiana University: Collaborative Research
- Louisiana State University: Collaborative Research; Personnel Exchanges
- Miami-Dade County Public Schools: Collaborative Research; Personnel Exchanges
Two of our Education and Outreach coordinators (Susan Dailey and Nick Oehm) have taught and given FCE LTER presentations at Miami-Dade County Public Schools. Our Research Experience for Teachers (RET) and Research Experience for Secondary Students (RESSt) programs have included teachers and students from Miami-Dade County Public schools.
- Michigan State University: Collaborative Research; Personnel Exchanges
- National Aeronautics and Space Administration: Collaborative Research; Personnel Exchanges
- National Audubon Society: Collaborative Research; Personnel Exchanges
- Nova Southeastern University Oceanographic Center: Collaborative Research; Personnel Exchanges
- The Pennsylvania State University: Collaborative Research; Personnel Exchanges
- South Florida Water Management District: Financial Support; In-kind Support; Collaborative Research
- Sam Houston State University: Collaborative Research
- Texas A&M University Main Campus: Collaborative Research; Personnel Exchanges
Collaborations with Stephen Davis.
- Texas A&M University at Galveston: Collaborative Research; Personnel Exchanges
- U.S. Department of the Interior: In-kind Support; Facilities; Collaborative Research

- Department of Interior U.S. Geological Survey: In-kind Support; Collaborative Research
- University of Alabama: Collaborative Research; Personnel Exchanges
- University of Colorado: Collaborative Research; Personnel Exchanges
- University of Florida: Collaborative Research; Personnel Exchanges
- University of Miami: Collaborative Research; Personnel Exchanges
- University of Miami Rosenstiel School of Marine & Atmospheric Science: Collaborative Research; Personnel Exchanges
Jack Fell through a separately funded NSF grant.
- University of North Carolina at Chapel Hill: Collaborative Research; Personnel Exchanges
- University of North Carolina at Wilmington: Collaborative Research; Personnel Exchanges
- University of South Florida: Collaborative Research; Personnel Exchanges
- University of Virginia: Collaborative Research; Personnel Exchanges
- Miami-Dade County, Department of Planning and Zoning: Collaborative Research

C. Other collaborators

We have maintained important collaborative partnerships with 5 federal agencies (Everglades National Park, USGS, NOAA, EPA, and NASA-JPL) during the fourth year of the FCE II LTER Program. We also partner with 1 state agency (South Florida Water Management District), 2 NGOs (Everglades Foundation and the National Audubon Society), and 19 other universities (Louisiana State University, College of William & Mary, Texas A&M University, and University of South Florida through subcontracts).

Some examples of specific collaborations include:

- Ft. Lauderdale Museum of Discovery and Science (working on a kiosk displaying work in consumer group; Heithaus collaborator)
- Don DeAngelis (Faculty, University of Miami; Trexler collaborator)
- Frank Mazotti (Faculty, University of Florida; Heithaus collaborator)
- Joe Boyer continued his collaboration with Linda Amaral-Zettler at International Census of Marine Microbiology, (ICoMM) (icomm.mbl.edu), Marine Biological Laboratory.
- The FCE Human Dimensions group is collaborating with Miami-Dade County's Department of Planning and Zoning to develop a methodology to incorporate historic zoning data into a GIS platform.
- Through our Education and Outreach program, we have developed strong working relationships with: Felix Varela Senior High School; Miami Dade County Public Schools; Miami Dade College Department of Biology, Health, and Wellness; Miami Dade College School of Education; Science Approach, LLC; and the Everglades Digital Library. We also work closely with CEMEX USA aggregate mining corporation and the Ft. Lauderdale Museum of Discovery and Science as our primary community partners.

II. ACTIVITIES AND FINDINGS

A. Research Activities

The second phase of Florida Coastal Everglades (FCE) research (FCE II) focuses on understanding how dissolved organic matter (DOM) from upstream oligotrophic marshes interacts with a marine source of phosphorus, the limiting nutrient, to control estuarine productivity in the estuarine ecotone. We also now incorporate a socio-ecological theme to our work, aimed at understanding how land use changes affect local ecological dynamics in south Florida. Our 15 ecological research sites are located along freshwater to marine transects in the Shark River Slough (SRS), and the Taylor Slough/Panhandle (TS/Ph) regions of Everglades National Park, in addition to a land use transect that cuts across southern suburban Miami-Dade County. FCE II research is organized into 4 working groups (Primary Production, Organic Matter Dynamics, Biogeochemical Cycling, Trophic Dynamics and Community Structure) and 4 cross-cutting themes (Hydrology, Human Dimensions, Climate and Disturbance, Modeling and Synthesis).

In this section, we include summaries of the third year of research by FCE II working groups, cross-cutting theme groups, and information management activities below. Our education and outreach activities are included in Sections C and D of this report. In addition, we have included a discussion of “science planning” activities after the working group reports.

1. Working Group Reports

a. Primary Production

Freshwater marsh

Two eddy covariance towers have been operating continuously at FCE-LTER sites TS/Ph1b and SRS2, sites that represent contrasting short- and long-hydroperiod marshes, respectively. Data collected at these towers on a half-hourly basis include carbon dioxide (CO₂), water, and energy exchange, as well as a suite of ancillary meteorological data. Other activities at these sites include monthly chamber measurements of ecosystem CO₂ exchange, periodic leaf-level photosynthesis measurements, and ongoing assessment of leaf area index.

Periphyton

We continue to measure periphyton biomass, productivity composition at FCE LTER sites. We are interpreting long-term trends in relation to those gathered from joint large-scale landscape surveys in the Everglades and Florida Bay and field and laboratory experiments. These data are being combined into models that predict changes in periphyton biomass, composition and nutrient content from hydrologic, water chemistry and other abiotic and biotic variables. Effects of variability in periphyton abundance, composition and quality on consumer standing stocks and composition continue to be examined using these surveys and linked experimental work in collaboration with Joel Trexler and the Trophic Dynamics group. We are also pursuing an understanding of mechanistic linkages between periphyton attributes to variability in hydrology,

light, nutrients and vegetation through field and lab experiments, presented in the thesis of FCE student Jay Munyon. In particular, manipulations of periphyton in laboratory chemostats have been revealing triggers for the pervasive inverse relationships of periphyton production to nutrient availability (Munyon 2010). Species-based models that predict salinity, nutrient availability and habitat structure are being used to environmentally calibrate sediment cores from the ecotone and Florida Bay so that modern fluctuations apparent in FCE data can be placed in a long-term context (Wachnicka et al., 2010; In Press). Through a joint DOE-NCCR project, we have been manipulating periphyton and plant production to determine controls on CO₂ sequestration or evasion in peat and marl-forming environments, and these findings will be interpreted with respect to atmospheric eddy covariance data obtained from our two marsh flux towers (Munyon 2010).

FCE graduate student, Sylvia Lee, is working on a master's thesis concerning Everglades diatom communities with major funding from the Everglades Foundation. The project aims to use CERP-MAP diatom data from 2005 through 2008 to develop landscape scale models represented visually on GIS maps. The models will show which regions of the Everglades have communities that are sensitive to change and therefore, should be the regions where restoration efforts are prioritized. The measure of sensitivity will be developed using trajectory analysis, which tracks the progression of individual communities through time in relation to important environmental drivers and determines whether the trajectories are moving toward or away from restoration goals. Preliminary analysis of data from 2005 and 2006 showed significant trajectories of communities in relation to periphyton total phosphorus and DSLD (days since last dry down).

Sawgrass

We continue to measure *Cladium* biomass on a bimonthly basis and calculate annual net aboveground productivity at freshwater slough sites TS/Ph1b, 2, 3 and 6 and SRS1-3. We have been exploring relationship of *Cladium* productivity to hydrologic and nutrient drivers.

Seagrass Ecoystems

We continue to assess primary production of the seagrass ecosystems in the FCE-LTER domain every 2 months. On these trips, we have been measuring seagrass leaf productivity using standard hole punch methods and periphyton productivity as described above since 2000. We have also been assessing the effect of addition of nitrogen and phosphorus to the benthic ecosystem across a natural fertility gradient in Florida Bay. This year we began the analysis of the interactions between light, nutrients, and community metabolism in this experiment. We also tested the relative importance of top-down and bottom-up effects on controlling primary producer biomass by experimentally evaluating the combined and separate effects of nutrient availability and grazer species composition on epiphyte communities and seagrass condition in Florida Bay.

Mangrove ecosystems

We investigated landscape patterns of above- and belowground biomass and Net Primary Productivity (NPP) of mangrove in sites along two Florida Coastal Everglades (FCE) estuaries: Shark River estuary (SRS-4, SRS-5, SRS-6) and Taylor River Slough (TS/Ph-6, TS/Ph-7, TS/Ph-8). In December 2000, two 20 x 20 m permanent plots were established between 30-50 m from shoreline in each site to monitor forest structural attributes and soil biogeochemical properties. In

addition, at the Shark River sites two transects, ranging from 100 to 200 m in length depending on the mangrove forest extension at each site, were established perpendicular to the shoreline in May 2002 to evaluate the spatial distribution, species composition and growth of mangrove species. All trees with diameter at breast height (dbh) ≥ 2.5 cm were tagged and initially measured within plots (May 2001) and transects (May 2002), and re-measured every year until May 2004. Mangrove trees were not measured at TS/Ph-6 & 7 due to the stunted physiognomy (tree height ≤ 1.5 m) of the mangrove forest.

Aboveground wood biomass was calculated for each individual tree tagged within plots and transects using species-specific allometric equations published for the study area. The annual net increase in wood biomass was calculated as the difference between the initial and final biomass within plots (2001 and 2004) and transects (2002 and 2004) of each individual tree. Litter production was measured in all Shark River sites and TS/Ph-8 from January 2001 to December 2005. At TS/Ph-6 & 7, litterfall production was not estimated due to the stunted physiognomy (tree height ≤ 1.5 m) of the mangrove forest. Litterfall was collected in 0.25 m^2 wooden baskets supported approximately 1.5 m aboveground, and the bottom of each basket was constructed of fiberglass screening (1 mm mesh). In each mangrove site, ten litter baskets were randomly placed inside the two 20 x 20 m permanent plots (5 baskets per plot). Litterfall was collected at monthly basis from each site. Root biomass and production was calculated for each of the FCE mangrove sites. Results from this study were reported in the 2009 FCE Annual Report. Total (to a depth of 90 cm of mangrove soils) root biomass was used to calculate the root:shoot ratio for all six sites and total root production was used to estimate the contribution of roots (NPP_B) to total NPP (NPP_T). Total root production represents the sum of fine (< 2mm in diameter), small (2-5 mm), and coarse (5-20 mm) root size classes. Root size classes >20 mm in diameter were not included in this study. Total NPP (NPP_T) represents the contribution of litterfall (NPP_L) + wood (NPP_W) + roots (NPP_B) for each mangrove site. We report on changes in biomass and NPP before the passage of Hurricane Wilma on October 2005 across our mangrove sites.

We also investigated the presence of non-native mangrove trees in the mangrove forests of south Florida. At least 2 species of southeast Asian mangroves have escaped cultivation in botanic gardens and are now expanding in south Florida. We estimated the areal extent of these invasions and estimated population growth rates from historical records of their abundance.

b. Organic Matter Dynamics

Mangrove zone research (Twilley et al.)

We investigated long-term (2001-2009) patterns of porewater biogeochemistry of mangrove sites along two Florida Coastal Everglades (FCE) estuaries: Shark River estuary (SRS-4, SRS-5, SRS-6) and Taylor River Slough (TS/Ph-6, TS/Ph-7, TS/Ph-8). In December 2000, two 20 x 20 m permanent plots were established between 30-50 m from shoreline in each site to monitor soil biogeochemical properties. Within each site, four repeated sampling stations were randomly established in each plot to measure porewater salinity, temperature ($^{\circ}\text{C}$), porewater nutrients and sulfide concentrations, and soil redox potential (Eh). Porewater samples were collected at 30 cm depth during the dry (May) and wet (October-November) seasons from 2001 to 2009 in all sampling stations. One porewater aliquot was assayed for temperature and salinity using a portable YSI salinity-conductivity-temperature meter (model 30, YSI Incorporated, Yellow

Springs, Ohio). A second sample was added to an equal volume of antioxidant buffer in the field and transported to the laboratory within 12 h to be analyzed for sulfide concentrations with a silver/sulfide electrode (model 9616BN, Orion Research, Beverly, MA). A third porewater sample was filtered using a GF/F filter and stored frozen until assayed for ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), soluble reactive phosphorus (SRP) using a segmented flow analysis Flow Solution IV autoanalyzer (OI Analytical, College Station, Texas). Nitrate concentrations have been measured since 2004 due to analytical problems with the analysis during previous years. Soil Eh (0, 10, 45 cm depth) was measured by duplicate in situ using a multi-depth platinum probe. Porewater sampling on the Taylor River (TS/Ph-6 & 7) sites was conducted up to 2006; and reestablished in May 2010.

Soil research (Chambers et al.)

This year continued the study-wide collection and analysis of soil cores for bulk organic matter, soil bulk density, and total carbon, nitrogen, and phosphorus. Soil extracts for inorganic sulfur and iron species were also completed. All of the extractions and analyses were completed by undergraduate research students at the College of William and Mary.

Paleoecological and soil accretion (Saunders et al.)

We continue to gather radiometric-based (^{137}Cs and ^{210}Pb) soil accretion rates from each of the FCE LTER sites, as part of an overall review of Everglades accretion studies. In the past year, we collected accretion rates from sawgrass habitats situated along a transect spanning FCE sites TS/Ph-3, TS/Ph-6 and TS/Ph-7, and including two additional sites, one in the white zone (intermediate to TS/Ph-3 and TS/Ph-6) and one near Pond-5 (intermediate to TS/Ph-6 and TS/Ph-7).

Organic geochemistry (Jaffé et al.)

Our group continues to investigate the sources, fate and transport of floc in the Everglades ecosystem. As such we continue to determine floc depth, in-situ density, chemotaxonomy and biomarker composition of both floc and periphyton from the FCE sites on a quarterly basis. The database is finally coming together to allow some statistical analyses of the results. In addition, we continue to assess both photo- and bio-reactivity of floc at one freshwater and one mangrove site in the FCE. Photochemically induced dissolution of floc and the resulting production of DOC, TN and TP was determined and suggested to potentially be an important contributor to the Everglades DOC pool. Bioincubation (respiration rates) were also determined to assess microbial recycling of floc.

With regards to dissolved organic matter (DOM) we continue to determine monthly DOM optical characteristics (UV-Vis and Fluorescence) to increase our existing database on DOM quality. In addition, we have continued making progress in assessing both reactivity (photo- and bio-) of DOM and have started generating the first data of its kind of DOM-associated black carbon in the Everglades as well as for other freshwater systems including the BNZ and KNZ LTER sites (inter-LTER collaboration). The black carbon work included fine tuning and development of methodological improvements of the analytical techniques.

Lastly, we have significantly advanced our research on applying biomarkers, in particular fatty acid distributions, is assessing trophic level dynamics in the Everglades. This is a collaborative

effort between the Organic Matter Dynamics group and the Trophic Dynamics and Community Structure group of the FCE. Findings can be found in the section corresponding to the Trophic Dynamics and Community Structure group.

c. Biogeochemical Cycling

Baseline Water Quality

For both SRS and TS, collections of samples for water quality, primary productivity, soil nutrients/physical characteristics, and physical data (rainfall/water level) are used to help answer key FCE-LTER questions. Dissolved and total nutrient analyses were carried out at all LTER sites in conjunction with SERC Water Quality Monitoring Network.

Microbial Dynamics

Three procedures were performed each month for all FCE II sites: bacterial production, bacterial enumeration, and the measurement of pigment, quantum yield, and excitation characteristics of phytoplankton using Phyto-PAM. Heterotrophic bacterial production is determined using tritiated 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 samples were analyzed using PAM fluorometry for CHLA content and productivity irradiance curves.

Microbial 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 is extracted from the samples using a FastDNA SPIN kit (for soil) and the extracted DNA is then amplified through PCR T-RFLP analysis.

Biogeochemical Cycling

Upstream/downstream sampling of mangrove ecotone

As part of a project funded by NOAA, collaborators from TAMU, LSU, and FIU have been looking at the influence of salinity and season on nutrient dynamics along the stretch of Taylor River, between TS-Ph6 and 7. During each 1-week sampling, water temperature, salinity, pH, and dissolved oxygen are measured at each sampling station hourly with a calibrated sonde. We also sample surface water at each site every six hours and analyze for nitrogen (total and inorganic) and the phosphorus (total and inorganic) content.

Sediment core flux studies

Beginning in January 2007, we initiated a set of experiments to quantify the vertical exchanges of nutrients (N and P) and DOC between the benthos and water column at various sites along Taylor River. During this first set of pilot incubations, we collected sediment/soil cores from two inland (TS/Ph 7 and Pond 1) and two bay sites (Little Madeira Bay east and west of Taylor River mouth). The surrounding of TS/Ph 7 is vegetated with dwarf mangrove. Both Little Madeira Bay sites were covered with seagrass (*Thalassia testudinum*). These samplings have been repeated through the May 2008 sampling. Beginning in May 2007, we also began

amending the water column (in a separate set of incubations) with 1 μM P (> 10X ambient concentrations) in order to understand the effects of limiting nutrient additions on benthic exchanges. Intact sediment cores were contained in the lower part of core tubes with overlying site water. Ten replicate cores from same study site were carefully placed in water bath tank to control water temperature. 20 L site water was pre-filtered with 0.2 mm pore size filter prior to incubation. Sediment cores were incubated in the water bath and overlying site water was replaced with filtered site water. Magnetic stirrers maintained the overlying filtered water in a homogeneous state without disturbing the sediment. Prior to the initiation of each incubation, we measured initial dissolved oxygen (DO) and took water samples for analysis of nutrients and DOC. At the conclusion of each incubation (approximately 4 hours), we measured final DO and took samples for analysis of nutrients and DOC. DO was recorded with a YSI Oxygen Sensor through the sampling port of each core. NO_3+NO_2 , NH_4 , SRP, and DOC samples were analyzed according to the methods described above.

Tamiami Swales Project

In a project related to modifications to Tamiami Trail, we have been monitoring water quality and periphyton characteristics at the Tamiami Pilot Swales sites. Monitoring began in October 2009 and will continue for at least one year subsequent to the installation of spreader swales at the sites. Water quality samples have been collected monthly from a series of grab sample sites located downstream of Tamiami Trail and daily by ISCO autosamplers at the extreme southern end of each site. Periphyton has been collected bi-monthly at each of the water grab locations. Additional water and periphyton monitoring is ongoing at two reference locations (SRS1-D and NESS-8) located to the south of the Swales sites.

d. Trophic Dynamics and Community Structure

Over the past year the consumer group has continued studies from the marshes to the coastal oceans. Studies in marsh communities have focused on maintaining time-series data on consumers populations and elucidating the factors influencing recolonization of marshes after drying events. The group also has continued studies of fish communities in the marsh-mangrove ecotone to elucidate trophic interactions and community dynamics. Specifically, we sampled fish assemblages in mangrove habitats along the SRS transect to examine the effect of hydrological conditions (e.g., marsh water levels and salinity) on predator-prey interactions among freshwater, estuarine and marine fishes. Because of our interest on how hydrology creates context-dependency for predator-prey interactions, food-web structure, and energy transfer, we conducted stable isotope and dietary analyses on key mesoconsumers. This year, we began sampling of fish communities using similar electrofishing techniques in canals bordering ENP to further understand how hydrological heterogeneity (or lack thereof) affects fish community structure and function.

In downstream portions of the estuary, studies have focused on factors driving movements and trophic interactions of top predators including American alligators and juvenile bull sharks. New studies have been initiated on mesoconsumers in downstream areas of the Shark River Estuary and on the abundance and distribution of bottlenose dolphins and large sharks. We also have expanded our work on alligators to collect stomach contents and a laboratory study of turnover rates of stable isotopes in various alligator tissues to aid interpretation of field data.

In Florida Bay, we tested the hypothesis that resting schools of fish sheltering on reefs would fertilize the seagrass beds around the artificial reefs and change the benthic community structure. We deployed nine artificial reefs constructed from 14 concrete blocks (20 cm × 20 cm × 40 cm) arranged in a pyramid formation. We also designated nine control plots, for a total of 18 experimental units, which were distributed randomly in a 3 × 6 grid with 5 m spacing between experimental plots. We conducted visual counts of the abundance of large conspicuous fish and invertebrates to ensure that the artificial reefs did in fact serve as attractants. Sediment nitrogen and phosphorus concentrations were measured from sediment cores. Chlorophyll *a* (Chl-*a*) concentrations in surface sediment were measured as a proxy for benthic microalgal biomass. The abundances and morphology of primary producer species were measured using a modified Braun Blanquet method. Nitrogen and phosphorus concentrations were measured in the tissue of seagrass species. The abundance of Chl-*a* was measured on periphytometers deployed in each plot to determine if a changing nutrient environment might be reflected in increased abundances of periphyton.

In 2010, due to an unusual January cold snap, we conducted additional sampling (i.e., visual surveys) to document the mortality effects on both native and nonnative taxa. Many of the native marine and estuarine species have a subtropical and tropical distribution, reaching their northern distributions in south Florida, and thus experience hypothermal stress during occasional extreme cold temperature events, with important consequences for population dynamics. The 16 nonnative fishes are also mainly of tropical origin, and subject to thermal stress.

A final area of new work has been collaborating with the Organic Matter working group to develop biomarkers (including fatty acids and compound specific isotopes) to determine the contribution of detritus to food webs and to gain more detailed insights into trophic interactions in the marsh and downstream areas than is possible with bulk stable isotopes.

e. Hydrology

One specific question guiding the hydrological research in FCE II is: Will an increase in inflows from the upstream Everglades affect the position of the oligohaline ecotone and change the geochemical conditions in the ecotone by suppressing brackish groundwater discharge? To answer this question, we used a number of techniques to quantify surface water flow rates as well as groundwater discharge estimates in both Taylor and Shark Sloughs. These techniques included the use of water budgets, water flow and water level measurements, inert and geochemical tracers, as well as temperature and heat flux measurements and modeling.

Taylor Slough Water Budget

Groundwater and surface water samples from FCE sites TS/Ph-7b, TS/Ph-6b, TS/Ph-3 as well as surface water from the mouth of Taylor River were collected monthly until December 2009. Pressure transducers installed in the surface water and groundwater at sites TS/Ph-7b and TS/Ph-6b continued to monitor water levels, conductivity/salinity and temperature at every 30 min. Furthermore the weather tower at TS/Ph-7b continued to operate throughout the year.

Xavier Zapata-Rios, an M.S. student in geosciences at FIU completed his thesis entitled “Groundwater/Surface Water Interactions in Taylor Slough Everglades National Park” in December 2009. Before graduating, he presented the results of his research at the 2009 Long Term Ecological Research Network All Scientist Meeting, in Estes Park, Colorado in September 2009 and at the American Geophysical Union’s 2009 Fall Meeting in San Francisco, CA in December 2009. The results of his research were further presented as an oral presentation by his advisor, Dr. René Price, at the Greater Everglades Ecosystem Research Meeting in Naples, FL in July 2010. A paper summarizing the results of his thesis is currently being prepared for submission to a scientific journal.

Taylor River Floc Tracer Experiment

Greg Koch, an FIU Ph.D. student along with scientists from the SFWMD, introduced a synthetic, para-magnetic, floc-resembling tracer (www.partrac.co.uk) to the floor of three Taylor River creek habitats (Fig. 5.1) in December 2009. The tracer was frozen in shoe-box sized cubes weighed down with stones. As the ice in the cubes melted, the tracer particles were freed to move through the system via water energy alongside natural detritus. They then captured the floc tracer particles after one week at sites both upstream and downstream of the release location using stationary magnetic rods (Fig. 5.2). The magnetic rods had a field of influence of approximately 2cm, capturing all tracer particles that pass within the field. Tracer particles were separated from the magnets in the field, dried at 60°C, and weighed to obtain a total amount of tracer that was collected on each magnet.

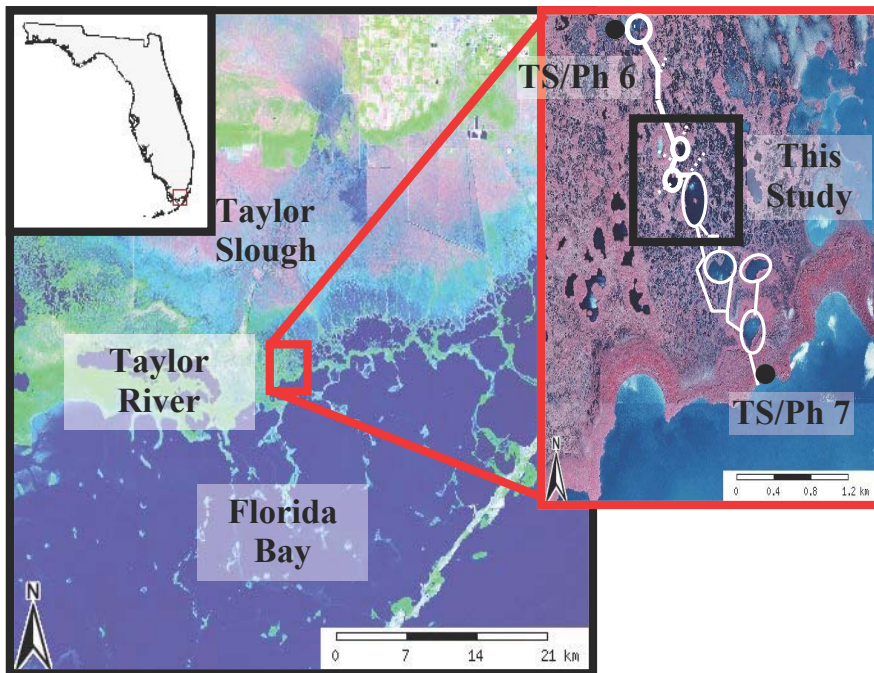


Figure 5.1: Satellite imagery showing the location of Taylor River within the Taylor Slough watershed of Everglades National Park. This research was conducted in three ponds (from south to north: Pond 3, Pond 4, and Pond 5) midway between FCE LTER sites TS/Ph6 (upstream) and TS/Ph7 (downstream).

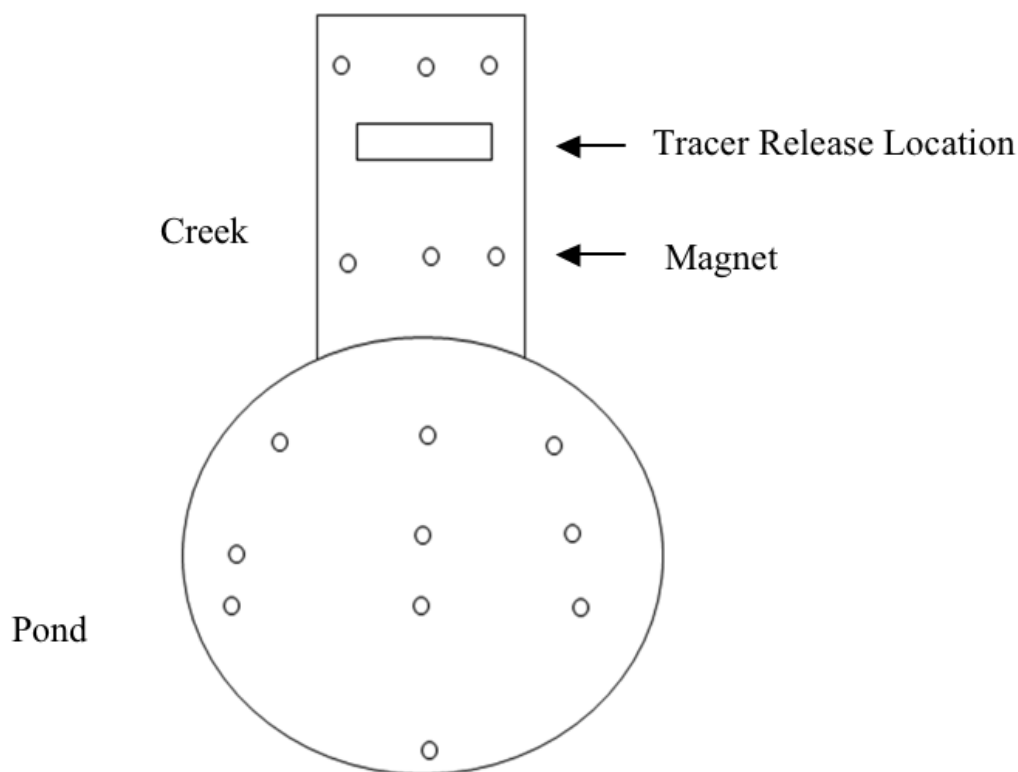


Figure 5.2: Schematic of magnet placement within a Taylor pond-and-creek pair. Frozen cubes of tracer were deployed on the floor of the creek sites and liberated tracer particles were captured both upstream and downstream of the release site.

Shark Slough Water Budget

Dr. Amarty Saha, postdoctoral researcher supported between the Hydrology and Modeling and Synthesis groups completed monthly and annual water budgets of Shark Slough for the years 2002-2008. That time period serves as a baseline for comparison of the effects of future restoration efforts that are expected to be finalized within the next decade. Inputs to the water budget include surface water inflows via hydraulic structures and precipitation, while outputs consist of evapotranspiration, discharge to the Gulf of Mexico and seepage losses to an eastern bordering canal. Using a mass balance approach, daily change in volume of SRS (from stage changes) is equated to the difference between input and outputs yielding a residual term, that includes error in each of the components as well as net groundwater exchange. In addition, collaborating with Dr. Christopher Moses, a postdoctoral research supported by the Climate group on correlations between groundwater discharge with groundwater and surface water salinity in the mangrove ecotone of Shark Slough. The results of their research were presented in poster format at the 2009 Long Term Ecological Research Network All Scientist Meeting, in Estes Park, Colorado in Sept., the Greater Everglades Ecosystem Research Meeting in Naples, FL in July 2010, and at the American Geophysical Unions Meeting of the Americas Conference in Iguassu Falls, Brazil in August 2010. A paper with the tentative title of “*A hydrological budget (2002-2008) for a large subtropical wetland ecosystem indicates seawater intrusion accompanies diminished freshwater flow*” is currently being prepared for submission to a scientific journal.

Surface water flow rates and levels continued to be monitored along the SRS transect. Two new Sontek Argonaut ADV cross-channel flow meters were installed at SRS-4 and SRS-6 in May 2010. Flow meters are now operating at SRS-1d, Gumbo Limbo tree island, SRS-2, SRS-4, and SRS-6. A flow meter to be installed at SRS-3 has been at the manufacturer for repair for most of the year, and will be installed in the Fall of 2010. Data from these flow meters was recently published in the journal *Wetlands*: He G, Engel VC, Leonard L, Croft A, Childers D, Laas M, Deng Y, and Solo-Gabriele H. 2010, *Factors controlling surface water flow in a low gradient subtropical wetland*, *Wetlands*, 30: 275-286. Furthermore, another paper utilizing data from these flow meters was submitted and accepted for publication in the *Journal of Hydrology*: Solo-Gabriele H. and others, *Impacts of Hurricanes on Surface Water Flow within a Wetland*.

Temperature as a Tracer

Dr. Mark Rains of University of South Florida and his graduate student Victoria Spence initiated a project aimed at using heat as a natural tracer to study ground-water discharge over the course of seasonal and tidal cycles in the mangrove ecotone regions of both Shark and Taylor Sloughs. In May 2010, they installed three vertical thermocouple sensor arrays to depths of 2 m or the top of bedrock, whichever was encountered first, at sites TS/PH-6b, TS/PH-7b, SRS-4 and SRS-6. Each vertical thermocouple sensor array consisted of a non-conductive wooden dowel with external thermocouples deployed at regular depths. Thermocouples were wired to data loggers mounted above high water. The first data were downloaded in July 2010, but have not been analyzed except inasmuch as was necessary to ensure that the instrumentation appeared to be operating correctly. Data will be analyzed using VS2DH, a code for simulating coupled water and heat transport (Healy and Ronan 1996), through VS2DI, a graphical-user interface that facilitates the application of VS2DH in specific problems (Hsieh et al. 2000).

Geochemical Tracers

In order to determine the sources of water, the interactions between the sources of water as well as to calculate residence times of different water source reservoirs and evaporative enrichment, the surface water samples collected along the SRS and TS/Ph transects were analyzed for major anion and cation concentrations (i.e., Cl, SO₂, Ca, K, Mg, and Na) using a Dionex 120 ion chromatograph by David Lagomasino, an FIU Ph.D. student, and Estefania Sandoval, an FIU undergraduate student. Each (1 L) sample that was collected by the ISCO 6172 autosampler was split in half in the laboratory, with one half analyzed for major cations and anions at FIUs hydrogeology laboratory and the other analyzed for total nutrient concentrations at SERCs Nutrient Laboratory. Prior to being analyzed for major cations and anions, the sample was filtered and split again with one half acidified with 10% HCl for the cations analysis. To date, Shark Slough samples collected from August 2008 through December 2008 and August 2009 through December 2009 have been analyzed. Taylor Slough samples collected between August 2008 and December 2009 have been analyzed to date.

Hydrologic/Vegetation Modeling

Vic Engel of ENP, and colleagues from Georgia Tech University (Dr. Marc Stieglitz, Y. Chen, and G. Turk) used a 2D advection-diffusion model developed by Rietkerk et al (2004) to describe the formation of vegetation patterns and peat formations which were parallel to the prevailing flow direction in the sawgrass (*Cladium jamaicense*) ridge and slough habitat of the Everglades, Florida, USA. They retained the basic equations of the Rietkerk model but allowed

for constant advection of water and nutrient to simulate gravitational flow, with evapotranspiration-driven advection of water and nutrients perpendicular to the downhill flow direction. To enhance understanding of fundamental processes that govern pattern formation, they employed advanced visualization techniques to improve simulation: Line Integral Convolution for flow visualization and Voronoi Tesselation Algorithm for tracer visualization.

Hydrology Working Group International Collaborations

Vic Engel of ENP and the Hydrology Group Co-lead, co-sponsored a special session entitled “Linking Hydrology and Nutrient Cycling in Large Wetland Ecosystems” at AGU’s Meeting of the Americas, held between 8-12 August 2010 in Iguassu Falls, Brazil. The session contained 8 talks and 4 posters of research conducted in both the FCE LTER and the Pantanal wetlands of Brazil. In addition, Vic Engel led an expedition of 8 FCE LTER researchers to the Pantanal where they met with scientists from the Pantanal Research Centre (CPP). During the trip they exchanged talks as well as explored a portion of the Pantanal wetlands. This effort is expected to result in proposals to initiate cross-site comparative research between the two wetland ecosystems.

NASA Waterscapes Research

The NASA funded project: *WaterSCAPES: Science of Coupled Aquatic Processes in Ecosystems from Space* is a 5-year, \$5M project based at FIU to develop a quantitative understanding of how wetland ecosystems are changing over time and space. The objective of *WaterSCAPES* is to quantification the stocks and fluxes of water, nutrients and biomass as they couple and aggregate into the spatial and temporal organization and adaptation mechanisms of vegetation at the ecosystems level. The research activities combine satellite imagery with field measurements and mathematical modeling performed on two wetland ecosystems: the Everglades of South Florida and the Sian Ka’an Biosphere Reserve in the Yucatan peninsula of Mexico. Research from this ancillary project is directly applicable to the main goals and hypotheses of the FCE LTER. Furthermore, an FCE LTER PI (Dr. René Price), collaborator (Dr. Fernando Mirrales-Wilhelm) and students (David Lagomasino, Pamela Sullivan, and Estefania Sandoval) are associated with both projects. The FCE LTER benefits from the research and findings obtained from this complementary project, and therefore, activities conducted in the past year as related to the hydrology group of the FCE LTER are included herein.

Using Remote Sensing to Estimate Evapotranspiration in Everglades National Park

A preliminary attempt was made by FIU Ph.D. student David Lagomasino to create and apply an evapotranspiration (ET) model using Landsat 5 TM images of ENP from the dry and wet seasons of 2008. Images collected from Landsat 5 TM were acquired from the NASA database. Cloud-free images from the dry and wet season of 2008 were selected and atmospherically corrected with the ATCOR2 model using ERDAS Imagine 9.3. The Landsat 5 TM images were also used to determine the location of mangrove vegetation using spectral methods described in Green et al. (1998) as well as to determine locations of pixels containing water.

An ET model was designed based on a modified version of the satellite-based ET model from Boegh et al. (2002). Calibration and input parameters of surface temperature, radiation (e.g., net, total, and longwave), and sensible heat fluxes were collected at half-hour intervals since 2006 from one eddy-covariance tower in southern Shark River (Table 5.1). Net radiation (R_n), soil

heat flux (G), and water heat flux (W) were calculated using equations shown in Fig. 5.3. Water heat flux was only determined for wet pixels using $Wet_pixels=NIR<10$, where NIR is the near-infrared wavelength, with the assumption that the wet pixels indicate standing water. Raster grids were calculated for R_n , G , and ET using the equations shown in Fig. 5.3.

	Field measured		Satellite-based	
	Apr-08	Jun-08	Apr-08	Jun-08
G	56.9*	13.3*	103.5	60.4
R_n	593.9	560.9	594.3	555.1
λE	184.3	92.9	359.4	294.7
	4.6-9.1;	2.1-3.5;		
ET	17.3-19.6	4.8-5.4	12.72	10.43

Table 5.1: Field-derived input values into the satellite-based ET model and the ranges of ET calculated.

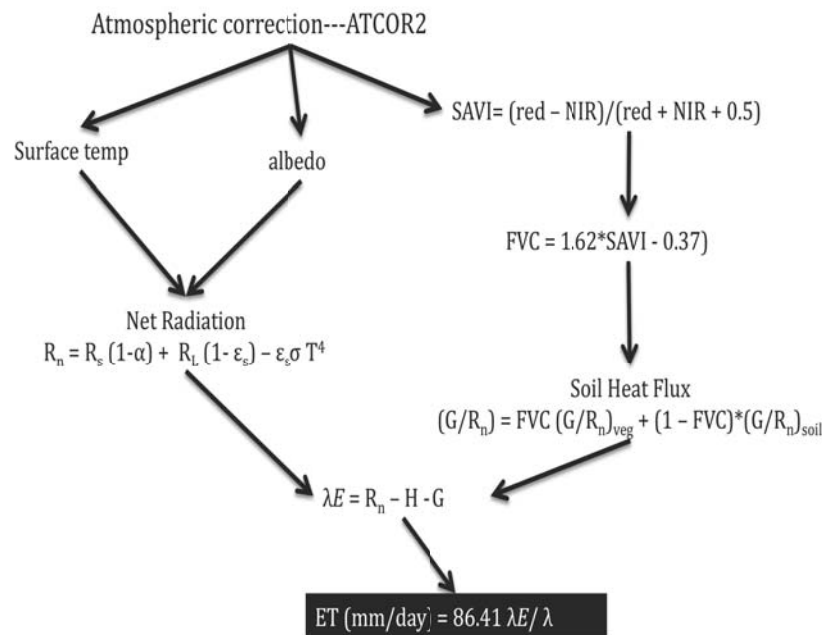


Figure 5.3: Schematic diagram of evapotranspiration model

Availability of groundwater and its associated nutrients in a Shark Slough tree island

This research was conducted by FIU Ph.D. student Pamela Sullivan, and involved determining groundwater-surface water interactions, their influence on water chemistry and their relationship

to the location and patterns of vegetation in tree islands. In order to investigate groundwater-surface water exchange at Satinleaf tree island, groundwater levels were monitored in three shallow (0.85m) wells from May 2009 through June 2010 (Fig. 5.4). In addition, surface water levels were monitored in the adjacent slough using HOBO U20-4 Water Data Loggers. An additional logger was placed in the air on the tree island to compensate the water level readings for barometric pressure. Three of the groundwater wells and two surface water sites were sampled bimonthly from October 2008 through June 2010 for chemical analysis. In addition to the wells, groundwater was collected from 10 shallow portable samplers in September 2009, January 2010, March 2010 and June 2010. These portable samplers were in the marsh and edge of the tree islands and formed one north-to-south transect and three east-to-west transects originating for the well locations.

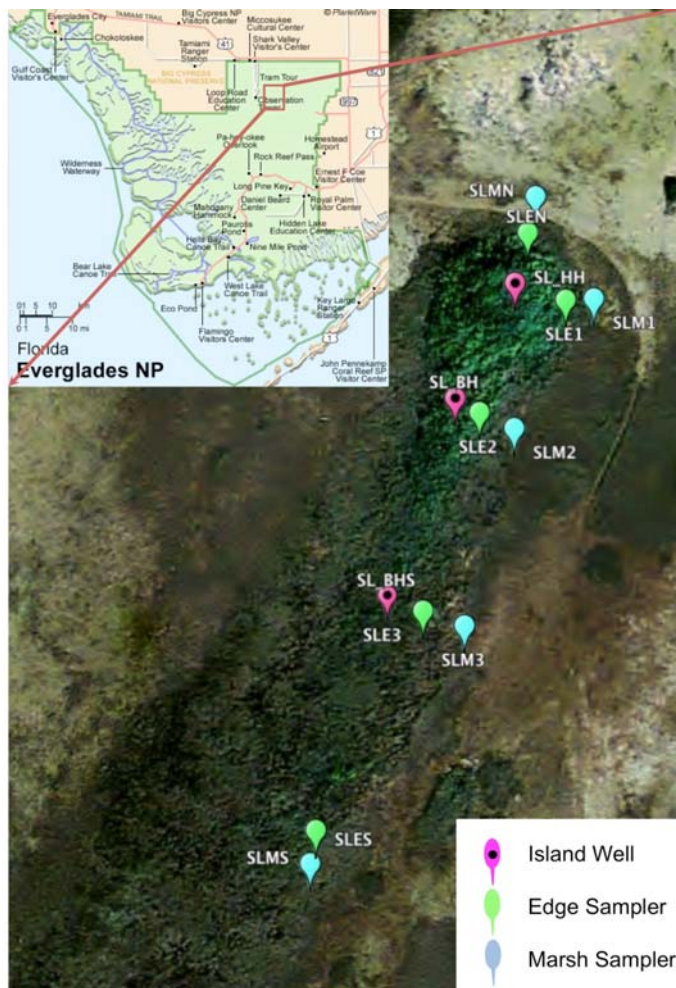


Figure 5.4: Water levels in three groundwater wells (pink) and one surface water site were monitored from May 2009 through June 2009 on Satinleaf tree island. Surface water and groundwater samples were also collected from the wells and from 10 portable sippers (green and blue) from Oct. 2008 – June 2010 for chemical analysis.

Modeling the Effects of Rising Sea Level and Storm Surge on Coastal Vegetation Communities

The spatially explicit mechanistic model, MANHAM, developed by Sternberg et al. (2007) and Teh et al. (2008) demonstrated that salinity change in the vadose zone, due to hurricane induced storm surges, can be a key trigger for vegetation shifts in coastal areas of ENP (e.g., from freshwater hardwood hammock vegetation to mangroves). However the model makes

simplifying assumptions regarding water movement in the vadose zone. The objectives for the past year were to improve on the realism of the MANHAM model, in particular, by modeling water and salinity movement in the vadose zone at finer spatial resolution and modeling the plant dynamics more realistically. We used individual based modeling to model mangrove and hardwood hammock tree dynamics, simulating the ontogenies of individual trees, because that allowed us to keep track of the size distribution within these forest areas (Berger et al. 2008), which is crucial to its interaction with the light and salinity environment. The individual based modeling of competing woody vegetation types was combined with a spatially explicit model of hydrologic and of salinity gradients (Fig. 5.5). Variability of salinity, both vertically in the vadose zone and horizontally across the landscape was modeled, which had effects on individual mangrove and hardwood hammock tree responses.

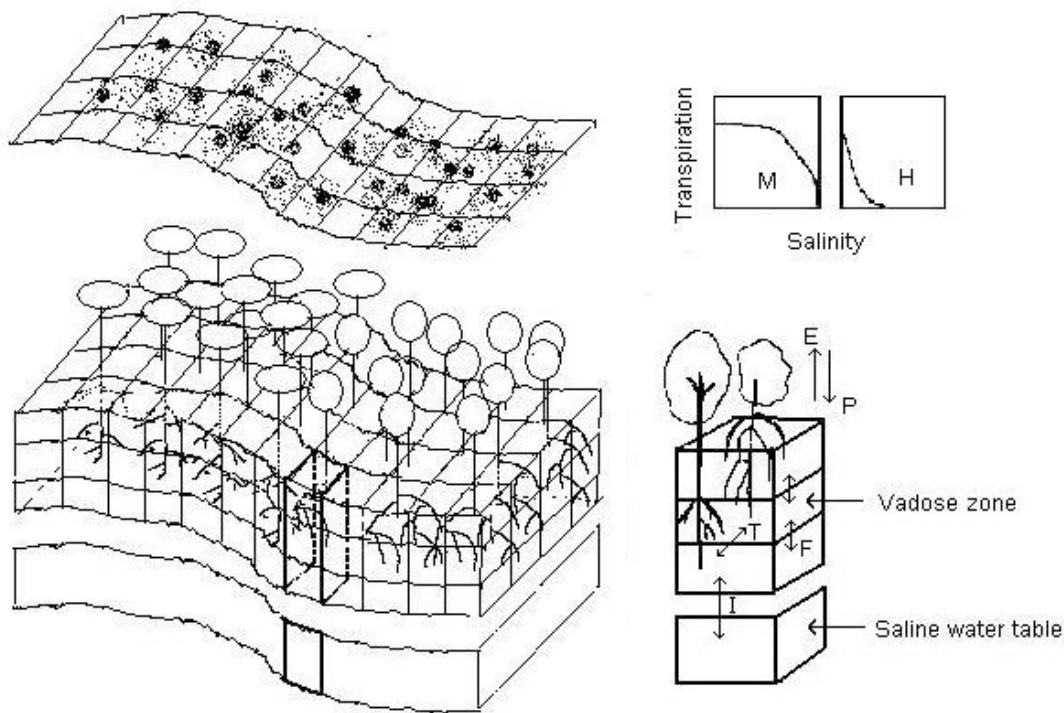


Figure 5.5: Bottom left: grid-based three dimension hammock/mangrove community, elevation decrease toward right side (seaward). Top left: two-dimensional continuous surface occupy by individual trees, dots show zone of influence (ZOI). Top right: transpiration of mangrove (M) and hammock (H) as a function of vadose zone water salinity. Bottom right: interaction between infiltration (I), plant water uptake (T), evaporation (E), precipitation (P) and water flux (F) at one of the cell.

f. Human Dimensions

The FCE Human Dimensions (FCE HD) research centers on understanding the human dimensions of land use change as it affects local ecological dynamics in south Florida. This research aims to: (1) develop spatial models of land use decision-making, (2) connect FCE ecological research within Everglades National Park to regional land use/cover dynamics, and

(3) adopt a methodology that facilitates cross-LTER site comparisons, and (4) understand the impacts of sea level rise on social vulnerability. Here we outline activities for two related FCE HD projects.

Our first in-depth analysis focuses on land use/cover change in southern Miami-Dade County, a critical buffer zone located between two national parks. For this work, we have been examining the processes of rapid suburbanization as agricultural lands transition to residential development. Associated with such transformations is the proliferation of the residential lawn, also under study in other LTER sites (PIE, CAP, and BES). To understand the types and classes of land use change in our study site, we have engaged in the following activities:

1) Database Management:

- a. Created a Personal Geodatabase (PGD) with a dataset assigned to the same projection as the relevant GIS layers (NAD 1983 State Plane Florida East FIPS 0901 Feet). This projected dataset ensures a standardization of projection for all layers placed within it, thereby mitigating potential project-related errors in the analysis. These layers were added: Zoning 2001, LandUse 1994, LandUse 1998), as well as several layers taken from the Miami-Dade County GIS group (CensusBlockGroup2000, CensusTrack2000, Municipalities, UrbanDevelopmentExpansion). Last, an existing layer showing the FCE-LTER area, plus the Human Dimensions group transect was added.
- b. Added parcel data from the Miami-Dade County Tax Assessor's office were added containing parcel valuation information for 2008 and 2009. Like the previous layers, this data was put into a PGD, though not the same one, due to space limitations.
- c. Added a Normalized Difference Vegetation Index (NDVI) for the Human Dimensions Transect (HDT) to the GIS layers.
- d. Acquiring high-resolution remotely-sensed GeoEye 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).

2) Observational Survey of Lawn Vegetation and Management: Summer fieldwork was conducted to characterize ecological structure, land management, and yard-use practices (e.g., lawn cover/quality estimates, maintenance practices, human activities) based on observations of front yards visible from sidewalks. This project was supported through NSF supplemental project funding. In the summer 2010, FCE, PIE, CAP and BES coordinated to implement the same survey protocol. In addition to the observational data collected at selected households in each region ($n = \sim 500$ sites), in-depth interviews ($n = \sim 8/\text{site}$) were conducted at a sub-set of households with similar attributes (e.g., yard/lawn characteristics) across sites. The survey sample was stratified based on three categories of land use (residential, apartment/duplex, and cluster housing). Based upon the observed range of ages of the building structures, 3 age ranges were targeted in the sample (1912-1963, 1964-1987, and 1988-2009). Two undergraduate students conducted the observational survey, with oversight by graduate student Rebecca Garvoille and FCE co-PI Laura Ogden.

Our second focus has been to examine the potential impact of sea level rise on our study site. The research focus of the HD working group on spatial models of land use decision-making gains a new level of complexity as South Florida moves closer to a realization that climate change induced sea-level rise (SLR) has to be accounted for in land use planning. Much past urban expansion has been into low-elevation areas out of the original higher elevation urban core on the coastal ridge. This expansion, still ongoing, is primarily into former Everglades land and follows a typical urban sprawl pattern. HD activities related to understanding the relationship between socio-ecological vulnerability, SLR, and land use planning include:

- 1) Organizing and participating in a workshop entitled “Developing a Sea Level Rise Vulnerability Framework for South Florida: Indicators, Metrics and Models.” The workshop was supported by the USGS, FIU, and FAU. FCE collaborator Hugh Gladwin co-organized the workshop and FCE collaborators Laura Ogden and Rene’ Price participated in the workshop.
- 2) Conducting surveys with decision makers on SLR vulnerability (see discussion under Findings).
- 3) Mapping the relationship between land conversion and elevation in our study site (see Fig. 6.1).
- 4) Coordinating our findings and approach with the Miami ULTRA-Ex project objectives.

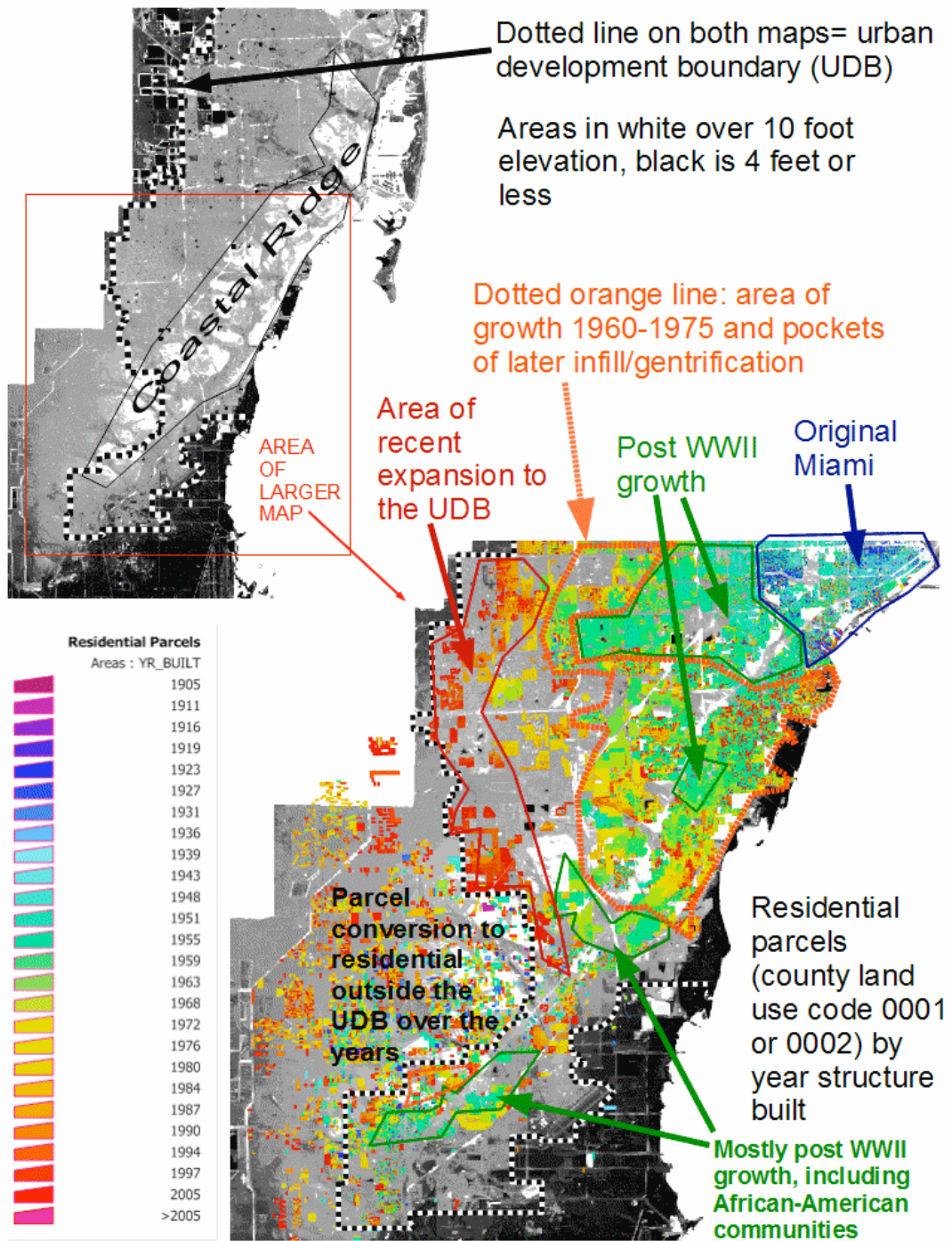


Figure 6.1: Parcel conversion and elevation for Miami-Dade County

g. Climate and Disturbance

The Climate and Disturbance Working Group has just completed its 4th year in the FCE organizational structure. At the 2009 3rd Year Review and at the 2010 ASM, we presented our immediate research goals for the next year, recent results and participated in the analysis of the 3rd Year Review. One of the main goals of the working group was to work with the new Post-Doc Chris Moses on analyzing climate variability within the FCE sites and greater South Florida (a collaborative effort with the SFWMD). Presented below are the results of the main activities of the working group ranging from paleo-based studies to modern climate analysis.

Paleoecological investigations and multi-centennial periodicities – (Saunders, Moses, Sklar and Anderson)

In 2009/2010, spectral analyses of paleoecological data from FCE sites in Shark Slough (reported in 2008 and 2009 FCE annual reports) were conducted to determine the correspondence of millennial-scale responses of Everglades vegetation and hydrology to global climate drivers. To elucidate potential long-term (multi-decadal to multi-century) periodicities in these responses, Discrete wavelet transforms (DWT) were conducted on both Everglades proxies (macrofossil and charcoal deposition rates) and sediment-based records of global climate drivers ENSO (from Rodbell et al., 1999) and the ITCZ (from Haug et al., 2001). Other FCE paleoecological investigations include an analysis of fossil diatom records to reconstruct recent (past few centuries) hydrologic changes in the freshwater portions of Shark Slough (Evelyn Gaiser, Colin Saunders, Chris Sanchez). These data are intended to provide independent proxies of hydrologic changes, previously determined through analyses of macrofossils and biomarkers (Saunders, Jaffe and Gao).

Limnological investigations of Lake Annie and Southern Everglades (Gaiser, Koch, and Quillen)

We continue to study climate and disturbance patterns at “reference” locations of low disturbance in our ecosystem, including Lake Annie, at the headwaters of the Everglades. Lake Annie exists on the undisturbed property of Archbold Biological Station, is considered one of the most pristine lakes in the state and has one of the longest continuous limnological records. Because it is in the same watershed, 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 and have contributed to two international and one LTER network manuscripts on the importance of reference systems in detecting effects of episodic meteorological events in ecosystems. To this end, high frequency aquatic sensors have been deployed contemporaneously in Lake Annie (Gaiser, unpubl.) and lakes of the southern Everglades (Koch, unpubl.) in order to detect system-scale influences of climatological variability in South Florida.

Paleoecological investigation of diatoms from Florida Bay (Wachnicka and Gaiser)

We investigated distribution and composition of contemporary diatom assemblages at 96 sites in Florida Bay and Biscayne Bay and published two manuscripts describing the results in *Estuaries and Coasts* and *Ecological Indicators* journals (see list of references below). At this moment, we are preparing manuscripts for the LTER special issue in *Journal of Paleolimnology* on

paleoenvironmental alterations in South Florida freshwater and marine ecosystems. These manuscripts describe results of our investigations of subfossil diatom assemblages obtained from sediment cores retrieved from four sites in Florida Bay to determine the extent of environmental change caused by anthropogenic activities in South Florida and climate change over the last ~ 130 years.

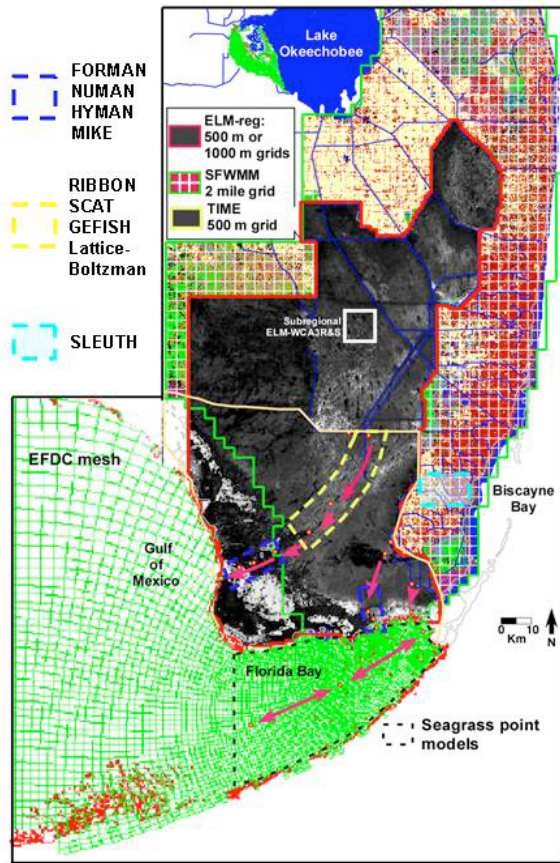
Regional to local gradients in precipitation and temperature in response to climate teleconnections in the FCE (Moses, Anderson, Saunders and Sklar)

Weather patterns across the South Florida region exhibit ecologically important spatial heterogeneity. The patterns of precipitation and temperature can be patchy on daily to weekly time scales [Pielke, 1974; Skinner et al., 2009], or form steep gradients over short distances on seasonal to yearly time scales [Henry et al., 1994]. Unfortunately, many climate observations or long time series of interpolated climate indices (e.g., Palmer Drought Severity Index [Dai et al., 2004]) are calculated on spatial scales too coarse to resolve the spatial heterogeneities in South Florida climate, which include the greater Everglades. We have explored the fine spatial scale variances associated with temperature and precipitation to better understand impacts of global teleconnections within the largest wetland restoration program in the world. Our approach provides insight to help better understand how the ecohydrology of other study areas are related to different climate teleconnection indices spatially (across a specific region).

h. Modeling and Synthesis

Review manuscript preparation

Following up on the FCE Modeling/Synthesis coordination workshop in June 2009, the FCE modeling and synthesis group continues to perform the writing tasks for the review paper (working title), “A strategy for integrating ecohydrological models of the Florida Everglades: Advances and limitations in the context of the restoration.” In addition to the detailed outline drafted during the June 2009 workshop, Jeff Onsted (Human Dimensions) has written sections addressing: a) the necessity of including a human aspect in ecological approaches; b) an overview of the SLEUTH model; and c) co-wrote the section dealing with the connection between water and socio-economic processes. Drs. Jeff Onsted, Laura Ogden, Amartya Saha, and Colin Saunders have also developed the Comprehensive Heuristic Model (an outcome of the 2010 ASM, described below) which will be integrated within the review manuscript as a means to provide the backdrop and context for the entirety of modeling and synthesis projects (Fig. 8.1). Additional contributions by other members are expected to continue being compiled in the summer and fall 2010. A second workshop is being planned to finalize the completion of the manuscript.



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, biogeochemistry, 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

Figure 8.1: Overview of the geographic domains and objectives of FCE modeling and synthesis activities

Landscape Ecosystem modeling – ELM and SEACOM

Carl Fitz has used the Everglades Landscape Model and Multi-Criteria Decision Analysis to explore the effect of simulated ecosystem performance, risk preferences and criteria weights on the ranking of three alternatives to restoring overland sheet flow in the Everglades, as described in their upcoming (in-press) manuscript Integrated Ecological Modeling and Decision Analysis within the Everglades Landscape.

Carl Fitz and Chris Madden continue to develop a linked ELM-SEACOM approach to understand impacts of freshwater landscape on estuarine processes, including a baseline case and a future with tripled inflows through S-332D. ELM is used to evaluate P accumulation along Everglades gradients, including the freshwater to coastal ecotone in Taylor Slough (our sites TS/Ph-1, -2, -3, -6 and -7), provide P outflow loads to Florida Bay, and evaluate seagrass/phytoplankton sensitivity to altered loads.

Mangrove Models

We use the HYMAN model to evaluate water and salt budgets in three mangroves sites along Shark River. We also use the MIKEFLOOD platform to evaluate water, nitrogen, and phosphorus budgets along Taylor River. Both models are currently used to forecast potential changes in water budgets and biogeochemistry processes as result of the Everglades restoration project.

Consumer dynamics

Spatially explicit modeling (DeAngelis, Jopp, Trexler). Small-bodied fishes constitute an important assemblage in many wetlands. In wetlands that dry periodically except for small permanent waterbodies, these fishes are quick to respond to change and can undergo large fluctuations in numbers and biomasses. We have been working on a spatially explicit model of community dynamics that accounts for the movement of fishes across the landscape in response to water level fluctuation. In our model, populations of small fish expand into newly flooded areas during the wet season and contract during declining water levels in the dry season. If the marsh dries completely during these times (a drydown), the fish need refuge in permanent waterbodies.

The spatially explicit modeling was also used to investigate biomass dynamics of an aquatic food web in an Everglades marsh landscape including the following components: primary producer, detritus, invertebrates, fish consumers and nutrients. Long-term simulations over a period of 10 years were performed and the responses of trophic organizational levels to the seasonal changes in water level were observed.

Human Dimensions modeling

FCE collaborator Jeff Onsted has calibrated and run the SLEUTH urban growth and land use change model in the Redlands area of Miami-Dade County. Onsted experimented with calibration conditions in order to better understand the role of zoning in past land use change and discovered that goodness of fit metrics are greater when lands zoned for agriculture are integrated into the Excluded Layer. Onsted also ran future simulations of urban growth and land use change in the Redlands area. Attached below are the land use layers used for 1994 and 2006 in the model (Figs. 8.2 and 8.3) as well as one Excluded Layer (Fig. 8.4) and its corresponding cumulative output of Monte Carlo iterations (Fig. 8.5).

REDLANDS 1994 LAND USE

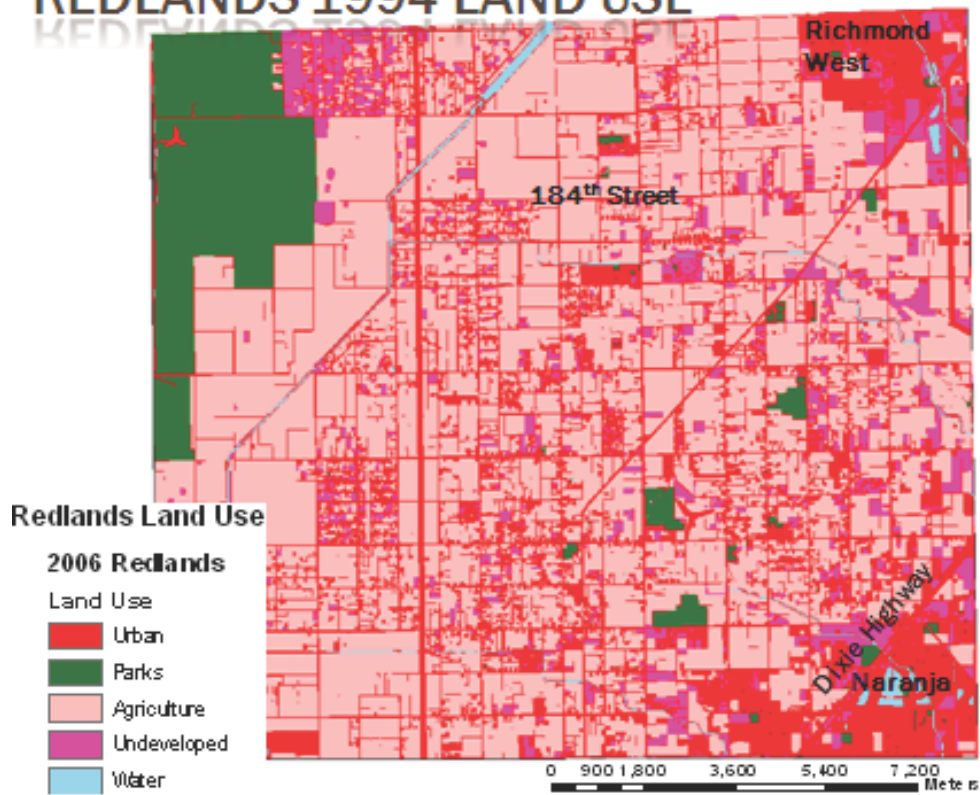


Figure 8.2: Land Use in the Redlands in 1994

REDLANDS 2006 LAND USE

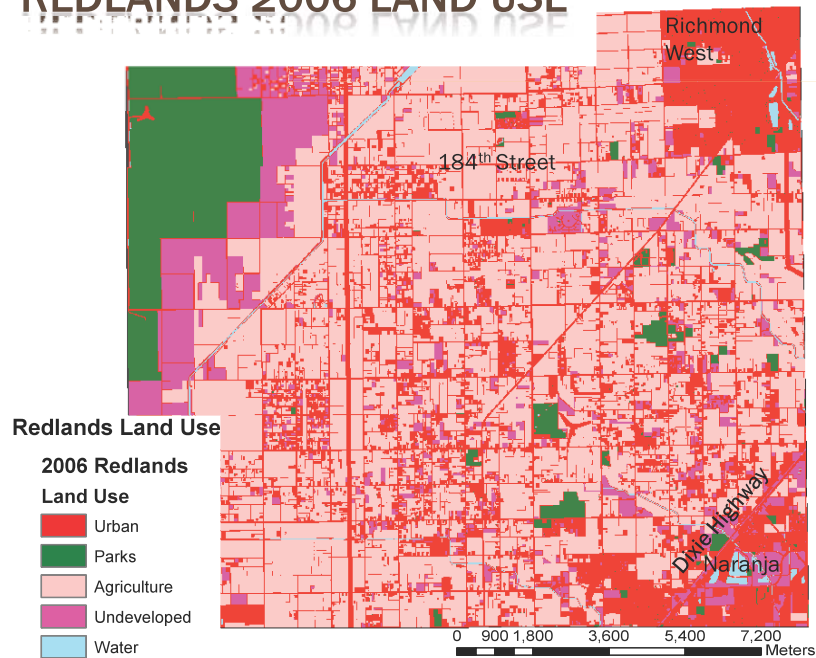


Figure 8.3: Land Use in the Redlands 2006

ADDING FLOOD ZONES

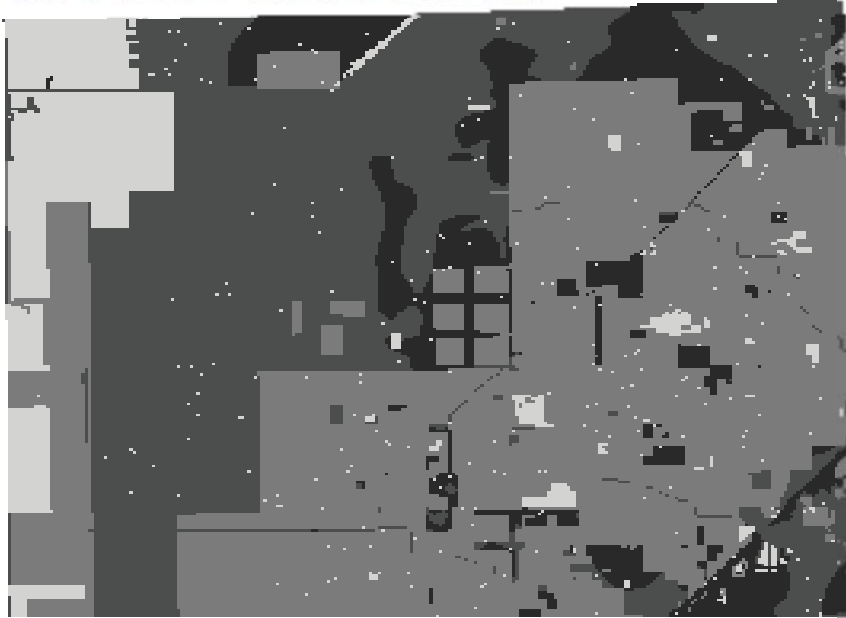


Figure 8.4: Sophisticated Redlands Excluded Layer used in SLEUTH calibrated urban growth simulation for Redlands. Lighter colors offer more resistance to development while darker colors offer less.

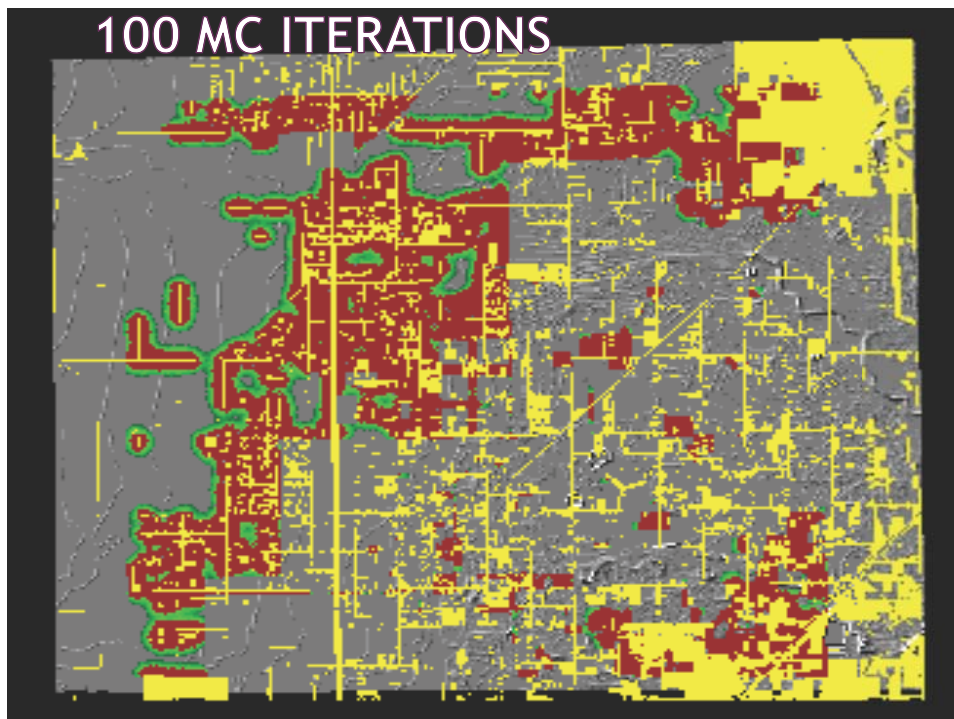


Figure 8.5: 100 runs of the SLEUTH model in the Redlands.

Other Synthesis

Hydrology synthesis:

Understanding and restoring the Everglades, a hydrologically-controlled ecosystem, requires a reasonably accurate quantification of the inflows, storage and outflows of water. As described in the Hydrology WG section of this report, a joint Hydrology/Modeling post-doc (Dr. Amartya Saha) has continued to develop an annual water budget of Shark Slough for 2002-2008, as described in the Hydrology section of the this report. This project budget will lay the groundwork for improved integration among FCE modeling efforts.

Paleoecological synthesis:

A synthesis of existing FCE paleoecological investigations is under way to understand the long-term changes in hydrologic, water quality, and ecosystem responses to past climate change and water management across the FCE landscape and the greater Everglades. The product of this synthesis will be a special issue of the Journal of Paleolimnology and is described in the Climate Change/Disturbance section of this report.

Accretion synthesis

Finally, a literature review of all published and newly emerging radiometric-based estimates of soil accretion over the greater Everglades (and including FCE sites) are being compiled by colleagues from SFWMD (Colin Saunders, Carlos Coronado, Dave Rudnick, and Fred Sklar), USGS (Debra Willard, Charles Holmes), and other FCE scientists. This study aims to quantify the primary abiotic and biotic determinants underlying regional and habitat-specific variation in soil accretion. Details are provided in the Organic Matter Dynamics sections of this report.

i. Information Management

Overview

The FCE Information Management team consists of the FCE Information Manager, Linda Powell, and the FCE Project Manager, Mike Ruge. The FCE IMS continues to facilitate the site's scientific work and to ensure the integrity of the information and databases resulting from the site's coastal Everglades ecosystem research. The major focus of its Information Management effort during this past year has been on FCE web site (<http://fcelter.fiu.edu>) enhancement in preparation for its 2009 National Science Foundation (NSF) mid-term review. In October 2009, the National Science Foundation's LTER Review team recognized our IMS as 'one of the finest in the LTER Network' and wanted to see the FCE IMS team play a leading role in the continued development of 'best practices' across the LTER network.

The FCE IMS is an active participant in LTER network level activities. Data contributions have been made regularly to the following LTER network databases: 1) ClimDB, 2) SiteDB, 3) All Site Bibliography, 4) Personnel, 5) Metacat XML database and 6) Data Table of Contents. The FCE IMS group is also a data contributor to the EcoTrends project managed by the Jornada Basin LTER.

The FCE information manager, Linda Powell, participated in the LTER IM Unit Dictionary and Controlled Vocabulary working groups this past year and both she and Mike Rugge will be attending the annual LTER Information Management Committee meeting held at the Kellogg Biological Station LTER site in September of 2010.

IT Infrastructure

The FCE IMS team manages 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. The servers housing the development and production versions of the FCE Oracle10g database are equipped with RAID5 technology (Redundant Array of Independent Disks). Connectivity within the FCE LTER Office is a gigabit switched Ethernet Network (Florida International University Computer Science Network). Linda Powell, who is located in Tallahassee, Florida, continues 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 web server and Oracle10g Database design issues, content and implementations.

Website Development

Although the FCE web site (<http://fcelter.fiu.edu>) went through a major redesign in 2007, this year's focus has been on FCE web site enhancement where we incorporated several LTER working group initiatives to improve standardization of data search and access across LTER sites through adoption of controlled vocabularies and common interface features. The website serves as the primary portal for dissemination of information about the FCE LTER program, for distribution of datasets, to coordinate our Education and Outreach activities, and to aid FCE scientists and students in their research so it is important that the FCE information management team continue to improve existing web pages and expand the web site capabilities. The small changes made to the FCE 'Data' web page structure allow users to more easily choose between FCE data products like our signature research datasets, LTER core research data and the FCE physical/chemical online database. Links to important LTER Network and outside agency data resources remain an important part of the FCE website 'Data' section. This year, the FCE IMS team worked with members of FIU's Periphyton Group to migrate their diatom image database to the FCE LTER data and web servers. The FCE IMS team created a new web interface to the database (<http://fcelter.fiu.edu/data/database/diatom/>) and linked the database to the FCE Data section of the FCE website.

Support for EML Metadata

The FCE IMS has fully adopted the LTER network metadata standard Ecological Metadata Language (EML) and one hundred percent of the FCE tabular data are accompanied by a Level 5 (Data Identification, Discovery, Evaluation, Access and Integration) EML (XML) metadata documents. FCE EML documents are harvested daily to the LTER network metacat XML database. The FCE Excel2EML metadata converter tool and template have been made available to the LTER network and broader ecological community via the LTER CVS repository and as download link on the FCE web site (http://fcelter.fiu.edu/research/information_management/tools/). The FCE IM team lends its expertise to site and network researchers when necessary by providing application support for

the Excel2EML tool and assisting with metadata entry.

FCE Website and Data Statistics

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 on-line 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 429 FCE datasets, of which a total of 397 are publically available online (Table 9.1).

<i>Archived FCE Datasets by Access Type</i>	
Access Type	Count
Public	397
FCE Only	6
Locked	16
Offline	10
All Access Types	429
<i>Public Access by Dataset Type</i>	
Public Dataset Type	Online Data
Climate	93
Physical	84
Primary Production	69
Nutrients & DOM	103
Soils & Sediments	25
Trophic Dynamics & Community Structure	23
All Data set Types	397

Table 9.1: FCE Data Archives, by access type and dataset type

Public downloads of FCE data sets from January 2001 to August 15, 2010 are listed in Table 9.2, broken down by data set type and user affiliation. The University community continues to be the largest user group and the FCE nutrient data is the most popular download.

Annual Downloads by Type											
Dataset Type	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	All
Climate	0	0	13	10	25	29	22	52	43	48	242
Nutrients	0	33	144	50	109	141	68	162	106	94	907
Physical	0	15	64	17	84	69	46	160	76	26	557
Primary Production	0	25	76	14	69	115	48	56	50	38	491
Soils & Sediments	0	11	35	5	36	59	34	39	63	23	305
Trophic Dynamics	0	0	9	5	10	4	22	21	24	17	112
All Types	0	84	341	101	333	417	240	490	362	246	2614
Annual Downloads by Affiliation											
Affiliation	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	All
Education (K-12) LTER	0	0	0	2	0	11	3	3	2	2	23
Education (K-12) Non-LTER	0	22	36	2	4	64	3	20	15	4	170
Government Research LTER	0	4	93	0	4	0	4	16	10	7	138
Government Research Non-LTER	0	0	6	3	8	25	21	159	7	12	241
Other LTER	0	0	1	1	13	5	0	0	0	0	20
Other Non-LTER	0	2	38	7	56	65	6	24	20	37	255
University Research LTER	0	47	128	57	158	206	81	157	196	78	1108
University Research Non-LTER	0	9	39	29	90	42	122	110	111	107	659
All Affiliations	0	84	341	101	333	418	240	489	361	247	2614

Table 9.2: Downloads of FCE data sets, Jan 2001 - Aug 15, 2010, by type and affiliation

Web site activity was slightly less active in 2009 than in the previous year (based on web log analysis). The most popular web directories visited in 2009 were about us, research, education & outreach, data and publications, respectively (Table 9.3).

Number of Page Requests by Year			
Website Directory Name	2007	2008	2009
about us	100,063	293,776	277,153
research	159,943	296,318	251,688
education & outreach	76,526	114,679	90,748
data	32,711	86,623	68,510
publications	76,199	88,311	60,378

Table 9.3: FCE Web site page requests compiled by year

2. Science Planning: 2010 ASM Break Out Group Reports

Our mid-term program review (October 2009) generated some important suggestions for thinking about the integration of our research areas as well as research design. We dedicated our 2010 ASM to developing new working groups to respond to suggestions made in the review and to help us plan for our program renewal. We divided the meeting into four break out groups, which were: An Analytic Framework for FCE, Heuristic Model Development, Human Dimensions and Water, and Community Ecology & Stoichiometry. An overview of the planning activities related to these break out groups follows and includes post-meeting follow-up activities.

a. An Analytic Framework (Trexler & Gaiser)

As noted in our mid-term site review, hydrological drivers of Everglades productivity gradients are a central and guiding theme of FCE-1 and 2. In fact, manipulation of hydrology by restoration of historical water flows from upstream of Everglades National Park is the primary motivation for our research agenda. Because of this, temporal analysis of change of parameters tied to ecosystem function and productivity before and after major restoration activities is the underpinning of our study design and research agenda funded by NSF. For this reason, a Before-After-Control-Impact (BACI) conceptual and analytical design is a natural structure for data gathering and analysis.

Applicability of BACI design

FCE has been discussing the applicability of the BACI analytical design approach to testing key hypotheses. This has become a topic of considerable importance as the “grand experiment” to modify flows into the SRS transect through Tamiami Trail has been delayed and other projects begin in TS. A sub-group met at the 2010 ASM to discuss this issue. One obvious benefit to project delays is a better understanding of “pre-treatment” conditions, especially important considering the great inter-annual variability in each slough. It is also possible to use the last ~10 years of data to test for common responses between the two sloughs, and to determine whether other “control” data series can be identified (i.e., in series of data within each slough instead of between them, or perhaps in water conservation areas?). The group consensus was that these possibilities are all testable and that progress on these analyses should be made before the next ASM.

What will happen when bridge goes in?

Since our mid-term review commentary on this topic, significant advancements have been made in the bridging project. The 1-mile bridge construction has begun and impact analyses are being undertaken for longer bridging options. Construction has also begun to increase water flow through the culverts at the head of SRS by creating spreader swales. FCE has acquired four new long-term research sites associated with these swales in order to document their effect to water delivery at the head of SRS. In addition, FCE is documenting changes relative to construction projects at the head of TS so it will be possible to contrast the magnitude of effects of these paired projects between sloughs. We will be able to examine the effect of intervention scale on fast and slow response variables, offering new research opportunities and approaches. In approaching FCE III, we will need to examine these projects and plans and determine whether new sites will be needed near anticipated change points, although several have already been established in obvious place, upon which FCE science can capitalize.

Take advantage of existing management science

FCE has abundant opportunities for new analytical approaches offered by ongoing management-related science in our group of collaborators. These projects need to be incorporated into FCE science to the maximum extent possible. For instance, sophisticated modeling efforts now offer output that can be used as the “control” setting to which FCE transect data are compared. This has great potential for addressing reference site issues, and should be explored more fully in

preparation for FCE III. In addition, much work has been done by FCE collaborators on deriving performance metrics based on variables measured regularly and widely in FCE. This offers the opportunity to identify those relevant to FCE hypotheses and use them to interpret trajectories of change.

The group committed to: 1) testing BACI and related analytical approaches, beginning with water-quality data (to be completed in Fall 2010 with aid of visiting scientist Saku Antilla), 2) integrate new long-term study sites into main database and track construction project planning (to be completed by two new post-doctoral scientists in Gaiser laboratory, with new Everglades Fellowship support from ENP) and 3) meet with Modeling and Synthesis group at 2011 ASM to associate FCE questions with model output.

b. The Comprehensive Heuristic Model (CHM) (Saunders and Saha)

“The review panel suggests that a comprehensive, heuristic model of the Everglades Ecosystem would be helpful for conceptualizing interactions of the multiple factors and processes that are foci of the different working groups. Most of the possible components of this model (runoff, phosphorus, lightning, solar energy, introduced species, people, rainfall, fossil fuels, importation of materials including drugs, frost, storms, tides, and sea level increase, etc.) were articulated at one time or another during the review, but never presented as a whole. The model should include all external forces that drive the complexity of the Everglades and show interactions among different parts of the system, including human dominated sectors.”—FCE NSF external examiner review 2009

A Comprehensive Heuristic Model (CHM) is currently being developed to tie together the various “ground-level” conceptual models currently guiding FCE research activities. The overall goal of the CHM is to (1) convey the strengths of FCE data & modeling; (2) highlight areas for improved integration of data and synthesis/modeling; and (3) generate future FCE research hypotheses and logical next steps;

Recommendations from ASM 2010 workshop

A two-session mini-workshop was held at the 2010 ASM to address FCE II midterm review’s recommendation to develop a comprehensive heuristic model of FCE II research. The primary tasks of these sessions were (1) to broadly canvas the FCE II group for ideas and guidelines on the content, approach and overall objectives of the CHM; and (2) to delegate follow-up tasks with a timeline for completing a first draft of the CHM

Recommendations are listed as follows:

GENERAL comments:

- A consensus that a 3-tiered approach of nested models is needed in order to encompass key FCE II concepts and research.
- Tier 1 is the “big picture model,” with coarse-scale linkages between the natural and urban systems, climate drivers, and ecosystem services;
- Tier 2 is composed of two models—the first includes, broadly speaking, the generalized components and processes of the geophysical system; the second includes the components and processes in the urban system. Each of these “big picture” models

should also demonstrate the common linkages through which the geophysical and urban systems interact (i.e., ecosystem services, modulation of environmental drivers).

- Tier 3 models will include the mechanistic detail of processes or linkages described in the Tier 2 models; development of these models will be an ongoing processes and adaptable to new concepts, research designs, improved synthesis of existing data
- The CHM should be able to easily demonstrate strengths, gaps and future priorities of FCE research
- CHM must include how the natural system directly impacts on urban system (usually perceived the other way round)
- CHM must include a water budget that applies comprehensively to both the ENP/geophysical system and Urban system
- CHM should be able to identify the difficulties of linking models and/or empirical results at different temporal, spatial scales
- CHM should be explicit in having units on all linkages: energy, matter, information, money
- CHM should be explicit to the timescale involved – e.g., modern, historical, millennial

GEOPHYSICAL SYSTEM components should:

- build on existing conceptual models (e.g., as in the 2009 Mid-Term report & forthcoming modeling review manuscript)
- accommodate consumer feedbacks on physical/biogeochemical processes
- accommodate disturbance effects on ecosystem function & services (e.g., storms & carbon sequestration)
- accommodate water use & availability on scenarios of sea-level rise/salt intrusion
- accommodate biogeochemical & ecological interactions w/ FW flow, sea-level rise, salt intrusion

URBAN SYSTEM components should:

- accommodate changes in land use, population/cultural demographics, stakeholders on water use, quality;
- include changes in social valuation of ecosystem services (e.g., wildlife)
- demonstrate variation in political scale (national, local, “mobile” stakeholders) on decision making
- link water management, hydrology and land use change
- include variation in temporal / spatial scale of climate links on social and natural systems
- include ecosystem services that vary in importance across spatial scale (e.g., biodiversity at national level, drinking water at local level)
- include tradeoffs occur when optimizing across ecosystem services

Follow-up tasks

The follow-up tasks to the workshop included a four-phased approach to building the CHM: (1) several focus-group sessions (2-3 people from Modeling/Synthesis and external themes/work groups) to build model Tiers 1 and 2; (2) focus-group sessions (2-3 people) to generate examples of Tier 3 models that link into Tiers 1 and 2, including demonstrating the useage of CHM for synthesizing new data; (3) feedback and revisions from the larger Modeling/Synthesis group and key external FCE personnel (section leads); and (4) a follow-up Modeling/Synthesis workshop to finalize CHM and fast-track the completion of the modeling review manuscript.

Steps taken since ASM

At the time of this report, Phase 1 has been completed and Phase 2 is in progress,. The first focus group (consisting of Amartya Saha, Jeff Onsted, Laura Ogden and Colin Saunders) generated model Tiers 1 and 2. The second focus group (Amartya Saha and Colin Saunders) has involved revising Tier 1 and 2 models in order to accommodate existing FCE conceptual models (mainly Tier 3) as nested within Tier 1 and 2 models, and still adhering to the principals and guidelines resulting from the ASM workshop. Results so far are provided in the section below. It is expected that feedback and revisions of the CHM from the larger Modeling/Synthesis section will begin in earnest starting in summer 2010 (phase 3), and a follow-up workshop is currently being planned for fall 2010.

Comprehensive Heuristic Model results (preliminary draft CHM)

The Conceptual Heuristic Model (CHM) provides a graphical representation of the various linkages between ecological, biogeochemical and anthropogenic processes operating in the FCE-LTER geographical domain, South Florida. The domain is partitioned into two sub systems, the natural (or ecogeophysical system) representing the Everglades, Florida Bay and coastal Gulf of Mexico while the anthropogenic system, geographically Miami-Dade county, represents the connection of man to the environment. The CHM highlights the interdependent nature of the ecosystem components (modules) as well as subsequently helps identify the various processes that can be affected by climate change and sea level rise. For instance, sea level rise can wipe out coastal freshwater-using plant communities and associated fauna in the natural ecosystem. Sea level rise can also lead to saltwater intrusion in groundwater as well as increase episodes of flooding in coastal urban areas. Freshwater flow reductions in the dry season can lead to accelerated seawater intrusion; this indicates management options to postpone the effects of SLR by maintaining freshwater flows in the dry season to act as a bulwark against seawater intrusion.

The 3-tiered approach:

The CHM has several levels:

- i. The top level represents the natural ecosystem, climate and urban ecosystem as the three main modules, with the linkages between them (Fig. 11.1).
- ii. Each module then has detailed graphics illustrating the various key processes that have interdependencies with factors external to that module (Fig. 11.2 and 11.3).
- iii. Finally there can be process-oriented graphics for specific important cases, such as water management and effects on natural and urban systems (Fig. 11.4 and 11.5).

Hydrology is the central variable in the South Florida ecosystem that affects all other processes, from water quality, availability and hydroperiod to nutrient transport and salinity. In turn this affects flora and fauna as well as ecosystem services for humans such as aquifer recharge and tourism. The linkages between hydrology and the ecosystem are two-way (Fig. 11.1).

CHM LEVEL 1: the system-wide model

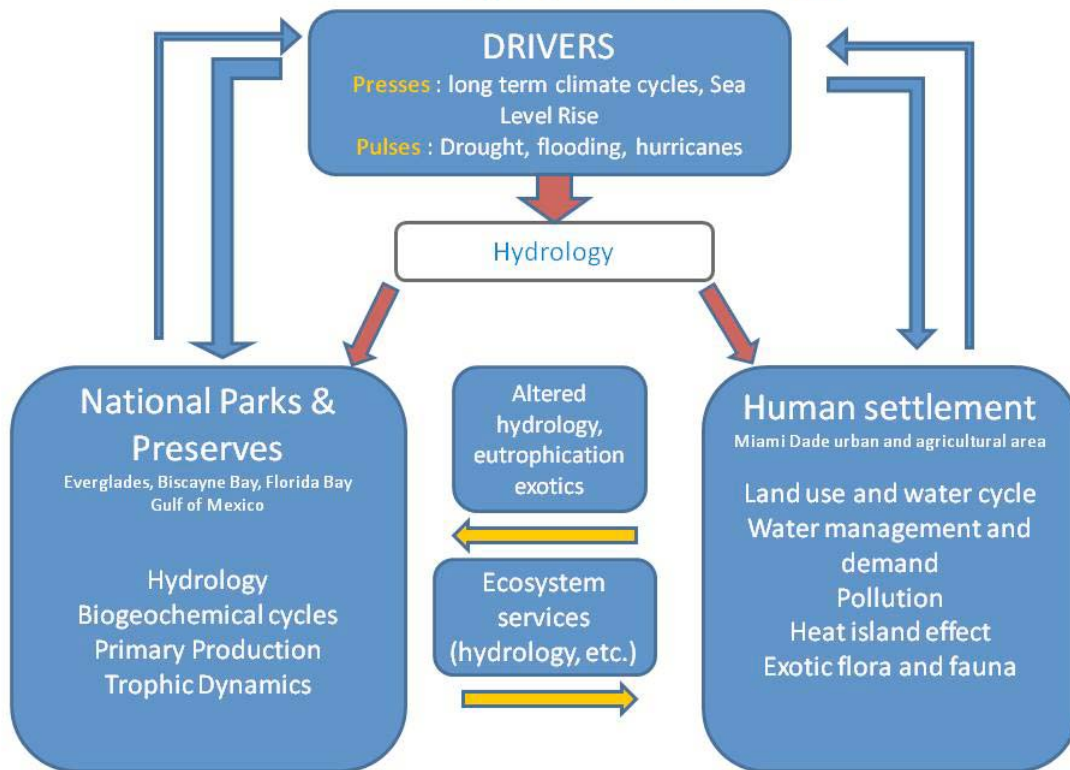


Figure 11.1: The top level of the CHM showing the ecogeophysical module (National Park and preserves), the human dimensions module and the climate module that impacts both the natural and the human modules.

Tier 2 of the CHM includes two modules – one focused on variables and processes within the human dimensions module and interactions with pulse and press drivers (mainly climate drivers) and ecogeophysical side (Fig. 11.2). In the human dimension module, key variables and processes include climate-modulation (heat island effect); land use change and associated resource demand and waste; water demand, cycling and quality; lifestyles and resource consumption; and education and health. The other Tier-2 module is focused on the ecogeophysical state variables and processes (Fig. 11.3), including interactions with pulse and press drivers and with the human dimensions module (including modulation of drivers and ecosystem services). The generalized variables and processes within the ecogeophysical side are broadly divided into freshwater/upstream, ecotone, and estuarine/marine zones. These components interact with each other through material exchanges (e.g., water flow or nutrient loading) and modulation of drivers (e.g., ecotone dampening of salinity intrusion in the freshwater zone).

Tier 3 models include the conceptual ecological models (CEMs) that have already been developed by FCE working groups, with the expectation that additional CEMs and modification of existing ones will be a natural progression. Figure 11.4 demonstrates the means in which a Tier-3 model, the coastal groundwater discharge hydrodynamic model (Price et al., 2006), can be expressed as a nested model within the Ecogeophysical Tier 2 model. Figure 11.5 demonstrates

graphically how we can use the overall Tier-3 framework to integrate new information and generate new hypotheses.

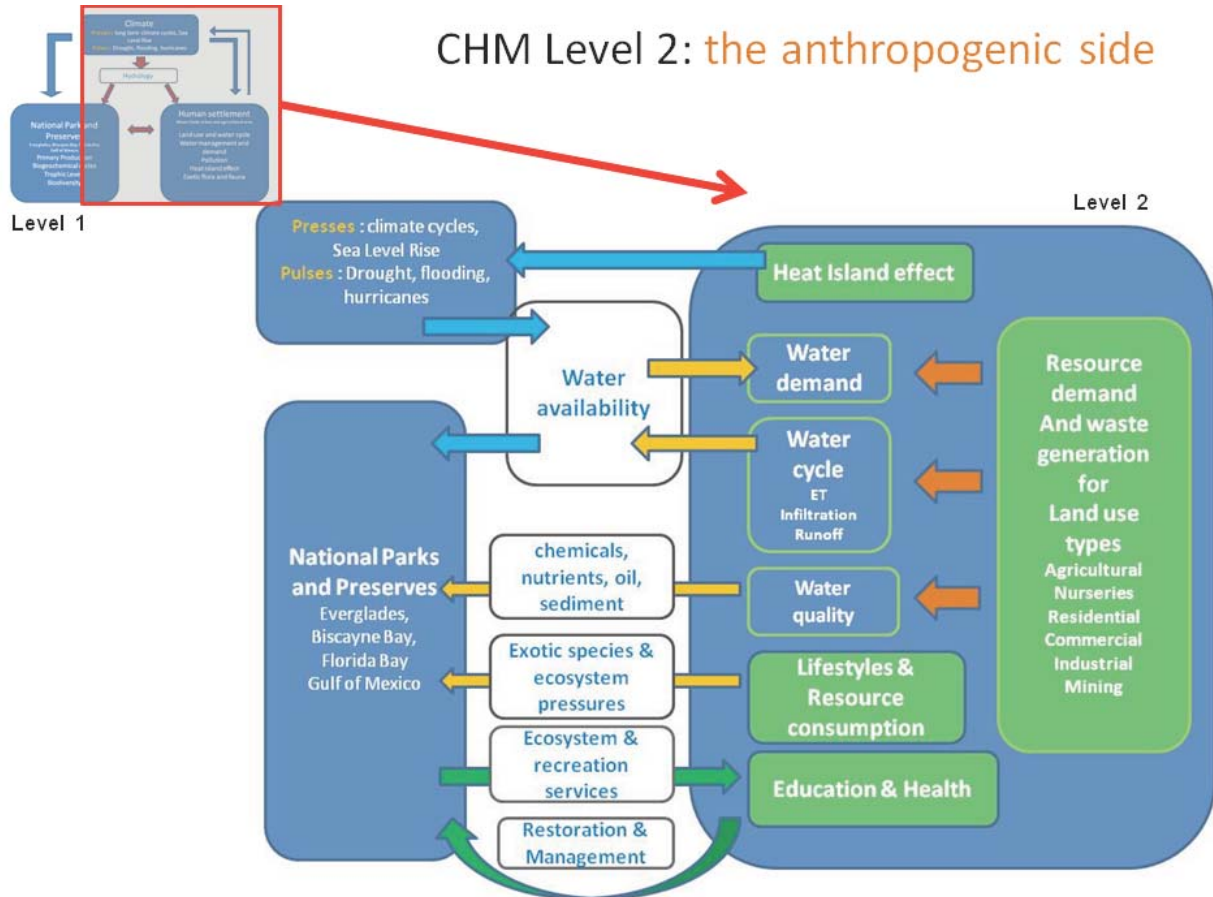


Figure 11.2: The human dimensions module in detail. Note that the complexity and number of processes inherent in the realm of human activities and their relation to the environment precludes the portrayal of specific examples in this illustration, such as listing all the effects of land use change from agricultural to residential on the water cycle and pollution.

CHM Level 2: the ecogeophysical side

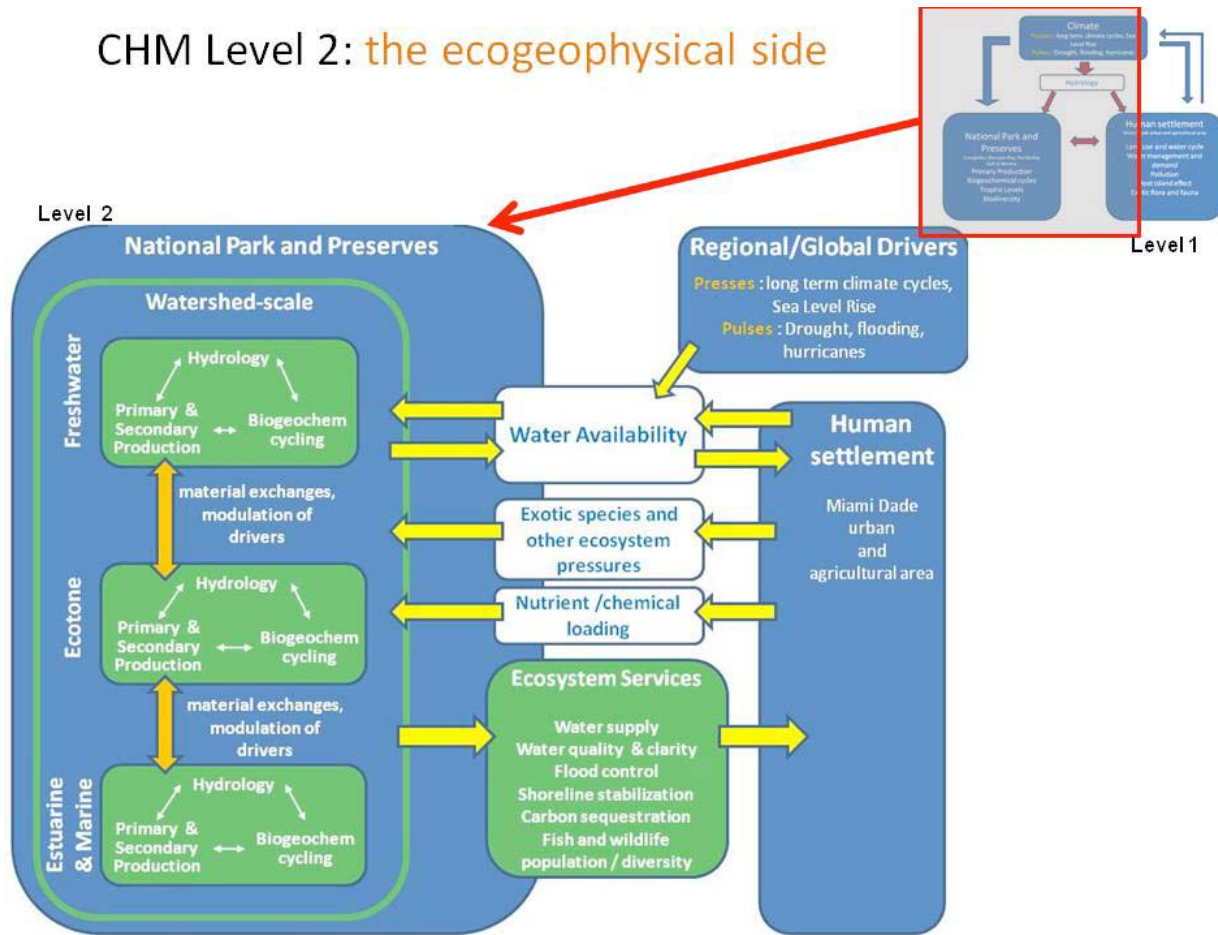
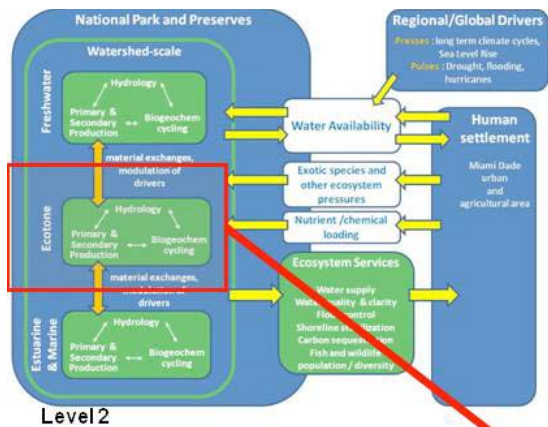


Figure 11.3: The ecogeophysical model



CHM Level 3: example using the hydrodynamic model of the coastal Everglades

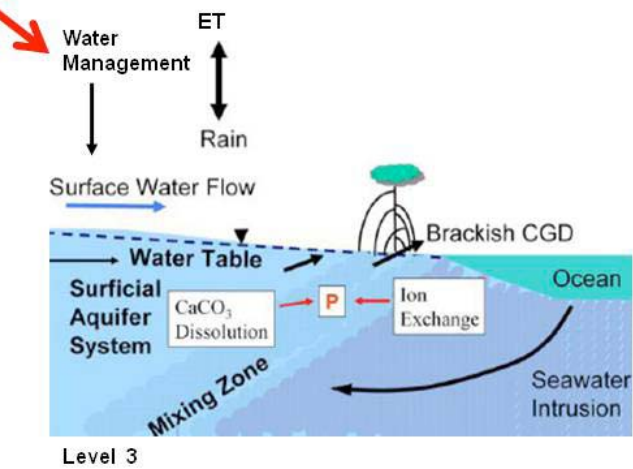


Figure 11.4: An example of level 3 of the CHM: a Level-3 phenomenon, brackish groundwater discharge observed in geochemical investigations (Price et al 2007) is modeled as an outcome of freshwater flows and seawater intrusion.

CHM Level 3: an example of the hydrodynamic model (level 3),
integration of new information, and hypothesis generation

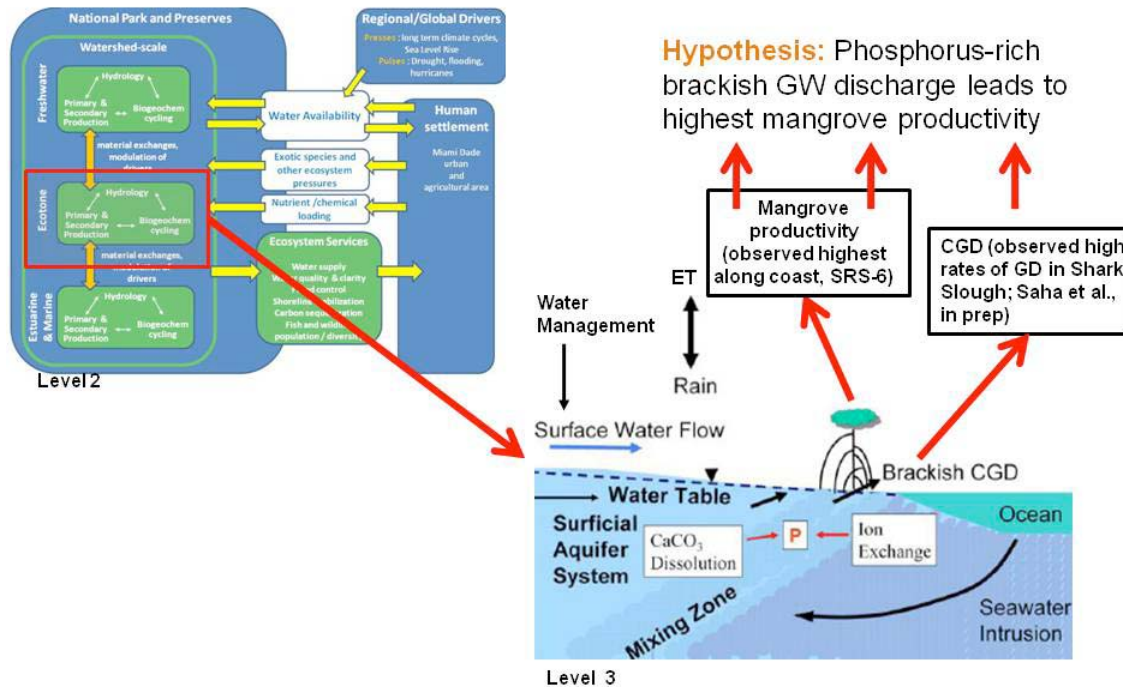


Figure 11.5: An example of level 3 of the CHM, integration of additional information and processes, and hypothesis generation using the coastal hydrodynamic conceptual model, and new FCE results indicating high rates of groundwater discharge (Saha et al., in prep). The high P content of brackish GW is used to develop a set of hypotheses (figure upper right) suggesting that the increased P availability causes higher productivity in coastal mangroves as compared to mangroves near the freshwater ecotone.

c. Hydrological Connections Between Social and Ecological Systems in South Florida (Ogden and Price)

This session at the ASM was to develop research strategies to address two key recommendations stemming from NSF’s mid-program review of the FCE program. These recommendations were: 1) better integrate the Human Dimensions research into the ecological research program -- with a particular emphasis on using hydrology to make these connections, and 2) understand how regional water management affects hydrologic conditions within the FCE study site. Currently, the Human Dimensions group is focusing on understanding the spatial, temporal, social and political dynamics of land conversion within southern Miami-Dade County. The Hydrology group’s focus has been on understanding the hydrologic patterns and interactions of different waters (freshwater, seawater, and groundwater) within the estuarine ecotone. Recommendations stemming from the working group participants at the 2010 LTER ASM meeting included:

1. Develop better maps that illustrate regional water flow patterns, gradient maps, and flux maps;

2. Understand the relationship between urbanization, local climate patterns (“rain machine,” heat island effects, dust effects, etc.), land use change (septic tanks, water use, flood control, impervious surfaces), and regional hydrologic patterns and processes;
3. Understand the decision making processes and politics that effect canal management (flood control, limiting seawater intrusion, reservoir management);
4. Analyze changes in water demand by land use over time, and
5. Develop water budgets by land use for urbanized areas within the FCE study site.

Since the ASM meeting, the “Hydrological Connections” working group was awarded supplemental funding from NSF to examine the relationship between land use change and water demand at the parcel scale, with attention to the role of drought and related water use ordinances in potentially mediating water use. This supplemental funding (to fund fieldwork during the Summer 2011) will help us meet recommendations 2 and 5 above.

d. Community Ecology/Stoichiometry (Jaffé, Heithaus, Rivera-Monroy)

Topic 1: Food web dynamics and incorporating research at intermediate trophic levels

Some research has already been accomplished addressing lower trophic level food web dynamics. In particular,

- Christopher Kelble: mesozooplankton in Florida Bay
- Jenn Rehage: patterns of mesoconsumers near SRS 3 and SRS 4; also manuscript in review on shrimp between SRS4-6
- Mike Heithaus’ students working on consumers along SRS transect (Adam—gators; Phil—sharks)
- Joe Boyer’s group: lots of work on bacterial community shifts in soils and sediments (freshwater and marine)
- There has also been work on grazer experiments in Florida Bay, some enclosure experiments in the ecotone region (Rehage), and some artificial reef work in Florida Bay
- Laura Belicka: currently working with Rudolf Jaffé, Mike Heithaus, and Joel Trexler on applications of lipid biomarkers to food web dynamics. Two projects are underway: linking observations of shark movements with diet history provided by lipid biomarkers; determining lipid biomarkers suitable for tracking periphyton versus floc inputs to higher trophic levels. Feeding experiments are also underway to see how periphyton and floc are metabolized and assimilated by consumers.

In the upcoming years, a greater effort will be made to focus food web studies at the ecotone regions. In addition, we will transition from the observational/monitoring approach to a more experimental approach for future work. However, in the next year we will continue to expand observational and monitoring work on intermediate trophic levels including exhaustive sampling of food webs at the mouth of the Shark River and nearby seagrass communities.

Topic 2: Shifts in species/Invasive species

Jenn Rehage has done some work on shifting mesoconsumer species in the SRS-3 and -4 region. Species shifts (esp. vegetation shifts) are an issue that will be enhanced in the next several years and is a potential area of concentration for the next proposal.

Topic 3: Nitrogen

The reviewers suggested that we focus largely on phosphorus and do not mention enough work that has been done on nitrogen in the FCE region. However, N simply isn't very important in the FCE compared to other LTER sites and we have research made possible through leveraged funds to show this. There will be effort put into creating a simplified box model of nitrogen inputs, transformations, etc., and a nitrogen synthesis paper focusing on the FCE LTER boundary region. The synthesis paper on N in the FCE will have three focus areas (marine—Jim Fourqurean, freshwater/ecotone—Jeff Wozniak, and estuarine/mangrove—Victor Rivera-Monroy). The synthesis of the existing N-dynamics in the FCE will be followed by a discussion on approaches to apply nutrient stoichiometric relationships as key ecological drivers in the face of environmental change and restoration.

Topic 4: Floc

Tracking the abundance and movement of floc is a difficult task for FCE researchers. Greg Koch (graduate student) has made some progress with recent experiments on movement of floc. Also, Oliva Pisani has been working to characterize the bio- and photo-reactivity of floc as well as determine lipid biomarkers specific to floc to assess spatial and seasonal OM input variations. Laura Belicka is working on biomarker identification to allow for tracking of floc to higher trophic levels. The graduate students of the FCE LTER have formed a floc working group to discuss the complexity of floc and best methods for collection, characterization, etc. There has also been some work characterizing the microbial portion of floc. Evelyn Gaiser expressed a desire to do microscopic analysis of floc and mentioned a student may be working on this over the summer.

B. Findings

1. Primary Production

Freshwater marsh

Data collected at both research sites indicate that the magnitude of ecosystem CO₂ exchange in these Everglades marshes is small relative to values reported in other tropical and sub-tropical areas. Maximum rates of net ecosystem exchange (NEE) average 3 μmol CO₂ m⁻² s⁻¹ in the short-hydroperiod marsh and 1 μmol CO₂ m⁻² s⁻¹ in the long-hydroperiod marsh. Seasonality strongly influences rates of CO₂ exchange at the short-hydroperiod marsh, such that rates are depressed during the wet season. This reduction in CO₂ exchange is driven largely by the high percentage of leaf area that is submerged during the wet season, as well as by significantly reduced photosynthetic rates. At the long-hydroperiod marsh, seasonality exerts little influence on rates of CO₂ exchange, though we have found that ecosystem respiration (ER) is slightly

greater in the wet season than in the dry season. Chamber measurements corroborate measurements of CO₂ exchange made at both tower sites.

On balance, the short-hydroperiod site is a small CO₂ sink with annual rates of carbon (C) storage totaling 49 g C m⁻² in 2008 and 18 g C m⁻² in 2009. The variation between years is driven largely by the length of the dry and wet seasons, such that the longer dry season and shorter wet season in 2008 relative to 2009 led to greater C storage. Annual rates of carbon storage at the long-hydroperiod site have not yet been computed because of instrument fouling during the 2009 dry season. However, monthly data indicate that the site is a small CO₂ sink during the dry season and a small CO₂ source during the wet season.

Periphyton

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). 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. Movement of this site in 2005 and 2006 to areas further from the S-12 water delivery structures dampened this trend. There was a general negative relationship between periphyton production and phosphorus availability and decreased production with increasing water depth, a trend reported extensively in this study and throughout the Everglades (Gaiser et al., 2006; 2009; In Press). An examination of diatom communities along the upper part of the SRS transect (SRS1, 2 and 3) over a 7-year period (1997 to 2003) showed significant differences between wet and dry season diatom communities (ANOSIM Global R = 0.112; p = 0.001). Pairwise comparisons of communities from different sites also indicated that distinct diatom communities existed at each site (SRS1 vs SRS2: p = 0.001; SRS1 vs. SRS3: p = 0.006; SRS2 vs. SRS3: p = 0.008), suggesting a community change along the SRS transect, with distance from the Tamiami Canal. A change in diatom community composition over the time period from 1997 to 2003 was observed at the northern –most sites (SRS1 and SRS2), with the major change having occurred after 2001. This change was not seen at the more southern SRS3 site.

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). The relationship of periphyton production to P availability along this transect is positive, but the gradient was within the natural range of variation exhibited in the Everglades rather than reflecting excess P income that instigates the disintegration of the mat matrix (Gaiser et al., 2005; In Press; Hagerthey et al., In Press). Epiphyte accumulation rates in Florida Bay were lower than those for the 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; 2009).

Collaborative mapping efforts to determine landscape scale distribution of periphyton in the Everglades are showing similar trends in production, relative to water quality, salinity and hydrologic gradients in the system. These relationships have been modeled and are being used to indicate ecosystem status, using an assessment approach that accounts for climate-driven inter- and intra-annual variability and builds upon those used for other sensitive organisms in this system (Gaiser et al., 2009). One exciting result of these large-scale mapping surveys has been the appearance of elevated periphyton phosphorus values throughout the ecotone, lending support to FCE hypotheses that coastal sources of phosphorus impact not just the estuaries but the adjacent marshes, as well, and enabling us to evaluate the seasonality of this response in a rapidly responding community. The cascading influence of periphyton productivity and composition on consumer dynamics were examined in a path analysis using data from these surveys (Seargent et al., 2010) and manipulative experiments (Ruehl et al., 2010).

Through international supplement support, we have been comparing periphyton and consumer standing stocks and composition between FCE and karstic wetlands of the Yucatan peninsula, Belize, and Jamaica. Across the Belize, Mexico and Jamaica locations periphyton biomass showed a negative correlation with water depth and mat TP, while periphyton mat percent organic content was positively correlated with these two variables. This is a pattern that has been well documented in the Everglades (Gaiser *et al.*, 2004; 2005; 2006) and suggests that water depth and TP availability are both drivers of periphyton biomass in karstic wetland systems within the northern Caribbean region. A total of 146 diatom species representing 39 genera were recorded from the three Caribbean locations, including a distinct core group of species that may be endemic to this habitat type. Weighted averaging models were produced that effectively predicted mat TP concentration from diatom assemblages for both Everglades ($R^2=0.56$) and Caribbean ($R^2=0.85$) locations. There were, however, significant differences among Everglades and Caribbean locations with respect to species TP optima and indicator species. This suggests that although diatoms are effective indicators of water quality in these wetlands, differences in species response to water quality changes can reduce the predictive power of these indices when applied across systems.

Sawgrass

We have been quantifying aboveground net primary productivity (ANPP) of the dominant macrophyte—sawgrass (*Cladium jamaicense*)—at seven FCE LTER sites for approximately a decade. Specifically, we present sawgrass ANPP data for TS/Ph-1, 2, 3 and 6 in Taylor Slough for 2000-2009 and for SRS-1, 2, and 3 for 2001-2009. Childers et al. (2006) present the methods used in these measurements and the statistical models used in calculating ANPP. Shark River Slough is typically characterized as a long hydroperiod marsh whereas Taylor Slough is more characterized as short hydroperiod. Over the entire decadal record (as reported in our FCE Three Year Review Report), mean ANPP rates (Fig. 1.1) continue to show site differences. Incorporating ANPP for 2009, the southernmost site in the Taylor Slough transect (TS/Ph-3) continues to more closely resemble a long hydroperiod marsh (i.e. *Cladium* ANPP in SRS) 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, by incorporating 2009 ANPP, the overall ANPP mean at the northernmost SRS site (SRS-1) now more closely resembles the long hydroperiod SRS marsh locations.

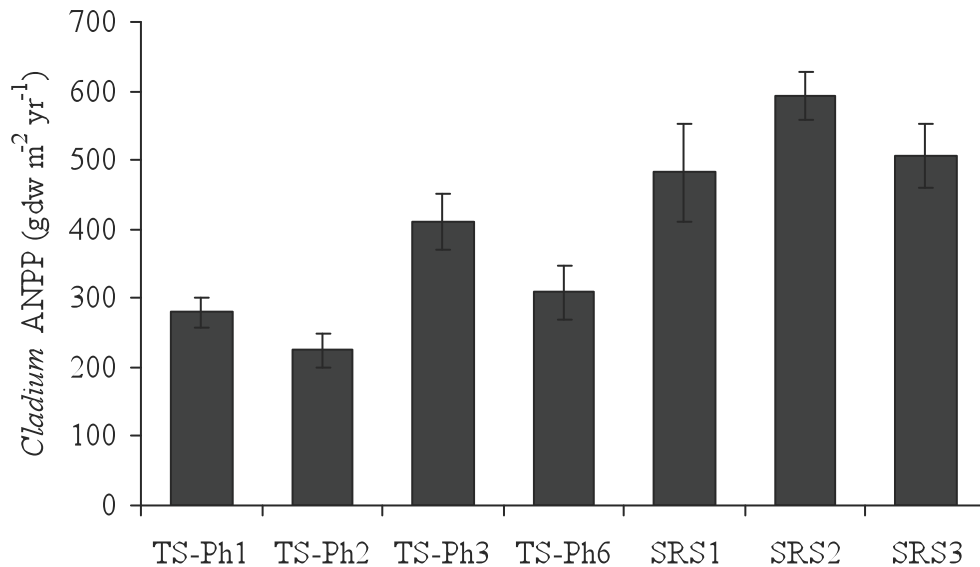


Figure 1.1: Overall time-series mean ANPP by site

The annual time-series of ANPP shows considerably more detail and provides critical information about interannual variability at the seven sites, across the 2 FCE basins, especially in short versus long hydroperiod marshes (Fig. 1.2). As is consistent with previous analyses, neither the Taylor Slough TS/Ph sites (Fig. 1.2, blue symbols) nor the longer hydroperiod sites in SRS showed relatively little consistency in trends related to interannual variability (Fig. 1.2, red symbols). However, two notable site trends are revealed with 2009 data. One, SRS1, our uppermost SRS freshwater marsh site, shows considerable interannual variability as compared with other sites at SRS and sites in TS/Ph. Overall, sawgrass ANPP at this site has increased from 166 ± 35 gdw m⁻² yr⁻¹ in 2003 to 776 ± 38 gdw m⁻² yr⁻¹ in 2009. Two, Taylor Slough site TS-Ph2 continues to show the lowest sawgrass ANPP of all sites within the Shark River Slough and Taylor Slough FCE Basins. Our recent findings are consistent with analyses presented previously of: 1) a “wetness maximum” in either water depth, hydroperiod, or both, at which sawgrass is most productive and 2) how soil P was insignificant in explaining ANPP variability.

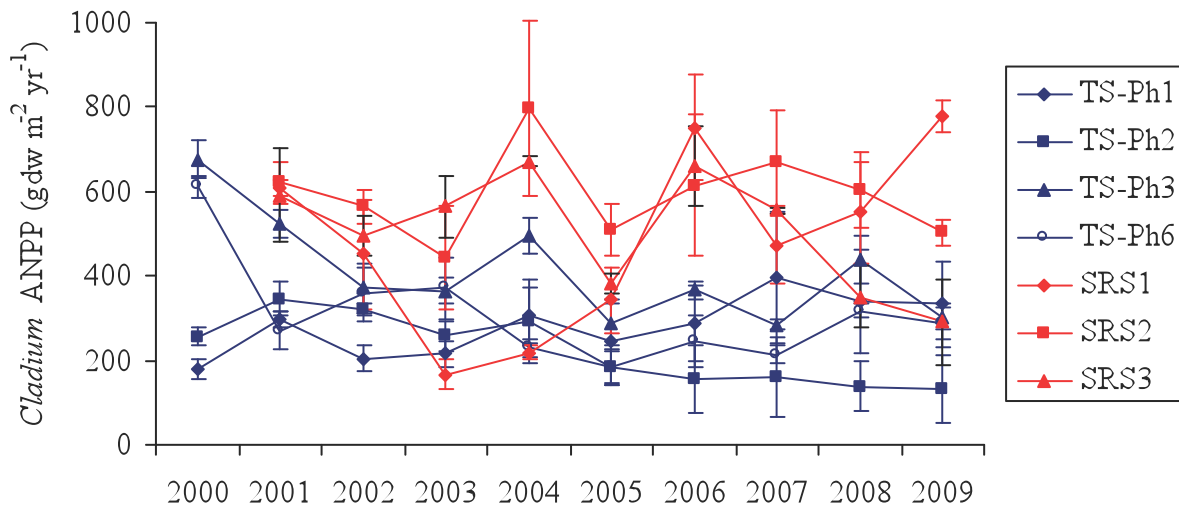


Figure 1.2: Time-series of ANPP by site and basin (Taylor Slough in blue; Shark River Slough in red).

Seagrass Ecosystems

Light, nutrients and community metabolism

We have found that nutrient addition both increases rates of metabolism (respiration and photosynthesis) in the nutrient limited parts of Florida Bay. Further, we have found that daytime net production is a linear function of light availability both in the eastern, nutrient-limited and the western, nutrient-replete ends of our nutrient availability gradient (Fig. 1.3). We found no evidence of photosaturation of primary production in our experiments at ecologically-relevant insolation rates.

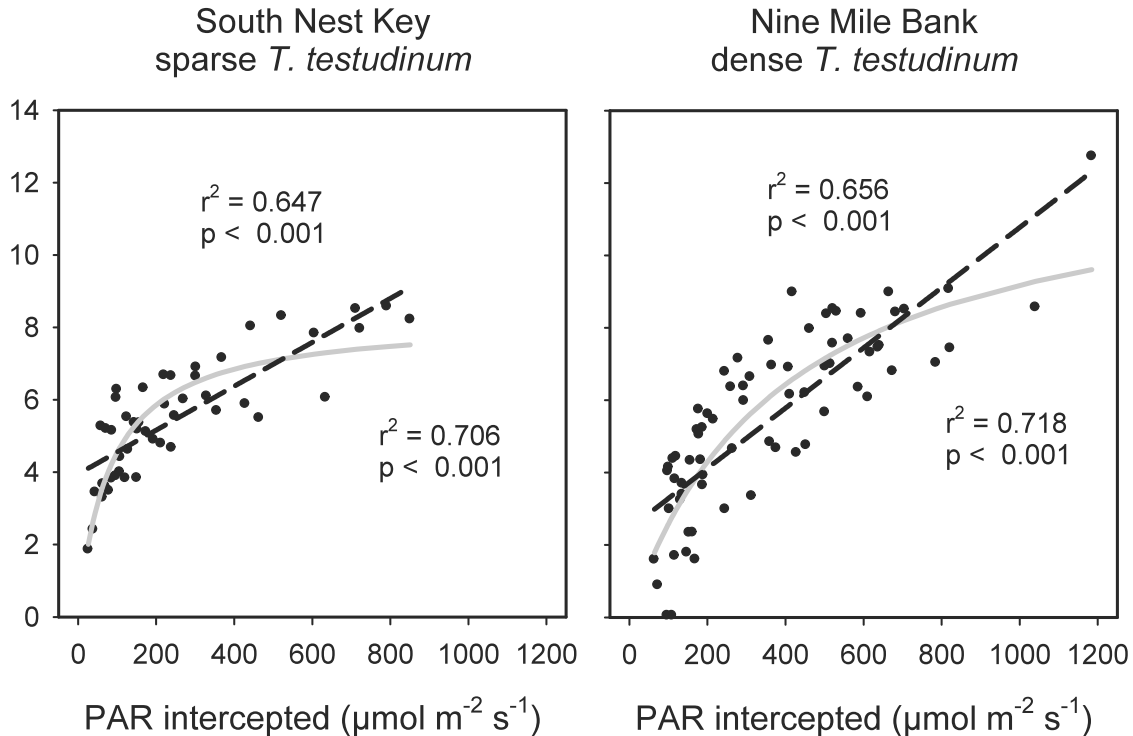


Figure 1.3: Across a natural nutrient availability gradient, net primary productivity increases linearly with light availability at both the eastern, oligotrophic end of the gradient (South Nest Key) and the western more eutrophic end of the gradient (Nine Mile Bank).

Top-down vs. Bottom-up control of primary producer biomass

Our experiments on the relative importance of bottom-up vs. top-down control of primary producer biomass yielded interesting, if not somewhat complicated, result (Baggett et al 2010). Although we succeeded in substantially enriching our experimental cylinders, as indicated by elevated nitrogen concentrations in epiphytes and seagrass leaves, we did not observe any major increases in epiphyte biomass or major loss of *Thalassia testudinum* by algal overgrowth. Additionally, we did not detect any strong grazer effects and found very few significant nutrient-grazer interactions. While this might suggest that there was no important differential response to nutrients by individual grazer species or by various combinations of grazers, our results were complicated by the lack of significant differences between control and grazer treatments, and as such, these results are best explained by the presence of unwanted amphipod grazers (mean = 471 ind. m^{-2}) in the control cylinders. Our estimates of grazing rates and epiphyte productivities indicate that amphipods in the control cylinders could have lowered epiphyte biomass to the same level that the experimental grazers did, thus effectively transforming the control treatments into grazer treatments. If so, our experiments suggest that the effects of invertebrate grazing (and those of amphipods alone) were stronger than the effects of nutrient enrichment on epiphytic algae, and that it does not require a large density of grazers to control epiphyte biomass even when nutrient loading rates are substantially elevated.

Epiphyte loads as an indicator of nutrient availability

Despite marked gradients in nutrient availability that control the abundance and species composition of seagrasses in south Florida, and the importance of nutrient availability in controlling abundance and composition of epiphytes on seagrasses in other locations, we did not

find that epiphyte load on the dominant seagrass, *Thalassia testudinum*, or that the relative contribution of algal epiphytes to the epiphyte community, was positively correlated with nutrient availability in the water column or the sediment in oligotrophic seagrass beds (Fourqurean et al 2010). Further, the abundance of microphytobenthos, as indicated by Chlorophyll-a concentration in the sediments, was not directly correlated with concentrations of nutrients in the sediments. Our results suggest that epiphyte and microphytobenthos abundance are not unambiguous indicators of nutrient availability in relatively pristine seagrass environments, and therefore would make poor candidates for indicators of the status and trends of seagrass ecosystems in relatively low nutrient environments like the Florida Keys.

Mangrove ecosystems

Mean aboveground wood biomass varied significantly among sites ranging from $447 \pm 46 \text{ g m}^{-2}$ (TS/Ph-8) to $15,207 \pm 609 \text{ g m}^{-2}$ (SRS-6; Fig. 1.4a). Along Shark River, wood biomass was higher in SRS-6 compared to SRS-4 ($9772 \pm 702 \text{ g m}^{-2}$) and SRS-5 ($10,879 \pm 567 \text{ g m}^{-2}$; Fig. 1.4a). Wood biomass in TS/Ph-6 & 7 was 1250 g m^{-2} (after Coronado-Molina et al. 2004; Fig. 1.4a). *R. mangle* comprised 66.8 % (SRA-4), 87.1 % (SRS-5), 26% (SRS-6), and 100% (TS/Ph-6 & 7) of the total biomass at each site, while *L. racemosa* and *A. germinans* accounted for 43 and 31% of the total biomass at SRS-6, respectively. At TS/Ph-8, *C. erectus* comprised 90% of the total biomass (Fig. 1.4a). Total (0-90 cm) belowground biomass varied from $2404 \pm 329 \text{ g m}^{-2}$ to $4673 \pm 401 \text{ g m}^{-2}$ among all six sites (Fig. 1.4a). Estimates of total belowground biomass followed the trend TS/Ph-7 > SRS-5 > TS/Ph-8 > SRS-4 > SRS-6 > TS/Ph-6 (Fig. 1.4a). The biomass root:shoot ratio in the Shark River sites was lower compared to all Taylor sites (Fig. 1.4b). Root:shoot ratio ranged from 0.33 ± 0.04 to 0.17 ± 0.01 in the Shark River sites, and from 1.92 to 9.75 ± 1.0 in the Taylor River sites (Fig. 1.4b).

Total annual wood production varied significantly among sites, with the highest wood production in SRS-6 ($384.0 \pm 34.2 \text{ g m}^{-2} \text{ yr}^{-1}$) and the lowest in TS/Ph-8 ($47.6 \pm 23.5 \text{ g m}^{-2} \text{ yr}^{-1}$; Table 1.1). Along Shark River, annual wood production was higher in SRS-6 and lower at sites upstream the estuary (Table 1.1). *L. racemosa* (SRS-6) had the highest wood production across sites, while *R. mangle* dominated wood productivity in the upstream sites (SRS-4 and SRS-5; Table 1.1). Annual wood production in TS/Ph-6 & 7 ranged from 64 to $75 \text{ g m}^{-2} \text{ yr}^{-1}$, respectively (after Ewe et al. 2006; Table 1.1). Annual litterfall ranged from $285 \pm 25 \text{ g m}^{-2} \text{ yr}^{-1}$ (TS/Ph-8) to $1014.1 \pm 74 \text{ g m}^{-2} \text{ yr}^{-1}$ (SRS-6) across sites, and followed the pattern SRS-6 > SRS-4 = SRS-5 > TS/Ph-8 (Table 1.1). Annual total litterfall along Shark River, was approximately 1.3 times lower in the upstream sites (SRS-4 and SRS-5) compared to SRS-6 (Table 1.1). Leaf fall comprised most of the total litterfall in all sites ranging from 66% (SRS-4) to 81% (TS/Ph-8). Wood fall accounted for 16% (SRS-5 and TS/Ph-8) to 24% (SRS-4) of the total litter production, while reproductive parts had the smallest contribution (<10%) among sites (Table 1.1).

Annual NPP_A ($\text{NPP}_L + \text{NPP}_W$) ranged from $322 \text{ g m}^{-2} \text{ yr}^{-1}$ (TS/Ph-6) to $1398 \text{ g m}^{-2} \text{ yr}^{-1}$ (SRS-6) across all six sites, with higher NPP_A rates in the Shark River sites compared to the Taylor River sites (Table 1.1). Average NPP_A was 3.4 times greater in the Shark River sites ($1154 \pm 127 \text{ g m}^{-2} \text{ yr}^{-1}$) compared to the Taylor River sites ($344 \pm 17 \text{ g m}^{-2} \text{ yr}^{-1}$). Estimates of NPP_B did not differ significantly among sites, and ranged from $407 \pm 23 \text{ g m}^{-2} \text{ yr}^{-1}$ (TS/Ph-7) to $643 \pm 93 \text{ g m}^{-2} \text{ yr}^{-1}$ (SRS-5; Fig. 1.5a). NPP_T ($\text{NPP}_A + \text{NPP}_B$) ranged from $785 \text{ g m}^{-2} \text{ yr}^{-1}$ (TS/Ph-7) to $1867 \text{ g m}^{-2} \text{ yr}^{-1}$ (SRS-6) across sites, with higher NPP_T rates in all Shark River sites compared to Taylor River

sites (Fig. 1.5a). Average NPP_T was twice in Shark River ($1680 \pm 95 \text{ g m}^{-2} \text{ yr}^{-1}$) compared to Taylor River ($829 \pm 29 \text{ g m}^{-2} \text{ yr}^{-1}$). On average, NPP_L accounted for 51% (Shark River) and 34% (Taylor River) of the NPP_T , while NPP_W only contributed 17% (Shark River) and 8% (Taylor River) to NPP_T (Fig. 1.5b). NPP_B had a significant contribution to NPP_T ranging from 32% in the Shark River sites to 58% in the Taylor River sites (Fig. 1.5b). The contribution of fine roots (<2 mm diameter) to NPP_T was 50% of the total NPP_B estimated for both Shark River and Taylor River estuaries. Results from this study suggest that the higher allocation of belowground biomass (high root:shoot) and NPP relative to aboveground in Taylor River compared to Shark River represent an adaptation of scrub mangroves to P limitation and flooded hydroperiods.

Two species of mangrove trees of Indo-Pacific origin have naturalized in tropical Atlantic mangrove forests in South Florida after they were planted and nurtured in botanic gardens. Two *Bruguiera gymnorrhiza* trees that were planted in the intertidal zone in 1940 have given rise to a population of at least 86 trees growing interspersed with native mangrove species *Rhizophora mangle*, *Avicennia germinans* and *Laguncularia racemosa* along 100 m of shoreline; the population is expanding at a rate of $5.6\% \text{ year}^{-1}$. Molecular genetic analyses confirm very low genetic diversity, as expected from a population founded by two individuals. The maximum number of alleles at any locus was three, and we measured reduced heterozygosity compared to native-range populations. *Lumnitzera racemosa* was introduced multiple times during the 1960s and 1970s, it has spread rapidly into a forest composed of native *R. mangle*, *A. germinans*, *Laguncularia racemosa* and *Conocarpus erectus* and now occupies $60,500 \text{ m}^2$ of mangrove forest with stem densities of $24,735 \text{ ha}^{-1}$. We estimate the population growth rate of *Lumnitzera racemosa* to be between 17 and $23\% \text{ year}^{-1}$. Populations of both species of naturalized mangroves are dominated by young individuals. Given the long life and water-dispersed nature of propagules of the two exotic species, it is likely that they have spread beyond our survey area. We argue that the species-depauperate nature of tropical Atlantic mangrove forests and close taxonomic relatives in the more species-rich Indo-Pacific region result in the susceptibility of tropical Atlantic mangrove forests to invasion by Indo-Pacific mangrove species.

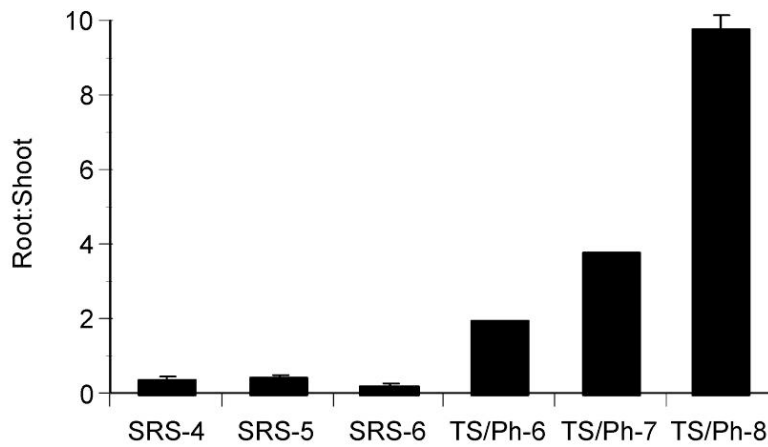
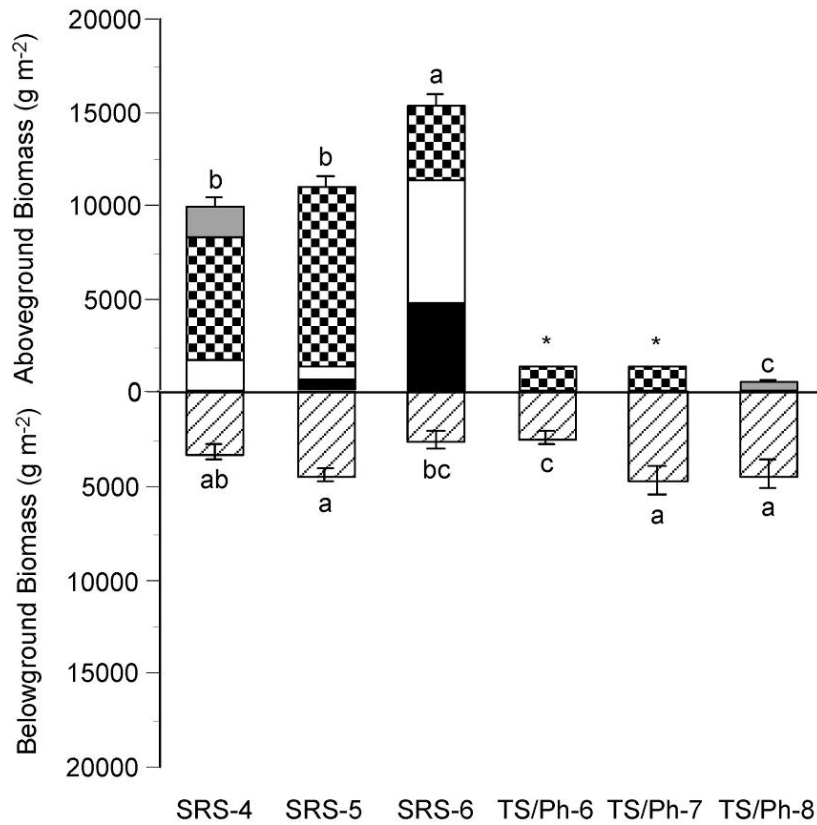
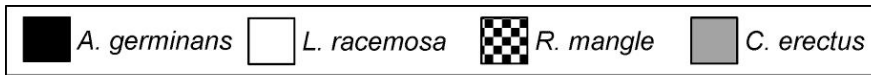


Figure 1.4: Total aboveground wood biomass and belowground biomass (a) and root:shoot ratios (b) in mangrove forests of the Florida Coastal Everglades. Means (± 1 SE) with different letters are significantly different ($p < 0.05$) among sites for each component of biomass. Asterisks indicate data from Coronado-Molina et al. (2004), and were not included in the statistical analysis.

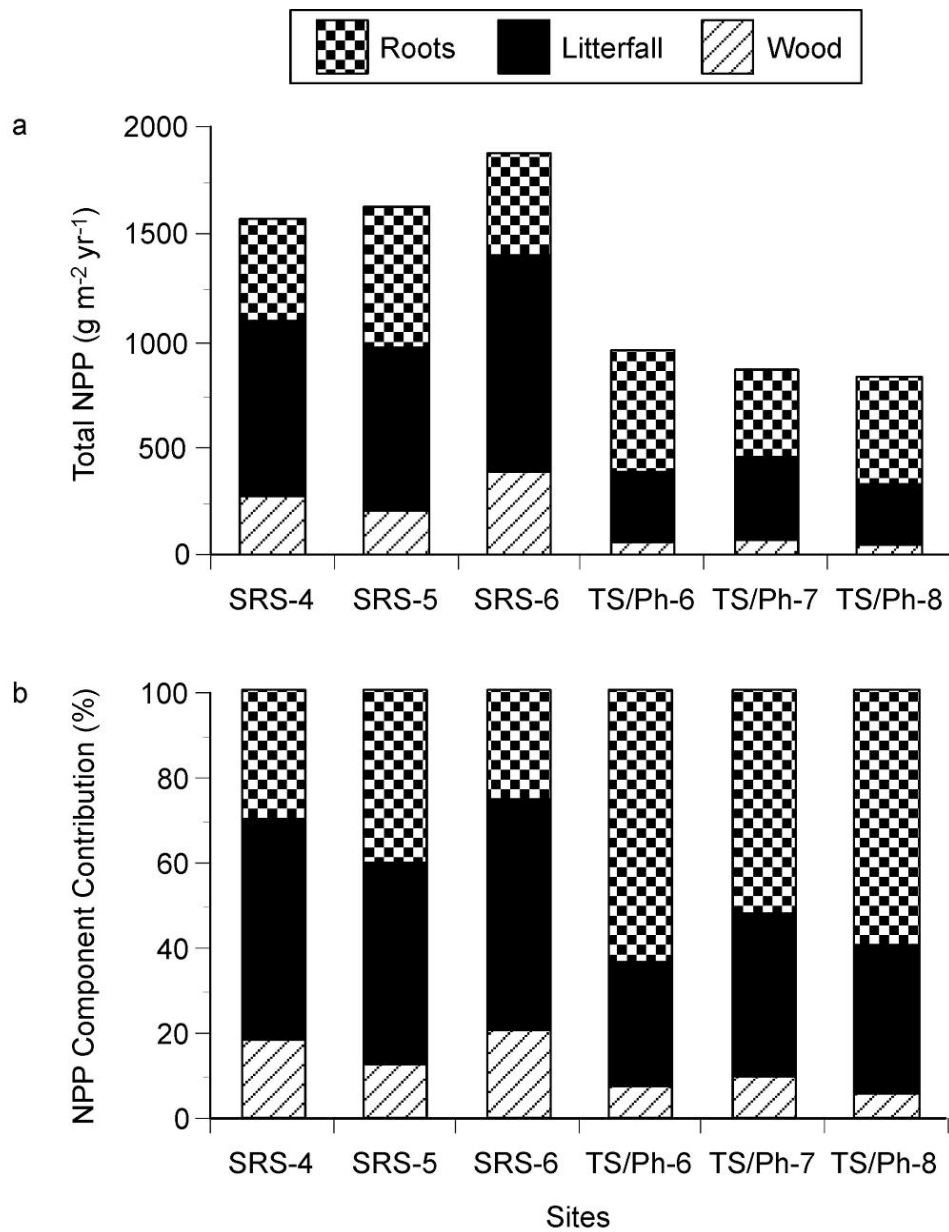


Figure 1.5: Total net primary productivity (NPP_T) including root, litterfall, and wood production (a) and NPP_T component contribution (b) in mangrove forests of the Florida Coastal Everglades during the period 2001-2004.

Variable	Sites					
	SRS-4	SRS-5	SRS-6	TS/Ph-6	TS/Ph-7	TS/Ph-8
Wood production (NPP_W)						
<i>A. germinans</i>		2.7 (1.4)	50.6 (12.2)	-	-	-
<i>L. racemosa</i>	53.5 (25.1)	36.3 (19.9)	210.4 (26.5)	-	-	3.2 (0.0)
<i>R. mangle</i>	179.6 (28.8)	167.2 (56.5)	123.0 (4.5)	64.0 *	75.0 *	
<i>C. erectus</i>	46.8 (10.2)	-	-	-	-	44.4 (25.1)
Total	279.9 ^{ab} (64.0)	206.0 ^{bc} (77.8)	384.0 ^a (34.2)	64.0 *	75.0 *	47.6 ^d (23.5)
Litterfall production (NPP_L)						
Leaves	534.6 (38.6)	581.2 (40.3)	741.4 (47.5)	258.0 *	303.0 *	230.7 (20.5)
Reproductive parts	196.4 (24.4)	123.7 (10.5)	184.9 (17.7)			45.2 (5.3)
Wood	79.6 (19.2)	62.4 (13.8)	87.7 (18.1)			9.3 (3.2)
Total	810.6 ^b (75.1)	767.3 ^b (53.0)	1014.1 ^a (74.0)	258.0 *	303.0 *	285.2 ^c (25.0)
NPP _A = NPP _W + NPP _L	1090.5	973.3	1398.1	322.0 *	378.0 *	332.8

* Data from Ewe et al. (2006); not included in any of the statistical analysis

Table 1.1: Aboveground NPP (NPP_A: g m⁻² yr⁻¹) of mangrove forests in the Florida Coastal Everglades. Means (± 1 SE) followed by different letters across each row are significantly different for each variable (Tukey HSD post hoc test, p < 0.05).

2. Organic Matter Dynamics

Mangrove zone research (Twilley et al.)

There was a consistent seasonal pattern in porewater variables for all mangrove sites along Shark River and Taylor River for the period 2001-2009 (Figs. 2.1 to 2.4). Mean salinity was higher during the dry season (23.2 ± 2.3 g kg⁻¹) compared to the wet season (11.6 ± 1.6 g kg⁻¹) for all Shark River sites; whereas salinity along Taylor River sites remained relatively constant during both the dry (21.3 ± 1.0 g kg⁻¹) and wet (21.1 ± 1.0 g kg⁻¹) seasons throughout the study period (Fig. 2.1). Along Shark River, salinity decreased with distance inland from the mouth of Shark River ranging from 27 ± 2.6 g kg⁻¹ at SRS-6 to 5 ± 1.1 g kg⁻¹ in SRS-4, suggesting the influence of the tidal regime along the estuary (Fig. 2.1) and groundwater flow upstream. Sulfide concentrations showed an opposite trend compared to salinity; with higher values during the wet

season and lower values in the dry season for all mangrove sites (Fig. 2.1). Along Shark River, sulfide concentrations ranged from 0.06 ± 0.02 mM (dry season) to 0.11 ± 0.02 mM (wet season), and from 1.1 ± 0.13 mM (dry season) to 1.43 ± 0.13 mM (wet season) along Taylor River. Overall, sulfide concentrations were higher for all Taylor River sites (1.3 ± 0.2 mM), with the highest values at TS/Ph-8 (1.72 ± 0.3 mM); sulfide concentrations for all Shark River sites were almost negligible (<0.1 mM) or below detection limit (<0.03 mM) for the period 2001-2009 (Fig. 2.1). Soil redox potential (Eh) did vary among sites ranging from 42 ± 28 to 133.5 ± 13.8 mv across all six sites. Soil Eh also was higher at 0 cm (125.3 ± 10 mv) and 10 cm (103.8 ± 12.7 mv) depths compared to 45 cm (-14.6 ± 16 mv). Overall, the Shark River sites (range: 73.2 ± 15.8 to 133.5 ± 13.8 mv) had higher soil Eh values compared to Taylor River sites (range: 42.0 ± 28.2 to 57.6 ± 28.3 mv). However, soil Eh values indicated slightly reducing conditions across all sites and depths (data not shown).

Porewater NO_2^- and NO_3^- concentrations were often <0.5 μM across all sites, seasons, and years. Thus, values for NO_2^- , NO_3^- , and NH_4^+ were pooled together to determine dissolved inorganic nitrogen concentrations (DIN; Fig. 2.3). DIN concentrations were higher at all Taylor River sites (19.1 ± 2.9 μM) compared to Shark River sites (5.7 ± 0.6 μM), with the highest concentrations at TS/Ph-6 (25.6 ± 6.2 μM) and the lowest at SRS-4 (4.8 ± 0.6 μM ; Fig. 2.3). Overall, DIN concentrations along Shark River were lower during the dry season (4.8 ± 0.5 μM) and higher during the wet season (6.7 ± 0.8 μM), while along Taylor River DIN concentrations did not vary between the dry and wet seasons (19.7 ± 3.3 and 18.6 ± 2.6 μM , respectively). Soluble reactive phosphorus (SRP) concentrations varied among sites, especially along Shark River estuary where concentrations increased from upstream to downstream (Fig. 2.4). Overall, SRP concentrations ranged from 0.5 ± 0.2 μM (SRS-4) to 1.9 ± 0.3 μM (SRS-6) along Shark River, and from 0.92 ± 0.2 μM (TS/Ph-7) to 0.96 ± 0.3 μM (TS/Ph-6 & 8) along Taylor River (Fig. 2.4). SRP concentrations were higher during the wet season (1.3 ± 0.3 and 1.0 ± 0.1 μM) compared to the dry season (0.83 ± 0.2 and 0.85 ± 0.1 μM) for Shark River and Taylor River (Fig. 2.4). Results from this study suggest the significant effect of hydroperiod (frequency, duration, depth of flooding) on porewater chemistry along Shark River and Taylor River sites. The strong tidal signature along Shark River reflects changes in salinity along the estuary and the lower accumulation of sulfides and DIN concentrations in soils, particularly ammonium. The higher DIN concentrations in Taylor River sites along with higher sulfide concentrations in soils are associated to the permanent flooding conditions and the lack of a tidal signature, thus promoting greater soil anaerobic conditions.

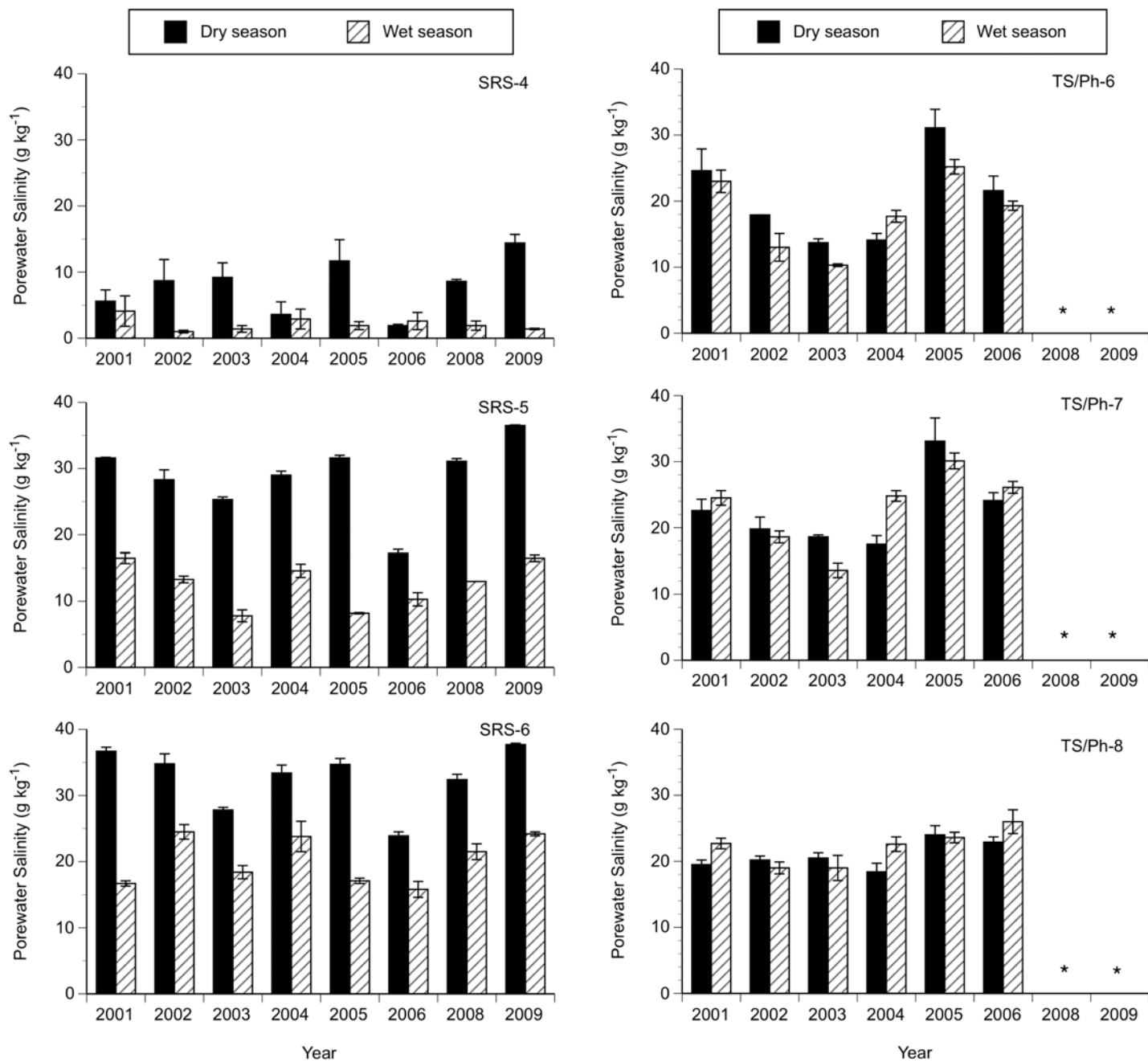


Figure 2.1: Spatial and seasonal variation in salinity measured in mangrove sites of the Florida Coastal Everglades during the period 2001-2009. Asterisks indicate porewater sampling was not performed.

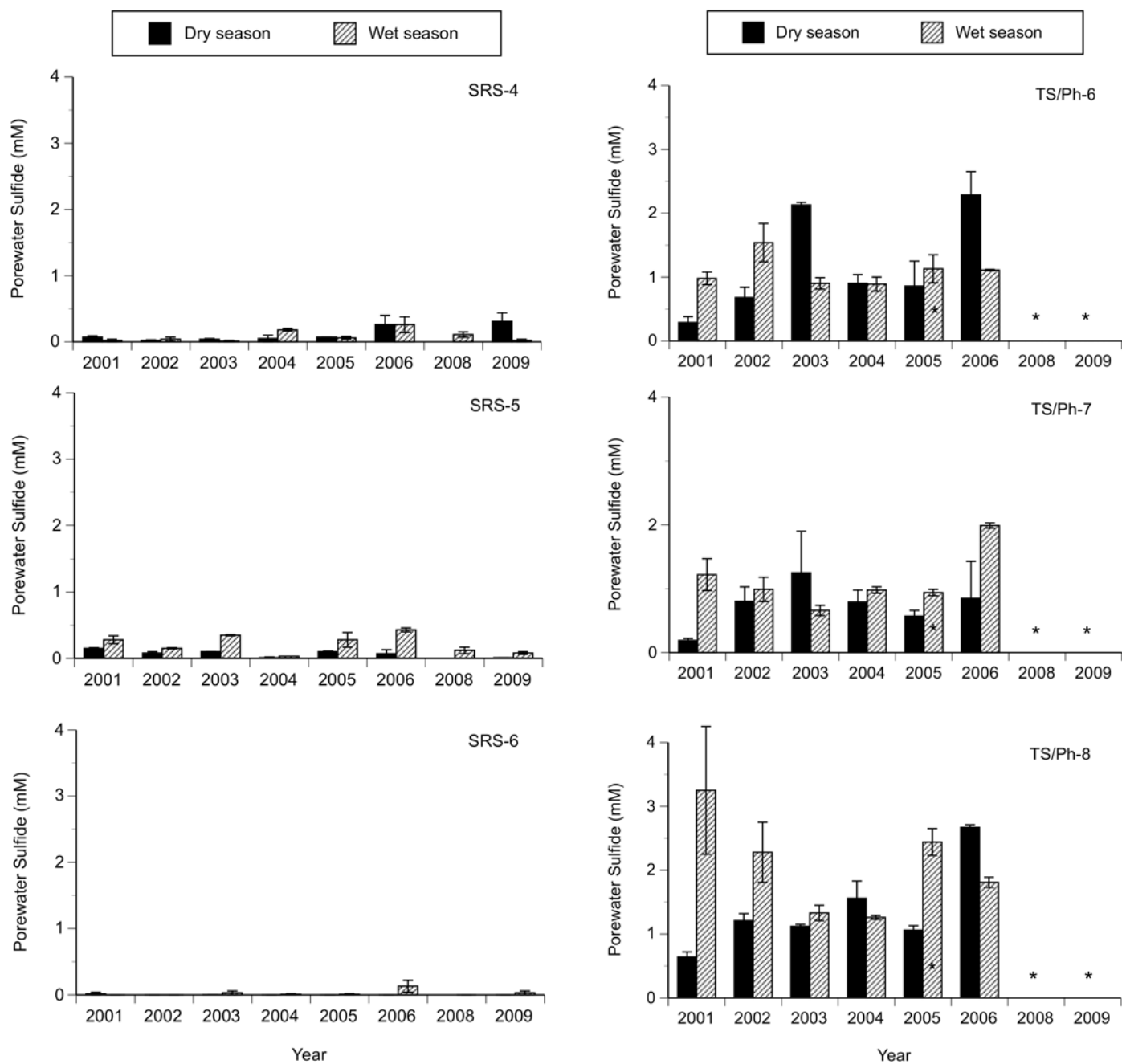


Figure 2.2: Spatial and seasonal variation in sulfide concentrations measured in mangrove sites of the Florida Coastal Everglades during the period 2001-2009. Asterisks indicate porewater sampling was not performed.

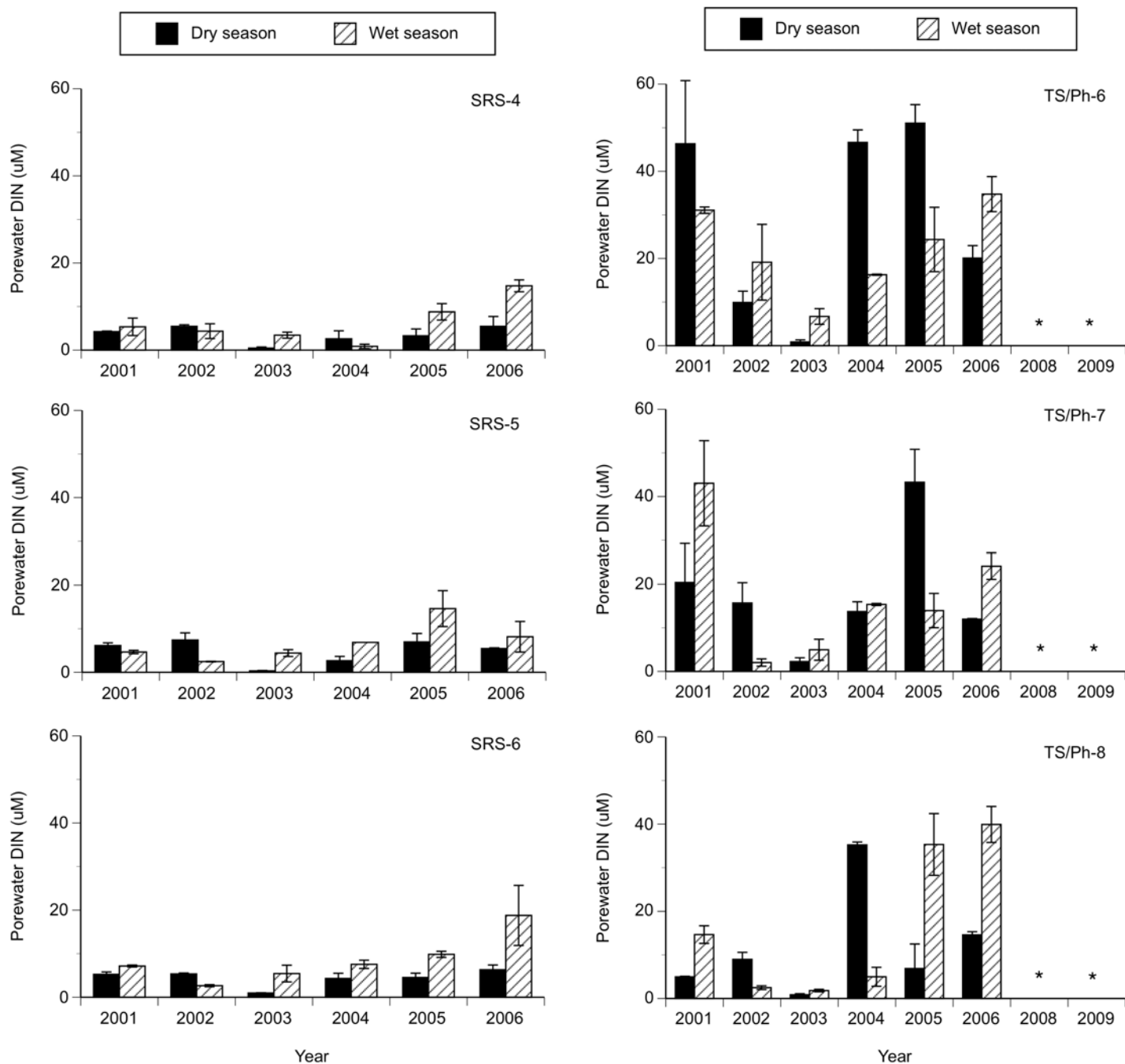


Figure 2.3: Spatial and seasonal variation in dissolved inorganic nitrogen (DIN) concentrations measured in mangrove sites of the Florida Coastal Everglades during the period 2001-2009. Asterisks indicate porewater sampling was not performed.

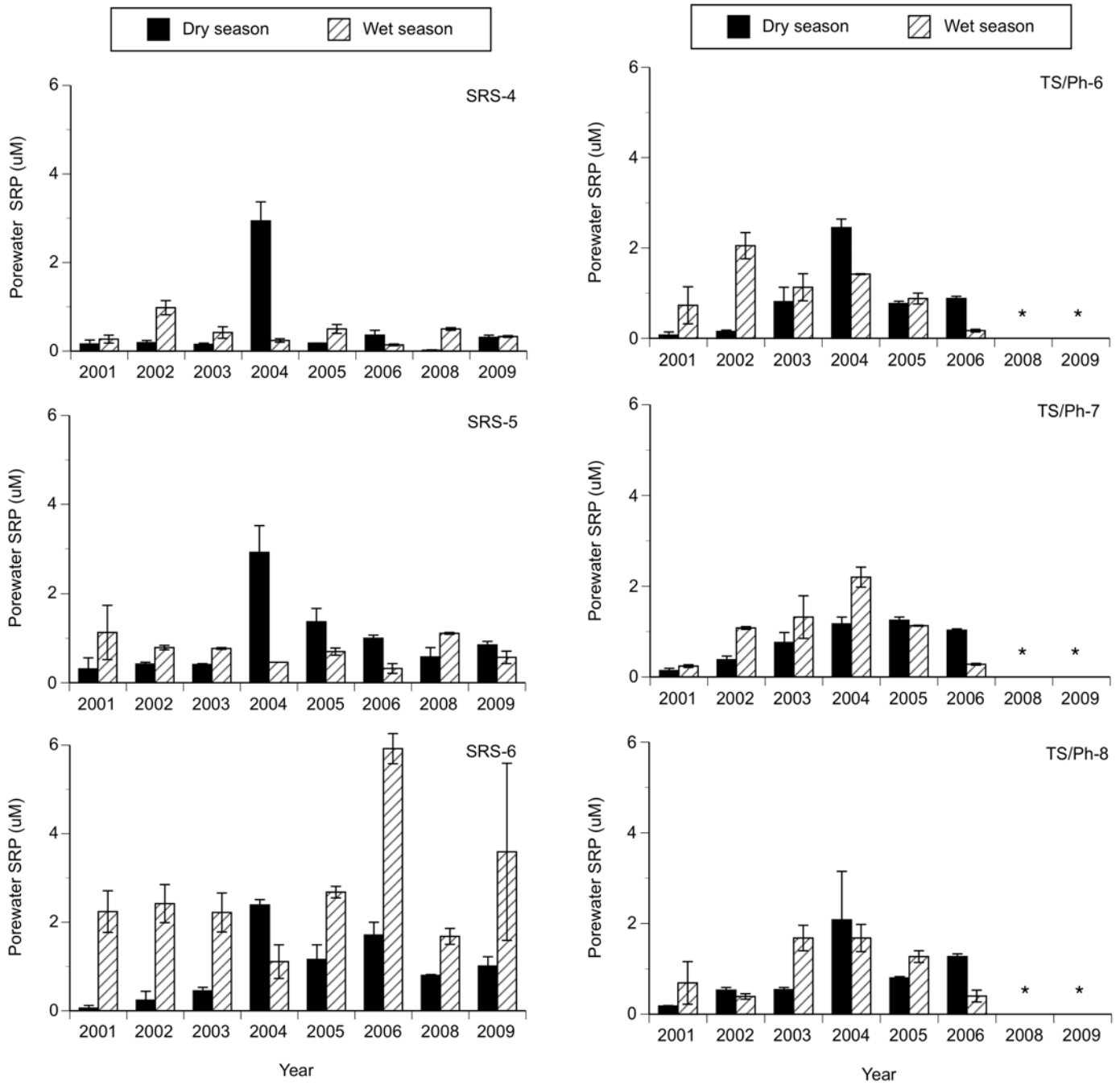


Figure 2.4: Spatial and seasonal variation in soluble reactive phosphorus (SRP) concentrations measured in mangrove sites of the Florida Coastal Everglades during the period 2001-2009. Asterisks indicate porewater sampling was not performed.

Soil research (Chambers et al.)

Soil phosphorus is positively and more strongly correlated with soil organic content than with mineral content. Although sorption and/or incorporation of P into calcium carbonate minerals is one component of the total P pool in south Florida soils, our data demonstrate that the organic P component is more closely associated with the total P pool size. More carbonate does NOT mean more phosphorus.

As shown in Figure 2.5, the Shark River ecotone (located within the region from SRS 3-4) is characterized by low bulk density, high organic content, and high P content. In contrast, the Taylor River ecotone (located within the region from TS/Ph 3-8) is much lower in % organic matter and moderate with respect to bulk density and %P. The location of ecotone sites within this soil parameter space is expected to change with upcoming increases in water delivery through each river system.

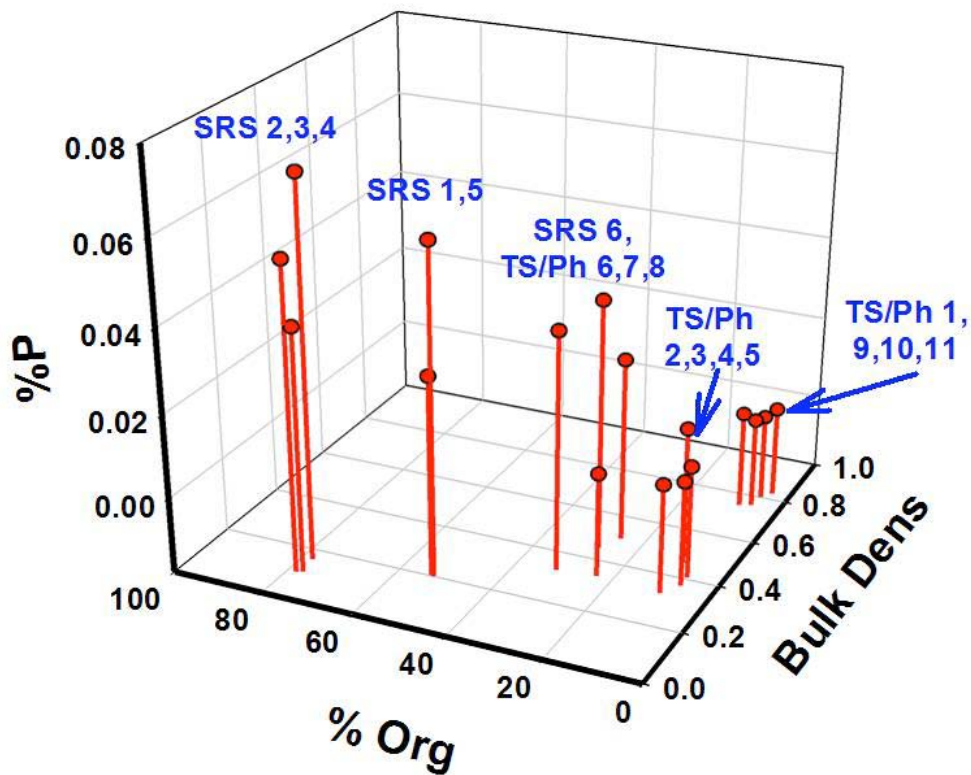


Figure 2.5: Graphical representation of spatial relationships between %P, %OM and bulk density for FCE LTER soils.

Paleoecological and soil accretion (Saunders et al.)

Accretion rates from the Taylor Slough transect are relatively high (2.3 – 3.0 mm/yr) in the northern-most freshwater and brackish-water locations (TS/Ph-3 to TS/Ph-6), comparable to the higher values of peat accretion observed in Shark Slough marshes and sloughs (Fig. 2.6). Lower rates (0.7 to 1.9 mm/yr) are observed nearer the coastline (Pond-5 to TS/Ph-7). This gradient of high-to-low accretion rates observed along the freshwater-to-coastal gradient appears consistent with data from previous studies (Fig. 2.7).

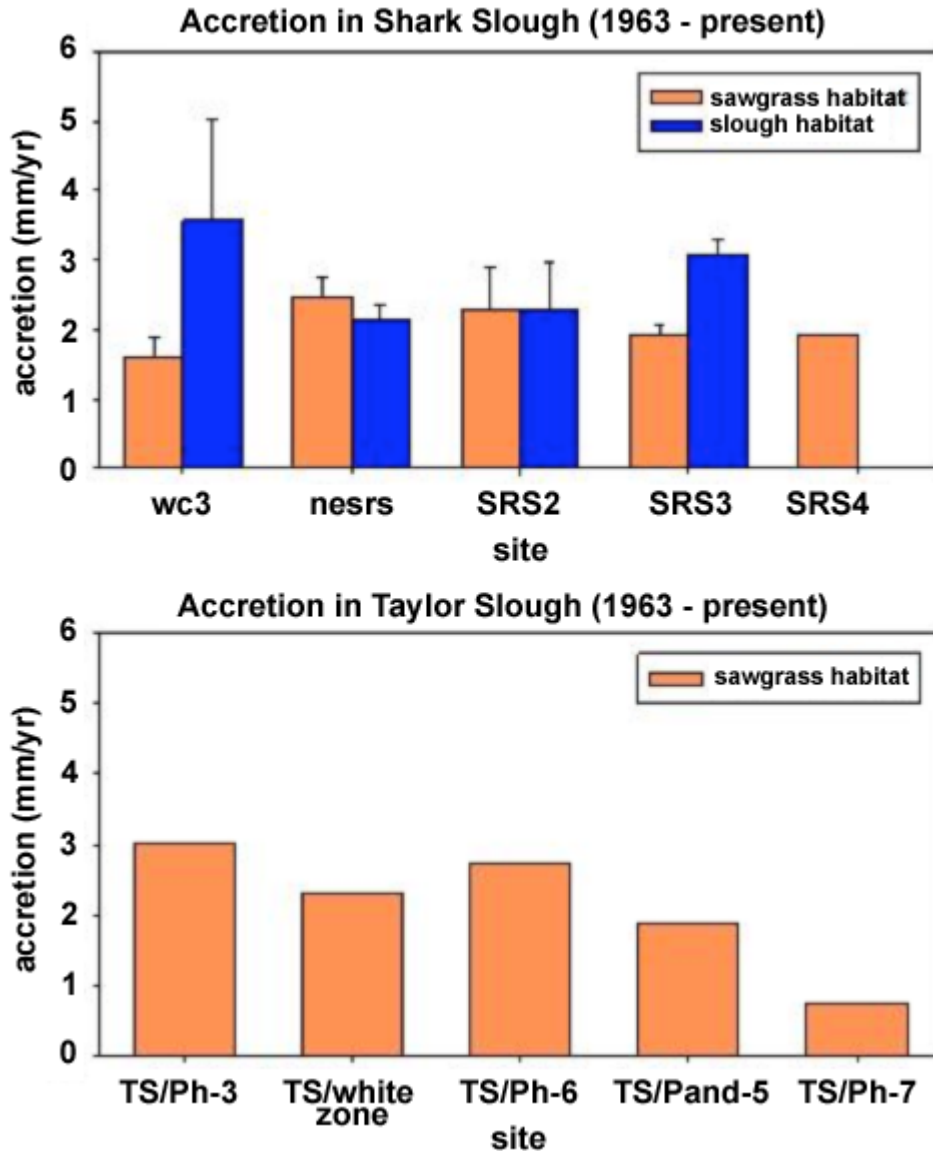


Figure 2.6: Spatial variation in soil accretion based on radiometric dating (^{210}Pb and ^{137}Cs) of soil cores taken throughout the Everglades. (top panel) Ridge and slough accretion rates in Shark Slough, from upstream (WCA-3) down to SRS-4 (no slough accretion rates are measured at SRS-4). (bottom panel) Accretion rates in sawgrass habitats (mixed with red mangrove) in southern Taylor Slough, from TS/Ph-3 to TS/Ph-7.1.

¹³⁷Cs-based accretion rates, Taylor Slough/C-111 region

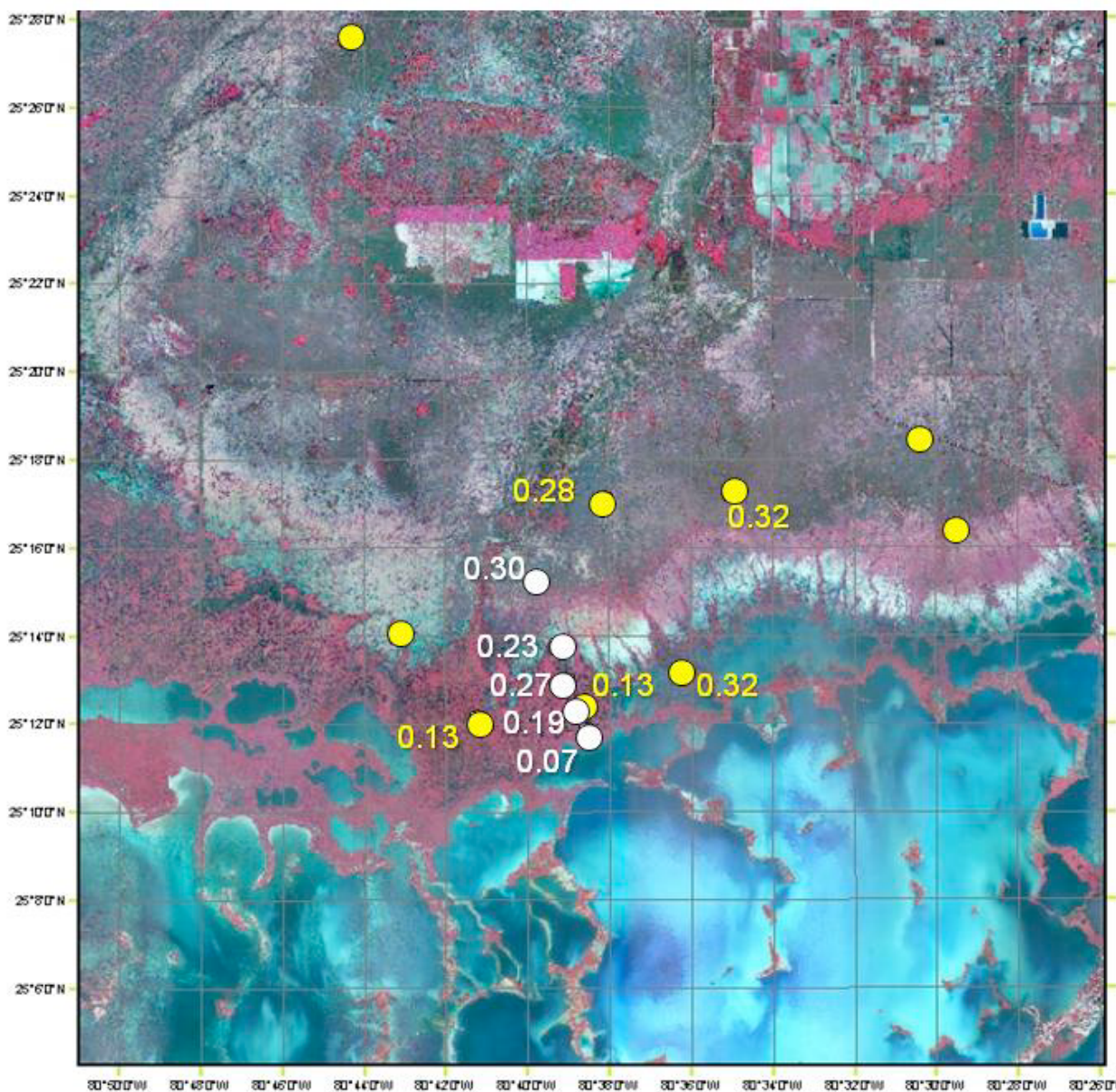


Figure 2.7: Accretion rates along a transect in southern Taylor Slough, from TS/Ph-3 to TS/Ph-7 (white circles and text), compared with published values (yellow symbols and text) from Willard et al. (2001).

Organic geochemistry (Jaffé et al.)

We have completed the flocculation photo-reactivity study, which showed that this material can undergo substantial photo-dissolution and as such make a potentially significant contribution to the DOC pool in the Everglades, with a significant contribution of chromophoric, humic-like DOM. This process could be particularly important in shallow open areas (e.g. Whitewater Bay) with high potential for exposure to sunlight and after storm events. It is at this point hard to estimate semi-quantitatively such contributions to the DOC pool. This study also demonstrated that simultaneously with the photo-dissolution of flocculation not only significant amounts of DOC were

generated, but also TN and TP. DOC photo-generation rates were different on both spatial and temporal scales and likely related to floc ‘quality’. As such, DOC generation rates were higher for (a) freshwater marsh floc compared to mangrove floc, and (b) dry vs wet season floc samples. In addition, floc respiration rates were assessed under natural conditions, after addition of P and both P and Glucose (G) (see Figure 2.8). The data clearly show that microbial degradation of floc is P-limited and that addition of G to induce co-metabolism did not enhance biodegradation of floc. Further experiments on this subject are presently being performed.

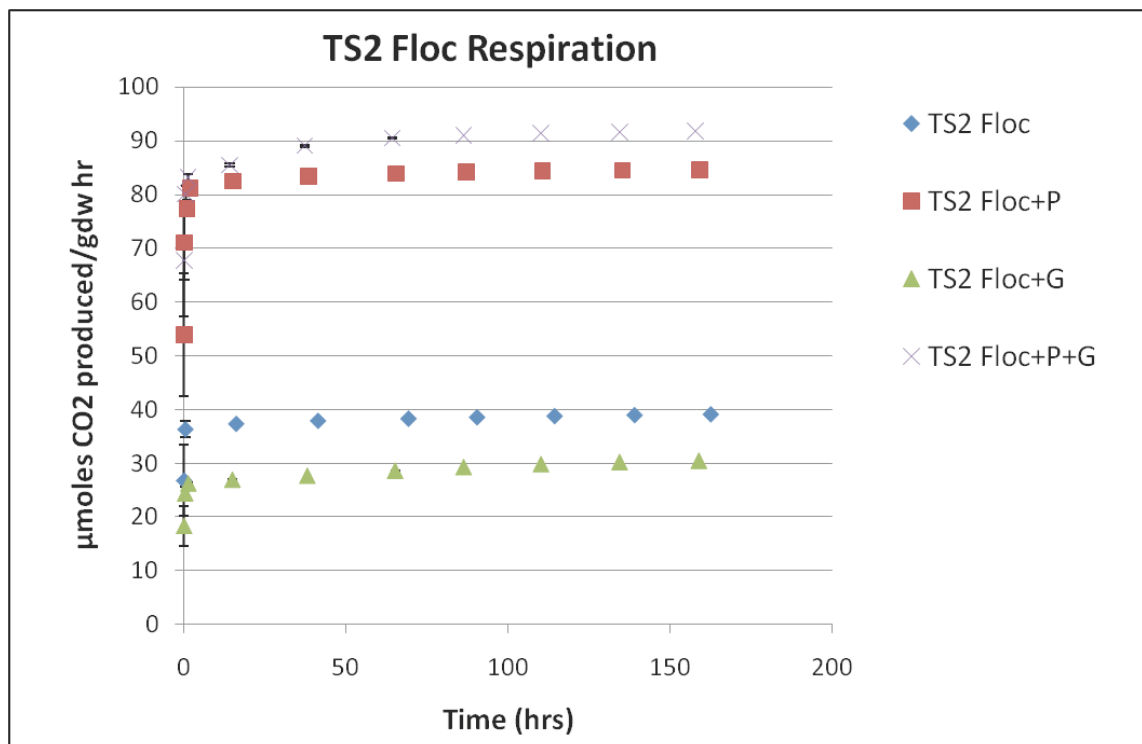


Figure 2.8: Preliminary results of floc biodegradation (respiration) for site TSPH2 including natural conditions and under phosphorus (P) and glucose (G) enrichment.

Regarding DOM reactivity, we determined reaction kinetics for both photo- and bio-incubations, which were monitored using Excitation Emission Matrix fluorescence with parallel factor analysis (EEM-PARAFAC). Reaction kinetics were observed to fit a two phase model extremely well, with one more labile and a more refractory OM pool represented. Based on local hydrological conditions and considering the relatively short residence time of a conservative tracer in the Everglades, we categorized DOM reactivity pools based on reaction half lives of DOM photo- or bio-reactivity as ‘labile’ if *ca.* 24 hrs and ‘refractory’ if >2 months. Substituting these residence times in the kinetic model equation we calculated the relative (%) DOM pools for labile ($t < 24$ hrs), semi-labile ($t > 24$ hrs and < 2 months) and refractory ($t > 2$ months). This approach allowed reactivity comparisons of individual DOM components (as defined by EEM-PARAFAC). In general terms, DOM in the Everglades was most labile from plant leachates, followed by soil leachates and least reactive as found in surface waters. Examples of a humic-like and a protein-like component are shown in Figure 2.10. These preliminary data seem to suggest that most DOM in this system is primarily refractory (at the discussed time scale), and increased water delivery (i.e. further reduced residence times) is not expected to have much

impact on the dynamics of DOM (with regards to photo- and bio-degradation). However, this can and should not be extrapolated to the coastal zone where residence times are expected to be larger. We are presently investigating the fate and effects of this Everglades-derived DOM in the coastal zones of S. Florida.

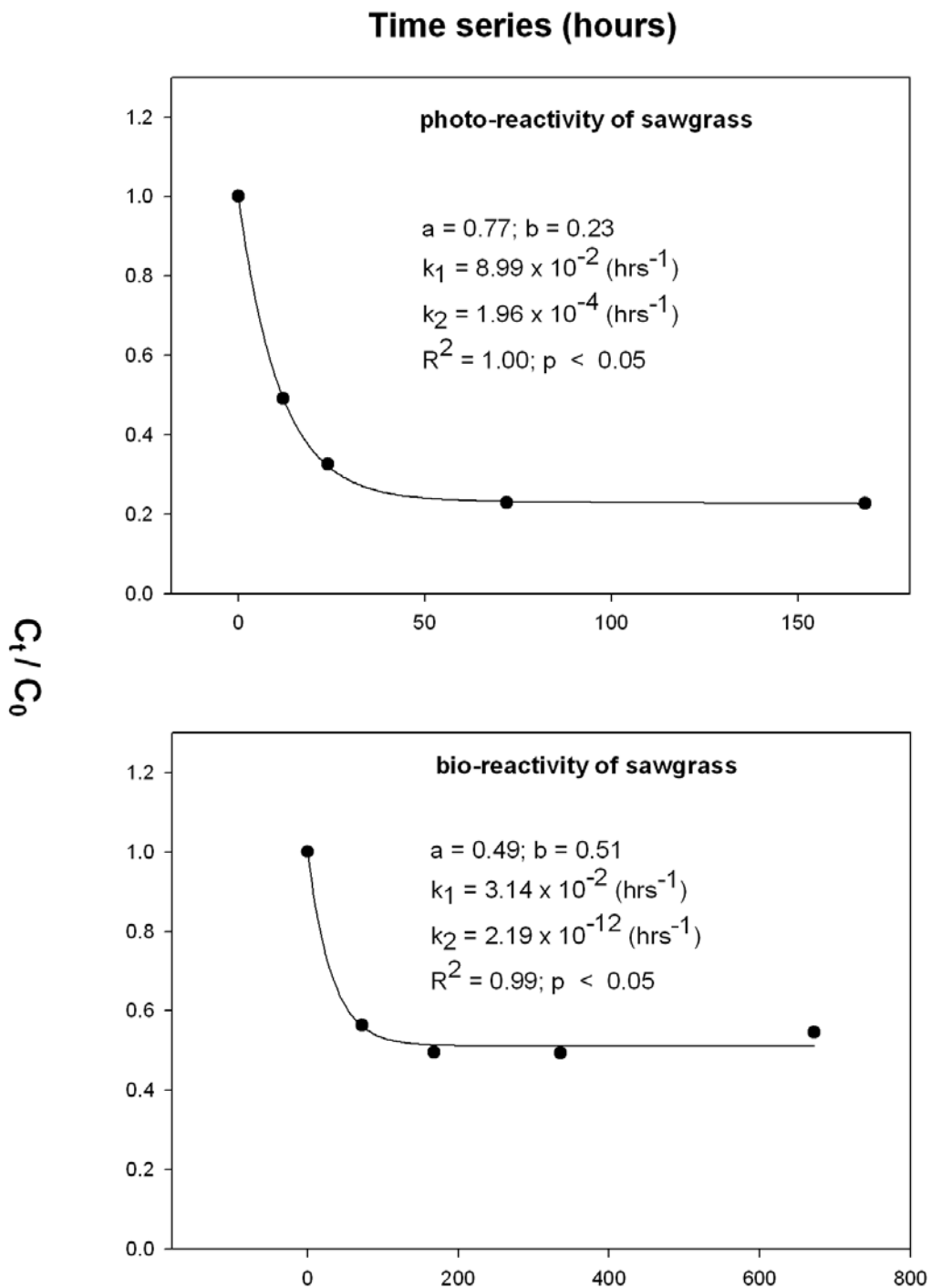


Figure 2.9: Examples of multi-pool first-order decaying kinetics model [$C_t / C_0 = a \cdot \exp(-k_1 \cdot x) + b \cdot \exp(-k_2 \cdot x)$] for the humic-like EEM-PARAFAC component C1 for photo- and bio-reactivity measurements of sawgrass leachates.

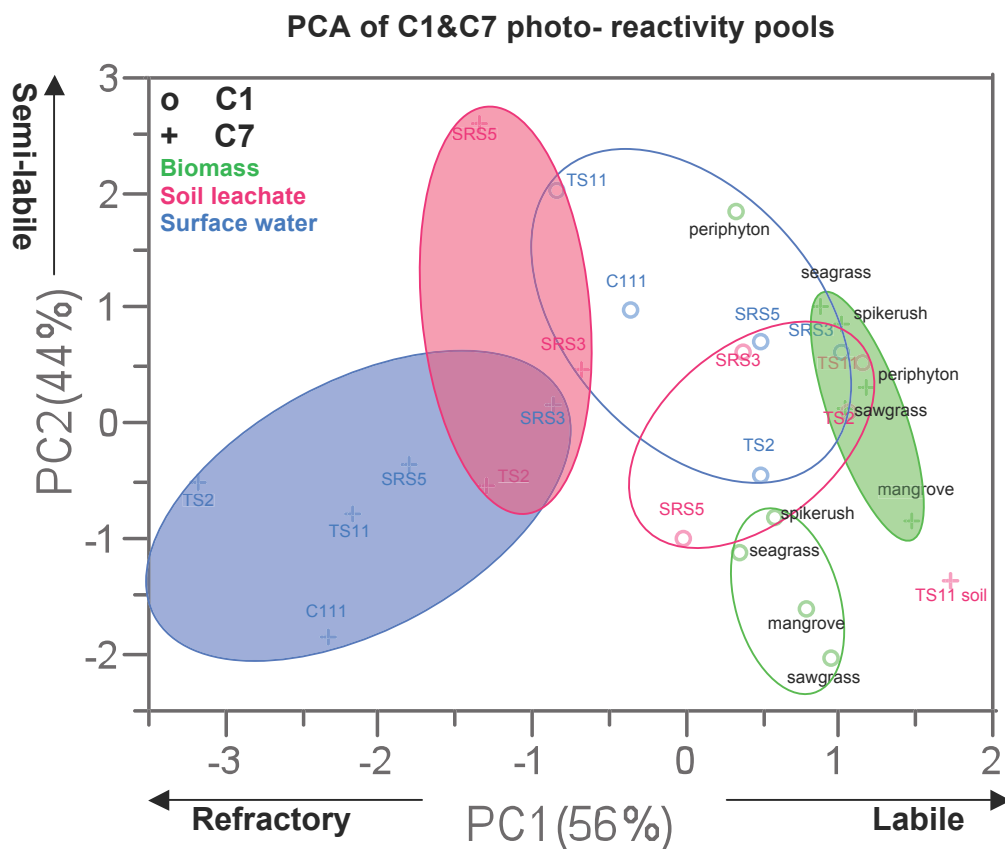


Figure 2.10: Principal component analyses of EEM-PARAFAC fluorescence data for the humic-like component C1 and the protein-like component C7 for DOM photodegradation data using the relative contributions of labile, semi-labile and refractory as defined in text.

3. Biogeochemical Cycling

Microbial Dynamics

We have noticed an overall decline in bacterial production since beginning fall of 2005 with no statistical decline in bacterial numbers. These changes seem related to hurricane impacts of extremely active 2005 season.

Biogeochemical Cycling

Upstream/downstream sampling of mangrove ecotone

We see considerable differences in water quality and constituent concentrations between TS/Ph 6 & TS/Ph 7 and across samplings, indicating strong spatial and seasonal controls on water quality and materials exchange in this region. During 2008 and 2009 samplings, SRP was low and averaged 0.07 μM at both sites. This is expected during the wet season, when flows are predominantly from the oligotrophic Everglades. Overall, TP, SRP, TSS, salinity, and pH were higher near the mouth of the river (TS/Ph 7) and seemingly highest during the dry season or the

transition from the wet to the dry season. Within each sampling, we also saw noticeable differences in water quality and nutrients as a result of wind forcing and precipitation events that affected salinity, temperature, pH, and DO concentrations at these sites. These trends indicate processing of materials at the landscape level, as concentrations increase or decrease from one end of the river to the other (e.g., significant DOC increase from TS/Ph 6 to TS/Ph 7 in August 2008) or the ratios of inorganic:total nutrients change from one end to the other (e.g., P in May 2009). The former reflects a mangrove source of DOC during the wet season, while the latter reflects a possible transformation of organic P to inorganic P or a new source of inorganic P at the lower end of the river during the dry season.

Sediment core flux studies

In order to evaluate the role of season and surface water quality in affecting benthic nutrient (N and P) exchange across lower Taylor Slough, we have conducted core incubation experiments for the past two years on control cores and cores that have enhanced P availability in the water column. Seasonal experiments have included wet season, dry season, and wet-dry transition incubations in each year and cores collected at TS/Ph 7b 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.

In each incubation, we measured initial dissolved oxygen (DO) and take water samples for analysis of nutrients and DOC. At the conclusion, (approximately 4 hours), we measure the final DO concentration and take final samples for nutrients and DOC. Significant DO removal occurred at all sites indicating net heterotrophy in the peat-dominated soils and sediments. Consistent $\text{NO}_3 + \text{NO}_2$ uptake and NH_4 release from soils and sediments suggest denitrification via microbial activity in addition to ammonification of organic material contributing to release of reduced inorganic nitrogen. DOC consumption supported this. In control conditions, we have observed weak, but significant PO_4 uptake from the water column to the sediment. Enhanced PO_4 uptake by sediments was found after the addition of $1 \mu\text{M}$ 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. Leading up to our most recent sampling (October 2008), we observed a gradual increase in the rate of P uptake in the P-addition treatment at each site over time, especially at TS-Ph 7b and Eastern Little Madeira Bay. 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 October 2009 showed that this trend ceased at all sites and reverted back to levels observed at the beginning of the study.

Tamiami Swales Project

Preliminary water quality data suggest that canal stage exerts a strong influence on the spatial heterogeneity of habitats downstream of culverts, and initial anecdotal evidence suggests that periphyton productivity also reflects these trends. Water quality characteristics and

predominance of periphyton mats are most consistent in culvert pools and in the southern transects at each site.

4. Trophic Dynamics and Community Structure

Dynamics of marsh consumer communities

We continue to add data to our time-series studies from the fresh-water Everglades and work on experimental and other studies to understand the interaction of hydrological disturbance and resource availability in shaping community dynamics there. During the past year we completed research developing a new method to evaluate fish movement by use of encounter rate data. We have one manuscript in review on this topic, and one in print that illustrates how those data can be applied. The latter paper evaluated three hypotheses to explain the rapid re-colonization of short-hydroperiod marshes by fishes early in the wet season. We found that a classic Skellam-type diffusion model was inadequate to explain this phenomenon when parameterized with our field velocity estimates, as was a model with dry-season refuges scattered throughout the landscape (they would have to hold too many fish to be realistic). However, a spatial ideal free model was able to produce patterns of marsh re-colonization consistent with our observations. While this doesn't prove that such a model is capturing real spatial dynamics, it does suggest where our next research steps should be. Specifically, our next research should examine the hypothesis that food resources are higher in newly re-flooded areas compared to those that remained flooded during the dry season. This is hypothesized to create an attraction for foraging fishes and draw them into the newly flooded sites, expanding throughout the ecosystem as water rises. It also raises the possibility that re-colonization from canals bordering the Everglades is not necessary to explain the current pattern of spatial dynamics.

In related work, we are also examining the movement of large fish across the Everglades landscape to better understand the role of aquatic refuges in sustaining their population dynamics, as well as shaping their impact on community dynamics through predation. New work this year documented the role of alligator ponds as aquatic refuges in the Everglades and evaluated three hypotheses about their benefits relative to the frequency of hydrological disturbance: that their benefit increases linearly as the frequency of disturbance increases, that their benefits is asymptotic with increasing frequency of disturbance, or that their benefit is modal such that there is an intermediate frequency where their benefits are maximized. Our data indicated that dry-season use of alligator ponds greatest when approximately 2 years passed since the last marsh drying event, and was less when drying was more recent (or recurred more frequently) or more distant in the past (or recurred less frequently). Alligator ponds close to canals were used less than those more distant to canals, demonstrating that landscape context also influences refuge use. We are currently tracking largemouth bass (a native species) and Mayan cichlids (a non-native species) using radio transmitters to evaluate their use of canal and marsh habitats.

Other work examined the relationship between measures of food-web function and hydrological and resource gradients. Total trophic diversity, measured by niche area, decreased with periphyton biomass and the relative abundance of several bluegreen algae species. Consumers' basal resource diversity, estimated by $\delta^{13}\text{C}$ values, was as related to algal community structure.

The range of trophic levels ($\delta^{15}\text{N}$ range) increased with time since the most recent drying and reflooding event, but decreased with intermediate consumer density, and was positively related to the relative abundance of green algae. Our findings suggest that algal quality, independent of quantity, influences food-web structure and demonstrate an indirect role of nutrient enrichment mediated by its effects on periphyton palatability and biomass. We have also found that herbivore and omnivore density increase as the relative abundance of green algae and diatoms increases, but is unrelated to algal biomass, while algal stoichiometric data are not well correlated with consumer density. These results support the hypothesis that algal palatability is a key factor in shaping food-web function in the freshwater Everglades.

Dynamics of fish communities at the mangrove-sawgrass ecotone

Fish abundance varies markedly yearly and seasonally in response to hydrological conditions, but functional groups are affected differently. Marsh fishes move into estuary in the dry season, locally increasing prey and predator abundance, but limited to the upper estuary, perhaps by salinity. Marine and estuarine predators seem to move to the upper estuary matching increases in freshwater prey, which vary in timing depending on marsh water levels. Freshwater prey taxa make large contributions to the prey base in the dry season, and their abundance is negatively related to marsh water levels. Marine prey show little spatial and seasonal variation.

Our results indicate that ecotonal creeks may serve as important dry-season refugia for freshwater taxa, and that pulses of freshwater taxa into tidal creeks may trophically link estuarine and marsh habitats. Furthermore, the nature and strength of these linkages appear to be affected by how species and functional groups respond spatially and temporally to abiotic conditions. Increases in freshwater inflows into the southern Everglades may affect this linkage by prolonging the pooling of freshwater in upland marshes and changing abiotic conditions at the ecotone.

Stable isotope analyses suggest similar resource bases for the four dominant mesoconsumers in the upper SRS (estuarine snook, and three freshwater taxa—largemouth bass, bowfin and Florida gar). Stomach content analyses from the 2010 dry season show that freshwater fishes and shrimp are key resources for all consumers. No estuarine teleosts were found in any stomach contents from this sampling period.

Drivers of habitat use and trophic interactions of top predators in the Shark River Estuary

One of the most interesting results to emerge from work with top predators this year is the prevalence and potential importance of individual specialization in movements and trophic interactions. A study of stable isotopic values from multiple tissues that varied in turnover rates in bull sharks in the SRS and tiger sharks in Western Australia showed different patterns of specialization. Although both species are dietary generalists and the population level, individual tiger sharks appear to have broad diets while the bull shark population of the SRS is made up of specialist individuals that collectively feed in a range of food webs (i.e. marine, estuarine, freshwater). A number of bull sharks captured within low salinity areas had stable diets based on marine food webs suggesting that they had moved to marine waters to feed. Such behavior could play a role in nutrient dynamics within the river. Ongoing studies will investigate links between trophic interactions and movements. We also are beginning to investigate ontogenetic changes in diets of bull sharks. As sharks grow, they tend to expand their activity area and incorporate more

marine prey into their diet. When bull sharks reach ~150 cm total length, they begin to regularly use downstream areas of the system and their diet is similar in isotopic values to that of coastal predators like lemon sharks. The risk of predation appears to be a strong driver of habitat use within the system – the smallest individuals tend to use Tarpon Bay almost exclusively, which may be due its distance from the mouth of the river (15-20 km away) where drumline catches of large sharks have shown it to be the most dangerous areas for small sharks.

Interestingly, alligators in the Shark River estuary also display individual variation in behavior. At the population level alligators in the FCE avoid downstream, marine influenced, areas during the high dry season and move into these areas during the wet season when salinities are much lower. At the individual level, about half of the alligators (downstream commuters (DCs)) frequently used downstream areas during the wet season while others (residents and upstream commuters (UCs)) never went into these areas. DCs did not generally stay in the downstream areas for long periods of time but instead made periodic trips into the region, staying for a short time and then moving back into the lower salinity upper reaches of the estuary. DCs have stable carbon values that suggest greater use of prey from marine food webs than residents and UCs. Therefore, it is likely that these alligators trade-off salinity stress for access to more abundant resources downstream.

Due to the extended period of cold temperatures in January 2010, the behavior and population dynamics of the Shark River bull sharks changed, and no sharks were captured or detected on acoustic monitors until late April. Some individuals left the system out the mouth of the river – entering coastal waters where temperatures were less extreme, but others remained in the system, and based on movement patterns, did not survive. The majority of juvenile bull sharks captured since the cold snap have been from Tarpon Bay and all were neonates, suggesting that population demography may have been substantially altered by the cold snap.

The role of consumers in nutrient dynamics in Florida Bay

The construction of artificial reefs in the oligotrophic seagrass meadows of central Florida Bay attracted large aggregations of fish and invertebrates, and assays of nutrient availability indicated increases in availability of nutrients to sediment microalgae, periphyton, and seagrasses around reefs (Dewsbury and Fourqurean 2010). An average of 37.8 large (>10 cm) mobile animals were observed on each small artificial reef. The dominant fish species present was the gray snapper (*Lutjanus griseus* L.). Four years after the establishment of the artificial reefs, microphytobenthos abundance was twice as high in reef plots ($1.7 \pm 0.1 \mu\text{g chl-}a \text{ cm}^{-2}$) compared to control plots ($0.9 \pm 0.1 \mu\text{g chl-}a \text{ cm}^{-2}$). The accumulation of periphyton on glass periphytometers was four times higher in artificial reef plots ($200.1 \pm 45.8 \text{ mg chl-}a \text{ m}^{-2}$) compared to control plots ($54.8 \pm 6.8 \text{ mg chl-}a \text{ m}^{-2}$). The seagrass beds surrounding the artificial reefs changed rapidly, from a sparse *Thalassia testudinum* (König) dominated community, which persisted at control plots, to a community dominated by *Halodule wrightii* (Ascherson). Such changes mirror the changes induced in experimentally fertilized seagrass beds in Florida, strongly suggesting that the aggregations of animals attracted by artificial reefs concentrated nutrients in this oligotrophic seascape, favoring the growth of fast-growing primary producers like microphytobenthos and periphyton, and changing the competitively dominant seagrass from slow-growing *T. testudinum* to faster-growing *H. wrightii* in the vicinity of the reefs.

Using biomarkers to elucidate trophic dynamics from the marsh to the coastal oceans

A critical uncertainty for the Everglades is how hydrological changes, causing by increased inputs of freshwater flow, will affect trophic interactions, community structure, and consumer-mediated nutrient transport. To address this question we are applying a coupled lipid biomarker and stable isotopic approach to food web analysis, focusing both on the role of a large mobile consumer (juvenile bull shark) in food webs as well as the role of nutrient gradients on the quality and quantity of detritus, algae, and vegetation available for intermediate trophic levels. Bulk $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ have been widely used to determine carbon source and trophic position, respectively, for food web studies. When combined with lipid biomarker analysis, which relies on specific lipid patterns in basal resources that become transferred to higher trophic levels upon ingestion, these molecular tools provide important information on food web structure.

Our initial efforts have focused on determining food sources for juvenile bull sharks in the Shark River Slough (SRS) ecotone. Preliminary data demonstrated that a subset of neonates and young-of-the-year were characterized by large abundances of the fatty acid 20:3 ω 9 (Mead Acid), a biomarker indicative of essential fatty acid depletion. Stable carbon isotopic composition of muscle tissue of these individuals was highly variable. The fatty acid and isotopic data suggests either that young sharks are exposed to highly different, but essential fatty acid poor, diets resulting in inconsistent $\delta^{13}\text{C}$ and accumulation of mead acid, or, alternatively, that young bull sharks initially undergo a starvation period where they rely upon maternally-provided lipid stores, resulting in essential fatty acid depletion. If the latter is true, juvenile bull shark muscle tissue isotopic composition may provide information on maternal dietary composition. We are currently focusing on determining the fatty acid composition of potential dietary items to further elucidate trophic linkages of bull sharks in the SRS ecotone.

In addition, we have focused on determining the effect of canal-induced nutrient gradients on food webs in the freshwater region near Taylor Slough. Fatty acid (FA) and stable isotopic composition of basal resources (periphyton and floc) and primary and intermediate consumers (chironomids, mayflies, snails, amphipods, grass shrimp, and eastern mosquitofish) were determined from samples adjacent to and far from the C-111 canal. Results suggest that the presence of canals complicates Everglades food webs, allowing for predator mobility and influx of nutrients and allochthonous food sources. Hierarchical cluster analysis of lipid composition demonstrated that chironomid FA signatures were most similar to floc FA signatures, suggesting that floc comprises a major portion of the chironomid diet. Similarly, amphipod FA composition was most similar to eastern mosquitofish FA composition. Interestingly, snail FA signatures were distinct from the signatures of floc and periphyton, suggesting additional items, perhaps emergent plants, are important for snail diet. On-going work is focusing on determining fatty acid signatures of additional consumers and determining the effect of consumer metabolism on tissue fatty acid signatures.

5. Hydrology

Taylor Slough Water Budget and Temperature Results

The results of this research provided evidence of groundwater discharge to the surface water in Taylor Slough. Although, there were clear periods of time when groundwater discharge or recharge was the main dominant process, measured fluxes underwent reversals in direction on a

daily scale. According to the water budget method, groundwater discharge was a dominant process between January 2008 and July 2009, and only between October 2009 and March 2009 was groundwater recharge significant (Fig. 5.6).

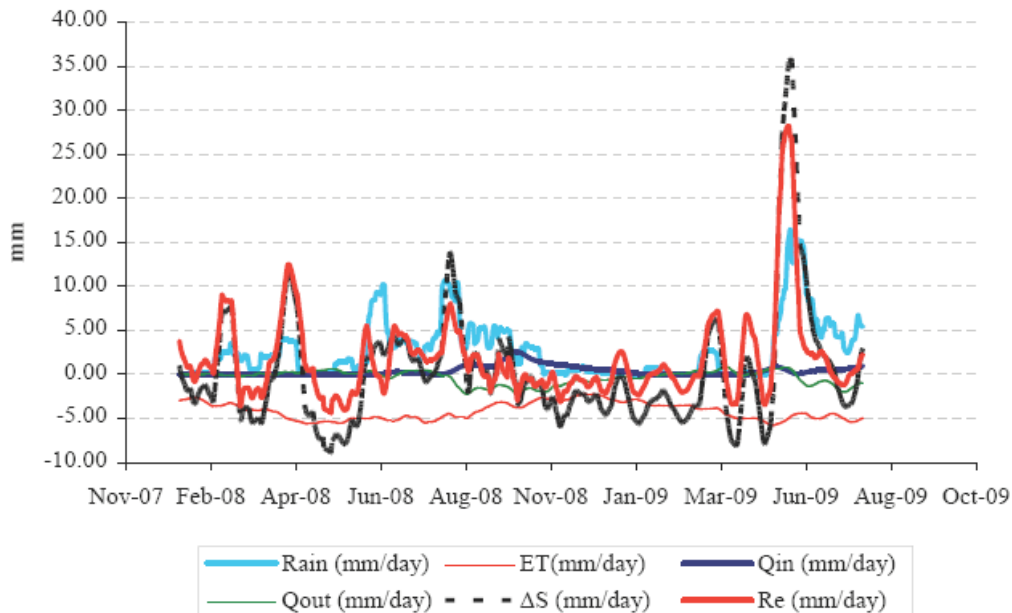


Figure 5.6: The major water balance parameters in Taylor Slough as measured in mm. All of the time series represent a 15-minute running average. Positive values of Re represent groundwater discharge while negative values of Re represent groundwater recharge.

Temperature measurements were determined to be an effective tool for determining the timing of the groundwater-surface water interactions (Fig. 5.7). Air and soil temperatures varied daily with diurnal variations of 5°C on average. In contrast, soil temperatures were more stable during the year with daily variations of 1°C. During the periods of groundwater recharge, the soil temperature replicated the diurnal variations observed in surface water as observed in Dec. 2008, Feb. and March 2009. When groundwater discharged to the surface water, the soil temperature profile did not replicate the surface water diurnal variations but instead was stable as observed in June 2008; May and June 2009.

Groundwater discharge (↑) and recharge (↓) rates estimated with the water budget method were near equal and averaged 14.6 (↑) and 13.1 (↓) mm/day in the period from January until September 2008; 6.0 (↑) and 9.3 (↓) mm/day for the period between October 2008 and March 13 2009; 15.3 (↑) and 7.8 (↓) mm/day for the period between March 14 and July 2009 (Zapata-Rios, 2009). Average rates calculated using differences in head measurements between surface water and groundwater for TSPH7b between February and July 2009 were 18.2 (↑) and 27.7 (↓) mm/day. The average discharge and recharge fluxes for TSPH6b between the end of May and July 31, 2009 were 5.1 (↑) and 0.8 (↓) mm/day. Discharge and recharge rates were different between methods because they differed in spatial and temporal scales.

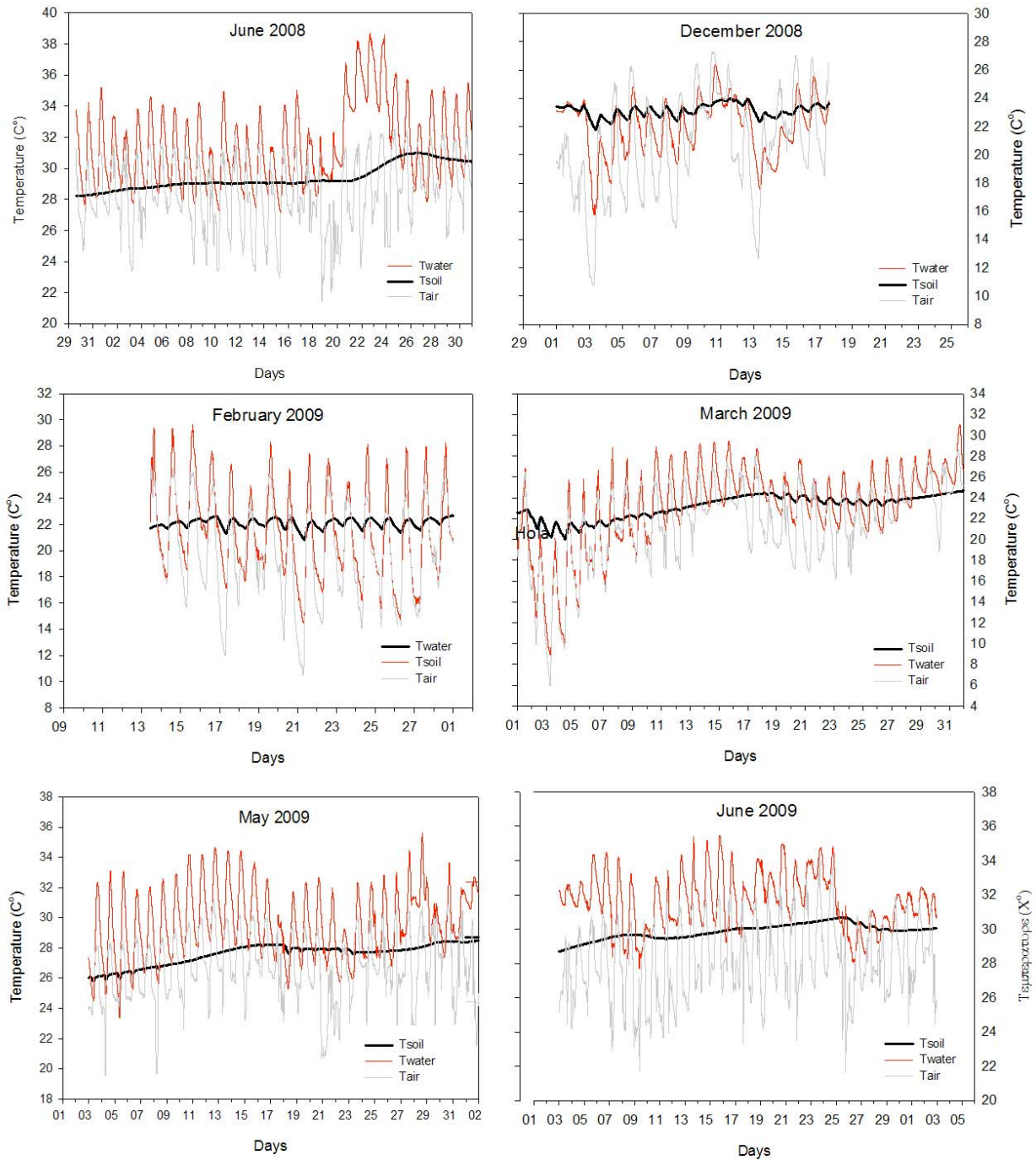


Figure 5.7: Air (gray), surface water (red) and soil (black) temperature at TSPH7b. The air and surface water temperatures consistently varied on a diurnal basis. During times when surface water recharged the groundwater, a diurnal signal in soil temperature was observed (Dec. 2008, Feb. and March 2009). Soil temperatures were stable during times of groundwater discharge (June 2008; May and June 2009).

Taylor River Floc Tracer Experiment

Tracer spatial distribution differed between pond-and-creek pairs, with no discernable common pattern across sites (Fig. 5.8). This was confounded by the changing orientation of water flow amongst each of the sites, with Taylor River turning eastward between Pond 4 and Pond 3 (Fig. 5.1). In the Pond 3 pair, tracer particles appeared to hug the southern bank of the upstream creek before dispersing into the pond (Fig. 5.8, top). In the Pond 4 pair, tracer distribution appeared more even, with one central magnet collecting a significantly greater amount than others. Lastly, tracer distribution in the Pond 5 pair was similar to that of Pond 4 except that greater amounts of tracer were found at pond magnet locations (Fig 5.8). Pond 4 retained the greatest amount of tracer within a single location than other pond-creek pairs, and this is likely due to the 90-degree change in water flow direction at this site (Fig. 5.1).

Shark Slough Water Budget

Using a mass balance approach, daily change in volume of SRS (from stage changes) was equated to the difference between input and outputs yielding a residual term, that included error in each of the components as well as net groundwater exchange. The net groundwater discharge (GWD) varied seasonally, with the largest inputs occurring in May-July, and a net recharge or input from the slough surface water in Jan-April (Fig 5.9). There was a large annual variation with the highest value of net discharge into the SRS (673 mm) happening in 2008 and a net recharge of groundwater (88 mm) occurring in 2003. Precipitation, the largest input to the SRS, was offset by ET (the largest output) both terms being of similar annual magnitudes (Fig. 5.10). Furthermore, monthly GWD was found to be positively correlated with surface water salinity ($p < 0.03$) at the mangrove ecotone site SRS-4, lagging by one month (Fig. 5.11). The same

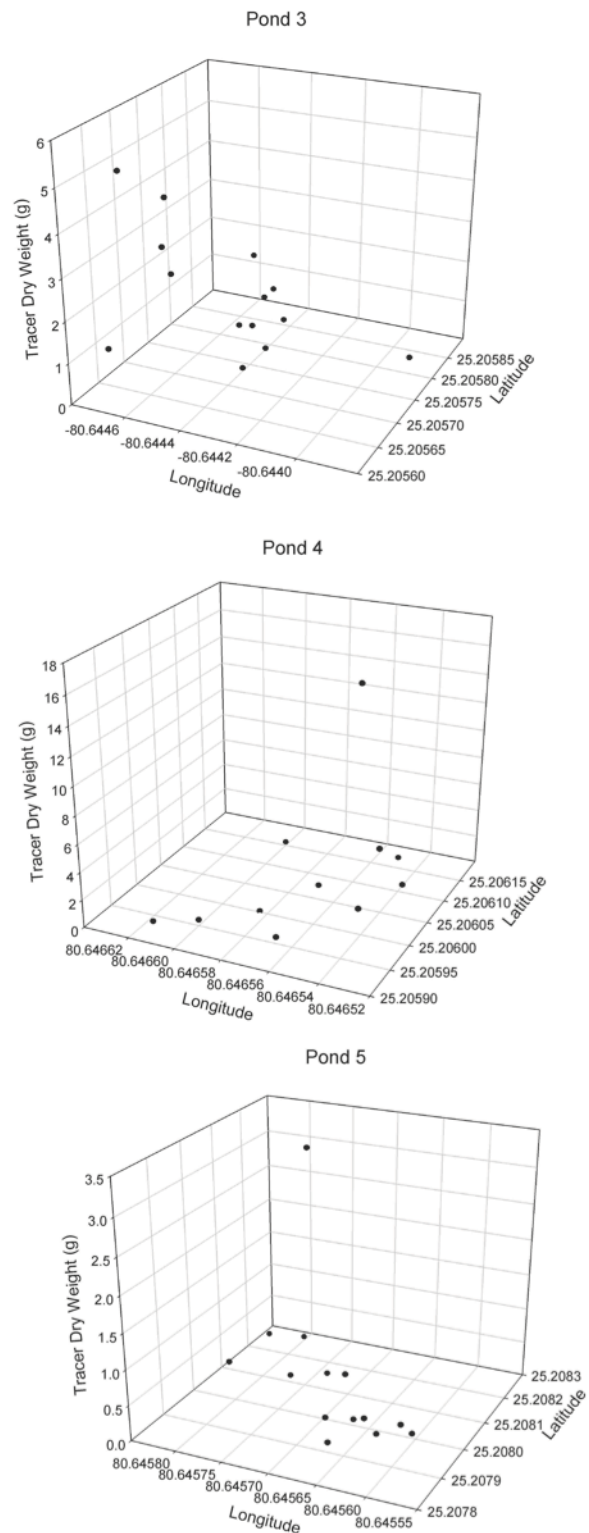


Figure 5.8: Three dimensional scatter plots showing the amount of dry tracer collected on magnets (Z-axis, height) and the latitude and longitude of the magnets on Y and X axes, respectively. Data shown are for the Pond 3 pond-creek pair (top), the Pond 4 pair (middle), and the Pond 5 pair (bottom).

pattern was demonstrated in the daily data, where the surface water salinity expressed a significant positive correlation to groundwater discharge when leading by 24-34 days ($p < 0.05$). The results of this research highlight the importance of increasing surface water inflows into ENP for hydrating the freshwater marsh as well as for greater freshwater discharge into the downstream marine ecosystems.

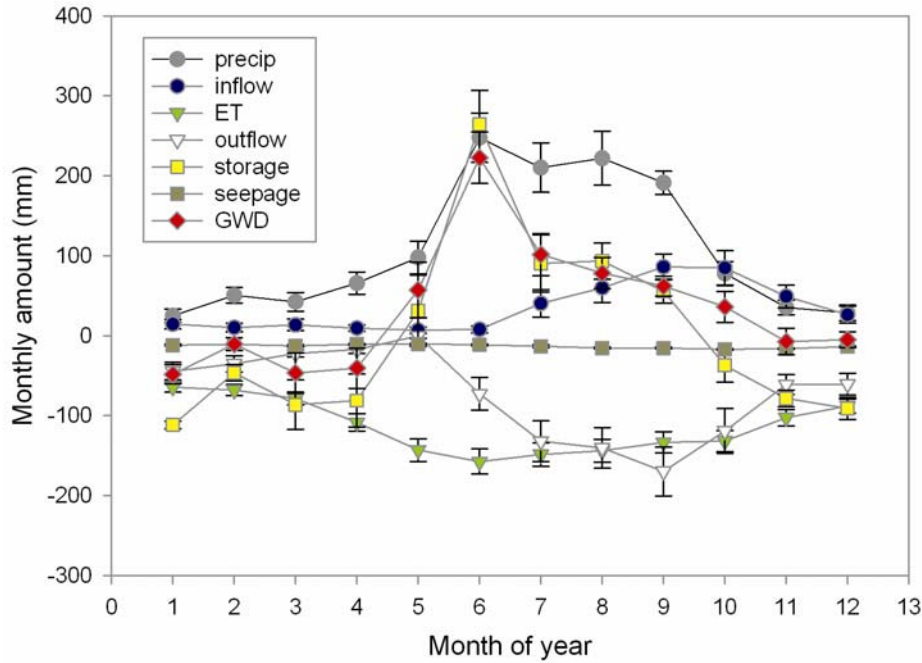


Figure 5.9: Monthly water budget components for Shark Slough over 2002-2008.

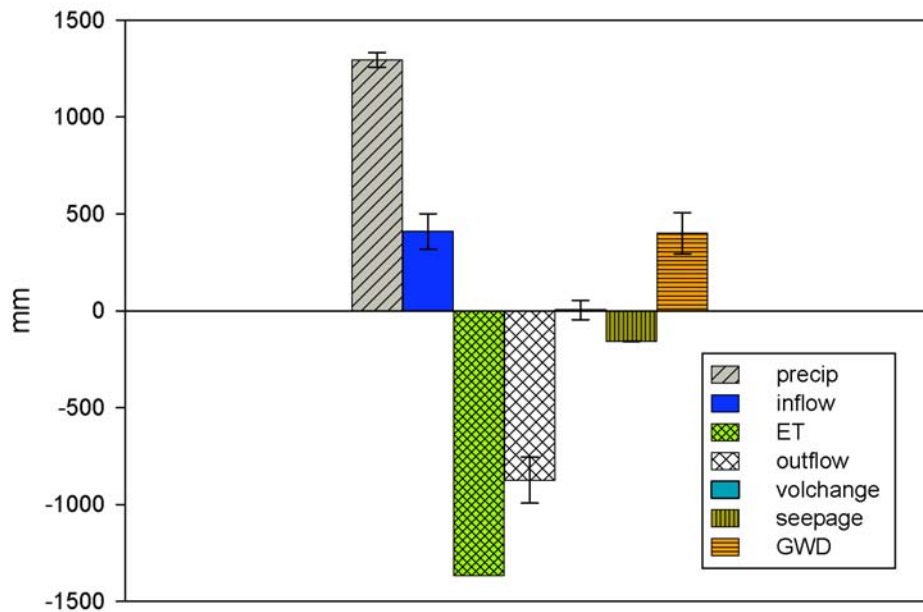


Figure 5.10: Annual water budget components for Shark Slough averaged over 2002-2008.

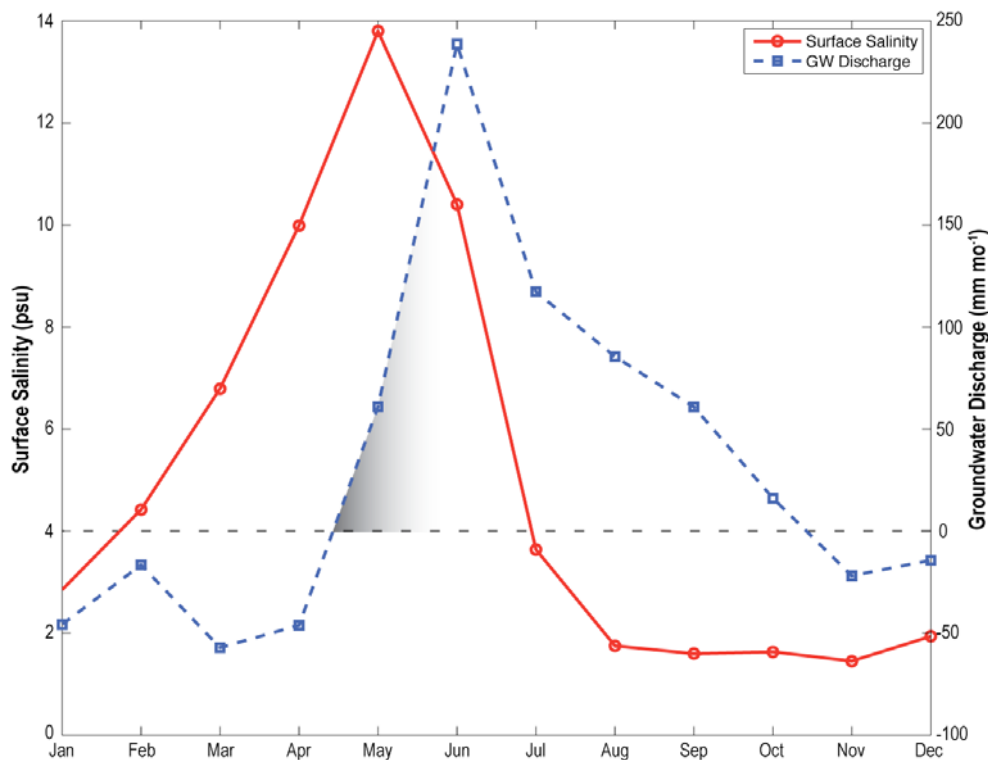


Figure 5.11: Monthly groundwater discharge to SRS compared with monthly surface water salinity at SRS-4 (the oligohaline ecotone) averaged over 2002-2008.

Geochemical Tracers

Chloride concentrations in the surface water of Shark Slough tend to be more variable at SRS1d as compared to the downstream sites, SRS2 and SRS3 (Fig. 5.2a,b). Mean sulfate concentrations were higher and more variable at SRS1d than at SRS2 and SRS3 for both 2008 and 2009. The higher concentration and less variability in chloride and sulfate concentrations at SRS2, and SRS3 in 2009 may be a result of less rainfall and greater evaporation effects. The variability in anions at SRS1d in 2008 is attributed to its proximity to Tamiami Trail and water discharge from Water Conservation Area 3.

In Taylor Slough, cation concentrations decrease in a downstream direction in the upland sites from TS/Ph-1, TS/Ph-2, TS/Ph-3 (Fig. 5.13a), suggesting either a dilution or a retention of cations with the sediments and vegetation as the water flows downstream. The coastal sites (TS/Ph-6 and TS/Ph-7) demonstrate the more predictable pattern of an increase in cation concentration in the downstream direction due to their proximity to the Florida Bay estuary (Fig. 5.13b). At TS/Ph-7, higher perturbations in salinity and cation concentrations particularly in Feb. 2009 may be due to wind effects from Florida Bay. The more moderate change in ion concentrations at TS/Ph-6 are indicative of the wet and dry seasons of the region. The effects of a

storm surge from the passage of Tropical Storm Fay in Aug. 2008 may be observed by a decrease in ion concentrations at the start of the record at both sites TS/Ph-6 and TS/Ph-7.

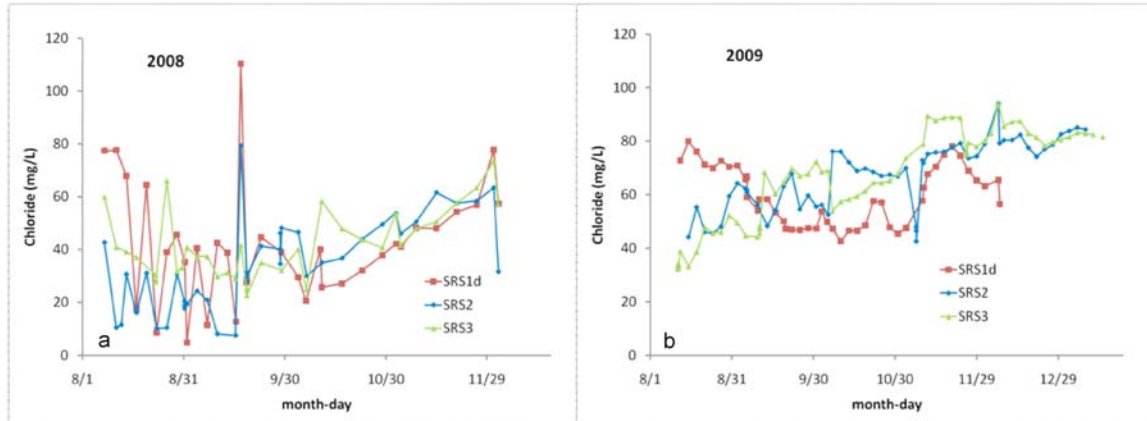


Figure 5.12: Chloride concentrations at Shark Slough surface water sites SRS-1d, SRS-2, and SRS-3 in a) 2008 and b) 2009.

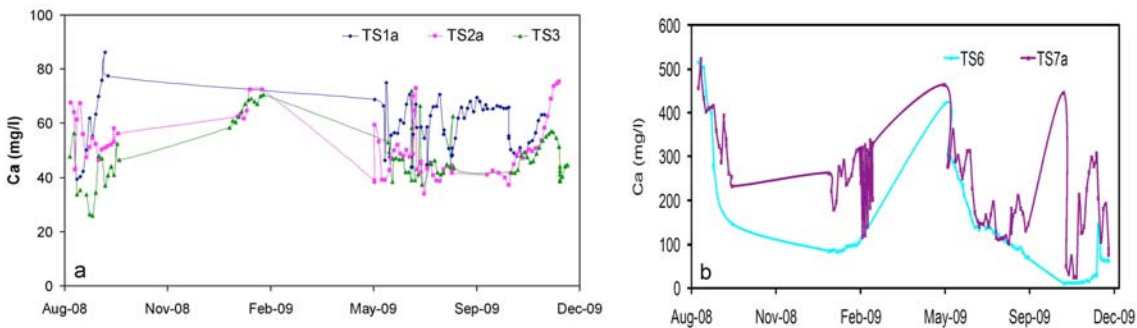


Figure 5.13: Calcium concentrations in Taylor Slough at the a) upland sites TS/PH-1, TS/PH-2, and TS-3 and b) coastal sites TS/PH-6 and TS/Ph-7.

Hydrologic/Vegetation Modeling

The results of the vegetation pattern modeling indicated that relatively higher rates of evapotranspiration on the vegetation patches (i.e. the sawgrass ridges) compared to the non-vegetated areas (the sloughs) create hydraulic gradients, which then drive the convergence of dissolved nutrients from the downhill flow to the growing vegetation. With time, the vegetation patches aggregate and spread laterally to create ridges in the direction of the downhill flow. Peat accumulation positively reinforces the stability of the ridges in the flow field, and simulations which incorporate multiple species are used to investigate the effects of plant competition on pattern formation. Transient disturbances to the model boundary condition illustrated the effects of changes in water management and nutrient inputs on community composition and patterning in the Everglades ridge and slough habitat.

Using Remote Sensing to Estimate Evapotranspiration in Everglades National Park

The net radiation (R_n) for April 23, 2008 (Apr08) and November 17, 2008 (Nov08) ranged between 488 and 677 W m^{-2} , with R_n values typically higher in Apr08 relative to Nov08 (Fig. 5.14). The highest R_n values were generally observed in areas that were determined to be wet pixels and most likely caused by a lower albedo. The modeled R_n for the area of SRS6 was very close to the measured values from the eddy-covariance tower.

Using the inputs for H , W , and G , estimates for ET (mm day^{-1}) ranged from 9.1 to 14.1 for Apr08 and 6.8 to 14.5 for Nov08 (Fig. 5.15). The greatest estimated ET was generally located in the mangroves and hardwood areas (e.g., tree islands, hammocks) and areas identified as wet pixels. The dry season (Apr08) had higher ET estimates relative to Nov08 and was a function of the higher R_n in Apr08. The ET estimates derived from the satellite-based models were two to three times greater than other reported ET values (e.g., German 2000; Abteu 2003). This may be a result of comparing instantaneous measurements with daily-averaged measurements. Because the Landsat image represents an instantaneous measurement, around 10:30 am (Eastern Time), the R_n exceeds the daily average values determined by German (2000). As a result of the higher R_n values, satellite derived ET estimates would be expected to be higher than the daily values determined by field based. However, the relative ET patterning obtained in this investigation agreed with those found by others, namely, that the highest ET estimates were associated with standing water (wet pixels). Furthermore, hardwood vegetation (e.g., mangroves, hammock species) accounted for the second highest ET rates for both wet and dry seasons, which was most likely associated with greater leaf area and water demand for those species. The spatial resolution of the Landsat 5 TM images allowed for the discrimination (using ET rates) of vegetation communities (e.g., tree islands).

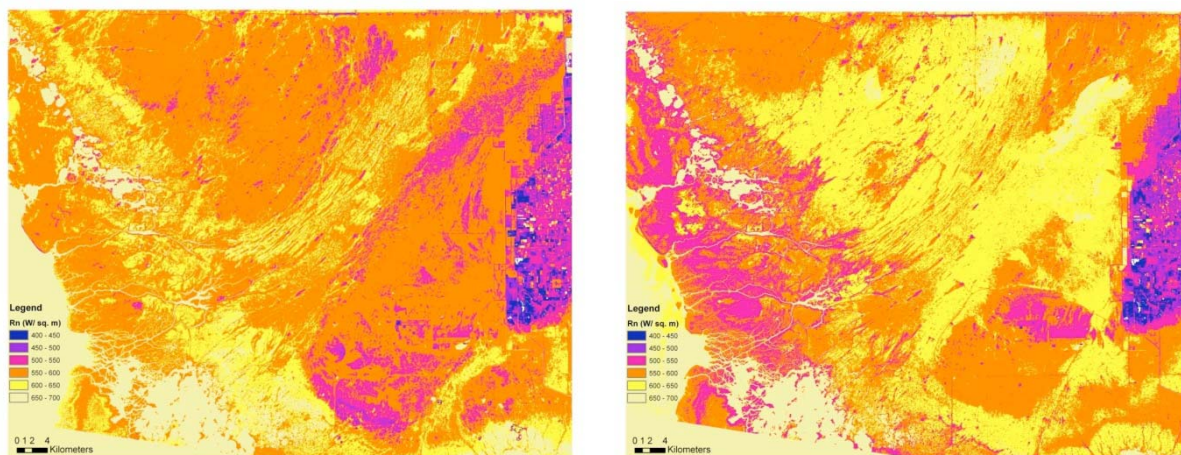


Figure 5.14: Net radiation maps of April 2008 (left) and November 2008 (right)

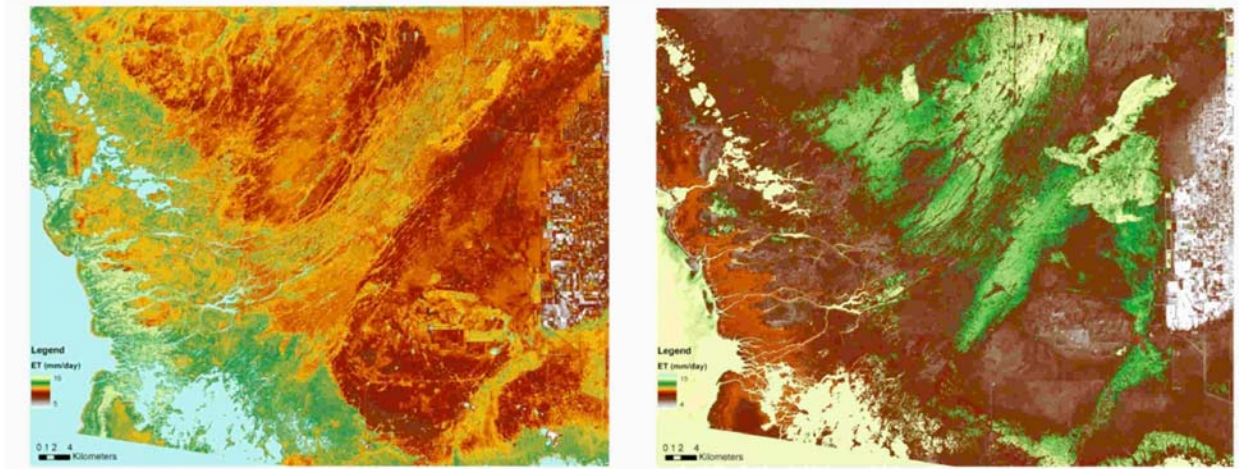


Figure 5.15: Estimated ET maps of April 2008 (left) and November 2008 (right). Values range from 4 mm/day (white) to 15 mm/day (light green).

Availability of groundwater and its associated nutrients in a Shark Slough tree island

Groundwater levels in the Bayhead (BH) and Bayhead Swamp (BHS) communities of Satin Leaf Tree Island were very similar but lower than that of the Hardwood Hammack (HH) and surface water from May 2009 through March 2010 (Fig. 5.14). The groundwater levels in the HH section of the tree island were lower than that of the surface water when the surface water was less than 1.6 m in elevation (June-July 2009, Dec 2009-March 2010). When surface water levels exceeded 1.6 m, groundwater levels in the center of the island were similar or slightly elevated compared to the surface water.

Groundwater chloride concentrations from October 2008-June 2010 varied seasonally, with the highest values detected in the wet season and the lowest values detected in the dry season (Fig. 5.15). Surface water concentrations of chloride were lowest during the wet season and highest during the dry season and averaged 56 mg l^{-1} . The average groundwater chloride concentrations in BH and BHS averaged 190 mg l^{-1} and 140 mg l^{-1} , and were significantly elevated as compared to HH, which had an average chloride value of 90 mg l^{-1} . The average dD and d^{18}O values were significantly depleted in the BH and BHS as compared to the HH and surface water.

Both the results of the water levels and chemical analyses indicated increased groundwater-surface water interactions during the dry season and reduced groundwater-surface interactions during the wet season in Satinleaf tree island. The groundwater-surface water interactions seem to be the greatest in the HH of the tree island, while the groundwater in the BH and BHS tended to be more isolated from the surface water.

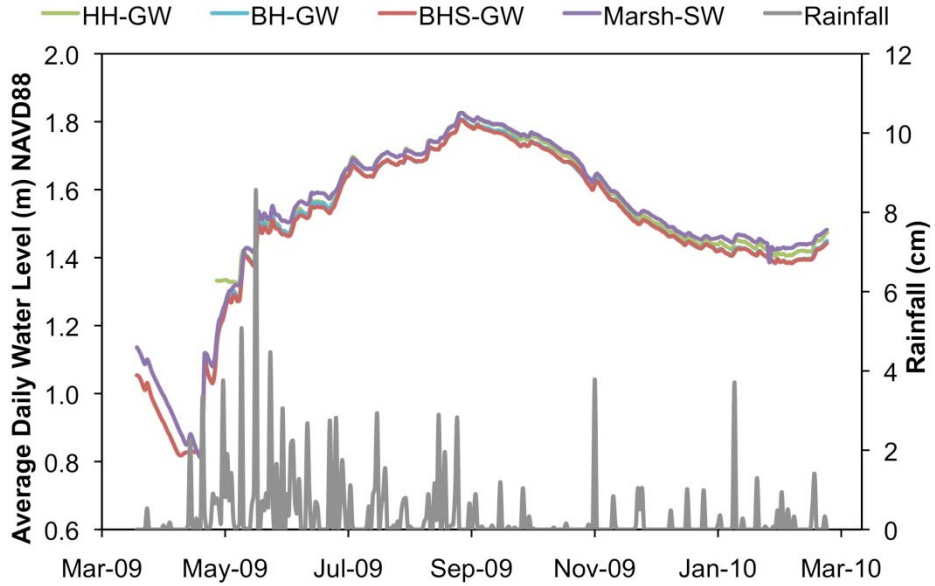


Figure 5.14: Surface (purple) and groundwater levels in the Hammock (HH-green), Bayhead (BH-blue) and Bayhead Swamp (BHS-red) communities on Satinleaf from May 2009-March 2010. During this period the amount of rainfall (gray) was greatest between May and September.

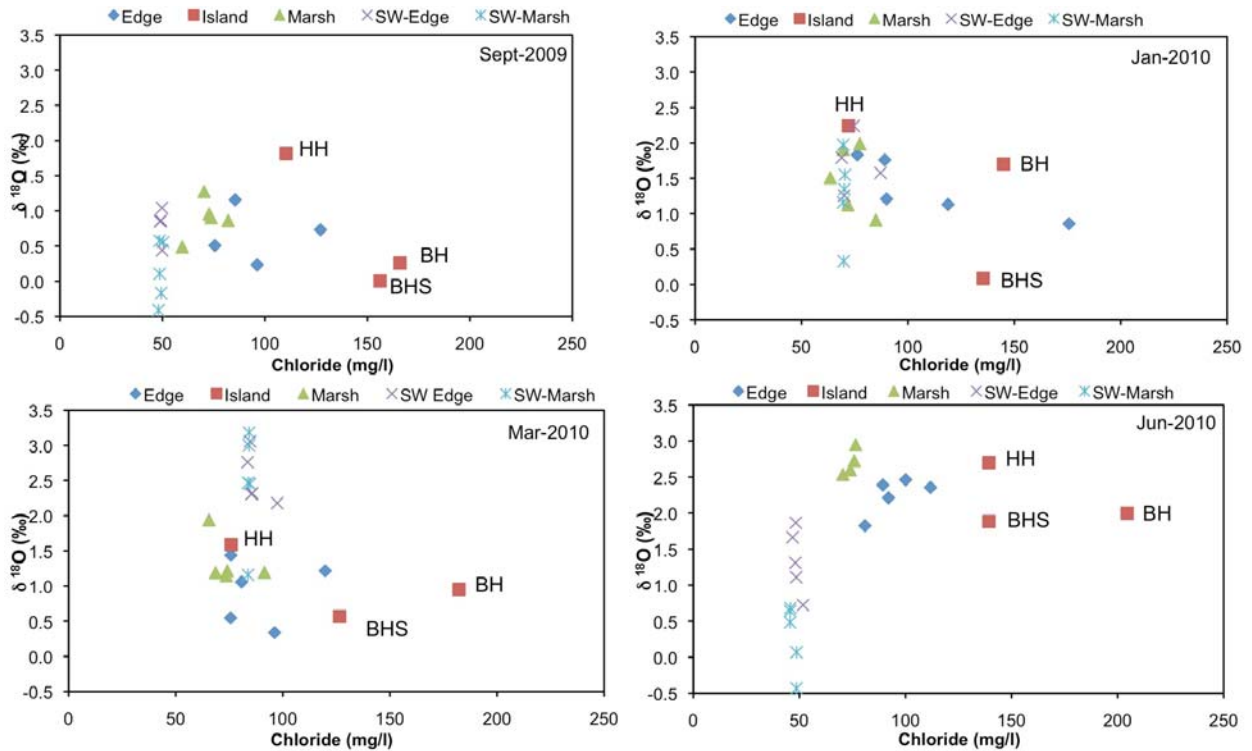


Figure 5.15: Groundwater (solid) and surface water (open) $\delta^{18}\text{O}$ values compared to chloride concentrations. During the wet season September 2009 and June 2010 the groundwater values distinctly separate from the surface water, while during the dry season the groundwater in the marsh and at the edges of the island are similar to those of the surface water.

Modeling the Effects of Rising Sea Level and Storm Surge on Coastal Vegetation Communities

Preliminary simulations using the revised MANHAM model resulted in a sharp transition in salinity along the elevation gradient (Fig. 5.16). The modeled salinity transition along elevation gradient occurs as a sharp boundary. The boundary moves landward when soil layer go deeper. This is probably due to percolation of water, carrying salt downward. The boundaries for the dry season and wet season are similar with the exception that the boundary of the surface layer during the wet season moves landward compared with the dry season. This is probably due to higher tides during the wet season, bringing sea water farther inland. When averaged over the whole vadose zone, the dry season has higher salinity than the wet season, because of less wash out of salinity by precipitation.

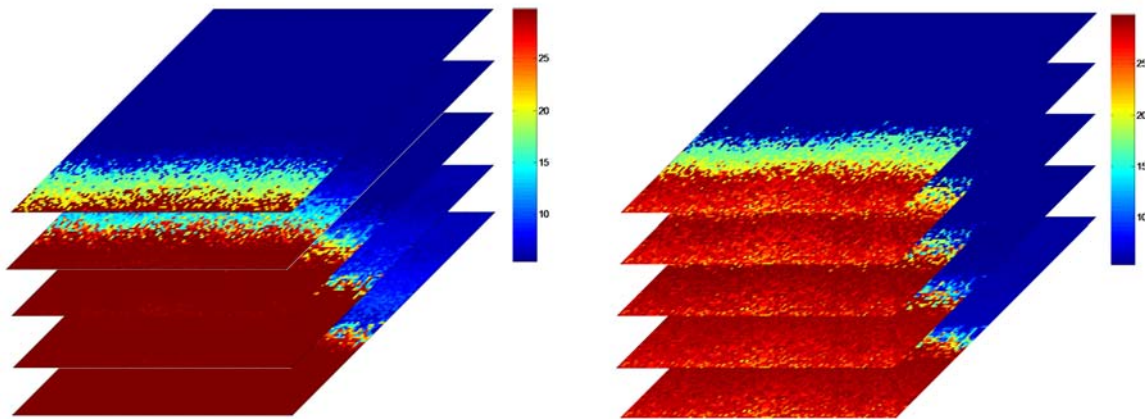


Figure 5.16: Salinity gradient of vadose zone at each compartment for dry season (left) and wet season (right). Five layers of the vadose zone are shown, and the elevation increases along the y-axis. The red color indicates high salinity, and the blue indicates low salinity.

6. Human Dimensions

- 1) *Exploratory Spatial Data Analysis & Pilot Econometric Models.* Preliminary econometric analysis was conducted on land use data for our study site to develop a pilot study, and was centered on parcels with the City of Homestead that were also within the FCE Human Dimensions transect (see Figure 6.2). The model targeted an explanation of average parcel greenness based on a very limited number of factors at this early stage. Specifically, a spatial econometric model was estimated using mean NDVI (hereafter mNDVI) for each parcel as the dependent variable and parcel size and 2009 valuation as independent variables. In ongoing analyses, zoning is being used as an additional variable within this analysis, which is also incorporating additional econometric techniques as well as alternative dependent and independent variable specifications (hypotheses) and better control variables.

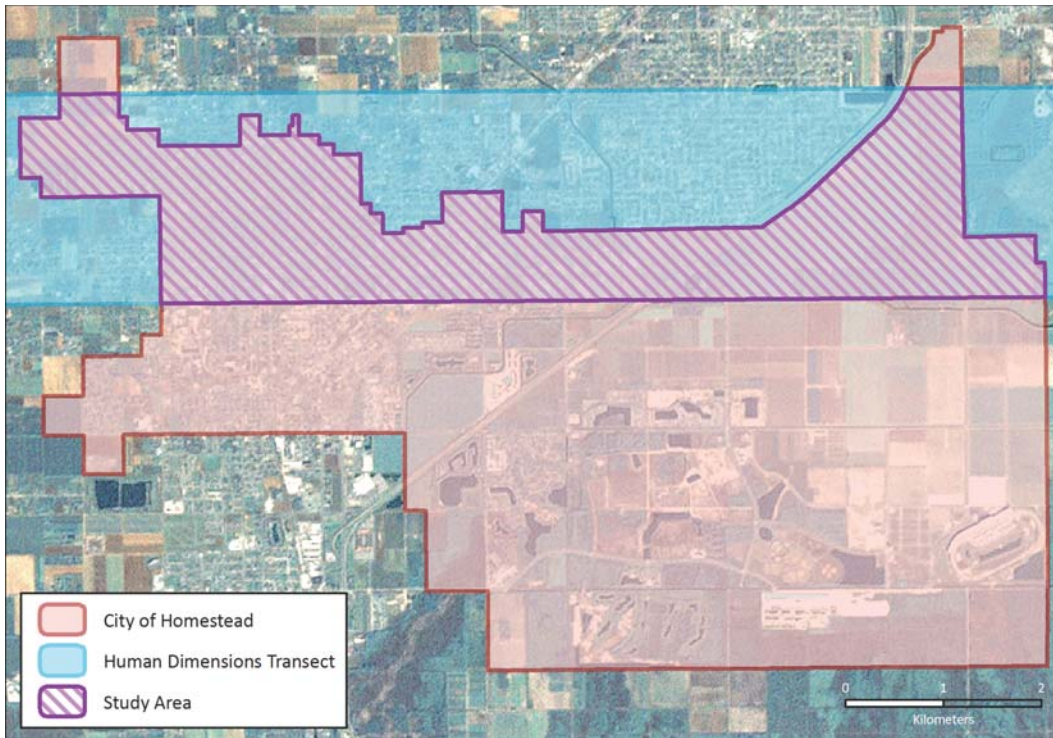


Figure 6.2: Site of preliminary pilot models of parcel land use (denoted by diagonal hatching in Study Area).

Exploratory Spatial Data Analysis

Lot size, valuation, and aggregate zoning categories were tested for multicollinearity and spatial autocorrelation (SA) as exploratory spatial data analysis (ESDA).

Multicollinearity tests were conducted in SPSS while SA evaluation took place within GeoDa (utilizing a k -nearest neighbors weights matrix, $k = 5$). Multicollinearity was not found to be significant with these data, however, SA was. Each of the aggregate zoning categories (see ‘Data Manipulation’ above), with the exception of Public, had a Moran’s I greater than 0.50 ($p = 0.001$). In particular, *Agriculture*, *Residential Single-Family*, and *Residential Multi-Family* had Moran’s I values greater than 0.90 ($p = 0.001$). SA was also found for mNDVI ($I = 0.654$, $p = 0.001$), but was weak for both lot size and valuation.

These ESDA results revealed that the Ordinary Least Squares (OLS) regression technique would probably not be ideal for modeling these data, as the presence of autocorrelation violates the OLS assumption of independent observations. However, OLS still serves as a benchmark for a Geographically Weighted Regression (GWR). OLS assumes a constant linear relationship:

$$y = a + bx + e$$

where

y is the dependent variable

a is the intercept

b is the estimated regression line's slope
 x is the observed value of the independent variable
 e is the residual.

These values are all global, meaning they apply equally to each observation within the dataset. In contrast, the GWR estimates linear regression equations for each observation separately:

$$y_i = b_{i0} + \sum_{j=1}^p b_{ij}x_{ij} + \varepsilon_i$$

This technique estimates a multivariate linear regression for each observation, i (note the subscript i indicates values are specific to observation i), where b_{i0} is the intercept at i , p is the number of independent variables, x_{ij} is the observed value of j at location i and ε_i is the residuals. Each x_{ij} value is weighted, with nearer neighbors receiving larger weights than distant neighbors. The spatially varying nature of the GWR makes the method more adept at estimating spatially autocorrelated data than the OLS.

Pilot Econometric Models

Three econometric models were estimated, two OLS and one GWR. The OLS models were used to further explore these data and to serve as a benchmark for the GWR, due to the limitations discussed above. Both OLS models were run in SPSS, whereas ArcMap v9.3 was used for the GWR. The detailed output from the estimated models is provided in Appendix A.

The first OLS (OLS1) specification modeled mNDVI as a function of two independent variables hypothesized to be the main predictors of parcel greenness: lot size and economic valuation. This model had little predictive capability, with an R^2 of 0.033. The second OLS (OLS2) built upon OLS1 by further including zoned land use as a dummy variable and had an improved predictive capacity, albeit still weak ($R^2 = 0.114$). Additional model results are available below in the appendix.

The GWR model (GWR1) predicted mNDVI using lot size and valuation, similar to OLS1. By comparison, GWR1 yielded a higher proportion of explained variance ($R^2 = 0.561$) than OLS1. In addition, the AICc (a goodness-of-fit) diagnostic comparison of GWR1 and OLS1 found GWR1 to clearly be the superior model. The AICc for OLS1 was -12,210.22, whereas for GWR1 it was -16,451.71. If these two values are within 4 points of each other, the models are considered to be equal, however if the gap is 10 or more, the model with the larger AICc is considered inferior. ArcMap's GWR functionality, at time of analysis, did not allow for binary variables and so a GWR2 which would correspond to OLS2 could not be estimated.

Currently, additional statistical methods and software packages are being investigated as to their suitability to these analyses, for example, a GWR application which will allow for binary variables, or using the Spatial Error Regression available in GeoDa.

- 2) Social vulnerability to Sea-level rise research. FCE collaborators conducted a survey related to vulnerability to sea-level rise. P. Mozumder, E. Flugman (graduate student), and Timothy Randhir (University of Massachusetts) conducted a survey to understand how decision makers in the Florida Keys evaluate the vulnerability posed by global climate change and sea-level rise. Survey findings revealed deep concern among decision makers about adverse impacts at the local level. A large majority of respondents recognized the increasing likelihood of potentially irreversible socioeconomic and ecological repercussions in the Florida Keys. Yet very few federal, state and local experts reported that their respective agencies have developed formal adaptation plans. Decision makers point out institutional and social barriers to adaptation and also convey their support for a host of measures to facilitate adaptation on an urgent basis.
- 3) Zoning and Land Use Change. Zoning ordinances serve as the primary method for lessening and prevent 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 our study area we have:
 - i. Analyzed the effectiveness of the minimum 5-acre zoning rule for lands zones as agriculture. Our findings (J. Onsted) suggest that for lands zoned for agriculture row and field crop retention increases with larger parcel sizes, peaking with parcels that are 20 to 40 acres, then steadily decreases with increasing parcel size. On interim zoned land retention increases, decreases, then increases again with increasing parcel size (see Figure 6.3, as example).
 - ii. Analyzed the spatial patterns of land conversion. Our findings (J. Onsted) suggest that land zoned for agriculture in 2001 that was surrounded by developed land represented only 1.8% of all land zoned for agriculture in 2001. However, these patches comprise 65% of all the land that was rezoned for development in 2009. The overwhelming majority of the remainder was adjacent to already developed areas.

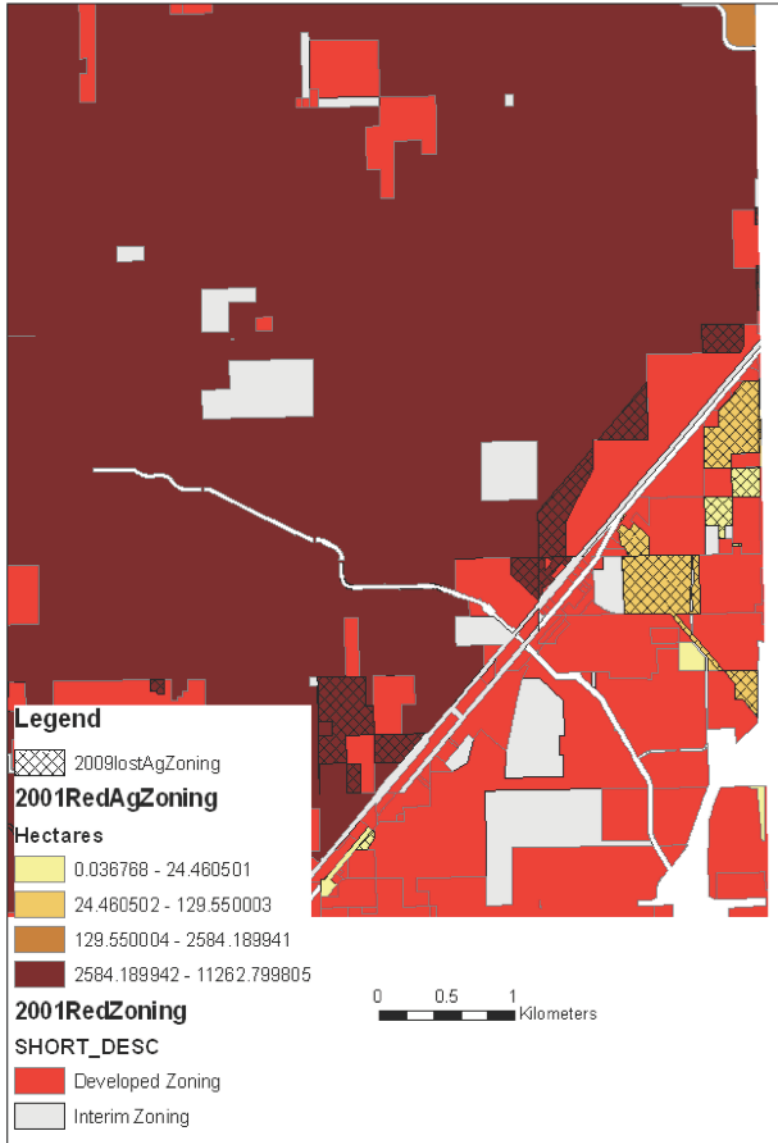


Figure 6.3: Southeastern portion of Human Dimensions Study Site. 2001 lands zoned for agriculture that were rezoned for development by 2009, categorized by size of continuously zoned area.

7. Climate and Disturbance

Paleoecological investigations and multi-centennial periodicities – (Saunders, Moses, Sklar and Anderson)

Spectral analyses of ENSO (Ecuador, Rodbell et al., 1999) and ITCZ (Cariaco Basin, Haug et al., 2001) and Everglades paleo-proxies indicate the occurrence of multi-centennial cycles. A prominent 350 year cycle was found in the ENSO record, spanning the period from 1.0 – 3.5ka (ka = thousand years ago) (Fig 7.1). The ITCZ record shows high amplitude wet-dry variability observed between 2.7 – 3.8ka (Fig 7.1). Discrete wavelet transform of the ITCZ record shows evolution of signal strength in at cycles of ~160 yrs and ~590 yrs in the lower section of the record below ~2.5ka. Everglades paleoecological proxies from the core taken at the SRS-3 sawgrass site (core C0010) indicate substantial dry periods during the period 2-3.5ka (high charcoal deposition), and wetter periods starting at ~2.0ka to present (high water lily seed deposition, Fig 7.2). Spectral analyses of the charcoal data indicate high spectral power at periodicities of 590, 350 and 235 years (Fig 7.2). These frequencies are similar to those seen in both the ENSO (Rodbell et al., 1999) and ITCZ (Haug et al., 2001) proxies. DWT analyses of the charcoal signal show the most substantial spectral power at a period of ~590 years from 1.0 – 3.4ka, and of 350 years from 2.5-3.4ka (Fig 7.3). As a preliminary attempt to analyze an integrative proxy of both macrofossil and charcoal, a combined paleo-proxy was developed with assigned weights of 1, -0.5, and -1.0, respectively, to charcoal, sedge and water lily data, based on their ranked hydrologic conditions (dry-to-wet). The first and second modes of variability (EOF no. 1 and 2) of the combined paleo-proxy indicate pronounced cyclicity at periods of 350 and 590 years through much of the record (Fig 7.4).

These results reiterate the importance of these multi-centennial cycles in South Florida and their impacts on Everglades ecosystems and hydrology. They suggest a real climate fluctuation may have affected wet-dry cycles over a wide geographic range of the western hemisphere, operating on cycles of ~350 and ~590 years (the strongest signals in our data). A mechanism for these wet/dry cycles is less well-understood at present. Nonetheless, these results bare similarity with those of Roth and Reijmer (2005) who found multi-century periodicities in Holocene sediments from the Great Bahama Bank (500-600, 380 and 260 years), which the authors ascribed to global climate processes and interactions with the Thermohaline Circulation.

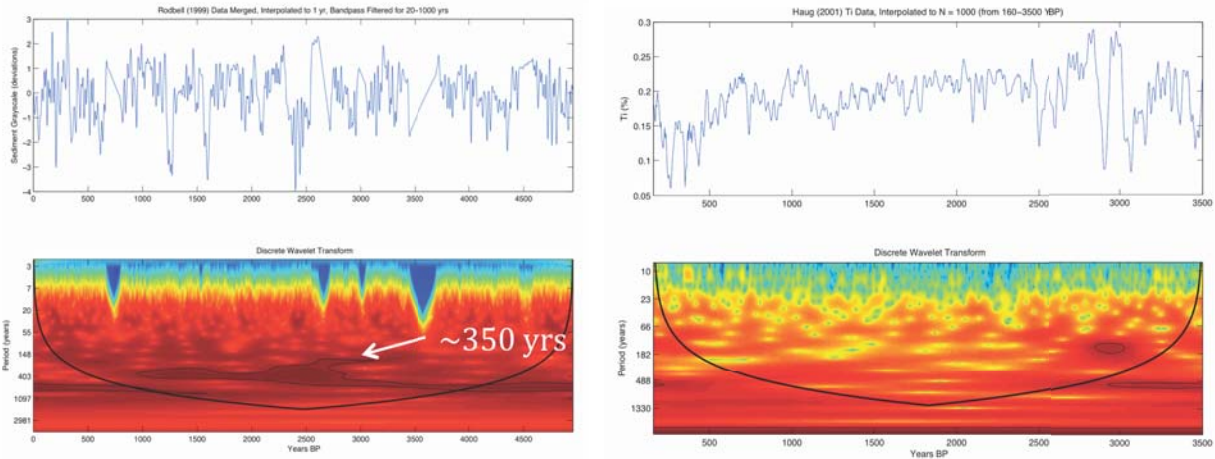


Figure 7.1: TOP PANELS: Climate proxies for ENSO (Rodbell et al., 1999) and ITCZ (Haug et al., 2001). Original sample frequency of ENSO proxy (measure of sediment gray scale) is 2-4 samples per year. Individual lengths of different cores were merged here to create a longer record, straight lines indicating the breaks between segments. All data shown here are filtered to remove cycles <20 years (to elucidate centennial cycles) and >1,000 years (which cannot be accurately studied in a record of this length). This removes the annual cycle, ENSO cycle, and some of the Pacific Decadal Oscillation (PDO). ENSO features include a drier period from ~0.3-0.6ka (coincident with the Little Ice Age [LIA]) and the subsequent wetting, and a major dry episode at ~1.3ka. ITCZ features include high amplitude oscillations between ~2.7-3.8ka and a dry period during the LIA (1300 – 1800 AD) with gradual wetting over the last 200 years. LOWER PANELS: Discrete wavelet transform (DWT) showing the upper signals in the frequency domain. Colors indicate spectral power (log scale) with blues for low values and reds for high values. Thin black lines highlight areas of substantial spectral power. Areas inside the thick black “U-shaped” line (cone of believability) indicate reliable spectral information.

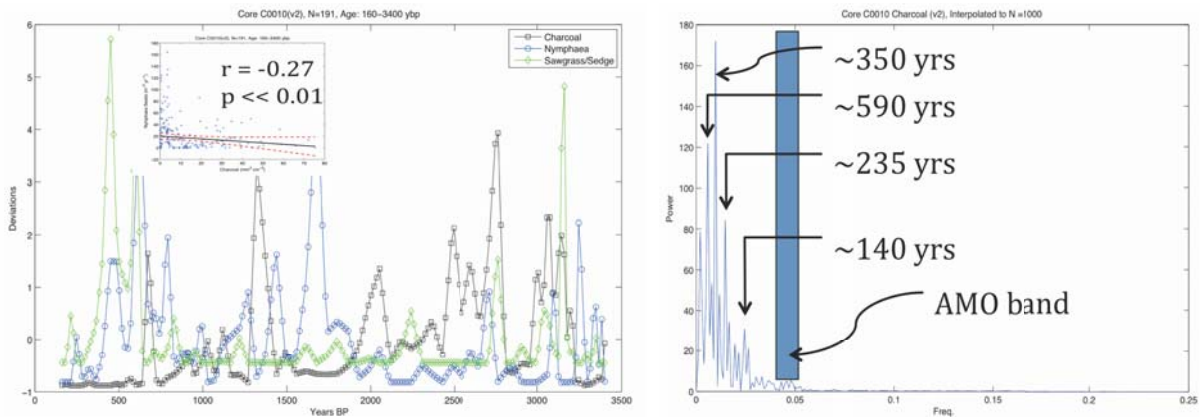


Figure 7.2: LEFT: Paleocological proxies from SRS-3 sawgrass core C0010. Records have been normalized (relative to the de-trended mean value) for comparison because of the wide range of values among the 3 indicators. Charcoal record represents dry periods; Nymphaea (water lilies) represent wet periods; and sedges (sawgrass and other sedges) represent intermediate wet periods. INSET: Regression (correlation) of charcoal and water lily indicates the expected significant inverse relationship. RIGHT: Charcoal periodogram, showing high spectral power at periodicities of 590, 350, and 235 years.

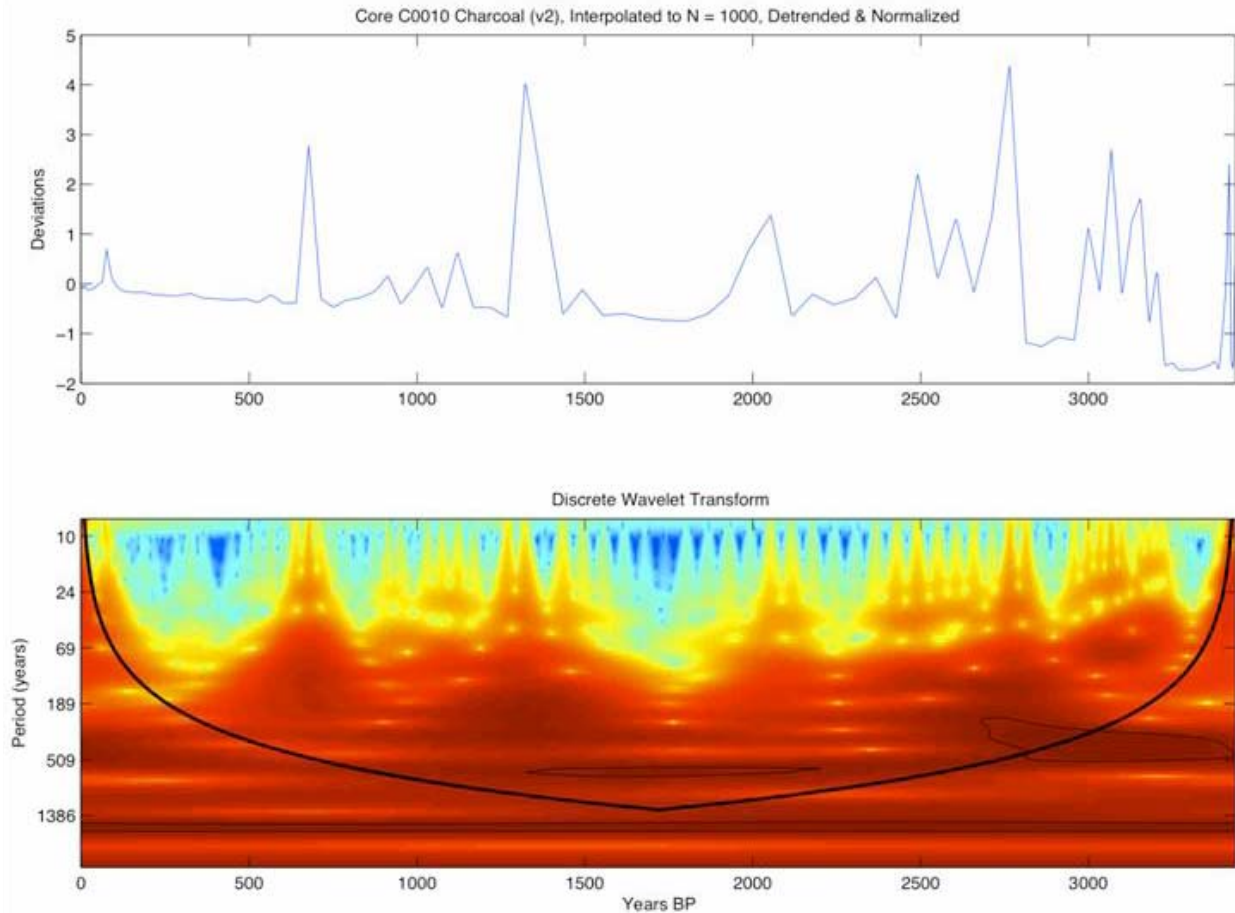


Figure 7.3: Upper panel: charcoal record (normalized and detrended); Lower panel: DWT showing the charcoal signal in the frequency domain. Note the substantial spectral power at a period of ~590 years from ~1,000-3,400 ybp. Substantial spectral power at a period of ~350 years occurs from ~1,000-1,500 ybp and ~2,500-3,400 ybp with the strongest signal in the lower part of the record where the high amplitude wet-dry cycles occur. The DWT also shows evenly spaced oscillations at less than ~70 years, but these are a mathematical artifact of the original sample interval, and subsequent interpolation and are not “real.”

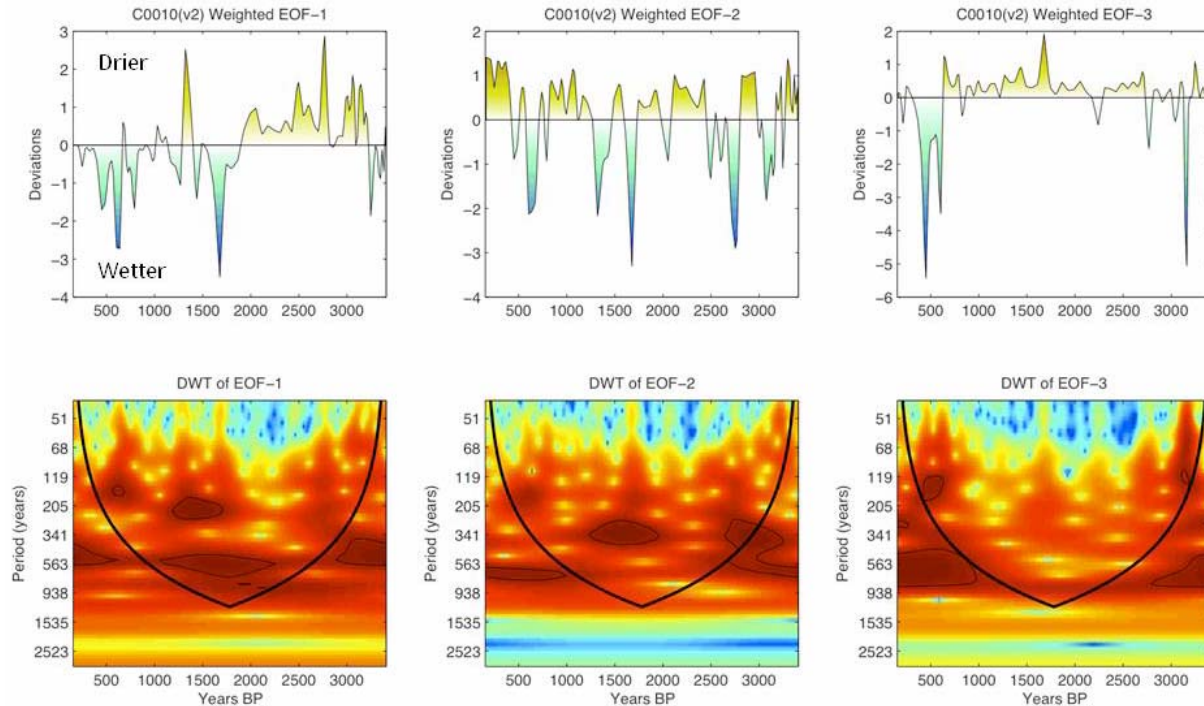


Figure 7.4: UPPER PANELS: The first three modes of variability from the empirical orthogonal function (EOF) of a combined paleo-proxy based on weighted water lily, sedge and charcoal records. LOWER PANELS: The DWT corresponding to the above mode of variability. The first and second modes demonstrate the pronounced cyclicity at periods of ~350 and ~590 years through much of the record, reiterating the importance of this cycle in the wet-dry cycles of South Florida.

Limnological investigations of Lake Annie and Southern Everglades (Gaiser, Koch, and Quillen)

We are examining long-term observational and paleoecological datasets for evidence of cyclical dynamics related to climate oscillations. We found signals of cyclical dynamics in a ‘reference’ (un-impacted by development) site in the upper Everglades watershed (Gaiser et al., 2009; Fig. 7.1) and in the Southern Everglades estuaries (Briceno et al., 2009), in addition to effects of episodic events such as tropical storms and hurricanes (Jennings et al., Submitted). Multi-billion dollar hydrologic restoration plans for South Florida have only just started to encompass recent entry into an AMO warm phase 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.

Paleoecological investigation of diatoms from Florida Bay (Wachnicka and Gaiser)

The composition of subfossil diatom assemblages at four sites (Trout Cove, Russell Bank, Bob Allen Bank and Ninemile Bank) in Florida Bay have been examined recently to determine how significant were the environmental changes that happened there over the last ~ 130 years. Analyses showed that the first large assemblage restructuring in central and east-central Florida Bay occurred in the late 1800’s and in the northeastern part of the Bay in the early 1900’s.

Changes in assemblage structure were much smaller in western part of the Bay during these periods. The late 1800's changes coincided with the time of the initial water drainage around Lake Okeechobee (1881-1894), while the early 1900's restructurings with the construction of several "muck-scalped canals" from Lake Okeechobee to the Atlantic Ocean (1910-1915) and building of railroad (1905-1916) from Miami to Key West. These constructions significantly lowered water level in Lake Okeechobee and throughout the Everglades basin, and had a great ecological impact on the adjacent estuaries. The next significant change in species composition occurred in northeastern and central Florida Bay in the 1960's and early 1970's, and in the southwestern Bay in the 1980's. These changes followed the period of the most intensive modifications of the Everglades hydroscape, which trapped water in water conservation areas in east-central Florida, significantly drained the southern Everglades, and noticeably decreased the inflow of water into Florida Bay and other South Florida estuaries. Severe weather events in the early 1960's, such as intensive droughts and Hurricane Dona, further decreased the resilience of diatom assemblages to environmental changes, and resulted in their major compositional alterations. The latest significant change in assemblage structure took place in Trout Cove and Ninemile Bank in the late 1980's, which corresponds to the time of the Bay's eutrophication and seagrass die-off events. The ~ 30% compositional changes in assemblages recorded in the cores most likely represent a "normal" response of diatom assemblages to inter- and intra-annual variability in water quality conditions in the Bay, while larger restructurings suggest occurrence of large-scale environmental perturbations. A gradual decrease of abundance of fresh- to brackish-water taxa over the last ~ 130 years implies that freshwater deliveries to Florida Bay were greater prior to major developments on the mainland.

Regional to local gradients in precipitation and temperature in response to climate teleconnections in the FCE (Moses, Anderson, Saunders and Sklar)

This study increased our understanding of climate gradients over short distances, and especially in light of the differential patterns of water management, development, and land use practices across South Florida. While previous work has indicated various degrees of connectivity between the AMO, ENSO, and the PDO with South Florida precipitation and temperature, those often broad-scale observations do not uniformly apply at smaller spatial scales. Our work suggests that each of these three climate indices has seasonally variable impacts across relatively small spatial scales (10^1 - 10^2 km) on time scales from interannual to multidecadal.

These gradients in correlation to major climate indices have noteworthy implications not only for ecological and hydrological modeling efforts of a region, but also for modern water management, and offer context for spatial variation in South Florida studies of paleoclimate and paleohydrology. They provide a useful first step for anticipating climate influences on hydrology at spatial scales relevant to the Everglades and South Florida water management, including the major sub-basins of the Everglades watershed. Additional implications for water management include the need to regionally improve the spatial resolution of coarse spatial scale global circulation models and create predictive climatic indices better suited for the southern peninsula of Florida. The demonstrated weaker influence of ENSO and PDO on winter precipitation along the southeastern Florida coast, compared to the rest of the South Florida, suggests local climate gradients may underlie, to some degree, the high sensitivity of southeastern Florida coastal marshes to past and ongoing water management [Gaiser *et al.*, 2006]. While paleoecological studies suggest a millennial-scale ENSO influence on South Florida climate [e.g., Donders *et al.*,

2005], the present work demonstrates that more studies are needed to refine the spatial extent of such paleoclimate teleconnections. The recognition of such high spatial resolution gradients in teleconnections presents another layer of challenges for the restoration of these coastal wetlands and the ecosystem services they provide.

8. Modeling and Synthesis

Landscape Ecosystem modeling – ELM and SEACOM

With higher inflow volumes (and more P mass), the HiFlo simulations of ELM displayed somewhat more P accumulation in the upstream region. In both runs, P accumulation decreased with distance downstream of inflow, but increased adjacent to FL Bay (areas downstream of site TS/Ph-6) (Fig 8.6). With increased P loads (HiFlo), SAV responded with generally lower biomass, largely due to phytoplankton shading (Fig. 8.7). Temporal variation in between-run loading differences led to non-linear SAV differences between runs.

Downstream P accumulation gradients

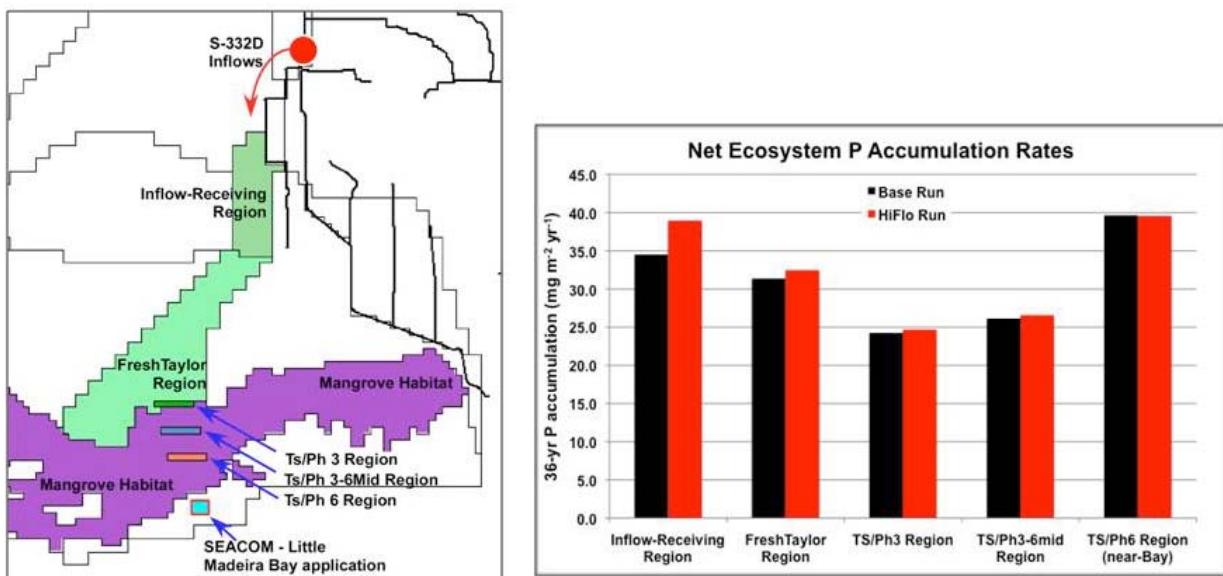


Figure 8.6: Left: Simulation study area for ELM-SEACOM sensitivity analyses. Right: Net ecosystem P accumulation rates simulated by ELM across the freshwater-to-coastal transect.

Seagrass/phytoplankton sensitivity to altered loads

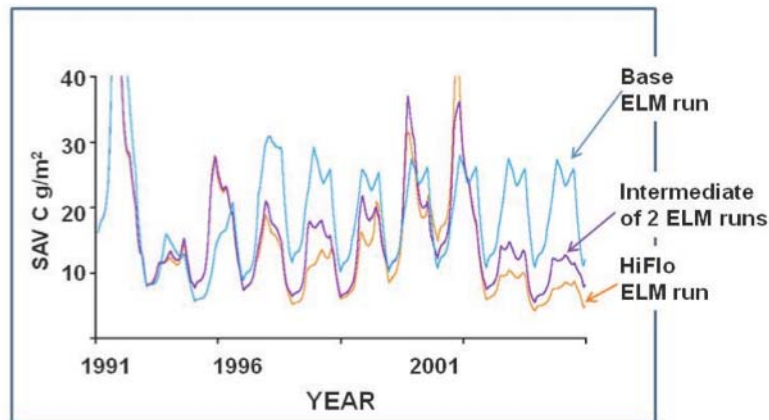


Figure 8.7: SEACOM output showing nonlinear responses of biomass to altered flow conditions simulated by ELM.

Mangrove Models

Porewater salinity output from HYMAN followed observed seasonal values currently monitored along FCE LTER sites in Shark River (SRS4, SRS5, SRS6) (Fig. 8.8). We run different scenarios and evaluate the critical role of precipitation, (especially at the beginning of the rainy season) in controlling porewater salinity maximum values. Results show that porewater salinity values at SRS4 (upstream station) is apparently controlled by groundwater flow that by overland flow. The HYMAN model showed robust forecasting in porewater salinity for sites SRS5 and SRS6.

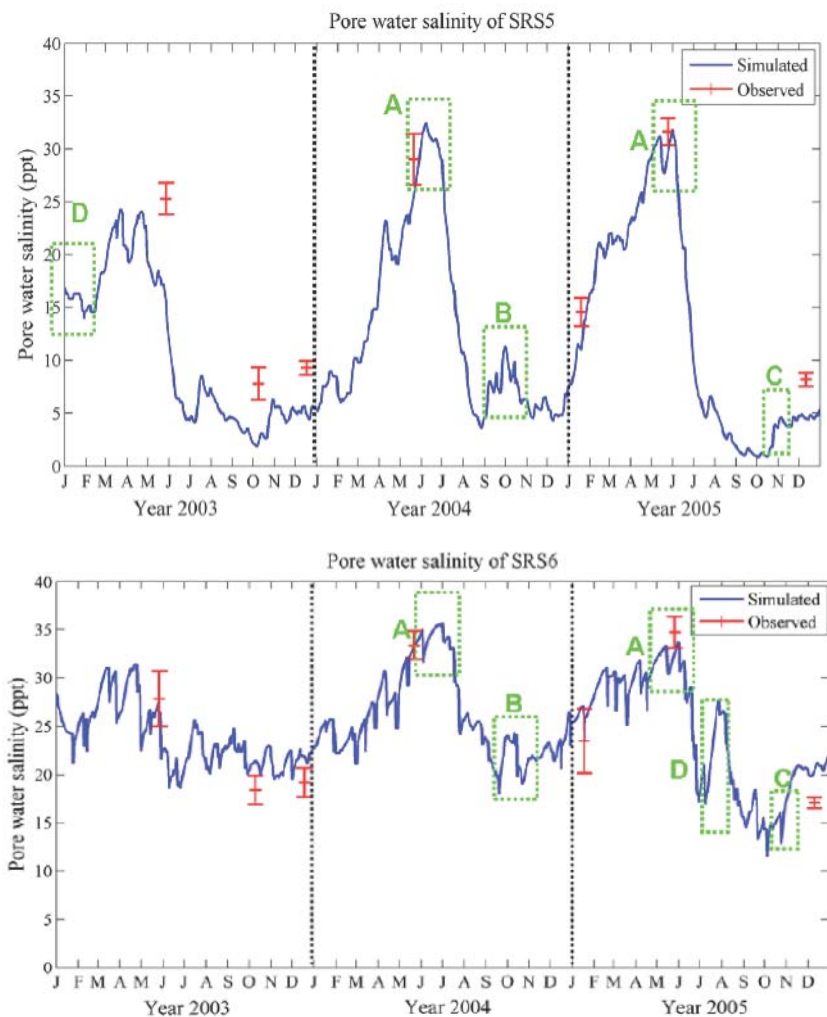


Figure 8.8: Simulated (HYMAN model) and observed pore water salinity in SRS5 (top panels) and SRS6 (bottom panels) in 2003, 2004 and 2005.

In the Taylor River ecotone, The MIKEFLOOD hydrodynamic model was calibrated against field measurements and showed satisfactory agreement (Fig. 8.9). A model efficiency (NSE Index) exceeding 0.70 was reached for all the simulation periods, with a 0.81 values obtained when simulating an overland inflow component. We were able to capture the overall salinity patterns and trends in the target model area. Three modeling periods were defined: 1) a dry period with minimum overland flow to calibrate the hydrodynamic parameters prevailing in the area (January to June 2001); 2) a dry season period with available groundwater data from December 2003 to June 2004 to determine the groundwater leakage factor – this period was then extended until May 2005 for salinity transport calibration; and 3) a period including overland flow simulation (March – October 2002), allowing to verify the hypothesis that the remaining budget closure term is directly linked to the overland flow (and the uncertainty associated with it). The largest term in the annual budget of this estuarine area is the outflow at Taylor mouth (17,265 mm y⁻¹ in 2002), while the major inflow term is the overland surface flow outside of the

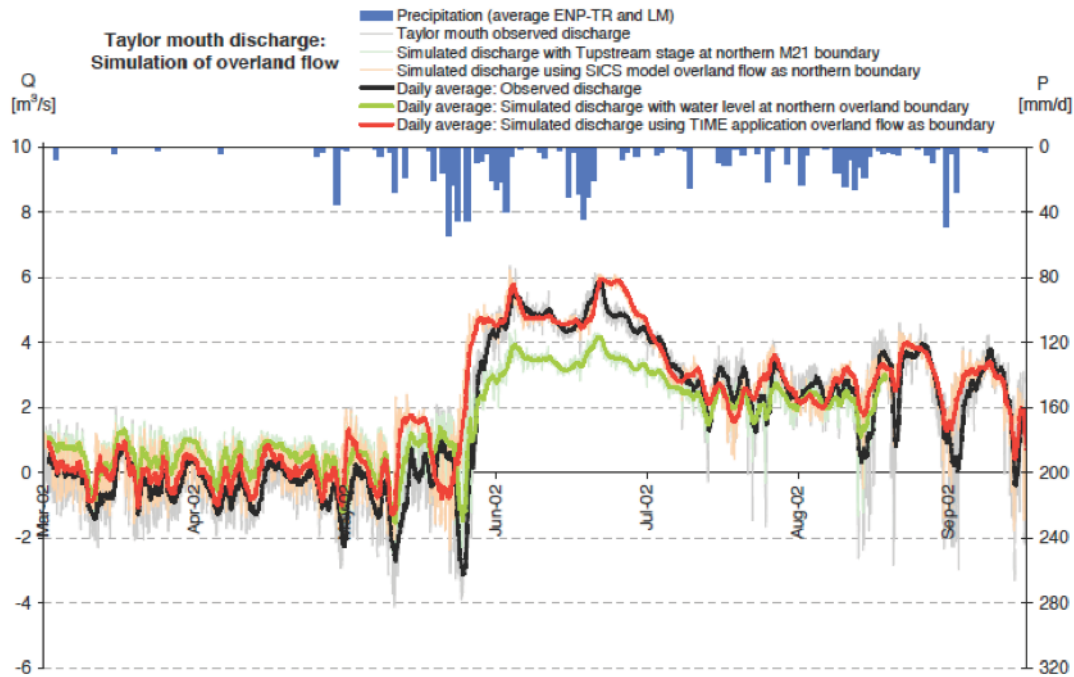


Figure 8.9: Overland flow simulation in the Taylor River area, March – September 2002

channel. Precipitation and evapotranspiration are relatively unimportant budget terms in this part of the Taylor Slough, which is dominated by the accumulation of water retained by the Buttonwood embankment. A comparison of our Taylor River water budget with a Taylor Slough water budget published in 2001 (encompassing the years 1996-1997) shows that the former includes a larger surface flow as compared to precipitation (P) and evapotranspiration (ET). Total N and total P budgets were calculated for the Taylor River region using annual and seasonal water budgets, as well as observed N and P concentrations near the northern boundary. Given the small size of the study area and large contribution of surface flow, the relative importance of atmospheric deposition is lower in the Taylor River region than in the entire Slough area as shown in previous studies. The relative magnitude of nutrient loads in both studies is dependent on the water flow volume and actual internal cycling processes such as burial and denitrification (Fig. 8.10). Current unpublished direct estimates of nitrification, denitrification, nitrogen fixation and burial rates in combination with estimated N and P budgets in this study indicate a large N and P deficit in the Taylor River model area. P burial rates for the modeling area ranged from 80 to 140 mg m⁻² y⁻¹, and were higher than the closure term ϵ estimated for the dry (64 mg m⁻² y⁻¹) and wet (-36 mg m⁻² y⁻¹) season in 2002; this result also indicates a large deficit of P as suggested by a) the low concentration of P in water and sediments in comparison to other sites in Southern Everglades, b) low mangrove vegetation stature (<5 m), and c) the regulatory control of soil (and porewater) P concentrations on nitrification rates in soils from up and downstream Taylor River.

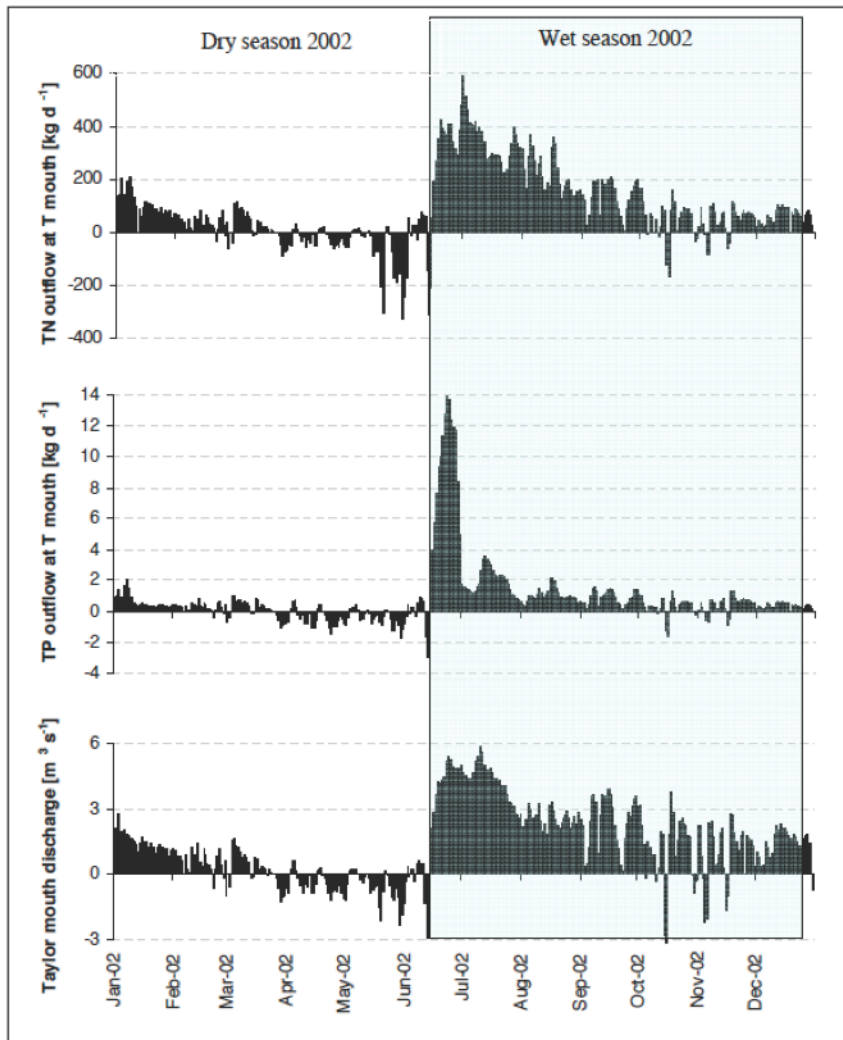


Figure 8.10: Taylor mouth daily water and nutrient outflow in 2002.

Consumer dynamics

Spatially explicit modeling work has continued to examine the impacts of water level fluctuations on fish populations. This approach involved using a simple analytically tractable model in comparison with the GEFish1 model (Jopp et al., Landscape Ecology 2010) and led to three new and general conclusions about the impacts of water level fluctuations: (1) there is an optimal rate at which fish should expand into a newly flooding area to maximize population production; (2) there is also a fluctuation amplitude of water level that maximizes fish production, and (3) there is an upper limit on the number of fish that can reach a permanent waterbody during a drydown, no matter how large the marsh surface area is that drains into the waterbody. Because water levels can be manipulated in many wetlands, it is useful to have an understanding of the role of these fluctuations.

Additional simulation modeling of aquatic communities that include primary primary producers and higher trophic levels, De Angelis and colleagues show the effects of water level fluctuations on the ecosystem organizational responses as a whole. First, they found that temporally and spatially varying patterns of trophic cascades can be discerned in the simulations, but they were relatively weak compared to such cascades that are observed in some lake ecosystems. Second, the fish showed distinctive pulses at the edge of the drying front as water levels declined. The retreating fish added to the fish already in the present in the still-flooded cells, forming a pulse of fish retreating towards the persisting bodies of water. Pulselike behavior could also be observed following the flooding front during rising water level, but the pulses were much smaller. Third, biomass levels, averaged over the whole model, tended to increase moderately with the amplitude of water level fluctuations. However, the piscivore biomass always reached a peak at some fluctuation amplitude and then declined with further increase in amplitude.

Human Dimensions modeling

Results of the SLEUTH model to date indicate that goodness of fit metrics (related to land use change based on zoning) are greater (Fig. 8.11) when lands zoned for agriculture are integrated in an Excluded Layer which also accounts for government ownership and parklands, and flood zones. Land use layers used for 1994 and 2006 in the model are presented in Figure 8.12. The Excluded Layer and corresponding cumulative output of Monte Carlo iterations are presented in Figure 8.13. Simulations indicate the degree to which the forecasted land use is dependent on the initial conditions of spatial coverage of the Excluded Layer, with varying levels of resistivity to development (Figure 8.13).

Lee-Sallee Results

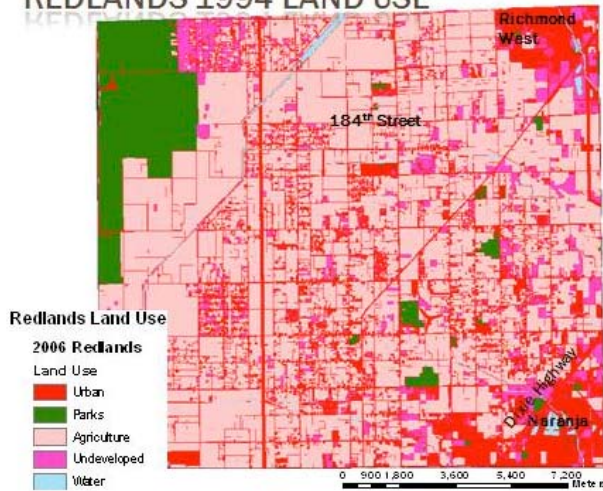
- ◉ Redlands With Zoning Coarse=0.42379
- ◉ Redlands No Zoning Coarse=0.42215

- ◉ Redlands With Zoning Fine=0.42418
- ◉ Redlands No Zoning Fine=0.42241

- ◉ Redlands With Zoning Final = 0.4243
- ◉ Redlands No Zoning Final=0.42279

Figure 8.11: Results from SLEUTH experimentation demonstrating the improvement of metrics when integrating Ag zoned lands into the Excluded layer during calibration.

REDLANDS 1994 LAND USE



REDLANDS 2006 LAND USE

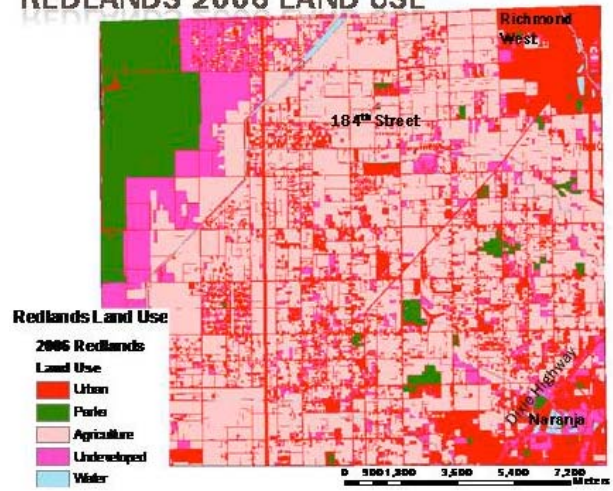


Figure 8.12: Land Use in the Redlands in 1994 and 2006

ADDING FLOOD ZONES

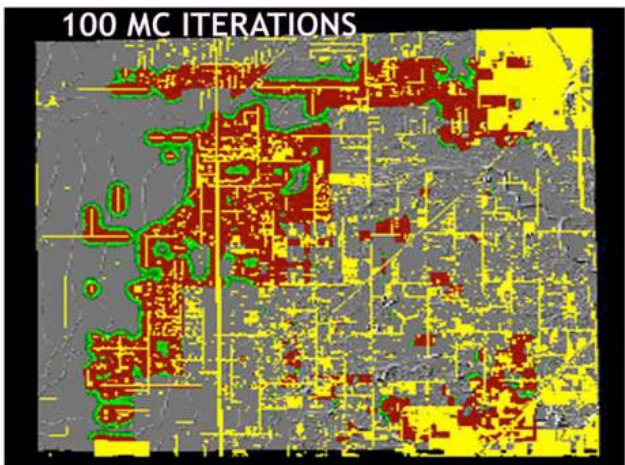


Figure 8.13: LEFT PANEL: Sophisticated Redlands Excluded Layer used in SLEUTH calibrated urban growth simulation for Redlands. Lighter colors offer more resistance to development while darker colors offer less. This excluded layer integrates government owned / parklands, land zoned for farmland, and flood zones. RIGHT PANEL: 100 runs of the SLEUTH model in the Redlands. Yellow cells were already developed in 2006, red cells were selected between 95 and 100 times out of 100 for development and the shades of green were selected between 50 and 95 times out of 100. Gray cells were selected between 0 and 50 times.

C. Training and Development

The primary objective for FCE II Education and Outreach Working Group is to address the strategic initiatives and goals of *The Decadal Plan for LTER*. Our approach for addressing the *Decadal Plan* 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 August 2009 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.

Education, Outreach, and Diversity Activities

FCE Research Experience programs work towards developing and improving environmental literacy by working with students of all ages from Kindergarten through graduate school (K-20). 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.

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. Throughout FCE II we have continued to provide ongoing support for our RESSt internships and in 2009-2010 FCE II has supported an additional 8 student interns who worked with FCE researchers.

Two of our Research Assistantships for High School Students (RAHSS) recipients (Christopher Sanchez and Jonathan Prendergast) won top prizes in local and state science fairs and both advanced to the international science fair this year.

Sanchez has worked with FCE since 2006. In his third year working with FCE scientists Evelyn Gaiser and Colin Saunders, Sanchez advanced to the 2009 Intel International Science and Engineering Fair (*ISEF*) where he received 2nd Place in "Plant Science" for his research project entitled "Interpreting the hydrologic history of an Everglades wetland through microscopic characterization of phytoliths." As a winner at 2009 ISEF, a minor planet was named in his honor by the MIT Lincoln Laboratory and can be tracked at <http://www.kentauren.info/cgi-bin/astorb2txt.pl?Suchname=Chrisanchez>

In 2010, Sanchez continued working with Gaiser and expanded the scope of his previous project to include new diatom work. As one of our Research Awards for High School Students (*RAHSS*) recipients, Sanchez competed on the 2010 Science Fair circuit which began at the 55th Annual South Florida Regional Science and Engineering Fair (*SFRSEF*) and is where he received a Superior in the "Earth and Planetary Science" division and the American Meteorological Society Award for his project entitled "Quantifying hydroperiod fluctuations across an Everglades wetland through microscopic analysis of siliceous microfossils." Sanchez's success continued at

the 55th Annual State Science and Engineering Fair of Florida in Orlando, FL where he received 2nd Place in “Earth and Planetary Science” and advanced to compete in the Intel International Science and Engineering Fair in San Jose, CA, in May.

First year intern, Jonathan Prendergast, worked with Ligia Collado. As another RAHSS recipient, Prendergast used the funds to complete his project and present the results in a poster entitled “Interpreting the nutrient limitation, salinity and seasonal variations of Florida Bay in order to analyze shifts in species and biomass productivity” at the *SFRSEF* where he received a Superior rating in “Environmental Management” division. Prendergast also received the International Sustainable World (I-SWEEP) Award and was invited to present his results at the I-SWEEP Project Olympiad in Houston, TX in April. He was also given the South Florida Regional US Stockholm Junior Water Prize, invited to compete in the US Stockholm Junior Water Prize Competition in St. Louis, and given the George N. Avery Award by the Florida Native Plant Society.

Prendergast also advanced to the 55th Annual State Science and Engineering Fair of Florida where he received 1st Place in “Environmental Science” and the Heartland Regional Science and Engineering Fair Award (\$75).

The continued success of these students allowed them to become two of 12 students to represent Miami Dade County Public Schools at the 2010 Intel International Science and Engineering Fair in San Jose, CA. This marked a historical moment for FCE and marks the first time that two FCE students advanced to *ISEF* in the same year.

Our RAHSS recipients have also presented their results to professional meetings and to members of our community. Jonathan was invited to present his results to the South Florida chapter of the Florida Native Plant Society. Later this year, both Sanchez and Prendergast presented their results in a poster at our annual ASM meeting

Sanchez also conducted a schoolyard program at Oliver Hoover Elementary School and constructed a butterfly garden emphasizing the importance of native Everglades plant species. Sanchez had many other outstanding accomplishments this past year and was named as Felix Varela Senior High School’s Silver Knight in Science and received an Honorable Mention in the Miami-Dade County Silver Knight competition against hundreds of competitors for his contributions towards Everglades restoration (<http://www.miamiherald.com/silverknights/>). Sanchez also graduated first in his high school class (of over 700) and will be attending the University of Miami majoring in Biology.

In 2007, we launched Research Experience for Middle Schools (REMS). As we move into our fourth year, REMS continues to expand and is largely supported through the financial support of our community partner and aggregate mining conglomerate, CEMEX.

Over the last year, we have begun discussions with Kimberly Allen, teacher at newly opened Gateway Environmental K-8 Learning Center, about developing a program at geared towards her K-5 students. We have recently been in contact with Principal Carmen Gutierrez of Gateway K-5 and will continue working towards implementing Research Experience for Elementary

Students (REES) program at their school. Our current plan is to, incorporate GIS/GPS technology, coordinate REES program with the expansion of the CEMEX restoration area and work on a habitat restoration area at the school site.

Nicholas Oehm, Education and Outreach Coordinator, is also a professional service teacher and presented information about FCE and the Everglades to his biology students. Together, Oehm, Casal and Laroche have given FCE presentations to over 300 students at FVSHS and approximately 150 at MDC

Pre-service Teachers

FCE has continued working with the Miami Dade College Department of Biology, Health and Wellness (MDC-DBHW) and has also begun working with the Miami Dade College School of Education (MDC-SE).

This year Nicholas Oehm has given presentations on FCE research to 117 undergraduate students enrolled in MDC's BSC1005: Introductory Biology for Non-majors and Teresa Casal using FCE lessons and FCE datasets with pre-service Math and Science teachers enrolled in the Miami Dade College School of Education (MDC-SE). Over 40 undergraduates enrolled in Teresa's EME 3410 Instructional Technology in Mathematics and Science were introduced to FCE lessons and downloaded two FCE datasets for use with Google Earth and My World GIS. She also introduced additional FCE lessons and datasets to students enrolled in a new data analysis course during the Fall 2009.

In 2009, our relationship with MDC-SE grew 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. The program is modeled after similar project entitled "Rip Rap Geology" at Golden Gate National Park (<http://www.nps.gov/goga/forteachers/park-teachers-home.htm>). Through the Everglades PARK program, Casal has worked with ENP and MDC-SE staff to assist pre-service teachers in developing hands on, laboratory activities while studying Everglades fire ecology in relation to soil and water characteristics.

Education and Outreach Web Page Development

Current year RET activities involved planning revisions to the FIU FCE Education and Outreach web page. Two advanced students from Felix Varela Senior High's web design classes reviewed and critiqued the FCE web page and recommended improvements to make the web page more appealing to younger students and to the general community. Recommended changes were quite detailed and complex and therefore required a multi-step implementation plan. To help students realize the complexities of the plan and how the plan would affect others involved in monitoring FIU's FCE web site, students were introduced to a project management life cycle plan commonly used in the business world. The use of a life cycle plan provided the students with an opportunity to use real-world business strategies and to recognize the importance of cooperative planning. The proposed changes to the webpage should be completed this fall.

In March 2010, Casal and Laroche, two of our RESSt interns, and Oehm accepted an invitation to meet with newly-appointed Director of the National Park Service, Jon Jarvis. Our students

summarized their research and described the importance of research opportunities for young students. Director Jarvis plans to use our suggestions to improve existing and develop new programs for teachers and students in working in our National Parks and in Everglades and Biscayne national parks

FCE has a large Hispanic community and we continue to translate our materials for Spanish speakers. Nearing completion, the FCE children's book *One Night in the Everglades* is currently in press and will soon be released. We have proposed using 2010 supplemental funds as partial support for producing an *En Español* version.

In an effort to establish international Education & Outreach partnerships, 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, Nicholas Oehm visited the 2010 World Expo in Shanghai, China. The theme of the 2010 Expo was *Better City, Better Life* and was an excellent opportunity to explore the environmental issues facing other nations around the world. Nicholas spent several days researching a variety of approaches to environmental education and will incorporate some of these ideas into existing FCE programs and have provided background for new ideas. He also visited the National Wetland Museum in Hangzhou, China and will use this experience to guide exhibit development for the FCE museum and science center kiosks.

Graduate Student Activities and Productivity

The FCE Affiliated Students Group includes over 40 graduate students who are members. The group meets once a month for meetings. They host seminars and social activities with other graduate student organizations. FCE students earned 4 MS theses and 2 Ph.D. dissertations from December 2009 to September 2010.

Theses and Dissertations

Castaneda, Edward. 2010. *Landscape Patterns of Community Structure, Biomass and Net Primary Productivity of Mangrove Forests in the Florida Coastal Everglades as a Function of Resources, Regulators, Hydroperiod, and Hurricane Disturbance*. Ph.D. dissertation, Louisiana State University

Dunlop, Katherine. 2009. *Examination of cue utilization & anti-predator responses by native Everglades taxa to a non-native predator, the African jewelfish*. Master's thesis, Nova Southeastern University Oceanographic Center.

McCarthy, Lauren. 2009. *Segregation of palaemonid shrimp species along a salinity gradient in Shark River, Everglades National Park*. Master's thesis, Nova Southeastern University Oceanographic Center.

Munyon, Jay. 2010. *The Effects of Hydrology and Phosphorus on Everglades Productivity*. Master's thesis, Florida International University.

Josette Marie La Hee. 2010. The Influence of Phosphorus on Periphyton Mats from the Everglades and Three Tropical Karstic Wetlands. Ph.D. dissertation, Florida International University.

Zapata-Rios, Xavier. 2009. Groundwater/surface water interactions in Taylor Slough-Everglades National Park. Master's thesis, Florida International University.

Dr. Price supervised an undergraduate student, Estefania Sandoval during this past year with funding from the NASA project: *WaterSCAPES: Science of Coupled Aquatic Processes in Ecosystems from Space*. Ms. Sandoval completed an independent study project entitled: "Using ion concentrations to investigate groundwater surface water interactions in wetlands." She presented the results of her research in the form of posters at both the FCE LTER 2010 ASM as well as at the NASA site review, both in March 2010. Ms. Sandoval is planning on continuing her education as an M.S. student under Dr. Price and will be directly funded from the NSF FCE LTER.

In addition to over 40 graduate students, FCE is actively improving our undergraduate and graduate program through ongoing mentoring and training through Research Assistantships and the REU program. In October 2009, FCE collaborator Dr. Randy Chambers gave a special lecture to his Wetlands Ecosystems class of 20 undergraduate students at William and Mary College entitled: Wetlands and Biogeochemistry- an FCE LTER Case Study. Dr. Colin Saunders, another of our research collaborators presented FCE paleo-ecological research data to an undergraduate student course (EVR 1007 Florida's Environmental History) of 19 students at Palm Beach State College. In addition, Laura Ogden and Evelyn Gaiser have offered workshops and reading groups to FCE students that focus on LTER readings and data analysis.

D. Outreach Activities

There are many ways in which FCE scientists, students, and staff interact with the greater public. Outreach often takes the form of presentations at forums such as community group meetings, publicized events, and secondary schools, or of specific training activities for students, teachers, or others. If a FCE scientist discusses their LTER research in such a presentation, we record that presentation as FCE outreach. The FCE Education and Outreach staff (including FCE high school interns) gave numerous presentations to schools in South Florida. FCE researchers also gave 81 presentations from September 2009 - September 2010.

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.

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.

Details of additional outreach by FCE scientists to restoration policymakers are listed in Section IVB (“Contributions to Other Disciplines”) of this report.

Outreach to policy makers – natural ecological variability (Gaiser and Wachnicka)

We have been attempting to interpret water management-derived changes in solute delivery and productivity on a backdrop of climate variability in order to effectively communicate to policy makers (1) the value of long-term data series in extracting water management changes from natural variability in ecological systems and (2) the extent to which temporal changes are controlled by water management. To this end, the FCE published a special issue of Ecological Indicators (Doren et al., 2009) that documents our conceptual approach and provides examples of application and modeling, and is coordinating with the South Florida Ecosystem Restoration Task Force to annually produce a glossy “stoplight” reporting document for distribution to Congress and other agencies to communicate the extent of ecological change derived from water manipulations.

Catherine Laroche is developing high school lessons that connect environmental studies of the Florida Coastal Everglades with the history and culture of the local Miccosukee Tribe of Indians.

Ania Wachnicka will be collaborating with federal and academic scientists involved in *Marine and Estuarine Goal Setting for South Florida* (MARES) project to develop an Integrated Conceptual Ecosystem Model (ICEMs) framework for South Florida shelf, including LTER study locations in Florida Bay and adjacent Biscayne Bay. ICEMs as used by the Comprehensive Everglades Restoration Plan’s RECOVER team, are heuristic planning tools that serve to identify (1) the major drivers and stressors upon natural ecosystems, (2) the ecological effects of these stressors, and (3) the indicators of the ecological responses to changes in those drivers and stressors.

Members of the Trophic Dynamics and Community Structure working group helped with production of three video-based lessons for Florida Science Fusion Program of Houghton Mifflin Harcourt. These include a Grade 4 lesson on the nature of science featuring the work of

graduate student Adam Rosenblatt, a Grade 7 lesson on food webs and abiotic factors featuring work by graduate student Philip Matich, and a Grade 8 lesson on energy flow in ecosystems featuring Dr. James Fourqurean and graduate student Justin Campbell.

Mike Heithaus received \$149,611 from NSF for a Communicating Research to Public Audiences grant to create a kiosk at the Ft. Lauderdale Museum of Discovery and Science featuring a video of work by the consumer group in the SRS and an interactive tracking tool for investigating abiotic drivers of alligator, shark, gar, and snook habitat use. These videos will be in a format similar to those Dr. Heithaus produced for his work in Shark Bay, Australia and can be viewed online at www.sberp.org.

J.S. Rehage acted as a SEEDS mentor at the Ecological Society of America national meetings in August 2009 & 2010 (www.esa.org/seeds). The SEEDS program aims to increase the participation of underrepresented groups in Ecology. At the meeting, the program matches minority undergraduates with faculty/postdoc mentors that guide the students throughout the meeting.

Hugh Gladwin served on the Miami-Dade Climate Change Advisory Task Force from 2006-present.

Hugh Gladwin served on the Steering Committee, Local Mitigation Strategy, Office of Emergency Management and Homeland Security, Miami-Dade County, Florida from 1997-present.

Jeff Onsted delivered an Agroecology Teachers Workshop Talk on July 7, 2010 entitled, “Urban Farmland Losses.”

Jeff Onsted represented the Department of Earth and Environment at the Fairchild Challenge student awards ceremony on May 17, 2010.

Jeff Onsted is a listed Mentor for an NSF proposal under review to provide outreach to local high school students, in order to increase the number of plant environmental biologists belonging to minority groups. He is also a listed faculty member under the Conservation Policy section of Fairchild’s Education website:

<http://www.fairchildgarden.org/education/graduatestudies/Faculty/>

We began working with Marine Lab, a non-profit educational organization in Key Largo. Their main purpose is to educate junior and high school students about the south Florida marine environment. Jeff Absten and Joe Boyer made a presentation to their staff concerning operation and maintenance of field meters and data analysis. We hope to use their volunteer data in our future analyses.

The FCE LTER Program reaches out to the public is through our web site and although our web statistics show a slight decrease in web activity in 2009, the numbers do show that we have been reaching a steadily growing number of new web clients since the inception of the web site in 2001, suggesting a strong positive trajectory for our web-based public outreach. We continue to

receive general questions from our visitors and requests for schoolyard visits and presentations. Additionally, visitors to the data section of our website downloaded 368 datasets from September 2009 through August 15, 2010.

E. Project Outcomes

1. Discovering that unlike most estuaries the Everglades is “upside-down” with its natural source of nutrients supplied not by upstream environments but by the downstream marine environments instead.

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. Wetland organisms also contradict conventional theories in their response to their environment, with producer communities that disintegrate with exposure to nutrient runoff and consumer communities that are much less abundant than they should be, given the ample resources available to them. While FCE 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 has been 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.

2. Discovering that dissolved organic matter (DOM) - which should be food for lower trophic levels - appears to move through the ecosystem but without appreciable consumption by organisms. At the same time, mobile predators create unexpected habitat linkages from the coastal oceans, through the estuary, and into freshwater creeks

Understanding the sources, fate, and transport of dissolved organic matter (DOM) is an important aspect of understanding the relationship of freshwater and marine environments in the Everglades. DOM in the Everglades is quite varied in composition and has both seasonal and spatial variability in its composition. It is also more bio-refractory than originally hypothesized. FCE researchers discovered 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 from restoration efforts 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 and this detrital component is important to food web dynamics and ecosystem energetics.

3. Demonstrating a “productivity paradox” in the Everglades – while microorganisms (such as algae) produce the vast majority of energy in the Everglades, little of this energy reaches higher-level plants and animals in the food chain (such as alligators or wading birds).

FCE researchers have found that the Everglades exhibits very high levels of primary productivity and biomass of algal producers, yet very low biomass of aquatic consumers. In fact, this research has demonstrated that microbial producers in karstic wetlands are more than two orders of magnitude more productive than expected from their limited P supply; less than 1% of this energy reaches upper trophic levels, resulting in a bottom-heavy energy pyramid. Our research indicates that anthropogenic nutrient enrichment erases the unusual Eltonian pyramid of biomass by decreasing standing crops of algae and increasing those of aquatic consumers.

4. Developing a “stoplight” reporting system to translate the best possible science on Everglades health and restoration efforts to the U.S. Congress and other policymakers.

The Everglades is imbedded in a human-dominated landscape that is constantly changing in response to local and global environmental manipulations; by working with an inter-governmental task force, FCE has created a reporting system so that the causes and consequences of these dynamics can be directly conveyed to the U.S. Congress for evaluating ecosystem restoration success. The “stoplight” reporting system allow us to communicate our science to other scientists and policy makers using a novel, statistically rigorous way of extracting management signals from long-term datasets. FCE scientists collaborated with the Federal Task Force on Everglades Restoration, National Park Service, US Army Corps of Engineers, US Fish and Wildlife Service, and other universities to develop this communication tool.

III. PUBLICATIONS AND OTHER SPECIFIC PRODUCTS

A. Publications

Books

Ogden, L. (In Press). *Swamp Life: The Entanglements of Mangroves, Alligators and Hunters in the Florida Everglades*. University of Minnesota, Minneapolis, MN.

Book chapters

Brondizio, E. and R. Roy Chowdhury. In Press. Spatio-temporal methodologies in Environmental Anthropology: Geographic Information Systems, remote sensing, landscape changes and local knowledge. in Ismael Vaccaro, Eric Alden Smith and Shankar Aswani (eds.) *Society and Environment: Methods and Research Design*. Cambridge University Press.

Cooper, S., E. Gaiser and A. Wachnicka. 2010. Estuarine paleoecological reconstructions using diatoms. In J. P. Smol and E. F. Stoermer, *The Diatoms: Applications in Environmental and Earth Sciences*. Cambridge.

Davis, S.E., D. Lirman, J. Wozniak. 2009. Nitrogen and phosphorus exchange among tropical coastal ecosystems . Pages 9-44 In Nagelkerken, Ivan (ed.) *Ecological Connectivity Among Tropical Coastal Ecosystems*. Springer, New York.

DeAngelis, D.L., J.C. Trexler, D.D. Donalson. 2010. Competition dynamics in a seasonally varying wetland . Pages 1-14 In Cantrell, S., C. Cosner, S. Ruan (eds.) *Spatial Ecology*. Chapman Hall/CRC Press, Boca Raton, FL.

Dittmar, T., B. Koch, R. Jaffe. 2009. Tools for studying biogeochemical connectivity among tropical coastal ecosystems . Pages 425-455 In Nagelkerken, Ivan (ed.) *Ecological Connectivity among Tropical Coastal Ecosystems*. Springer, New York.

Gaiser, E. and K. Rühland. 2010. Diatoms as Indicators of Environmental Change in Wetlands and Peatlands. J. P. Smol and E. F. Stoermer, *The Diatoms: Applications in Environmental and Earth Sciences*. Cambridge.

Glibert, P.M., J.N. Boyer, C. Heil, C.J. Madden, B. Sturgis, C.S. Wazniak. 2010. Blooms in lagoons: Different from Those of River-Dominated Estuaries . Pages 98-113 In Kennish, M.J., H.W. Paerl (eds.) *Coastal Lagoons: Critical Habitats of Environmental Change*. CRC Press, Boca Raton, FL.

Heithaus, M.R., A. Frid, J.J. Vaudo, B. Worm, A.J. Wirsing. 2010. Unraveling the ecological importance of elasmobranchs . Pages 611-637 In Heithaus, M.R., J.C. Carrier, J. Musick (eds.) The biology of sharks and their relatives II: Biodiversity, adaptive physiology, and conservation. CRC Press, Boca Raton, FL.

Journal articles

Armitage, A.R., J.W. Fourqurean. 2009. Stable isotopes reveal complex changes in trophic relationships following nutrient addition in a coastal marine ecosystem. *Estuaries and Coasts*, 32: 1152-1164.

Baggett, L.P., K.L. Heck Jr., T.A. Frankovich, A.R. Armitage, J.W. Fourqurean. 2010. Nutrient enrichment, grazer identity and their effects on epiphytic algal assemblages: field experiments in sub-tropical turtlegrass (*Thalassia testudinum*) meadows. *Marine Ecology Progress Series*, 406: 33-45.

Barr, J.G., V. Engel, J.D. Fuentes, J.C. Zieman, T.L. O'Halloran, T.J. Smith, G. Anderson. 2010. Controls on mangrove forest-atmosphere carbon dioxide exchanges in western Everglades National Park. *Journal of Geophysical Research*, 115: G02020.

Briceño, H. O., and J. N. Boyer. 2010. Climatic controls on nutrients and phytoplankton biomass in a sub-tropical estuary, Florida Bay, USA. *Estuaries and Coasts* 33(2): 541–553.

Campbell, J.E., J.W. Fourqurean. 2009. Interspecific variation in the elemental and stable isotopic content of seagrasses in South Florida. *Marine Ecology Progress Series*, 387: 109-123.

Castaneda-Moya, E., R.R. Twilley, V.H. Rivera-Monroy, K. Zhang, S.E. Davis, M.S. Ross. 2010. Sediment and Nutrient Deposition Associated with Hurricane Wilma in Mangroves of the Florida Coastal Everglades. *Estuaries and Coasts*, 33(1): 45-58.

Chen, M., R.M. Price, Y. Yamashita, R. Jaffe. 2010. Comparative study of dissolved organic matter from groundwater and surface water in the Florida coastal Everglades using multi-dimensional spectrofluorometry combined with multivariate statistics. *Applied Geochemistry*, 25(6): 872-880.

Chin, D.A., R.M. Price, V.J. DiFrenna. 2009. Nonlinear Flow in Karst Formations. *Ground Water*, 47(5): 669-674.

Clement, B.M., J. Javier, J.P. Sah, M.S. Ross. 2010. The effects of wildfires on the magnetic properties of soils in the Everglades. *Earth Surface Processes and Landforms*. DOI: 10.1002/esp.2060

DeAngelis, D. L., J. C. Trexler, C. Cosner, A. Obaza, and F. Jopp. 2010. Fish population dynamics in a seasonally varying wetland. *Ecological Modelling* 221(8):1131-1137.

- Dewsbury, B.M., J.W. Fourqurean. 2010. Artificial reefs concentrate nutrients and alter benthic community structure in an oligotrophic, subtropical estuary. *Bulletin of Marine Science*, 86(4): 813-828.
- Ferretti, F., B. Worm, G.L. Britten, M.R. Heithaus, H.K. Lotze. 2010. Patterns and ecosystem consequences of shark declines in the ocean. *Ecology Letters*, 13(8): 1055-1071.
- Fourqurean, J.W., M.F. Muth, J.N. Boyer. 2010. Epiphyte loads on seagrasses and microphytobenthos abundance are not reliable indicators of nutrient availability in coastal ecosystems. *Marine Pollution Bulletin*, 60: 971-983.
- Fourqurean, J.W., T.J. Smith, J. Possley, T.M. Collins, D. Lee, S. Namoff. 2010. Are mangroves in the tropical Atlantic ripe for invasion? Exotic mangrove trees in the forests of south Florida. *Biological Invasions*, 12: 2509-2522.
- Frankovich, T.A., J.W. Fourqurean, D. Morrison. (In Press). Benthic macrophyte distribution and abundance in estuarine mangrove lakes: relationships to water quality. *Estuaries and Coasts*, Online First, DOI 10.1007/s12237-010-9279-0
- Frankovich, T.A., A.R. Armitage, A. Wachnicka, E.E. Gaiser, J.W. Fourqurean. 2009. Nutrient effects on seagrass epiphyte community structure in Florida Bay. *Journal of Phycology*, 45: 1010-1020.
- Gaiser, E.E., J. La Hee, F. Tobias, A. Wachnicka. (In Press). *Mastogloia smithii* Thwaites ex Wm. Smith: A structural engineer of calcareous mats in karstic subtropical wetlands. *Proceedings of the Academy of Natural Sciences of Philadelphia*
- Gaiser, E.E., P. McCormick, S.E. Hagerthey. (In Press). Landscape patterns of periphyton in the Florida Everglades. *Critical Reviews in Environmental Science and Technology*
- Gaiser, E.E., N. Deyrup, R. Bachmann, L. Battoe, H. Swain. 2009. Multidecadal climate oscillations detected in a transparency record from a subtropical Florida lake. *Limnology and Oceanography*, 54(6): 2228-2232.
- Gaiser, E.E., R. Bachmann, L. Battoe, N. Deyrup, H. Swain. 2009. Effects of climate variability on transparency and thermal structure in subtropical, monomictic Lake Annie, Florida. *Fundamental and Applied Limnology*, 175(3): 217-230.
- Glibert, P.M., C. Heil, D.T. Rudnick, C.J. Madden, J.N. Boyer, S.P. Kelly. 2009. Florida Bay: Water quality status and trends, historic and emerging algal bloom problems. *Contributions in Marine Science*, 38: 5-17.
- Hagerthey, S.E., B.J. Bellinger, K. Wheeler, M. Gantar, E.E. Gaiser. (In Press). Everglades periphyton: A biogeochemical perspective. *Critical Reviews in Environmental Science and Technology*

- He, G., V. Engel, L. Leonard, A.L. Croft, D.L. Childers, M. Laas, Y. Deng, H. Solo-Gabriele. 2010. Factors Controlling Surface Water Flow in a Low-gradient Subtropical Wetland. *Wetlands*, 30: 275-286.
- Ikenaga, M., R. Guevara, C. Pisani, A. Dean, J.N. Boyer. 2010. Changes in Community Structure of Sediment Bacteria Along the Florida Coastal Everglades Marsh-Mangrove-Seagrass Salinity Gradient. *Microbial Ecology*, 59(2): 284-295.
- Jopp, F., D.L. DeAngelis, J.C. Trexler. 2010. Modeling seasonal dynamics of small fish cohorts in fluctuating freshwater marsh landscapes. *Landscape Ecology*, 25(7): 1041-1054.
- Kelble, C.R., P.B. Ortner, G.L. Hitchcock, M.J. Dagg, J.N. Boyer. 2010. Temporal and Spatial Variability of Mesozooplankton in a Shallow Sub-Tropical Bay: Influence of Top-Down Control. *Estuaries and Coasts*, 33(3): 723-737.
- Mancera Pineda, J.E., R.R. Twilley, V.H. Rivera-Monroy. 2009. Carbon (d13c) and Nitrogen (d15n) Isotopic Discrimination in Mangroves in Florida Coastal Everglades as a Function of Environmental Stress. *Contributions in Marine Science*, 38: 109-129.
- Matich, P, MR Heithaus, and CA Layman. In press. Contrasting patterns of individual specialization and trophic coupling in two marine apex predators. *Journal of Animal Ecology*.
- Matich, P., M.R. Heithaus, C. Layman. 2010. Size-based variation in intertissue comparisons of stable carbon and nitrogen isotopic signatures of bull sharks (*Carcharhinus leucas*) and tiger sharks (*Galeocerdo cuvier*). *Canadian Journal of Fisheries and Aquatic Sciences*, 67: 877-885.
- Price, R.M., M.R. Savabi, J.L. Jolicoeur, S. Roy. 2010. Adsorption and desorption of phosphate on limestone in experiments simulating seawater intrusion. *Applied Geochemistry*, 25(7): 1085-1091.
- Rehage, J.S., K.L. Dunlop, W.F. Loftus. 2009. Antipredator Responses by Native Mosquitofish to Non-Native Cichlids: An Examination of the Role of Prey Naivete'. *Ethology*, 115: 1046-1056.
- Rivera-Monroy, V.H., R.R. Twilley, S.E. Davis, D.L. Childers, M. Simard, R.M. Chambers, R. Jaffe, J.N. Boyer, D.T. Rudnick, K. Zhang, E. Castaneda-Moya, S.M.L. Ewe, R.M. Price, C. Coronado-Molina, M.S. Ross, T.J. Smith, B. Michot, E. Meselhe, W.K. Nuttle, T. Troxler, G.B. Noe. (In Press). The Role of the Everglades Mangrove Ecotone Region (EMER) in Regulating Nutrient Cycling and Wetland Productivity in South Florida. *Critical Reviews in Environmental Science and Technology*

- Saha, A.K., L.d.S.L. Sternberg, M.S. Ross, F. Miralles-Wilhelm. 2010. Water source utilization and foliar nutrient status differs between upland and flooded plant communities in wetland tree islands. *Wetlands Ecology and Management*, 18: 343-355.
- Sargeant, B., J.C. Trexler, E.E. Gaiser. 2010. Biotic and Abiotic Determinants of Intermediate-Consumer Trophic Diversity in the Florida Everglades. *Marine & Freshwater Research*, 61: 11-22.
- Schedlbauer, J., S. Oberbauer, G. Starr, K.L. Jimenez. 2010. Seasonal differences in the CO₂ exchange of a short-hydroperiod Florida Everglades marsh. *Agricultural and Forest Meteorology*, 150(7-8): 994-1006.
- Sih, A., D.I. Bolnick, B. Luttbeg, J.L. Orrock, S.D. Peacor, L.M. Pintor, E. Preisser, J.S. Rehage, J.R. Vonesh. 2010. Predator-prey naivete', antipredator behavior, and the ecology of predator invasions. *Oikos*, 119(4): 610-621.
- Stoffella, S., M.S. Ross, J.P. Sah, R.M. Price, P. Sullivan, E. Cline, L.J. Scinto. (In Press). Survival and growth responses of eight Everglades tree species along an experimental hydrological gradient on two tree island types. *Applied Vegetation Science*, DOI: 10.1111/j.1654-109X.2010.01081.x
- Sullivan, P., R.M. Price, M.S. Ross, L.J. Scinto, S. Stoffella, E. Cline, T.W. Dreschel, F.H. Sklar. (In Press). Hydrologic Processes of Tree Islands in the Everglades: Tracking the Effects of Tree Establishment and Growth. *Hydrogeology Journal*
- Wachnicka, A. and E. Gaiser. In Press. Autecology and distribution of diatoms in Biscayne Bay, Florida: implications for biomonitoring and paleoenvironmental studies. *Ecological Indicators*.
- Wachnicka, A., E.E. Gaiser, L. Collins, T.A. Frankovich, J. Boyer. (In Press). Distribution of Diatoms and Development of Diatom-Based Models for Inferring Salinity and Nutrient Concentrations in Florida Bay and Adjacent Coastal Wetlands of South Florida (USA). *Estuaries and Coasts*, 33(5): 1080-1098.
- Walsh, V., R.M. Price. 2010. Determination of vertical and horizontal pathways of injected fresh wastewater into a deep saline aquifer (Florida, USA) using natural chemical tracers. *Hydrogeology Journal*, 18(4): 1027-1042.
- Wetzel, P., F.H. Sklar, C. Coronado-Molina, T. Troxler, S.L. Krupa, S. Newman, P. Sullivan, S.M.L. Ewe, W.H. Orem, R.M. Price, T.W. Dreschel. (In Press). A review of our understanding of the biogeochemical processes on tree islands in the Greater Everglades. *Critical Reviews in Environmental Science and Technology*
- Whitmer, A., L. Ogden, J. Lawton, P. Sturner, P.M. Groffman, L. Schneider, D. Hart, B.S. Halpern, W. Schlesinger, S. Raciti, N. Bettez, S. Ortega, L. Rustad, S.T.A. Pickett, M.

Killelea. 2010. The engaged university: providing a platform for research that transforms society. *Frontiers in Ecology and the Environment*, 8(6): 314-321.

Williams, C.J., R. Jaffe, W.T. Anderson, F.J. Jochem. 2009. Importance of seagrass as a carbon source for heterotrophic bacteria in a subtropical estuary (Florida Bay). *Estuaries, Coastal and Shelf Science*, 85: 507-514.

Xu, Y., R. Jaffe. (In Press). Occurrence, distribution and origin of C30 cyclobotryococenes in a subtropical wetland/estuarine ecosystem. *Chemosphere*

Yamashita, Y., L.J. Scinto, N. Maie, R. Jaffe. (In Press). Assessing the environmental dynamics of dissolved organic matter in an oligotrophic subtropical wetland by optical means. *Ecosystems*

B. Other Specific Products

Presentations at Professional Conferences

The FCE LTER Program has not generated any tangible economically-valuable products to date. However, we view the dissemination of our results at professional scientific conferences as a tangible intellectual product. FCE scientists and students have made 81 such presentations during the fourth year of FCE II.

We continue to dedicate FCE resources to provide travel support for FCE scientists, students, and educators to attend professional conferences. This is important for their professional development, but is also important as a mechanism for disseminating products of FCE LTER research. Disseminating this intellectual product is critical to helping guide the science of Everglades Restoration.

Data or databases

We have 429 FCE and historical Everglades datasets. Datasets include climate, consumer, primary production, water quality, soils, and microbial data as well as other types of data. An Oracle10g relational database has been designed to accommodate the diverse spatial and temporal heterogeneous core data and accompanying metadata submitted by the FCE researchers. Datasets are available for public download from the data section of the Florida Coastal Everglades LTER website at <http://fcelter.fiu.edu/data>.

The FCE IM team lends its expertise to site and network researchers when necessary by providing application support for its Excel2EML tool, available to the community via the FCE website (http://fcelter.fiu.edu/research/information_management/tools/).

C. Internet Dissemination

The url of the main FCE LTER Program website is <http://fcelter.fiu.edu>. Detailed discussion of FCE's data management and website management is available in Section IIAi ("Information management") of this report.

IV. CONTRIBUTIONS

A. Contributions within Discipline

Everglades Climate Change Drivers Workshop (FCE and SFWMD). Chris Moses (FCE, now at NOAA) organized a climate themed workshop on October 30, 2009. This workshop on past, present, and future climate change drivers that impact the Everglades was a joint effort between SFWMD and FCE-LTER. Various types and quality of climate data is available for the Everglades region, and numerous local area scientists are collecting and using data for thus-far relatively disconnected purposes. This workshop was intended as an opportunity to bring together experts from diverse scientific specialties in an effort to reduce the number of gaps in our understanding of past and present Everglades climate, and improve our ability to model the impacts of future climate scenarios. Attendees included individuals not only from FIU and the SFWMD, but also NOAA, NHC, and USGS.

LTER Hurricane Research Coordination Meeting (Gaiser et al.). FCE hosted the second LTER Hurricane Research Coordination Network meeting in Miami, Florida in December 2009, supported by a supplement award to the FCE and LUQ LTER. This meeting solidified 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 report at <http://lno.lternet.edu/merida>). Moreover, meeting participants continued to develop two manuscripts and met on subsequent occasions to prepare a proposal to the Research Coordination Network program, submitted in July 2010. They 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.

Gaiser coordinated a network science workshop with Alber (GCE) and Hopkinson (PIE) on “Understanding and Adapting to Climate Change in the Coastal Zone” where ecological and social scientists discussed a framework for a cross-site network of science focused on effects of sea-level rise in coastal areas.

Gaiser is a collaborator on an NSF Research Coordination Network grant for the Global Lakes Ecological Observatory Network. This is a grassroots network of limnologists, engineers and information specialists who aim to equip lakes and wetlands with high-resolution sensors and real-time global conveyance to evaluate large-scale patterns in ecological change in aquatic ecosystems. Participation in GLEON will facilitate future high-resolution sensor data collection and communication within the FCE LTER and a site at the head of the FCE watershed at Archbold Biological Station and in the southern Everglades (FCE sites TSPH6 & 7).

Roy Chowdhury, Rinku. 2010- Chair, Human Dimensions of Global Change (HDGC) Specialty Group, Association of American Geographers.

Ogden, Laura A., Executive Board, Anthropology and Environment Section, American Anthropological Association.

Dr. Price continues to serve as an Associate Editor of the journal Applied Geochemistry. She also reviews papers for hydrology focused journals such as: Hydrobiologia, Journal of Hydrology, Water Research, Journal of Hydrology, Hydrogeology Journal, and Water Resources Research. Furthermore, she has reviewed proposals for the Israel Science Foundation and the National Institute for Water Resources.

Dr. Joe Boyer continued his collaboration with Linda Amaral-Zettler at International Census of Marine Microbiology, (ICoMM) (icomm.mbl.edu), Marine Biological Laboratory. They received NSF funding to support massively-parallel, 454-based tag sequencing strategy that allows extensive sampling of marine microbial populations (PNAS 103: 32 p. 12115-12120). The strategy is based on sequencing of hypervariable regions of the SSU rRNA gene which 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 started this fall on aquatic component at 4 sites in FCE during wet and dry season.

B. Contributions to Other Disciplines

Dr. Price participated as a speaker at a public meeting on the Everglades National Park's Tamiami Trail Modifications: Next Steps Project. The Project includes a review of alternatives and actions related to increasing surface water flow across Tamiami Trail in an effort to restore hydrological and ecological conditions in ENP. Dr. Price spoke at the meeting held on June 24, 2010 as a hydrologist familiar with water issues related to ENP in favor of the Tamiami Trail modifications.

Dr. Rene Price participated in the following workshops:

- Indicators of Global Climate Change on Everglades Ecosystem meeting at SFWMD on Oct. 30, 2009;
- Biscayne Bay water Chemistry and modeling workshop sponsored by Biscayne Bay National Park and FIU, on January 14, 2010;
- Developing a Sea Level Rise Vulnerability Framework for South Florida: Indicators, Metrics and Models, sponsored by FIU, FAU and Miami-Dade County on June 2, 2010.

Dr. Colin Saunders is an ongoing participant in the design and initiation of field implementation of the Decentralization Physical Model (DPM). The DECOMP Physical Model (DPM) is a large-scale field test designed to address uncertainties associated with the Comprehensive Everglades Restoration Project (CERP) Water Conservation Area (WCA) 3 Decentralization and Sheet Flow Enhancement Project (DECOMP).

J.S. Rehage reviewed the *Scientific & Technical Knowledge Gained in Everglades Restoration (1999-2000)* document, a compilation of new scientific information relevant to Everglades restoration that has been gained in the 10 years since CERP was initiated.

J.S. Rehage contributed data & provided technical review to the *CERP 2009 System Status Report*, which provides a summary of system-wide monitoring and supporting research and assesses data biennially to establish pre-CERP reference conditions.

J.S. Rehage collaborated and provided data to ENP on the effects of the 2010 winter cold snap, which caused significant mortality of Everglades biota.

Joe Boyer attended the following meetings:

- CERP RECOVER Southern Coastal Systems meeting. Homestead – Aug. 26, 2009.
- EPA-FDEP Meeting on Water Quality Criteria Development. Tallahassee – Aug. 31, 2009.
- NOAA MARES Kick-off PI Meeting. Miami – Sep. 10, 2009.
- FKNMS Sanctuary Advisory Council Meeting. Ocean Reef – Oct. 20, 2009.
- Southeast Florida Coral Reef Initiative Technical Assessment Committee. Ft. Lauderdale – Nov. 12-13, 2009.
- Ecosystem Restoration Working Group of FKNMS SAC. Marathon – Jan 7, 2010.
- FDEP Numeric Nutrient Criteria meeting. Miami – Mar. 2-3, 2010.
- NOAA MARES Quantitative Ecosystem Indicators for Florida Keys/Dry Tortugas Meeting. Homestead – Mar. 22-23, 2010.
- Southern Association of Marine Laboratories. Gulf Breeze, FL – Apr. 12-14, 2010.
- FKNMS Sanctuary Advisory Committee Meeting. Marathon – Apr. 20, 2010.
- Southeast Florida Coral Reef Initiative Technical Assessment Committee. Ft. Lauderdale – May 6-7, 2010.
- South Florida Ecosystem Restoration Task Force, Science Coordination Group. Coral Springs, FL – May 26, 2010.
- Ecosystem Restoration Working Group of FKNMS SAC. Marathon – May 27, 2010.
- FIO Council Meeting, St. Petersburg, June 2, 2010.
- FKNMS Sanctuary Advisory Committee Meeting. Key West – June 15, 2010.
- FKNMS Water Quality Protection Plan Committee Meeting. Marathon – July 7, 2010.
- FKNMS Sanctuary Advisory Committee Meeting. Marathon – Aug 11, 2010.
- NOAA MARES Integrated Conceptual Ecosystem Model for SW Florida Coast Meeting. Ft. Meyers – Aug. 19-20, 2010.

Documents related to Everglades restoration:

Mc Voy C. and C.J. Saunders. June 2010. “1.1 Pre-drainage Hydrology of the Everglades” Pp.2-7 in *Scientific and technical knowledge gained in Everglades Restoration (1999-2009)*. RECOVER document (draft) 262 pages.

C. Contributions to Human Resource Development

Pre-Service and Professional Service Teacher Education

Key to working with pre-college students is providing the appropriate training for pre-service teachers and professional development to professional service teachers. 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.

Professional Service Teachers

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 and providing professional development to other pre- and professional service teachers.

In 2009-2010, Teresa Casal and Catherine Laroche continued working with FCE as RETs and remain an integral part of our Education and Outreach Program. This year's RET consisted of three components: field experience, curriculum development, and presentation of their products.

D. Contributions to Resources for Research and Education

This year, FCE RETs Teresa Casal and Catherine Laroche used their experiences with FCE to develop several types of highschool student curriculum. Working with graduate student Phil Match, Casal and Laroche trapped, tagged and released juvenile bull sharks. Casal kept a photographic log that was developed into a presentation and used to illustrate the scientific method and other standards within "The Nature of Science" components of Florida's Sunshine State Standards in Science. Upon revision, the lesson will be posted on the FCE Ed & Outreach webpage.

Casal continued working with our Data Manager to develop a new investigative module entitled "Wising Up About Water". The modules incorporate the downloading, use, and analysis of FCE datasets and will be posted to our website upon their final revision.

Catherine Laroche, is also working with our data manager and other FCE researchers to further modify "Coastlines" GIS lessons and incorporate FCE data and research themes. These lessons were also incorporated into professional development workshops through *Project RISE*, a five-year Department of Education grant awarded to Miami Dade County Public Schools (MDCPS) in order to improve student learning by improving teacher's instructional skills. Laroche, a National Board Certified Teacher (NBCT), has become a professional development trainer for Project RISE and the MDCPS Teacher Education Center (TEC) and delivered two professional development workshops: Project RISE – GIS Overview; and Project RISE – Designing GIS Lessons. A total of 80 teachers enrolled in these workshops and a core group of 5 teachers sustained an interest and are now developing their own lessons utilizing GIS technology and incorporating LTER data within their lessons.

In particular, lessons were developed for 9th grade earth and space science students to explore the effects of hurricanes on the Florida Everglades. These lessons involved plotting FCE datasets

into a *My World GIS* (a geospatial program developed by ESRI) project and analyzing the results for environmental impact on the Florida wetlands. Through these activities, 150 students were able to utilize GIS skills and learn from the results in FCE datasets.

Casal and Laroche also worked with Science Approach as participants and presenters for the second year of Coastlines at BES in the summer of 2010. Later they presented some of these results and experiences with Ali Whitmer and Steve Moore at the 2009 All Scientists' Meeting in Estes Park, CO in a talk entitled "CoastLines NSF iTEST Project: A model for integrating GIS-based inquiry learning into LTER education outreach." Teresa was also a co-presenter with Marcia Nation (CAP) and Nick Oehm in "Blogs, Posts, and Tweets: Potential uses of web-based and social networking media for communicating LTER science and conducting citizen science."

Based on their interdisciplinary graduate seminar on socio-ecological research methods, Ted Gragson (Coweeta), Laura Ogden (FCE), Morgan Grove (BES) and Chris Boone (CAP) organized a workshop for past participants in the distributed seminar "From Yarksticks to Gyroscopes: Interdisciplinary Methods for Socio-ecological Research" to develop web content for socio-ecological research methods. They are developing an e-textbook.

Hugh Gladwin, co-developed course entitled "Our Coastal Environment from the Bay to the World" for FIU's Global Learning objectives.

Jeff Onsted presented "Agricultural Land Use Change in Miami-Dade" as a guest lecturer to the Sustainable Agriculture Class at FIU (March, 2010). He also presented "Urban Ecology" as a guest lecturer for FIU's Environment and Society Class (September, 2009).

Catherine Laroche is working with high school teachers in developing GIS lessons using LTER datasets. She is also developing cross-curricular high school lessons that connect environmental studies of the Florida Coastal Everglades with the history and culture of the local Miccosukee Tribe of Indians.

Website

The FCE LTER website (<http://fcelter.fiu.edu/>) provides a variety of information, including data, educational activities, maps, project information, site information, publications, presentations, and photos. Visitors to the data section of our website downloaded 368 datasets from September 2009 through August 15, 2010.

E. Contributions Beyond Science and Engineering

Rehage, J.S., E. Gaiser, M. Heithaus, M. Ross & P. Ruiz. Effects of a rare cold snap on Everglades biota: what are the long-term consequences for the ecosystem? LTER Newsletter, Spring 2010 issue (LTER Newsletter 23-1; <http://www.lternet.edu/news/>).

V. REFERENCES

- Abtew, W., J. Obeysekera, M. Irizarry-Ortiz, D. Lyons, and A. Reardon. 2003. Evapotranspiration Estimation for South Florida. P. Bizier and P. A. DeBarry (eds.). Proceedings of the World Water and Environmental Resources Congress 2003, Symposium on Integrated Surface and Groundwater Modeling, ASCE Conference at Philadelphia, PA. Technical Paper No. EMA#407.
- Baggett, L.P., K.L. Heck Jr., T.A. Frankovich, A.R. Armitage, J.W. Fourqurean. 2010. Nutrient enrichment, grazer identity and their effects on epiphytic algal assemblages: field experiments in sub-tropical turtlegrass (*Thalassia testudinum*) meadows. *Marine Ecology Progress Series*, 406: 33-45.
- Berger, U., Rivera-Monroy, V.H., Doyle, T.W., et al. 2008. Advances and limitations of individual-based models to analyze and predict dynamics of mangrove forests: A review. *Aquatic Botany*, 89, 260-274.
- Briceno, H.O., J.N. Boyer. 2009. Climatic Controls on Phytoplankton Biomass in a Sub-tropical Estuary, Florida Bay, USA. *Estuaries and Coasts*, DOI:10.1007/s12237-009-9189-1.
- Childers, D.L., D. Iwaniec, D. Rondeau, G.A. Rubio, E. Verdon, C.J. Madden. 2006. Responses of sawgrass and spikerush to variation in hydrologic drivers and salinity in southern Everglades marshes. *Hydrobiologia*, 569(1): 273-292.
- Coronado-Molina, C., J.W. Day Jr., E. Reyes, B.C. Perez. 2004. Standing crop and aboveground biomass partitioning of a dwarf mangrove forest in Taylor River Slough, Florida. *Wetland Ecology and Management*, 12: 157-164.
- Dai, A., K. E. Trenberth, and T. Qian, 2004. A global data set of Palmer Drought Severity Index for 1870-2002: Relationship with soil moisture and effects of surface warming. *J. Hydrometeorology*, 5, 1117-1130.
- Donders, T.H., F. Wagner, D.L. Dilcher, H. Visscher. (2005b) Mid- to late-Holocene El Niño—Southern Oscillation dynamics reflected in the subtropical terrestrial realm. *Proc Natl Acad Sci USA* 102:10904–10908.
- Fourqurean, J.W., M.F. Muth, J.N. Boyer. 2010. Epiphyte loads on seagrasses and microphytobenthos abundance are not reliable indicators of nutrient availability in coastal ecosystems. *Marine Pollution Bulletin*, 60: 971-983.
- Frankovich, T.A., A.R. Armitage, A. Wachnicka, E.E. Gaiser, J.W. Fourqurean. 2009. Nutrient effects on seagrass epiphyte community structure in Florida Bay. *Journal of Phycology*, 45: 1010-1020.

- Frankovich, T.A., E.E. Gaiser, J.C. Zieman, A. Wachnicka. 2006. Spatial and temporal distributions of epiphytic diatoms growing on *Thalassia testudinum* Banks ex König: Relationships to water quality. *Hydrobiologia*, 569(1): 259-271.
- Gaiser, E., R. Bachmann, L. Battoe, N. Deyrup and H. Swain. 2009a. Effects of climate variability on transparency and thermal structure in subtropical, monomictic Lake Annie, Florida. *Fundamental and Applied Limnology*. 175: 217-230.
- Gaiser, E., N. Deyrup, R. Bachmann, L. Battoe, and H. Swain. 2009b. Multidecadal climate oscillations detected in a transparency record from a subtropical Florida lake. *Limnology and Oceanography*. 54: 2228–2232.
- Gaiser, E.E., J.H. Richards, J.C. Trexler, R.D. Jones, D.L. Childers. 2006. Periphyton responses to eutrophication in the Florida Everglades: Cross-system patterns of structural and compositional change. *Limnology and Oceanography*, 51(1): 617-630.
- Gaiser, E.E., J.C. Trexler, J.H. Richards, D.L. Childers, D. Lee, A.L. Edwards, L.J. Scinto, K. Jayachandran, G.B. Noe, R.D. Jones. 2005. Cascading ecological effects of low-level phosphorus enrichment in the Florida Everglades. *Journal of Environmental Quality*, 34(2): 717-723.
- German, E.R. (2000). Regional Evaluation of Evapotranspiration in the Everglades. USGS. Water-Resources Investigations Report 00-4217, Tallahassee, FL. No. 4217, 48p.
- Hagerthey, S.E., B.J. Bellinger, K. Wheeler, M. Gantar, E.E. Gaiser. (In Press). Everglades periphyton: A biogeochemical perspective. *Critical Reviews in Environmental Science and Technology*
- Healy, R.W., and A.D. Ronan. 1996. Documentation of Computer Program VS2DH for Simulation of Energy Transport in Variably Saturated Porous Media – Modification of the U.S. Geological Survey’s computer program VS2DT. U.S. Geological Survey Water-Resources Investigations Report 96-4230. U.S. Government Printing Office, Washington, D.C.
- Henry, J.A., Portier, K.M. and Coyne, J., 1994. The climate and weather of Florida. Pineapple Press, Inc., Sarasota, FL, 279 pp.
- Hsieh, P.A., W. Wingle, and R.W. Healy. 2000. VS2DI – A Graphical Software Package for Simulating Fluid Flow and Solute or Energy Transport Through Variably Saturated Porous Media. U.S. Geological Survey Water-Resources Investigations Report 99-4130. U.S. Government Printing Office, Washington, D.C.
- Haug, G. H., K. A. Hughen, D. M. Sigman, L. C. Peterson, and U. Rohl. 2001. Southward migration of the Intertropical Convergence Zone through the Holocene. *Science* 293:1304-1308.

- Iwaniec, D., D.L. Childers, D. Rondeau, C.J. Madden, C.J. Saunders. 2006. Effects of hydrologic and water quality drivers on periphyton dynamics in the southern Everglades. *Hydrobiologia*, 569(1): 223-235.
- Jopp, F., D. L. DeAngelis, J. C. Trexler. 2010. Modeling seasonal dynamics of small fish cohorts in fluctuating freshwater marsh landscapes. *Landscape Ecology* 25:1041-1054.
- Moses, C.S., Anderson, W.T., Saunders., C., and Sklar, F., in review, Regional to local gradients in precipitation and temperature in response to climate teleconnections in the Greater Everglades system of South Florida: JGR – Biogeosciences.
- Munyon, Jay. 2010. The Effects of Hydrology and Phosphorus on Everglades Productivity. Master's thesis, Florida International University.
- Pielke, R.A., 1974. A comparison of three-dimensional and two-dimensional numerical predictions of sea breezes. *J. Atmos. Sci.*, 31: 1577-1585.
- Quillen, Amanda Kay. 2009. Diatom-Based Paleolimnological Reconstruction of Quaternary Environments in a Florida Sinkhole Lake. Ph.D. dissertation, Florida International University.
- Rietkerk, M., S. C. Dekker, P. C. de Ruiter, and J. van de Koppel. 2004. Self-Organized Patchiness and Catastrophic Shifts in Ecosystems, *Science* **305** (5692), 1926. [DOI: 10.1126/science.1101867].
- Rodbell, D. T., G.O. Selzer, D.M. Anderson, M.B. Abbott, D.B. Enfield, J.H. Newman. 1999. An ~15,000-Year Record of El Niño-Driven Alluviation in Southwestern Ecuador. *Science* 283: 516-520.
- Roth, S. and J. J. G. Reijmer. 2005. Holocene millennial to centennial carbonate cyclicity recorded in slope sediments of the Great Bahama Bank and its climatic implications. *Sedimentology* 52:161-181.
- Skinner, C., F. Bloetscher, C.S. Pathak. 2009. Comparison of NEXRAD and Rain Gauge Precipitation Measurements in South Florida. *Journal of Hydrologic Engineering*, 14(3):248.
- Sternberg, L.D.L., Teh, S.Y., Ewe, S.M.L, Wilhelm, F.M., DeAngelis, D.L. 2007. Competition between hardwood hammocks and mangroves. *Ecosystems*, 10, 648-660.
- Teh, S.Y., DeAngelis, D.L., Sternberg, L. et al. 2008. A simulation model for projecting changes in salinity concentrations and species dominance in the coastal margin habitats of the Everglades. *Ecological modelling*, 213, 245-256.

- Wachnicka, A. and E. Gaiser. In Press. Autecology and distribution of diatoms in Biscayne Bay, Florida: implications for biomonitoring and paleoenvironmental studies. *Ecological Indicators*.
- Wachnicka, A., E. Gaiser, L. Collins, T. Frankovich and J. Boyer. 2010. Distribution of diatoms and development of diatom-based inferences of environmental change in Florida Bay and adjacent coastal wetlands of South Florida. *Estuaries and Coasts*. DOI: [10.1007/s12237-010-9283-4](https://doi.org/10.1007/s12237-010-9283-4)
- Willard, D. A., C. W. Holmes, and L. M. Weimer. 2001. The Florida Everglades ecosystem: climatic and anthropogenic impacts over the last two millennia. Pages 41-55 in B. R. Wardlaw, editor. *Bulletins of American Paleontology*