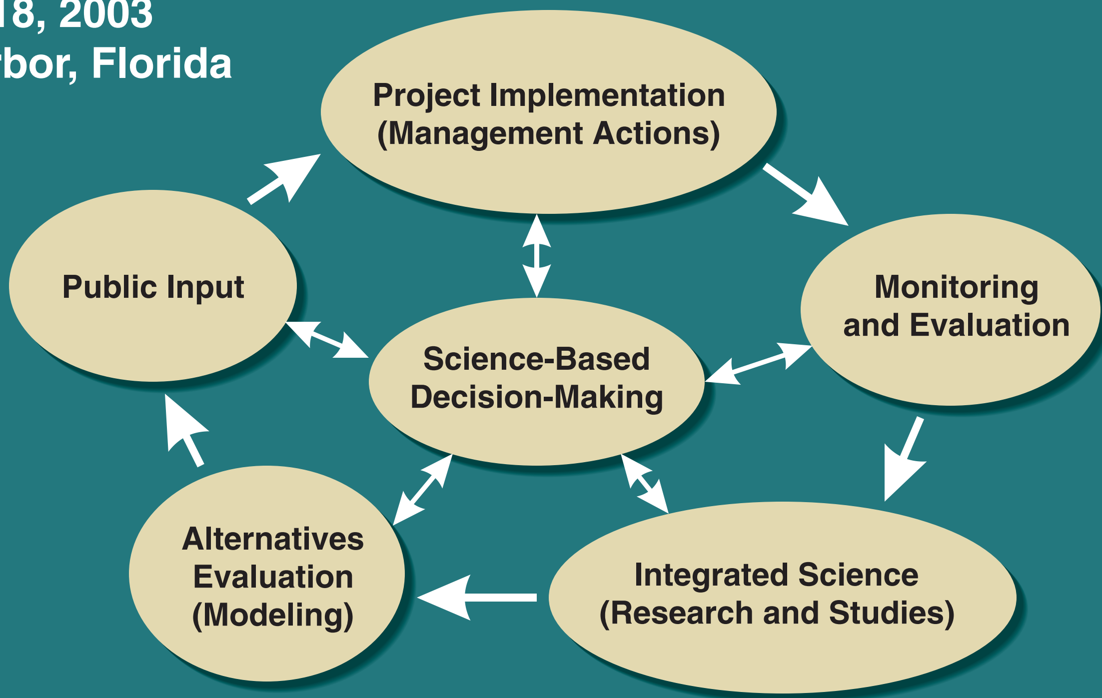
U.S. Geological Survey Greater Everglades Science Program: 2002 Biennial Report

Including USGS abstracts of presentations made at the Joint Science Conference* on Florida Bay and Greater Everglades Ecosystem Restoration (GEER) – "From Kissimmee to the Keys"

April 13-18, 2003
Palm Harbor, Florida



Open-File Report 03-54
U.S. GEOLOGICAL SURVEY

*Science Conference hosted by:
The Science Coordination Team
a committee of the
SOUTH FLORIDA ECOSYSTEM RESTORATION TASK FORCE AND WORKING GROUP

Collaborators (Federal, State, Local and Tribal Agencies):

- Florida Department of Environmental Protection
- Florida Fish and Wildlife Conservation Commission, Eustis, FL
- Florida Marine Research Institute, St. Petersburg, FL
- National Marine Fisheries
- National Marine Sanctuary
- National Park Service
- National Resource Conservation Service
- National Oceanic and Atmospheric Administration
- National Water Research Institute, Environment Canada, Burlington, ONT, Canada
- Netherlands Institute of Ecology
- NOAA Fisheries, Southeast Fisheries Science Center, Miami, FL
- NOAA Fisheries, Estuarine Habitats and Coastal Fisheries Center, Lafayette, LA
- NOAA, NCCOS, Center for Coastal Fisheries and Habitat Research, Beaufort, NC
- Seminole Tribe of Florida
- South Florida Water Management District
- U.S. Army Corps of Engineers
- U.S.D.A. Forest Service, Southern Research Station, Pineville, LA
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service

Collaborators (Universities):

- Annis Water Resources Institute, Muskegon, MI
- Carleton University, Ottawa, Ontario, Canada
- Duke University, Durham, NC
- Florida Cooperative Fish and Wildlife Research Unit, University of Florida, Gainesville, FL
- Florida International University, Miami, FL
- Florida State University, Tallahassee, FL
- Nicholas School of the Environment Marine Laboratory, Beaufort, NC
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- University of California, Department of Ecology, Evolution and Marine Biology
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- University of Guelph, Guelph
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- Washington University, St. Louis, MO
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- Yale University, New Haven, CT

Photographs:

Photographs and images used in this report are from studies performed by the U.S. Geological Survey, Greater Everglades Science Program.

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Compiled by Arturo E. Torres, Aaron L. Higer, Heather S. Henkel, Patsy R. Mixson, Jane R. Eggleston, Teresa L. Embry, and Gail Clement

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Coordinator

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Tallahassee, Florida
2003

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
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U.S. Geological Survey Greater Everglades Science Program: 2002 Biennial Report

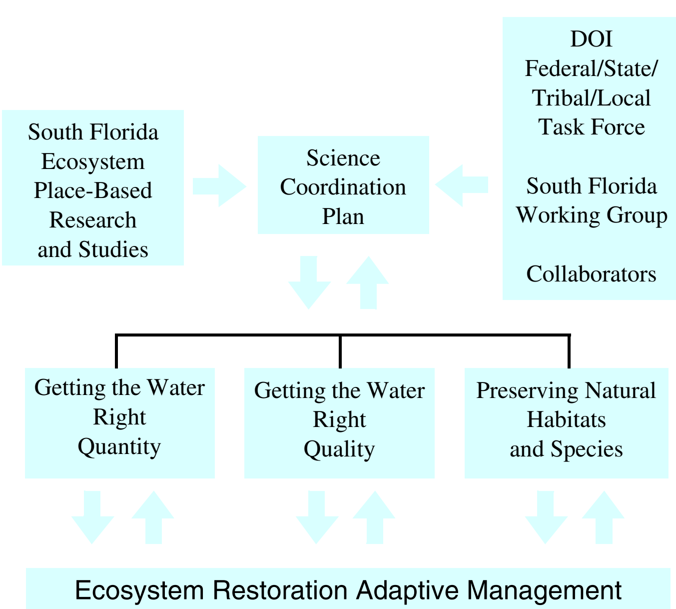
Introduction

The U.S. Geological Survey (USGS) conducts scientific investigations in south Florida to improve society's understanding of the environment and assist in the sustainable use, protection, and restoration of the Everglades and other ecosystems within the region. The investigations summarized in this document have been carried out under the Greater Everglades Science Program (previously known as the South Florida Ecosystem Program), which is part of the USGS Place-Based Studies initiative.

The USGS Placed-Based Studies initiative is a nationwide program that concentrates on areas with severe environmental problems. Through interdisciplinary investigations the Program provides sound scientific information on which to base informed resource management decisions. Individuals from all the USGS programs (hydrology, geology, biology, mapping) work together with other scientists to cover the diverse scientific disciplines involved in this complex and challenging task. The Greater Everglades Science Program began in 1995 as one of the initial Place-Based Studies programs and serves as a model for similar future collaborative studies. Placed-Based Studies are also being conducted in the San Francisco Bay area, Chesapeake Bay, the Platte River, Greater Yellowstone, Salton Sea, and the Mojave Desert.

The South Florida Ecosystem Program is part of a coordinated federal effort, under the South Florida Ecosystem Restoration Task Force. The Task Force was started in 1993, through interagency agreement, to coordinate the efforts of the agencies within six federal departments. In 1996, statutory authority formalized the Task Force and expanded it to include tribal, state, and local governments. The Task Force conducts its activities through the South Florida Ecosystem Working Group and teams, such as the Science Coordination Team. A Science Plan and Integrated Financial Plans are established to focus efforts and prevent duplicative efforts by the agencies.

Diagram of Greater Everglades Science Program Place-Based Study Relations



Organization and Content of the Document

This document presents the results of over 60 studies and 200 investigators that are active in the USGS Greater Everglades Science Program during the year 2003. The studies are categorized according to the major focuses of the South Florida Ecosystem Restoration Task Force.

Getting the Water Quantity Right – establishing the volume, quantity, timing and distribution of surface and ground waters to approximate pre-development conditions.

Getting the Water Quality Right – reducing or eliminating pollutants and other undesirable substances from the water.

Preserving Natural Habitats and Species – providing the needs of the diverse flora and fauna of this ecologically unique area

Information Availability – exchanging information regarding programs, projects, and activities to promote ecosystem restoration and maintenance - through South Florida Information Access (SOFIA)

This document also includes a bibliography of reports either published or in press, from the Greater Everglades Science Program Place-Based Study initiative.

Restoring the Nation's Greater Everglades Ecosystem

Restoring the Everglades is an enormous challenge, that involves returning essential functions to a large (over 11,000 square miles) and diverse ecosystem that has had significant adverse impacts from man's activities over the past 50 years. America's Everglades is a National treasure which must be restored to ensure that south Florida's unique and irreplaceable natural environment is preserved, assure the quantity and quality of drinking water as well as agricultural and industrial water supplies, and in general improve the quality of life for all south Florida's inhabitants.

The Comprehensive Everglades Restoration Plan (CERP) was developed over a period of six years by the U.S. Army Corps of Engineers in partnership with the South Florida Water Management District and more than 30 tribal, federal, state and local agencies. It is the primary planning vehicle for achieving the goal of improving the quantity, quality, timing and distribution of water that will return health to this seriously degraded system. CERP proposes costs in excess of $7.8 billion and a time frame of about 30 years to complete this massive and unprecedented restoration effort.

Both the U.S. Government and the State of Florida have made initial funding commitments for Greater Everglades ecosystem restoration.

The complexity of this undertaking and the magnitude of the risks involved in an undertaking that includes some 68 interrelated engineering projects and feasibility studies mandates a science-based approach to implementation of CERP. The USGS, through its Greater Everglades Science Program Place Based Studies initiative, has committed to providing the highest level of scientific expertise to support decision-making and ensure a successful restoration of the Greater Everglades and adjacent coastal ecosystems.

USGS Role in South Florida Ecosystem Restoration

In keeping with the mission of the USGS to provide the Nation with reliable, impartial information to describe and understand the Earth, the USGS is involved in biologic, geologic, hydrologic, land use, mapping and topographic studies that contribute to the safety, health, and well-being of Florida's citizens. The work conducted encompasses basic data collection, hydrological and ecological modeling, and experimental research and monitoring. The USGS is capable of conducting multidisciplinary work due to the availability of expertise in geologic, biologic, mapping, and water resources investigations. Expertise is available nationally and can be called upon as needed for complex investigations, training of local personnel, and development of new approaches and technology to address the complex science issues involved in ecosystem restoration.

As the Department of the Interior's science agency with a multi-disciplinary, non-regulatory, and non-advocacy focus, as well as an established, long-term presence in south Florida, the USGS is well positioned to pursue baseline and monitoring activities such as data collection from surface- and ground-water monitoring networks, cooperative studies with local and State agencies, and research through extensive national programs such as Place-Based Studies, Global Change Research, National Water Quality Assessment program (NAWQA), and other national research programs. In addition, about one half of the area to be restored is public land administered by the National Park Service (NPS), Fish and Wildlife Service (FWS), state agencies, and the South Florida Water Management District (SFWMD). The U.S. Geological Survey science leadership in the South Florida Ecosystem Restoration Task Force's Working Group and Science Coordination Team, CERP, and other ecosystem restoration efforts in south Florida is closely linked to its mission goal "to provide science for a changing world in response to present and anticipated needs; to expand our understanding of environmental and natural resource issues on regional, national, and global scales; and to enhance predictive/forecast modeling capabilities." The multidisciplinary approach applied by the USGS is necessary to provide a process level as well as holistic ecosystem-level evaluation of system responses to proposed restoration alternatives and plans.

Historically, the USGS in Florida has operated basic data collection networks and conducted investigations that provide the foundation for the wise stewardship of water and biological resources of the State. The hydrogeologic framework has been described in many reports, aquifer characteristics have been determined through geophysical logging and pumping tests, and ecological conditions have been monitored. The data that have been collected for the advancement of general knowledge of our natural resources provide the foundation for the understanding of the fate of contaminants in the environment. The data also have been used in the development of hydrologic and ecological models for predicting the effects of additional stresses on the natural resources and provide the tools for evaluation of effects of land use changes and potential contaminant releases in the environment. Real-time data networks, which include the application of satellite or cellular telephone technology to existing data-collection sites across the State, are providing needed information for advanced warning of floods and droughts.

Building Scientific Knowledge

Develop new information – Identify the pertinent issues, formulate critical scientific questions related to the issues, and address the questions through appropriate modeling, monitoring and empirical studies.

Communicate – Promote improved communication among restoration scientists and managers through scientific conferences, workshops and the mutual exchange of information.

Synthesize Scientific Knowledge Relevant to the Issues – Develop techniques for integrating and synthesizing restoration data and distribute the techniques to others involved in restoration efforts.

Manage Integrated Data – Archive inventories and other available databases in multigovernmental database management systems that are accessible through the internet and updated regularly.

Acknowledgements

The USGS's Greater Everglades Science Program Place-Based Studies initiative is supported by several USGS national research programs including: biological research and monitoring; earth surface dynamics; geographic research and application; ground-water resources; hydrologic network and analysis; hydrologic research and development; and toxic substances hydrology. Although most studies included in this 2002 biennial report are supported through the Greater Everglades Place-Based Studies initiative, some studies were supported by additional funding provided by the Department of Interior's Critical Ecosystem Studies Initiative (CESI) administered by the National Park Service through Everglades National Park, the U.S. Army Corps of Engineers, the South Florida Water Management District, the Seminole Tribe, and others.

Summary of Greater Everglades Ecosystem Restoration Workshop: Introduction

The Workshops

During April and May 2002, the United States Geological Survey's (USGS) Greater Everglades Place Based Studies (PBS) held five information workshops in south Florida to discuss status of greater Everglades ecosystem research, and to solicit suggestions for additional studies from greater Everglades restoration partners. These USGS Workshops included: 1.Paleoecology and Ecosystem History, April 29, 2002; 2. Hydrologic Modeling and Processes, May 7-8, 2002; 3. Ecological Modeling and Processes, May 9-10, 2002; 4. Landscape Mapping and Topography, May 23, 2002; and 5. Contaminants and Biogeochemistry, May 29, 2002.

Background

The greater Everglades restoration program is prescribing ecosystem-wide changes to some of the physical, hydrological, and chemical components of this ecosystem. The ability to accurately understand natural (prior to significant human alteration) conditions within the greater Everglades ecosystem is crucial for success of greater Everglades ecosystem restoration and successful implementation of the Comprehensive Everglades Restoration Plan (CERP). Information on the historical and current natural system allows restoration planners to establish realistic baseline conditions, restoration goals, and performance measures; create predictive models; and monitor success of restoration efforts. Understanding past conditions and cycles of change also allows for better-informed planning, project implementation, and land management decisions.

Many organizations and programs are dependent on scientific knowledge and more accurate models for restoring the greater Everglades ecosystem. These include federal, state, and local agencies, Native American tribal governments, as well as private organizations.

Research Needs

Research needs, including those directly related to ecosystem history and those relevant to other research topics, were compiled during the workshop based on discussions among the represented organizations and individuals having interests and roles within greater Everglades restoration.

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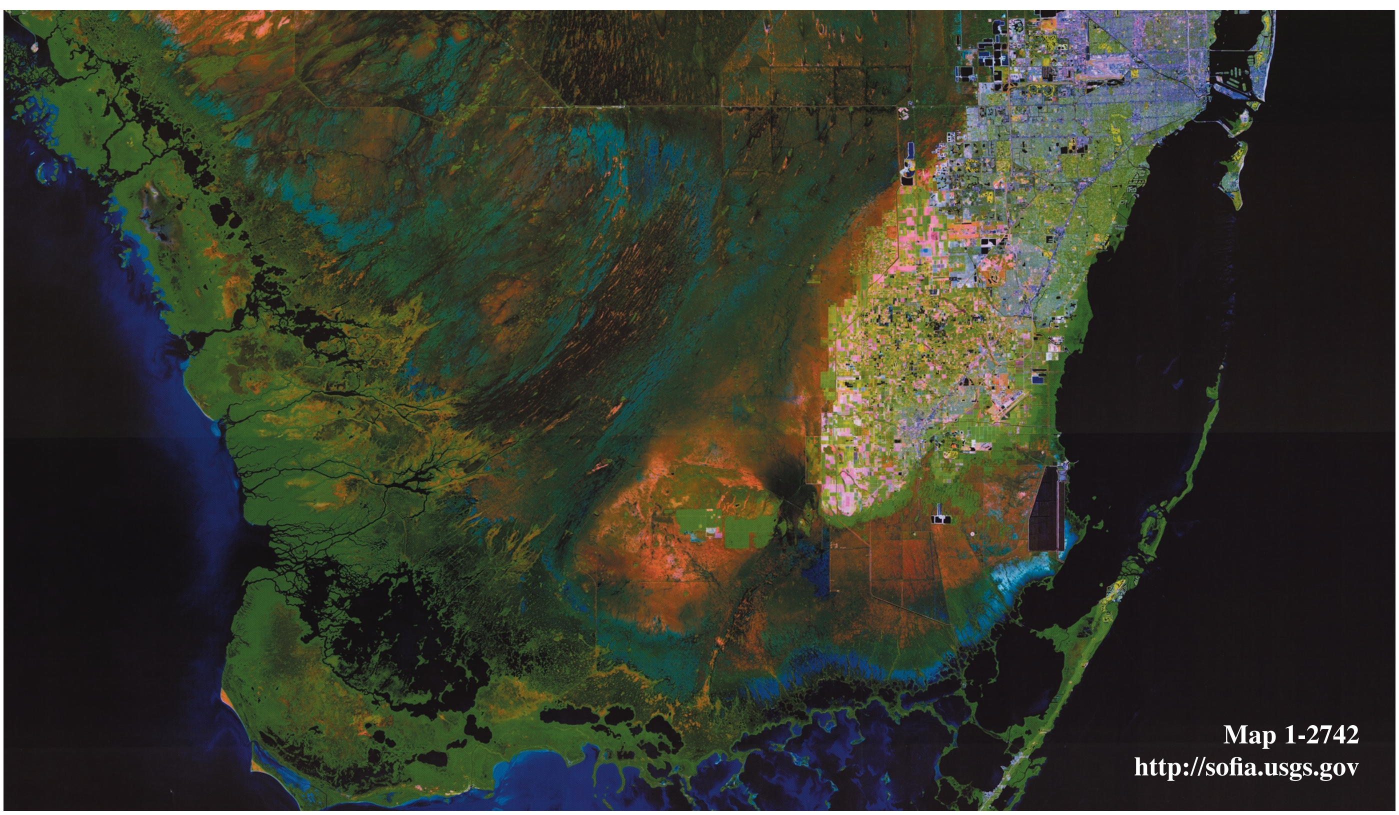

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Summary of Greater Everglades Ecosystem Restoration Workshop: 1. Paleoecology and Ecosystem History, April 29, 2002

Paleoecology and Ecosystem History Research Needs

Expand paleoecological sediment analyses to include: Biscayne Bay; Card Sound; transects that include sawgrass ridges, sloughs, and tree islands; southwest coast of Florida; the eastern boundary of Everglades National Park and adjacent agricultural areas; and Estero Bay tributaries.

Compare current versus historical ecologic aspects of: Biscayne Bay, Barnes and Card Sounds, marl prairies, location of ridge and slough landscape; freshwater inputs to Biscayne Bay; and Florida Bay nutrient inputs.

Determine historic trophic conditions within the Everglades.

Compare historical ecological conditions north and south of Tamiami Trail.

Determine impact on coral reefs due to changes in natural hydrology of the Everglades.

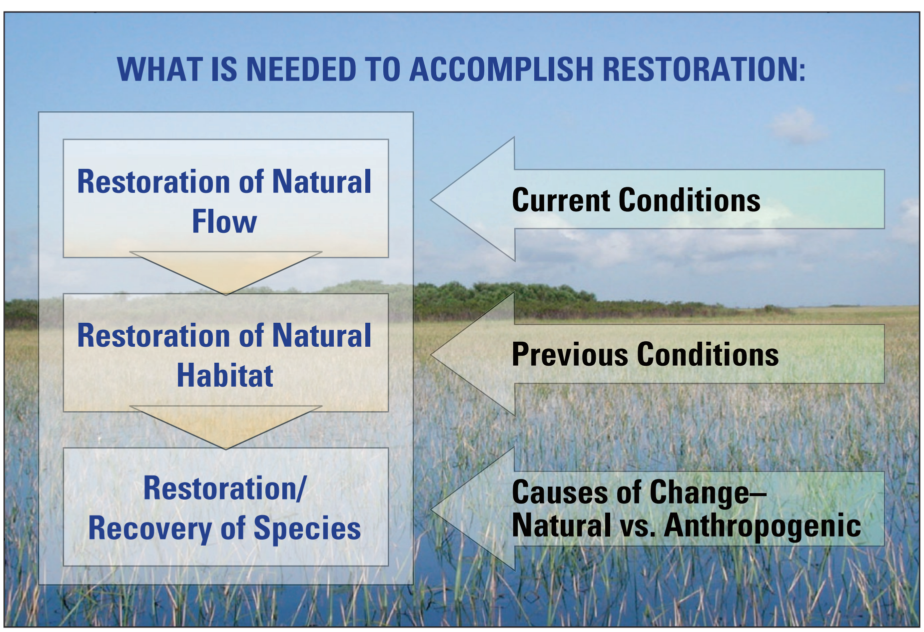
Determine the origin of long-term salinity variation in Florida Bay (e.g., climate, runoff, groundwater).

Present paleoecology data within the context of the Natural System Model (NSM) when applicable.

When presenting ecological models and their components, and paleoecological analyses of sediment cores, include associated levels of certainty.

Determine rates of sea level rise during the past several decades; use these data to forecast future rates, which can be incorporated into CERP implementation.

Document historical events and cyclic meteorological phenomena (e.g., hurricanes, el niño, la niña) and incorporate these within forecasting models.



What can ecosystem history studies tell us?

About the terrestrial Everglades . . .

Hydroperiod and water depth
- Pre-drainage conditions
- Natural spatial and temporal variability

Tree Islands
- Geologic and hydrologic requirements
- Historical patterns of change
- Longevity and stability
- Response to hydrologic changes

Ridge and Slough systems

Fire History and Water Depth

Water Quality

About the estuaries. . .

Salinity
- Historical range of salinity
- Natural seasonal variation
- Timing and delivery of freshwater

Water Quality

Seagrass
- Understanding the causes of die-offs
- Historical patterns of change

Biodiversity

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Research Needs Relevant to Other Workshops Topics

Bathymetric data for southwest Florida and Biscayne Bay.

Create a Florida Bay circulation model/bathymetry for the year 2100 that considers sea level rise.

Model changes in precipitation that could occur due to CERP implementation.

Expand current ecological modeling efforts into southwest Florida.

Determine water levels and flows that allow both tree islands and the ridge and slough landscapes to exist.

Create estuarine/freshwater models for southwest Florida.

Determine the role of nutrients recycling versus introduced nutrients on coastal ecosystems.

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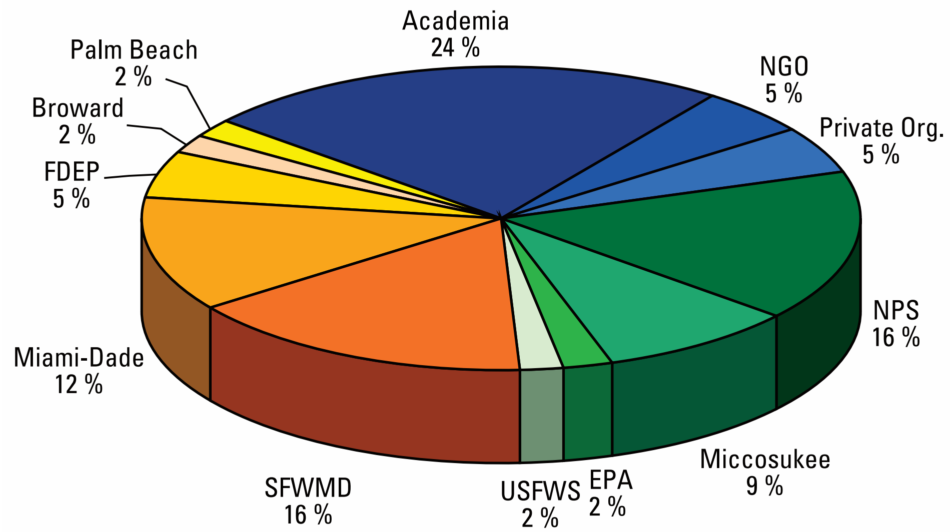

Participation by greater Everglades restoration partners during the 65-person Paleoecology and Ecosystem History Workshop (excluding USGS participants).

Summary of Greater Everglades Ecosystem Restoration
2. Hydrologic Modeling and Processes, May 7-8, 2002

Hydrologic Modeling Research Needs

Enhance connectivity between SFWMM (South Florida Water Management Model) and Southern Inland and Coastal System (SICS) and Tides and Inflows in Mangroves of the Everglades (TIME) models.

Develop internet-accessible SICS and TIME model real-time animations.

Collect TIME equivalent data from outside of TIME model domain.

Develop additional salinity simulation capability to support Across Trophic Level System Simulation (ATLSS)
program for developing estuarine species models.

Expand boundaries of SICS and TIME models to the entire CERP project area including areas east of US 1.

Incorporate solute-transport and simple settling algorithms in regional models to assist in setting CERP water quality performance measures.

Model CERP implementation impacts on transport of nutrients within the Everglades.

Incorporate seepage effects associated with the eastern boundary of the Everglades within all applicable models.

Complete additional work to couple water quality and hydrologic monitoring data with SICS and TIME models.

Measuring flow velocity in Taylor Slough wetlands to develop a simulation model. {Photo by Eric Swain, 1997.}

Increase spatial resolution of surface water and groundwater elevation and salinity monitoring.

Improve discharge and recharge estimates associated with stormwater treatment areas.

Increase spatial extent of monitoring of flow structure in wetlands to assess flow impacts on landscapes and habitat, including tree islands.

Conduct additional studies on the hydraulic properties of the surficial aquifer system including the overlying peat and marl unit.

Collect additional information on Floridian Aquifer hydrogeology.

Develop additional models and model inputs for the southwest coast of Florida.

Develop stochastic methods for generating rainfall input data needed for applicable models.

Improve understanding of groundwater solute transport and upwelling (such as sulfates), and subsequent surface water mixing in central Everglades, particularly WCA-3A south of Alligator Alley.

Create probabilistic/stochastic approaches to better define trends and certainties within models.

Incorporate climate-change variables into model simulations.

Research Needs Relevant to Other Workshops Topics

Complete USGS Aerial Height Finder (AHF) topographic survey in Everglades National Park, Loxahatchee, Big Cypress and Water Conservation Areas.

Map and delineate unique landscape features such as tree islands and hammocks using AHF system.

Establish NAVD88 control along the southwest Gulf coast in Everglades National Park.

Conduct bathymetric surveys of tidal rivers and creeks along the southwest coast of Florida.

Create a centralized ecosystem data repository system.

Gather reliable farm elevation/ topographic information at appropriate resolution.

Use multi-agency collaboration to address data quality issues.

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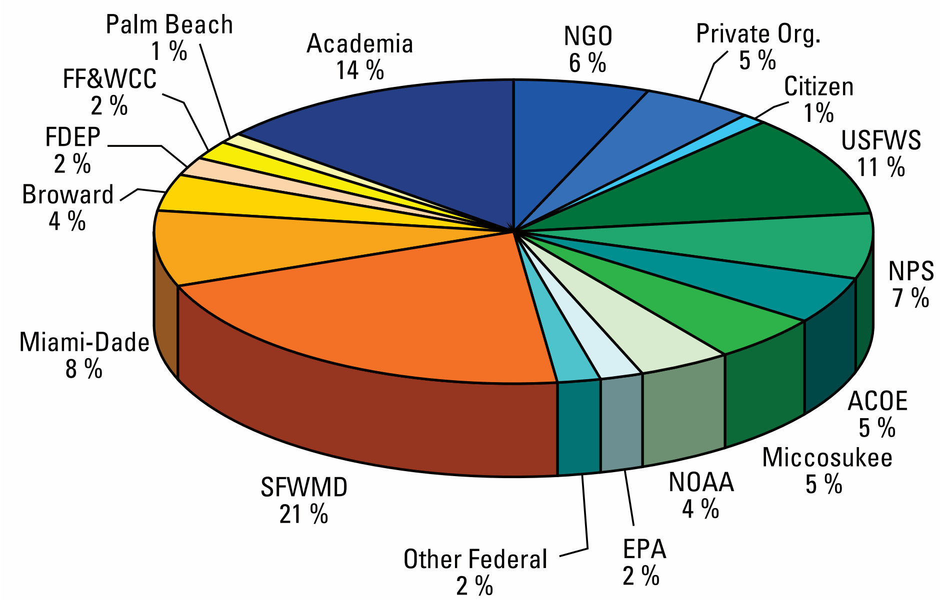

Participation by greater Everglades restoration partners during the 85-person Hydrologic Modeling Workshop (excluding USGS participants).

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Summary of Greater Everglades Ecosystem Restoration
3. Ecological Modeling and Processes, May 9-10, 2002

Ecological Modeling and Processes Research Needs

Develop spatially explicit species index (SESI) models for southwest Florida indicator species (i.e., wading birds, manatees, seagrasses, oysters, red cockaded woodpeckers, panthers, amphibians, and/or others) to assist in establishing restoration targets.

Incorporate fire impacts into SESI models.

Extend vegetation, landscape, and mangrove models into southwest Florida.

Develop an estuarine model that can be integrated with a hydrologic model that predicts seagrasses, oysters, fish populations, and crab populations based on surface-water management.

Create a fish migration/spawning model for major tributaries, such as the Caloosahatchee River and tributaries in the Ten Thousand Islands.

Develop freshwater amphibian, reptile, insect, and forage fish models to predict success of restoration efforts in short hydroperiod wetlands (i.e., seasonal marshes/pine flatwoods complexes, wet prairies, hydric pine and mixed/pine/cypress systems).

Wet prairie communities appear to be extremely important in providing prey organisms for higher trophic level animals. Research efforts should closely examine hydrology, fire, nutrient loading, and effects of exotic species on the dynamics of wet prairies.

Model patterns of saltwater- versus freshwater-wetlands use by wading birds, with special emphasis on wood storks and roseate spoonbills.

Create user-friendly predictive tools for evaluating effects of floods and droughts on availability of habitat for wading birds, snail kites, and other indicator species.

Integrate model results into tools that match analyses with specific decision-making objectives and tools that guide conflict resolution among multiple objectives.

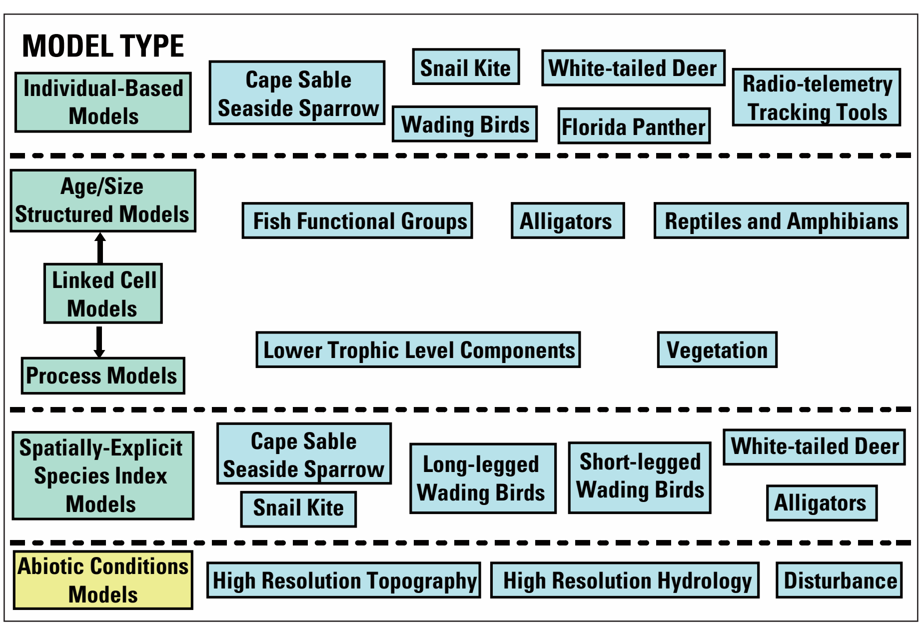
Ensure capability to run ATLSS ecological models using the Natural Systems Model (NSM). Plus, couple ATLSS models with evolution of the NSM and the South Florida Water Management Model (SFWMM) to ensure long-term compatibility. Develop comparable/repeatable protocols for monitoring status and trends in amphibians and reptiles, migratory birds, and wading birds (i.e., link modeling and monitoring).

Draft additional documentation for ecological models that includes: parameter certainty, appropriate model use, description of model input sources, and model logic.

Evaluate historical water quality, water quantity, and fire on current vegetation patterns with recommendations for future water and fire management.

Create user-friendly predictive models for evaluating effect of floods, droughts and different control strategies on exotic plant proliferation (specifically, *Lygodium* and *Melaleuca*).

Study changes in manatee behavior and critical habitat based on surface



Across Trophic Level System Simulation (ATLSS) Structure water input through canals and natural habitat restoration.

Determine conditions under which (model variables) sawgrass out-competes cattails.
Include species-specific pesticide sensitivity within models.

Continue Florida panther monitoring at historical levels (i.e., collaring all captured cats).

Investigate and model *Lygodium* control mechanisms.

Research Needs Relevant to Other Workshops Topics

Develop a tool to establish estuarine flow targets.

Extend existing coastal models (i.e. SICS and TIME) east of Route 1 to cooling canals at Turkey Point.

Collect additional topographic and bathymetric data.

Collect topographic data with higher spatial resolution for unique and/or critical habitat.

Create updated land cover data using classes predetermined to be compatible with ecological modeling classification schemes.

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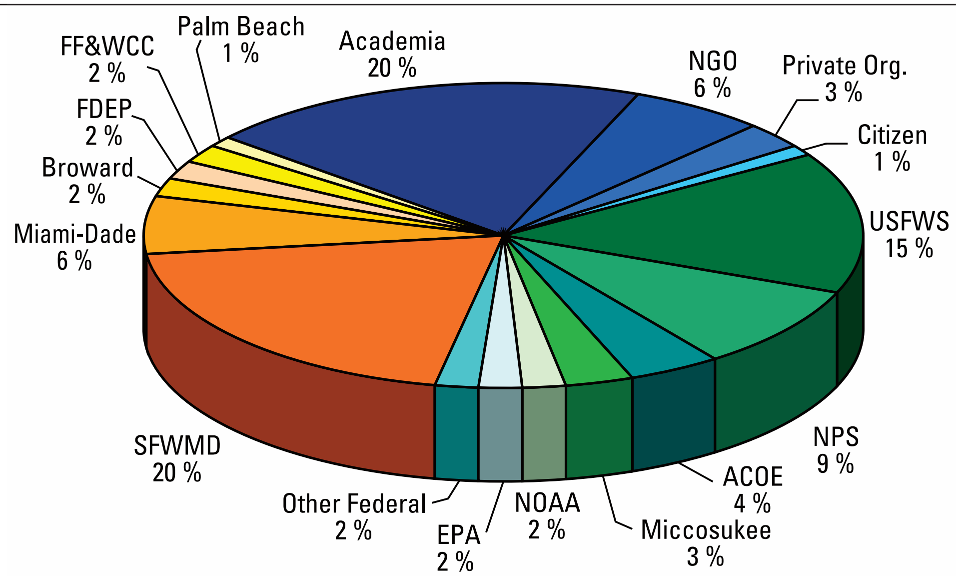


Participation by greater Everglades restoration partners during the 91-person Ecological Modeling Workshop (excluding USGS participants).

Summary of Greater Everglades Ecosystem Restoration
4. Landscape Mapping and Topography, May 23, 2002

Landscape Mapping Research Needs

Expand the coverage of digital and hard copy satellite image maps like those created for the Southern Everglades.

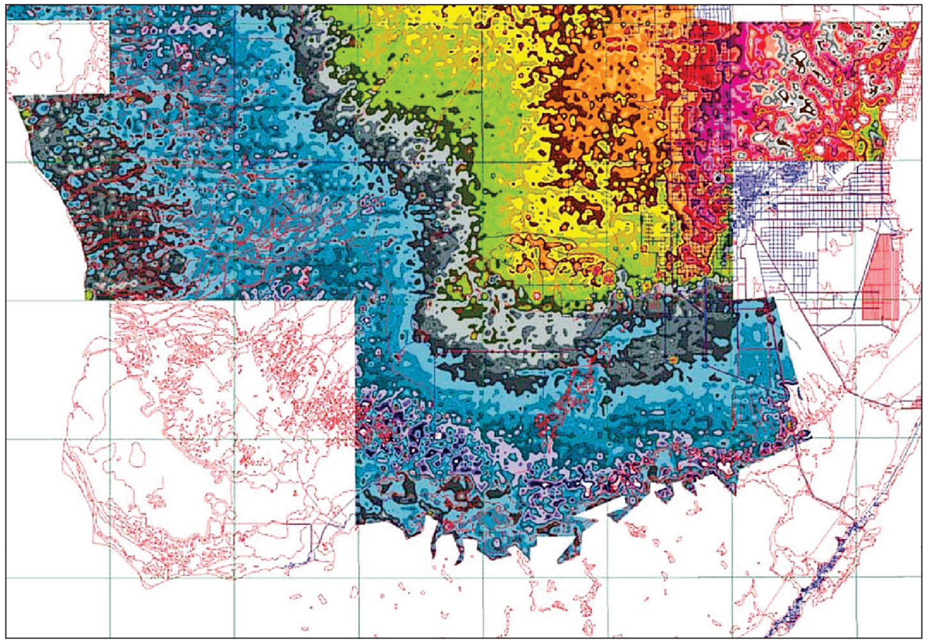
Develop techniques to detect relevant land surface changes using remote sensing.

Collect data required to detect landscape change due to implementation of CERP and Modified Water Deliveries (MWD) projects.

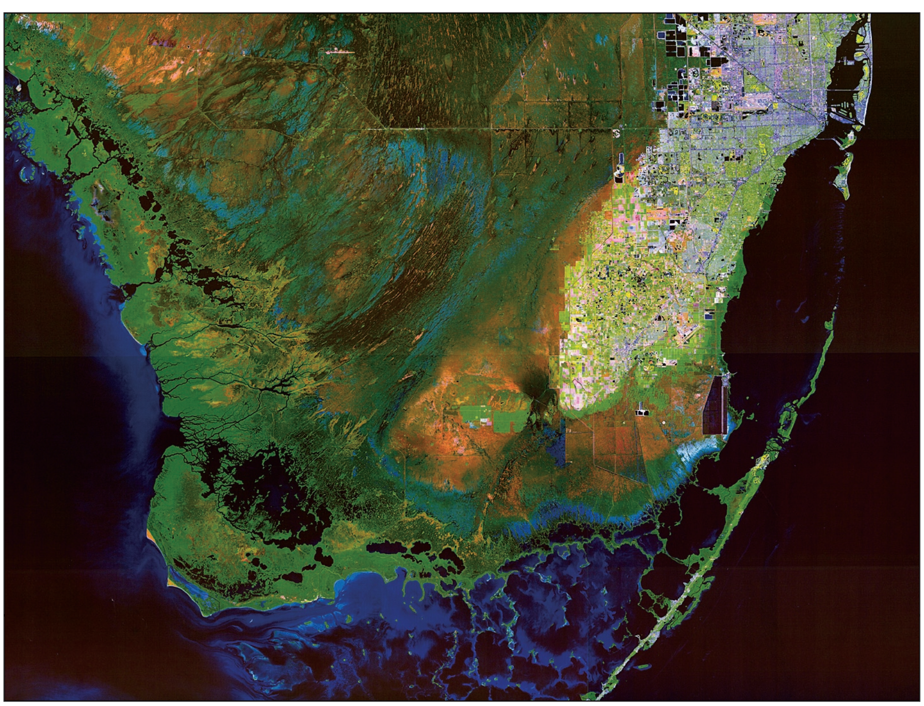
Collect data required to track vegetative change from wet to dry season.

Create a process for mapping water flow resistance due to vegetation.

Explore methods for estimating water elevations using past and future satellite data sources.


Southern Everglades topographic image

Develop mechanism for multi-agency coordination of ground-truthing and aerial/satellite data acquisition.


Southern Everglades satellite image map

Topography Research Needs

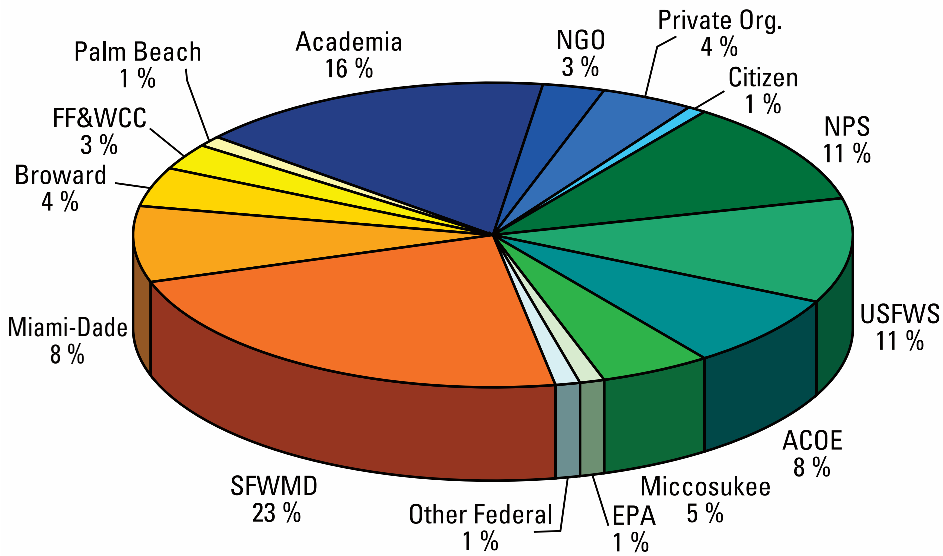
Complete topographic maps for the area encompassing the TIME (Tides and Inflows in the Mangrove Ecotone) models.

Create high resolution/accuracy topographic maps for WCA-1, WCA-2, and northern WCA-3A.

Collect bathymetric data for near-shore areas that have not been recently surveyed, including the southwest coast.

Increase spatial resolution of topographic data within selected landscape types, including ecotones, tree islands, ridge and slough, and rocky glades.

Map physical features including alligator holes and tree islands.



Participation by greater Everglades restoration partners during the 50-person Landscape Mapping and Topography Workshop (excluding USGS participants).

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Summary of Greater Everglades Ecosystem Restoration Workshop: 5. Contaminants and Biogeochemistry, May 29, 2002

Contaminants Research Needs

Determine relative contribution of local, regional and global sources to mercury deposition within south Florida.

Forecast mercury fate and toxicity due to structural and hydrologic changes during CERP implementation.

Determine mercury methylation /demethylation rates and factors affecting these rates.

A general predictive tool is needed to determine mercury methylation potential based on inputs of soil type, mercury, sulfur, DOC concentrations, hydroperiod, fire and drought. A tool is needed as a stopgap measure for near-term activities using existing research.

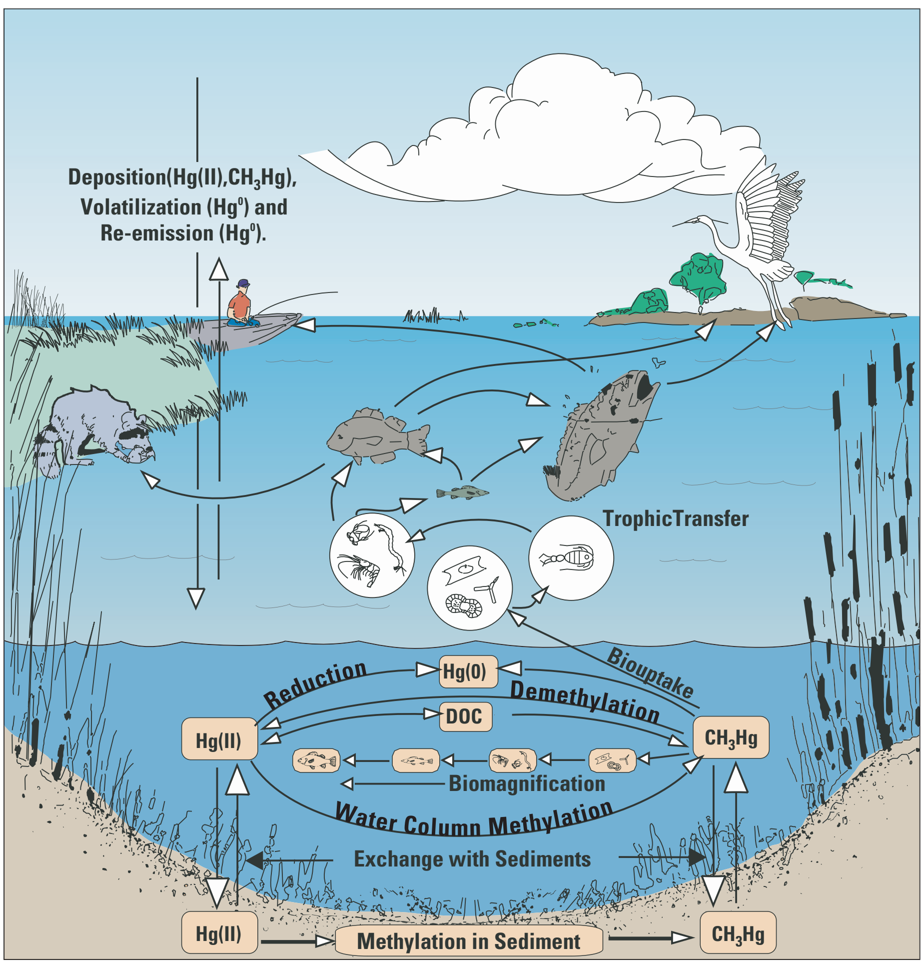
Determine if increased Everglades flows will increase mercury delivered to Florida Bay. Will increased flows scavenge mercury or methyl mercury associated with particles or sediment, and/or increase loading of dissolved mercury or mercury associated with DOC/colloids?

Determine if lower salinities within Florida Bay, which will result from increased flow within the Everglades, will enhance mercury methylation.

Determine possible impacts of aluminum, iron, and chloride on mercury methylation rates.

Determine if northern Everglades methyl mercury generation and nutrient mobilization after fire/drought also occurs within the more pristine southern Everglades.

Derive data to support a sulfur module for the Everglades Mercury Cycling Model (E-MCM).



Theoretical mercury cycle within the Everglades

Wildlife Effects Research Needs

Expand current research on effect of ambient levels of mercury and pharmaceuticals on Everglades wildlife. Suggested species include freshwater mussels, largemouth bass, marine fish, and alligators.

Further investigate effect of food web structure and seasonal variation in structure on mercury bioaccumulation.

Determine mercury dose-response relations for wading bird, fish, and other wildlife.

Archive biological samples as a baseline for future investigations.

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July 2002 PBS Information Sheet IS 02-05

Biogeochemistry Research Needs

Assess possible chemical reactions that may occur within the subsurface during Aquifer Storage and Recovery (ASR). Mercury methylation rates, and DOC-aquifer substrate interactions were explicitly mentioned.

Determine potential effects on the Everglades of reducing or eliminating anthropogenic sources of sulfate.

Determine the effect of increased flows and levee/canal degradation on the areal extent of sulfur contamination.

Collect additional information on sulfur/sulfite within Big Cypress Preserve.

Quantify sources of phosphorous in Florida Bay.

For Further Information

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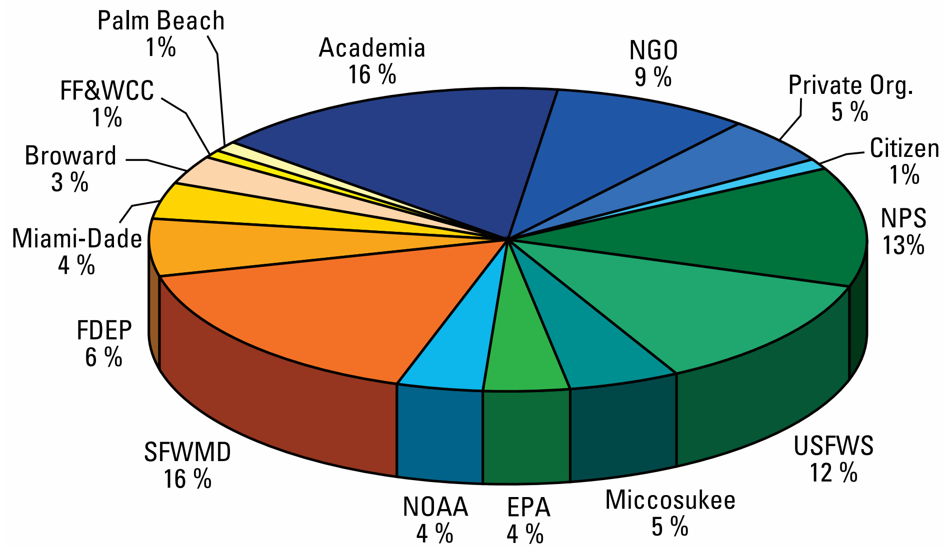
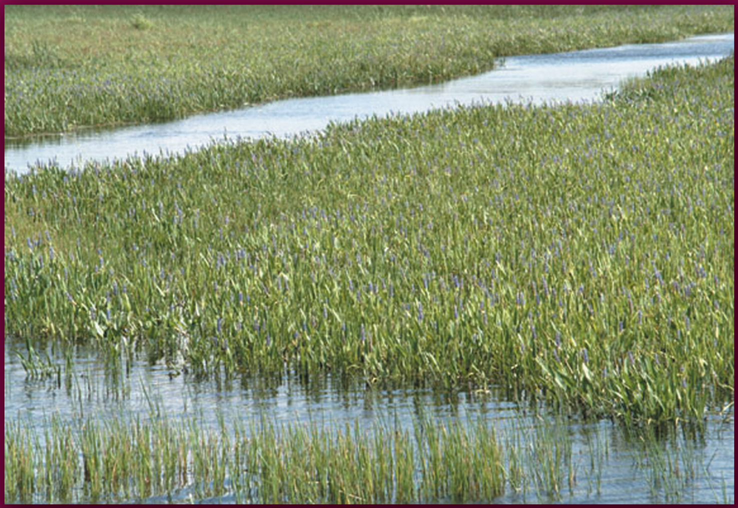


Participation by greater Everglades restoration partners during the 50-person Contaminant and Biogeochemistry Workshop (excluding USGS participants).



Section I

Get the Water Quantity Right

Contents

Section I: Get the Water Quantity Right

Long-Term Data from the USGS/BRD Mangrove Hydrology Sampling Network in Everglades National Park

By Gordon H. Anderson[1], *and* Thomas J. Smith III[2]

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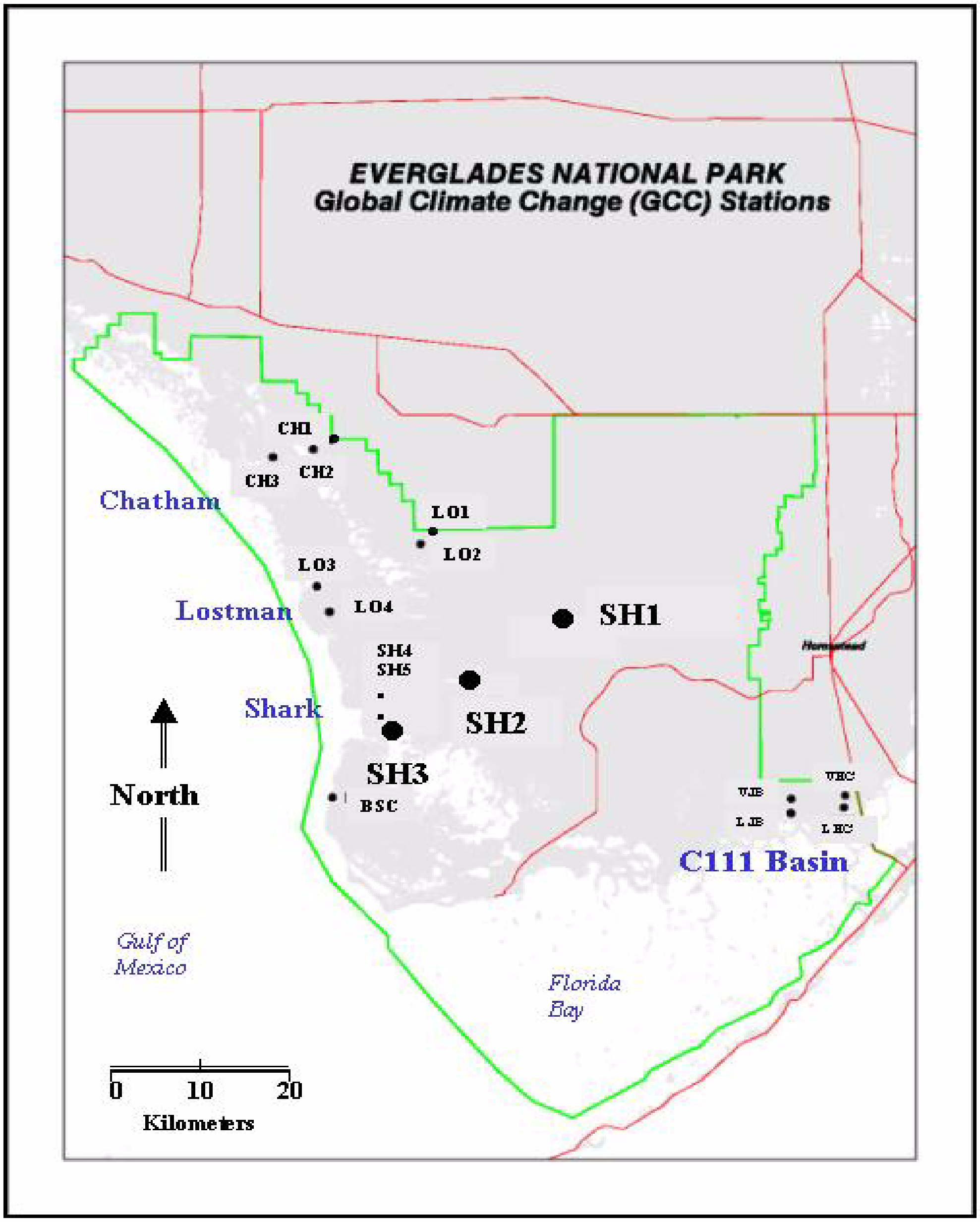

Figure 1. Locations of hydrologic sampling sites within Everglades National Park.

In 1992, under the guidance and support of the USGS Global Change Research Program (GCRP), The "Groundwater-surface water interactions and sea-level rise in southern Florida study" was initiated. The principle focus of the study was to develop a systematic network of shallow groundwater well and surface water monitoring sites to evaluate the hydrodynamic changes across the transition zone or ecotone between the freshwater Everglades and coastal mangrove estuaries. Located on the southwestern coast of Florida, within Everglades National Park, transects were established along the three principal tidal rivers: Shark, Lostman, and Chatham River (fig. 1). Shark River slough and its estuary were selected as the primary study area, because of their significance to the freshwater Everglades system. Each transect is ~30 km in length (the mesoscale) and has three permanent, continuously recording hydrologic monitoring stations. On the Shark River transect, Shark 1 (SH1) represents the upland non-tidal freshwater region; Shark 2 (SH2), the transitional ecotonal area between the two hydrologic systems; and Shark 3 (SH3) the coastal mangrove estuary region. Two additional hydrology stations (SH4 and SH5) were set up to monitor hydrologic changes across the fringe mangrove/coastal marsh ectone which is approximately 300m in length (the micro-scale). Shallow ground and surface water levels, temperature and specific conductance, and rainfall are the principal parameters measured at each monitoring site.

Hydrologic data from the Shark River Transect has been compiled for seven water years: 1996-2002 (fig. 2). Daily surface water from SH1 shows the wet tropical summer (June-October) weather and drier cooler winter (November-May) climate patterns of south Florida. The non-tidal, freshwater marshes respond quickly to local rainfall and evaporation, and surface-water discharge from upstream. Water levels in Shark Slough were significantly higher in 1995 and 1999. Hurricane Irene in October 1999 was the largest single event recorded at SH1 since 1995. SH2 is located on the terminus of the freshwater slough, at the ecotone with downstream tidal systems. Principally, SH2 showed a tidal signal in the daily surface water, however, it was dampened by the overland flow of surface water during the summer months, primarily June and in September. Tropical storm Harvey in September 1999 was the largest single event recorded at SH2 since 1995. SH3 is located on a red mangrove delta island near the mouth of the Shark River estuary. It is overwhelmingly a tidally influenced site, receiving a tidal influx twice daily. Tropical Storm Harvey in September 1995 was the single largest event recorded at SH3 since 1995.

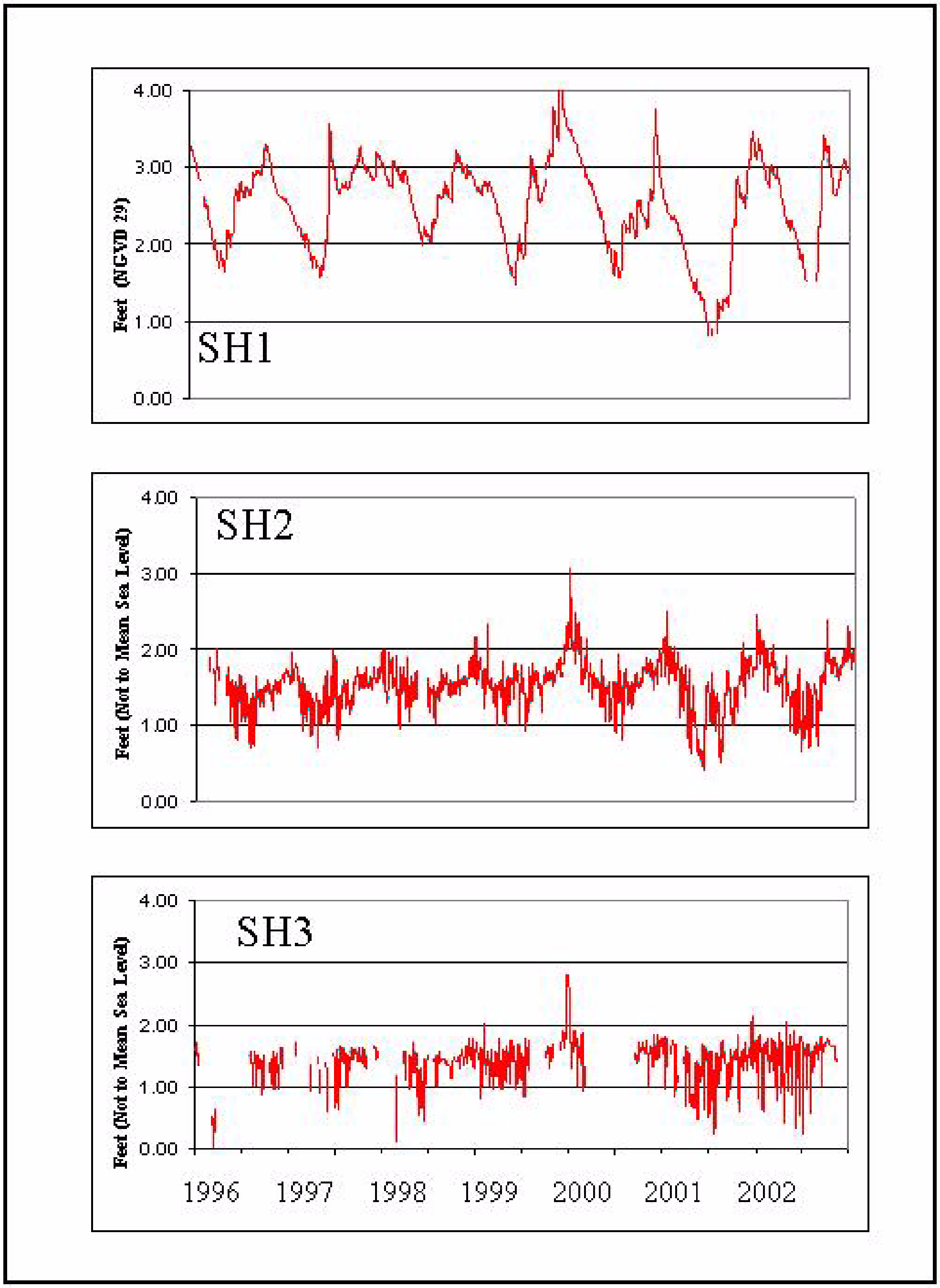

Figure 2. Period of record for surface water stage along the main Shark River transect.

The project is developing a common vertical reference for the southwest coast to provide greater comparative analysis of hydrologic data (DeWitt et al., this volume). The Shark River hydrologic network is centrally positioned to provide essential baseline empirical physical data needed for numerous research efforts and modeling involved with Everglades restoration. Such projects include the Tides and Inflows in the Mangroves of the Everglades (TIME) and a variety of interrelated USGS hydrological, ecological, geological, and mapping investigative studies. These data provide valuable integration with south Florida National Parks resource management; the Comprehensive Everglades Restoration Plan (CERP); and the Florida Coastal Long Term Ecological Research (LTER) project.

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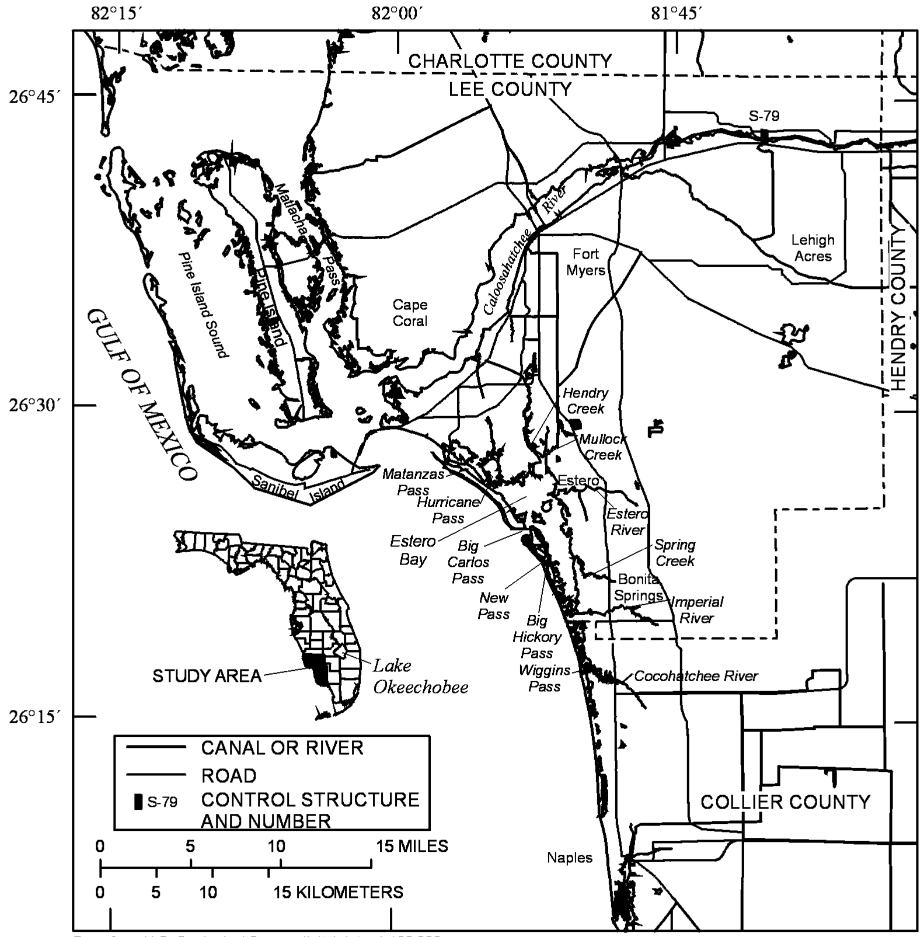
Discharge from Caloosahatchee River that enters Estero Bay

By Michael J. Byrne, U.S. Geological Survey, Center for Water and Restoration Studies, Fort Myers, FL., USA

Estero Bay is a State aquatic preserve located about 3 miles south of the Caloosahatchee River along the coast of southwestern Florida. Five major tributaries flow into this long and shallow body of water including Hendry Creek, Mullock Creek, Estero River, Spring Creek, and Imperial River (fig. 1). Most water exchange between Estero Bay and the Gulf of Mexico is through four inlets through a chain of barrier islands; Matanzas Pass, Big Carlos Pass, New Pass, and Big Hickory Pass. Lands surrounding Estero Bay, including the barrier islands, are highly developed.

The hydrologic relation between the Caloosahatchee River and Estero Bay is poorly understood. The quantity and timing of freshwater flow into the Caloosahatchee River estuary has been altered due to anthropogenic activities. Principal discharge of water from the Caloosahatchee River into Estero Bay is through Matanzas Pass and Hurricane Pass. The discharge of the organic-rich water reduces water clarity and salinity in the northern part of Estero Bay.



Base from U.S. Geological Survey digital data, 1:100,000
Universal Transverse Mercator projection, zone 17

Figure 1. The Estero Bay watershed.

Research reveals that the altered flow pattern impacts the Caloosahatchee River estuary and Estero Bay. The U.S. Geological Survey has undertaken a study to examine hydrology and salinity patterns in Estero Bay. Continuous salinity and flow measurements are being taken at Mullock Creek, Estero River, Imperial River, Matanzas Pass, Big Carlos Pass, and Big Hickory Pass (fig. 1). Surface-water salinity and temperature data also are being collected near the mouth of the Caloosahatchee River; at points in Matlacha Pass, Pine Island Sound, and Sanibel Island; and as far south as Wiggins Pass. These data, collected on a monthly basis, will be used to generate salinity maps. The salinity, flow, and temperature data and additional discharge measurements may be collectively used to quantify the volume of water from the Caloosahatchee River that enters Estero Bay.

The Caloosahatchee River receives water from Lake Okeechobee (to the northeast) and from numerous tributaries. The tributaries north and south of the river drain a large basin consisting mainly of agricultural fields. The South Florida Water Management District (SFWMD) regulates releases from Lake Okeechobee to the Caloosahatchee River. Flow on the Caloosahatchee River is controlled by a series of gated structures, operated by the U.S.

Army Corps of Engineers (USACE). South Florida Water Management District permits discharge into the river in regulated pulses. The low-level pulse release is designed to limit negative impacts to the estuary. However, the river must also be maintained for navigation, water supply, and flood control. The USACE controls the locks on the river to meet these water demands. During summer 2002, the flow-way gates of the westernmost lock (Franklin Lock, S-79) were open almost continuously. Consequently, the Caloosahatchee River release occurred all summer, with highest flows during the period of discharge from Lake Okeechobee.

Water from the Caloosahatchee River was detected in the near-shore waters of the Gulf of Mexico as far south as Wiggins Pass, which is about 20 miles south of the mouth of the river. Salinity in the Gulf of Mexico substantially decreased during periods of large water releases from the river and was significantly lower off of the northern barrier islands than farther south where Caloosahatchee discharges had less effect. Freshwater entering the Gulf of Mexico from the Caloosahatchee tends to color the oceanic water brown or black. Further research will be required to understand the full extent of the freshwater discharge from the Caloosahatchee River.

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Monitoring and Mapping Salinity Patterns in Estero Bay, Southwestern Florida

By Michael J. Byrne, U.S. Geological Survey, Center for Water and Restoration Studies, Fort Myers, FL., USA

Estero Bay is a very long and shallow estuary located about 3 miles south of the Caloosahatchee River along the southwestern coast of Florida. Abundant and diverse flora and fauna exist within the bay and its watershed including threatened and endangered species. Historically, sheet flow from several sloughs drained into Estero Bay. Most flow now is concentrated at several inflow points as a result of rapid development within the watershed. The principal inflows come from Hendry Creek, Mullock Creek, Estero River, Spring Creek, and Imperial River (fig. 1).

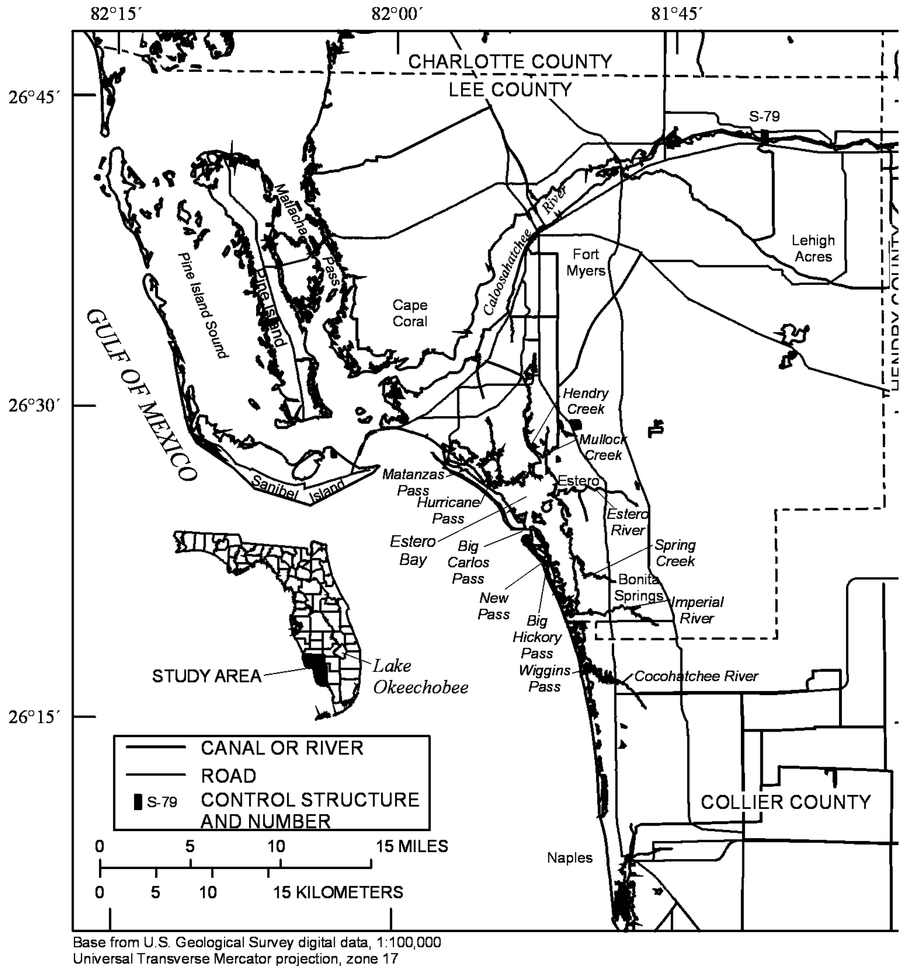

Figure 1. The Estero Bay watershed.

Water exchange with the Gulf of Mexico is restricted by a series of barrier islands, with most exchange through four passes; Matanzas Pass, Big Carlos Pass, New Pass, and Big Hickory Pass. Monitoring and mapping salinity in Estero Bay will help determine the effects that altered flows have had on the aquatic health of the bay.

Baseline data for Estero Bay and its tributaries are needed to provide regional resource managers information to manage future development around the bay and its watershed. The U.S. Geological Survey has undertaken a study to map salinity patterns and determine freshwater residence times in Estero Bay. Salinity is the chemical tracer that will be used to map water movement through Estero Bay and the information generated from this project will be used in the development of hydrodynamic models and statistical analysis of salinity variance the bay.

The study began in April 2001 and will end in September 2004. Monthly surface-water salinity and temperature data are presently being collected throughout Estero Bay. The methods of data collection involve attaching a water-quality sensor to the stern of a boat just beneath the water surface and logging the precise location of data points using a global positioning system (GPS) receiver. Two boats are used to collect about 6,000 individual data points in the estuary over an 8-hour period. These data are used to generate the surface-water salinity maps and for statistical analysis of salinity variability due to stormwater releases through the Caloosahatchee River.

Salinity results reveal a large volume of water from the Caloosahatchee River moves a short distance through the Gulf of Mexico and then enters Estero Bay through Matanzas Pass. This organic-rich water may reduce light penetration and salinity and increase sedimentation in the northwestern part of the bay. Water entering the northeastern part of the bay travels south and mixes with water from the Estero River before flowing through Big Carlos Pass. In the south-central bay, hydrologic exchange is limited and salinities increase. Salinity data in southern Estero Bay suggest the Imperial River discharges to the south and north in similar volumes. The Imperial River discharge leaves Estero Bay through Big Hickory Pass and New Pass.

The salinity maps can be used to assess trends in saltwater movement within the estuary and improve an understanding of manatee and fish migration. The information from these maps also can be used for hydrodynamic model verification and to help map seagrass beds.

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Do Surface and Groundwater Fluctuations Influence Sediment Surface Elevation in the Coastal Everglades Wetlands?

By Donald R. Cahoon[1], James C. Lynch[1], T. J. Smith III[2], Kevin R.T. Whelan[2], Gordon H. Anderson[2], *and* Christa Walker[3]

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The Greater Everglades ecosystem stretches over 360km, from Lake Kissimee in the north to Florida Bay in the south. At its widest point it covers more than 100km from west to east. The vast flow way has been dissected by a network of canals and levees over the recent past to control flooding, provide water storage for human consumption, and protect croplands. Natural surface water flows into Everglades National Park have been seriously disrupted, in terms of quantity, quality, and timing of flow. Presently federal, state, and local agencies have established a $7.8 billion ecosystem restoration program for the Everglades, known as the Comprehensive Everglades Restoration Plan (CERP). Many science questions remain unanswered as the restoration begins. Major questions exist concerning rates of soil formation in the various wetland plant communities and about factors regulating surface elevation in these wetlands.

This report provides data from a network of Surface Elevation Tables (SETs) in the southwest coastal wetlands of Everglades National Park. At each of eight sites, three SETs were established. Three study locations were along each of the Shark and Lostmans Rivers, the two major coastal drainages of the southwest Everglades. On each river one site is in an upstream freshwater wetland, a second site is in the middle reach of the river in a brackish marsh – mangrove forest community, and the third site is downstream near the river's mouth in a pure stand of mangrove forest. The two freshwater sites are non-tidal and highly seasonal with respect to surface water flows and depths (both highest in summer and negligible in the winter dry season). Tides are measurable, but small, at the brackish waters sites and there is a noticeable variation in surface water. Tidal activity dominates the hydrological signature at the saline, downstream, mangrove forest sites. The seventh and eighth sites are located at Big Sable Creek, a marine dominated region on northwest Cape Sable. The cape was devastated by the 1935 Labor Day Hurricane and again by Hurricane Donna in 1960. At this location three SETs are in mangrove forest and three are in open, unvegetated, intertidal mudflat. Ground-water and surface-water sampling wells are present at all sites and are instrumented to record elevation and conductivity at hourly intervals. SETs have been sampled at 3-6 month intervals for more than three years (fig.1). For each of the eight sites we calculated the rate of change in relative wetland surface elevation (only one site is currently surveyed to mean sea level) between sampling intervals. We also calculated the rate of change in daily ground and surface water elevation for the same intervals. Average surface and groundwater stage was determined for the day of SET sampling, and for the 15 and 30 days prior to sampling. Simple linear regression was used to test for differences between surface elevation change and the water level parameters and to calculate the slope of that relation for each site.

Sediment surface elevation at all sites showed apparent annual cycles that differed between sites. Surface elevation appeared to be greatest during the dry season at upstream freshwater locations (fig.1) and lowest during the dry season at downstream saline locations. The two brackish water, middle river, sites showed little variation in sediment surface elevation. Surface-water stage, over the 15 days prior to sediment sampling, was strongly related to the change in sediment elevation between samplings (fig. 2). Most importantly, this relation was the opposite between sites. At freshwater sites, as average stage **increased,** sediment change **decreased**, whereas at saltwater sites, **increasing** surface-water stages led to **increasing** sediment elevation between sampling periods. The pattern at the two brackish sites was intermediate.

Why these two wetland systems behave in an opposite manner is unclear at this time. One hypothesis is that in the freshwater systems, a sedimentation – re-suspension process is occurring whereby, as the dry season progresses, flocculent material in the water column settles out, and as the wet season sets in and water levels (and current velocities) go up, this material becomes re-suspended and lost from the site. This hypothesis will be tested in coming months.

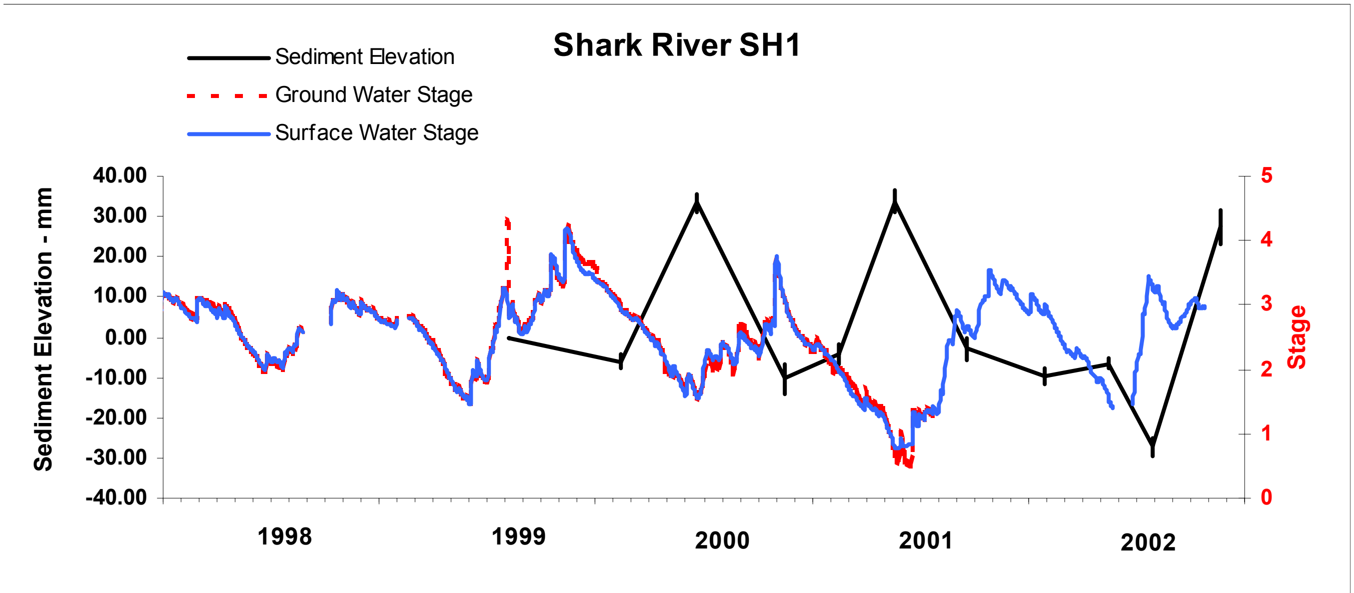

Figure 1. Representative data showing the time series of surface & groundwater stage and sediment surface elevation at the upstream freshwater site on the Shark River (SH1).

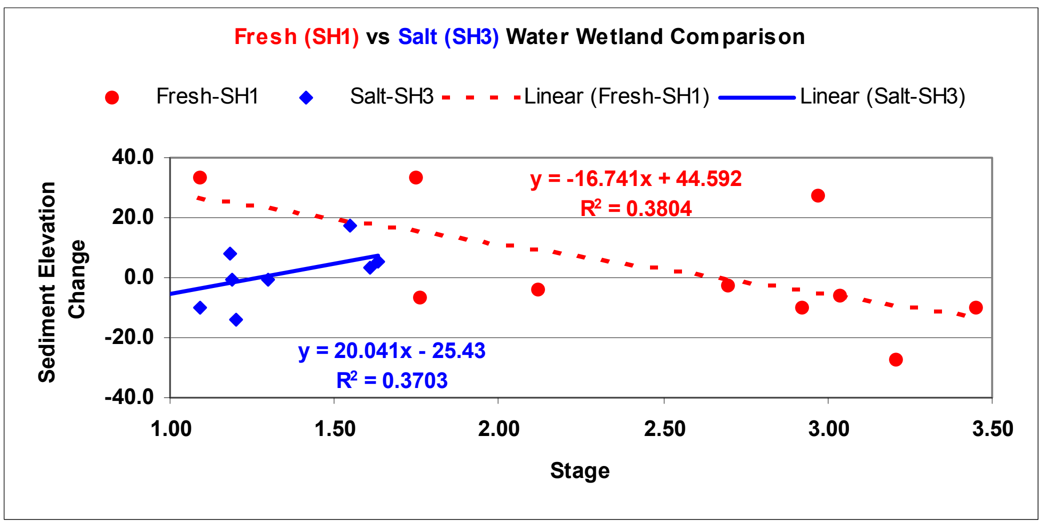

Figure 2. Sediment elevation change versus average surface water stage for a freshwater marsh (SH1) and a salt water mangrove forest (SH3).

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Significance of Microtopography as a Control on Surface-Water Flow in Wetlands

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Microtopography rarely has been considered in wetland surface-water flow models, even though the ground surface often undulates significantly. We define microtopography as topographic variations in the wetland occurring at a small spatial scale (1m or less) between hummocks and depressions, as well as an intermediate spatial scale (tens or hundreds of meters) between the tops of ridges and the bottom of nearby sloughs. To our knowledge, no previous model of surface-water flow in the Everglades has considered how microtopography (1) decreases the cross-sectional area available for flow at low water levels, (2) increases surface-water exchange with sediment porewater, and (3) increases flow resistance due to flow over and around microtopographic features.

The goal of the present project was to expand on the concepts and modeling of Hammer and Kadlec (1986) and Kadlec (1990) by developing a governing equation that more explicitly isolates the effects of microtopography on surface-water flow in wetlands,

$$f_w \cdot S_s \cdot \frac{\partial h}{\partial t} + (1 - f_w) \cdot S_y \cdot \frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left(f_w \cdot K_f \cdot d^{\beta+1} \cdot \frac{\partial h}{\partial x} \right) + (P - ET + GW_i) \ , \qquad (1)$$

where f_w is the fraction of free surface water normal to flow (a function of water level and microtopographic distribution), S_s is the surface-water storage coefficient, h is the surface-water elevation, S_y is the specific yield of the wetland sediments (i.e. subsurface-water storage coefficient), K_f is the flow conductance, d is the surface-water depth, β is the exponent on depth, P is precipitation, ET is evapotranspiration, and GW_i is ground-water inflow.

A schematic of Everglades topography (fig. 1) illustrates how the cross-sectional area available for surface-water flow is dependent on the microtopographic distribution as well as on surface-water stage. According to Harvey and others (this volume), the ground-surface elevation in Water Conservation Area 2A (WCA-2A) (fig. 2) varies as much as 0.4 meters vertically over a horizontal distance of 100 meters, which is one third of the typical vertical fluctuation in surface-water depth (1.2 m) in that part of the Everglades. Variability in topography and surface-water depth at WCA-2A makes this an ideal location for testing a model of the effects of microtopography on surface-water flow.

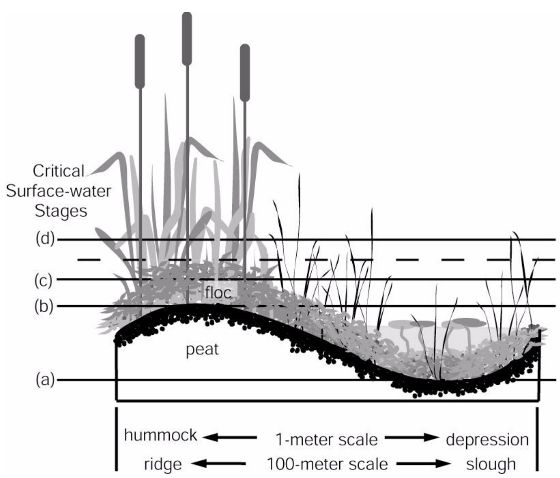

Figure 1. Schematic of wetland topography showing change in cross-sectional area for surface-water flow for "critical" surface-water stages.

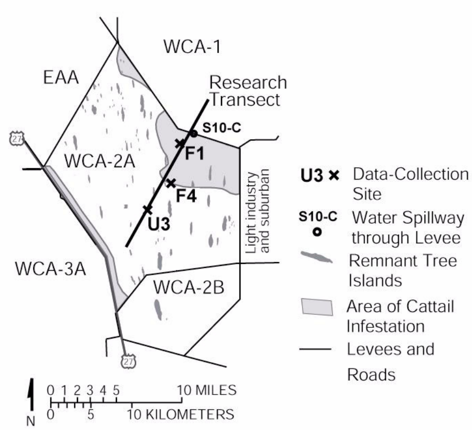

Figure 2. Water Conservation Area 2A, central Everglades, south Florida.

Three different models were applied and compared by selectively combining three effects of microtopography on surface-water flow. Model 1 was the base model simulation, which did not incorporate any of the effects of microtopography. Model 2 included the effects of microtopography on cross-sectional area of surface flow, and surface and porewater exchange. Model 3 included the depth-dependent influence of microtopography on flow resistance in addition to those considered by model 2. All three models used daily water levels measured by South

Florida Water Management District at sites F1, F4, and U3 in WCA-2A and field measurements of f_w, d, S_s, S_y, P, ET, and GW_i. The two reaches that were modeled (F1-F4 and F4-U3) differed mainly in their vegetative characteristics (fig. 2). The inverse modeling program, UCODE (http://www.usgs.gov/software/ ucode.html), was used to objectively estimate the optimal values for K_f, and β for each model (table 1).

Surface-water flow simulations from model 2 showed a 15 percent improvement of the Root Mean Squared Error (RMSE) over the model 1 results, demonstrating that consideration of the effect of microtopography on flow cross-sectional area and storage-exchange improves the accuracy of the surface-water flow model (fig. 3). We observed additional improvements in the model 3 simulation (40 percent decrease in RMSE from that of model 1) through incorporating stage-dependence in the flow parameters, K_f and β. The stage-dependent parameters were determined from separate inverse modeling runs of the low-stage period (first 45 days, fig. 3) and the high-stage period (remaining 65 days, fig. 3). Flow parameters in model 3 are varied according to the critical stages defined by field measurements of microtopography at sites F1 and U3 in WCA-2A (fig. 1).

Table 1. Optimized flow parameters (K_f, β) for models 1, 2, and 3 as determined from inverse modeling. Notes: Model 3 parameters vary with critical stage (see fig. 1), Parameters vary linearly for depth ranges (c) to (d) and (a) to (b).

	Reach 1 (F1 to F4)		**Reach 2 (F4 to U3)**	
	K_f (m/d/m$^{\beta-1}$)	*b*	K_f (m/d/m$^{\beta-1}$)	*b*
Model 1	1.8 x 10^7	0.60	4.7 x 10^7	0.64
Model 2	3.4 x 10^7	0.41	8.9 x 10^7	0.16
Model 3				
Stages greater than (d)	2.5 x 10^7	0.39	5.6 x 10^7	0.56
Stages (c) to (b)	8.2 x 10^6	0.46	5.6 x 10^7	0.56
Stages less than (a)	0.98	0.00	0.98	0.00

Results of this study indicate that microtopography is a significant control on surface-water flow in the Everglades, especially when the surface-water elevation declines to depths that begin to expose microtopographic highs. Our current modeling effort focuses on objectively determining the critical stages that affect stage-dependence in flow parameters through inverse modeling.

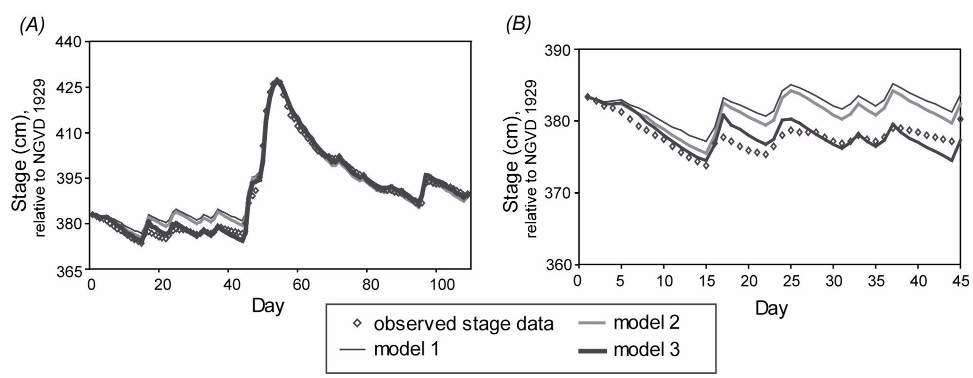

Figure 3. Comparison of simulation results from models 1, 2, and 3 at site F4 for the entire modeling period *(A)* and the low-stage modeling period *(B)*.

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Measuring and Mapping the Topography of the Florida Everglades for Ecosystem Restoration

By Greg Desmond
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One of the major issues facing ecosystem restoration and management of the Greater Everglades is the availability and distribution of clean, fresh water. The south Florida ecosystem encompasses an area of approximately 28,000 square kilometers and supports a human population that exceeds 5 million and is continuing to grow. The natural systems of the Kissimmee-Okeechobee-Everglades watershed compete for water resources primarily with the region's human population and urbanization, and with the agricultural and tourism industries. Therefore, surface water flow modeling and ecological modeling studies are important means of providing scientific information needed for ecosystem restoration planning and modeling. Hydrologic and ecological models provide much-needed predictive capabilities for evaluating management options for parks, refuges, and land acquisition and for understanding the impacts of land management practices in surrounding areas. These models require various input data, including elevation data that very accurately define the topography of the Florida Everglades.

Surface water levels and sheet flow in the Everglades are very sensitive to any differences in topography because of the region's expansive and extremely flat terrain. Therefore, hydrologic models require very accurate elevation data in order to simulate and predict water flow direction, depth, velocity, and hydroperiod. Water resources, ecosystem restoration, and other land management decisions will rely, in part, on the results of these models, so it is imperative to use the best elevation data available in order to achieve meaningful simulation results. Elevation data points are being collected every 400 meters in a grid pattern to meet the requirements of various hydrologic models. The vertical accuracy specification for these elevation data is ±15 centimeters (6 inches) as referenced to the North American Vertical Datum of 1988 (NAVD88).

Because traditional methods for collecting elevation data for the Everglades are impractical or too costly, the U.S. Geological Survey (USGS) conducted a feasibility study to determine if state-of-the-art techniques using the Global Positioning System (GPS) could meet the strict vertical accuracy specifications of the elevation data. The feasibility study successfully demonstrated that differential GPS techniques, using airboats to navigate transects, could in fact meet the vertical accuracy requirement. Also, the land surface being surveyed in the Everglades is typically under water and obscured by vegetation. This precludes the use of other methods for collecting very accurate elevation data, such as photogrammetry, Light Detection And Ranging (lidar), Interferometric Synthetic Aperture Radar (insar), or other alternative remote sensing technologies. Therefore, topographic surveys over such a large area of the Everglades with such a stringent accuracy specification can only be accomplished efficiently by using GPS technology. This is especially the case in a harsh and inaccessible wilderness environment with unique landscape characteristics.

Because the Everglades is so expansive and remote and includes environmentally sensitive areas, impenetrable vegetation, or other areas unapproachable by airboat, access to many places is possible only by helicopter. To solve this accessibility problem, the USGS developed a helicopter-based instrument, known as the Airborne Height Finder (AHF), which is able to measure the terrain surface elevation in a noninvasive, nondestructive manner. Using an airborne GPS platform and a high-tech version of the surveyor's plumb bob, the AHF system distinguishes itself from remote sensing technologies in its ability to physically penetrate vegetation and murky water, providing reliable measurement of the underlying topographic surface.

Accuracy tests have shown that the AHF system can consistently measure elevation points at the subdecimeter level. An accuracy test of the AHF was conducted in May 2000 when 17 National Geodetic Survey (NGS) first-order benchmarks were measured at two different helicopter hover heights. The average difference between the AHF measured elevations and the NGS published data sheet values was 3.3 cm. The largest difference was 8.6 cm, and the smallest difference was 0.2 cm. The root mean square error was 4.1 cm. These accuracy test results provide confidence that the elevation dataset being produced meets the ±15 cm vertical accuracy specification.

Elevation data collected with the AHF have been applied in the USGS-developed Southern Inland and Coastal System (SICS) numerical simulation model, which requires very accurate data for its hydrodynamic surface-water computations. The SICS model was originally constructed with topographic estimates based on pre-existing contour maps. Although these contour maps meet national map accuracy standards, the derived elevation data are not adequate for hydrologic modeling purposes for the Florida Everglades. However, the distribution of surface-water flows simulated by the SICS model was greatly improved when the AHF elevation data replaced the previously estimated topography in the model. Flow and inundation estimates north of the West Lake area (southwest portion of the SICS model domain) are most significantly affected by this elevation difference.

To date, tens of thousands of elevation data points covering significant parts of the Florida Everglades have been collected and processed using differential GPS methods with airboats and the helicopter-based AHF system. These data are organized by USGS 7.5-minute quadrangle maps and are available from the South Florida Information Access Web Site at http://sofia.usgs.gov.

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Progress and Future Direction in Topographic Modeling for ATLSS Models

By Scott M. Duke-Sylvester, *and* Louis J. Gross, University of Tennessee, Knoxville, TN., USA

Topographic variation in south Florida, though generally small, is very important for the flora and fauna of the region. Recently the U.S. Geological Survey (USGS) started the High Accuracy Elevation Data (HAED) collection project with the goal of obtaining an estimate of topography in south Florida at a high spatial resolution (nominally 400x400 meters) with high vertical accuracy (vertical estimates are accurate to within about 3 cm). The project has now collected, processed, and made available topographic data for a large portion of the natural areas in south Florida, including most of the Everglades National Park (ENP), portions of Big Cypress National Preserve (BCNP) and Water Conservation Area 3.

Prior to the existence of the HAED project there were no topographic maps of south Florida with both the spatial resolution and spatial extent needed to model the ecology of fauna and flora in south Florida. To fill this void, the Across Trophic Level System Simulation (ATLSS) project developed the High Resolution Topography (HRT) model. This model estimates elevation for 30x30 meter grid cells across the natural regions of south Florida. The estimation is based on the types of vegetation and the patterns of hydrology at each location. The founding assumption of the HRT model is that plants tend to be in places where local topography and hydrology combine to create a suitable habitat. Knowledge of the vegetation and hydrology at a location can be used to estimate elevation by choosing an elevation that results in hydrologic conditions suitable for local vegetation.

Three data sets form the basic inputs into the HRT model: a map of the distribution of vegetation in south Florida, a map of the history of hydroperiod distributions, and a table of hydroperiod preferences for each of the vegetation types in the vegetation map. The hydroperiod preferences are derived from a review of available literature. The vegetation distribution map used is the Florida GAP (FGAP) map (version 2.1) created by Leonard Pearlstine at the University of Florida. The FGAP map assigns one of 43 vegetation types to each 30x30 meter cell over most of South Florida.

The hydroperiod data for the HRT model is created from the Calibration/Verification run of the South Florida Water Management Model (SFWMM). The SFWMM is managed by the South Florida Water Management District (SFWMD) and is the standard hydrologic model for South Florida. The Calibration/Verification run of this model is considered to be the one that most accurately reflects the historical pattern of hydrology in South Florida from 1979 to 1995. The SFWMM partitions south Florida into a grid, where each grid cell is 2x2 miles. The model estimates water depth in each 2x2 mile cell on a daily time step from January 1, 1979 to December 31, 1995.

Over the past two years there have been a number of advances in the ATLSS High Resolution Topography (HRT) modeling project. An extensive literature review, Plant Community Parameter Estimates and Documentation for the Across Trophic Level System Simulation (ATLSS) by Paul Wetzel has been completed and peer-reviewed. This document describes the hydroperiod preferences of the natural vegetation types used in the 6.1 version of the Florida GAP (FGAP) map.

The second major advance is the development of a new HRT map. This new version is based on FGAP 6.1, hydrology data from the South Florida Water Management Model (SFWMM) version 3.7, and the hydroperiod estimates that appear in Wetzel's report. We are currently waiting for a more current version of the SFWMM Calibration/Verification output before completing a final version of the new HRT map.

Finally, we have begun an analysis that looks at the relation between HAED elevations, distribution of vegetation as provided in the FGAP map, and hydrologic parameters as predicted by the SFWMM. This analysis uses a multiple regression model with vegetation type and a number of yearly average hydrologic variables as predictors, and elevation estimates from the HAED collection project as the response variable. There are two major purposes in performing this analysis. The first is to test an assumption made by the HRT model that there is a relation between the elevation of a location and the vegetation associated with that location by FGAP. The second is to determine if a multiple regression model can be used to predict HAED elevation based on vegetation and hydrology. Both of these results provide a basis for evaluating the output of the HRT model.

This analysis has been completed for the Big Boy Lake HAED sampling unit. The regression coefficients for several of the vegetation types in this region are significantly non-zero. This indicates that vegetation provides some information about variation in topography. However, the r^2 and PRESS (Prediction Sum of Squares Statistics) values for the regression model are not sensitive to the presence of vegetation as a descriptor variable. This indicates that in the Big Boy Lake region the overall contribution of vegetation to explaining variation in elevation is small. The conclusion we draw from this result is that for the Big Boy Lake HAED region we do not expect the HRT to perform well when compared to the HAED data because the inputs to the HRT model have very little relation to the HAED elevation data. The limited scope of this analysis leaves a number of unanswered questions. The relation between vegetation and HAED elevation in other regions and at other spatial scales has not yet been explored. While working with the HAED data we have noticed that elevations were not sampled in some tree islands. According to Greg Desmond, HAED project leader at USGS, the methods used to collect elevation data for HAED result in the systematic omission of tree islands. The effect of the sampling bias that arises from this omission is to compress the variance in measured elevations relative to the actual variance.

The HAED data will become the primary basis for topography used by ATLSS models. However, the availability of the HAED topography does not completely eliminate the need for the HRT model. In the short term, there is still a need to use HRT estimates of topography for regions not yet covered by the HAED project. In the long term, the methodologies used in the HRT model may be needed to augment the topography generated by the HAED. We propose using the HRT map and the HRT methodologies to augment the HAED topography in areas where HAED has omitted vegetation structures, or has compressed variation. Work has begun on identifying regions where the HRT model can be useful for augmenting the HAED topography and the methods needed to incorporate HRT output into a HAED-based topography.

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Evapotranspiration Rates from Two Different Sawgrass Communities in South Florida During Drought Conditions

By Edward R. German, *and* David M. Sumner
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Evaporation and plant transpiration (ET) are significant components of the water budget in south Florida. Water loss through ET can exceed rainfall during dry years. Recent advances in instrumentation and measurement techniques have made it possible to develop a better understanding of ET processes and to quantify ET rates. ET rates at two sites vegetated primarily by sawgrass, one in Blue Cypress Marsh near Vero Beach in the St. Johns River floodplain and the other in the southern Everglades of Everglades National Park (fig. 1), yield significantly different ET rates during drought conditions that occurred in January through June of 2000.

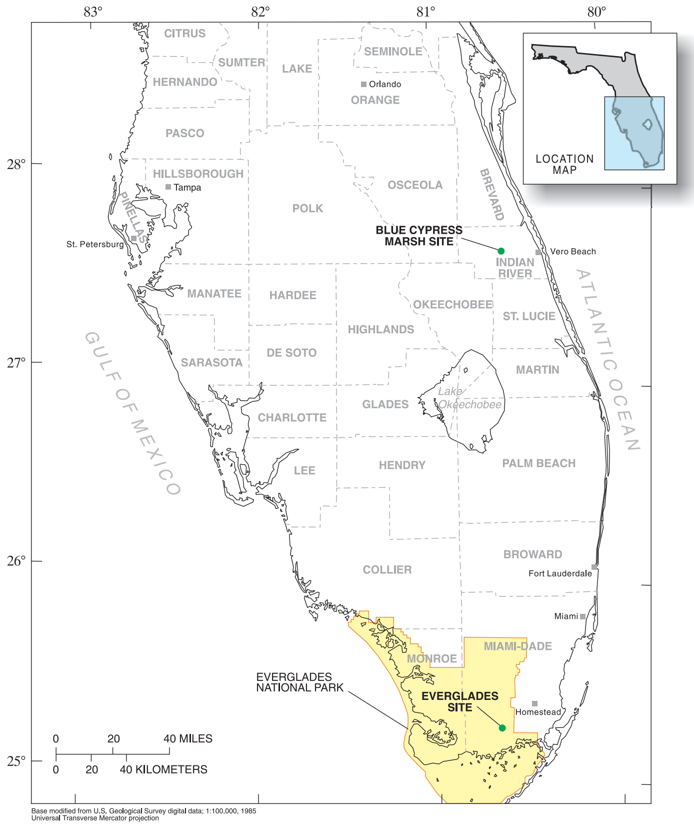

Figure 1. Location of Blue Cypress Marsh site and Everglades site.

The Blue Cypress Marsh site (BCM) has dense sawgrass in a thick peat soil. At this site, the ET fraction (EF), which is the ratio of latent heat (the energy equivalent of ET) to the sum of latent heat and sensible heat (convective heat transport), was affected little by the change in water level even when nearly 3 feet below land surface. The Everglades National Park site (ENP) has a relatively sparse rush/sawgrass community in a thin marl soil. At this site, the EF decreased markedly as the water level dropped to about 2 feet below land surface.

The monthly total ET was greater at BCM than at ENP for each month except January (fig. 2). The largest differences in monthly ET rates (greater than 1 inch) occurred from March through July, when water levels were below land surface at one or both sites. Annually, the total ET was 55.7 inches at BCM and 43.5 inches at ENP. This difference in annual total ET is not explainable by differences in available energy (138 watts/m^2 at BCM and 132 watts/m^2 at ENP for 2000), and is the result of the differences in EF between the two sites.

The EF (and hence ET) apparently are related to water level at the ENP site but not at the BCM site. The reason for this difference in behavior of EF is not understood, but probably is related to the differences in plant cover and soil type between the two sites. The thick sawgrass cover at BCM apparently is able to transpire at maximum efficiency even when the water level is more than 2.5 feet below land surface. The thick peat soil layer may play a role in this high EF even during low-water conditions by providing a reservoir of soil moisture from which the sawgrass can draw. Additionally, the sawgrass coverage at BCM is relatively uniform and thick, and the incident solar radiation only penetrates the top of the sawgrass. At ENP the vegetative cover is thinner and less extensive. Heating of the sawgrass probably is less than heating of the land surface in exposed locations, so that the utilization of available energy for sensible heat transport likely is less at the BCM site than at the ENP. Less sensible heat transport relative to latent heat transport would cause a relatively high EF.

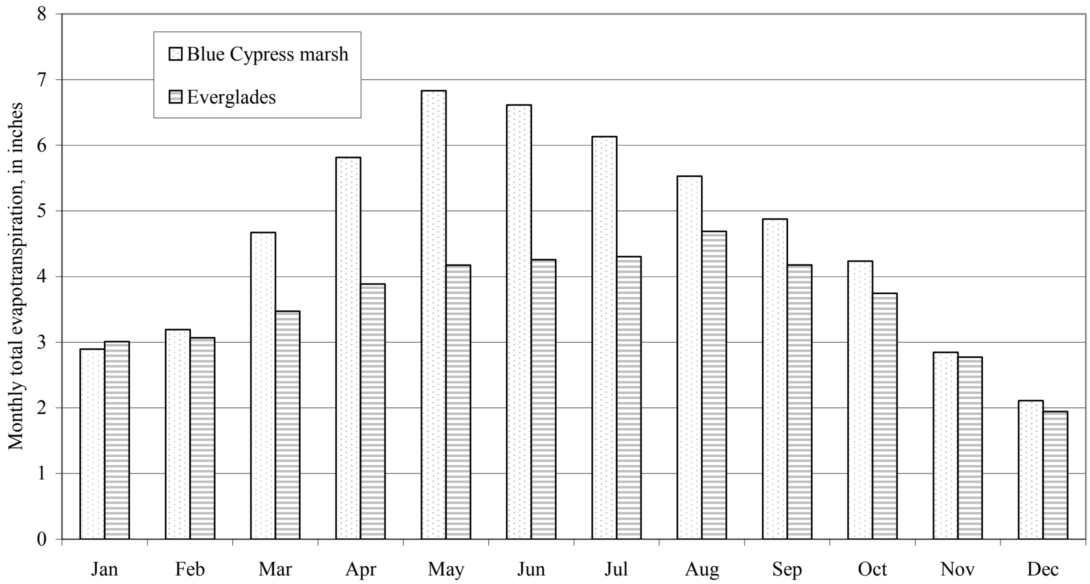

Figure 2. Monthly total evapotranspiration, January 2000 through December 2000.

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Characterization of Microtopography in the Everglades

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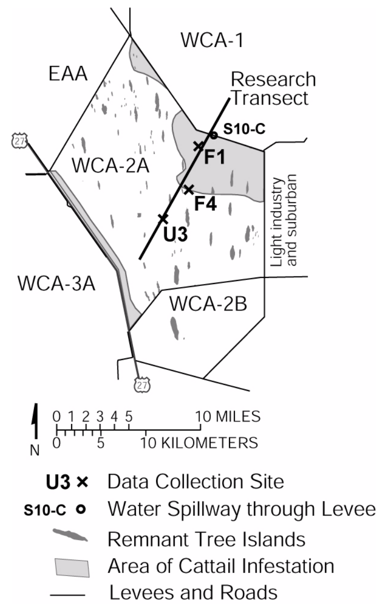

Figure 1. Location of data-collection sites in WCA-2A, central Everglades, south Florida.

As concerns over how to restore the Everglades intensify, the need to improve capabilities of surface water flow models becomes increasingly important. One of the physical factors not often considered in surface flow modeling is the microtopography of the wetland surface. At the local scale (1-m horizontal), the elevation of the wetland surface undulates between hummocks associated with macrophytes and the depressions between them. At a larger spatial scale (100 m), topography varies between the tops of ridges and the bottom of nearby sloughs. We refer to all of these topographic variations as "microtopography."

Microtopography affects the cross-sectional area of a wetland that is available for surface-water flow. As water levels decline seasonally, the tops of ridges and hummocks become exposed, making flow paths more sinuous, and therefore, increasing the resistance to surface flow. Microtopography also plays a role in the water exchange between wetland surface water and porewater of sediments.

To characterize microtopography, elevations of the top of the peat surface and the top of the layer of flocculent organic material, or "floc," were estimated in Water Conservation Area 2A (WCA-2A) at sites F1 and U3 (fig. 1). These two sites are located along a research transect where water generally flows toward the southwest.

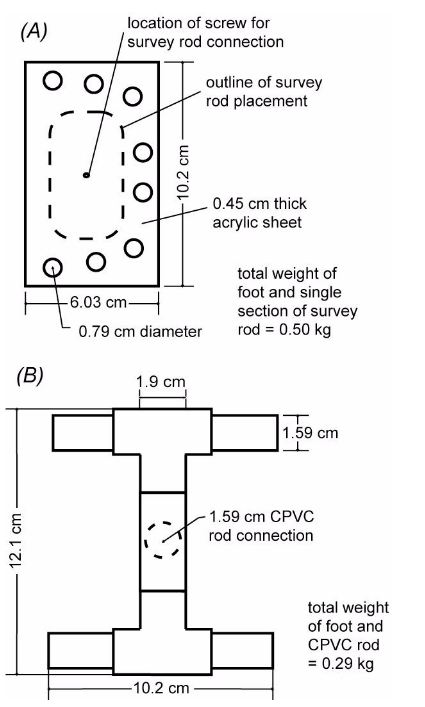

Figure 2. Top view schematics of type I *(A)* and type II *(B)* measuring tools.

Two types of measurement tools were used to determine the microtopography at different vertical and horizontal scales. Schematic diagrams of the measurement tools are shown in figure 2. The type I tool generally did not penetrate the floc, and estimated the elevation of the top of the floc layer. Due to its more open footprint, the type II tool penetrated the floc and was used to measure the elevation of the peat surface, which is considerably firmer than the floc. Field measurements of microtopography were made in different vegetative conditions near sites F1 and U3 (fig. 3), and the measurements were distributed so that the variability of the wetland surface could be characterized for 100-meter and 1-meter spatial scale. Measurements show that the elevation of the peat surface varies 3-4 times more at the 100-m scale compared with the 1-m scale (table 1, and fig. 4).

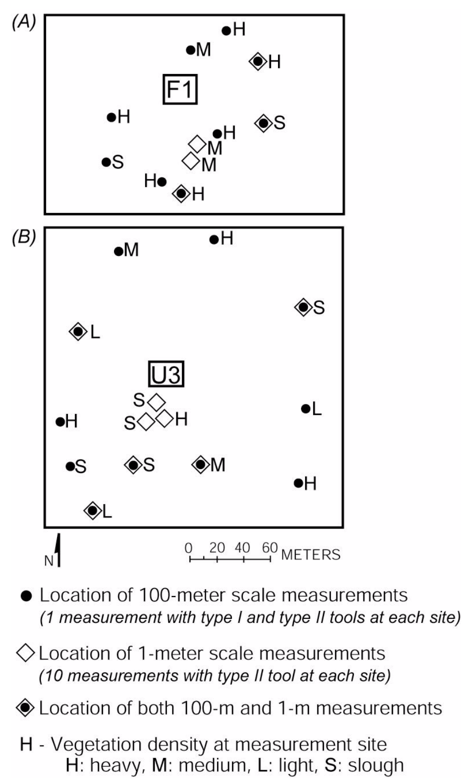

Figure 3. Location of microtopography measurements at site F1 *(A)* and site U3 *(B)*, WCA-2A, central Everglades, south Florida.

Table 1. Microtopographic variability of peat surface elevation (type II tool).

Horizontal Scale of Measurement	2 Standard Deviations of the Peat Surface Elevation	
	F1	U3
1-meter	0.20 ft	0.14 ft
100-meter	0.76 ft	0.48 ft

Microtopography data for sites F1 and U3 are summarized in figure 5 by plotting an inverse distribution function, i.e. elevation of the peat or floc surface versus the probability of occurrence when sampling at the 100-m scale. The x-axes in figure 5 can be interpreted as the fraction of wetland cross-section that has an elevation equal to or less than a given elevation. Using this function allows estimation of the average wetland cross-section available for surface flow at a given surface-water level.

Our ongoing work focuses on using the microtopography distributions in a surface-water flow model. In addition to using microtopography data to compute the cross-sectional area of surface flow over a period of fluctuating water levels, these data are being used to quantify the water exchange fluxes that occur between the surface water and the porewater of sediments that become exposed at low water levels. The micro-topography measurements are also being used to identify critical surface-water levels below which the micro-topography becomes a dominant factor in flow resistance.

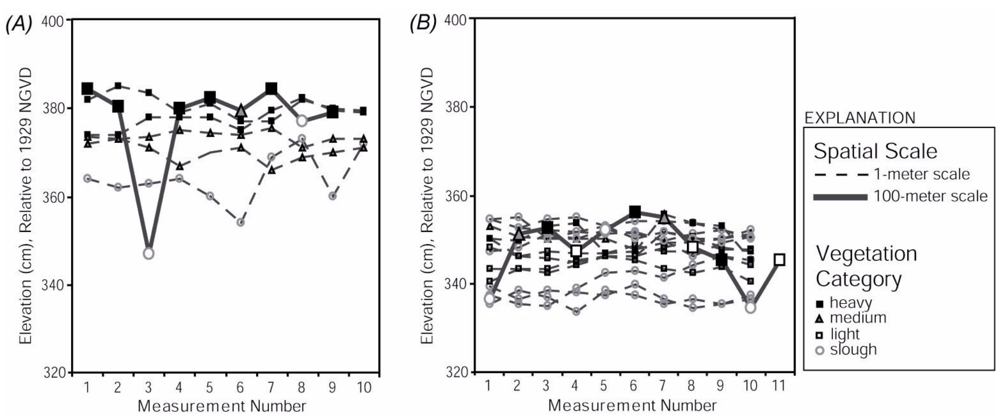

Figure 4. Variability of peat surface elevation (type II tool) at 1-meter and 100-meter measurement scale. Site F1 *(A)* and site U3 *(B)*, WCA-2A, central Everglades, south Florida.

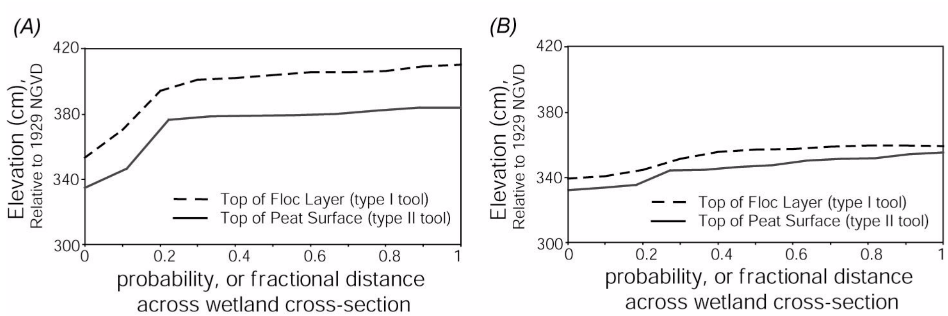

Figure 5. Inverse cumulative distribution function of elevation measurements at site F1 *(A)* and site U3 *(B)*, WCA-2A, central Everglades, south Florida.

Contact: Judson W. Harvey, U.S. Geological Survey, 430 National Center, Reston, VA 20192, Phone: 703-648-5876, Fax: 703-648-5484, jwharvey@usgs.gov, Hydrology and Hydrologic Modeling

Estuarine Creek Responses to Extreme Hydrologic Events in Northeastern Florida Bay

By Clinton Hittle
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Understanding salinity and circulation dynamics along the boundary between the Everglades and Florida Bay is an important component of Everglades restoration. Hydrodynamic models that simulate flows, water levels, and salinity within Florida Bay and the interior wetlands are considered valuable tools for assessing proposed management practices in the Comprehensive Everglades Restoration Plan (CERP) and for evaluating water control structural modifications. Detailed information on how estuarine creeks respond to extreme hydrologic conditions along the boundaries between estuaries and wetlands will improve model verification.

Data on water velocity, water level, salinity, and temperature are currently being collected continuously at 14 U.S. Geological Survey (USGS) monitoring stations in northeastern Florida Bay (fig. 1). Data from the monitoring stations are available from 1996 to present.

These data allow a detailed examination of estuarine creek response to extreme hydrologic events. Two creeks (McCormick and Trout) are presented here for comparison. Daily mean values of stage for Trout Creek (fig. 2) identify most of the major storms that affected northeastern Florida Bay since 1996, including five hurricanes, two tropical storms, and an El Niño related winter storm.

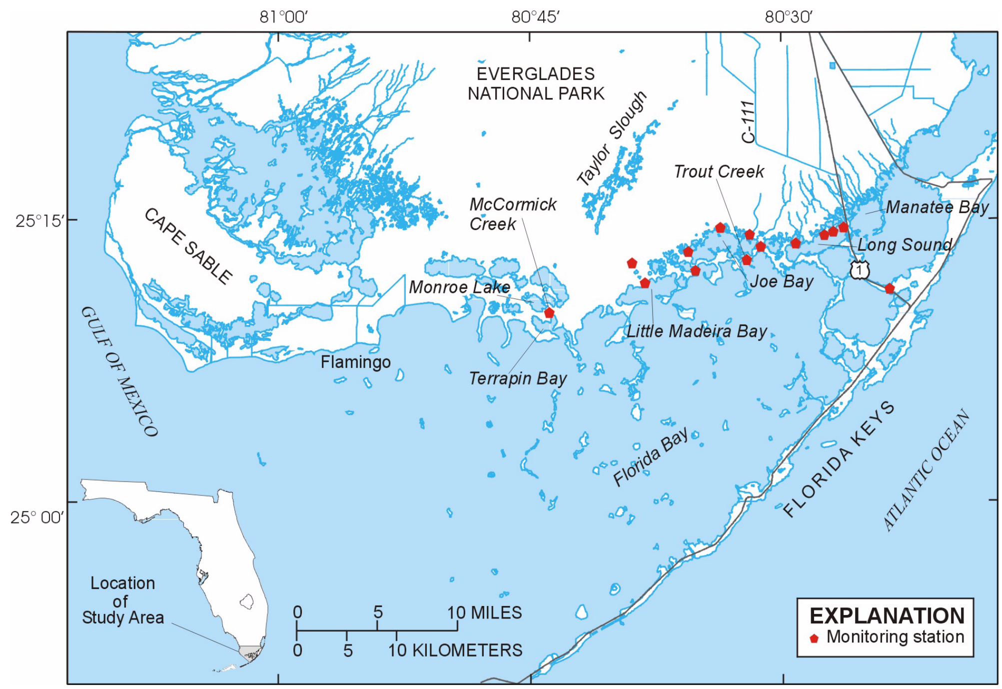

Figure 1. Location of Florida Bay monitoring stations.

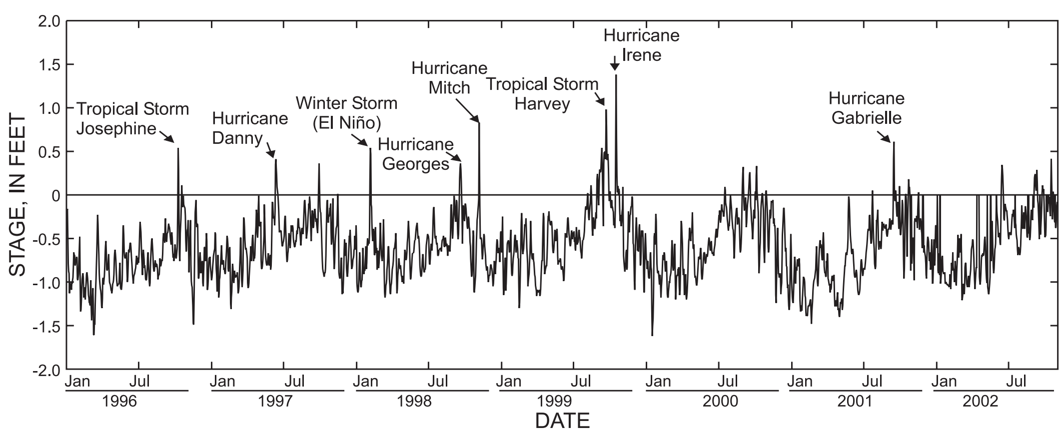

Figure 2. Daily mean values of stage for Trout Creek, 1996 – 2002.

A comparison of storm surges between McCormick Creek and Trout Creek for Tropical Storm Harvey and Hurricane Irene indicates how storm strength and path can affect water levels and salinities across central and eastern Florida Bay. Tropical Storm Harvey made landfall near Everglades City on September 21, 1999 and moved east-northeast across Florida. Water levels between the two creeks were similar in magnitude during Harvey (fig. 3).

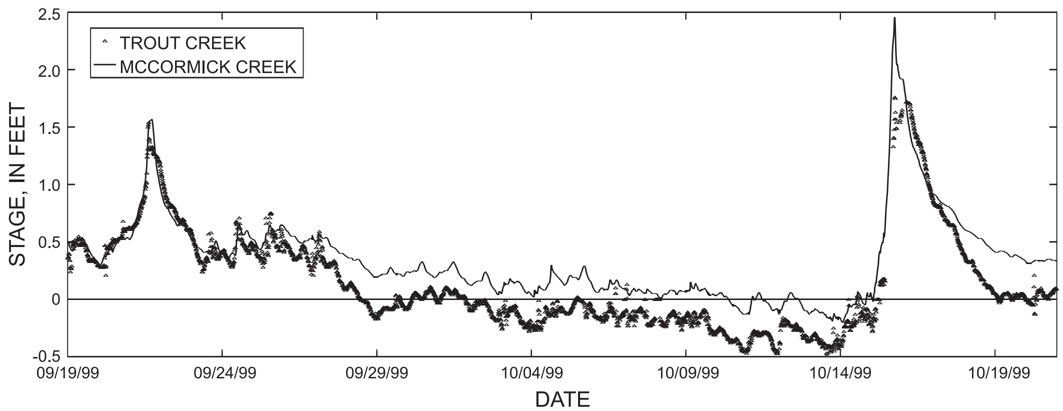

Figure 3. 15-minute interval stage values for McCormick and Trout Creek during Tropical Storm Harvey and Hurricane Irene.

Hurricane Irene made landfall near Cape Sable on October 15, 1999 and moved to the northeast across Florida. Storm surge from Irene increased water levels at McCormick Creek about one foot more than at Trout Creek.

Increases in salinity at McCormick Creek and Trout Creek were observed during storm surges for both Harvey and Irene. During Harvey, McCormick Creek experienced an increase in salinity from about 20 to 30 parts per thousand (ppt) in 20 hours, with a subsequent decrease back to 20 ppt in only four hours (fig. 4).

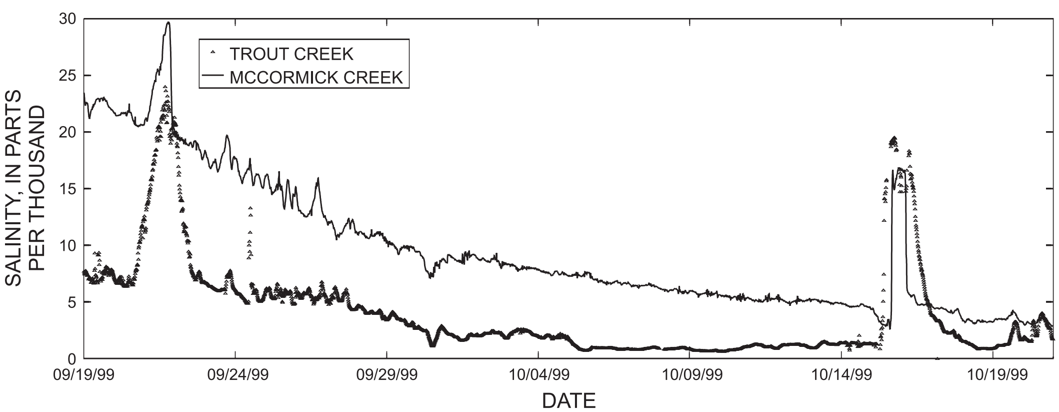

Figure 4. 15-minute interval salinity values for McCormick and Trout Creek during Tropical Storm Harvey and Hurricane Irene.

At Trout Creek, salinity increased from about 7 ppt to 24 ppt in 24 hours, but took another 24 hours to drop back to 7 ppt (pre-surge conditions). During Hurricane Irene, McCormick Creek salinity increased from about 5 ppt to 17 ppt in 6 hours with a subsequent decrease to 5 ppt in 13 hours. Trout Creek salinity during Irene's passage increased from about 1 ppt to 20 ppt in 10 hours, decreasing back to 5 ppt over the next 24 hours. After an additional 42 hours, salinity returned to the pre-storm level of about 1 ppt. Both creeks experienced a greater salinity increase from Irene than Harvey. Residence time was also greater because more saline water associated with the surge was pushed upstream.

A detailed evaluation of estuarine creek responses to extreme hydrologic conditions and subsequent comparison to hydrodynamic model output will help verify model capabilities in simulating natural systems. The evaluation also will support a science-based approach for CERP activities.

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Continuous Hydrologic Data in Florida Bay Channels

By Clinton Hittle and Grant Poole
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Hydrologic data from six channels within Florida Bay (fig. 1) are being collected by the U.S. Geological Survey (USGS) to help understand flow characteristics and better define the transport of post-larval Pink Shrimp into and out of the bay. The data will improve hydrodynamic and biological models being developed for use with the Comprehensive Everglades Restoration Plan (CERP), a goal of which is to improve the quantity, quality, timing, and distribution of flows within the Everglades ecosystem. Continuous water velocity, stage, salinity, and temperature data have been collected at 15-minute intervals since January 2002. Monitoring stations are co-located with post larval pink shrimp nets managed by the USGS, National Oceanographic and Atmospheric Administration (NOAA), and the University of Miami Rosenstiel School of Marine and Atmospheric Science (RSMAS).

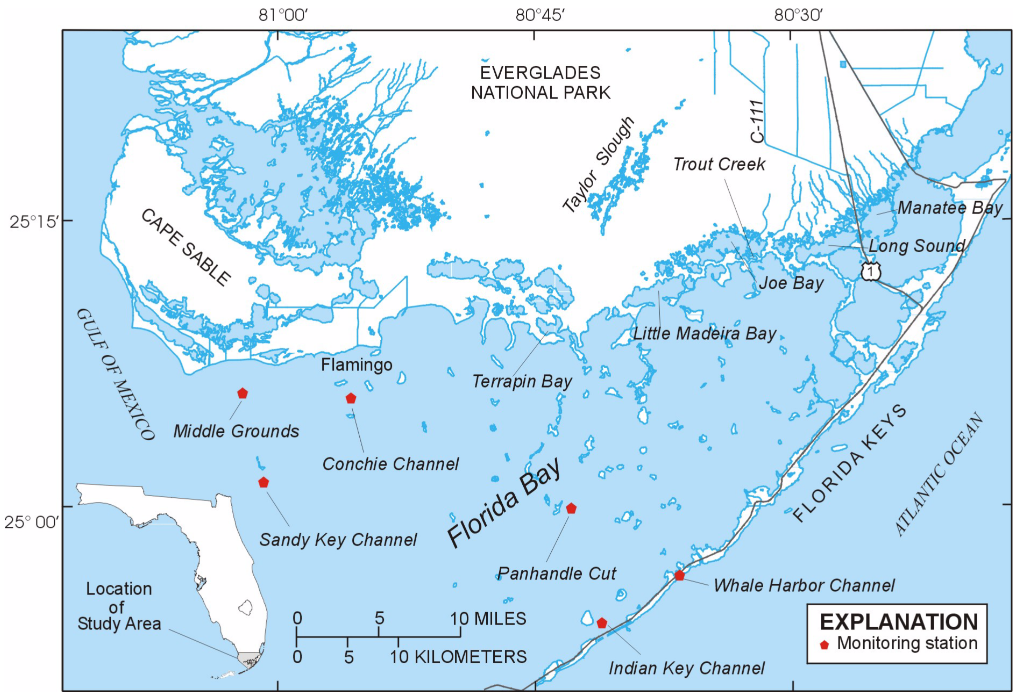

Figure 1. Location of Florida Bay monitoring stations.

Figure 2. Helicopter based survey method.

All stations have salinity/temperature probes installed at about mid depth in the channel; probes are cleaned and calibrated during routine site visits. Elevations were established on each station in 2002 by the USGS and are referenced to the North American Vertical Datum of 1988 (NAVD 88). Elevation data was computed using a helicopter-based differential global positioning system coupled with a mechanical height finder (fig 2). The elevation data established at each monitoring station allows for comparisons of water level between the sites.

Acoustic Doppler Velocity Meters (ADVM) continuously monitor flow conditions and water levels within the channels. The ADVM measures an average water velocity within a fixed sample volume. Continuous channel discharge is computed using velocity data collected from the ADVM and a boat mounted Acoustic Doppler Current Profiler (ADCP). Regression analysis is used to relate the ADVM velocity to mean measured velocity calculated during ADCP discharge measurements. The resulting equation, known as an index velocity rating, converts all ADVM index velocities into approximate mean channel velocities. These corrected velocities are multiplied by the channel area to produce continuous discharge record. Acquiring ADCP discharge measurements over the entire range of flow conditions expected to occur at the site improves this computation method. Figure 3 shows the relation between index velocities and ADCP mean measured velocities at Whale Harbor Channel.

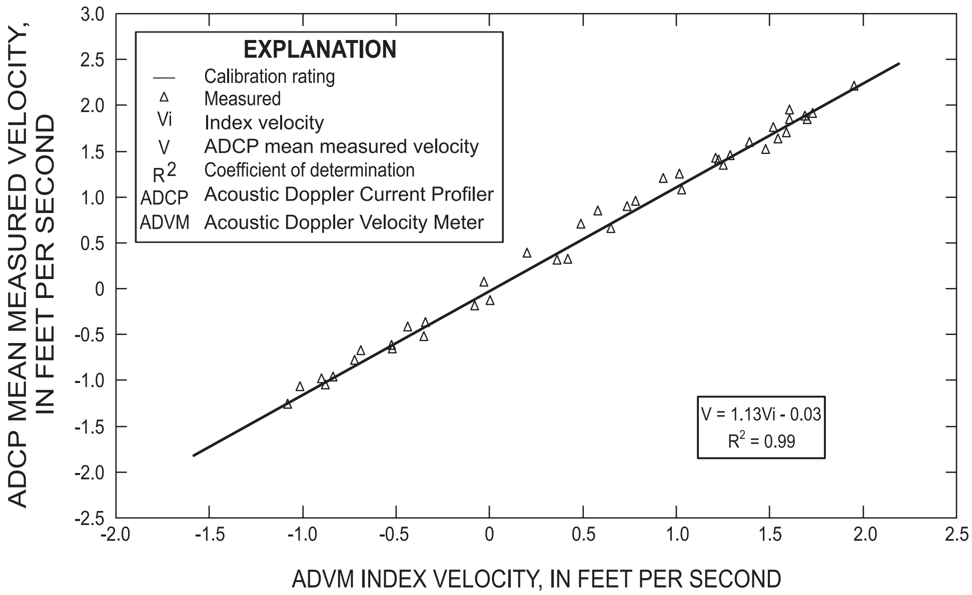

Figure 3. Velocity relation for the Whale Harbor monitoring station

The continuous discharge data from these sites will benefit studies that require estimates of total hydraulic transport into and out of the bay, while the continuous data for all parameters will be valuable for verifying future simulations of Florida Bay hydrodynamics.

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Vegetative Habitats of Water Conservation Area-3A: Hydrologic Impacts of IOP

By Wiley M. Kitchens[1], and Paul Wetzel and Erik Powers[2]

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A vegetation monitoring study has been initiated in Water Conservation Area-3A (WCA-3A) to document impacts of a new hydrologic regulation schedule implemented 1 July 2002 under the Interim Operation Plan for the Protection of the Cape Sable Seaside Sparrow, Everglades Park – Alternative 7R (IOP-Alt.7R). This study was implemented to address the concern that IOP-Alt.7R could adversely affect the endangered snail kite (*Rostrhamus sociabilis)* and their habitat in WCA-3A, the largest and most consistently utilized of designated critical habitats. Much of the area is already currently seriously degraded. Various studies have documented the conversion of wet prairies (preferred foraging habitat) to aquatic sloughs in that area along with losses of interspersed herbaceous and woody species essential for nesting habitat. The concern is carrying capacity (habitat quality) will be further impaired from elevated water depths and increased hydroperiods indicated by hydrological predictions.

The principal objective is to separate plant community responses due to typical seasonal and year-to-year variances from effects due to new and (or) predicted hydrologic regimes. The vegetative community structure of these sites is an expression of *both* recent past and current hydrological conditions. It is critically important to determine how the species associations within these communities respond differentially to changes in hydrology through time and over space. Given the immense area of WCA 3A, this study focuses on areas represented by two Indicator Regions (IR's 14 and 17). The areas include major gaging stations (GS 63, 64, and 65) and traditional foraging and nesting regions used by kites.

A multi-tiered approach was required to determine community change through time and space while differentiating seasonal responses from projected hydrologic changes.

1) Spatial Patterns and Change Detection at the Broad Vegetation Class Level- (example, sawgrass strands, tree islands, cattail patches, and wet prairie/slough). Aerial or satellite imagery will be used to remotely sense spatial distributions, extent, and patterning of broad major vegetation classes. Change detection will conducted on at least three sets of imagery, 4-5 years pre-project, at project onset, and 3-4 years post-project.

2) Development of "modeled-topographic" database and hydrologic characterization of Indicator Regions. Stage information generated by SFWMM model for the units comprising each Indicator Region is gridded 2 mi. on a side. Stage duration curves generated from this data are determined from estimated ground surface elevations generalized from a weighted mean over the 4 sq. mi. area of each grid. This level of detail is far too generalized for assessment impacts to habitat suitability of wetland vegetation for subtle changes in hydroperiods and inundation depth regimes. To resolve this issue, we have located 10 sample complexes (1 kilometer on a side) within each of the indicator regions (14 and 17) (Fig. 1) using a stratified random approach (peat depths, general elevation, and snail kite nest density). Water levels will be continuously monitored in each complex. Each complex is subdivided into a grid 100-m on a side. Replicate ground surface elevations will be measured (survey-grade GPS) in each major plant community types (as per vegetation maps as per above) near the intersection points in the grid. Elevations will be surveyed for each of the plant types separately in each grid by confining kreiging routines for the elevations for that plant type only within polygons labeled for that type. This is repeated for each plant type and each cell. Polygons are re-composited and merged in a GIS providing a topographic database driven by plant community types. Stage data for the sample complex will be related to elevation data specific to each plant community type creating stage duration curves for each vegetation type in the individual cells. Long term and predicted hydroperiod and depth duration data for each vegetation type in each cell will be generated by statistical regression with the nearest permanent gaging station.

3) Establishment of permanent transects plots across elevation gradient in each Indicator Region. Permanent monitoring plots (combinations of quadrats and transects) have been established in the sample complexes across the local elevation gradient in each complex. Regularly placed multiple or replicate quadrats arrayed as continuous belts along a transect perpendicular to the elevation gradient within each sample complex. Each site is sampled seasonally (3 times/yr) for species numbers, stem counts, and biomass (both living and standing dead). Water depths are monitored continuously within each sample complex for determinations of hydroperiods and depth duration curves. Each complex consists of three belt transect complexes, five plots of the principal habitat types (sawgrass, wet prairie, sloughs), and five permanent tree island/ shrub heads plots sites typical of kite nest habitat. Multivariate techniques (NMS and multivariate regression tree, and structural equation models) will be used to resolve relation between plant community structure and hydrology. Structural equation modeling (SEM) will define statistical correlations among species and associated hydrologic and other environmental parameters and provide probabilistic measures for environmental mechanisms involved in plant community succession.

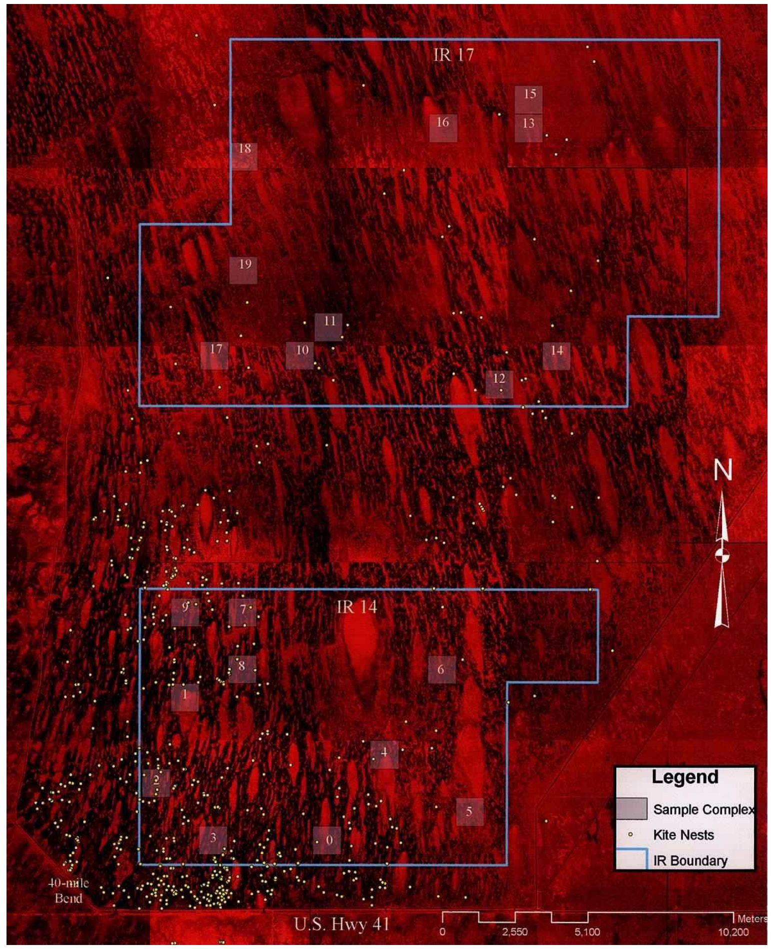

Figure 1. Image of WCA-3A indicating IR and sample complex locations.

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The Role of Seasonal Hydrology in the Dynamics of Fish Communities Inhabiting Karstic Refuges of the Florida Everglades

By Robert M. Kobza *and* William F. Loftus
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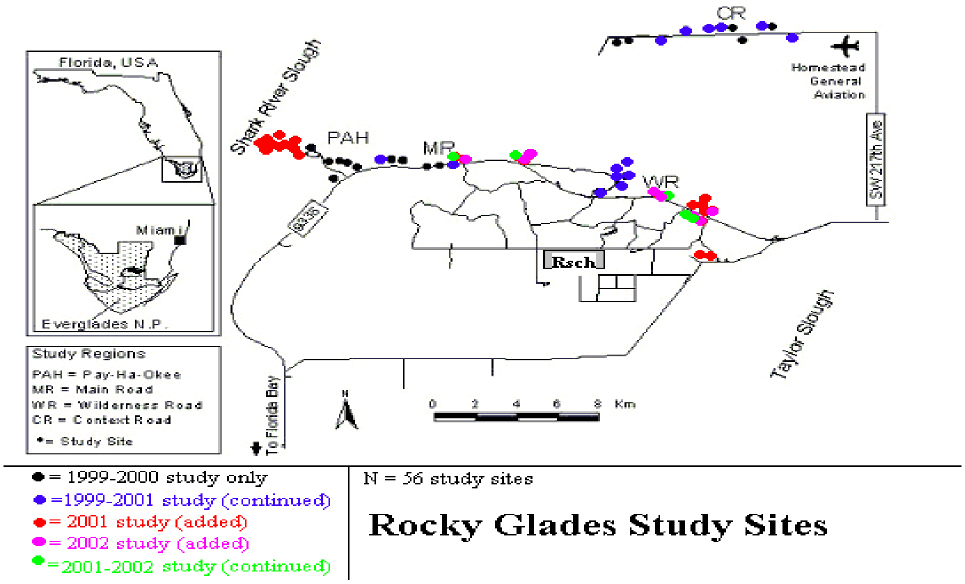

Figure 1. Map of sampling locations in Everglades N.P.

Our goal is to understand the influence of altered surface flooding on access to groundwater refuges for surface-dwelling aquatic animals, primarily fishes, in the karstic wetlands east of Shark River Slough, Everglades National Park, Florida, USA. The current management proposal for these wetlands call for water levels to not fall more than 46 cm (1.5 ft) below ground level for greater than 90 days per year at an average periodicity of no more than once in three years. This study includes four areas in the extreme southeastern Everglades (fig. 1) and is in its fifth year. We will present the results of data collected in 1999-2000 in addition to those from 2001-2002. We suggest that the impact of groundwater management on dry-season refuges should be considered when establishing criteria for species management.

The solution hole environment became more lethal to fishes as water levels receded. From analysis of a number of factors, temperature, pH, dissolved oxygen, and chlorophyll a were most significant in structuring dry-season fish communities in 1999 and 2000. These factors changed on a seasonal basis, with nutrient concentrations increasing (fig. 2) and dissolved oxygen decreasing in holes during the dry season. In our four study regions, 84 percent of solution holes were less than 46 cm deep, and those deeper than 1 m were rare (< 3 km^{-2}) (fig. 3).

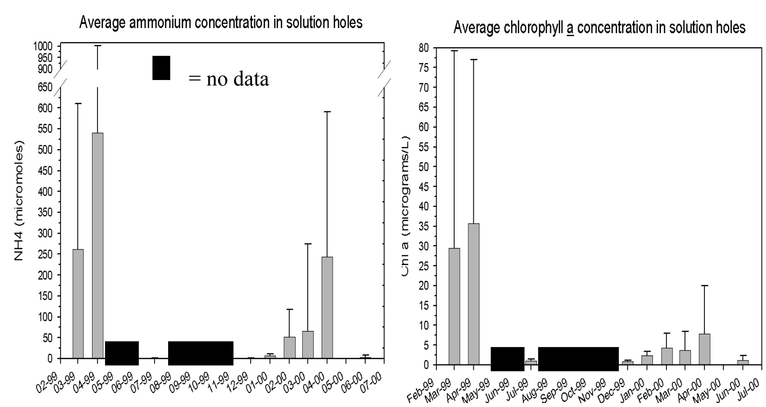

Figure 2. The concentration of nutrients in solution holes by month.

The capture of fishes in solution holes increased as water levels fell until mid-dry season. This was followed by a significant decline in the late dry season, and a subsequent increase in early wet season (fig. 4). This pattern indicates that fishes are surviving in solution holes until conditions become critical. Mortalities then occur, but holes are repopulated by subsequent re-invasions of foraging and nesting species upon

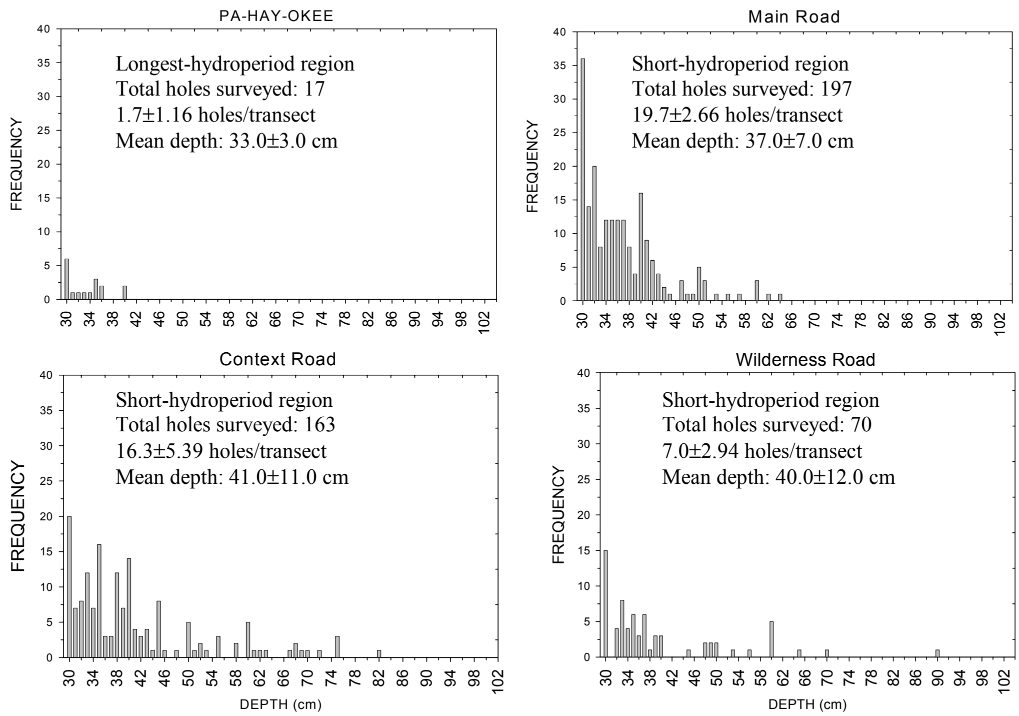

Figure 3. Depth frequency of solution holes by region.

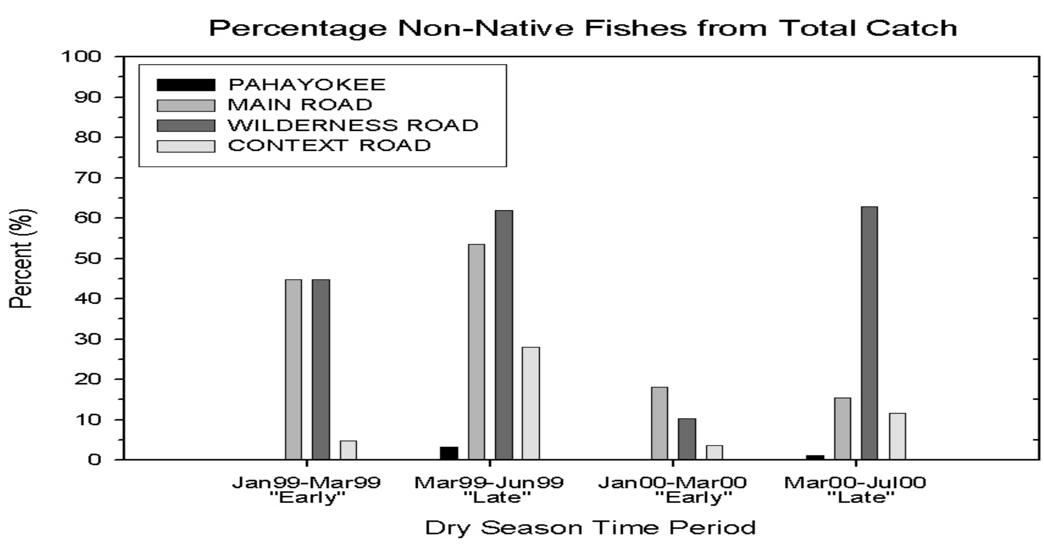

Figure 4. Average catch-per-unit-effort (CPUE) of fishes and average water depth across all regions in 1999 and 2000.

inundation. Native cyprinodontiforms were abundant in shallow solution holes that dry annually under current management, while predatory species (often non-native) tended to dominate deeper holes. The percentage of non-native fishes captured varied by season and across regions, with a maximum of 63 percent occurring at the Wilderness Road region, and an average of 23 percent non-native fishes across all regions and seasons (fig. 5).

Our work suggests that solution holes serve as necessary dry-season habitat and that an immense loss of fish biomass occurs when water levels fall 46 cm below ground surface within our study regions. We recommend that the effect of groundwater management on dry-season and drought refuges should be included while developing criteria for minimum flows and levels for the management of the Everglades and other aquatic ecosystems.

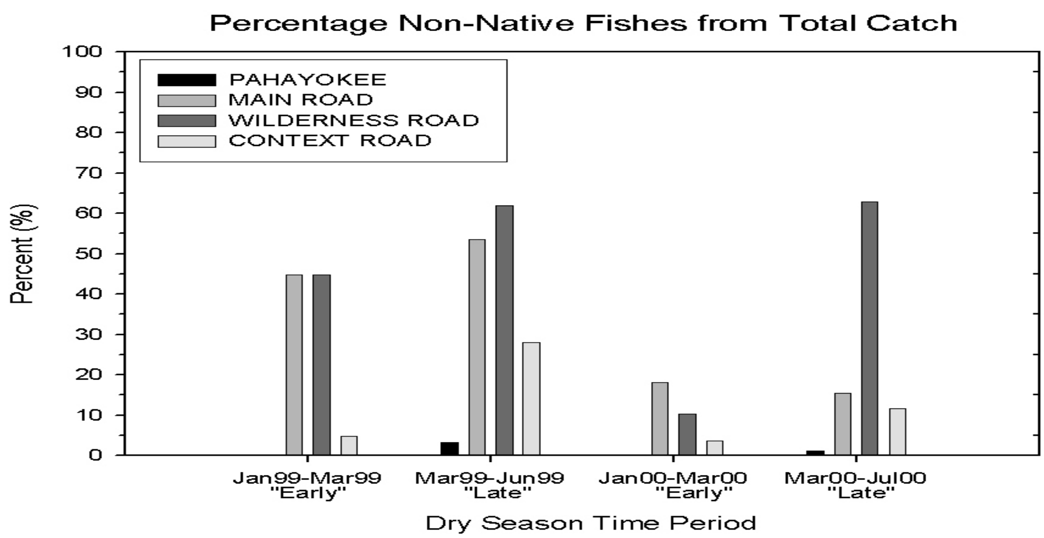

Figure 5. Percentage of non-natives in total fishes captured in holes by “early” (January-March) and “late” (March-July) dry-seasons for 1999 and 2000.

This research was funded through the Critical Ecosystem Studies Initiative by agreement between the U. S. Geological Survey (USGS) and the U. S. National Park Service.

Contact: Kobza, Robert, U. S. Geological Survey, 40001 State Road 9336, Homestead, FL, 33034-6733, Phone: 305-242-7800, Fax: 305-242-7836, Robert_kobza@usgs.gov, Ecology and Ecological Monitoring

The Effects of Hydroperiod on Life-History Parameters of two Species of Livebearing Fish (Poeciliidae) in the Florida Everglades

By Timothy Konnert[1], Joel C. Trexler[1], *and* William F. Loftus[2]

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Ecologists often make assumptions about the “stressfulness” of habitats based on fluctuation in the physical environment and its presumed effects on organismal vital rates such as age-specific survivorship or fertility. In aquatic habitats, fluctuations in water level leading to dry-down events are often considered “stressful” for fishes because it is assumed that reduced habitat area and crowding have adverse effects on survivorship and fertility. However, the degree of drying, as demonstrated by variations in minimum surface-water depths, is rarely constant among years in the Everglades. That variation may produce dramatically different effects on the fish community, depending on factors such as availability and quality of refuges that remain wetted. Furthermore, organisms typically have physiological and behavioral adaptations to compensate for environmental variability, including synchronization of reproductive and migratory patterns with environmental fluctuation, and phenotypic plasticity. Consequently, the matching of recurrent “stress” with measures of survivorship and reproduction are critical to produce predictive demographic models. While comparative statements about the relative stressfulness of habitats are common in the literature on life histories, we question the ability to make such comparisons without age-specific survival and fertility data. To improve the utility of management models such as ATLSS, we sought to estimate explicitly the effects of hydroperiod on demographic rates of two of the most common species in the Everglades, the sailfin molly and the least killifish (Poeciliidae) (fig. 1).

Figure 1. Top: sailfin molly (*Poecilia latipinna*); bottom: least killifish (*Heterandria formosa*).

We used estimates of age-length relation to estimate age-specific survival and fertility for sailfin mollies and least killifish from six sites in the Everglades that experience a gradient of hydrological conditions (fig. 2). These six sites are the focus of long-term monitoring of fish communities, and we used samples collected from 1997 to 1999 to estimate age-specific survivorship curves and fertility schedules. From those data, we constructed life tables to compare patterns in vital rates of each species with hydroperiod. Also, we compared the idealized estimate of population growth rate from the life table to real population dynamics over the same time period. Otoliths were used (fig. 3) to determine the relation between size and age for male, female, and juvenile sailfin mollies from the six study sites (fig. 4).

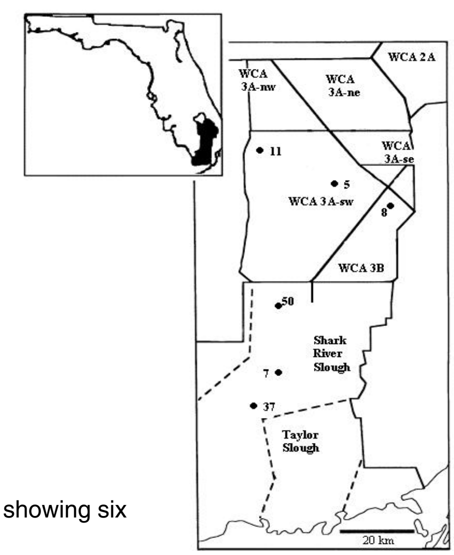

Figure 2. Map showing six study sites.

Calibrations indicated that this method was very accurate for juvenile fish, but tended to under-estimate age in older, mature specimens.

We also dissected female fish from the long-term field collections to estimate size-specific fertility for females of each species. We used the otolith data to estimate the age of females based on size in order to transform these data into age-specific fertility tables for each study site.

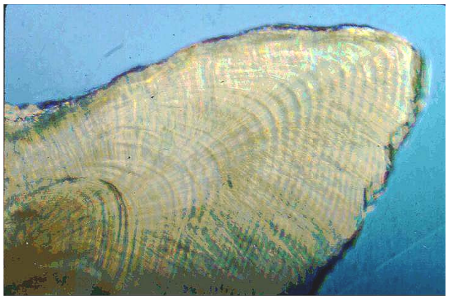

Figure 3. Cross-section of a sailfin molly otolith. The number of rings indicates the fish's age in days.

The analyses indicated that growth rate and age-specific fertility differed among locations, and that some patterns could be explained by hydroperiod. However, many of the patterns were not consistent with the expectation that short-hydroperiod sites are more stressful for these two species. For example, the longest life expectation and highest lifetime fertility were noted at the short hydroperiod sites for both taxa. These results yielded greater estimates of population growth rate [r] for the two short-hydroperiod sites. Either both species have adaptations that permit them to circumvent the conditions that make these sites appear stressful to ecologists, or immigration is subsidizing populations in short-hydroperiod sites yielding a more favorable demographic profile than is actually realized by residents of the site. Ongoing research on dispersal by similar species before and after droughts suggests a complex pattern that may include dispersal from long-hydroperiod sites to the short-hydroperiod sites, and persistence in local refuges. The exact role of dispersal in re-establishing short-hydroperiod fish populations appears to depend on local topography and ambient rainfall. On the other hand, our data are consistent with the long-held hypothesis that small fish species experience less predation from piscivorous fish in short-hydroperiod than in long-hydroperiod habitats. This hypothesis predicts that these fishes should experience longer life spans in short-hydroperiod sites, as we observed. More research is needed on the relative role of immigration as a mechanism to sustain small fish populations in short-hydroperiod marshes of the Everglades. This study suggests that management models of fishes must incorporate rapid recovery from drought events. Some species may experience greater population growth rates in short-hydroperiod habitats, although ultimate population sizes may be limited by periodic dry down, site productivity, and other factors.

This research was funded through a cooperative agreement between the USGS and FIU under the Place-Based Studies initiative of the USGS (CA 1445-CA09-95-0112, Sub-agreement No. 12).

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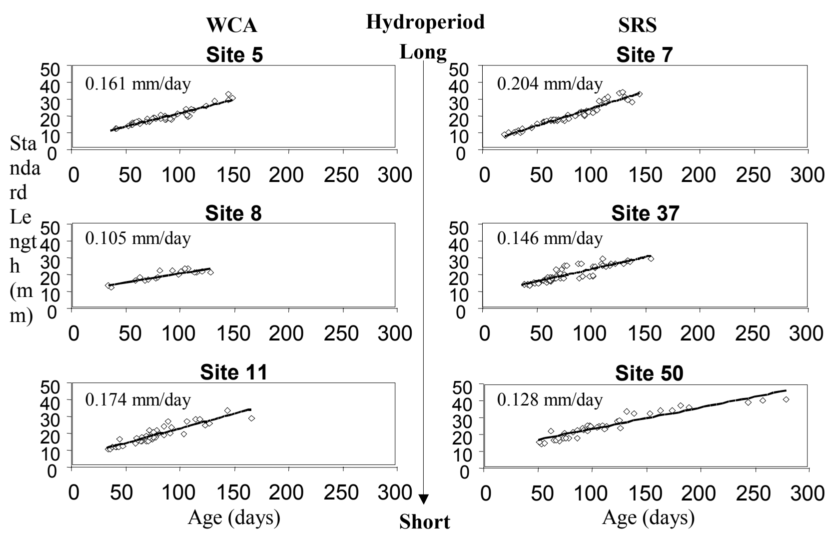

Figure 4. Size-age relationships for female sailfin mollies from our six study sites. The slopes of each line are indicative of growth rate.

Recharge and Discharge Measurements in the Everglades using Short-lived Radium Isotopes

By James M. Krest *and* Judson W. Harvey

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The Everglades peat layer acts as an interface between groundwater and surface water, a zone where the interactions between physical, chemical and biological processes are enhanced, influencing the cycling of elements between water and sediments. Common methods for measuring exchange across the peat layer are prone to complications. For example, hydrologic approaches yield results with high variances when small hydraulic gradients are encountered, especially over short distances. Likewise, direct seepage-meter measurements tend to be imprecise at low seepage rates. Furthermore, some geochemical approaches (e.g. radon and chloride) rely on the measurement of fine scale gradients that are frequently affected by processes independent of recharge or discharge (e.g. methane ebullition or mechanical disturbance of the surface sediments). We present here a new method to quantify these slow vertical fluxes through the peat layer by modeling the pore-water profiles of ^{223}Ra and ^{224}Ra.

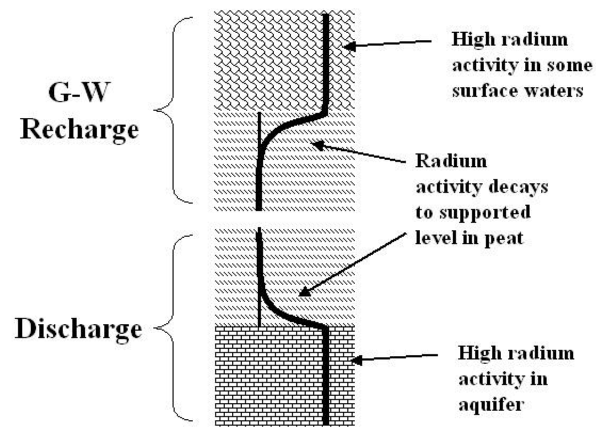

Figure 1. Idealized profiles showing the expected radium activities in surface water and peat pore-water for the cases of groundwater recharge (top) and groundwater discharge (bottom). Mixing due to dispersion could look similar to either of these profiles.

^{223}Ra ($t_{1/2}$ = 11.4 d) and ^{224}Ra ($t_{1/2}$ = 3.7 d) are naturally occurring isotopes of radium which are useful tracers for quantifying rates of groundwater recharge and discharge in wetlands, particularly for time scales of a few days to weeks. Near the interface between peat sediments and the underlying aquifer, or near the interface between the peat and overlying water, pore-water radium activities are commonly different than the amount expected from the radium production rate (fig. 1). This disequilibrium results from vertical transport of radium by pore water. In situations where groundwater recharge or discharge is significant, the rate of vertical water flow can be determined from this disequilibrium using a combined model of radium transport, production, decay, and exchange with solid phases:

$$\frac{\partial C}{\partial t} = \underbrace{D\frac{\partial^2 C}{\partial Z^2} - v\frac{\partial C}{\partial Z}}_{\text{transport}} + \underbrace{\frac{\hat{P}\rho}{f\,K_D + (1-f)}}_{\text{production}} - \underbrace{\lambda C}_{\text{decay}} + \underbrace{\frac{\partial C^*}{\partial t}\frac{\rho}{K_D}}_{\text{exchange}}$$

where C is the number of dissolved radium atoms per volume of water, C^* is the number of adsorbed radium atoms per mass of dry sediment, t is time, Z is depth below the peat surface, D is the hydrodynamic dispersion coefficient, v is the pore-water advective velocity, f is the mass of dry sediment per mass of bulk sediment, K_D is the ratio of adsorbed to dissolved radium, $\hat{P}$ is the production rate exchangeable radium (adsorbed plus dissolved), is the radium decay constant, and is the pore water density.

We have developed and tested this technique at three sites in the freshwater portion of the Everglades by quantifying vertical advective velocities in areas with persistent groundwater recharge or discharge, and estimating a coefficient of dispersion at a site that is subject to reversals between recharge and discharge (Krest and Harvey 2003). Groundwater velocities (v) were determined to be between 0 and -0.5 cm d^{-1} for a recharge site, and 1.5 ± 0.4 cm d^{-1} for a discharge site near Levee 39 in the Everglades (fig. 2). Our approach has a distinct advantage in the Everglades because strong gradients in ^{223}Ra and ^{224}Ra usually occurred at the base of the peat layer, which avoided the problems of other tracers (e.g. chloride) for which greatest sensitivity occurs near the peat surface – a zone in which gradients are readily disturbed by processes unrelated to groundwater flow.

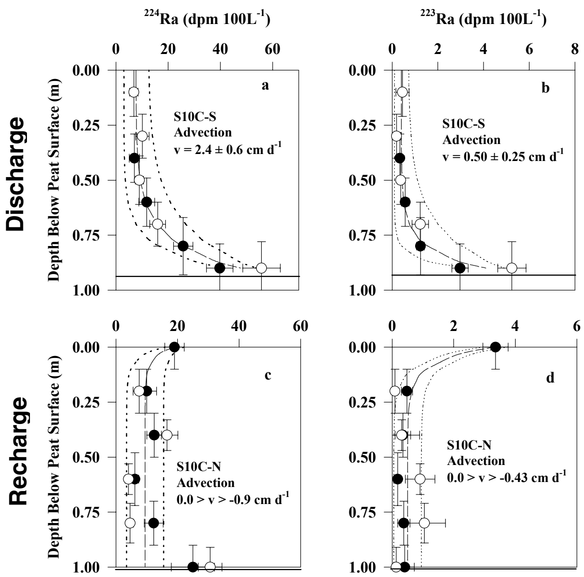

Figure 2. Pore-water radium activities as a function of depth. a) ^{224}Ra, and b) ^{223}Ra activities at site S10C-S are highest at the base of the peat and decrease upwards as the excess radium in discharging groundwater decays to a level supported by its equilibrium production and exchange with the adsorbed fraction. c) ^{224}Ra and d) ^{223}Ra activities at S10C-N are elevated only in the upper portion of the peat, suggesting that recharge occurs at this site.

This technique should be readily applicable to any wetland system that has different production rates of these isotopes in distinct sedimentary layers or surface water. The approach is most straightforward in freshwater systems because constant pore-water ionic strength can usually be assumed, which simplifies the modeling of radium exchange with solid phases. In estuarine or marine systems, changing ionic strength could be addressed with additional data and an extended model.

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Contact: Krest, James M., U.S. Geological Survey, 12201 Sunrise Valley Drive, Mail Stop 430, Reston, VA 20192; Phone: (703) 648-5472; Fax: (703) 648-5484; jmkrest@usgs.gov; Hydrology and Hydrological Modeling

Flows, Stages, and Salinities: How Accurate is the SICS Integrated Surface-Water/Ground-Water Flow and Transport Model?

By Christian Langevin, Eric Swain, *and* Melinda Wolfert

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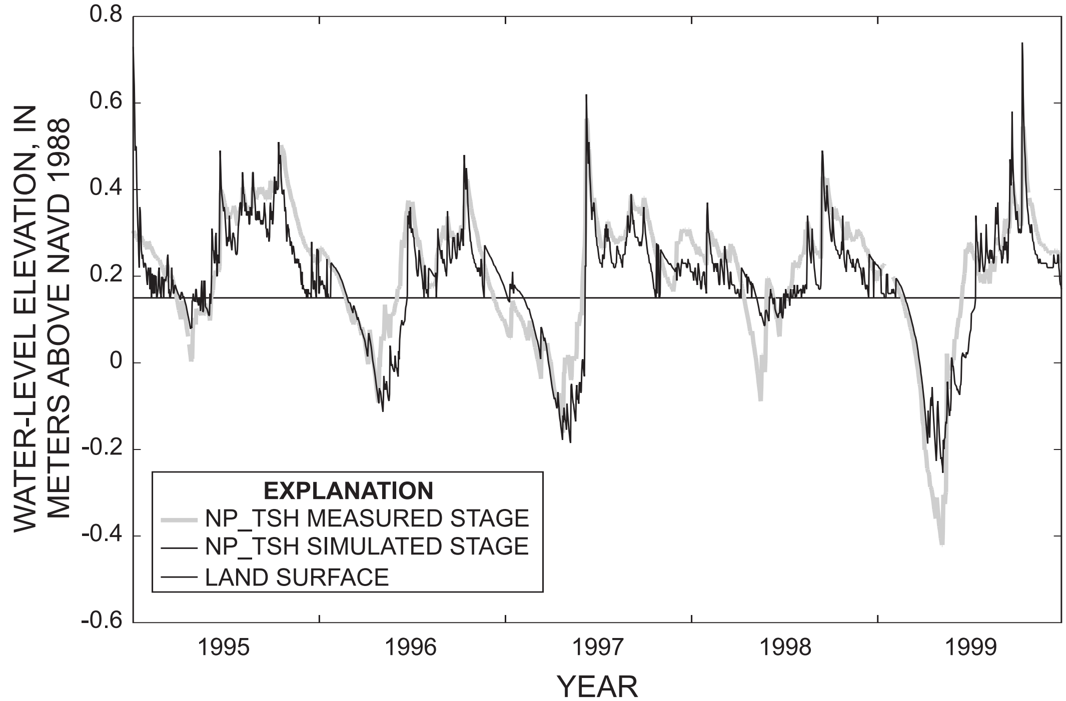

Figure 1. Measured and simulated stage at the TSH monitoring site, located in central Taylor Slough.

The Southern Inland and Coastal Systems (SICS) model was developed by the U.S. Geological Survey to simulate flows, stages, and salinities within the area surrounding Taylor Slough and northeastern Florida Bay. The SICS model consists of a two-dimensional hydrodynamic surface-water flow and transport model coupled to a three-dimensional variable-density ground-water flow and transport model. A description of the computer code used for the simulations is described in a companion abstract included in these proceedings. The current version of the model represents a 5-year period from January 1995 to December 1999. Comparisons between observed and simulated values of flow, stage, and salinity suggest that the model provides a good representation of the physical system; and that, with some additional effort, the model could be used to evaluate the hydrologic effects of the Comprehensive Everglades Restoration Project (CERP) on the coastal wetlands and northeastern Florida Bay.

Water-level hydrographs are useful ecological indicators because they can be used to calculate hydroperiod, which is the number of days per year with standing water. Within the Taylor Slough area, the SICS model seems to provide an accurate description of water-level fluctuations. Figure 1 compares measured and simulated stage for monitoring station TSH in central Taylor Slough. The mean absolute error in simulated water level for the 5-year period is 0.06 meters. The average hydroperiod at TSH calculated by the model (259 days) compares to within 2 percent of the hydroperiod calculated using measured data (255 days).

Trout Creek is the major outlet for freshwater flow from the coastal wetlands into northeastern Florida Bay. An advantage of using a fully hydrodynamic surface-water model instead of a simplified model that neglects the effect of wind, for example, is that volumetric discharge (and thus salinity) in complex coastal environments can be represented. For example, figure 2 shows the comparison between measured and simulated discharges for Trout Creek. Flow is positive for most of the simulation period, indicating discharge into Florida Bay. During periods of southerly winds, however, brackish water from Florida Bay is forced inland into the coastal wetlands. Although the current version of the SICS model simulates total discharge at Trout Creek that is slightly higher than measured discharge, figure 2 suggest the model is capable of representing overall discharge trends. The ability to represent transport, and thus salinity patterns, is another advantage to using a fully hydrodynamic surface-water model. Figure 3 shows the comparison between measured and simulated surface-water salinities at the mouth of Trout Creek. The mean absolute difference in salinity is 4.6 parts per thousand.

The SICS model has the potential for providing the important link between the managed hydrologic system of southeastern Florida and the Florida Bay estuary. One of the current plans is to complete the coupling of the SICS model with the South Florida Water Management Model (2x2). The linked SICS model could then be used to determine the effect of alternative water management scenarios on coastal wetland salinities and freshwater flows to Florida Bay.

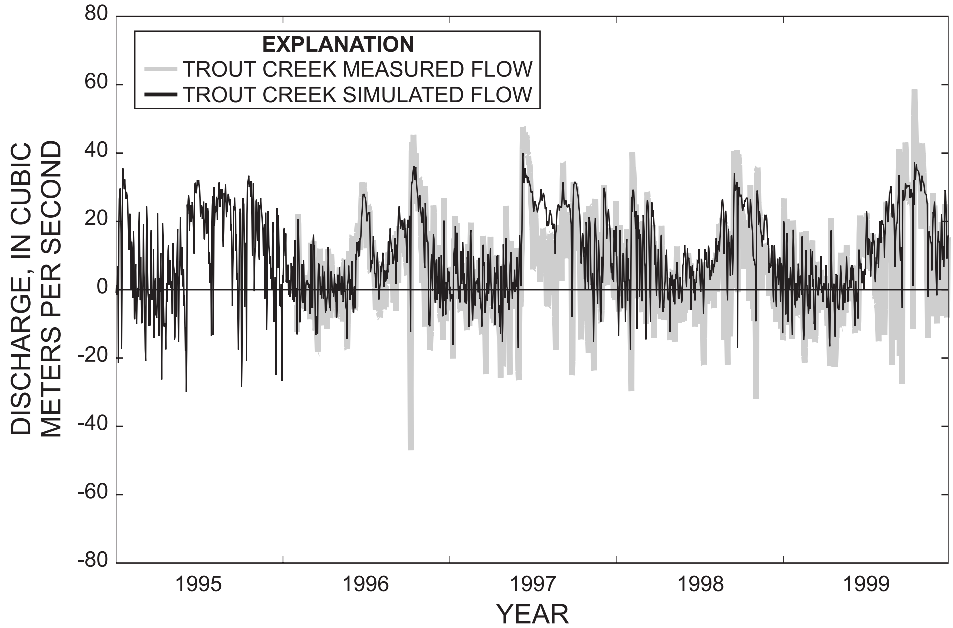

Figure 2. Measured and simulated discharge values for Trout Creek.

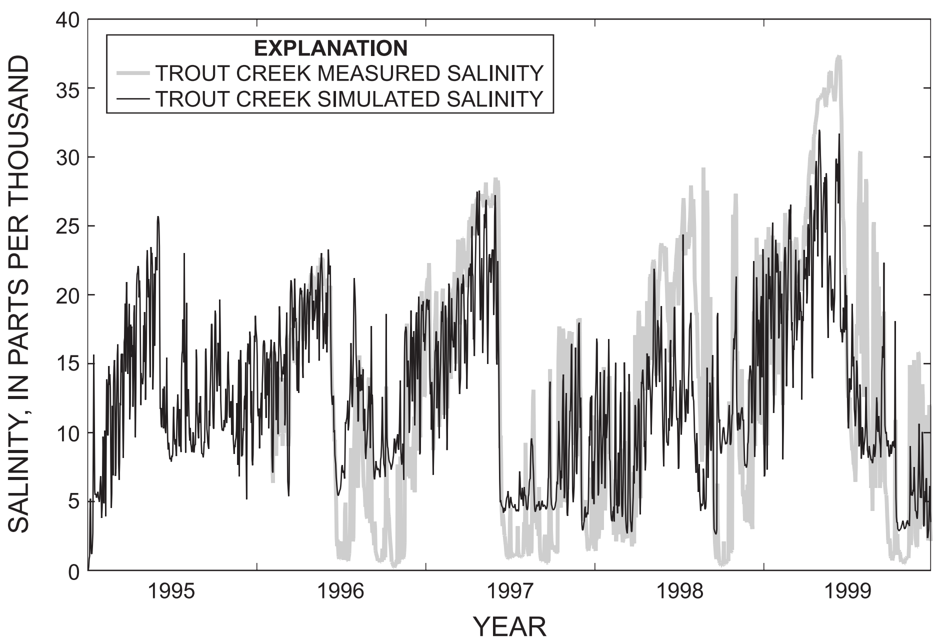

Figure 3. Measured and simulated salinity values for Trout Creek.

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Quantifying Internal Canal Flows in South Florida

By Mitch Murray, *and* Rick Solis

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The need to determine future surface-water flow requirements in the interior canal system of south Florida is being met with the successful implementation of strategic placed stream-flow and water-quality gaging sites in the interior of southern Florida. The multi-agency effort involves four entities that collect, analyze, and distribute information for water managers. In 1995 the U.S. Geological Survey (USGS) established three monitoring sites south of Lake Okeechobee in an effort to accurately gage flows in canals entering and exiting Tribal lands, the Big Cypress National Preserve, and Water Conservation Area 3A in southern Florida. These flows are also being monitored to calculate nutrient loads in the canals that cross or border Tribal lands. Two of the gaging sites, L-28U and L-28IN, are located on the southern border of the Seminole Tribal lands along the L-28 canal and the L-28 Interceptor canal, respectively, west of Water Conservation Area 3A in Hendry County (fig. 1). The third gaging site, L-28IS, is located along the L-28 Interceptor canal where flows enter the western lands of the Miccosukee Indian Tribe from the Big Cypress National Preserve in Collier County and has been discontinued.

Acoustic instrumentation, in lieu of standard methods for field data collection and flow computations, is used to quantify flows in the canals. Using the acoustic velocity meter (AVM), Acoustic Doppler Velocity meter (ADV), and the Acoustic Doppler Current Profiler (ADCP), it is possible to more accurately gage flows in this type of environment because of new capabilities to quickly measure low or rapidly changing water velocities. Construction, instrumentation, and calibration of the flow gaging sites were completed by the USGS during 1996 and 1997. The South Florida Water Management District (SFWMD)

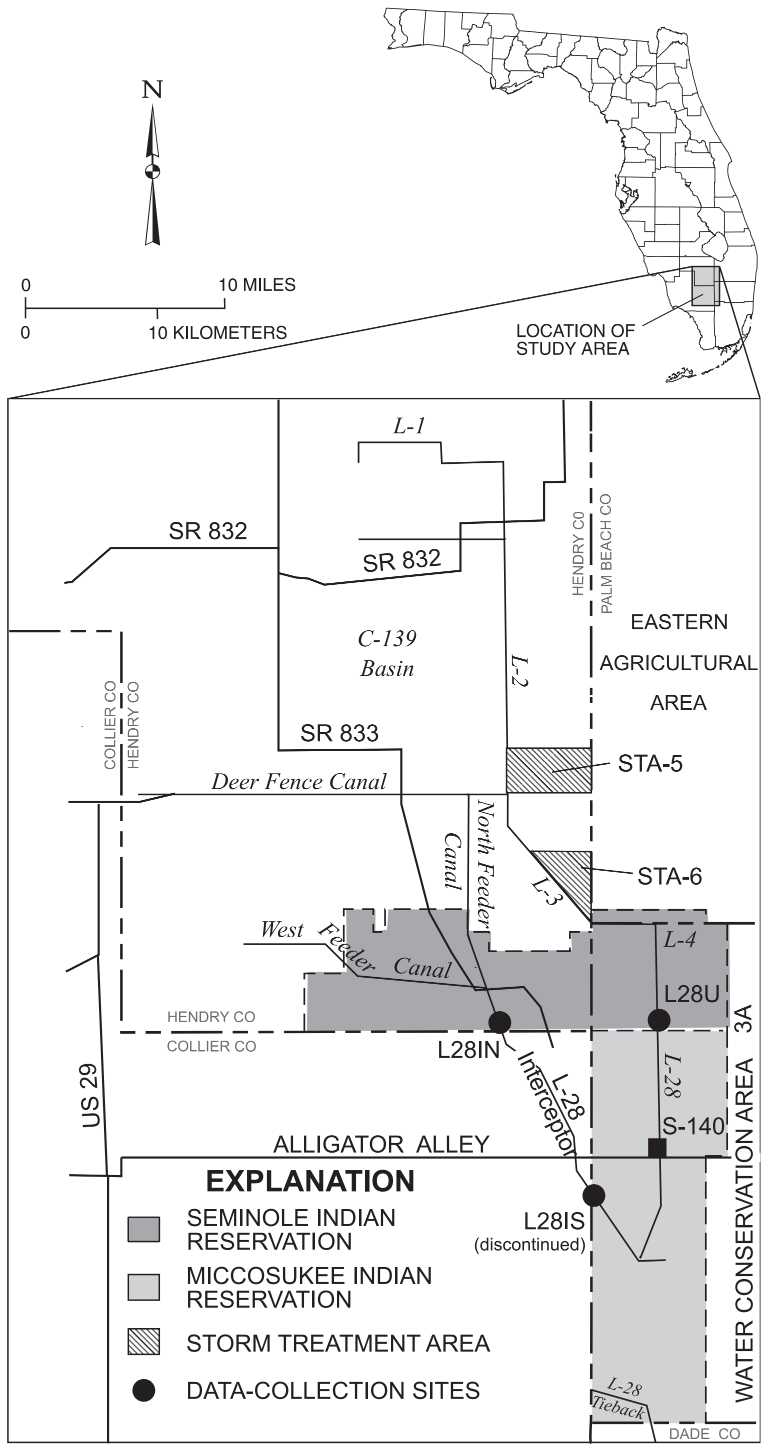

Figure 1. Study area showing location of Tribal lands, data-collection sites, and major canals and levees.

installed flow-weighted samplers at the gaging sites for nutrient analysis in conjunction with the stream flow monitoring; the Seminole and Miccosukee Indian Tribes have serviced the flow-weighted samplers. Real-time telemetry instrumentation and programming assistance along with phosphorus and nitrogen load calculations have been provided by the SFWMD. ADCP calibration of the installed acoustic velocity meter indexes is ongoing and development of the "sum of least squares regression" has been provided for data processing at all sites and continues to be refined. Velocity data collected during the dry season has displayed a phenomenon known as acoustic refraction or ray bending produced by thermal stratification in the water column during extended periods of very slow vertical flow. Various installed electromagnetic and new Doppler mean velocity-indexing techniques have been tested and proven largely successful.

The L-28U site along the L-28 canal is used to monitor freshwater flows from the lands of the Seminole Tribe and to provide nutrient data load summaries. Average annual runoff of 63,930 acre-feet for the period from 1997 to 2001, represents about twice the inflow amount determined by the SFWMD at their upstream U.S. Sugar Outflow (USSO) site located on the northwestern border of the Seminole Tribal lands. The L-28IN site along the L-28 Interceptor canal is used to monitor flows from the lands of the Seminole Indian Tribe to the Big Cypress National Preserve and ultimately to Miccosukee Tribal lands as well as providing nutrient data for water-resources planning and management. Annual runoff averaged 53,140 acre-feet from 1997 through 2001. The L-28IS site along the L-28 Interceptor canal, discontinued September 1999, was used to monitor flows from the lands of the Seminole Indian Tribe and the Big Cypress National Preserve to the lands of the Miccosukee Indian Tribe. For the three years of operation this site also provided flows and associated nutrient load data for water managers, and was instrumental in bracketing and quality assuring the flow calibration conditions for the upstream L-28IN site. Average annual runoff at the site for the 1997-1999 periods was calculated to be 49,070 acre-feet.

Measuring flow-weighted nutrient loads requires extremely accurate flow-data collection combined with a highly coordinated nutrient collection and analysis procedure. A collaborative product that meets this need is provided as part of current efforts and has been documented in seven semi-annual progress reports presented to the SFWMD/Seminole Working Group. An ancillary report was produced from funding sources outside of the USGS Placed Based Studies (PBS) program budget during the 2002 water year (Lietz, 2002). The report examines the feasibility of estimating concentrations and loads based both on USGS acoustic backscatter data and Seminole Tribe nutrient water quality data.

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Contact: Mitch Murray, mmurray@usgs.gov, Rick Solis, rsolis@usgs.gov, U.S. Geological Survey, 9100 NW 36 St., Ste. 107, Miami, FL, 33178. Phone: (305) 717-5827, Fax: (305) 717-5801. Question 1.

Hydrologic Information for Tidal Rivers along the Southwest Coast of Everglades National Park

By Eduardo Patino, Lars Soderqvist, *and* Craig Thompson

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The health of estuaries and bays along the mangrove zone of southwest coast of Everglades National Park (ENP) is dependent on the amount and quality of fresh water the area receives. For decades this area has been affected by management practices that control freshwater flows across Tamiami Trail and determine water budgets of ENP. Until recent years however, limited hydrologic information has been collected in the area, making it difficult to understand and describe the magnitude of the effects along the mangrove zone.

Figure 1. Photograph of the Harney River monitoring station in 1960.

From 1960 to 1969, the U.S. Geological Survey (USGS) conducted a study of tides and flow in coastal rivers (fig. 1) along the Shark River Slough system to aid in the calculation of water budgets for ENP. In 1996, the USGS initiated a second hydrologic study to determine the flow and nutrient characteristics of some of the same tidal rivers of the Shark River Slough system, and in 2001 the study was expanded to cover the area from Whitewater Bay to Everglades City (fig. 2). USGS hydrologic data from these stations and others in nearby coastal marshes, along with hydrologic data from the Marine Monitoring Network of ENP, can now be used to describe the flow and water-quality characteristics of estuaries along the southwest coast of ENP.

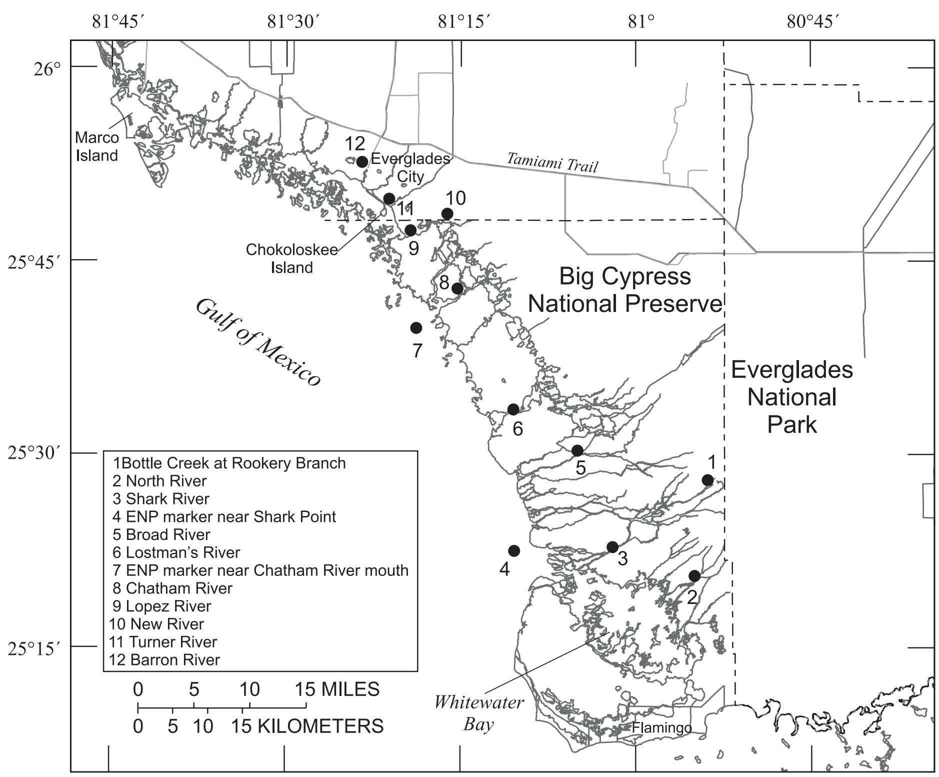

Figure 2. Location of monitoring stations for coastal rivers along the southwest coast of Everglades National Park.

The primary goals of the current study are to describe the salinity patterns along the southwest coast of ENP in relation to freshwater inflows to the estuaries and tidal exchange with the Gulf of Mexico, provide support to the USGS Tides and Inflows in the Mangroves of the Everglades model (TIME), and to aid programs such as Everglades Long Term Ecological Research (LTER).

Continuous salinity data from the main rivers and along transects from freshwater wetlands to the Gulf of Mexico (fig. 3) will be useful for describing both spatial and seasonal variation of salinity throughout the study area. The data also will help scientists and managers determine how salinity patterns may change in response to restoration efforts affecting freshwater deliveries to ENP and Big Cypress National Preserve.

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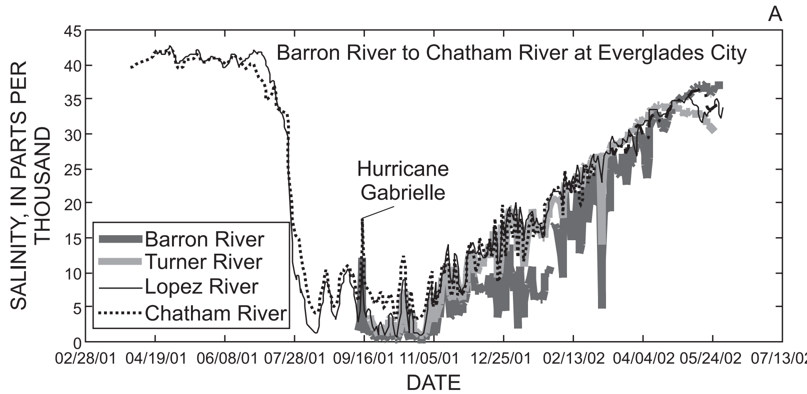

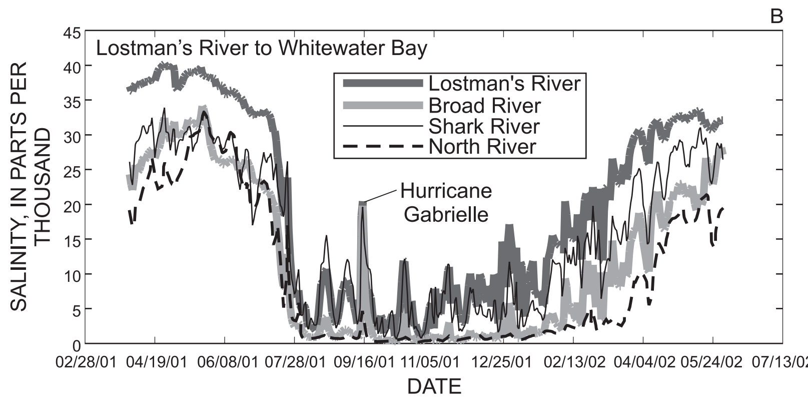

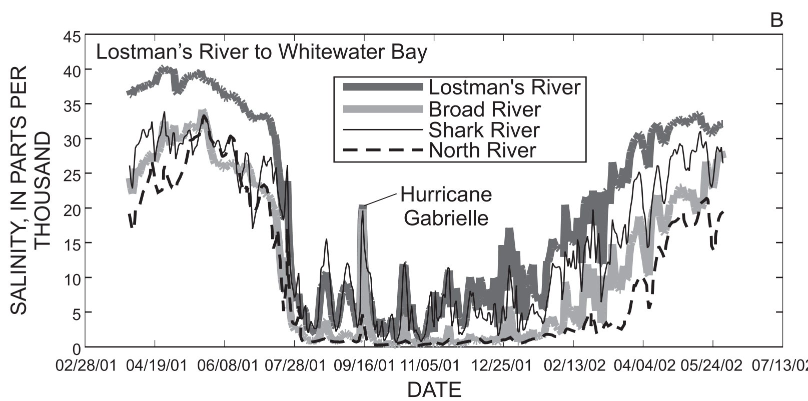

Figure 3. (A and B) Daily salinity values for rivers along the southwest coast of Everglades National Park, and (C) for a transect along the Shark River System.

Inventory and Review of Aquifer Storage and Recovery in Southern Florida

By Ronald S. Reese

U.S. Geological Survey, Center for Water and Restoration Studies, Miami, FL., USA

Aquifer storage and recovery (ASR) in southern Florida has been proposed on an unprecedented scale as part of the Comprehensive Everglades Restoration Plan (CERP). ASR wells were constructed or are under construction at 27 sites in southern Florida, mostly by local municipalities or counties in coastal areas. The Upper Floridan aquifer, the principal storage zone of interest to the Restoration Plan, is the aquifer being used at 22 of the sites. The aquifer is brackish to saline in southern Florida, which can greatly affect the recovery of the freshwater recharged and stored.

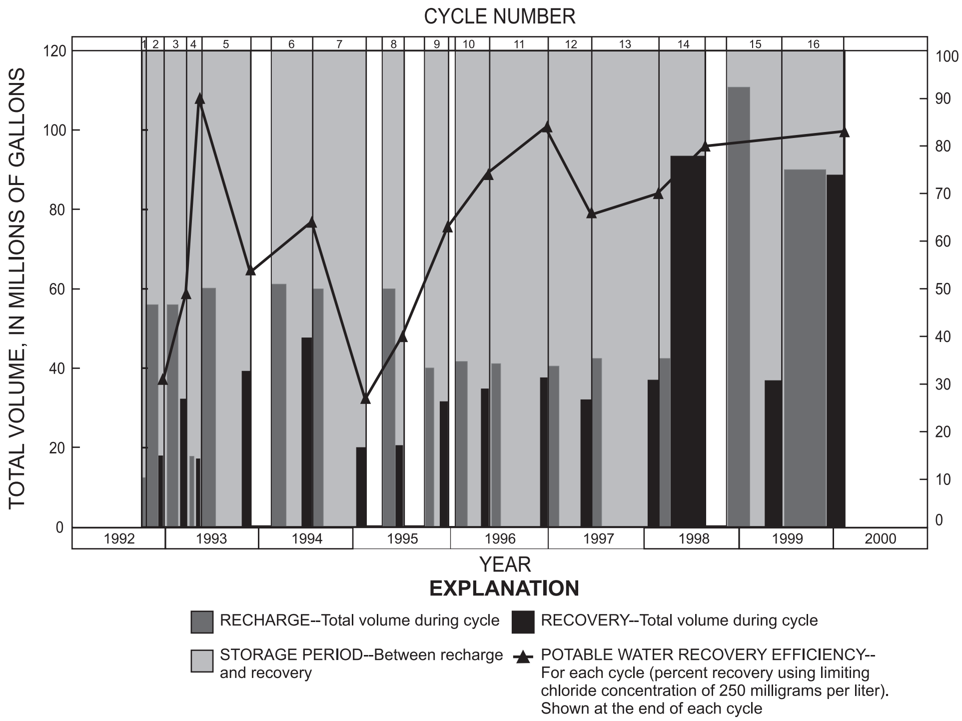

Figure 1. Operational cycles at the Boynton Beach East Water Treatment Plant site in Palm Beach County and relations of volumes recharged and recovered, time, and percent recovery for each cycle. Recovery for cycle 15 was 34 percent for and ending chloride concentration of 146 milligrams per liter.

The purpose of this study is to inventory and compile data for existing ASR sites in southern Florida and identify various hydrogeologic, design, and management factors that control the recovery of freshwater injected (recharged) into ASR wells. Data for all wells at most of the 27 sites were compiled into four main categories: (1) well identification, location, and construction data; (2) hydraulic test data; (3) ambient formation water-quality data; and (4) cycle testing data. Each cycle during testing or operation includes periods of recharge of freshwater, storage, and recovery that each last days or months. Cycle testing data include calculations of recovery efficiency, which is the percentage of potable recharged water recovered for each cycle.

Potable water recovery efficiencies for 16 of the 27 sites were calculated and, generally, recovery efficiency improves with the number of cycles. Except for two sites, the highest number of cycles was five. Only nine sites had a recovery efficiency above 10 percent for the first cycle or two. However, at two out of the other seven sites, low recharge volumes per cycle of less than 10 million gallons (Mgal) could explain the poor recovery. Ten sites achieved a recovery efficiency above 30 percent during at least one cycle. The highest recovery efficiency achieved per cycle was 84 percent for cycle 16 at the Boynton Beach site (fig. 1). Recharge volume per cycle averaged 95 Mgal, ranging from 0.6 to 714 Mgal, for 55 cycles at 14 Upper Floridan aquifer sites. Recharge volume for cycle 3 at the West Well Field site in Miami-Dade County was 714 Mgal and included simultaneous recharge into 3 ASR wells. All cycles were conducted in a single well, except for two cycles at the West Well Field site.

Factors that could affect recovery of freshwater varied widely among sites. The thickness of the open storage zone at all sites ranged from 45 to 452 feet. For Upper Floridan aquifer sites, transmissivity based on tests of the storage zones ranged from 800 to 108,000 ft^2/d (feet squared per day), chloride concentration of ambient water ranged from 500 to 11,000 mg/L (milligrams per liter), and leakance values indicated that confinement between the storage zone and lower zones may be limited in some areas. High transmissivity can adversely affect recovery, because it may equate to high dispersive mixing in a limestone aquifer. Additionally, depending on the ambient salinity of the storage zone, the probability of buoyancy stratification increases as transmissivity increases. At three sites that have transmissivities above 70,000 ft^2/d with 3 to 5 cycles at each, recovery efficiencies over 10 percent per cycle were not obtained.

Based on review of four case studies and data from other sites, several hydrogeologic and design factors appear to be important to the performance of ASR in the Floridan aquifer system. Performance is maximized when the storage zone is thin and located at the top of the Upper Floridan aquifer (fig. 2), and transmissivity and ambient salinity of the storage zone are moderate (less than 30,000 ft^2/d and 3,000 mg/L of chloride concentration, respectively). The structural setting at a site could also be important because of the potential for updip migration of a recharged freshwater bubble due to density contrast or loss of overlying confinement due to deformation.

This five-year study is divided into two phases, the first of which lasted two years. The first phase laid the groundwork for data inventory, review, and analysis. The second phase will allow for collection of additional data as it becomes available, expand the hydrogeologic framework, and perform a more complete comparative analysis of ASR sites. Results from the first phase are provided in Reese (2001); results from the current phase also will be published.

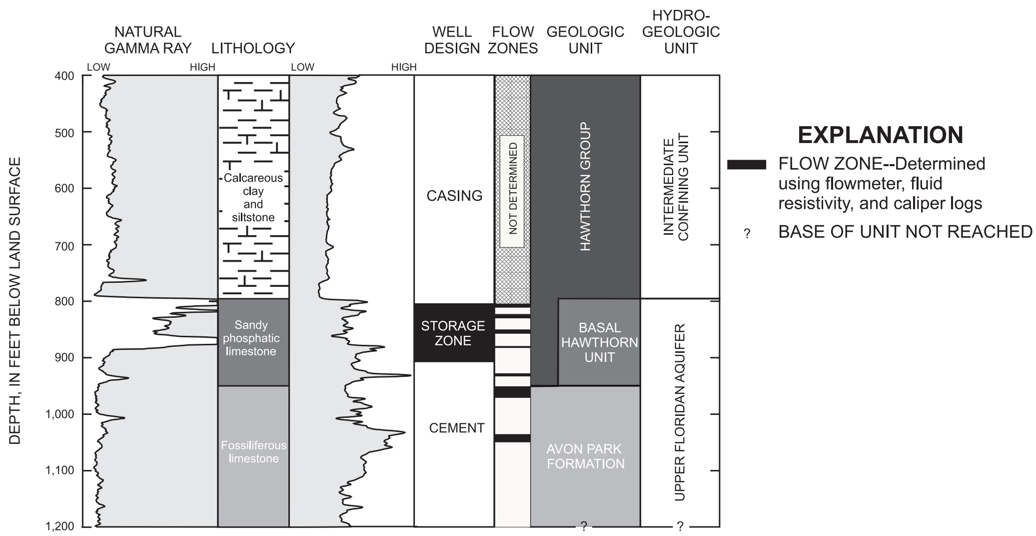

Figure 2. Location of storage zone in relation to geophysical logs, lithology, flow zones, and geologic and hydrogeologic units for the aquifer storage and recovery well at the Boynton Beach East Water Treatment Plant site in Palm Beach County.

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Impact of Water Management on Coastal Hydrology in Southeastern Florida

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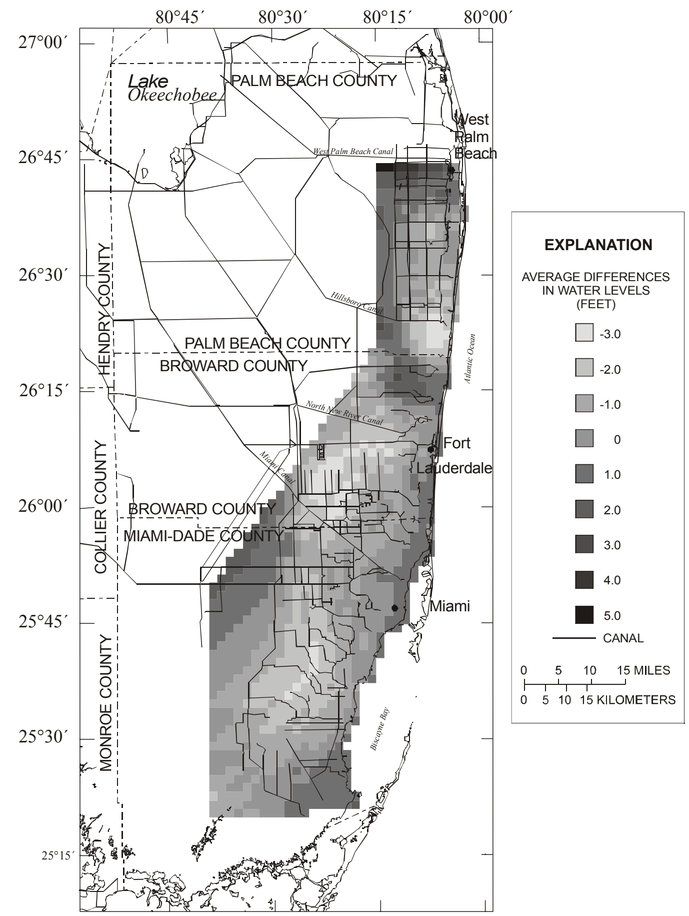
Surface and ground water hydrology and natural ecosystems of southeastern Florida have been subjected to conflicting anthropogenic stresses, which are attributed to the development of a highly controlled water-management system designed to reclaim land for urban and agricultural development. During the first half of the 20th century, Everglades wetlands and coastal estuaries were viewed as a wasteland suitable only for drainage and development. Predevelopment surface- and ground-water systems were intensely transformed by construction of a complex system of canals, impoundments, control structures, levee systems, and many large well fields. These features were collectively designed to manage the competing needs of agriculture, urban users, and natural ecosystem areas. Water-management systems were used to control floods, sustain ecosystems, prevent overland flow from moving eastward and flooding urban and agricultural areas, maintain water levels to prevent saltwater intrusion, and provide an adequate water supply.



Average difference in water levels between October 1940-44 and October 1990-94

Miami-Dade, Broward, and Palm Beach Counties have experienced explosive population growth, increasing from less than 4,000 inhabitants in 1900 to more than 3.8 million in 2000. The use of ground water, the principal source of municipal supply, has increased considerably, from 3 well fields producing 65 Mgal/d (million gallons per day) in 1930 to more than 770 Mgal/d from 79 operating well fields in 1995. Agricultural water use increased from 505 Mgal/d in 1953 to almost 1,150 Mgal/d in 1988, but has since declined to 764 Mgal/d in 1995. This decline is partly due to the displacement of agriculture by urban growth. Present-day agricultural supplies are obtained largely from surface-water sources in Palm Beach County and ground-water sources in Miami-Dade County, whereas agricultural growers in Broward County have been largely displaced.

Before 1948, surface-water conveyance canals provided unregulated flow and were incapable of effectively transporting floodwaters. A lack of canal control structures exacerbated overdrainage of the aquifer during periods of low rainfall and drought. The Central and Southern Florida Flood Control project restructured the existing conveyance system through canal expansion, construction of protective levees and control structures, and greater management of ground-water levels within the surficial aquifer. Currently, gated canal control structures discharge excess surface water during the wet season and remain closed during the dry season to induce recharge.

Managed surface-water conveyance has been used successfully to increase ground-water levels near the coast to impede saltwater intrusion, minimize urban and agricultural flooding, and maintain lower inland ground-water levels. Measured canal stage at the coastal reaches increased during the latter half of the 20th century, whereas surface-water discharge to coastal bays and the Atlantic Ocean declined. Stage increase is presumably the result of efforts to prevent saltwater intrusion into major canals and aquifers. The decline in coastal surface-water discharge is attributed to municipal ground-water withdrawals that induce recharge from the canal to the aquifer. The rerouting of surface water in major canals to secondary canals to elevate coastal ground-water levels also may have contributed to these declines. In contrast to coastal areas, long-term canal flow near the western margin of the urban area has remained relatively consistent (without a general increase or decrease in flow). Consistent long-term surface water flow along the western edge of urban areas and a decline in flow near the coast further supports municipal well withdrawals as a causative agent of declining coastal discharge.

Ground-water levels within the surficial aquifer respond quickly to rainfall; annual wet- to dry-season fluctuations within the aquifer can range from 2 to 8 ft. Wide seasonal variability in water levels can tend to obfuscate longer-term patterns. To better illustrate the effect of canal drainage on the water table, long-term "average condition" analyses were used to dampen storm and drought climatic events. During 1990-94, wet-season (October) and dry-season (April) inland water levels within the surficial aquifer averaged 1 to 4 ft lower than the "average" water levels experienced during 1940-44. However, coastal ground-water levels averaged 1 to 2 ft higher, thus reflecting efforts to minimize coastal saltwater intrusion as previously described.

A broad zone of diffusion defines the saltwater interface, and its position is largely a function of lateral movement of seawater from the ocean, seepage from tidal canals, and upconing of relict seawater. The predevelopment balance between freshwater and saltwater was altered considerably following construction of conveyance and drainage canals and municipal supply wells. Saltwater intrusion has been an issue of concern in southeastern Florida since the early 1930s; its effects were most prominent in Miami-Dade and Broward Counties during the 1940s and 1950s, respectively. Canal drainage seems to have had the most widespread impact on saltwater intrusion, lowering water levels within the surficial aquifer and contributing to landward movement of the interface

The pre-1900 Biscayne Bay coastal ecosystem and salinity was different than it is today as recorded in sediment cores. Salinity increased in the early 1900s, remained stable until the early 1940s, and then increased above levels recorded in the early 1900s. The marine fossil record shows that coastal vegetation changes that have occurred. Sea grass became more abundant during the past century in the central bay and in the coastal Manatee Bay region. Increasing epiphytal and macro-algal habitat dwelling organisms indicate a change in substrate conditions. From the late 1980's to present time, salinity has decreased slightly in Manatee Bay, and field observations in this region suggest the health of sea grasses is deteriorating.

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Sheet Flow in Vegetated Wetlands of the Everglades

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Little is known about the behavior of shallow surface-water (sheet) flows in and through the vegetated wetlands of the Everglades, including the nature and extent of the effects of water-management controls. This project focuses on quantifying flow velocities and investigating local and regional forces both internal and external that affect sheet flows in varied vegetative communities of the southern Everglades. The purpose of the project is to determine the magnitude, direction, and nature of flows in the wetlands of Everglades National Park (ENP). Insight into sheet flow behavior in wetlands is essential to the development and use of models to evaluate and compare restoration scenarios for the Greater Everglades ecosystem.

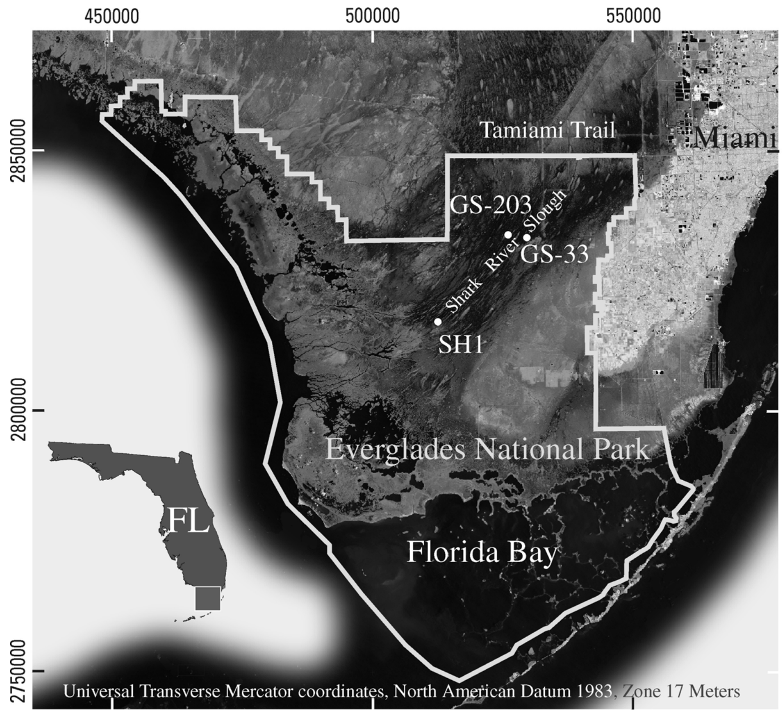

Figure 1. South Florida image showing stations GS-203, GS-33, and SH1.

Three stations were established in 1999 and 2000 to monitor flows and related hydrologic conditions in differing vegetative communities within Shark River Slough (fig. 1). Monitoring station SH1 was established in medium dense spikerush (*Eleocharis*) on the edge of a dense sawgrass (*Cladium jamaicense*) stand; GS-203 was located in medium dense sawgrass at the edge of dense sawgrass; and GS-33 was established in an area of patchy, medium dense spikerush with significant concentrations of submerged aquatic vegetation and periphyton. All three stations were co-located with hydrologic stations to provide water level and rainfall data for flow analyses. Additionally, GS-33 was located near a gage that provided meteorological data for use in flow analyses.

Flow velocities, water and air temperatures, and specific conductances were monitored continuously, typically bi-hourly, at all sites. Flow velocities were measured at a fixed point in the water column using autonomous-recording, acoustic Doppler velocity (ADV) meters. The ADV meter yields 3-D velocity components to a resolution of 0.1 mm/s with an accuracy of 1 percent of measured velocity (Sontek, 2001). Water and air temperatures were monitored using thermistors spaced at 5-cm or 10-cm depth intervals above the plant litter layer. Specific conductances were sampled at a fixed point in the water column near the plant litter layer. All data were collected, edited, and filtered according to methods established and documented in Riscassi and Schaffranek (2002).

Vectors showing flow speeds and directions, in the horizontal plane relative to magnetic north, during the 2000-2001 wet season at GS-203 are shown in figure 2. Flow velocities were measured 10 cm above the plant litter layer throughout the wet season. Water depths at the ADV probe (fig. 2) were fairly constant at approximately 40 cm in late October through early November, but fell steadily in late November through mid-January (31 to 16 cm) except for one 4-cm increase on December 9th due to a rain event. Early in the wet season when water levels were relatively high, flow speed and direction averaged 0.62 cm/s and 235 degrees, respectively, with standard deviations of 0.06 cm/s and 7 degrees. As water levels declined in the later part of the wet season, the average flow velocity was slightly lower at 0.53 cm/s with an identical average direction. However, there was more than a threefold increase in the

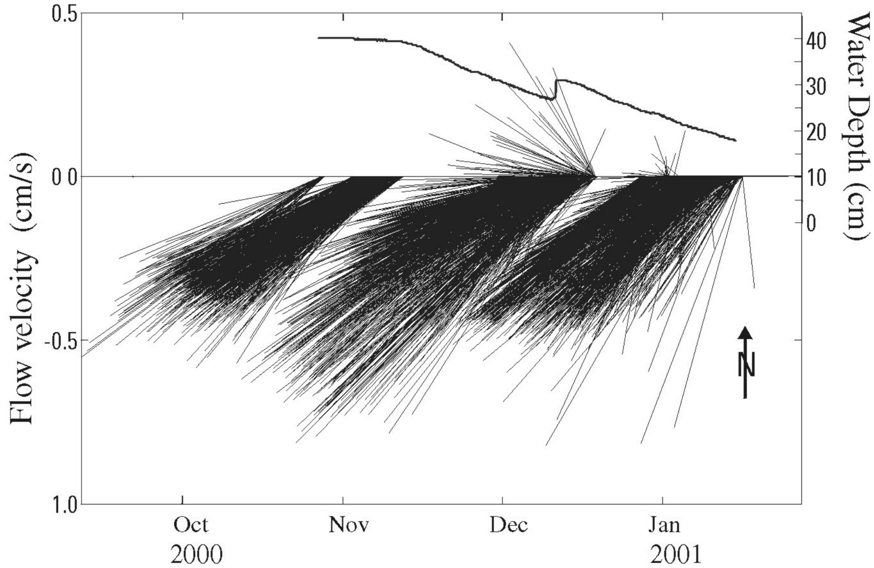

Figure 2. Water depths and flow velocities at station GS-203.

range of measured flow speeds and directions with standard deviations increasing to 0.19 cm/s and 22 degrees, respectively. Perturbations on the flow are considerably damped with increased flow depth as is clearly evidenced by both the quality and range of measured flow velocities. Implications are that during times of higher water levels more stable regional factors appear to drive flows more uniformly, however, as water levels fall, flow velocities at the sample depth decrease and become more susceptible to dynamic forces imposed by wind and rainfall at the water surface. Changes in the relation between the water depth and vegetation composition as water levels fall also appear to alter the influences that vegetation has on vertical flow structure and, therefore, local sheet flow behavior.

Data sets similar to that for GS-203 illustrated in figure 2, collected at the other sites, have yielded additional insight into the typical range of flow velocities found in particular vegetative communities and the dynamics of velocities and sheet flow conditions within and between sites. Findings from all data collected and analyzed to date at all sites indicate that dynamics in the magnitude, direction, and nature of sheet flows are attributed in varying degrees to both internal and external effects, both locally- and regionally-driven. Local conditions include the type, density, and physical attributes of vegetation in the area, as well as the presence and composition of submerged aquatic vegetation and (or) periphyton. Upstream vegetation, water levels, water-surface slopes, landscape gradients, proximity of airboat trails, presence of tree islands, and vegetative heterogeneity are regional factors that affect sheet flow conditions. Dynamic forces such as storm and rainfall events also have variable effects on sheet flow behavior.

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Applications of a Numerical Model for Simulation of Flow and Transport in Connected Freshwater-Wetland and Coastal-Marine Ecosystems of the Southern Everglades

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Water-management agencies responsible for implementing the Comprehensive Everglades Restoration Plan (CERP) need to ensure that hydrologic conditions are maintained in land-margin ecosystems of Everglades National Park (ENP) that satisfy habitat requirements of endangered freshwater and estuarine species. The U.S. Geological Survey has developed a hydrodynamic/transport model uniquely suited to simulate flow and salt flux through these coupled surface- and ground-water ecosystems. A numerical algorithm was developed to synchronize surface-water tidal-compatible time steps with ground-water stress periods and to assure mass conservation of simulated flux quantities across the surface-/ground-water interface and land-surface boundary in the model (Swain and others, 2002). Hydraulic expressions, derived from hydrologic process studies in the Everglades, have been formulated to link flow resistance (Lee and others, 2002), wind stress (Jenter and Duff, 1999), and evapotranspiration processes (German, 2000) to vegetation properties and shallow flows typical of these low-gradient wetlands.

Two applications of the coupled model have been made that are largely within the confines of ENP (fig. 1). The Southern Inland and Coastal Systems (SICS) model encompasses the Taylor Slough wetlands, part of the C-111 drainage basin, and sub-tidal embayments along the northern coastline of Florida Bay. The Tides and Inflows in the Mangrove Ecotone (TIME) model encompasses the SICS model domain, Shark River Slough, other western sloughs, and sub-tidal embayments and tidal creeks along the southwest Gulf coast. Measured surface-water flow discharges, water levels, and salt concentrations at tidal creeks (fig. 1) (Hittle and others, 2001); wetland water levels and flow velocities (Tillis, 2001; Riscassi and Schaffranek, 2002); and ground-water heads and salinities (Price, 2001) supplemented by sub-surface salinity maps (Fitterman and Deszcz-Pan, 1998) and peat thickness and hydraulic gradients (Harvey and others, 2000) were used for model calibration and verification. Tide levels and salt concentrations along the coast and discharges and water levels at hydraulic structures (fig. 1) and road culverts constitute the data used to drive the SICS and TIME simulations.

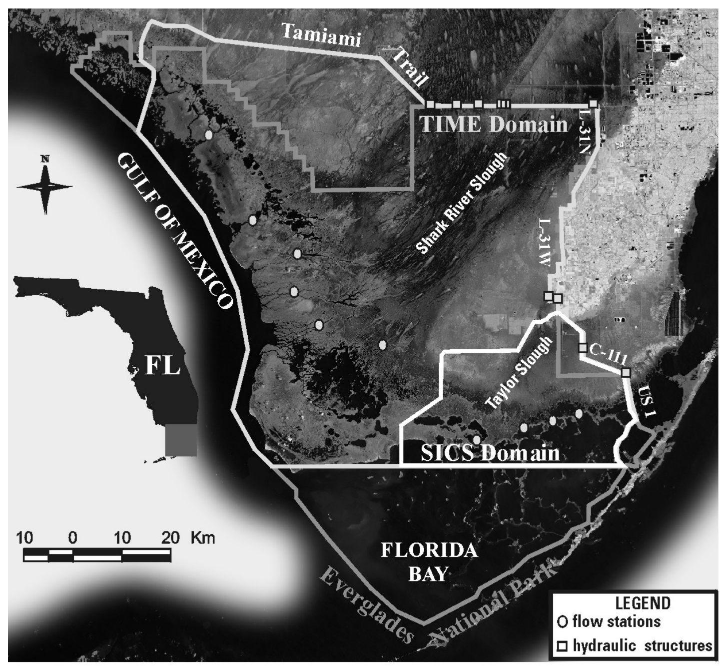

Figure 1. South Florida satellite image showing SICS and TIME model domains.

Flow exchanges between the surface- and ground-water systems simulated by the SICS model are presented in figure 2 to demonstrate its capability and illustrate typical model output. Positive exchanges, expressed as averages in cm/day for the 5-year simulation, indicate areas of recharge to the aquifer and negative values indicate areas of discharge to the wetlands. Similar output is available that identifies salt fluxes between the surface- and ground-water systems. Model output such as this is needed to fully evaluate the potential impact of restoration decisions for the Greater Everglades on coastal land-margin ecosystems of ENP.

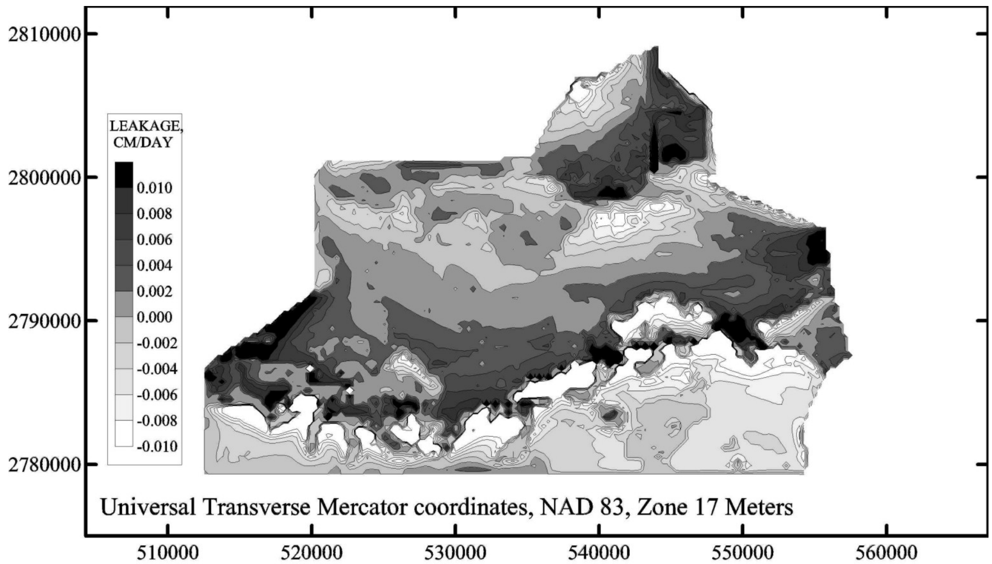

Figure 2. SICS model output showing surface-/ground-water exchange.

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Fire Effects on Flow in Vegetated Wetlands of the Everglades

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Fires are a critical, but not well-understood, dynamic occurrence that randomly and variously affect the Everglades ecosystem. However, fire impacts on subsequent surface-water (sheet) flow conditions have never been investigated. The nature of sheet flow in burned areas has not been documented and compared to adjacent unburned areas and any residual effects of fire on sheet flow behavior during vegetation recovery have not been assessed. The potential impacts of fire disturbances on vegetation and sheet flow behavior should be recognized and considered in the analyses of restoration scenarios being evaluated for the Greater Everglades ecosystem.

In the late afternoon of June 2, 2001, lightning ignited a fire about 10 km west of Pa-hay-okee Lookout Tower in Everglades National Park (ENP). The fire was centered in a dense stand of sawgrass (*Cladium jamaicense*) at the headwaters of Squawk Creek, a narrow tributary of Tarpon Bay, approximately 5 km south of the ENP P35 water-level gage (fig. 1). On the afternoon of June 3, a rainstorm extinguished the fire but not before it burned approximately 202 hectares. Residual sawgrass plant stems, about 10 to 15 cm in length, remained above the top of the root zone. The location of the burn area afforded the opportunity to quantify the effects of fire on sheet flow conditions and to investigate flow behavior during vegetation recovery.

In August 2001, two flow-monitoring stations were established at the southern extent of the Squawk Creek burn area (fig.1). Located in burned and unburned vegetation approximately 280 m apart, each station consisted of a self-recording, point-sampling, acoustic Doppler velocity (ADV) meter. The ADV meters were set to record mean flow velocities simultaneously over two-minute sample intervals every 15 minutes. Analyses of initial continuous ADV data revealed periods during which flow velocities in the burn area were on the order of two times faster than in the unburned vegetation. During intermittent site visits, vertical velocity profiling was conducted at 3-cm depth intervals to document the water-column flow structure (fig. 2a) in conjunction with 10-cm incremental determination of vegetation volume (fig. 2b). Data from eight sets of vertical velocity profiles covering a depth range of 22 to 42 cm revealed similar two-fold velocity magnitude differences between the sites, particularly in the upper part of the water column (fig. 2a).

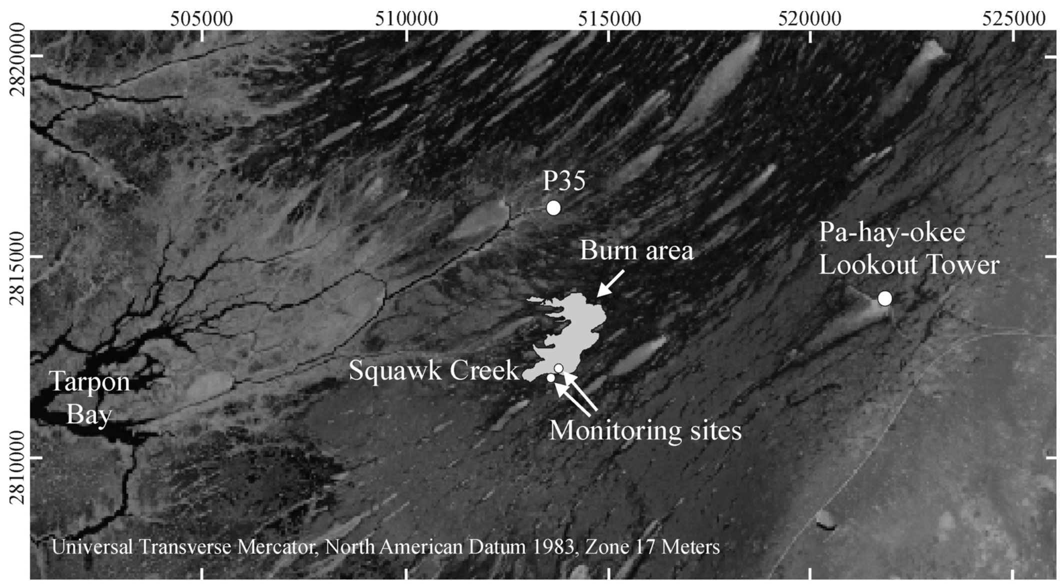

Figure 1. Satellite image of Squawk Creek burn area.

During site visits, vegetation types and densities immediately upstream and within the flow paths to the ADV meters were assessed by measuring vegetation properties in selected areas of similar composition in the local vicinity of, but removed from interference with, the ADV probes. Initial vegetation differences, observed in August 2001, included lower plant heights and less biomass in the burn area as implied by the smaller number of leaves per

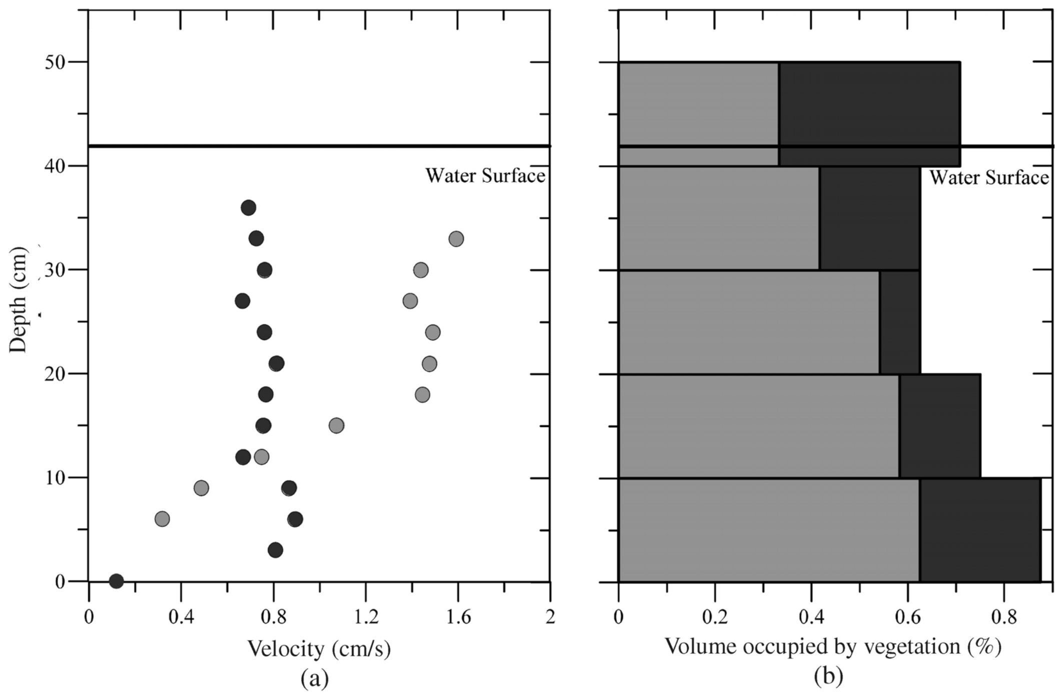

Figure 2. Velocity (a) and vegetation volume (b) measured at the burned (light gray) and unburned (dark gray) sites in June 2002.

sawgrass culm than in the unburned vegetation. During June and October 2002, emergent stem densities and vegetation volumes (expressed as a percentage of the water column volume) were measured at 10-cm depth intervals in three 0.04 m^2 quadrats at each site. Additionally, the diameters of all plant stems in the top 10 cm of the water column were measured to calculate stem spacing near the water surface. Plant heights were measured and qualitative observations of vegetation type and density also were recorded. In June 2002, the dominant plant species was sawgrass at both sites with lower plant heights measured in the quadrats and observed throughout the burn area. Vegetation volume within the 41-cm water column was less at the burn site (0.54 vs. 0.69 percent) (fig. 2b) and stem spacing near the water surface was greater (3.4 vs. 2.5 cm). In October 2002, sawgrass remained the dominant plant species at both sites with lower plant heights again measured in the quadrats and observed throughout the burn area. However, significant quantities of periphyton and muskgrass (*Chara* sp.) also were found in the burn area. Both vegetation volume within the 32-cm water column, which included the periphyton and chara, (1.28 vs. 1.14 percent) and stem spacing near the water surface (5.9 vs. 3.6 cm) were greater at the burn site.

Implications from measured, vertical velocity profiles (fig. 2a) are that remnant dead plant stems continue to impart equivalent, pre-fire shear-resistance effects on flow in the lower part of the water column. Although flow depths at the two monitoring stations were similar during all site visits, unit mass flux through the upper part of the water column at the burn site was computed to be equivalently greater than at the unburned site due to the greater flow velocities near the water surface. Reduced plant heights above the water surface as well as greater stem spacing just below the water surface appear to yield diminished sheltering effects from wind and reduced shear-resistance effects from vegetation thus contributing to the greater flow velocities in the upper part of the water column at the burn site.

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Developing a Computational Technique for Modeling Flow and Transport in a Density-Dependent Coastal Wetland/Aquifer System

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The USGS Center for Water and Restorations Studies has continued its numerical modeling in the coastal regions of the southern Everglades. A combined model referred to as Flow and Transport in a Linked Overland-Aquifer Density Dependent System (FTLOADDS) is the latest step in an ongoing effort to develop and refine the numerical representation of flow and transport in this area. FTLOADDS is a numerical framework that includes and coordinates execution of the SWIFT2D hydrodynamic surface-water model and the SEAWAT ground-water model. The SWIFT2D and SEAWAT models are designed to account for salinity transport in each regime, surface-water and ground-water flow, and the associated affects of density variations on flow. The FTLOADDS coupling passes the necessary information between the two models. This involves passing aquifer heads and ground-water salinity from SEAWAT to SWIFT2D and computed leakage volumes and salt fluxes from SWIFT2D to SEAWAT.

The original modeling application is referred to as the Southern Inland and Coastal Systems (SICS) model. As part of this application, the SWIFT2D model was used to represent the surface-water regime and modified to account for the effects of rainfall, evapotranspiration, and other factors. Model setup utilized numerous field studies to define the input parameters for frictional resistance, evapotranspiration, land elevation, and flow calibration. Approximate ground-water boundaries were defined, but a more accurate scheme was needed. Previous coupled models represent the water-level/flow relation in both the surface-water and ground-water regimes to various degrees of complexity. However, to represent the hydrologic conditions in a coastal area, such as the northeastern shoreline of Florida Bay, salinity transport must be considered, because the induced density variations affect ground-water flow, surface-water flow, and the leakage rate between the two regimes. Consequently, transport must also be represented in these flow computations. The ideal candidate for simulating the ground-water regime is the SEAWAT model, which links the well-known MODFLOW three-dimensional ground-water flow model with the MT3DMS transport code. The FTLOADDS coupling allows SWIFT2D and SEAWAT to retain as much of their original form as possible, because only relevant information is exchanged.

A primary requirement of any simulation is to conserve mass. In FTLOADDS, the amount of water and salt passed from one model must equal the amount received by the other, and be computed by the most valid technique known. To conserve mass between the models, their timesteps must be reconciled. Given the hydrodynamic nature of the surface-water computation, the surface-water timesteps are almost always much shorter than the ground-water timesteps. As in other models, the most logical place for the computation of leakage is in the shorter timestep surface-water model, SWIFT2D. A subroutine was created for SWIFT2D that computes a leakage volume for each timestep based on ground-water and surface-water head using the equation:

$$Q_{leak} = C_{leak} A_{cell} (H_{gw} - H_{eq} + D_{\rho}),$$

where

Q_{leak} =leakage flow (L^3/T),

C_{leak} =leakage coefficient (1/T),

A_{cell} =surface area of model cell (L^2),

H_{gw} =freshwater equivalent aquifer head (L),

H_{sw} =freshwater equivalent surface-water head (L),

D_{ρ} =$(Z_{cell}-Z_{elev})\ (\rho_{ave}-\rho_f) / \rho_{f,}$

Z_{cell} =elevation of center of aquifer cell (L),

Z_{elev} =land elevation (L),

ρ_{ave} =average density of ground water and surface water (M/L^3), and

ρ_f =density of fresh water (M/L^3).

Within this equation, effects of density variation on head gradient are accounted for in the subroutine when calculating leakage. The leakage flow is multiplied by the timestep length to obtain a leakage volume, which is added or subtracted from the surface-water cell. The leakage volumes for each surface-water timestep are summed, and sent back to the ground-water model to be added or subtracted from the corresponding aquifer cell.

The net salt flux between surface water and ground water must also be taken into account. When the leakage volume is computed for a surface-water timestep, salt flux is computed based on flow direction. If the flow is upward from ground to surface water, the salt mass flux is calculated by multiplying leakage volume and ground-water salinity. The calculated salt mass is added to the surface-water salt mass in the SWIFT2D transport subroutine. If flow is downward from surface to ground water, the salt mass flux is calculated as the product of leakage volume and surface-water salinity. The total salt mass flux is summed for the surface-water timesteps and divided by the total leakage volume. This gives an equivalent salinity concentration for the total leakage over the ground-water timestep. Whichever direction the leakage is moving, the computed equivalent salinity is used in SEAWAT as the concentration of the water added or removed from the aquifer as leakage. This concentration only reflects the proper salt mass exchanged; If there are multiple reversals in leakage direction during the surface-water timesteps, and the salinity of the ground water and surface water are very different, the equivalent concentration can be very large. If the direction of the net leakage water volume is opposite than the direction of net salt flux, the equivalent concentration computed can be negative.

The flowchart of FTLOADDS is shown in figure 1. For each ground-water timestep, SWIFT2D is called first, using the final ground-water head from the previous timestep to compute leakage. Computed leakage and salinity is passed to SEAWAT for the ground-water timestep. A comparison of measured salinity values at McCormick Creek, a coastal creek in the SICS study area, with values computed in SWIFT2D alone (no ground water), and in FTLOADDS (with ground water) is shown in figure 2. The coupling to the SEAWAT model within FTLOADDS has resulted in a marked improvement in the ability to represent salinity.

The FTLOADDS coupled SWIFT2D/SEAWAT model has greatly improved the ability to model coastal wetland scenarios for restoration science. Using this continuously improving tool, water resource managers will be able to answer the critical restoration questions for the Everglades and Florida Bay.

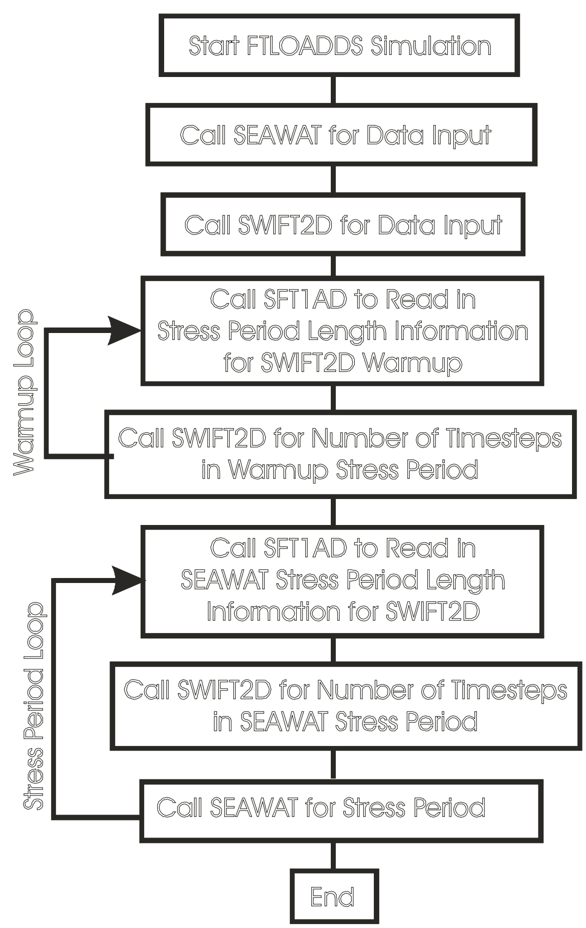

Figure 1. FTLOADDS flowchart.

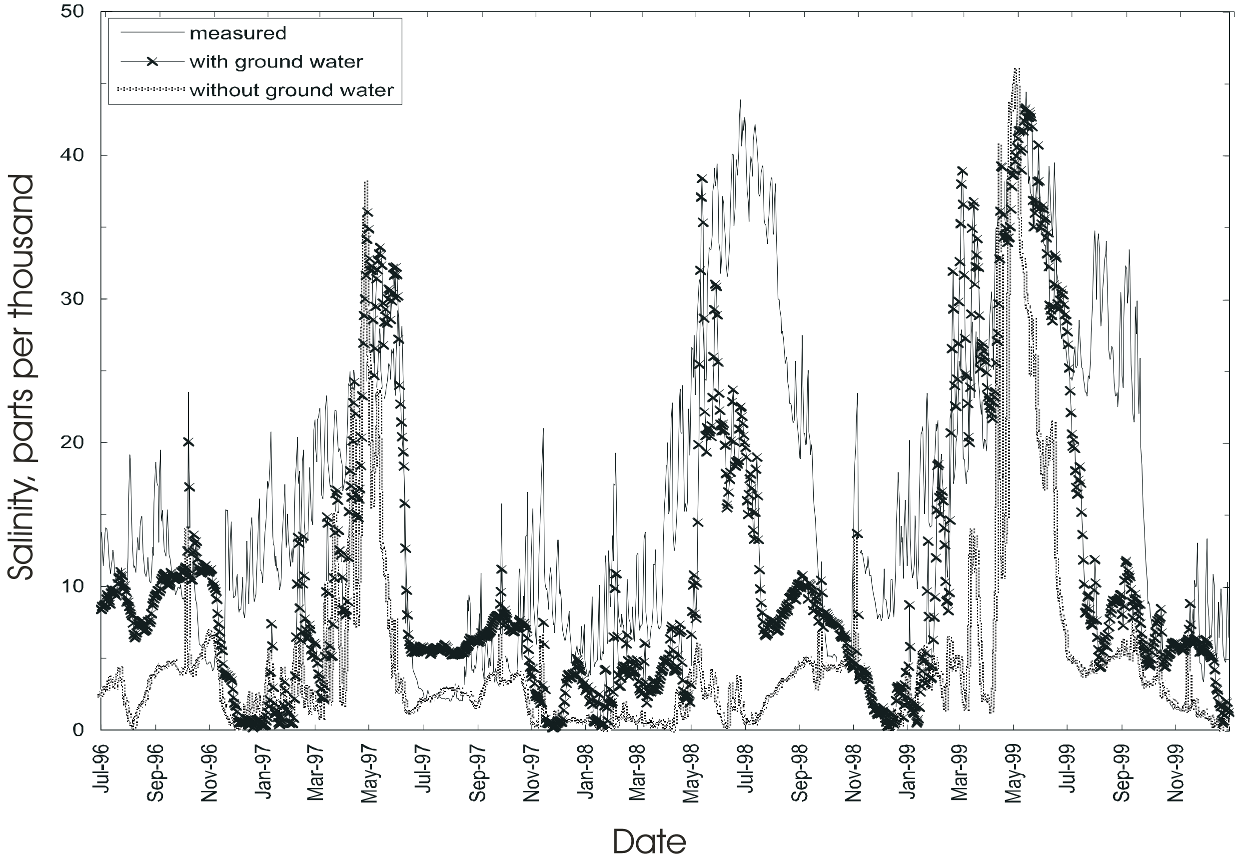

Figure 2. Salinity at McCormick Creek.

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Everglades Tree-Island Response to Hydrologic Change

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The stability of Everglades tree islands is influenced strongly by hydrologic parameters, including water depth, hydroperiod, and seasonality of flow. Based on analysis of pollen from sediment cores, we have reconstructed changes in vegetation and tree island size in response to hydrologic changes of the last century.

Transects of sediment cores were collected on 29 tree islands throughout the Everglades: five in Arthur R. Marshall Loxahatchee National Wildlife Refuge, two in Water Conservation (WCA) 2A, eleven in WCA 3A, two in WCA 3B, four in Shark River Slough, and five in Taylor Slough, Florida (fig. 1). The tree islands are geologically old features, with mature tree-islands present in the northern and southern Everglades for at least 2,000 and 1,000 years, respectively. Even before classical tree-island formation, sites now occupied by tree-island heads were drier than surrounding marshes and sloughs; this finding is consistent with the hypothesis that topographic highs in the underlying limestone were favorable sites for tree-island development.

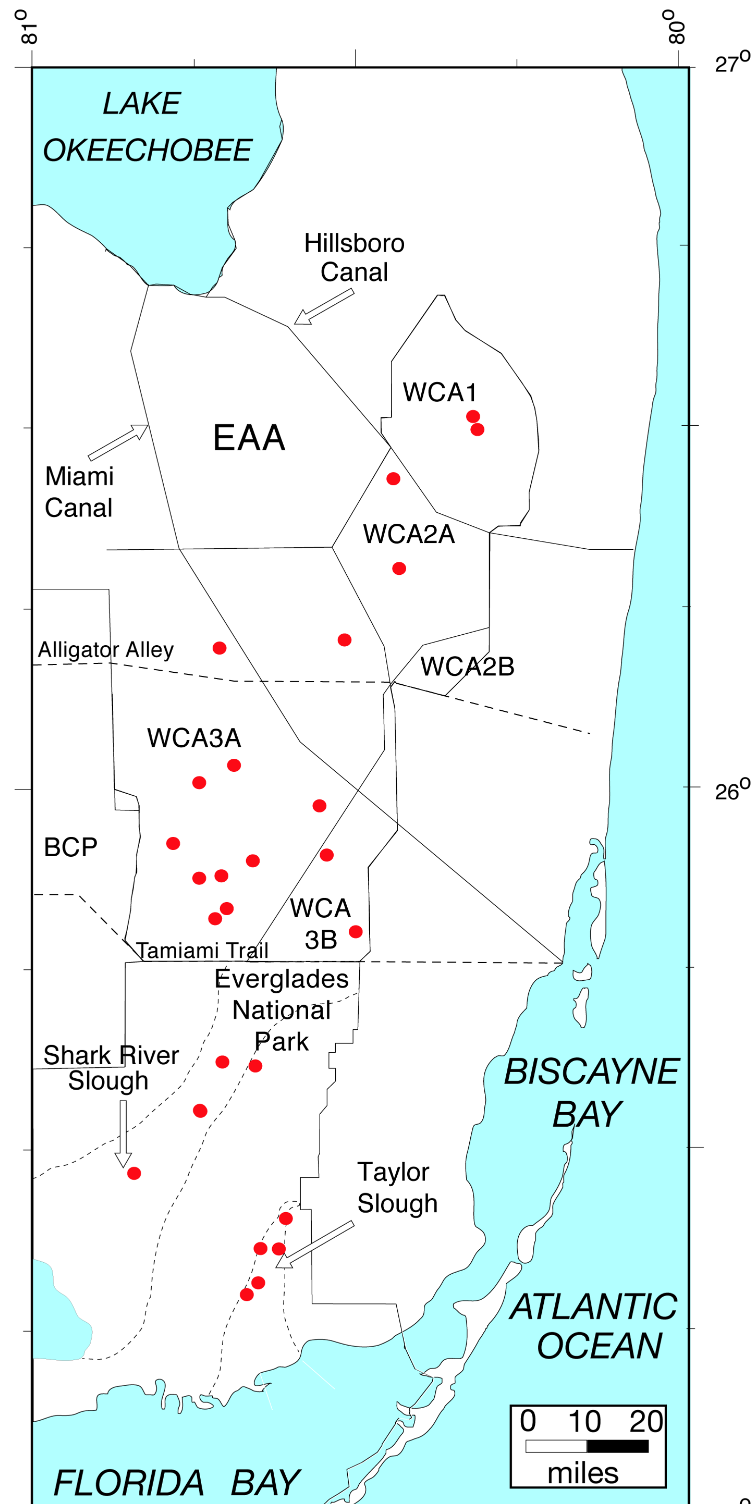

Figure 1. Location of tree islands sampled in the Everglades, 1998-2002.

The response of tree-island vegetation to 20th century hydrologic changes varied with location within the Greater Everglades ecosystem. On strand islands in Loxahatchee NWR, slight increases in abundance of shrubby taxa (holly, wax myrtle) and weedy species occurred in the early 20th century. After 1960, pollen of trees and shrubs increased at least fivefold, resulting in the dominance of holly and bays now seen on these islands. On a "drowned" tree island in WCA 2A, the abundance of tree-island taxa decreased greatly whereas water lily pollen increased during the 1960's; this finding is consistent with sustained flooding after construction of the Central & South Florida (C&SF) Project. The subsequent replacement of waterlily by sawgrass in the 1970's reflects altered water management practices, which incorporated periodic drawdowns into the management scheme. Overall, the vegetational pattern indicates the loss of tree-island vegetation after sustained high water for 10-15 years.

Sites in WCA 3A and 3B have insufficient sedimentation rates to resolve 20th century changes; however, assemblages from sediments deposited during the last 500 years show little change.

On and around tree islands in Shark River Slough in Everglades National Park, pollen of marsh taxa disappeared almost entirely around 1930, when initial canal and road construction was completed. After 1960, replacement of taxa characteristic of relatively wet conditions with tree-island taxa suggests that the tree island head expanded southward as fresh-water flow was reduced to Shark River Slough.

Our results indicate that tree-island response to future hydrologic changes will not be uniform within the Greater Everglades ecosystem. Restoration pre-20th century hydroperiods and water depths to Shark River Slough is likely to result in a decrease in size of tree-island heads, whereas drowned tree islands in WCA 2A may see a gradual increase in size and restoration of previous tree-island plant communities. The distinctive composition of Loxahatchee strand islands also is a recent vegetational feature, and changes in biodiversity at those sites are likely as hydrology is altered. Our results highlight the variability of tree-island composition within the Everglades and indicate that no single performance measure should be devised to evaluate the success of tree-island restoration throughout the Everglades.

Contact: Debra A. Willard, U.S. Geological Survey, 926A National Center, Reston, VA 20192, Phone: 703-648-5320, Fax: 703-648-6953, dwillard@usgs.gov, Oral, Hydrology and Hydrological Modeling

Using Hydrologic Correlation as a Tool to Estimate Flow at Non-Instrumented Estuarine Creeks in Northeastern Florida Bay

By Mark Zucker

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Understanding the quantity, timing, and distribution of freshwater flow to northeastern Florida Bay and other coastal environments is critical for restoring south Florida estuaries. A coastal monitoring network was established in 1996 by the U.S. Geological Survey to provide flow at five estuarine creeks in northeastern Florida Bay. Four additional estuarine creeks were not instrumented and discharge was estimated using hydrologic correlation. This technique assumes that flow from streams near each other correlate because of similarities in geomorphology, rainfall, and distance from source waters. To verify this technique, East Highway Creek, Oregon Creek, and three creeks in Joe Bay were instrumented in July 2001 to quantify the accuracy of the estimated discharge at non-instrumented sites. A test case is presented here for East Highway Creek comparing computed and estimated discharge.

Initially, discharge was estimated at East Highway Creek using hydrologic correlation. Diascharge measured using Acoustic Doppler Current Profiler (ADCP) at East Highway Creek was related to the instantaneous discharge computed using the calibrated velocity meter at West Highway Creek. The equation generated from regression analysis provided the means to estimate discharge over time using computed discharge from West Highway Creek as the explanatory variable. To compute discharge at East Highway Creek, continuous velocity and stage data were collected using an Acoustic Doppler Velocity Meter (ADVM) with an upward acoustic stage sensor. The ADVM velocities were calibrated to the mean channel velocity over a range of velocity conditions using an ADCP. A more detailed discussion of acoustic methods and discharge estimation techniques is provided in Hittle and others (2001).

Differences in discharge volume, wet season discharge volume, and dry season discharge volume were evaluated for the period of record. From February 10, 2002 to September 30, 2002, computed and estimated discharge volume equaled 17,277 acre-feet (mean = 37.5 ft^3/s) and 14,788 acre-feet (mean = 32.1 ft^3/s), respectively. During the 233-day comparison, the estimated discharge volume was 14.4 percent lower than the computed discharge volume. An evaluation of seasonal discharge volume indicated that dry season estimates were less accurate than wet-season estimates. Computed and estimated dry season flows equaled 4,316 acre-feet (mean = 19.6 ft^3/s) and 853 acre-feet (mean = 3.9 ft^3/s), respectively. During the 111-day dry season comparison, the estimated discharge volume was 80 percent lower than the computed discharge volume. Computed and estimated wet season discharge volume equaled 12,961 acre-feet (mean = 53.7 ft^3/s) and 13,935 acre-feet (mean = 57.7 ft^3/s), respectively. During the 122-day wet season comparison, the estimated discharge volume was 7.5 percent greater than the computed discharge volume. Since the regression equation used to estimate discharge at East Highway Creek from 1996 to 2001 was similar to the regression equation used in this analysis, it is probable that these findings apply to prior estimates (fig. 1).

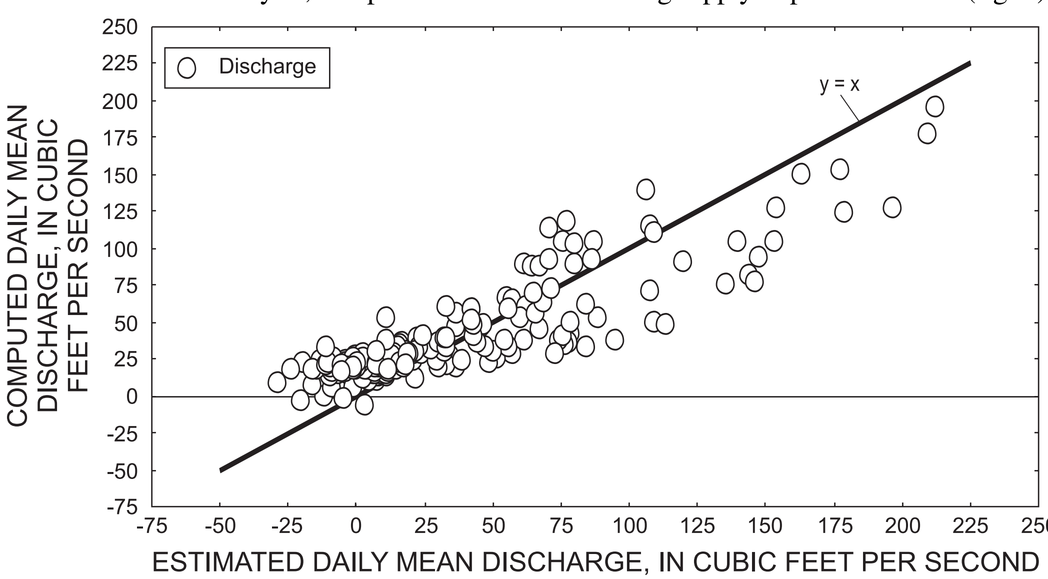

Figure 1. Scatterplot of computed and estimated daily mean discharge at East Highway Creek including the line of equality.

Although wet season discharges were slightly overestimated at East Highway Creek, the discharge trend was reproduced (fig. 2). Dry season discharges were underestimated at East Highway Creek and primarily represent saline exchanges between northeastern Florida Bay and the estuarine creeks, rather than freshwater runoff. However, the exchange of saline water towards upstream wetlands, to ground-water systems, and the impact on local ecology may be important. Concerns over the accuracy of the computed East Highway discharge record is considered critical because only five flow conditions have been measured. Improvements to the computed discharge record are possible with additional ADCP measurements at low flow conditions.

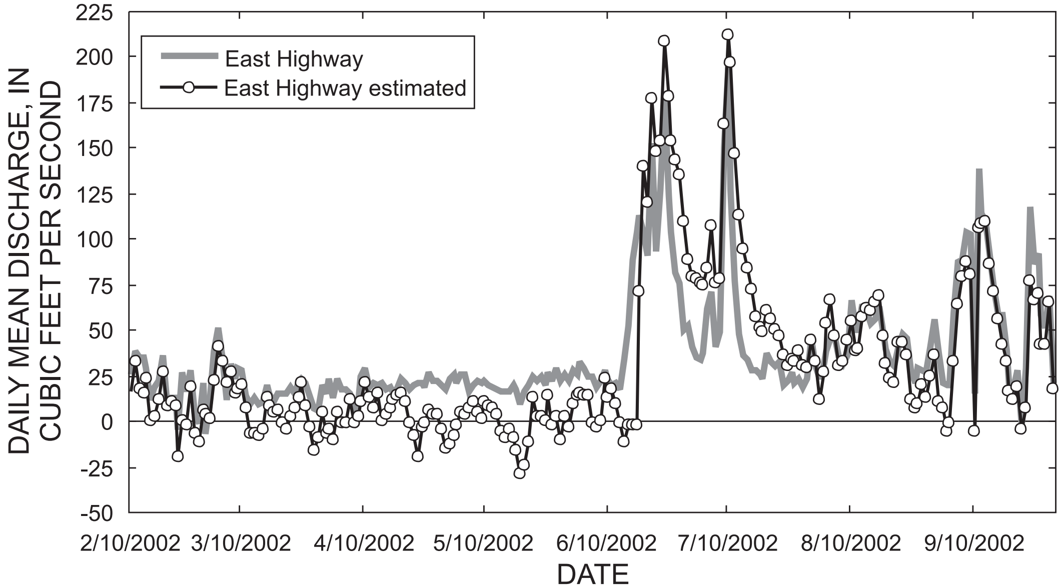

Figure 2. Time-series graph of computed and estimated daily mean discharge at East Highway Creek.

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Section II

Get the Water Quality Right

Contents

Section II: Get the Water Quality Right

Interactions of Dissolved Organic Matter with Mercury in the Florida Everglades

By George Aiken

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Interactions of mercury (Hg) with dissolved organic matter (DOM) are hypothesized to play important roles in controlling the reactivity, bioavailability, and transport of Hg in the Everglades. Little is known, however, about how Hg interacts with DOM or how strong these interactions are. The questions being addressed by this research are: 1) By what mechanisms and how strongly does Hg interact with DOM, and 2) What role do these mechanisms play in controlling the effects that Hg has on organisms. This research is driven by the hypothesis that the chemistry and structural characteristics of the DOM in the Everglades strongly influence the processes that control Hg cycling and bioavailability in the environment. A combined field/laboratory approach designed to characterize DOM in the Everglades and to relate the structural characteristics of the DOM to its reactivity with Hg is being used to test this hypothesis.

Most of the DOM in the Everglades originates from the degradation and leaching of organic detritus derived from the algae, bacteria, and macrophytes living within the wetland environment. In addition, organic matter is transported to the Water Conservation Areas of the Everglades in the canals that drain the Everglades Agricultural Area. Areas strongly influenced by the Everglades Agricultural Area had higher dissolved organic carbon (DOC) concentrations, had a greater amount of hydrophobic acids and hydrophobic neutrals, and the DOM was more aromatic than samples collected from less impacted areas. Pore waters were found to contain greater DOC concentrations than overlying surface waters, with the highest DOC concentrations in pore waters from the more eutrophic study areas. DOC concentrations and the contributions of aromatic organic molecules to the pool of molecules comprising the DOM were lower in those areas with higher concentrations of methylmercury. The amount and nature of DOM in the Everglades was found to be dependent on the dominant vegetation types, hydroperiod, interactions of surface water with peat pore waters, and interactions with canal water.

To better define the nature and strength of interactions between DOM and Hg, the hydrophobic acid fraction (HPOA), hydrophilic acid fraction (HPIA), hydrophobic neutral fraction (HPON), fulvic acid, and humic acid were isolated from various surface waters in the Florida Everglades. Using these isolates, Hg-DOM binding constants were determined over a wide range of Hg(II) to DOM concentration ratios by means of a modified equilibrium dialysis ligand exchange method. Very strong interactions ($K_{DOM}' = 10^{23.2\pm0.5}$ L kg^{-1} at pH = 7.0 and I = 0.1), indicative of Hg-thiol bonds, were observed at Hg(II)/DOM ratios below approximately 1 µg Hg(II) per mg DOM. Hg(II)/DOM ratios above approximately 10 µg Hg(II) per mg DOM gave much lower K_{DOM}' values ($10^{10.7\pm0.5}$ L kg^{-1} at pH = 4.9 to 5.6 and I = 0.1), consistent with Hg(II) binding mainly to oxygen functional groups. These results suggest that the binding of Hg(II) to DOM under natural conditions [very low Hg(II)/DOM ratios ranging from 0.01 to 10 ng of Hg/mg of DOM] is controlled by a small fraction of DOM molecules containing reactive thiol functional groups. Similar strong Hg-DOM binding constants were obtained in studies of the partitioning of Hg(II) between DOM and particulate organic matter (POM). In this work, the HPOA isolate from F1, a northern, eutrophic site, was more effective at competing with POM for Hg(II) than the sample from 2BS, a more pristine site.

Under most environmental conditions, therefore, it can be expected that only the strongest DOM sites will interact with Hg(II). In the case of fully oxygenated Everglades water (sulfide-free), the binding of Hg(II) by DOM should dominate Everglades dissolved inorganic mercury speciation. However, even for the case of strong binding sites ($K_{DOM}' = 10^{23.2\pm0.5}$), Hg-sulfide complexes are predicted to dominate dissolved inorganic Hg solution speciation in the presence of small concentrations (nanomolar) of sulfide because of the strong sulfide affinity for Hg. Where measurable total sulfide concentrations are present in the surface water and pore water of the Everglades, therefore, Hg-sulfide complexes likely predominate.

A chemical equilibrium approach does not completely explain the behavior of Hg(II) in the presence of DOM, however. For instance, chemical speciation models indicate that pore waters in the Everglades, especially in the eutrophic areas, are supersaturated with respect to cinnabar (mercuric sulfide, HgS); however, no cinnabar has been found in the peat soils of the Everglades. Therefore, to better define the geochemical interactions between DOC, Hg(II) and sulfide, experiments were designed using the organic matter isolates and whole water samples to study interactions of DOC with Hg in cinnabar dissolution and precipitation experiments. Cinnabar is a relatively insoluble solid (log K_{sp} = -52.4) under most environmental conditions, but, in the presence of DOM, particularly the humic fractions (HPOA, humic acid, and fulvic acid), a significant amount of Hg (up to 1.7 µM/mg C) was released from cinnabar over a period of seven days at pH 6.0. The amount of Hg dissolved by various fractions of organic matter followed the order: humic acid > HPOA ≅ fulvic acid >> HPIA. The hydrophobic and hydrophilic neutral fractions dissolved insignificant quantities of Hg from cinnabar. Model compounds such as cysteine and thioglycolic acid dissolved small amounts of Hg from the cinnabar surface, while other model compounds such as acetate, citrate, and EDTA dissolved no detectable Hg. There was a positive correlation (R^2 = 0.84) between the amount of Hg released and the aromatic carbon content of the DOM.

Precipitation and aggregation of metacinnabar (black HgS) was inhibited in the presence of low concentrations of humic fractions of DOM isolated from the Florida Everglades. At low Hg concentrations [$\leq 5\times10^{-8}$ molar (M)], DOM prevented the precipitation of metacinnabar. At moderate Hg concentrations (5×10^{-5} M), DOM inhibited the aggregation of colloidal metacinnabar (Hg passed through a 0.1 µm filter, but was removed by centrifugation). At Hg concentrations greater than 5×10^{-4} M, mercury formed solid metacinnabar particles that were removed from solution by a 0.1 µm filter. Organic matter rich in aromatic moieties was preferentially removed with the solid. HPOA, humic and fulvic acids inhibited aggregation better than HPIA. Inhibition of metacinnabar precipitation appears to be the result of strong DOM-Hg binding. Prevention of aggregation of colloidal particles appears to be caused by adsorption of DOM and electrostatic repulsion.

A general observation that can be drawn from all of our studies of Hg(II)-DOM interactions is that the amount of dissolved Hg(II) present in a given system is greater in the presence of reactive DOM. This is significant because many of the processes (both abiotic and biotic) involved in Hg cycling in the Everglades are hypothesized to be strongly dependent on the concentration of total dissolved Hg. Preliminary results of ongoing wetland enclosure (mesocosm) experiments in the Everglades are consistent with this hypothesis. In these experiments, mesocosms amended with the most reactive organic matter from the Everglades, the HPOA fraction of the DOM obtained from site F1, contained higher concentrations of total dissolved Hg than control enclosures containing less reactive, native DOM. The DOM amended enclosures also were found to have enhanced methylation (both biotic and abiotic pathways) of Hg(II) and enhanced photo-oxidation of methylmercury relative to the controls. Future research will address the mechanisms by which DOM influences these important reactions.

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Using Nitrogen and Carbon Isotopes to Explain Mercury Variability in Largemouth Bass

By Bryan E. Bemis[1], Carol Kendall[1], Ted Lange[2], *and* Linda Campbell[3]

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We are investigating whether variations in the nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) isotopic composition of largemouth bass (*Micropterus salmoides*) tissue can explain a significant amount of the variation in mercury concentrations in this top predator fish. The $\delta^{15}N$ and $\delta^{13}C$ values of tissues are integrated measures of diet assimilated over time, with consumers enriched in the heavier isotope relative to their diet. This stepwise isotopic increase toward higher trophic positions has been used for decades to reconstruct relative food web structure in a variety of ecosystems, with a focus on intercomparison of northern temperate lakes. Relatively few studies have applied this technique to wetlands.

One of the goals of restoration efforts in the Everglades is to better understand the sources and distribution of mercury in the food web, in order to develop management strategies to minimize mercury contamination of the ecosystem. Because bioavailable methyl mercury is retained in tissues of Everglades biota, successive trophic levels within the food web accumulate higher mercury levels. Mercury concentrations in top predators such as the sport fish largemouth bass typically exceed EPA safety limits. Isotopic estimates of diet and energy flow within the food web are expected to provide potential information about the sources and pathways of mercury bioaccumulation in Everglades marshes.

Stepwise multiple regression is used to identify parameters that explain a significant amount of variance in largemouth bass total mercury (THg) at 12 marsh and canal sites throughout the Everglades representing a variety of hydropatterns (extremely short to long). The five predictor variables include: latitude of collection site (i.e., spatial influence), collection year (1996-1998; i.e., temporal influence), total fish length (a size estimate), $\delta^{15}N$, and $\delta^{13}C$. In addition, we repeat the regressions for individual sites to identify locally important influences.

Of the twelve marsh and canal sites we are investigating, seven have complete data for the years 1996-1998. When data for these seven sites are combined, spatial differences (i.e., latitude) explain the most THg variance in largemouth bass tissue (approximately 38 percent), which is consistent with locally differing influences (Kendall et al., 2001). Fish length explains approximately an additional 15 percent of THg variance, with relatively minor contributions by $\delta^{15}N$ (approximately 5 percent) and interannual differences (approximately 3 percent). $\delta^{13}C$ is not a significant influence at this landscape scale. The spatial differences may reflect differences in hydropattern, available methyl mercury concentrations (Gilmour et al., 1998), or other environmental variables such as dissolved organic carbon (DOC) concentration or water pH. Future addition of these data to the regression models may help identify the sources of the intersite differences.

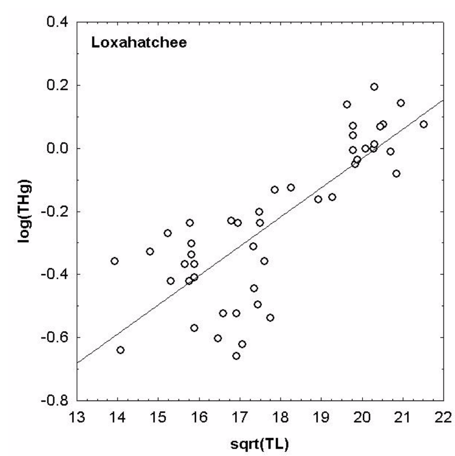

Figure 1. Correlation of the $\log_{10}$ of total mercury concentration (THg as µg/g ww) with the square root of total fish length (TL in mm) for largemouth bass at Loxahatchee. Symbols represent individual fish.

When the data are analyzed separately for the twelve collection sites, fish length explains the most THg variance (approximately 34-77 percent) for ten of the twelve sites (fig. 1). Length is the second most important predictor at another site, explaining ~11% of THg variations. The importance of fish size on THg found here is consistent with the results of the site-grouped analysis in this study, as well as previous studies (Lange et al., 1999); larger fish are typically older and have had more time to accumulate mercury in their tissues.

In contrast with the findings for the site-grouped analysis, the site-specific analyses indicate that $\delta^{15}N$, $\delta^{13}C$, and temporal variations can be locally important predictors of THg in largemouth bass (fig. 2). $\delta^{15}N$ is a significant predictor of THg variation at four sites (approximately 16-27 percent variance explained), and explains the most variance in two of these (likely an indicator of relative trophic level differences among largemouth bass within a site). $\delta^{13}C$ is a significant predictor of THg at three sites. At one of these sites, $\delta^{13}C$ is the best predictor of THg variation (approximately 23 percent), whereas at the other two it explains only about 2-6 percent of THg variation. The small expected consumer-diet enrichment of ^{13}C (compared to ^{15}N) and large $\delta^{13}C$ spatial variations (Kendall et al., 2001) suggest that $\delta^{13}C$ is tracking something other than trophic position (perhaps micro-environmental variations). Interannual variations are a significant influence at ten of the twelve sites, where they explain approximately 5-31percent of variation in THg. The importance of these predictor variables in explaining largemouth bass mercury does not appear to correlate with marsh versus canal sites.

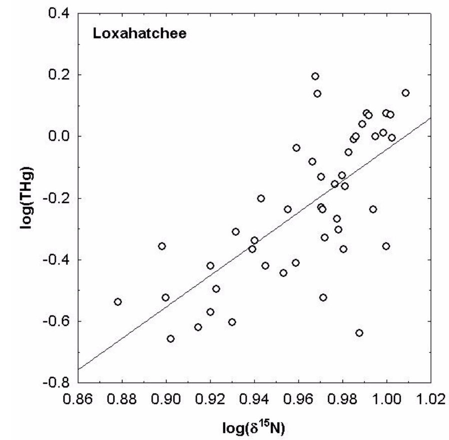

Figure 2. Correlation of the $\log_{10}$ of total mercury concentration (THg as µg/g ww) with the $\log_{10}$ of $\delta^{15}N$ (‰) for largemouth bass at Loxahatchee. Symbols represent individual fish.

In summary, $\delta^{15}N$ and $\delta^{13}C$ can provide locally important information about mercury variations in largemouth bass tissue in the Everglades. However, fish size and temporal changes in the ecosystem are typically much more important influences that may mask information that could contribute to better understanding the transfer of mercury within food webs.

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Isotopic Evidence for Spatial and Temporal Changes in Everglades Food Web Structure

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Trophic structure within a food web is often implicated as a control on how mercury is distributed and transferred throughout an aquatic ecosystem. Methyl mercury bioaccumulates in the food web, with higher concentrations typically found in tissues of organisms that occupy higher trophic positions. Reducing mercury contamination in the ecosystem is a major focus of restoration efforts in the Everglades. Therefore, knowledge about Everglades trophic structure is critical for making management decisions about how to effectively minimize mercury concentrations in biota.

The nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) isotopic composition of tissues is a tracer of diet that can be used in many aquatic ecosystems to distinguish the relative trophic positions of organisms. We use measured $\delta^{15}N$ and $\delta^{13}C$ values of Everglades biota to investigate spatial and temporal variability in food web structure. Plants, invertebrates, and fish were collected from 16 well-studied ACME (Aquatic Cycling of Mercury in the Everglades) sites during 1995-1999 as part of a collaboration between the USGS and the Florida Fish and Wildlife Conservation Commission (FFWCC). These collections provided more than 350 site-date sampling groups.

Within this massive data set, we focus on several sites with multiple collection periods during 1996-1998 that have a sufficient number of organisms to investigate spatial and temporal differences in food web structure. The organisms analyzed for tissue $\delta^{15}N$ and $\delta^{13}C$ represent a broad range of trophic positions within the food web, from primary producers to top-tier predator fish. $\delta^{15}N$ and $\delta^{13}C$ values of primary producers reflect those of the water chemistry, modified by isotopic fractionations associated with nutrient uptake and growth. The isotopic compositions of invertebrates and fish are integrated measures of diet, with an expected relative enrichment of the heavier isotope (i.e., higher $^{15}N/^{14}N$ and $^{13}C/^{12}C$) at each trophic level.

We use $\delta^{15}N$ versus $\delta^{13}C$ plots to identify relative trophic positions of biota within the food web for each site and collection date. Based on laboratory and field studies, the expected pattern of trophic enrichment is increasing $\delta^{15}N$ and $\delta^{13}C$ toward higher trophic positions (for example, site U3, September 1997) (fig. 1). The magnitude of $\delta^{15}N$ and $\delta^{13}C$ ranges varies among sites and collection dates. This is not entirely surprising, given the large range of consumer-diet isotopic fractionations reported for different species (for example, McCutchan, 1999). However, the statistically significant, yet different, $\delta^{15}N$:$\delta^{13}C$ slopes for the biota analyzed in each site-date group suggest that processes influencing consumer-diet isotopic fractionations within a food web are spatially and temporally unique. The $\delta^{15}N$:$\delta^{13}C$ slope differences likely indicate spatial and temporal differences in the food web base and/or complexity of trophic interactions.

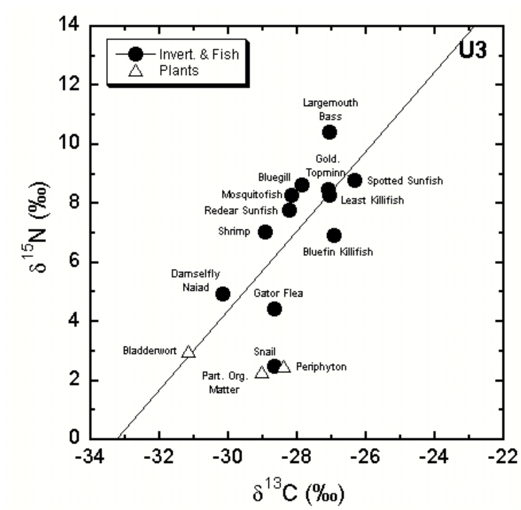

Figure 1. $\delta^{15}N$ versus $\delta^{13}C$ at site U3 during September 1997. The $\delta^{15}N$:$\delta^{13}C$ slope for invertebrates and fish is +1.3 (n = 12; p = 0.02; R^2_{adj} = 0.37). Symbols are median values.

$\delta^{15}N:\delta^{13}C$ slopes are typically positive, as expected (fig. 1). However, rare negative slopes (for example, site F1, September 1997) suggest the unlikely possibility that consumers are relatively depleted in the heavier isotope of carbon than their diets (fig. 2). Figure 3 shows location of sampling sites U3 and F1, in Water Conservation Area 2. Although this pattern has been observed for individual species in controlled growth experiments (for example, DeNiro and Epstein, 1978), an alternative explanation for the multiple-species pattern plotted here is that the biota isotopes reflect the presence of multiple food web bases with distinct $\delta^{13}C$ and $\delta^{15}N$ values. For example, if mosquitofish, bluefin killifish, least killifish, and shrimp are components of one food chain at site F1 and golden topminnow and gator flea utilize another food web base (fig. 2), then this could explain the appearance of a single, "reversed" trophic hierarchy in carbon isotope space.

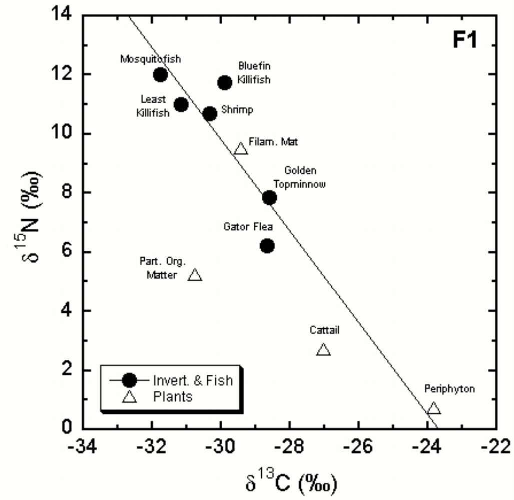

Figure 2. $\delta^{15}N$ versus $\delta^{13}C$ at site F1 during September 1997. The $\delta^{15}N:\delta^{13}C$ slope for invertebrates and fish is –1.5 (n = 6; p = 0.03; R^2_{adj} = 0.66). Symbols are median values.

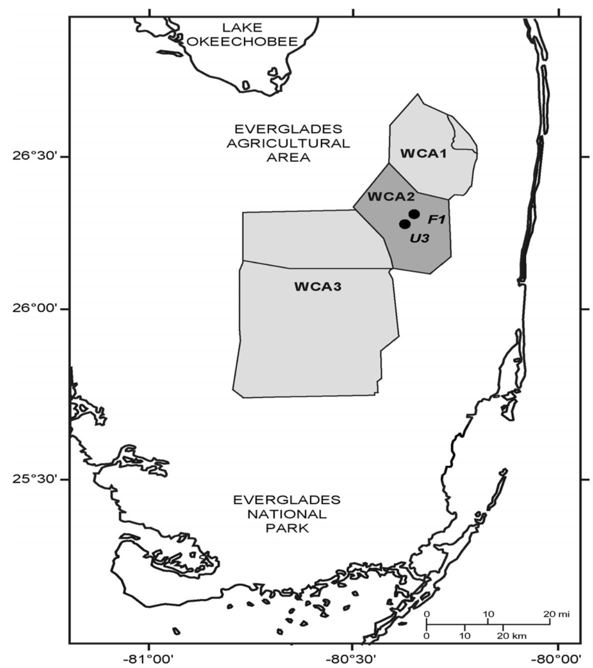

Figure 3. Location of sampling sites U3 and F1, in Water Conservation Area 2.

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Origins and Isotopic Characteristics of Dissolved Nitrogen Species in Ground Water, Imported Domestic Water, and Wastewater in the Florida Keys

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Marine and estuarine ecosystems in the region surrounding the Florida Keys may be sensitive to minor changes in the abundance of nitrogen in surface water and discharging ground water. Because there are many potential natural and anthropogenic sources of nitrogen, the origins and isotopic characteristics of nitrogen species were investigated in various water sources in the region including the Florida Keys, Florida Bay, and the offshore reef tract. The $\delta^{15}N$ values of ammonium in saline ground waters in karst aquifers underlying most of the region ranged from about +2 to +7 ‰ and were correlated spatially with the $\delta^{15}N$ values of organic matter in overlying sub-aqueous carbonate sediments. Those data are consistent with the hypothesis that much of the ground-water ammonium was derived naturally from diagenesis of organic matter in the overlying sediments and transported downward in hypersaline bay water and offshore seawater. In contrast, wastewater from small-scale sewage treatment plants and wastewater injection sites in the Keys generally had large concentrations of waste-derived nitrogen (mainly nitrate, generally less ammonium) with $\delta^{15}N \geq 7$ ‰. Tap water imported to the Florida Keys from the south Florida mainland also contained substantial amounts of nitrate and ammonium, representing as much as 5 to 10 % of the anthropogenic load of fixed nitrogen to the Keys. Chemical and isotopic analyses indicate that the tap-water nitrate ($\delta^{15}N$ = 16 to 22 ‰) was derived from nitrate-bearing ground water that was pumped and processed for distribution, whereas the tap-water ammonium ($\delta^{15}N$ = 0 to 5 ‰) was largely the result of the water treatment. Fresh ground water at the water-supply well field on the mainland, and brackish ground water beneath the Keys and near-shore areas, commonly had excess non-atmospheric nitrogen gas ($\delta^{15}N$ = -0.7 to +5.0 ‰) that is attributed to denitrification, which also increased the $\delta^{15}N$ values of nitrate after it was recharged on land or injected with wastewater.

These results indicate that some of the anthropogenic sources of nitrogen in the Keys that are abundant locally in shallow fresh and brackish ground waters (largely nitrate and derivative nitrogen gas) may be distinguished chemically and isotopically from major natural sources of fixed nitrogen that are widely distributed in saline and hypersaline ground waters underlying the region (mainly ammonium). Overall, the data do not indicate direct anthropogenic contributions to nitrogen in ground water beneath the reef tract or most offshore areas including Florida Bay, but they do indicate localized anthropogenic contributions to nitrogen in shallow ground waters near onshore development. Denitrification reduced substantially the concentration of nitrate in the Keys water supply before it was pumped from the source, and it reduced the concentration of nitrate in treated wastewater after it was injected beneath the Keys. Nevertheless, nitrogen was moving through both ends of the anthropogenic water cycle, some being introduced with the drinking water supply and some ultimately discharging to near-shore surface waters after use and disposal.

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Salinity History of Florida Bay: An Evaluation of Methods, Trends, and Causes

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Concern exists over hypersalinity – salinity exceeding marine salinity of approximately 35 ppt – in Florida Bay and its negative impact on the ecosystem. High salinity is one of several factors that may cause changes in seagrass distribution, abundance, and density (Fourqurean and Robblee, 1999). To determine the causes of historical changes in seagrass communities, as well as other ecosystem disturbances, and to improve model ability to simulate ecosystem response to future restoration, the patterns and causes of salinity variability in Florida Bay must be determined.

We describe progress towards distinguishing natural salinity variability due to climate variability from changes caused by water diversion in the Everglades during the 20^{th} century. Variability in salinity in Florida Bay reflects the bay's geometry, which features the Gulf of Mexico to the southwest, the Florida Keys to the southeast, and the Everglades to the North, and its shallow bathymetry and circulation resulting from the complex of mudbanks in the bay. Florida Bay salinity varies over seasonal, interannual, and decadal timescales but the instrumental record prior to the 1990s is insufficient to attribute cause to decadal trends. Here we specifically address the application of quantitative "retrodictive" estimates of past salinity patterns derived from geochemical studies of ostracodes from sediment cores from the central part of Florida Bay. Parallel studies of molluscan shell chemistry and seasonal salinity variability using the same sediment cores will be given in a separate presentation at the meeting.

The ratio of magnesium to calcium (Mg/Ca) ions in the calcium carbonate shells of the crustacean group ostracodes is strongly influenced by the salinity and temperature in which the organism secretes its shell (see Dwyer et al., 2002). The variability in Mg/Ca ratios of Florida Bay water is "captured" in the Mg/Ca ratios of the ostracode shell when it secretes its adult shell. It is conventional to express the relationship between shell and water chemistry as follows:

$$(\mathrm{Mg/Ca})_{\text{ostracode calcite}} = (K_{\text{D-me}})(\mathrm{Mg/Ca}_{\text{water}})$$

where

Mg/Ca represents the atomic ratio of Mg to Ca and $K_{\text{D-me}}$ is the partition coefficient for magnesium (Dwyer and Cronin 2001). Mg/Ca ratios in fossil ostracodes from sediment cores were used to construct a paleosalinity curve for central Florida Bay. The results showed that 20^{th} century decadal oscillations in salinity were related mainly to regional rainfall variability, which in turn was influenced by climate processes associated with interannual El Niño-Southern Oscillation and decadal Pacific North American patterns (Cronin et al., 2002).

In this study, the accuracy of the Mg/Ca salinity curve was "groundtruthed" against instrumental records of salinity from Florida Bay (Nuttle et al., 2000). Figure 1 shows the Mg/Ca paleosalinity curve plotted against the instrumental record of salinity for the last 50 years. The instrumental record was constructed from mean monthly salinity values for Whipray, Rankin, and Bob Allen Basins pooled to yield a grand mean for the central region. Table 1 summarizes the paleosalinity-instrumental salinity comparison for Russell Bank.

Table 1. Comparison between Mg/Ca paleosalinity and instrumental record salinity minima

Salinity Maxima	Mg/Ca Salinity	Instrumental Salinity	Salinity Max. Difference	Salinity Minima	Mg/Ca Salinity	Instrumental Salinity	Salinity Min. Difference
1990-1993	40.63	41.70	-1.08	1993-1995	36.15	36.45	-0.30
late 1970s	45.03	44.08	0.95	1980s	24.91	28.53	-3.61
mid 1960s	51.37	48.41	2.96	late 60s-early 70s	28.35	30.22	-1.87
1950s	57.02	47.32	9.70	~1960	27.05	27.89	-0.84

Both records exhibit large decadal swings in salinity in central Florida Bay ranging from > 50 ppt to the low 20s. For salinity maxima during the early 1990s, late 1970s and mid-1960s the difference between paleo and instrumental salinity was approximately -1.1., 0.9, and 3 ppt, respectively. The paleosalinity method overestimated the maxima for the 1950s by 9.7 ppt, however the instrumental record stops in 1957 and it is unlikely the two records had a similar period of record for this high salinity event. The differences for four periods of Florida Bay salinity mimima approximately 1993-1995, the 1980s, the late 1960s-early 1970s and around 1960 were 0.3, 3.6, 1.9 and 0.8 ppt, respectively. Given the temporal gaps in the instrumental record, the error bar on the sediment core age estimates, and the spatial and temporal averaging used for both records, these comparisons provide a remarkable confirmation that the Mg/Ca-based shell chemistry method yields accurate estimates of past salinity to within < 1 to 4 parts per thousand.

Figure 1 also compares paleosalinity with hydrological instrumental records from south Florida: mean monthly water height at USGS well 196a, Homestead, Florida, annual discharge at Taylor Slough since 1961, and NOAA monthly regional rainfall anomalies. The results reveal decadal patterns in rainfall and water well height since the 1930s and an inverse correlation between salinity and well height, rainfall and discharge. For example, wet periods (i.e., approximately 1960, late 1960s, early 1980s) were characterized by positive precipitation and well height anomalies and relatively low Florida Bay salinity. Periods of low salinity recorded in the Mg/Ca paleosalinity curve during the early 1950s and the early 1940s are also evident in the precipitation and well height curves. Decadal salinity oscillations over the past century are also evident from Mg/Ca analyses from Park and Bob Allen Keys, and Little Madeira Bay (Dwyer and Cronin 2001).

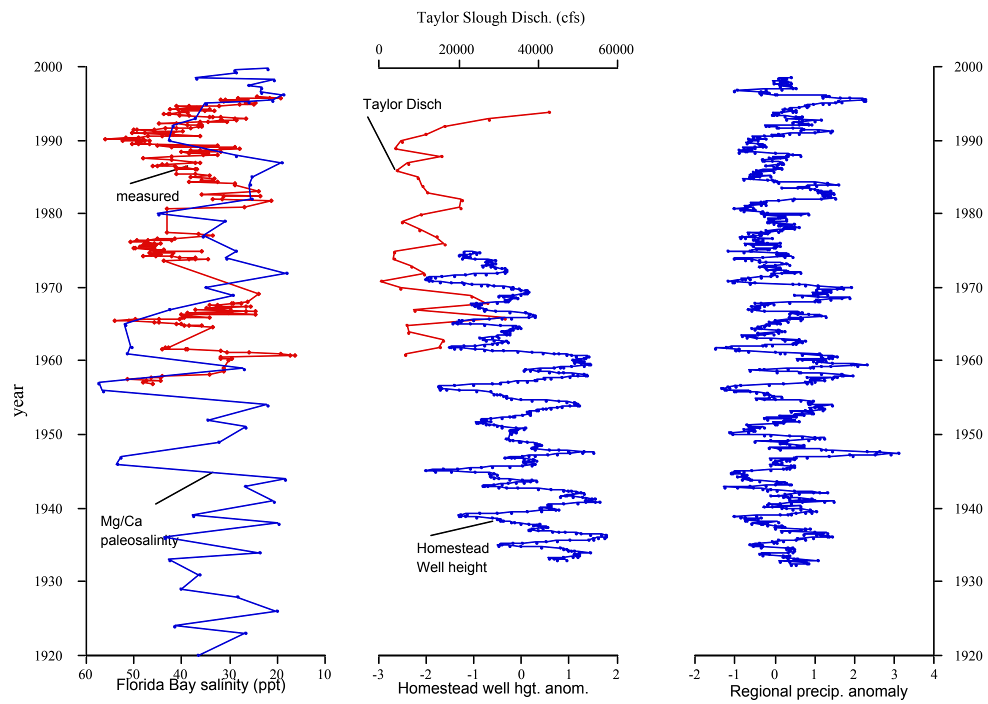

Figure 1. Comparison between paleosalinity and measured salinity (left), Homestead well level and Taylor discharge(center), and NOAA regional rainfall (right).

These results demonstrate that the Mg/Ca method reconstructs salinity patterns that faithfully record salinity extremes to within a few parts per thousand and that the Mg/Ca method could be applied to new core sites to build a network of long-term salinity records in Florida Bay and adjacent bays.

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Estimating Water Quality Along the Southwest Florida Coast for Hydrologic Models Using Helicopter Electromagnetic Surveys

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Modern, three-dimensional hydrologic models are valuable tools for understanding and managing groundwater resources. Great quantities of data in the form of hydrologic properties are needed to build these models; adding solute transport to the model requires thousands of estimates of water quality. Traditional approaches relying upon water quality measured in wells and then interpolated or extrapolated across the model can be woefully inadequate, especially when well data are sparse. Combining well information with the results of helicopter electromagnetic (HEM) surveys produces a better hydrologic model.

HEM surveys measure the electrical conductivity of the ground at multiple frequencies using an instrument pod slung beneath a helicopter. A measurement is made about every 5-10 meters along flight lines. Flight-line spacing is typically 400 meters. The depth of exploration varies from 20 to 50 meters depending upon the formation resistivity. (Electrical resistivity is the reciprocal of electrical conductivity.) In more conductive zones, such as those saturated with seawater, the exploration depth is diminished, while in freshwater saturated zones deeper exploration is possible. The HEM data are used to estimate a layered-earth electrical resistivity model at every measurement point. The data can then be used to create a three-dimensional grid of electrical properties.

Electrical resistivity of geologic materials is controlled by the amount of pore space, the electrical resistivity of the pore fluid, the degree of saturation, and the presence of clay minerals. The relationship between specific conductance (SC) of the pore water and the formation resistivity can be determined by correlation of data from wells. Using this correlation, the HEM-determined electrical resistivity model can be turned into estimated water quality.

This approach was used on a previous HEM survey (see fig. 1) in Everglades National Park (Fitterman and Deszcz-Pan, 2001, 2002). We are using the same approach with a survey flown in October 2001 over parts of Big Cypress National Preserve (BCNP) and Everglades National Park (ENP). The survey has 2,692 line-km of flight lines covering an area of approximately 1,020 sq-km (see fig. 1).

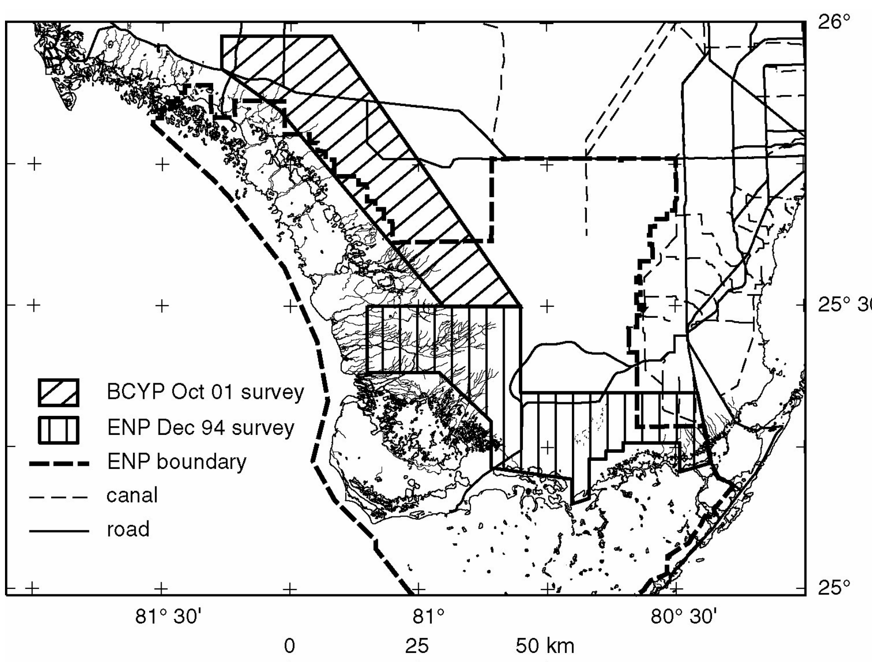

Figure 1. Location of south Florida HEM surveys.

The primary products of this survey are apparent resistivity maps, one for each of the five measurement frequencies. Lowering the frequency probes deeper into the subsurface. The data are converted into resistivity-depth functions, which are then used to produce formation-resistivity, depth-slice maps. The depth-slice maps are used to create a formation resistivity volume that can be interactively displayed. The cell size of this volume is 200 m horizontally and 5-10 meters vertically, dimensions that are commensurate with the Tides and Inflows in the Mangrove Ecotone (TIME) hydrologic model being developed by Schaffranek et al., 2003.

The depth-slice maps show a general decrease in formation resistivity (0.5-10 ohm-m) moving towards the coast with resistivities inland that are in the range of 20-100 ohm-m. (Images of the depth slices can been seen at the South Florida Information Exchange web site: http://sofia.usgs.gov/projects/geophys_map/.) The transition between the conductive and resistive zones deepens in the landward direction starting near the surface and reaching a depth of 50 meters over a distance of 2 to 5 km. This feature is interpreted as being the freshwater/saltwater interface. There do not appear to be any influences on this transition that can be related to natural drainages or manmade features as are seen in ENP (Fitterman and Deszcz-Pan, 2001).

Weedman et al. (1997, 1999) developed relation between the formation water SC and the bulk formation resistivity in the northern part of the BCNP survey that we use in creating a three-dimensional water quality estimate. In turn this information is used in the TIME model as data to compare against the calculated salinity variations (Schaffranek et al., 2003).

The use of HEM data combined with water quality information from selected wells is a new approach for meeting the data demands of three-dimensional hydrologic models. The relatively flat lying geology in south Florida justifies the use of one-dimensional interpretation of the HEM data. The sparsity of clay minerals in the aquifer makes establishing the relation between water quality and formation resistivity relatively straightforward. The combined use of well and HEM data could be used to meet the data requirements of modern hydrologic models in other study areas.

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Atrazine Exposure and the Occurrence of Reproductive Abnormalities in Field Caught *Bufo marinus* From South Florida

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Many chemicals in our environment are suspected or known to influence endocrine system function. Endocrine disrupting chemicals (EDCs) have been broadly defined as exogenous agents that interfere with the production, release, transport, metabolism, binding, action, or elimination of natural hormones responsible for maintenance of homeostasis and regulation of developmental processes. Since hormones are important modulators of tissue differentiation, developing organisms are thought to be especially sensitive to EDCs. Indeed, many agricultural contaminants such as herbicides, fungicides, and insecticides have been shown to induce developmental toxicity through alterations in hormonal activity. For example, the insecticide DDT and its metabolite p,p'DDE are known to affect development through an anti-androgenic mechanism.

Atrazine is the most commonly used herbicide in the United States. Recent reports have suggested that environmentally relevant levels of atrazine can alter sexual development in laboratory exposed African Clawed frogs (*Xenopus laevis*), however, similar experiments have been unable to replicate these findings. The goal of the current study was to document whether similar reproductive system anomalies were common in anurans from Florida sugarcane agricultural areas, which have the highest per acre atrazine use in the U.S. The giant toad or cane toad (*Bufo marinus*) was chosen as the focal species because they posses a nonfunctional rudimentary ovary (Bidder's organ), which potentially makes them sensitive to EDCs that influence gonad development. They are an invasive species, so destructive sampling is not expected to cause negative impacts on local diversity, and they are found in large numbers in sugar cane fields were atrazine is extensively applied. The goal of the current study was to document whether exposure of frogs to sugarcane agricultural areas in south Florida would result in a higher incidence of intersex and/or developmental anomalies. Sugarcane agriculture has the highest per acre atrazine use in the U.S., which could represent the highest potential risk for exposure of native anuran species to atrazine.

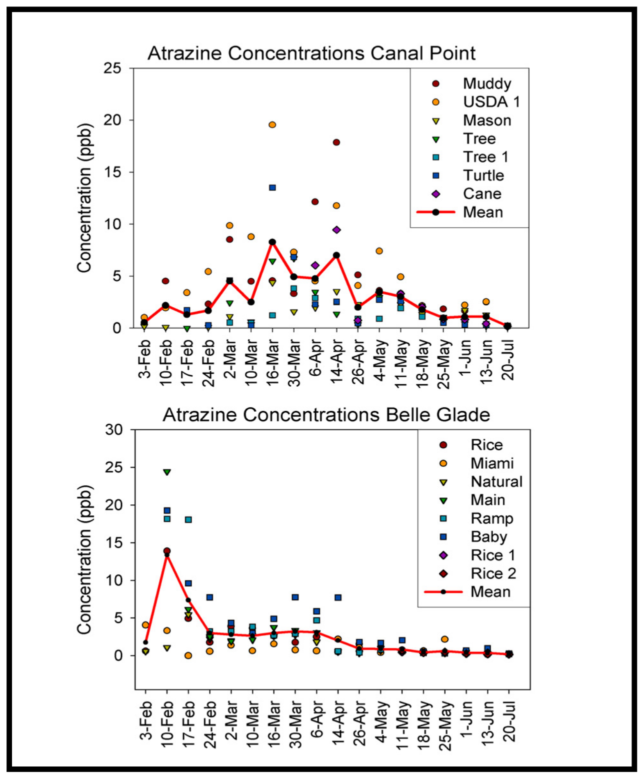

Figure 1. Atrazine concentrations in water for both sugarcane agricultural sites. Line indicates mean concentrations across each site.

To determine the distribution and concentration of atrazine at south Florida sites, multiple water samples were colleted from several canals/ditches at each of two agricultural sites every two weeks from February through June, 2002 (fig. 1). Adult toads were collected from two sugarcane agricultural areas Canal Point (CP), and Belle Glade (BG) as well as from a University of Miami pond/canal (reference site with little to no atrazine use or agricultural input) during April-June 2002. Adult *Bufo marinus* were collected from these three sites: Canal Point (N=55), Belle Glade (N=50), and University of Miami (N=24). Body weight, length, and coloration were recorded, blood was collected, and gonads were removed and weighed.

This species is sexually dimorphic, with females having a mottled appearance and males having a solid coloration. Sex was identified as follows: the presence of ovarian tissue and absence of testicular tissue = female; presence of testes and absence of developing eggs, oviduct, and ovarian tissue = normal male; and presence of testes with developing eggs or oviduct or ovarian tissue = intersex . Macroscopic identification of additional testicular anomalies included: segmented testes, abnormal shaped testis, twisted or curled testes, and multiple testes. Gonads from each individual that had testicular tissue were both macroscopically and histologically examined. Blood plasma was analyzed for phospho-lipoprotein (an indirect measure of vitellogenin) and estradiol and testosterone concentrations were analyzed using RIA procedures.

Atrazine levels were highest at Canal Point during March, but were highest at Belle Glade in February**.** *B. marinus* tadpoles were potentially exposed to atrazine concentrations as high as 20ppb during development at Canal Point and 26ppb at Belle Glade during 2002. Toads collected from the nonagricultural /reference, University of Miami, site exhibited the characteristic gender-specific pattern which correlated to subsequent gonadal morphology and histology. However, all toads collected from both agricultural sites, Belle Glade and Canal Point, exhibited the distinctive female pattern, although subsequent gonadal morphology and histology demonstrated male, intersexed, and female toads. The frequency of males exhibiting “testis abnormalities” was not significantly different among sites. The frequency of intersexed animals was significantly different among sites: 39 percent and 29 percent of the individuals at the agricultural sites, Canal Point and Belle Glade. No individuals from the non-agricultural/reference site were intersexed. The types of abnormal female tissue found in association with testicular tissue varied between CP and BG. Plasma sex steroids did not differ between intersexed and normal males. However, plamsa phospholipoprotein (an indirect indicator of vitellogenin was increased in intersexed males to levels which were similar to those for vitellogenic females.

The purpose of this preliminary study was to determine if animals found in sugarcane exhibit reproductive abnormalities similar to those seen in African Clawed Frogs exposed to atrazine in the laboratory. The incidence of testicular anomalies, other than intersex were similar across sites. However, the incidence of intersex was increased for both agricultural sites as compared to the non-agricultural/reference site. Nonetheless, *Bufo marinus* adults were active and breeding at all sites. Data suggests that agricultural exposure, including exposure to atrazine, may explain the differences in the percent of intersexed individuals and length of oocytes between Canal Point and Belle Glade sites. However, we can not conclude that atrazine is responsible for these abnormalities, since other agricultural chemcials are likely present at both sites. In addition, water quality analyses were not conducted for the non-agricultural/reference site (University of Miami) and exposure to atrazine at this site is unknown. The University of Miami site is expected to have low levels of atrazine, but is probably not atrazine free. Further research should be conducted to determine whether atrazine is capable of causing the effects we have documented in *B. marinus* under controlled laboratory conditions as well as expanded field studies of these and other sites. Nonetheless, these results indicate an increased incidence of intersex in toads exposed to agricultural contaminants. The implications of these data to future and ongoing restoration is unknown, however, a redistribution of water resources in the greater everglades ecosystem could result in additional exposures for amphibian populations in this sensitive ecosystem.

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Characterization of Solute and Fine-Particle Transport in Shark Slough, Everglades National Park by a Tracer Release in the Florida International University (FIU) *In Situ* Flumes

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Experiments that introduce dissolved or particulate tracers into flowing water are useful to characterize rates of material movement and mixing. Parameters determined from tracer experiments, such as advection and dispersion, are especially needed in models that simulate the effects of flow and mass transport on biogeochemical reactions and water quality. Presently, there are few data or guidelines available to understand mechanisms that control transport of materials with flowing water in the Everglades. Recently, a group of USGS and university researchers conducted a tracer experiment in central Shark Slough at one of the Florida International University (FIU) phosphorus dosing flume facilities. Each flume consists of 4 side-by-side channels, each enclosing a 3-m wide by 100-m long flow-way oriented with the natural direction of surface-water flow. More about flume design and results of the low-level phosphorus dosing can be found at several FIU websites (http://www.fiu.edu/~ecosyst/index.htm).

This abstract provides a brief description of a tracer experiment conducted from November 20-22, 2002 in flume A. The purpose of the experiment was to characterize transport of both solutes and fine-particles in Shark Slough, including surface-water exchange with subsurface water in the floc and underlying peat. The experiment was conducted in the westernmost channel of flume A. That channel receives the 'middle' level of phosphorus dosing being applied to determine the effects of added phosphorus on the Everglades ecosystem. At the time of the experiment, visible differences in macrophyte density were not apparent in the experimental channel when compared with areas immediately outside the flume. The depth of surface water was approximately 60 cm at the time of the tracer test and the location of the injection was 0.75-m upgradient of the 0-m reference point in the channel, which is the location where the 'mixing' reach for phosphorus dosing ends and the front edge of vegetation begins. The experiment consisted of a constant-rate injection for 22 hours of a sodium bromide (NaBr) solution made up in 0.2 um filtered Everglades water. The injection was accomplished using two metering pumps to deliver the tracer; dividing the flow between four soaker hoses (2.65-m long) stationed horizontally across the channels at evenly spaced depths. After termination of the NaBr injection, fine particles composed of titanium dioxide (TiO_2) were injected into the flume for a period of six hours. The TiO_2, which has a density of 3.9 g/cm^3, was suspended in filtered Everglades surface water by stirring and delivered by metered injection through a single slotted tube, oriented horizontally and positioned at a depth of 30 cm. Sampling for the tracers began before the start of the NaBr injection and lasted for 48 hours. Concentrations of both dissolved and particulate tracers were monitored at four stations at distances of 6.8, 26, 43, and 86m down the channel from the injection site. At each monitoring station, small-volume (20-ml) water samples were repeatedly collected by suction at seven discrete points, which characterized horizontal and vertical variability in tracer distribution across the channel. In addition to sampling surface water, porewater was sampled at two locations at a distance of 6.3 m downstream from the injection site. Analysis of bromide concentration in each sample is being conducted by ion chromatography, while concentrations of TiO_2 particles are being determined by inductively coupled plasma-atomic emission spectrometry following acid digestion of the particles.

Results from the experiment are not available at this time, due to the limited number of analyses completed. A full presentation of findings will be prepared upon completion of the sample processing and simulation modeling. In addition to providing fundamental information about transport processes in the Everglades, the expectation is that results can be combined with complementary data to better characterize rates of biogeochemical reactions in the Everglades. Parameters describing solute and particle transport will also be available as inputs for the water-quality and landscape-process models that are currently guiding restoration planning in the Everglades.

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Thermally-Driven Vertical Mixing in the Everglades

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Vertical mixing in most natural freshwater bodies is driven predominantly by boundary shear stresses such as wind stress on the free surface of a lake or bed friction on the channel bottom and banks of a rapidly flowing river. However, in the slowly flowing wetlands of the Everglades, thermally-driven convection is the dominant mixing mechanism. This diel mixing has potential implications for mercury methylation, evapotranspiration, oxidation, nutrient and contaminant transport and cycling, and other processes of concern in the Everglades wetlands.

Flow-velocity measurements and temperature profiles collected within an area of medium-dense spike rush on the edge of a large area of dense sawgrass in lower Shark River Slough within Everglades National Park reveal the behavior, timing, and extent of thermal mixing. Flow velocities were sampled using an acoustic Doppler velocity meter capable of resolving very low velocities to an accuracy of 1 mm/s over a range of a few cm/s. Two 600-sample measurement bursts are depicted in Figure 1. Each burst was collected at 10 Hz and, therefore, represents a one-minute sample. There are two plots for each burst. The first shows the three components of flow velocity: east-west, north-south and up-down. The second shows a signal quality statistic, correlation, which can be considered an indicator of small-scale turbulence in the acoustic pathway. Lower correlations indicate higher turbulent mixing.

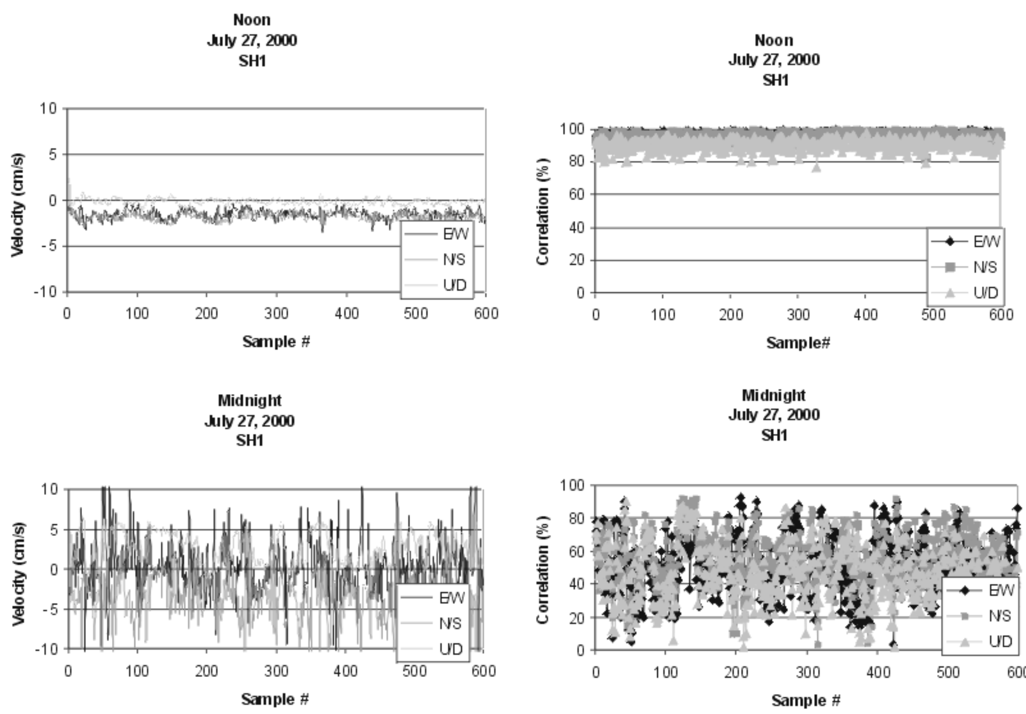

Figure 1. Typical flow velocity and signal correlation at SH1.

Velocity data in the first pair of plots, collected during the daytime, fluctuate minimally about their median values and have very high correlations. In strong contrast, velocity data in the second pair of plots, collected at midnight, fluctuate wildly and have substantially more variable and lower correlations. This phenomenon is typical and constitutes a pattern observed nearly every day.

Highly variable flow velocities in the hours after sunset can be linked to thermal convection by considering temperature data obtained from a set of thermistors, having an accuracy of 0.1 °C, cabled vertically 10 cm apart in a string deployed near the velocity meter. Thermistor data show the heavily vegetated water column to be isothermal at the beginning of each day (fig. 2). Initial heating of the water surface at sunrise is followed by progressive heating of the water column with depth throughout the day, resulting in increasing stratification throughout the late morning and early afternoon. Maximum stratification occurs at mid-afternoon and averages approximately 3°C through 60 cm of the water column (5°C/m). Typically, the water column reaches its maximum temperature around mid-afternoon. The water column cools through the remaining daylight hours, but remains stratified until approximately sunset when the air temperature begins to fall sharply and eventually drops below the water temperature at the surface.

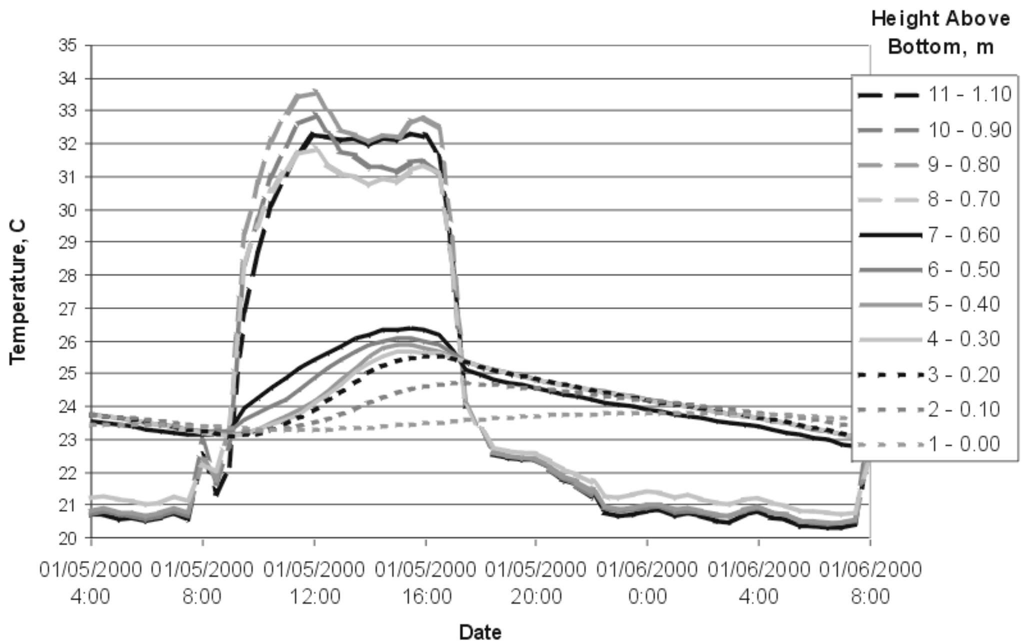

Figure 2. Typical temperature at SH1 (curve 1 = plant litter, 2-7 = water, 8-11 = air).

Diel coincidence of the thermal destratification and pronounced velocity fluctuations indicates the onset of mixing in the water column driven by thermal convection. The mixing process begins abruptly within approximately the upper 40 cm of the water column. Temperatures within this layer coincide through the remainder of the night. This mixed layer continues to cool and deepen throughout the night, not warming until just after sunrise the next day. A thin layer at the water surface remains slightly cooler than the mixed layer through the night, providing a constant source of negatively buoyant water that drives the mixing process. The mixing process continues until the air temperature rises above the temperature of the water at the surface.

The thermally-driven mixing process also affects the temperature structure within the upper portion of the plant-litter layer at the bottom of the water column. The slow exchange of mass and heat across the water-column/litter-layer boundary causes temperatures in the plant-litter layer to lag temperatures in the water column. Decreased heat exchange causes the peak temperature in the litter layer to occur after midnight and the minimum temperature to occur around noon. There is a brief time just before sunrise when the temperature in the litter layer is greater than in the water column. The daily range of temperatures in the litter layer (approximately 0.5°C) is much smaller than the range of temperatures at any particular point in the water column (approximately 3-5°C).

Individual daily temperature profiles in the Everglades wetlands are observed to vary only slightly with meteorological conditions and indicate that daytime destratification rarely occurs. Thermally-driven mixing appears to dominate at SH1 during more than 90 percent of the days. Only in the case of persistently strong winds, heavy rainfall, or dramatic drops in air temperature is the water column in the Everglades wetlands thermally well-mixed during the daytime. The presence of vegetation appears to be the primary factor increasing the consistency with which thermally-driven convection dominates the vertical mixing process in the Everglades. The ubiquitous nature of this mixing implies a likely role in a number of important processes in the ecologically stressed Everglades wetlands.

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Is Food Web Structure a Main Control on Mercury Concentrations in Fish in the Everglades?

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Many lake studies have found good correlations between the mercury (Hg) concentrations in fish and the relative trophic positions of fish as determined by analyses of gut contents and (or) stable isotopes. But is this true in dynamic marsh ecosystems such as the Everglades? Based on the extensive REMAP (Regional Environmental Monitoring and Assessment Program) assessment of the Everglades ecosystem, Stober et al. (2001) concluded that spatial (especially N-S) differences in "food web structure" are a likely cause of spatial differences in Hg concentrations in mosquitofish. Food web structure is a general term that encompasses differences in food chain length, food web complexity, and food web base. The extensive isotope and gut contents datasets assembled by several agencies can be used to evaluate this hypothesis.

Over 5000 algae, macrophyte, invertebrate, and fish samples were collected at 15 sites studied by the USGS ACME (Aquatic Cycling of Mercury in the Environment) team during multiple trips 1995-1999. These samples were analyzed for $\delta^{13}C$ and $\delta^{15}N$ to determine temporal and spatial differences in food web structure; a smaller subset was also analyzed for $\delta^{34}S$. Samples consisted of both composites and individuals. Most samples were analyzed in bulk; however, muscle tissue was analyzed for most large fish. This large dataset was used to calculate the differences in $\delta^{15}N$ and $\delta^{13}C$ between all possible consumer-diet pairs. The difference in $\delta^{15}N$ between consumer and diet ($\Delta\delta^{15}N$) is a proxy for the length of the food chain between the species at a particular site and date, and the difference in $\delta^{13}C$ ($\Delta\delta^{13}C$) reflects differences in the base of the food webs of the species. An evaluation was then made of how often the $\Delta\delta^{15}N$ and $\Delta\delta^{13}C$ values differed between types of sites. There were no statistically significant differences in $\Delta\delta^{15}N$ values between high and low nutrient sites, suggesting that there was no evidence for shorter food chains at high nutrient sites, as found by Stober et al. (2001). However, there are statistically significant differences in $\Delta\delta^{13}C$ values between low and high nutrient sites. One likely explanation for the $\Delta\delta^{13}C$ differences is a difference in the dominant base of the food webs at such sites. Food webs at low nutrient sites appear to be more algal dominated while macrophyte debris appears to be a significant contribution to the base of the food webs at high nutrient sites.

Samples of periphyton, mosquitofish, and sediment samples collected during September 1996 at about 100 REMAP marsh sites were analyzed for $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$. The $\Delta\delta^{15}N$ calculated for periphyton and mosquitofish pairs (n = 68) showed no significant correlation with region (Above Alligator Alley, Between Alligator Alley and Tamiami Trail, Below Tamiami Trail) ($p = 0.67$) or latitude ($p = 0.20$), and no correlation with mosquitofish Hg levels ($p = 0.55$), suggesting a lack of evidence for spatial differences in food chain length. However, the $\Delta\delta^{13}C$ values showed strong spatial patterns, including statistically significant differences between data from different regions ($p = 0.04$) and latitudes ($p < 0.01$) (fig. 1).

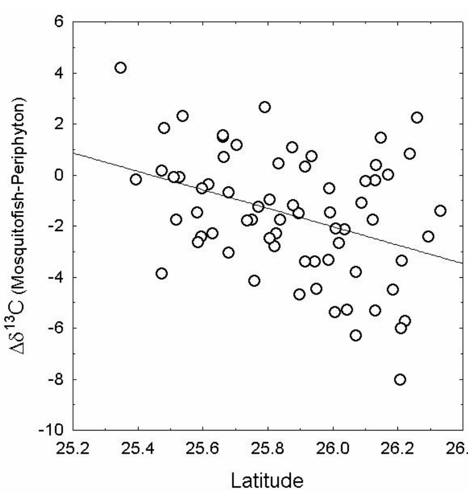

Figure 1. Graph showing significant correlation of $\Delta\delta^{13}C$ with latitude ($n = 68$; $p < 0.01$; $R^2_{adj} = 0.13$).

One likely explanation for the patterns is that they reflect spatial differences in the relative importance of algae versus macrophyte debris to the mosquitofish food web. In general, the spatial patterns of $\Delta\delta^{13}C$ values are very similar to spatial patterns interpreted by Stober et al. (2001) as differences in food web structure. Hence, two very different sets of samples and data from the same regional assessment agree that there are similar spatial differences in some aspect of the food web structure, but disagree about whether this difference is mostly due to trophic variations or food base differences. An evaluation of the gut contents of mosquitofish collected in 1996 and 1999 at the same REMAP sites, indicated that these data did not support the hypothesis that trophic position could be used to explain spatial differences in Hg concentrations (Stober et al., 2001). We are currently re-evaluating the isotope data in conjunction with the gut contents data to see if this will provide new insights into causes of spatial variations in food web characteristics.

This work was made possible by contracts from and collaborations with the US Geological Survey, US Environmental Protection Agency, and Florida Fish and Wildlife Conservation Commission.

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Biogeochemical and Hydrologic Controls on Food Web Structure in the Everglades

By Carol Kendall[1], Bryan E. Bemis[1], Scott D. Wankel[1], Ted Lange[2], *and* David P. Krabbenhoft[3]

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A clear understanding of the aquatic food web -- the relative trophic positions of different fish, birds, and other aquatic life -- is essential for determining the entry points and subsequent biomagnification pathways of contaminants such as methyl-mercury (MeHg) in the Everglades. Anthropogenic changes in nutrients and sulfur can significantly affect the entry points of MeHg by changing food web structure from one dominated by algal productivity to one dominated by macrophytes and associated microbial activity. These changes in the base of the food web also influence the distribution of animals within the ecosystem, and subsequently the bioaccumulation of MeHg up the food chain. We are attempting to use the ^{15}N, ^{13}C, and ^{34}S of biota in marshes and canals in the Everglades as (1) indicators of local environmental conditions that may impact water quality and biota, and (2) indicators of food web structure.

The isotopic compositions of several thousand sediment, plant, invertebrate, and fish samples collected in collaboration with several agencies from several hundred sites in the Everglades show strong spatial patterns on a landscape scale. The spatial variability of ^{15}N, ^{13}C, and ^{34}S values reflects spatial variability of reducing conditions in the marshes that promote methane production, sulfate reduction, and denitrification. The isotopic compositions of aquatic plants integrate the variability in water column isotopic compositions, and the resulting spatial patterns are incorporated throughout the food web. Therefore, organisms that live in sites where geochemical conditions are dominated by particular redox reactions have distinctive isotopic compositions. The temporal and spatial variability in the isotopic compositions of aquatic plants at the base of the food webs complicates the use of isotopic techniques for determining food web structure in the Everglades. In particular, the isotopic effect of these biogeochemical reactions must be removed from the isotopic compositions of biota before it is possible to evaluate temporal and spatial changes in food webs.

The temporal and spatial variability of biota isotopic compositions provide very useful insight into seasonal and spatial changes in biogeochemical and hydrological processes across the Everglades. For example, aquatic vegetation and detritus samples collected in September 1998 and March 1999 from various sites along two parallel transects in WCA (Water Conservation Area) 2A show that $\delta^{15}N$ values of vegetation tend to decrease (from around +5‰ to around 0‰) with distance from the canal, while $\delta^{13}C$ values show an increase with distance from the canal (from –30‰ to –26‰). Shrimp and other invertebrate samples collected at the same times also show approximately a 2‰ decrease in $\delta^{15}N$ and ~5‰ increase in $\delta^{13}C$ along the same gradient. Also, we find that plants and macroinvertebrates collected from microhabitats (such as open-water sloughs, cattail marsh, sawgrass marsh, and spikerush stands) within 100 m of site U3 in WCA2A have 0.5 to 1‰ variation in $\delta^{13}C$ and a 1 to 2‰ variation in $\delta^{15}N$ between marsh types. The differences in isotopic composition of biota within microhabitats at each site suggest that local influences, such as differences in the relative rates of photosynthesis and respiration, and differences in nitrification and denitrification, strongly affect the $\delta^{13}C$ and $\delta^{15}N$ (respectively) of local biota. Temporal changes in these same processes, as well as changes in species composition, cause algae samples collected weekly from three slightly different microhabitats near U3 to have $\delta^{13}C$ values that range from –32‰ to –27‰, and $\delta^{15}N$ values that range from +2‰ to +6‰ during the fall of 1997.

The δ values of organisms collected at the same site usually show an inverse relation between $\delta^{13}C$ and $\delta^{15}N$ over time. Seasonal shifts in water level can cause shifts in biogeochemical reactions and nutrient levels, with corresponding variations in the δ values of biota. For example, small changes in water level may change the balance of photosynthesis, respiration, and atmospheric exchange reactions that control the $\delta^{13}C$ of dissolved inorganic C (DIC). Such changes probably also will affect the $\delta^{15}N$ of dissolved inorganic N (DIN) because of corresponding changes in N uptake and redox conditions. During the dry season, the marshes probably become more anoxic due to shallower water levels, less photosynthesis, and increased quantities of decaying vegetation. At some sites, the $\delta^{13}C$

and $\delta^{15}N$ of algae show strong positive correlations with water level fluctuations. These oscillations are substantially damped up the food chain, probably because of the longer C and N integration times of animals vs. plants.

Our large dataset of $\delta^{13}C$ and $\delta^{15}N$ analyses of samples collected at 15 sites studied by the USGS ACME (Aquatic Cycling of Mercury in the Environment) team during multiple trips in 1995-1999 was used to calculate the differences in $\delta^{15}N$ and $\delta^{13}C$ between all possible consumer-diet pairs. The difference in $\delta^{15}N$ between consumer and diet ($\Delta\delta^{15}N$) is a proxy for the length of the food chain between the species at a particular site and date, and the difference in $\delta^{13}C$ ($\Delta\delta^{13}C$) reflects differences in the base of the food webs of the species. An evaluation was then made of how often the $\Delta\delta^{15}N$ and $\Delta\delta^{13}C$ values differed between types of sites. There were no statistically significant differences in $\Delta\delta^{15}N$ values between high and low nutrient sites, suggesting that there was no evidence for shorter food chains at high nutrient sites. However, there are statistically significant differences in $\Delta\delta^{13}C$ values between low and high nutrient sites.

We find that $\delta^{13}C$ values provide a powerful tool for distinguishing between sites where algae is the dominant base of the food web vs. sites where macrophyte debris (and the bacteria living on it) is also a significant food source. The $\delta^{13}C$ values of organisms from relatively pristine marsh sites sampled by the USGS are consistent with algae being the dominant food web base most of the time (perhaps depending on water levels). At the more nutrient-impacted sites, the $\delta^{13}C$ and $\delta^{15}N$ values of scavengers such as shrimp and crayfish are consistent with macrophyte debris being an important food source most of the time. The $\delta^{13}C$ values of samples collected by the EPA REMAP program in September 1996 also show spatial differences in the importance of algae as a base of the food web. Macrophyte debris appears to also be important to the mosquitofish food web at about half of these sites.

The $\Delta\delta^{15}N$ calculated for periphyton and mosquitofish pairs at the REMAP sites showed no correlation with region or latitude, and no significant correlation with mosquitofish Hg levels, suggesting a lack of evidence for spatial differences in food chain length. However, the $\Delta\delta^{13}C$ values showed strong spatial patterns, including statistically significant differences between data from different regions ($p = 0.04$) and latitudes ($p < 0.01$). One likely explanation for the patterns is that they reflect spatial differences in the relative importance of algae vs. macrophyte debris to the mosquitofish food web. In general, the spatial patterns of $\Delta\delta^{13}C$ values are very similar to spatial patterns interpreted by Stober et al. (2001) as differences in food web structure. Hence, two very different sets of samples and data from the same regional assessment agree that there are similar spatial differences in some aspect of the food web structure, but disagree about whether this difference is mostly due to trophic variations or food base differences.

Several chemical parameters measured at the sites by the REMAP program show significant differences between sites where the food webs are predominantly algal versus ones with appreciable contributions from macrophyte debris. These data are consistent with macrophyte-impacted sites generally having more anoxic conditions than sites where algae is the dominant base of the food web. The general agreement of the REMAP data with the conceptual model developed to explain temporal and spatial variability in food webs at USGS sites provides moderate evidence that spatial differences in the dominant food web base across the Everglades are related to environmental conditions such as nutrient availability, redox conditions, and hydroperiod.

Applications of our isotopic investigations to the Everglades Restoration include: (1) Biota isotopes provide a map of the current spatial distributions of the extent of several biogeochemical reactions (especially sulfate reduction) affecting nutrient and Hg uptake. (2) By comparing the spatial patterns in the biota with those in the shallow sediments, recent anthropogenic changes in biogeochemical processes at the landscape scale can be demonstrated and dated. (3) Isotopes provide detailed information about temporal and spatial changes in trophic relations that complements traditional gut-contents analyses used by the Florida Fish and Wildlife Conservation Commission (and others) for understanding food webs and the bioaccumulation of contaminants. (4) The preliminary synthesis of the biota isotopes at USGS and 1996 REMAP sites provides a mechanism for extrapolating the detailed food webs developed at the intensive USGS sites to the entire marsh system sampled by REMAP. (5) Biota isotopes provide a simple means for monitoring how future ecosystem changes affect the role of periphyton (vs. macrophyte-dominated detritus) in the mosquitofish food chain, and for predictive models for MeHg bioaccumulation under different proposed land-management changes.

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Unraveling the Complexities of Mercury Methylation in the Everglades: The Use of Mesocosms to Test the Effects of "New" Mercury, Sulfate, Phosphate, and Dissolved Organic Carbon

By David P. Krabbenhoft[1], William H. Orem[2], George Aiken[3], *and* Cynthia Gilmour[4]

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Mercury (Hg) contamination of the Everglades ecosystem is one of the most severe cases in the published literature. Currently, no human consumption of any Everglades sport fish is recommended. Although it is widely recognized that mercury contamination of aquatic ecosystems is largely the result of atmospheric mercury emissions, long-range transport and subsequent deposition, providing a scientific understanding of this problem with the necessary detail to prescribe appropriate corrective measures has remained unclear. From 1995 to 1999, the Aquatic Cycling of Mercury in the Everglades (ACME) project studied the biogeochemical cycling of Hg in detail at a series of sites spanning most of the north-to-south extent of the Everglades, and many of the major sub-ecosystem types. The ACME project revealed that mercury and methylmercury (MeHg) distributions in water, sediment and biota show complex seasonal and spatial trends, and that the cycling rates of Hg and MeHg are so rapid that many measurements must be conducted on a diel basis in order to provide an adequate understanding of the controlling factors. These studies revealed relations between biogeochemical factors and the production rate of MeHg, which is the most bioaccumulative and toxic form of mercury, and thus is central to understanding the mercury problem in the Everglades and elsewhere. Specifically, through field experiments and laboratory studies, we established links between MeHg production and several key ecosystem factors, including: hydroperiod, atmospheric Hg loading, sulfate loading from Everglades Agricultural Area (EAA) runoff, and dissolved organic carbon (DOC) levels in surface water. However, because all these driving factors of MeHg production co-vary spatially across our study sites, definitive quantitative assessments of which parameters are most important for limiting future methylmercury production remained unclear. In addition, because all of these factors are likely to be altered by the Everglades Restoration Project, a more "controlled" experimental approach was developed to estimate how this ambitious project might affect mercury toxicity for the Everglades in the future.

One approach for sorting out the complex responses of MeHg formation to alterations in critical water quality constituents (Hg, sulfate, phosphate and DOC) is through the use of *in situ* mesocosms (or wetland enclosures), in which dosing studies can be conducted. Such an approach has the advantage of maintaining many of the qualities of natural ecosystems that are very difficult to replicate in a laboratory setting, such as soil structure, redox, rainfall inputs, diel temperature and light cycles, as well as indigenous flora and fauna. On the other hand, mesocosms do potentially suffer from so called "wall" effects, and thus strict monitoring of the enclosed and native environment must be maintained to validate results. Starting in May 2000, the ACME Phase II project initiated mesocosm experiments at four of our long-term study sites (F1, U3, 2BS, and 3A15) located in Water Conservation Areas (WCA) 2A, 2B and 3A. Initial experiments were limited only to mercury dosing to quantify the ecosystem response to changes in mercury loading. At each site, we added mercury to mesocosms at 0.5, 1.0, and 2.0 times the current ambient loading rate (about 22 $\mu g/m^2/y$), and dedicated two mesocosms as experimental controls. At each site we also constructed clear plastic "roofs" for two mesocosms, which excluded mercury deposition from contemporary rainfall, but allowed for exchange of air and light to promote algal and plant productivity.

To distinguish between "new" and "old" (previously existing) mercury, mesocosm dosing was conducted using stable isotopes of mercury (e.g., ^{201}Hg, ^{202}Hg), which can be distinguished from ambient, mercury using a mass spectrometer. The examination of new versus old mercury was also tested by adding multiple Hg doses in the same mesocosms but, at different times, and using different isotopes for each addition. It had been hypothesized that the mercury contamination problem may continue for very long periods of time if existing mercury pollution in soils and sediment sustained the mercury cycle. Results of these types of experiments, therefore, are significant for assessing the potential effectiveness of mercury emissions reductions on mercury cycling in the Everglades.

Results from the mercury dosing experiment revealed several important findings. First, there is a positive and linear relation between mercury added and the production of MeHg in the Everglades. Second, there is an exceptionally close tie between mercury added and bioaccumulation of the added mercury in fish (Gambusia); the relation has a coefficient of determination greater than 0.9. Last, there is an "aging effect" for new mercury added to the ecosystem, such that more recent doses of mercury isotopes are more likely to be bioaccumulated than older mercury. All these results support the conclusion that recent mercury additions are proportionally more responsible for sustaining mercury exposure to wildlife and humans in south Florida, and any attempts to reduce current loading rates would likely have rapid and positive effects.

In 2001 we expanded the experimental design of our mesocosm experiments to examine the effects of sulfate, phosphate, and DOC dosing on mercury cycling. In addition, a new experimental site in Loxahatchee National Wildlife Refuge (WCA1) was added. Because DOC and sulfate levels in WCA2 and WCA2B are elevated due to runoff from the EAA, sulfate and DOC dosing could only be performed at our sites in WCA 1 and 3, where more pristine conditions exist. Also, because ecosystems can require extended periods of time to achieve a new equilibrium after the addition of phosphate, phosphate-dosing mesocosms previously established by researchers from the South Florida Water Management District were accessed and sampled. Lastly, in some mesocosms, we conducted mixed addition experiments (mercury and sulfate, and mercury and DOC) to test for possible synergistic or antagonist effects of co-dosing.

The mercury, sulfate, DOC, and phosphate addition experiments revealed several novel observations. Surprisingly, the addition of DOC alone stimulated the production of additional MeHg from "old" mercury in sediments. In the mixed DOC plus mercury addition experiments we observed greatly elevated methylation of the added mercury isotope, about 4 to 8 times greater than when mercury alone was added. These results suggest DOC is directly involved in the methylation process, rather than the common assumption that DOC is simply an attractive ligand for mercury in aqueous solution. Finally, when compared against the mercury-only dosed mesocosms, the mixed sulfate plus mercury mesocosms, yielded significant additional isotopically-labeled MeHg. However, high sulfate dosing levels gave rise to lower overall MeHg formation, which is consistent with our previous field observations in WCA2 where very high levels of sulfate contamination exist and these high levels reduce mercury methylation rates by sulfide inhibition. Lastly, no clear trend could be observed between phosphate dosing level and MeHg formation and accumulation.

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Water Quality in Big Cypress National Preserve and Everglades National Park --- Trends and Spatial Characteristics of Selected Constituents

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The National Park Service (NPS) maintains hydrologic monitoring stations for measuring water level (stage) and water quality in Big Cypress National Preserve and Everglades National Park (fig 1**)**. The data collected at these stations provide a historical baseline for assessing hydrologic conditions and making a wide range of management decisions. We have assessed selected water-quality data at these stations and at nearby canal sites for the period of record, 1959-2000, to define baseline conditions and to evaluate whether long-term trends have occurred.

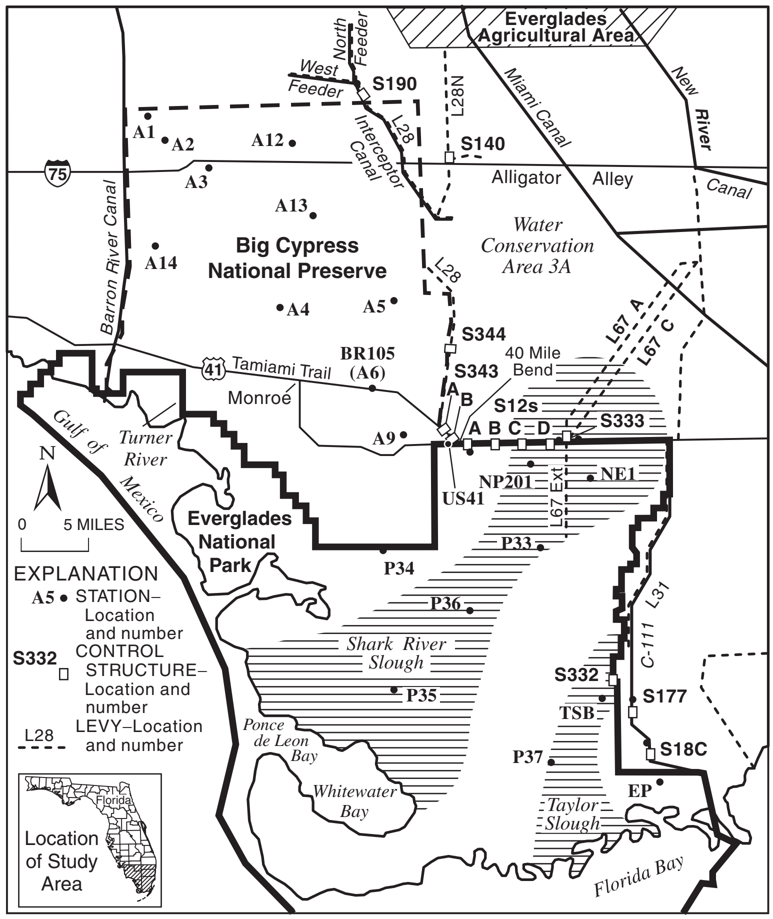

Figure 1. Hydrologic monitoring stations in Big Cypress National Preserve and Everglades National Park

Seasonal changes in water levels and flows in Big Cypress National Preserve and Everglades National Park affect water quality. As water levels and flows decline during the dry season, physical, geochemical, and biological processes increase the breakdown of organic materials and the build-up of organic waste, nutrients, and other constituents in the remaining surface water. For example, during much of the year, concentrations of total phosphorus in the marsh usually are less than 0.01 milligrams per liter (mg/L), but during the dry season, concentrations sometimes rise briefly above this value and, occasionally under drought conditions, exceed 0.1 mg/L.

Long-term changes in water levels, flows, water management, and upstream land use also affect water quality in Big Cypress National Preserve and Everglades National Park, based on analysis of available data (1959-2000). Specific conductance and concentrations of chloride increased in the Taylor Slough and Shark River Slough in the 1980s and early 1990s; for example, chloride concentrations more than doubled from 1960 to the 1990, primarily due to greater canal transport of high-dissolved solids into the sloughs. Some of the long-term trends in sulfate and total phosphorus were likely attributable to the high percentage of values reported as “less-than” and “zero”, and to changes in reporting levels over the period of record. High spikes in nutrient concentrations were evident during dry periods of the 1980s and attributable to (1) increased canal inflows of water that is nutrient-rich relative to marsh inflows, (2) increased nutrient releases from breakdown of organic bottom sediment, or (3) increased build-up of nutrient waste from concentrations of aquatic biota and wildlife in remaining ponds. Long-term changes in water quality over the period of record are less pronounced in the western Everglades and the Big Cypress Swamp, however, seasonal and drought-related changes are evident.

Water quality varies spatially across the region due to natural variations in geology, hydrology, and vegetation and because of differences in water management and land use. Nutrient concentrations are relatively low in Big Cypress National Preserve and Everglades National Park compared with concentrations in parts of the northern Everglades that are near agricultural and urban lands. Concentrations of total phosphorus generally are higher in Big Cypress National Preserve (median values, 1991-2000, were mostly above 0.015 mg/L) than in Everglades National Park (median values, 1991-2000, below 0.01 mg/L), probably because of higher phosphorus in natural sources such as shallow soils, rocks, and ground water in the Big Cypress region than in the Everglades region. Concentrations of chloride and sulfate, however, are higher in Everglades National Park (median values in Shark River Slough, 1991-2000, mostly above 2 mg/L sulfate and 50 mg/L chloride) than in Big Cypress National Preserve (median values, 1991-2000, less than 1 mg/L sulfate and at most sites less than 20 mg/L chloride) probably due to the canal transport system that conveys more water from an agricultural source into Everglades National Park than into Big Cypress National Preserve.

Trace elements and contaminants such as pesticides and other toxic organics are in relatively low concentrations in Big Cypress National Preserve and Everglades National Park compared with concentrations in parts of the northern Everglades, which are near agricultural and urban sources. Concentrations rarely exceeded aquatic life criteria in Big Cypress National Preserve and Everglades National Park. Atrazine was the only pesticide that exceeded the criteria (in 2 out of 304 samples). The pesticides p, p′-DDE, lindane, and heptachlor expoxide exceeded criteria in canal bed sediments in 16, 2, and 1 percent of the samples, respectively.

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Whole-ecosystem phosphorus budgets for freshwater Everglades wetlands

By Gregory B. Noe[1], *and* Daniel L. Childers[2]

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We are currently developing synthetic, whole-ecosystem phosphorus (P) budgets for freshwater Everglades wetlands. The development of P budgets will aid attempts to understand the impact of P enrichment on oligotrophic Everglades wetland ecosystems and prioritize future research by identifying knowledge gaps. Preliminary P budgets were developed for oligotrophic wet prairie (slough; fig. 1), oligotrophic *Cladium*, mixed *Cladium/Typha*, and *Typha* marsh ecosystem types. Mean P standing stocks (g P m^{-2}) for each component were quantified by reviewing published and unpublished literature on biomass and P concentrations in the Everglades. Fluxes (g P m^{-2} yr^{-1}) were determined by a variety of methods, including estimates of C turnover (assuming fixed C:P), water velocity, ^{32}P cycling, and long-term soil accretion rates. No reasonable estimate could be independently derived for many flux rates, in which case flux was determined by mass balance. As a first approximation, the P budgets assume steady-state conditions, 12-month hydroperiod, no mega-consumers, and no consumption of macrophyte detritus by consumers. In addition, nutrient turnover rates of periphyton, floc, and consumers in *Cladium* marsh were assumed to be equivalent to wet prairie marsh.

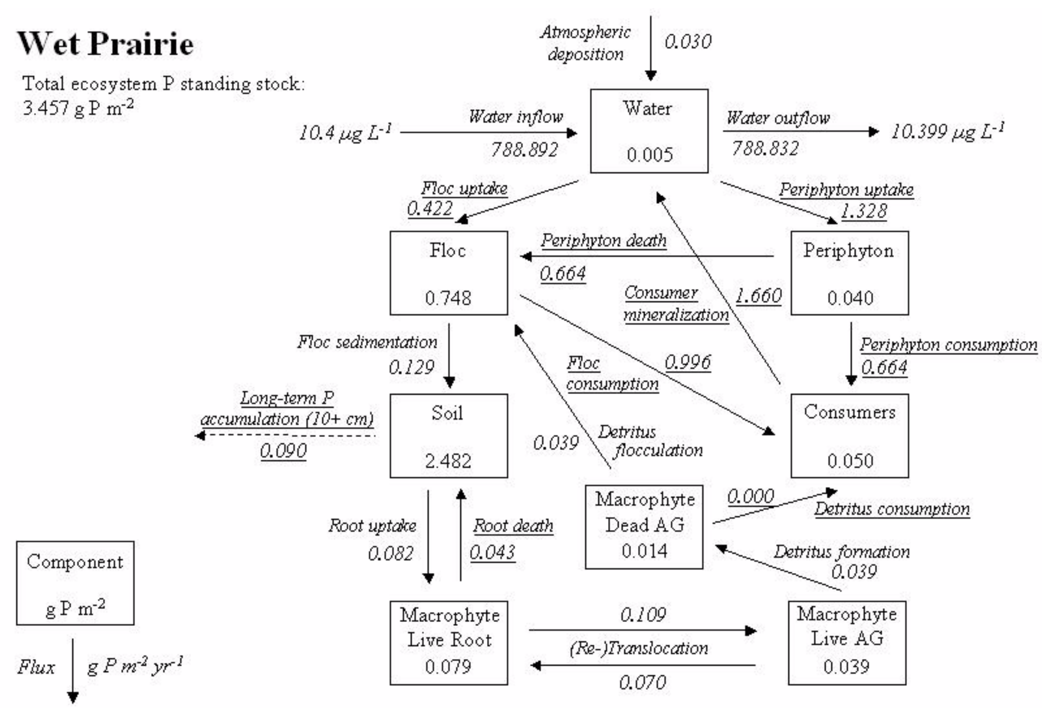

Figure 1. The P budget for oligotrophic wet-prairie marsh. Boxes represent the P standing stock (both organic and inorganic) of the different ecosystem components (g P m^{-2}) and arrows indicate net annual P fluxes between components (g P m^{-2} yr^{-1}). Underlined fluxes have high uncertainty.

Mean total ecosystem P standing stocks ranged from 3.46 in wet prairie, 3.65 in *Cladium*, 7.29 in *Cladium/Typha*, to 10.44 g P m^{-2} in *Typha* marsh. In wet prairie, soils (0-10 cm) held the most P in the ecosystem (72 percent), followed by floc (22 percent), live macrophyte rhizomes and roots (2.3 percent), aquatic consumers (1.5 percent), periphyton (1.2 percent), live aboveground macrophytes (1.1 percent), dead aboveground macrophytes (0.4%), and the water column (0.2 percent). Phosphorus partitioning, the percentage of total ecosystem standing stock, differed in oligotrophic *Cladium* and P-enriched *Cladium/Typha* and *Typha* marshes. In *Cladium* marsh, P partitioning is 4x and 6x greater in live and dead aboveground macrophytes, respectively, and 5x less in periphyton compared to the same components in wet prairie. As Everglades wetlands receive additional P loading and shifts in macrophyte species occur, live and dead aboveground macrophytes store increasingly larger proportions of whole-ecosystem P standing stock. Live aboveground macrophyte tissues store 3x and 9x larger proportions of ecosystem P in *Cladium/Typha* and *Typha* marsh, respectively, than in oligotrophic wet prairie. Similarly, dead aboveground macrophyte tissues increase P partitioning 11x in *Cladium/Typha* and 7x in *Typha* marsh. Periphyton partitioning increases slightly in the P-enriched ecosystems. Finally, floc stores 2x smaller proportions of P in the ecosystem as it enriches with P.

Long-term, steady state P dynamics in oligotrophic Everglades marshes are limited by average inputs (atmospheric deposition, 0.03 g P m^{-2} yr^{-1}) and outputs (soil burial, 0.09 g P m^{-2} yr^{-1}). Very large quantities of P flow in and out of a given area of oligotrophic marsh (~ 800 g P m^{-2} yr^{-1}), but net ecosystem uptake from the water column (0.06 g P m^{-2} yr^{-1}) is constrained by atmospheric input and soil burial. In wet prairie marsh, slow turnover of macrophyte stems and low P standing stocks result in relatively low net annual P flux from macrophytes compared to periphyton, floc, and consumers. For example, periphyton net annual through-flux is estimated to be 1.33 g P m^{-2} yr^{-1}, while live aboveground macrophyte tissues cycle 0.04 g P m^{-2} yr^{-1}. The smaller periphyton and greater macrophyte biomass in *Cladium* marsh relative to wet prairie are paralleled in less periphyton (0.27 g P m^{-2} yr^{-1}) and more macrophyte (0.23 g P m^{-2} yr^{-1}) throughput. Phosphorus enrichment, and the invasion of *Typha*, greatly increases the importance of macrophytes (both P standing stocks and throughput) to the ecosystem P budget. Macrophyte senescence results in the annual net movement of 1.59 g P m^{-2} yr^{-1} in *Typha* marsh.

Although data on biomass and P concentrations, and hence P standing stocks, are plentiful, few measurements of P fluxes exist. Relative to fluxes involving soils and macrophytes, fluxes between the water column, floc, periphyton, and consumers are less well quantified. In addition, most P flux rates have been measured in wet prairie and few rate measurements exist for *Cladium* or *Typha* marsh. Furthermore, most P cycling occurs in the water column between water, periphyton, floc, and consumers, while soil stores the largest amount of P in the ecosystem. Finally, P enrichment in the Everglades results in an increased importance of macrophytes to P cycling.

As part of the Florida Coastal Everglades LTER, these nutrient budgets will be expanded in the future to include site-specific data and nitrogen and carbon dynamics. In addition, nutrient budgets can serve as an integrative and synthetic tool for comparing freshwater marsh, mangrove, and seagrass ecosystems, and the impacts of nutrient enrichment on ecosystems.

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Sulfur Contamination and Geochemistry of the Everglades

By William Orem, Harry Lerch, Anne Bates, Margo Corum, *and* Marisa Beck

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Sulfur is an important water quality issue in the Everglades because of its role in microbial sulfate reduction and the methylation of mercury. Microbial sulfate reduction produces toxic hydrogen sulfide (H_2S) as an endproduct, and accumulation of H_2S in sediment porewater may change sediment redox chemistry and the ability of aquatic macrophytes and other marsh plants to maintain necessary oxygen levels in root systems. Microbial sulfate reduction also produces methylmercury (MeHg), a neurotoxin that is bioaccumulated. MeHg has been found in high concentrations in freshwater fish from the Everglades, and poses a potential threat to fish-eating wildlife and to human health (especially pregnant women) through fish consumption. Based on USGS results, sulfur appears to play a key role in regulating both the magnitude and distribution of MeHg within the ecosystem.

Freshwater wetlands typically have low sulfur concentrations, but we discovered high concentrations of sulfate sulfur in surface water of the northern Everglades. Independent studies conducted by the U.S. EPA and the South Florida Water Management District have also documented high concentrations of sulfate in large parts of the northern Everglades. Marshes in portions of the Water Conservation Areas (WCA's) have surface water sulfate concentrations that average nearly 60 mg/l, compared to concentrations of ≤1 mg/l in pristine areas of the Everglades. Areas with high surface water sulfate concentrations are concentrated in the northern WCA's, and especially near sites of canal discharge and along canal levees. Even higher concentrations of sulfate (average >70 mg/l and sometimes approaching 200 mg/l) were found in canal water draining from the Everglades Agricultural Area (EAA). This canal water appears to be the major source of excess sulfate entering the Everglades. The high loads of sulfate entering the ecosystem stimulate microbial sulfate reduction, and areas with high concentrations of sulfate in surface water also have very high levels of toxic H_2S in sediment porewaters. Porewater sulfide concentrations range from 5,000 ppb at marsh sites near canal discharge, to <0.05 ppb at pristine sites. Porewater sulfide concentrations were highly correlated with surface water sulfate concentrations.

We used sulfate concentration data and the sulfur (d34S) and oxygen (d18O) isotopic composition of sulfate in marsh surface water, canal water, rainwater, and groundwater to trace the source(s) of the excess sulfate entering the Everglades. Although the canals originate in Lake Okeechobee, the lake on average contributes only about 20 percent of the sulfate observed in the canals. Rainwater has too little sulfate to account for the high sulfate concentrations observed in the canals and in large portions of the Everglades. Groundwater beneath the Everglades has either too low a sulfate concentration or a d34S signature that is inconsistent with that of surface water in the Everglades. Both sulfate concentration data and the d34S values of sulfate in surface water from the Everglades and canal water confirm that canals in the EAA are the major source of excess sulfate entering the ecosystem. Furthermore, results showed that canal water with the highest sulfate concentrations had d34S values of +16 per mil, which is consistent with the d34S signature of agricultural sulfur (a soil amendment used in the EAA). Sulfate extracted from the upper 10 cm of soil in a sugarcane field in the EAA also had a d34S value of about +16 per mil. These data suggest that agricultural sulfur is the principal source (but not the only source) of excess sulfate entering the canals and Everglades wetlands.

The high levels of sulfate entering the Everglades from canal discharge have had important effects on the ecosystem. The H_2S buildup in sediment porewater at sites in the northern Everglades has significantly lowered redox potentials in the sediments. The lower redox conditions and high levels of H_2S in the sediments may have an impact on vascular plant growth in the Everglades by limiting oxygen penetration to roots. It is noteworthy that cattails have replaced sawgrass as the dominant macrophyte at sites heavily impacted by sulfur, although factors other than sulfur (e.g. eutrophication and high water levels) may also be influencing this change. Similarly, tree islands have disappeared mostly from the northern Everglades, in areas heavily impacted by sulfur.

The effect of excess sulfur load on MeHg production in the Everglades is complex. Sulfur appears to stimulate MeHg production through increased microbial sulfate reduction, but buildup of sulfide in sediment porewater inhibits MeHg production. The balance between these two effects of sulfur influences both the magnitude and location of

MeHg production in the Everglades, and produces the interesting effect that the zone of maximum MeHg production occurs in areas with sulfur loads only moderately higher than natural. This MeHg "Goldilocks" zone (where sulfur levels are just right) occurs in the central portion of WCA 3A, at the front end of the northern Everglades sulfur contamination plume. The complex relationship between sulfur geochemistry and MeHg production in the Everglades was first hypothesized from field studies at various sites in the ecosystem. This hypothesis has been further solidified from experimental studies in the Everglades using mesocosms. These mesocosm studies show that increasing sulfate concentrations increases MeHg production up to sulfate concentrations of about 10 mg/l. At sulfate concentrations >10 mg/l buildup of sulfide from microbial sulfate reduction inhibits the methylation of Hg.

The principal sink for sulfur entering the Everglades ecosystem is long-term storage in sediments. Sequestration of sulfur in sediments typically results from microbial reduction of sulfate to sulfide, and subsequent reaction of sulfide with either organic matter, to form organic sulfur compounds; or metals, to form insoluble metal mono- and disulfides. The dominant sulfur species in Everglades sediments is organic sulfur. Sulfur accumulation rates (gm^{-2} day^{-1}) in Everglades sediments ranges from 9.0×10^{-3} to 0.38×10^{-3}, a difference of more than 20 fold. The highest sulfur accumulation rates occur in brackish water mangrove (average of 6.0×10^{-3}), and sulfur-contaminated freshwater marsh areas (average of 4.5×10^{-3}). Sulfur accumulation rates average about 1.6×10^{-3} at pristine sites.

Sulfur in sediments represents a reservoir of reduced sulfur that may be reoxidized and remobilized during drought/fire and subsequent rewetting. Because drought and fire are frequent occurrences in the Everglades ecosystem, the remobilization of sulfur from sediments is an important factor influencing sulfur and mercury geochemistry. Studies of sulfur remobilization were conducted in northern WCA 3A following a burn and subsequent rewetting in that area during 1999. The average sulfate concentration in surface water at 14 sites was 58.6 mg/l immediately after the burn and rewetting of this area, compared to an average sulfate concentration of 5.10 mg/l before and over a year after the burn. The sulfate remobilized after the burn and rewet stimulated sulfate reduction and extreme levels of MeHg production (see abstract by Krabbenhoft et al., this volume). Cores from burned and control (e.g. unburned) sites in northern WCA 3A showed that burned sites had significantly lower total sulfur contents in sediments. A simulated laboratory experiment was conducted in which mini-cores were dried under simulated natural sunlight in controlled laboratory conditions for a specified period of time and then rewetted to further examine the effects of fire/drought on S geochemistry and MeHg production. Results verified the remobilization of sulfate and stimulation of MeHg production following fire/drought events. Ecosystem and water managers must consider the effect of drying and rewetting portions of the Everglades in order to avoid exacerbating the already extensive MeHg problem in the Everglades.

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Source Identification of Florida Bay's Methylmercury Problem: Mainland Runoff versus Atmospheric Deposition and *In Situ* Production.

By Darren Rumbold[1], Larry Fink[1], Nicole Niemeyer[1], Angela Drummond[1], David Evans[2], David Krabbenhoft[3], *and* Mark Olson[3]

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Mercury is a contaminant of concern in many areas of the world, including the Florida Everglades and Florida Bay, where fish consumption advisories have been issued for select species. Although atmospheric loading is often the dominant proximate source of inorganic mercury to many water bodies, the complication lies in the relation between influx of inorganic mercury and the amount that is methylated post deposition by sulfate reducing bacteria. The latter process is of fundamental concern because methylmercury (MeHg) is the more toxic and bioaccumulative form that can build up in the food chain to levels harmful to humans and other fish-eating animals. While much has been learned recently about mercury cycling in the Everglades, less is known about Florida Bay's mercury problem. Most importantly, there remains an incomplete understanding of the factors that govern production, transport and fate of MeHg in the bay.

Accordingly, in 2000, we integrated two on-going studies into a single multi-agency study, the objectives of which were to: 1) determine the source of MeHg driving bioaccumulation in eastern Florida Bay and, 2) assess the potential for modifications in freshwater delivery stemming from the Comprehensive Everglades Restoration Plan (CERP) to affect the bay's mercury problem. As a first step, we began collecting surface water, sediment and fishes along two transects into the bay. The first transect begins in the C-111 Canal and extends south through Joe Bay out to Nest Key. The second transect follows the flow path of Taylor Slough out through Little Madeira into the bay. In addition, a single reference site was sampled in the center of Whipray Basin, which receives little direct runoff. Finally, to assess the potential for *in situ* production of MeHg in Florida Bay sediments, we conducted a series of net methylation rate assays using intact sediment cores and stable mercury isotopes.

Sampling was completed in September 2002. Preliminary results describe significant spatial distributions and, in some instances, seasonal differences. Most importantly, levels of mercury in certain gamefish exceeded 0.5 mg/kg and sometimes exceeded 1.5 mg/kg (for further details on mercury in bay fishes, see Evans et al. this volume). Concentrations of total mercury (THg) in unfiltered surface water collected quarterly along the transects ranged from 0.38 ng/l to 5.98 ng/l (median was 1.55 ng THg/l; n = 115); whereas MeHg concentrations ranged from <0.02 ng/l to 1.79 ng/l (median was 0.08 ng MeHg/l; n = 115). Both THg and MeHg concentration increased substantially in the mangrove transition zone following late summer rains, with concentration maxima occurring in Taylor River (fig. 1).

On average, non-filterable or dissolved forms (<0.45 µm) accounted for 80 percent and 73 percent of the THg and MeHg, respectively. MeHg constituted 8 percent of the non-filterable THg, but ranged up to 36 percent in the transition zone of Taylor River. Interestingly, concentrations of THg and MeHg in the surface water collected from the reference site in Whipray Basin (medians of 1.29 ng/L and 0.15 ng/L, respectively; n = 10) were not significantly different than concentrations observed along the two flowpaths.

THg and MeHg in sediments collected semi-annually from the bay and upstream canals ranged from 5.8 to 145.6 ng/g dry weight (median was 19.9 ng THg/g) and from 0.05 to 5.4 ng/g dry weight (median was 0.26 ng MeHg/g), respectively. Although the highest median THg concentration occurred in sediment from the C111 Canal (115 ng/g), sediments from the mangrove transition zone along both flowpaths also contained relatively high levels of THg. The highest median sediment-MeHg (1.76 ng/g) occurred at the mouth of Taylor River. While these data must be normalized based on total organic carbon (measured in later cores) before any definitive conclusions can be reached, it was clear that sediments both from upstream marshes and from the bay often contained elevated concen-

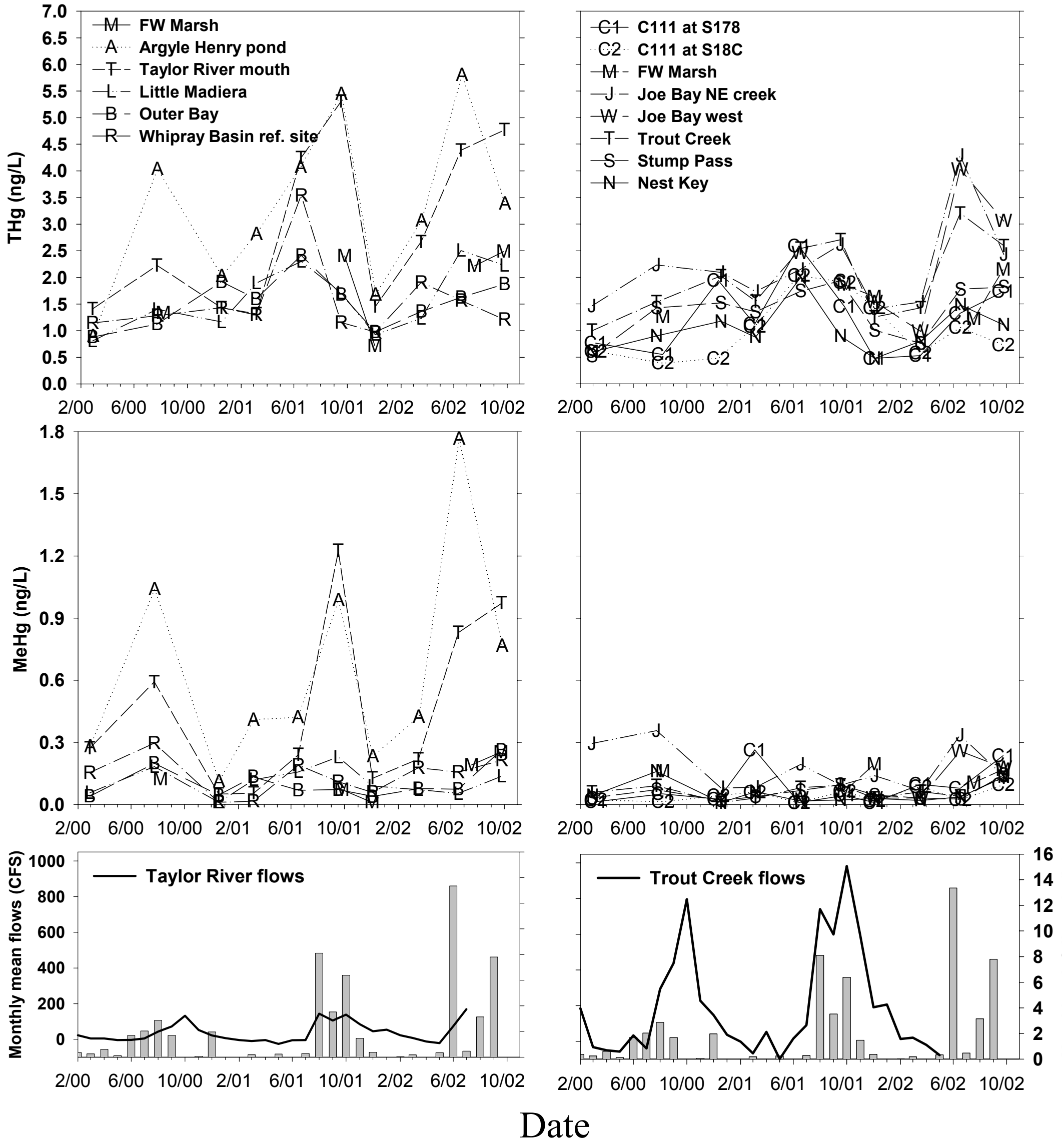

Figure 1. Time series of total mercury (THg), methylmercury (MeHg), flows and rainfall (bars) measured along two transects into northeastern Florida Bay. Note, rainfall was recorded in Joe Bay and flows after 6/2002 not yet available.

trations of MeHg. Sediments collected from near Nest Key, for example, contained up to 1.8 ng MeHg/g, which constituted almost 8 percent of the THg present. These results came as a surprise because, except for one or two recent studies, inhibition of mercury methylation had been reported for marine environments due to sulfidic pore-waters and salinities. For these reasons, net methylation rates were measured in intact cores using stable isotope tracers of ^{202}Hg (and more recently, to measure demethylation, $CH_3{}^{199}Hg$). Results from the first set of cores showed methylation rates in the 0-4 cm horizon to range from <1 percent to 11.2 percent conversion during the 24-h incubation period, with sediments from several sites in the bay having higher methylation rates than sediments from the mangrove transition zone. Although these data must be viewed in the context of a completed loading assessment, they indicate that mercury bioaccumulation in the bay is, at least in part, driven by *in situ* production. These data also indicate that understanding the MeHg problem in the bay will require a more complete understanding of the fluxes and bioavailability of inorganic mercury for methylation.

When completed, results of this study should improve our understanding of mercury cycling in Florida Bay, and our ability to make informed decisions about the management of Everglades inflows for the restoration of the sport fishery and the protection of fish-eating wildlife in Florida Bay.

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Effects of Microhabitats on Stable Isotopic Composition of Biota in the Florida Everglades

By Scott D. Wankel[1], Carol Kendall[1], Paul McCormick[2], *and* Robert Shuford[2]

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Attached algae (periphyton) serve an extremely important role in the Everglades ecosystem as a source of organic carbon to foodwebs. As important primary producers within the wetland ecosystem, they establish the isotopic composition of the base of the foodweb. However, this initial algal composition is established by the composition of the inorganic nutrients (DIC and DIN) in the water column, the compositions of which can vary significantly. Subsequently, the detrital foodweb begins with the decomposition of this plant material (composed of both emergent macrophytes and periphyton). The bacteria decomposing the detritus may have a lower $\delta^{13}C$ value than the original plant material – imparting a lower $\delta^{13}C$ signature to organisms consuming the detritus and assimilating the lighter bacterial carbon. Thus, foodwebs capitalizing on detrital components will exhibit isotopic variability due both to the variations in the original plant material and the processes decomposing the detrital material itself. An understanding of how these processes and linkages operate is critical to any interpretation of stable isotope data from the Everglades and to evaluating the success of the restoration process.

Aquatic vegetation and detritus samples were collected from various sites along two parallel transects in WCA 2A (Sites E1, E4, E5, F1, F4, F5, and U3). Sampling was carried out during the wet season (September 1998) and the dry season (March 1999) in order to discern any seasonal variations in isotopic composition. While the data indicate very little difference in $\delta^{13}C$ and $\delta^{15}N$ between seasons, there was a strong spatial trend moving from the canal into the marsh center. $\delta^{15}N$ values of vegetation (living and dead) tend to decrease (from around +5‰ to around 0‰) with distance from the canal, while $\delta^{13}C$ values show an increase with distance from the canal (from –30‰ to –26‰). Shrimp and other invertebrate samples collected at the same times also show approximately a 2‰ decrease in $\delta^{15}N$ and approximately a 5‰ increase in $\delta^{13}C$ along the same gradient.

In addition to the sampling of the primary vegetation and detrital matter at each site, benthic macroinvertebrates were collected within several microhabitats at each site. Microhabitats sampled at each site varied but included open-water sloughs, cattail marsh, sawgrass marsh and spikerush stands. The microhabitats were not farther than 100m apart within each site. At each site, there were differences between the $\delta^{13}C$ and $\delta^{15}N$ of invertebrates from different habitats. At U3, for example, there was a 0.5 to 1‰ variation in $\delta^{13}C$ and a 1 to 2‰ variation in $\delta^{15}N$ between marsh types (fig. 1). However, the only generalization that can be made for the microhabitat variations between sites was that invertebrates had lower

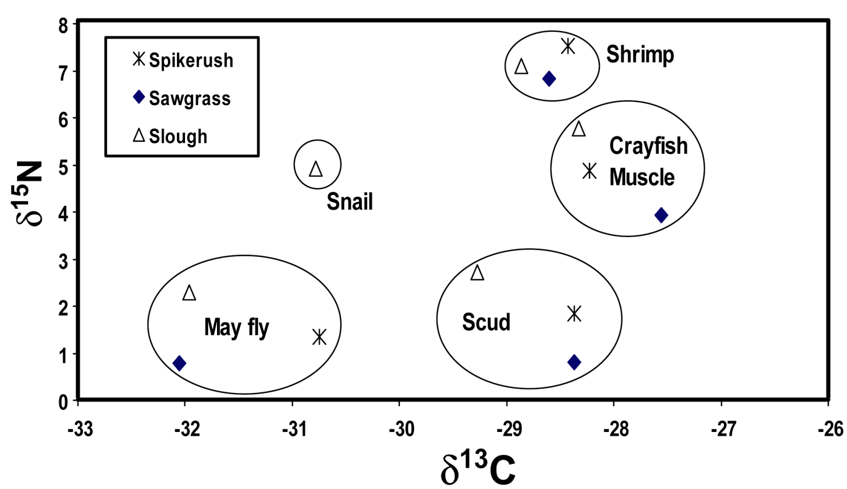

Figure 1. Differences in the $\delta^{13}C$ and $\delta^{15}N$ of selected invertebrates collected during the dry season (March 1999) at 3 different types of microhabitats (spikerush marsh, sawgrass marsh, open slough) near site U3 in WCA2A.

$\delta^{13}C$ values in sloughs than in cattail or sawgrass marshes. The differences in isotopic composition of benthic macroinvertebrates within microhabitats at each site suggest localized influences, perhaps due to the relative rates of photosynthesis and respiration.

Additionally, in October 1997, algal growth experiments were conducted at site U3, a pristine marsh site within WCA 2A. Plexiglass plates were submerged within three slough-wet prairie habitats and allowed to colonize with algae for 8 weeks. Site U3-1 was a slough with abundant water lilies whereas the other two sites were spikerush marshes. Weekly samples collected from each site were analyzed for $\delta^{13}C$ and $\delta^{15}N$, as well as diatom species composition (fig. 2). $\delta^{13}C$ of the algae ranged from –32‰ to –27‰, while the $\delta^{15}N$ ranged from +2‰ to +6‰. Isotopic compositions showed discrete temporal trends over the 8-week experiment that correlated well with changes in the dominant diatom species. These data are consistent with spatial variation in local microhabitat biogeochemistry and species composition controlling bulk algal isotopic composition.

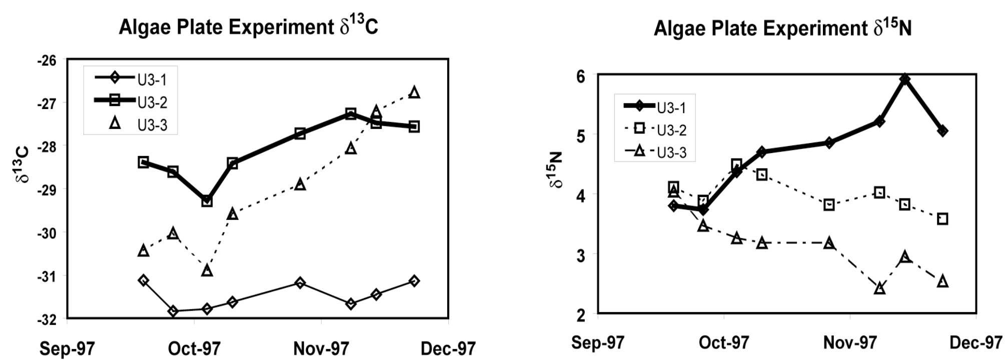

Figure 2. Changes in $\delta^{13}C$ and $\delta^{15}N$ of algae growing on plates at 3 locations near site U3 in WCA2A.

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Spatial and Temporal Patterns in Isotopic Composition of Aquatic Organisms at Everglades Nutrient Removal Project Sites

By Scott D. Wankel, and Carol Kendall

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The Everglades Nutrient Removal Project (ENR) began in 1994 with the goal of reducing the phosphorus (P) load downstream of the Everglades Agricultural Area. The effects of different vegetative habitats in treatment cells on P loads were evaluated. Cell 3 is dominated by emergent macrophytes such as cattails and water hyacinths, while cell 4 is dominated by an assemblage of submerged macrophytes and periphyton. During some sampling periods, there appeared to be significant differences in the mercury (Hg) concentrations of some aquatic organisms from the different cells, perhaps as a consequence of differences in food web structure (Hurley et al., 1999). We have analyzed sets of biota collected in 1997-98 from several locations in the four different cells of the ENR for $\delta^{15}N$ and $\delta^{13}C$ to (1) better understand the biogeochemical controls on the isotopic composition of Everglades foodwebs, and (2) assess whether there is any evidence for differences in food webs at the different sites that might explain differences in Hg concentrations.

Statistically significant differences in the isotopic composition (both $\delta^{13}C$ and $\delta^{15}N$) of muscle tissue from mosquitofish, least killifish, bluefin killifish, sailfin molly, and grass shrimp in Cell 3 between June 1997 and June 1998 suggest a shift in the isotopic composition of the diets of these fish. Samples collected in June 1997, January 1998, and June 1998 show increasing $\delta^{15}N$ values and decreasing $\delta^{13}C$ values. For example, the $\delta^{15}N$ of least killifish increase from +11.3 to +13.2‰ while the $\delta^{13}C$ values decrease from -25 to -29‰. This swing in the isotopic composition of these fish can be explained either by a change in diet or by a shift in the isotopic composition of their food source. The close tracking of the isotopic compositions of omnivorous fish (mosquitofish, killifish) with herbivorous fish (sailfin molly) over time suggests changes in the isotopic compositions of the algae. Since the isotopic composition of algal material is controlled largely by the composition of the inorganic nutrients within the water column, the isotopic composition of the fish reflects changes in the biogeochemistry operating in the water column at the time of algal growth.

The $\delta^{15}N$ and $\delta^{13}C$ values for mosquitofish, sailfin molly, and shrimp collected in June 1998 from Cell 3 and Cell 4 show significantly different averages and distributions (fig. 1). The data from Cell 3 plot in distinct clusters whereas data from Cell 4 show a striking alignment along a negative slope. It is not clear whether these differences reflect differences in diet or just differences in the isotopic composition of plants at the base of the food webs. At

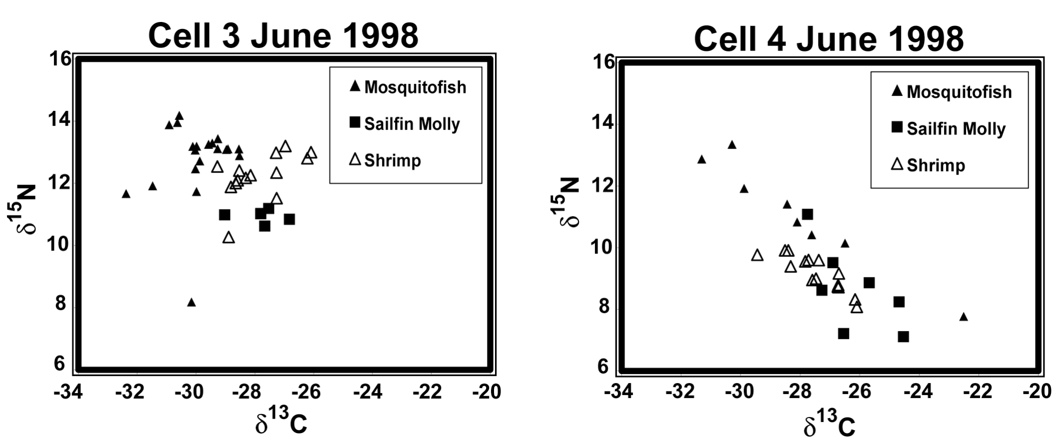

Figure 1. $\delta^{13}C$ and $\delta^{15}N$ values of selected biota collected from Cell 3 and Cell 4 in June 1998.

both sites, sailfin mollys have the lowest $\delta^{15}N$ and highest $\delta^{13}C$ values, shrimp have intermediate values, and mosquitofish have the highest $\delta^{15}N$ and lowest $\delta^{13}C$ values. Hence, there appears to be no major differences in their relative trophic positions in June 1998. Therefore, it is likely that the differences in $\delta^{13}C$ and $\delta^{15}N$ of organisms between Cell 3 and Cell 4 reflect differences in the isotopic composition of the diets between cells. Aquatic plants from Cell 4 show a much greater range of $\delta^{13}C$ values than plants from Cell 3, but a similar range of $\delta^{15}N$ values. The larger range of $\delta^{13}C$ values in Cell 4 may be related to the higher amounts of open water and periphyton growth in Cell 4 compared to Cell 3. Increased light penetration may cause larger changes in the $\delta^{13}C$ of dissolved inorganic carbon (DIC) in the water column by allowing more light penetration and therefore more benthic photosynthesis. Higher rates of benthic photosynthesis would lead to higher $\delta^{13}C$ values as seen in the organisms sampled in Cell 4.

The variations in isotopic composition over both time and space within the ENR emphasize the importance of localized biogeochemistry for interpretation of stable isotope data. Fluctuations in water depth (hydroperiod) and plant cover over time in the ENR may explain a significant portion of the variability of $\delta^{13}C$ and $\delta^{15}N$ of primary consumers (mosquitofish, killifish, sailfin mollies). Understanding the mechanisms for the foodweb base shift, whether it is a shift in diet or isotopic composition of the diet (or both?), is critical to tracing contaminant bioaccumulation within these Everglades foodwebs.

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An Evaluation of Contaminant Exposures and Potential Effects on Health and Endocrine Status for Alligators in the Greater Everglades Ecosystem

By Jon J. Wiebe, Ken Rice, Carla M. Wieser, *and* Timothy S. Gross

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Alterations in sexual differentiation, endocrine function and health have been documented among alligators in Central Florida as a potential response to environmental contaminants. These data suggest that exposure to site-specific sources, primarily agricultural sites and pesticides, may be responsible for these toxicities. The assessment of exposures for alligators within the Greater Everglades Ecosystem is an essential component of current and future assessments of risks and potential effects of proposed and ongoing restoration. To enable an assessment of contaminant risks for the Greater Everglades Ecosystems it is critical that an initial, complete food-chain, characterization of contaminants be conducted. These results would form the critical basis of any initial risk assessment and are necessary for any evaluation and/or assessment of risk that may be related to restoration of the Greater Everglades Ecosystem. In addition, these results would form the basis of any future evaluations of adverse effects, paired field and laboratory studies, and the critical assessments or evaluations of restoration success or resultant adverse effects.

The current study evaluated contaminant exposures and potential physiological effects on alligators in the Greater Everglades Ecosystem. Alligators (approximately 5 ft in length; n=10 animals per site during Fall 1999 and 2000) were collected and sacrificed from several specific sites involved in future restoration efforts: Everglades National Park, Loxahatchee National Wildlife Refuge, Big Cypress National Preserve, and Water Conservation Areas 2A, 3A-N and 3A-S. Several tissues were collected for contaminant analysis: blood, scute, liver, muscle, bile, and fat. Contaminant analyses will include an assessment of chlorinated hydrocarbons (i.e. pesticides, PCB's, PAH's), water-soluble herbicides, organophosphates, carbamates, and metals (i.e. mercury, lead, selenium etc). Blood was utilized for blood chemistry assessments of health status and endocrine status (sex steroids and thyroid function). Gonadal and liver tissues were examined histologically for an evaluation of reproductive status and liver toxicity. Selected samples from several alligators were composited to assess the appropriate tissues for each contaminant analysis. Samples collected during 1999 (approx. 3 animals per site) were also composited and analyzed for selected contaminants (persistent pesticides and several current use pesticides). Plasma was analyzed for biomarkers of reproductive status (estradiol and testosterone) and metabolism/thryroid function (T3 and T4).

Results for the preliminary phase of this project indicated a differential tissue distribution for each class of contaminant. Lipid soluble pesticides (i.e. chlorinated hydrocarbons) were detectable in all tissues examined except blood and scute. Blood and scute concentrations of the chlorinated hydrocarbon pesticides were, in general, below detection limits. In contrast, analyses of water-soluble pesticides (i.e. current use pesticides), organophosphates and carbamates were routinely detected in blood. Muscle tissue (i.e. fillets) were chosen for the focus of these preliminary analyses for the organochlorine pesticides, while blood plasma was utilized for the other pesticide contaminants. Initial analyses were conducted on a composite of three alligators from each site and preliminary results are summarized in figures 1 and 2.

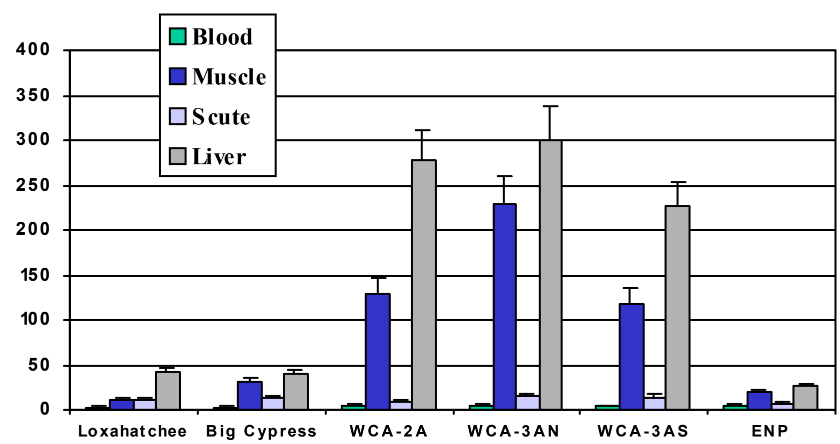

Figure 1. Preliminary analysis of total organochlorine hydrocarbon pesticides for several tissues from alligators across several broad regions of the Greater Everglades ecosystem. Results are as ppb for wet weight of tissue. Lipid concentrations did not differ between sites for each tissue. Note the differential distribution of pesticides across tissues.

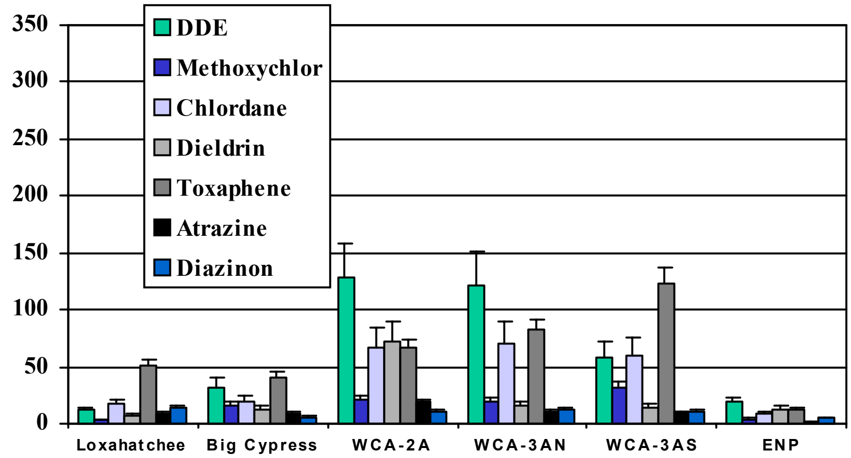

Figure 2. Preliminary analysis of organochlorine pesticides in muscle tissue for alligators across several regions within the Greater Everglades ecosystem. Data is listed as ppb. Note the increased exposures at the WCA;'s as compared to the other sites.

Results indicate site-specific patterns of contaminant exposure for alligators in the Greater Everglades Ecosystem, and the potential for endocrine system and reproductive effects. These data demonstrate the need for a thorough assessment of exposures for wildlife within the Greater Everglades ecosystem as an essential component of current and future assessments of risks and the potential effects of proposed and ongoing restoration.

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An Evaluation of Contaminant Exposures and Potential Effects on Health and Endocrine Status for Largemouth Bass in the Greater Everglades Ecosystem

By Carla M. Wieser[1], Jon J. Wiebe,[1], D. Shane Ruessler[1], Timothy S. Gross[1], *and* Ted Lange[2]

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[2]Florida Fish and Wildlife Conservation Commission

Alterations in endocrine function and reproductive success have been documented among largemouth bass in Central Florida as a potential response to environmental contaminants. These data suggest that exposure to site-specific sources, primarily agricultural sites and pesticides, may be responsible for these toxicities. The assessment of exposures for largemouth bass within the Greater Everglades ecosystem is an essential component of current and future assessments of risks and potential effects of proposed and ongoing restoration. To enable an assessment of contaminant risks for the Greater Everglades Ecosystems it is critical that an initial, complete food-chain, characterization of contaminants be conducted. These results would form the critical basis of any initial risk assessment and are necessary for any evaluation and (or) assessment of risk that may be related to restoration of the Greater Everglades Ecosystem. In addition, these results would form the basis of any future evaluations of adverse effects, paired field and laboratory studies, and the critical assessments or evaluations of restoration success or resultant adverse effects.

The current study evaluated contaminant exposures and potential physiological effects for largemouth bass in the Greater Everglades ecosystem. Largemouth bass were collected and sacrificed from several specific sites involved in future restoration efforts (32 sites, n=20 per site, over 750 samples): Everglades NP, Loxahatchee NWR, Big Cypress NP, Canals including C111, L39, L5, U3, S5A, G3, Holyland; STA's 1, 2, 3, 4, 5 and 6; Water Conservation Areas 2A, 3A-N, and 3A-S. Several tissues were collected for contaminant analysis: blood, liver, muscle, and gonad. Contaminant analyses will include an assessment of chlorinated hydrocarbons (i.e. pesticides, PCB's, PAH's), water-soluble herbicides, organophosphates, carbamates, and metals (i.e. mercury, lead, selenium, etc.). Blood was utilized for blood chemistry assessments of health status and endocrine status (sex steroids and thyroid function). Gonadal and liver tissues were examined histologically for an evaluation of reproductive status and liver toxicity. Sex was identified as follows: the presence of ovarian tissue and absence of testicular tissue = female; presence of testes and absence of ovarian tissue = normal male; and presence of testes with ovarian tissue = intersex . Selected samples from several fish were composited to assess the appropriate tissues for each contaminant analysis. Samples collected during 1999 (approx. 5 animals per site) were also composited and analyzed for selected contaminants (persistent pesticides and several current use pesticides). Plasma was analyzed for biomarkers of reproductive status (estradiol and testosterone) and metabolism/thryroid function (T3 and T4).

Results of the preliminary phase of this project indicated a differential tissue distribution for each class of contaminant. Lipid soluble pesticides (i.e. chlorinated hydrocarbons) were detectable in all tissues examined except blood. Blood concentrations of the chlorinated hydrocarbon pesticides were, in general, below detection limits. In contrast, analyses of water-soluble pesticides (i.e. current use pesticides), organophosphates and carbamates were routinely detected in blood and tissues at similar levels. Muscle tissue (i.e. fillets) was chosen for the focus of these preliminary analyses for the organochlorine pesticides, while blood plasma was utilized for the other pesticide contaminants. Initial analyses were conducted on a composite of five fish from each site and preliminary results are summarized in figures 1 and 2.

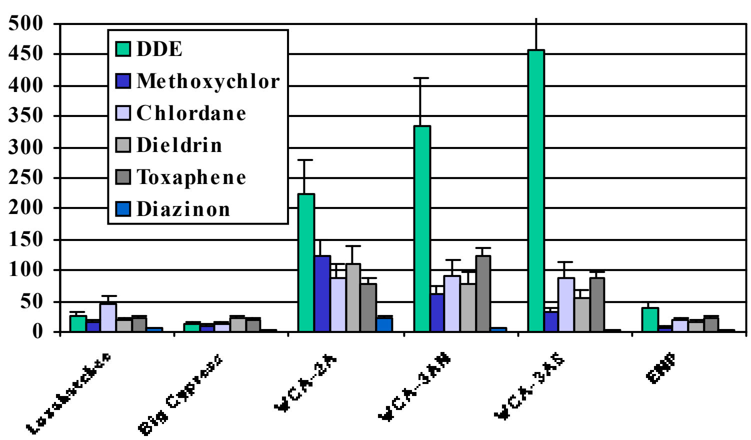

Figure 1. Preliminary analysis of chlorinated hydrocarbon pesticides for muscle tissue from largemouth bass across several broad regions of the Greater Everglades ecosystem. Results are as ppb for wet weight of tissue. Lipid concentrations did not differ between sites.

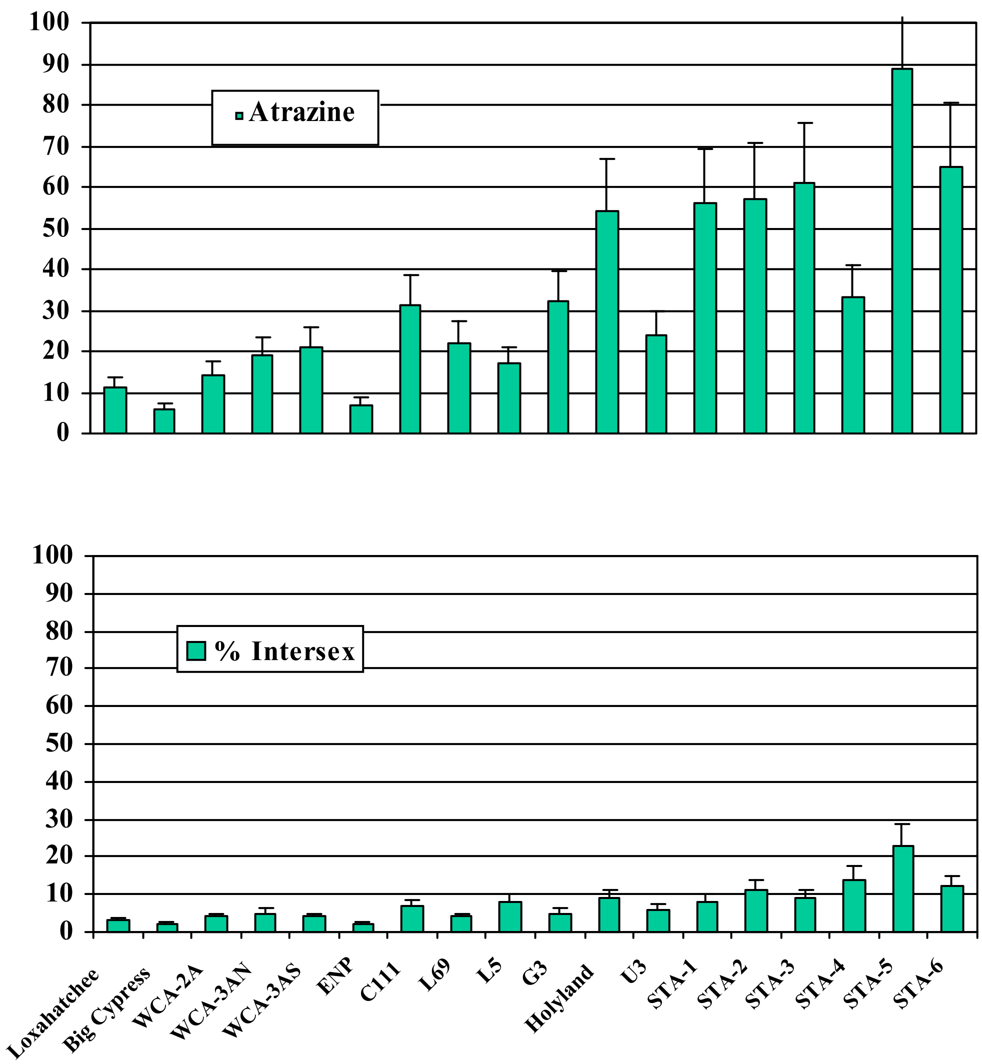

Figure 2. Preliminary analysis of plasma atrazine and incidence of intersex for sites throughout the Greater Everglades ecosystem. Atrazine data is listed as ppb. Note low background level of intersex for all sites and increased incidence of STA's 2, 4, 5 and 6.

Results indicate site-specific patterns of contaminant exposure for fish in the Greater Everglades ecosystem, and the potential for endocrine system and reproductive effects. These data demonstrate the need for a thorough assessment of exposures for wildlife within the Greater Everglades ecosystem as an essential component of current and future assessments of risks and the potential effects of proposed and ongoing restoration.

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Long-Term Water-Quality and Streamflow Monitoring in the Lake Okeechobee Watershed

By Molly S. Wood[1], *and* Pamela A. Telis[2]

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Lake Okeechobee is a large, shallow lake located in south-central Florida. With a surface area of 730 square miles, it is the second largest lake within the contiguous United States and has an average depth of 9 feet. The lake is the heart of south Florida's water supply and flood control system and is a major source of water for the Everglades. Agricultural development in the drainage area and construction of the Central and Southern Florida (C&SF) project during the last century has resulted in excess nutrient inputs and more efficient delivery of stormwater to the lake. As a result, in-lake phosphorus concentrations have doubled since 1970. This increase in phosphorus has shifted the natural balance of nutrients in the lake, led to conditions that are favorable for blue-green algal blooms, and contributed to the accumulation of phosphorus-rich bed sediments over an extensive area of the lake. The C&SF project canals that discharge waters from Lake Okeechobee to the St. Lucie and Caloosahatchee estuaries and to the Everglades have severely impacted these ecosystems.

Many agricultural sources of phosphorus pollution in the Lake Okeechobee watershed have been regulated under the Taylor Creek-Nubbin Slough Rural Clean Waters Program, the Dairy Rule, and South Florida Water Management District (SFWMD) Works of the District Program through installation of farm-level best management practices. Some reductions in phosphorus loads to the lake were observed in the mid-1980s to early 1990s, perhaps due to these activities. However, phosphorus loads into the lake have since been rising, and in-lake concentrations are well above the level needed to restore the lake to more natural conditions (fig. 1). Additional programs have been established under the Surface Water Improvement and Management (SWIM) Act and the Lake Okeechobee Protection Bill to help improve water quality, but these activities alone will not accomplish restoration of the lake and downstream waters.

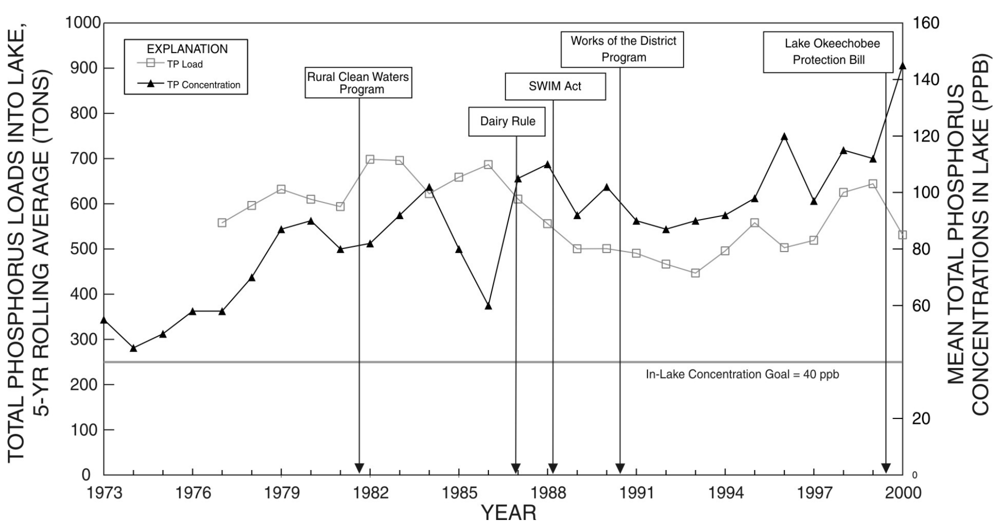

Figure 1. Five-year rolling average loads and annual mean concentrations of phosphorus in Lake Okeechobee. *Source: Surface Water Improvement and Management (SWIM) Plan, Update for Lake Okeechobee, SFWMD, 2002.*

In the 1990s, the U.S. Army Corps of Engineers re-evaluated the C&SF project and developed the Comprehensive Everglades Restoration Plan (CERP) for the restoration, protection, and preservation of water resources of central and southern Florida. This plan was signed into law by President Clinton in December 2000. To help fill the gap in Lake Okeechobee restoration and further understand watershed processes, the Lake Okeechobee Watershed Project (LOWP) was developed, incorporating 4 of the 68 major components of CERP. The LOWP has two major objectives; to improve water quality and to attenuate flood flows to Lake Okeechobee. LOWP activities will include the construction of stormwater treatment areas, restoration of wetlands, and dredging of sediment from canals.

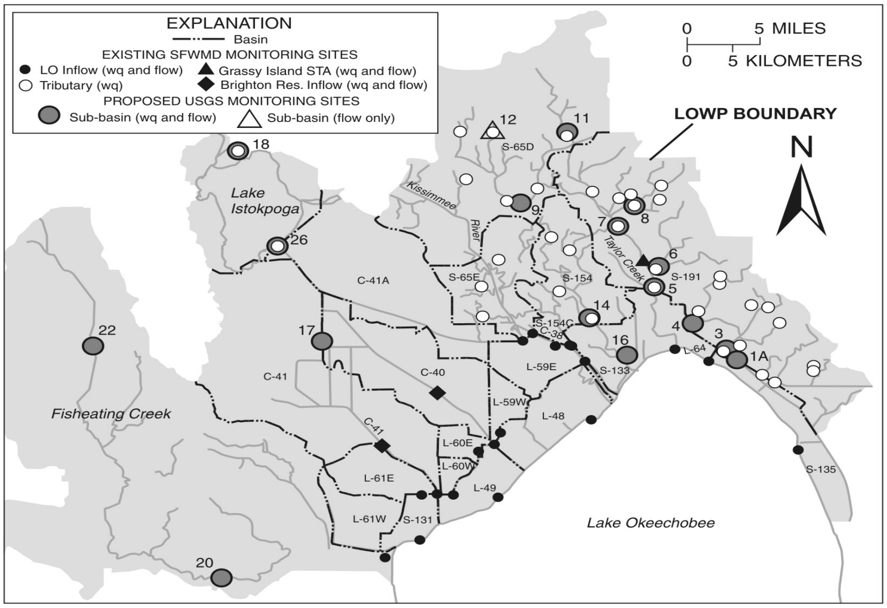

Figure 2. Existing and proposed monitoring sites in the LOWP area.

As part of the LOWP, the U.S. Geological Survey (USGS) will conduct a 10-year water-quality and streamflow monitoring program at the sub-basin scale in the LOWP area. Previous water-quality monitoring in the watershed has been focused on concentrations, not loads, or has been limited in scale and frequency. The objectives of the monitoring program are to compute loads, examine spatial and temporal trends in loads, and compare pre- and post-restoration activity conditions. The monitoring network will be composed of 16 water-quality and streamflow monitoring sites and 1 streamflow-only monitoring site (fig. 2). Data collection is anticipated to begin in mid-2003. Load monitoring is currently conducted by the SFWMD at inflow points to the lake, and additional monitoring sites will be established at individual stormwater treatment areas and wetlands to evaluate the effectiveness of those restoration activities.

Two types of water-quality samples will be collected weekly by the USGS; flow-weighted composite samples collected using an autosampler and equal-width-increment samples collected manually. The samples will be analyzed for three forms of phosphorus, three forms of nitrogen, and total suspended solids. In addition, weekly field measurements of water temperature, specific conductance, dissolved-oxygen concentration, and pH will be made. Streamflow will be determined through continuous monitoring of stream stage and index velocity, using hydroacoustic Doppler instruments. This monitoring network poses unique challenges to the collection of high quality data. The LOWP area is a low-gradient watershed that has numerous flow-control structures, and streams are subject to bidirectional flow and backwater conditions. These challenges present an opportunity to apply and test national data-collection protocols and cutting-edge instrumentation.

The establishment and operation of this monitoring network by the USGS provides a foundation for other research opportunities that are not part of CERP, thus adding value to the network. Integrated, multidisciplinary research will be possible, such as the co-location of biological research sites with water-quality monitoring sites and the subsequent sharing of data and observations. Additional water-quality parameters may be added relatively inexpensively because the primary cost of data collection is already covered within the monitoring network, thus leading to additional scientific research that may improve the understanding of the complex south Florida ecosystem and the effects of the Everglades restoration.

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Surface Water Geochemical Surveys in Florida Bay

By Kimberly Yates, Iuri Herzfeld, Nathan Smiley, *and* Chris Dufore

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Monitoring changes in surface water geochemistry is critical for identifying and predicting ecological response to restoration in Florida Bay. Many basic estuarine processes directly impact water quality and vice versa. For example, calcification, photosynthesis, and respiration directly affect dissolved oxygen, pH, dissolved inorganic carbon, and a number of other chemical characteristics of the water column. Alternatively, changes in salinity, carbon speciation in the water column, and other water quality parameters affect rates of metabolism and growth of estuarine species and rates of carbonate sedimentation. These processes are sensitive to changes in water quality that result from flow modifications in the Everglades. Bay-wide geochemical surveys were conducted bimonthly throughout the year to establish baseline data from which to gauge restoration impacts.

Geochemical survey tracts target the perimeter of each of the smaller basins within Florida Bay, transect larger basins, and include sampling sites near canal and slough discharge areas. Salinity, conductivity, temperature, pH, and dissolved oxygen were measured using a flow-through analytical system towed at a speed of less than 15 knots. Data from each parameter was logged once every 4 to 8 seconds of travel resulting in collection of approximately 20,000 data points for each parameter through the entire bay within three to four days. Water samples were collected from each of 24 sites distributed throughout the Bay and analyzed for total alkalinity and total carbon via rapid scan linear array spectrophotometry and carbon coulometry, respectively. Air:sea CO_2 gas fluxes were directly measured at each of the 24 sampling sites using a floating bell and a LiCor 6252 infrared CO_2 gas analyzer. Each carbon dioxide exchange rate reflects the linear slope with a best Pearson product moment correlation coefficient (r^2) calculated from a curve of approximately 900 data points.

Results from bimonthly geochemical surveys show the persistence of elevated salinity events in central Florida Bay during spring and early summer months. Air:sea CO_2 gas flux data show a persistent trend of CO_2 uptake into surface waters in the central region, and CO_2 out gassing in the eastern region throughout the year (fig. 1). Carbon dioxide gas flux data were superimposed over bottom-type data to identify potential correlations between

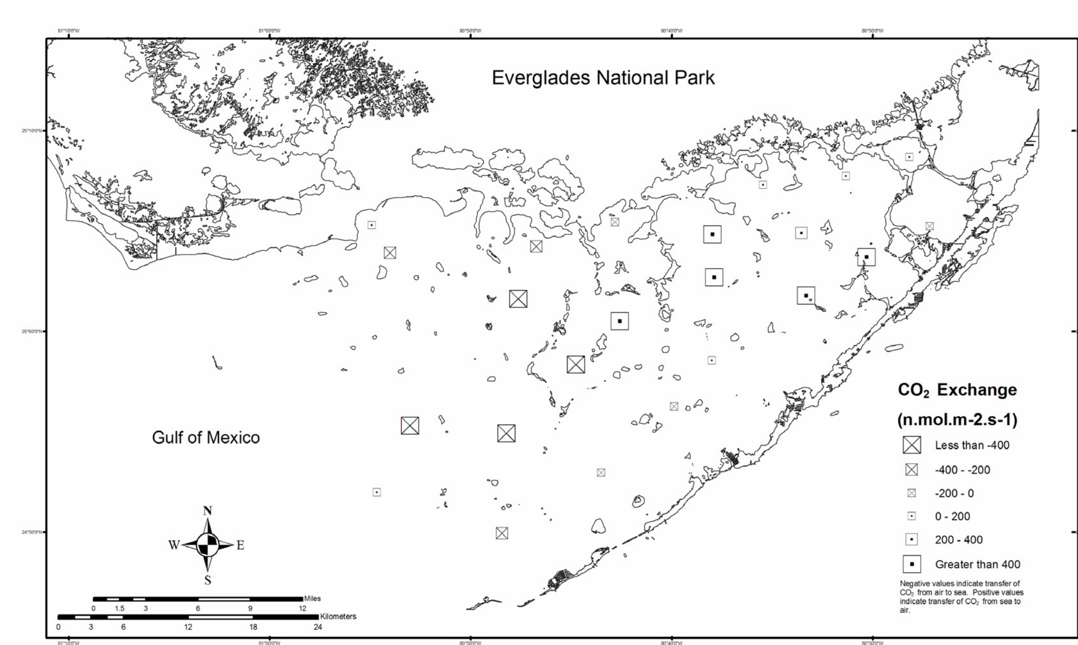

Figure 1. Example of Florida Bay air:sea carbon dioxide exchange data from April 2001. Boxes with and "x" indicate transfer of CO_2 from the air to surface waters. Boxes with a "•" indicate transfer of CO_2 from surface water to the air. Similar maps have been generated for salinity, temperature, pH, dissolved oxygen, total alkalinity, and total carbon.

benthic processes and gas exchange trends. No apparent correlation exists between bottom type and gas exchange rate. Other processes that may affect gas flux rates include plankton and macro-algal blooms, transport and degradation of dissolved and particulate organic carbon, and changes in other physicochemical parameters. Potential correlations among these parameters remain to be determined. Preliminary analysis of pH and dissolved oxygen data show no consistent spatial trends in variation. Total alkalinity and total carbon data are currently being analyzed. Statistical correlations will be made between surface water geochemical parameters to gain insight into the interdependencies of water quality parameters, the processes affecting them, and the potential impact of freshwater flow modifications resulting from restoration.

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Section III

Preserving Natural Habitats and Species

Contents

Section III: Preserving Natural Habitats and Species

Development and Stability of the Everglades Ridge and Slough Landscape

By Christopher E. Bernhardt[1], Debra A. Willard[1], *and* Charles W. Holmes[2]

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[2]U.S. Geological Survey, Center for Coastal and Watershed Studies, St. Petersburg, FL., USA

The Ridge and Slough landscape is a widespread habitat type in the Everglades, consisting of a system of dense sawgrass ridges separated by relatively open waterlily sloughs. The ridges run approximately parallel to each other, oriented in the direction of flow. Using pollen and chronological analyses of sediment cores, we tested the hypotheses that 20th century compartmentalization and water-management practices have altered the ridge and slough landscape and that ridges are expanding at the expense of sloughs.

A suite of surface samples collected in different subenvironments of the landscape were analyzed to determine which vegetation types were distinguishable in the pollen record. These include: dense *Cladium* (sawgrass) with scattered *Cephalanthus* (buttonbush) in the central ridge; less dense, shorter *Cladium*, with abundant *Cephalanthus* and occasional *Crinum* and *Sagittaria* in the ridge-slough transition zone; and *Nymphaea*, *Utricularia*, *Panicum*, *Pontederia*, and *Eleocharis* in the slough. Using Mann-Whitney tests and cluster analyses, it was shown that ridge and slough assemblages differ significantly, primarily in abundance of *Cladium* pollen. Incorporation of these data into the existing database of 170 sites and eight vegetation types provides a tool reconstruct past vegetation and its response to hydrologic changes based on pollen analysis of sediment cores.

Transects of sediment cores were collected across ridges and sloughs in Water Conservation Area (WCA) 3A and 3B (fig. 1); these transects include cores collected in the central part of the dense sawgrass ridge, the ridge-slough transition zone, and central slough. Analysis of the slough core indicates that slough vegetation occupied the site for >2,000 years; however, increased abundance of sawgrass pollen during the 20th century indicates the onset of drier conditions. Likewise, the central ridge site was occupied by sawgrass for approximately 2,000 years. The central ridges and sloughs appear to have been stable over long time scales. At the ridge-slough transition site, however, slough vegetation was present for >2,000 years before expansion of sawgrass ridge sometime in the last 200 years. Completion of geochronological analyses will document the timing of the expansion more precisely.

These preliminary data provide evidence that sawgrass ridges have expanded laterally into sloughs. Future coring strategies will address the issue of north-south stability of ridges and sloughs and will expand into WCA 2A to determine whether the ridge and slough landscape previously occupied more northerly sites and, if so, when it shifted to predominantly sawgrass vegetation.

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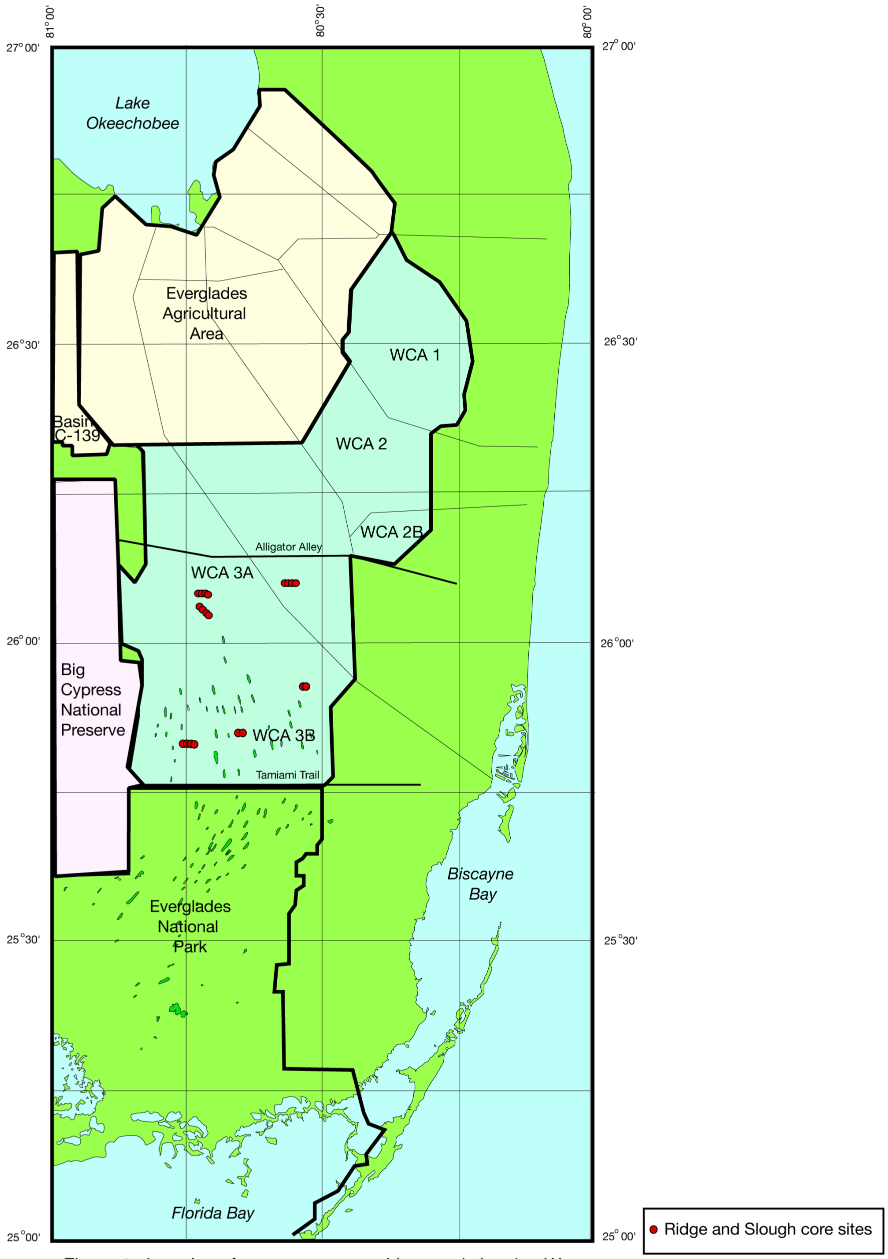

Figure 1. Location of transects across ridges and sloughs, Water Conservation Area 3A, Everglades, Florida.

Functional Response of Three Wading Bird Species to Prey Density

By Erynn Call[1], *and* Dale E. Gawlik[2]

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Declining wading bird populations in the last century have been considered one of the most prominent signs of the degradation of the Everglades ecosystem. Consequently, recovery of these populations will be a key indicator of successful restoration efforts. It has been hypothesized that the specific mechanism by which Everglades degradation has led to declining bird populations is related to changes in hydropatterns. These changes have most likely altered the availability of prey to wading birds.

Prey availability is determined by both the abundance of prey and the vulnerability of prey to capture. Prey abundance is affected by factors such as nutrient levels and hydroperiod whereas vulnerability to capture is affected by such things as behavior of the prey species, water depth, vegetation density, and body size.

Each component of prey availability is affected differently under various water management scenarios. For example, management for long periods without severe drydowns changes the species composition of the fish community. Different species of fishes exhibit different behavioral response to predators, thus changing their availability to capture. Moreover, these behavioral differences of the prey may be dependent on water depths. When the water column is deep, social species like the golden shiner (*Notemigonus crysoleucas*) may occur in schools and present wading birds with a very different capture probability than more solitary fishes like the bluegill (*Lepomis macrochirus*). However, as the water level recedes, capture probabilities of the two species may converge.

Ongoing modeling efforts in south Florida, such as the U.S. Geological Survey Across Trophic Level System Simulation (ATLSS) program, integrate information on hydrology and wading bird food availability to provide predictive power for future water management decisions. Currently, the biggest information gap limiting the wading bird component of ATLSS is foraging success as a function of prey availability and water depths. We conducted a series of experiments aimed at determining the effects of water management (manifested through changes in prey availability) on the use of foraging sites by wading birds. Here we present the preliminary analysis and results of the experiment addressing the effect of fish species, fish density, and water depth on wading bird foraging behavior.

The study was conducted in the Everglades Nutrient Removal Project adjacent to the northwest boarder of A.R.M. Loxahatchee National Wildlife Refuge, Palm Beach County, Florida (fig. 1). The experiment was initiated on 10 March 1997 when ponds were stocked with golden shiners (*Notemigonus crysoleucas*) and bluegill (*Lepomis macrochirus*), and was completed on 15 March 1997 when bird use nearly ceased. Treatments were assigned randomly among 12 ponds using a 2x2x2 (water depth 10 cm, 28 cm; fish density low and high; fish species golden shiner and bluegill) factorial arrangement with two replicates.

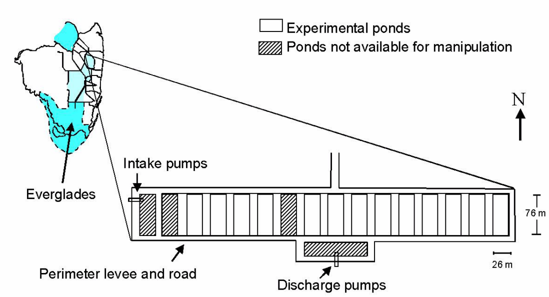


Figure 1. Location and arrangement of experimental ponds.

A video camera was used to monitor foraging flocks. Following the video monitoring, time-activity budgets of focal birds were constructed using information from videotapes. Three bird species were observed during this experiment: Great Egret (*Ardea alba*; visual feeder), White Ibis (*Eudocimus albus*; tactile feeder), and Wood Stork (*Mycteria americana*; tactile feeder). Two measures of prey consumption were calculated, mean prey capture per minute and the mean time interval between prey captures. The relation between these two measure of prey consumption and predicted fish density (fish/m^2) was investigated. We wanted to determine if capture rates were affected by low versus high fish density treatments.

Capture rate (fish/min) and the mean time interval between prey captures were plotted against predicted fish density for visual (figs. 2, 3) and tactile (figs. 4, 5) feeding wading birds. After visually inspecting the data, it appeared that prey density did not influence capture rates for visually feeding birds. In other words, wading birds had similar capture rates at low and high predicted fish densities. Sample sizes were too small to draw conclusions about the tactile feeding species.

Several of our experiments showed a strong numerical response to prey density by wading birds, in contrast to the apparent lack of functional response shown here. In other words, once these birds were at the ponds, capture rates were similar. One possible explanation for constant capture rates is that wading birds will leave a patch before intake rates decrease substantially. As a result, no decreasing intake rates can be detected. The fish density at which an individual wading bird will leave a pond in search of a new foraging locale is termed the giving up density (GUD). Further investigation of the relationship between prey density and wading bird foraging behavior will be conducted. The GUD will be calculated for this experiment and offer useful insight into the linkage among dry-downs, fish populations, and wading birds.

Fig. 2 - Predicted fish density vs. capture rate for **visual** feeding wading birds at 10 and 28 cm water depths.

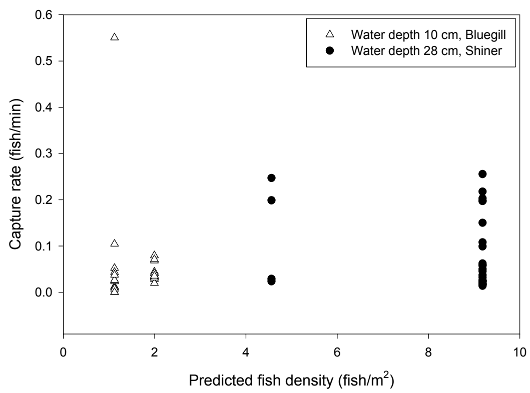


Fig. 3 - Predicted fish density vs. mean interval between captures for **visual** feeding wading birds at 10 and 28 cm water depths.

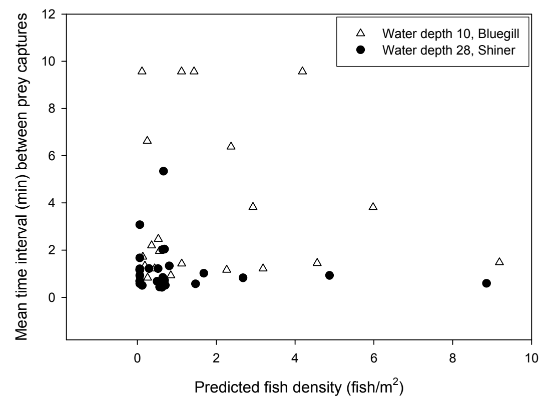


Fig. 4 - Predicted fish density vs. capture rate for **tactile** feeding wading birds at 10 and 28 cm water depths.

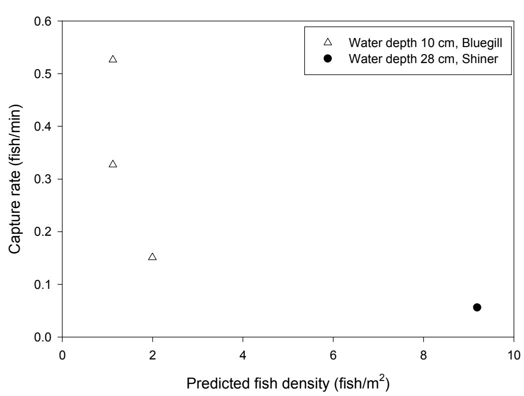
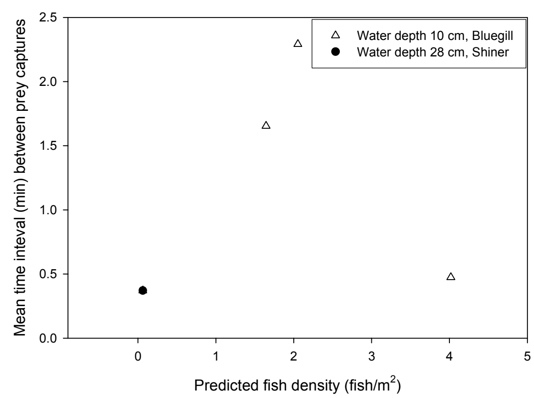


Fig. 5 - Predicted fish density vs. mean inteval between captures for **tactile** feeding wading birds at 10 and 28 cm water depths.



Contact: Call, Erynn M. and Dale E. Gawlik, South Florida Water Management District, 3301 Gun Club Road, West Palm Beach, FL 33406, Phone: 561-686-8800, Fax: 561-681-6310, ecall@sfwmd.gov

Northern Everglades Canals: Alligator Population Sources or Sinks?

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The Comprehensive Everglades Restoration Plan (CERP) includes the proposed removal of canals that fragment the Everglades wetland landscape. Dense populations of American alligators (*Alligator mississippiensis*) exist in canals throughout the system. Clutch and hatchling survival in canal and interior habitats at A.R.M. Loxahatchee National Wildlife Refuge (LNWR) were calculated during 2000 and 2001 to investigate the effects of canal habitats on alligator production. Data were collected from 112 nests and 779 hatchling alligators. Individuals from 57 hatchling pods were recaptured during this study.

No sampled clutches in the interior experienced flooding during 2000 and 2001 (fig. 1). However, most clutches in canal habitats were flooded or partially flooded (fig. 1). Nests were depredated by raccoons (*Procyon lotor*) at a higher rate during 2001 than 2000 (fig. 2). The number of clutches successfully producing at least one hatchling was greater during 2000 than 2001, and greater in interior than canal habitats (fig. 3). Survival probability estimates for 2000-cohort hatchlings for the first 6 and 13 months of life were 44 percent and 20 percent, respectively. Mean production per nest after 13 months was 2.4 ± 0.5 in interior and 0.8 + 0.8 in canal habitats.

Compared to nests in interior habitats, canal nests were subjected to a larger range of water levels during clutch incubation and were more susceptible to flooding. Flooding was found to be the greatest risk to canal nests at LNWR. The majority of nests in LNWR interior habitats were on tree islands. High clutch mortality, small pod size, and overall low mean hatchling survival at LNWR, resulted in negligible production in canal habitats during 2000 and 2001. Comparatively high adult densities in canals at LNWR, and likely other areas of the Everglades, are sustained by immigration and high adult survival rates. Everglades canals appear to be population sinks for alligators and canal removal will probably not affect the overall population.

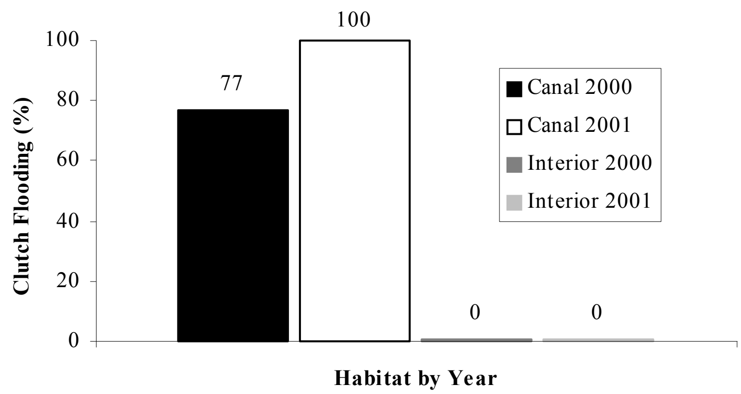

Figure 1. Percentage of American alligator clutches that experienced flooding during incubation in canal (*n* = 13 and 30) and interior (*n* = 35 and 24) habitats at A.R.M. Loxahatchee National Wildlife Refuge during 2000 and 2001, respectively.

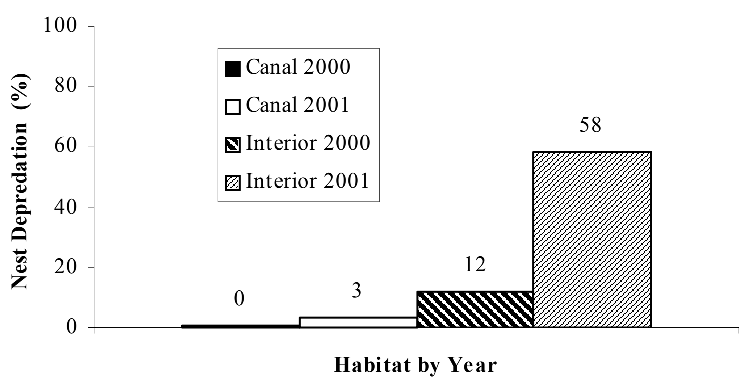

Figure 2. Percentage of American alligator nests that experienced depredation during incubation in canal (*n* = 13 and 29) and interior (*n* = 33 and 24) habitats at A.R.M. Loxahatchee National Wildlife Refuge during 2000 and 2001, respectively.

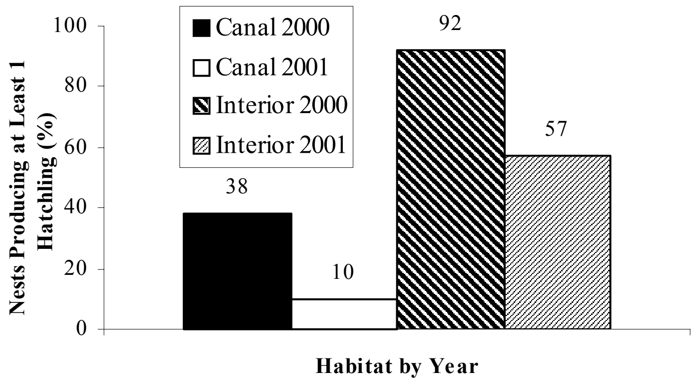

Figure 3. Percentage of American alligator nests that successfully produced at least one hatchling during the hatch event in canal (*n* = 13 and 30) and interior (*n* = 36 and 35) habitats at A.R.M. Loxahatchee National Wildlife Refuge during 2000 and 2001, respectively.

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Postlarval Transport of Pink Shrimp into Florida Bay

By Maria M. Criales[1], John Wang[1], Joan A. Browder[2], Thomas Jackson[2], Mike Robblee[3], *and* Clinton Hittle[3]

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The life cycle of the ecologically and commercially important pink shrimp (*Farfantepenaeus duorarum*) of the Dry Tortugas involves complex migrations between spawning and nursery grounds. To effectively manage population dynamics of this species, it is necessary to have accurate knowledge of the number of postlarvae that enter the nursery grounds and the processes linking nursery and spawning ground populations. Spawning and early larval development stages occur in the vicinity of the offshore Tortugas fishing grounds, while late stage postlarvae and juveniles occur in south Florida coastal waters and Florida Bay, approximately 120 km to the northeast. Population dynamics of this species are thus affected by factors occurring in Florida Bay, the Atlantic coastal zone, the Florida Shelf, and the Gulf of Mexico. Physical oceanographic processes may affect transport and supply of postlarvae. Until recently, transport across channels in the Lower and Middle Keys has been the most widely recognized larval transport pathway of pink shrimp to Florida Bay. Larvae drifting downstream with the Florida Current may enter Florida Bay by onshore Ekman surface transport when southeast winds blow along the east-west aligned coastline. Eddies that propagate downstream with the Florida Current from the Dry Tortugas also may serve as a transport mechanism of postlarvae in the Middle Florida Keys. In contrast, larval transport across the broad, shallow southwest Florida Shelf has not been considered an important pathway because the main surface current at the Tortugas grounds is toward the southwest and subtidal currents nearshore are of small amplitude and mainly in the alongshore (north-south) direction as a direct response to the wind events.

With the support of the South Florida Ecosystem Restoration Prediction and Modeling (SFERPM) program and as part of the development of a simulation model of the pink shrimp in south Florida, efforts have been focused on determining the most common migration route of pink shrimp postlarvae entering Florida Bay and physical processes affecting transport along this route. A multidisciplinary study of postlarval influx entering the Bay was initiated in January 2000. Pink shrimp postlarvae have been collected in western Florida Bay (Sandy Key, Middle Grounds) in wide channels that connect the Bay with the southwestern Shelf of the Gulf of Mexico, and in tidal channels in the Middle Florida Keys (Whale Harbor, Indian Key) that connect the southeastern margin of the Bay with the Atlantic Ocean. In July 2001 two interior bay stations were added, Conchie Channel in western Florida Bay and Panhandle Key in south central Florida Bay. Sampling has been conducted during two nights around the new moon using two moored subsurface channel nets (0.75 m^2 opening, 1-mm mesh net, 500-µ mesh in the cod end) per channel. Cod ends are placed on the nets before dusk and removed shortly after dawn each day. Acoustic Doppler Velocity Meters (ADVM's) that measure continuous velocity, and associated CTD instruments that measure conductivity, temperature, and depth (tide/stage) were installed in each channel in January 2002. A boat-mounted Acoustic Doppler Current Profiler (ADCP) is used to calculate total discharge along a transect of the channels during monthly samplings. Surface current, temperature and salinity data from ADCP's, and sensors moored at two stations on the inner shelf of the Gulf of Mexico, about 25 and 35 km north from Cape Sable, have been provided by the Florida Bay Circulation and Exchange Study team (T. Lee, E. Williams, RSMAS and L. Johns, NOAA).

Our monthly catches of postlarvae indicate that the greatest influx occurs at the western border of the Bay, with a strong seasonal pattern from July through September over three years (2000-2002). The influx of postlarvae is approximately ten times higher in magnitude and less variable at the western stations than at the Florida Keys stations (fig.1). This difference may indicate that onshore mechanisms across the southwestern shelf are more effective in transporting pink shrimp postlarvae. Based on this result, recent efforts have focused on defining transport mechanisms of postlarvae to western Florida Bay across the shelf. Our working hypothesis is that postlarvae may be transported by a selective tidal stream mechanism, which assumes that postlarvae control their movements in the water column by sitting on the bottom during the ebbing tide and rising into the water column on the flood tide. A harmonic analysis was conducted on 3-yr ADCP data from two inner-shelf stations to define tidal components and current

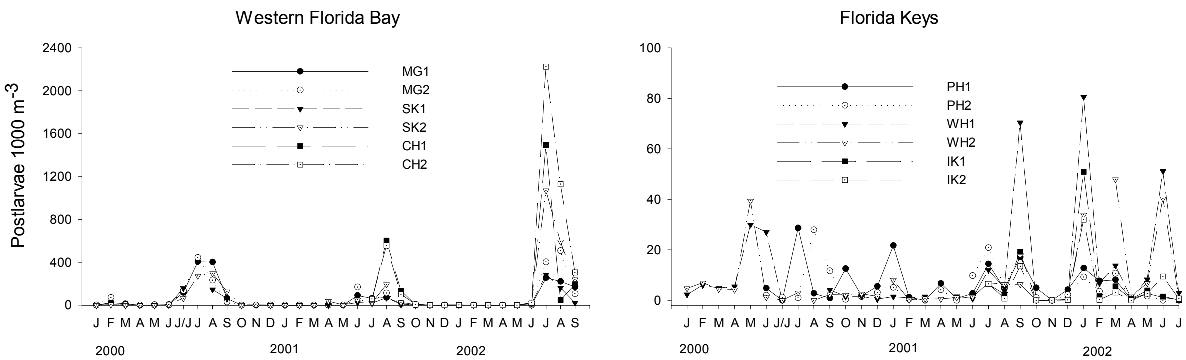

Figure 1. Densities of pink shrimp postlarvae at the two sampling sites.

magnitude. Results show a dominance of the semidiurnal tidal constituent M_2, with an east-west velocity of 0.3 m/sec, and north-south velocity of 0.07 m/sec. For the analysis period, astronomical semi-diurnal and diurnal tidal components accounted for 97 and 71 percent of the total variance in the east-west and north-south current data respectively in the onshore station and 97 percent and 30 percent of the total variance in the east-west and north-south current data respectively in the offshore station. Interestingly, this east-west tidal velocity is much stronger than the averaged subtidal current of the east-west component at both stations (0.01 m/sec). Assuming that postlarvae use the eastward flow only during the night flood, they may be transported from the spawning grounds to the western border of Florida Bay in 26.9 days. This estimated time agrees well with the duration of larval development of this species, which is approximately 25 days to become late stage postlarvae ready for settlement. Experiments were conducted in summer 2002 at one of the western stations to determine the response of postlarvae to tidal currents. Consecutive pairs of dark-flood and dark-ebb plankton samples were taken in two new moon and one full moon periods at Sandy Key. Overall catches showed clearly that dark-ebb catches were negligible (< 10%) by comparison with dark-flood catches (> 90%). This result may suggest that pink shrimp postlarvae respond to tidal cycles, migrating into the water column during the dark-flood cycle. However, environmental factors that trigger migration, the age at which postlarvae recognize the tidal signal, and the behavior of postlarvae during ebb flow need to be defined. A simulation model that uses current meter and salinity observations to simulate transport on tides at night and the influence of salinity gradients is under development. These simulations will help to explore cause-and-effect relationships and the effect of seasonally varying subtidal transport.

The influx of postlarvae through Middle Keys passes is smaller but more continuous through the year than that entering Florida Bay through western passes. Influxes through the Middle Keys passes occurred in May, July, August and October in 2000; in January, April, July and October in 2001; and in January, March and June in 2002 (not complete year yet). The high temporal variability of postlarval influx observed at the Middle Florida Keys may be related to the arrival of coastal eddies that propagate downstream from the Tortugas area; however alternative mechanisms should be investigated.

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The Effect of Plant Community Structure on Apple Snail Abundance in the Everglades

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As the exclusive food of the endangered snail kite and prey to a variety of other wetland fauna, apple snails are generally recognized as a critical resource warranting monitoring in the context of the Greater Everglades ecosystem restoration. Snail kite abandonment of wetlands in dry down conditions have led to unsubstantiated conclusions that drying events (presumably of any timing and duration) devastate snail populations, thus forcing kites to leave. Researchers and natural resource managers have subsequently recommended nearly continuous inundation of wetlands deemed critical habitat to kites. However, suppressing drying events would be contrary to critical aspects of snail autecology that have been documented: 1) longer hydroperiods decrease the abundance of emergent wet prairie macrophytes needed for snail oviposition and aerial respiration and 2) snails do tolerate dry down conditions (the majority surviving up to 4 months once they reach a threshold size) and that this species has a life history well adapted to periodic dry downs. Not only are snails adapted to dry downs, we believe that drying events are essential to supporting suitable snail habitat. Elucidating the relationship between apple snail abundance and habitat structure also relates directly to habitat management for snail kites. As visual hunters, snail kites cannot forage in densely vegetated habitats such as sawgrass and cattail, but selection among more structurally 'open' habitats (slough or prairie) have not been documented. If they have a preference, it could be because some habitats support more snails than others, or because the structure of some habitats may render snails more available to foraging kites. This study tests the hypothesis that snail abundance is greater in prairie versus slough habitats, and contributes to an understanding of habitat selection by foraging kites.

Two concurrently funded projects were initiated in Spring 2002 in two different Everglades wetland units: WCA-1 (funded by U.S. Fish and Wildlife Service) and WCA-3A (funded by U.S. Geological Survey), which taken together will function as a single more comprehensive study. A total of six sites were selected to test hypotheses about snail abundance and habitat structure. Each site consisted of prairie habitat (dominated by emergent species of *Eleocharis, Rhynchospora* or *Panicum*) juxtaposed and/or interspersed with slough habitat (dominated by *Nymphaea odorata*). In most sites, the prairie (especially) or slough was not contiguous; i.e., the prairie habitat sampled within a site may have been partitioned into three or more patches. Patches of habitat judged as transitional or intermediate between prairie and slough (i.e., patches with both *Nymphaea* and emergent macrophytes) were avoided.

Snail density was determined using 1-m^2 throw traps (n≈50-70 throw traps in a 50 x 50 m area) extracted with a dip net, with explicit estimation of capture probabilities to assess sampling efficiency across different habitat types. The 1-m^2 throw trap method has also proven effective in estimating crayfish (*Procambarus alleni*) and freshwater prawn (*Palaemonetes paludosus*) densities; therefore, we recorded numbers of these important prey items found during our snail sampling effort. Throw trap sampling was conducted from approximately February through early May in order to avoid the annual post-reproductive die-off. Egg cluster production was monitored in transects established in each sampling site in order to document that throw trapping was completed prior to the die-off.

At this point we have not completed our analyses; thus, any conclusions should be considered preliminary. Data were analyzed within a generalized linear modeling framework. Preliminary results indicate consistently higher snail densities in the prairie habitat relative to the *Nymphaea*-dominated slough. A similar trend was found for crayfish. Habitat effect on freshwater prawn density varied among sites, but no overall habitat effect was indicated. The data appear to support the hypothesis that snail abundance in prairie exceeds that in slough habitats.

Qualitative assessment of the data thus far suggests that within the wet prairie communities, there may be specific associations among snails and some plant species. Such associations will be a primary focus of this study over the next two years, and we expect to refine the hypothesis regarding apple snail-plant community-snail kite interactions accordingly. Given the inextricable link between hydrology, vegetation and apple snails, this research effort will support the development of ecologically significant performance measures that respond to the Greater Everglades restoration activity.

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Overview of the Across Trophic Level System Simulation (ATLSS) Program: Model Development, Field Study Support, Validation, Documentation, and Application

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An overview of the ATLSS Program is presented. The program has produced a set of models of spatially explicit species index, population demography, and ecosystem process models that are available for applications. In addition, the program has supported field studies designed to produce data for model construction and validation. This report describes the following aspects of the program.

The Spatially Explicit Species Index (SESI) models quantify relative effects of hydrologic conditions on the habitat suitability of species. There are several currently available ATLSS SESI models:

- Cape sable seaside sparrow breeding potential index (Version 1.1)
- Snail kite breeding potential index (Version 1.1)
- Long-legged wading bird foraging condition index (Version 1.1)
- Short-legged wading bird foraging condition index (Version 1.1)
- Empirically-based fish biomass index (Version 1.1)
- White-tailed deer breeding potential index (Version 1.1)
- American alligator breeding potential index (Version 1.1)
- Everglades and slough crayfish (Version 1.1)
- Apple snail SESI model (Version 1.1)

The ATLSS SESI models accomplish the following. They produce values for habitat suitability ranging from 0.0 to 1.0 for all 111,000 cells of the 500 x 500 m array. These can be calculated for every individual year in the multi-year sequence (1965-1995 for the Restudy scenarios), or averages can be taken over any set of years (e.g., wet years, dry years, all 31 years). The SESI models are intended to be used to make relative comparisons between scenarios, not to produce absolute evaluations of habitat quality. The output can be viewed using the ATLSS Data Viewer, which allows viewing at any scale and performing of statistics. The ATLSS Data Viewer is available to all agencies that are interested. Training sessions can be scheduled when requested.

There are currently three available ATLSS Demographic Models. The ATLSS demographic models are spatially explicit individual-based (SEIB) models of the dynamics of the populations:

- Cape sable seaside sparrow demographic model (SIMSPAR - Version 1.3)
- Snail kite demographic model (EVERKITE - Version 3.1)
- American alligator (Version 1.1)

The ATLSS Structured Functional Group models simulate the size-structured and biomass dynamics of the population. There is currently one available ATLSS Structured Functional Group model:

- Freshwater fish dynamics (ALFISH - Version 3.1.17)
- There are background models that provide landscape information for other ATLSS models:
- High Resolution Topography (HRT - Version 1.4.8)
- Vegetation productivity (HTDAM -Version 1.1)
- High Resolution Hydrology (HRH - Version 1.4.8)

ATLSS model runs for scenario evaluations can be made in the following ways for particular models. The Snail kite demographic model (EVERKITE) is available in PC form for use (can be downloaded from Web) and user support for those wanting to use this model. Alternatively, this model will be run at the University of Miami and results posted. Currently, the remaining ATLSS models can be run at the University of Tennessee, which is funded to carry out several such runs. Results will be posted. Also, these models can be installed at agencies that have Unix workstations. A NSF-funded project at the University of Tennessee is currently underway to allow dispersed resource managers to access remotely the capabilities of the SInRG (Scalable Intracampus Research Grid) at the University of Tennessee. This will allow users at resource agencies in south Florida, with relatively little computer expertise, to initiate ATLSS simulations on the computers at the University of Tennessee.

Technical documentation of ATLSS models is available on the ATLSS web site (ATLSS.ORG) and listed in ATLSS Program Publications (available) - and will be further improved. Open literature publications exist for the available ATLSS models. Nearly all models have appeared in open-literature, peer-reviewed papers (see ATLSS Publications). An internal USGS panel reviewed the ATLSS Program in May 2002. Additional review by the Model Refinement Team of CERP is planned.

Validation of models is an important issue. Some degree of model validation has been performed on some models (SIMSPAR, ALFISH). Model validation on other models depends on the availability of data sets. Now data sets are becoming available for several species, and new data for others. A "validation tool", which can be applied along with the ATLSS Data Viewer, allows empirical data (e.g., nest success rate, fish biomass) to be compared spatially with SESI index values at any spatial scale. Statistical testing can be done using spreadsheets programs. Validation is being done, or will be done soon on Cape Sable seaside sparrow, snail kite, and American alligator SESI models.

User interfaces for running models and analyses have been developed. For running SESI models, only a UNIX platform is currently available, but extension to PC is planned. The snail kite model (EVERKITE) runs on a PC.

Output of the SESI models can be displayed on the ATLSS Data Viewer. This will be extended to the demographic models.

ATLSS models nearly completed or under development include:

- Vegetation succession model
- Alligator structured population model
- Apple snail structured population model
- Crayfish structured population model
- Roseate spoonbill SESI model
- Estuarine fish dynamics

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SELVA-MANGRO—Integrated Landscape and Stand-Level Model of Mangrove Forest Response to Sea-Level Rise and Hydrologic Restoration of the Everglades

By Thomas W. Doyle[1], Kenneth W. Krauss[1], Marcus Melder[2], *and* Jason Sullivan[2]

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The near sea-level elevation and flat slope of the protected Everglades ecosystem accounts for one of the largest contiguous tracts of mangrove forests found anywhere in the world and punctuates their potential vulnerability to rising sea level and changes in freshwater runoff. These forests are subject to coastal and inland processes of hydrology largely controlled by regional climate, disturbance regimes, and water management decisions. Mangroves are highly productive ecosystems and provide valued habitat for fisheries and shorebirds. Mangrove forests are universally composed of relatively few tree species and a single overstory strata. Three species of true mangroves are common to intertidal zones of the coastal margin of the Everglades, namely black mangrove, *Avicennia germinans* (L.) Stearn, white mangrove, *Laguncularia racemosa* (L.) Gaertn.f., and red mangrove, *Rhizophora mangle* L.

Mangroves are halophytes and can, therefore, tolerate the added stress of waterlogging and salinity conditions that prevail in low-lying coastal environments influenced by tides. Global warming has been projected to increase sea water temperatures and expansion that may accelerate sea level rise and further compound ecosystem stress in mangrove dominated systems. While early researchers attributed zonation patterns to salinity gradients, more recent field and experimental studies indicate that mangroves have wide tolerances to salinity and other soil factors and may be influenced to a greater degree by local hydrology and episodic disturbance events. Increases in relative sea level will eventually raise saturation and salinity conditions at ecotonal boundaries where mangroves are likely to advance or encroach upslope into freshwater marsh/swamp habitats. Changes in freshwater runoff as a result of climatic variability and water management controls may alter the health and migration of mangrove communities in conjunction with potential sea-level rise.

A landscape simulation model, SELVA-MANGRO, was developed for mangrove forests of south Florida to investigate the potential impacts of climate change and freshwater flow on the quality and distribution of future mangrove habitat. The SELVA-MANGRO model represents a hierarchically integrated landscape model that manages the exchange of system parameters up, down, and across scale between linked simulation models SELVA and MANGRO. SELVA is a Spatially Explicit Landscape Vegetation Analysis model that tracks predicted changes in the biotic and abiotic conditions of each land unit (1 sq ha) on an annual basis for the entire simulated landscape. The SELVA model administrates the spatial articulation of the landscape composed of land units composed of habitat classifications (forest, marsh, aquatic) and any forcing functions that predict changes in hydrology and disturbance. Intertidal forest units are then simulated using the MANGRO model based on unique sets of environmental factors and forest history. MANGRO is a spatially explicit stand simulation model constructed for mangrove forests of the neotropics. MANGRO is an individual-based model composed of a set of species-based functions predicting the growth, establishment, and death of individual trees. MANGRO predicts the tree and gap replacement process of natural forest succession as influenced by stand structure and environmental conditions.

Model applications were conducted to forecast mangrove migration under projected climate change scenarios of sea-level rise and saltwater intrusion for the Everglades coastal margin without hydrologic restoration. A high resolution model of surface topography was needed to predict the rate and fate of coastal inundation from sea-level rise over the next century. Tidal inundation and circulation are key factors controlling mangrove distribution in this coastal environment. The ability to predict landward transgression of mangrove caused by sea-level rise depends on the relation between landward slope and elevation in relation to tide range and extent plus an understanding of relative sea-level rise. A historic topographic and drainage map circa 1940-50 with 1 ft contour intervals across the south Florida Everglades was rectified and digitized into a geographic information systems application. Boundary zones of major habitat classes were also digitized from the natural vegetation map of Florida produced by Davis (1943) to delineate the lower and upper elevations of the intertidal zone as defined by mangrove extent. The coastline was assigned an elevation of mean sea level while the upper transition zone of mangrove extent was approximated at mean high water for available tide datums along the southwest coast of Florida. These combined data sources and proxy contours served as baseline elevation values for constructing a detailed digital elevation model of south Florida for SELVA-MANGRO application.

Sea-level rise was modeled as a function of historic sea-level conditions at Key West, Florida based on mean annual tide records (1940 to present) projected into the 21st century with the addition of curvilinear rates of eustatic sea level expected from climate change. The data record was extended into the next 100 years for sea-level rise scenarios of 15 cm to 1.1 m by year 2100 based on low, mid, and high projections obtained from global climate change models. Model results show that species and forest cover will change over space and time with increasing tidal inundation across the simulated landscape for all sea-level rise scenarios. The greater the rate of sea-level rise the faster or more extensive the encroachment of mangroves onto the Everglades slope. The model shows that freshwater marsh/swamp habitats will be displaced as the tidal prism increases over time as it moves upslope without Everglades hydrologic restoration. Under these modeling assumptions, mangrove habitat will increase over the next century under climate change and conversely, freshwater marsh/swamp is expected to decrease.

Modeling upgrades are under development for the SELVA-MANGRO model to assess the impact of increased freshwater runoff under various Everglades restoration alternatives. Empirical data of riverine and basin mangrove forests show that precipitation and runoff events effect short-term hydrology and salinity conditions that are relatively minor in relation to coastal influences of daily and seasonal tidal forcing. Everglades restoration alternatives will increase runoff conditions above current normal patterns and may abate any influence of sea-level rise in the near future. Model trials indicate that proposed freshwater flow rates may need to exceed current engineering design to affect stage and salinity at the coastal margin to affect potential mangrove migration and expansion into freshwater habitats.

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ATLSS Vegetation Succession Model Project

By Scott M. Duke-Sylvester[1], Louis J. Gross[1], *and* Paul R. Wetzel[2]

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The U.S. Geological Survey Across Trophic Level System Simulation (ATLSS) models in their current form all assume that vegetation will remain unchanged over the period of the model simulations. This is not likely to be true, as changes in hydrology are almost certain to result in changes in vegetation patterns in many parts of the Everglades over periods of decades. There is already some evidence of changes in vegetation types in some areas of the Everglades over the last 10 years.

The development of a set of succession models for the major vegetative types in the Everglades region is generally regarded as being essential, if scientists and managers are to be able to project the possible effects of changes in the hydrology of the region. Vegetation response is also sensitive to changes in nutrient concentrations and fire. Furthermore, important animal species, such as wading birds, the snail kite, and the Cape Sable seaside sparrow, have specific habitat needs that are tied to particular types of vegetation. The basic goal of this ATLSS project is to develop succession models that estimate future patterns of vegetation for targeted habitats and to describe how these habitats are affected by changes in hydrology, available nutrients, fires and the interaction of these processes. Three basic community types, pine/scrub/flatwood, cypress forest, and herbaceous plant communities will be included in the modeling. Within these types, a more detailed structure using Florida GAP vegetation alliances has been developed, allowing for explicit alliance responses to patterns of hydrology, nutrients, and fire.

The vegetation succession model will cover approximately 48 percent of the total area in south Florida (urban, agricultural, and mining areas excluded), uses all 22 of the Florida GAP alliances present in the ATLSS study area and will provide yearly estimates of vegetation alliance distribution at a 100x100 meter resolution. Model parameters have been determined from an intensive literature review followed by an extensive compilation and synthesis of the available data [available in two documents: Plant Community Parameter Estimates and Documentation for the Across Trophic Level System Simulation (ATLSS), and Nutrient and Fire Disturbance and Model Evaluation Documentation for the Across Trophic Level System Simulation (ATLSS)]. The information from the literature review was structured around the Florida GAP vegetation alliances, which provided a basis for the model parameters and succession models of the three basic community types.

Review of the data suggests that, at the spatial scale of the ATLSS succession model, the effects of hydrology, phosphorous, and fire are very important, while the effects of nitrogen enrichment are of lesser importance and will not substantially affect model dynamics. Two different fire types will be included in the model; those that damage the soil, commonly referred to as muck fires, and surface fires that destroy vegetation but do not burn the soil. Making a distinction between muck and non-muck fires is important for succession modeling because burning soil changes local topography, which in turn changes the hydrology of local habitats. The interactions between fire and hydrology, and fire and nutrients also have been estimated in the succession documentation, based upon the limited available information on interaction effects for the vegetation alliances in south Florida.

The model uses a two-part approach to simulating the process of succession. First, a static look up table was constructed for each basic community type. Each look up table describes the potential future states of a plant community as a function of the history of hydrology, fire, nutrients and the interaction between these processes. The table also provides parameters for the expected time for a change to take place for each of the different processes affecting succession. The look up table is based on the literature review and synthesis.

Secondly, once local environmental changes indicate that succession to a new vegetation alliance is possible, the succession pathway is treated as a Markovian stochastic process. The change to the new vegetative state is random with the probability distribution for the various new states and the expected time for transformation given by the look up table.

Presenting the output of the vegetation succession model will follow the relative assessment approach using three panel maps applied in the analysis of other ATLSS models. This synthesis will present two maps representing the distribution of FGAP vegetation alliances produced by two different hydrology scenarios with the third map indicating locations and type of differences between the two distributions. The classification of differences is still an open question and depends largely on what information is most useful to the various scientific, managerial and policy making entities operating in south Florida.

ATLSS model evaluation will begin in the earliest stages of model development. The evaluation effort is necessary to determine the usefulness and accuracy of plant community succession in ATLSS. Peer review, Turing tests, gradient response and extreme condition tests, and tracing the behavior of specific variables or vegetation types through a model run are all possible model evaluation procedures suitable for the plant community succession module of ATLSS.

There are several goals for the succession model: it will provide an estimate of relative changes in vegetation distribution in response to changes in the abiotic environment and it will provide additional information about the potential effects of restoration. Model results also will be useful as input to other ATLSS and non-ATLSS models, including SIMSPAR and the ATLSS SESI models, that simulate processes sensitive to changes in the distribution of vegetation in south Florida.

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Using Strip-Transect Aerial Surveys to Estimate Manatee Abundance and Population Trend in the Ten Thousand Islands Region of Southwest Florida

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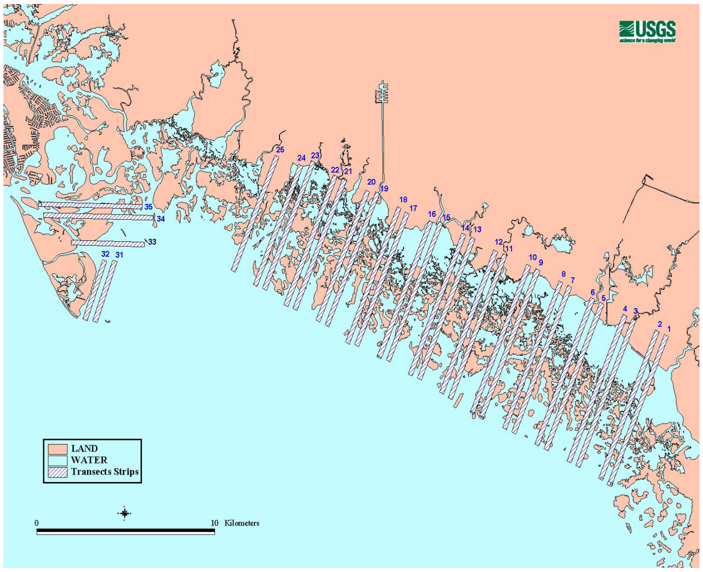
Strip-transect aerial surveys have been used extensively in Australia to estimate trends in offshore dugong populations (Marsh and Sinclair, 1989). The use of strip–transect methods in estimating manatee population size and trend, however, has been limited (Miller *et al*. 1998). Manatee surveys have typically not been designed to sample quantified survey areas, or to produce estimates of abundance. While useful in obtaining minimum manatee counts and distribution information, the latter surveys do not permit statistical comparison of survey results over time (Lefebvre et al., 1995). Our objective in this study is to determine if manatee density and distribution in the nearshore waters of the Ten Thousand Islands and the Everglades National Park change in response to restoration of natural hydrologic patterns in southwestern Florida. The Ten Thousand Islands region is of particular interest because of proposed changes to the Southern Golden Gate Estates and Faka Union Canal drainage. We want to statistically compare pre- and post-restoration indices of manatee abundance. We also believe that strip-transect methods are likely to be successful in the Ten Thousand Islands region, unlike many other regions of Florida, in which manatees may be highly aggregated at winter sites, or their density may be too low and distribution too linear to permit this approach.

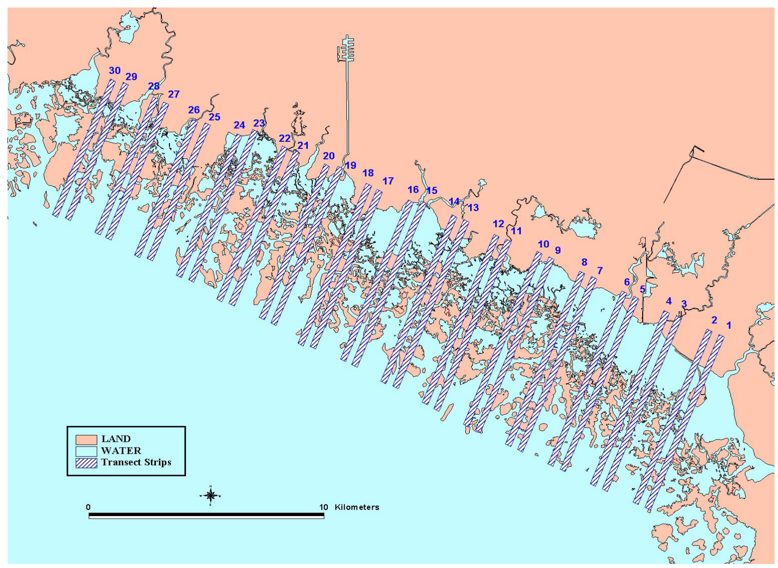
Six surveys were conducted between 25 July and 22 October 2000, eight were conducted between 15 July and 30 August 2001, and eight were conducted between 20 June and 17 September 2002. We established parallel transects, 1 km apart, with a survey strip width of approximately 250 m. Transects flown during July-October 2000 were oriented perpendicular to shore, between Palm Bay and the Ferguson River (fig. 1A). Based on results from these surveys, we omitted 5 transects (26-30; fig.1A) and established 5 new transects (31-35; fig.1B) near Cape Romano for the 2001 and 2002 surveys. Transect lengths ranged from 6.6 to 8.4 km in 2000 and 3.4 to 8.4 km in 2001 and 2002, respectively; water area surveyed ranged from 0.79 to 1.53 km² per transect in 2000 and 0.83 to 1.53 km² per transect in 2001-2002. Manatee locations were plotted on topographic maps, and flight paths were recorded on a Trimble Basic Plus GPS. Surveys were conducted from a Cessna 172 at an altitude of 153 m, traveling at approximately 120-140 km per hour. Perception bias, which occurs when some of the manatees visible within a strip transect are missed by an observer, was estimated by applying a Petersen mark-recapture model to counts made by two observers (Pollock and Kendall 1987; Marsh and Sinclair 1989). We did not attempt to develop a correction factor for manatees that were not visible within the transects (availability bias), thus our results are underestimates of actual manatee numbers and densities.

The corrected number of manatee groups (a group = 1 or more individuals in the same location) sighted on transects ranged from 7.0 to 25.7, 12.9 to 27 and 15.0 to 20.4 per survey during 2000, 2001, and 2002, respectively. The corrected number of individuals counted ranged from 10.0 to 39.8 in 2000, 15.1 to 61.7 in 2001, and 24.6 to 61.2 per survey in 2002. Mean group size per survey ranged from 1.0 to 2.0, 1.1 to 2.3, and 1.4 to 3.0 during 2000, 2001, and 2002 respectively. Survey-specific population estimates in this study were 1.09 to 4.57 per km² in 2000, 1.62 to 6.64 per km² in 2001, and 2.65 to 6.58 per km² in 2002. Excluding the Cape Romano transects, the overall distribution of sightings was somewhat bimodal, with average (mean = 0.44 groups per transect) or higher than average number of groups sighted on transects 1-9 and 17-21 during 2000. Transect 6 starts near the mouth of the Barron River, and Transects 19 and 20 start near the mouth of the Faka Union Canal. Virtually no manatee sightings were made on transects 25-30, at the western end of the study area during 2000. The replacement of these five transects with five transects near Cape Romano (31-35) in 2001 produced a somewhat higher estimate of manatee abundance in the region. The Faka Union Canal is known to attract large numbers of manatees, particularly in the winter, presumably because of the availability of freshwater at its head and thermal buffering provided by its depth. In this study, we considered the canal to be a separate, high-density stratum, analogous to the "hot spots" described by Miller *et al*. (1998). When manatee counts from this stratum were added to the transect-based estimates, estimates for the whole study area on all dates ranged from 39 to 187 in 2000, 59 to 247 in 2001, and 95 to 235 in 2002.



A

Figure 1. Spatial arrangement of 30 manatee aerial survey strip-transect polygons in the Ten Thousand Islands during flights July-October 2000 (A) and July 2001-September 2002 (B).



B

Population estimates and densities in this study were similar to those for the Banana River, an important area for manatees on the Atlantic coast in the warm season. The latter estimates ranged from 112 to 209, or approximately 0.67 to 1.26 per km² (Miller *et al*. 1998). Mean group size per survey in Ten Thousand Islands (1.62) was lower than in Banana River surveys (2.19). Group size was 2.00 in 18 of the 22 Ten Thousand Island surveys and 2.00 in 13 of 15 Banana River surveys (Miller *et al*. 1998). These findings suggest that poorer water clarity in the Ten Thousand Islands than in the Banana River, where the bottom can be seen in most of the survey area, may contribute to greater variability and smaller observed group size in our surveys.

To assess the potential for detecting statistically significant trends in the Ten Thousand Islands population, we used the TRENDS software (Gerrodette, 1993) with estimated CVs of 0.30 and 0.15, based on observed survey results. We determined that we would need a minimum of eight surveys per year for a minimum of 4 years to detect an annual rate of change of 10 percent per year. Variation in group size and population estimates is a reflection of the challenging survey conditions presented by the Ten Thousand Islands, as well as additional variability caused by weather. Nevertheless, the strip-transect approach shows promise for monitoring the manatee population using this region during the warm season, if weather-related variability can be minimized.

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Shifts in the Position of the Marsh/Mangrove Ecotone in the Western Florida Everglades

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The Everglades of southern and central Florida are a unique system that has been recognized as a valuable global resource. Up until the 1940's it had remained relatively undisturbed, with only minor incursions along the coastal fringe. This results in a situation in which to study the impacts of both global climate change and land use change on coastal ecosystems. In 1900, a broad freshwater system stretched from Lake Okeechobee southward for more than 160 km before draining into the estuaries along the southern tip of the Florida mainland. Today, over 600,000 ha of marsh have been converted to the Everglades Agricultural Area for production of sugarcane, sod and winter vegetables.

It has been hypothesized that shifts in the position of the mangrove/marsh ecotone are pulsed events, possibly initiated by large-scale disturbance and (or) influenced by sea level rise. As the flow of freshwater to the estuaries decreases, this results in an emulation in the rise in sea level. This reduction in freshwater flow, in conjunction with events such as hurricanes, fire, sea-level rise, and decreased precipitation may be influential in the migration of the mangrove forest into the freshwater marsh.

Select areas along the western coast of Everglades National Park (fig.1) are examined using a time series of aerial photographs from the park archives (Briere et al, this volume; Coffin et al, this volume).

In some of the areas we examined, the decreases in the freshwater marsh occur closest to the coastline. In these areas the marsh has persisted further inland and has even shown signs of returning along the edges of some rivers and bays (fig. 2). Historical aerial photos have shown in some areas that the migration of the mangrove forest into the freshwater marsh is evident. In other regions no change is apparent.

Figure 1. Western coast of Everglades National Park. The area in the vicinity of the Lopez River is enclosed in a box in the upper left corner.

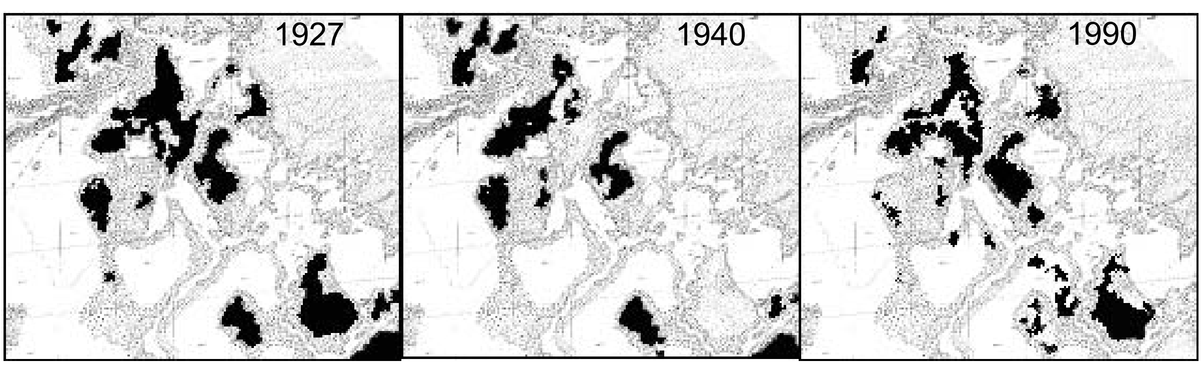

Figure 2. Location of the marsh in the vicinity of the Lopez River in 1927, 1940, and 1990. The shaded areas indicate the extent of the marsh for a specific year.

Determining which factor or combination of factors contributes to this migration remains to be answered. However, it would appear given the diversity of patterns we see along the marsh/mangrove ecotone, it is a complex process.

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ATLSS PanTrack Telemetry Visualization Tool

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ATLSS PanTrack is a visualization tool designed to display and analyze spatial movement data of panthers over georeferenced landscape maps. It has been customized for the display of radiotelemetry observations collected for the Florida panther endangered species recovery project. PanTrack was developed to help define panther behavior rules for the spatially explicit, individual-based ATLSS Deer/Panther model. The effectiveness of individual-based models depends upon the availability of detailed observations about individuals on the landscape, and on the ability to find patterns in these observations that provide insight into key animal behaviors. The availability of PanTrack, a programmable tool customized for the Florida panther data set, has facilitated the evaluation of telemetry data, and has also proved invaluable in facilitating interaction and exchange of information between the modeler and field biologists, allowing on-the-spot confirmation of field observations in the context of the full set of monitoring data and rapid visual identification of patterns in landscape/panther associations. Having a readily customizable display and analysis tool has also enabled researchers to study published panther analyses closely, evaluating whether trends reported in spatial and temporal subsets of panther data are reflected in the entire data set.

South Florida is home to the last remaining population of endangered Florida panthers (*Puma concolor coryi*). Panther survival is threatened by habitat loss and degradation, geographical isolation, disease, and problems associated with small population size, including inbreeding and sensitivity to stochastic events. The current verified population size is 80 adult and subadult panthers. Because the few remaining panthers have been intensively studied, a fairly detailed database is available for individuals in the population. Monitoring of Florida panthers by radiotelemetry, initiated in 1981 with the radio-collaring of two individuals, has now expanded to include 39 panthers. Over 60,000 telemetry locations are available over the monitoring period. Four Global Positioning System (GPS) collars were deployed for the first time in 2002, providing as many as eight locations around the clock compared to the current collection schedule of three daytime locations per week.

Recent demographic trends in the panther population are in sharp contrast to earlier observations, necessitating a thorough reevaluation of rules and parameters in light of changes in the population. A genetic restoration project was initiated in 1995 because of low genetic variation and health and reproductive problems likely caused by inbreeding. Eight reproductive females from a closely related subspecies of *Puma concolor* were translocated from Texas and introduced into the south Florida population. Five of those females have mated with Florida panthers, producing a total of 17 F1 offspring over a 7-year period. F1 panthers and their offspring have been vigorous and healthy thus far, showing none of the heart and reproductive problems seen in Florida panthers. The success of genetic restoration in increasing genetic variation and producing healthy intercrossed panthers has changed the course of panther recovery, and has confounded published theories and opinions about panther ecology in south Florida.

The panther population has more than doubled since 1995, including a 5-fold increase in formerly sparsely populated areas of BCNP and ENP, thought by some researchers to be unsuitable habitat for panthers. Earlier observations and theories about habitat use, home range establishment, dispersal patterns, and rates of reproduction and kitten survival must now be reevaluated in light of new data. Pre-introgression panther habitat selection studies that focused narrowly on forest were based on the unsupported assumption that habitats associated with daytime telemetry locations are representative of total habitat use. Panther distribution patterns previously attributed to habitat suitability now appear to have resulted from dynamics associated with limited dispersal potential in a small, inbred population with low reproductive rates living in a barrier-rich environment.

Panther recovery and Everglades restoration efforts, and the modeling projects that support and guide them, depend on accurate characterizations of panther habitat use and requirements, based on all available information. With these changes in mind, the set of panther location observations (1981-1995) on which preliminary panther behavior rules for the ATLSS Deer/Panther model were originally based has been expanded to include post-introgression observations so that recent trends can be reflected in revised rules for behavior and habitat use. The PanTrack Tool is being used to display and analyze the full set of available panther telemetry data for the purpose of redefining behavior rules. The predictive capabilities of an individual-based model are closely tied to the realism of the decision rules that determine how individual animals move across the landscape, interact with one another and respond to their environment. The definition of these rules is in turn tied to the availability and interpretation of empirical observations about these behaviors and movement patterns. In this context, PanTrack has been used to study abundance and distribution; movement and dispersal patterns; seasonal effects; home range characteristics; patterns of reproduction, recruitment, and mortality; effects of gender, age, and genetic group, and patterns of habitat use.

ATLSS panther researchers have reported results of their analyses in an extensive article in the online journal *Conservation Ecology*. Using programming extensions to PanTrack, innovative telemetry mapping and fractal analysis techniques were used to explore panther habitat use and home range characteristics. Wildlife biologists contributed field observations indicating that habitat selection is considerably broader during active nighttime hours than during daytime. The paper provides a critical evaluation of the assumptions and limitations of the dominant forest-centered view of panther ecology, concluding that percent forest cover is a poor predictor of home range size and that forest cannot be considered a surrogate for useful panther habitat. Factors other than habitat have contributed substantially to habitat suitability, population density, and distribution.

The authors conclude that *Puma concolor* in Florida, as elsewhere in their range, are habitat generalists, exploiting the broad spectrum of available habitats for hunting, resting, mating, travel, denning, and dispersal. While panthers readily utilize forested habitat with understory and prey, we found no support for the view that only forested land within a habitat mosaic is potential panther habitat, or for the contention that only forested habitats are used by panthers within existing home ranges. This work suggests a more ecologically-consistent management and recovery paradigm based on maintaining the integrity of the system of overlapping home ranges that characterizes panther social structure and satisfies breeding requirements. Such a paradigm focuses on the requirements for reproductive success of a small population in a changing environment.

PanTrack currently operates on Sun workstations or on PC's with a LINUX operating system installed. Installation of PV-WAVE Version 7.50 (Visual Data Analysis Software by Visual Numerics) is required. PanTrack data and program installation require 15MB of disk space. The run-time PanTrack screen consists of a Landscape Map Window and a menu board user-interface. Zoom and animation windows may be created and dismissed during the session. Data may be subset for display by time period (day, month, year) and (or) by group (e.g., individuals, age, gender, genetic lineage, cause of death).

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Evaluation and Calibration of ATLSS SESI Models

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A primary product of the U.S. Geological Survey Across Trophic Level System Simulation (ATLSS) Program is the set of Spatially Explicit Species Index (SESI) models developed for the Greater Everglades area. These models (eight as of 2002) produce values for habitat suitability ranging from 0.0 to 1.0 for all 111,000 cells of the 500 x 500 m array. These habitat suitability values are typically calculated for every individual year in a 31-year sequence, simulated using inputs from the South Florida Water Management Model (SFWMM) as processed by the ATLSS High Resolution Hydrology Model. Averages can also be computed over any set of years (e.g., wet years, dry years, all 31 years), and over a variety of sub-regions within the total region included. The SESI models are used for relative comparisons between alternative future scenarios, not for producing absolute evaluations of habitat quality.

The current versions of ATLSS SESI models were evaluated and calibrated with historical demographic observations to the maximum extent possible, given data availability and time constraints. Abundance data for many Everglades species are scarce/sporadic, and methods of collection and reporting are often inconsistent over time and space. The degree to which SESI model evaluation was possible has also been limited by delays in availability of calibration water data for the model for recent years, when more complete and consistent species abundance data have been collected. The lack of high-spatial-resolution water data continues to limit evaluation efforts.

As an example of using the best available data in SESI calibration, spatial abundance data were extracted for each group of wading birds from Systematic Reconnaissance Flight (SRF) records as they became available. The 3-level estimates of water depth recorded along with SRF observations (dry, transitional, wet) were used to approximate historical water depths. Abundance counts were summed and demographic trends were graphed over each sub-region. These trend graphs were compared to SESI output, graphed over model sub-regions, for year-to-year trends, and trends in wet, average, and dry periods. These evaluations were all made based upon the SFWMM Calibration/Verification data available through 1995.

There was no opportunity during the rapid cycle of model development to formalize and document these efforts to compare SESI model output to empirical observations and adjust model parameters to reflect historical biological responses to hydrologic parameters such as hydroperiod and water depth. This process is being formalized and improved as additional monitoring data become available and as restoration modifications proceed. The SESI model code is in an object-oriented structure that readily allows for model modification as data collection proceeds.

As with the SESI models, availability of new data has required testing and revisions of the SFWMD Hydrology Model, which produces hydrology data sets used to drive ATLSS scenario evaluations. An expanded set of hydrologic calibration data, providing daily water depths over the model area during the period 1979 to 2000, will become available from the SFWMD. Generation of this data set has required hydrology model modifications and revisions that will result in output that differs from the original calibration hydrology data. Together with recent data documenting species abundances over the model area, this extended and modified set of hydrologic inputs will enable further testing, evaluation, and revision of SESI models. This activity is essential in order to increase the reliability of the relative predictions made by SESI models.

Some approaches to be used in current and further SESI model development, evaluation, and refinement include the following activities.

(1) Extensive model runs have already been performed to evaluate the sensitivity of the models to wet, dry, and typical hydrological patterns as represented in both the F2050 base and the AltD13R scenario. These model runs were accomplished by creating new water data sets by extracting wet, dry, and typical years of water data from the existing water files and recombining them to create multiple water files representing scenarios which were

wetter, drier, and more average for each of the F2050 and the AltD13R scenarios than the original F2050 and AltD13R scenarios. The model output for these resultant water files was then summarized for both the entire model region and selected sub-regions and compared to the summarized output for the original water file. Analysis of these results has indicated that the models do indicate the appropriate response to water level differences (index values increase on average across the region for the American Alligator under wetter conditions). These results also indicate a fairly consistent relative pattern of differences for the models (e.g., if the average index value from a model for AltD13R is higher than its value for F2050, this ranking usually holds true for scenarios comprised of wet, dry, and typical water years). An expansion of this methodology is planned to evaluate the sensitivity of scenario rankings to variation of model parameters.

(2) A web-based interface to the SESI models as an extension of the ATLSS Data Viewer will be made available that allows authorized users to make modifications to selected model parameters and execute models on an ATLSS computational server. The resultant output file(s) could then be downloaded to the user's computer and the ATLSS Data Viewer used to compare different model runs and compare abundance data. The ATLSS Data Viewer tool would be invaluable in comparing model output with empirical data, as this tool incorporates many of the spatial summary routines required for such analysis.

The original restoration science concept for south Florida included continuing feedback between modeling, monitoring, and management programs. This must incorporate open lines of communication among modelers, biologists, and managers. Long-range stable funding must be secured for model evaluation, updating, and analysis as new monitoring and calibration data become available. Planned, periodic version updates of SESI models should incorporate information from trends reflected in current monitoring data.

In order for modeling to play an effective role in the restoration process, the following tasks necessary for model development, updating, and effective use over the period of adaptive restoration management in south Florida should be explicitly planned and funded:

Accumulation and timely distribution of monitoring data.

Maintenance of links and dialogues with experts, ensuring that models continue to reflect what is known about modeled species as the knowledge base grows.

Liaison with users of model output, explaining caveats and restrictions, what output represents and how it should be interpreted.

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Pulley Ridge—The United States' Deepest Coral Reef?

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Pulley Ridge is a 100+ km-long series of N-S trending, drowned, barrier islands on the southwest Florida Shelf approximately 250 km west of Cape Sable, Florida (Fig. 1). The ridge has been mapped using multibeam bathymetry, submarines and remotely operated vehicles, and a variety of geophysical tools. The ridge is a subtle feature about 5 km across with less than 10 m of relief. The shallowest parts of the ridge are about 60 m deep. Surprisingly at this depth, the southern portion of the ridge hosts an unusual variety of zooxanthellate scleractinian corals, green, red and brown macro algae, and typically shallow-water tropical fishes.

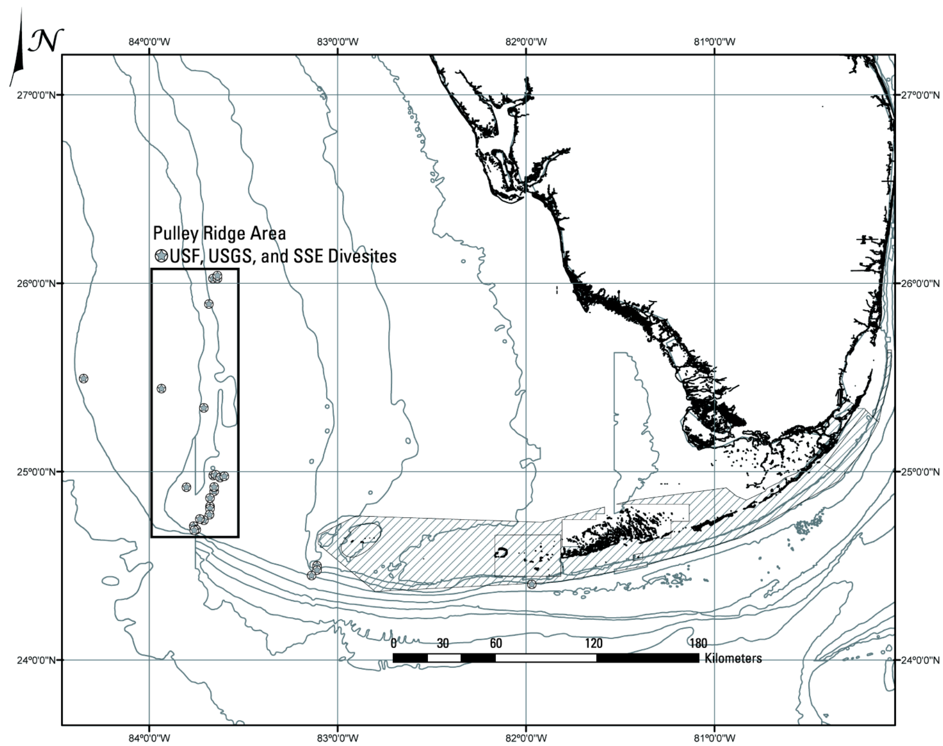

Figure 1. Location of Pulley ridge study area and divesites.

The corals *Agaricia* sp. and *Leptoceris cucullata* are most abundant, and are deeply pigmented in shades of tan-brown and blue-purple, respectively. These corals form plates up to 50 cm in diameter and account for up to 60 percent live coral cover at some localities. Less common species include *Montastrea cavernosa, Madracis formosa*, *M. decactis*, *Porities divaricata*, and *Oculina tellena*. Sponges, calcareous and fleshy algae, octocorals, and sediment occupy surfaces between the corals. Coralline algae appear to be producing as much or more sediment than corals, and coralline algal nodule and cobble zones surround much of the ridge in deeper water (greater than 80 m).

In addition to coralline algae other abundant macro algae include *Halimeda tuna*, *Lobophora variegata, Ventricaria ventricosa, Verdigelas peltata, Dictyota* sp., *Kallymenia* sp., and particularly striking fields of *Andaymonene menzeii*. The latter algae covers many hectares at densities of tens of individuals per square meter, constructing regions that appear like lettuce fields growing in the dusk at this depth on the sea floor.

The fishes of Pulley ridge comprise a mixture of shallow water and deep species sharing this unusual habitat. More than 60 species have been identified. Commercial species include *Epinephelus morio* (red grouper) and *Mycteroperca phenax* (scamp). Typical shallow-water tropical species include *Thalassoma bifasciatum* (bluehead), *Stegastes partitus* (bicolor damselfish), *Cephalopholis fulva* (coney), *Lachnolaimus maximus* (hogfish), *Pomacanthus paru* (French angelfish), and *Holacanthus tricolor* (rock beauty). The deepwater fauna is represented by *Chaetodon aya* (bank butterflyfish), *Sargocentron bullisi* (deepwater squirrelfish), *Bodianus pulchellus* (spotfin hogfish), *Pronotogrammus martinicensis* (roughtongue bass), and *Liopropoma eukrines* (wrasse bass). *Malacanthus plumieri* (sand tilefish) and several other species construct large burrows and mounds that serve as refuge for multiple species. Mounds and pits larger than $1m^2$ are apparent on side-scan sonar images and have been counted in excess of $200/km^2$ in parts of the ridge.

The extent of algal cover and abundance of herbivores suggest benthic productivity is moderate to high on parts of the ridge. Such productivity is unusual, if not unique at this depth in the Gulf of Mexico and Caribbean. Several factors help to account for the existence of this community. First, the underlying drowned barrier islands provided both elevated topography and lithified substrate for the hard bottom community that now occupies the southern ridge. Second, the region is dominated by the western edge of the Loop Current that brings relatively clear and warm water to the southern ridge. Third, the ridge is within the thermocline, a water mass that is known to provide nutrients during upwelling to shallow reefs in Florida.

Notwithstanding the positive factors for reef growth listed above, this largely photosynthetic community appears to be thriving on 1-2 percent (5-30 microEinsteins/m^2/sec) of the available surface light (PAR) and about 5 percent of the light typically available to shallow-water reefs (500 – 1000 microEinsteins/m^2/sec). The corals generally appear to be healthy, with no obvious evidence of coral bleaching or disease. Although the community is clearly one adapted to low light conditions, the variety and extent of photosynthetic organisms between 60 and 70 meters depth is impressive.

Is southern Pulley Ridge the deepest coral reef in the United States? That depends, of course, on one's preferred definition of a coral reef. There are deeper, ahermatypic coral buildups both in the Gulf of Mexico and Atlantic off Florida coasts. Classically, a coral reef is a wave resistant structure built by hermatypic corals and hazardous to shipping. From a geologist's point of view, Pulley Ridge corals appear to have built a biostrome, an accumulation at least a few meters thick, although corals may not account for the bulk of the topography. From that of a biologist, the most abundant corals in the ridge are hermatypic corals but they are lying, mostly unattached, on the surface. Clearly a ship's captain could not run his vessel aground on this reef, so mariners would not consider this a reef. Nevertheless, from the scientific perspective of a structure built from hermatypic corals, southern Pulley Ridge may well be the deepest coral reef in the United States.

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Distribution, Abundance, and Population Structure of a Broadly Distributed Indicator Species, the Diamondback Terrapin (*Malaclemys terrapin*), in the Mangrove-Dominated Big Sable Creek Complex of Southwest Florida, Everglades National Park

By Kristen M. Hart[1], Carole C. McIvor[2], *and* Gary L. Hill[3]

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Diamondback terrapins (*Malaclemys terrapin*) are long-lived turtles that exist as continuously distributed geographic populations along North America's Atlantic and Gulf coasts. Residing in salt marshes, mangroves, and tidal tributaries, the terrapin is the only North American turtle that lives exclusively in brackish water. One of the top predators of benthic macrofauna in the estuarine food chain, terrapins may play an important ecological role, and may thus be particularly suitable for monitoring as an indicator species. Additionally, the terrapin is a species of conservation concern. The historical harvest resulted in population crashes that, coupled with disappearing coastal wetlands, have greatly reduced the numbers of terrapins across their range.

Because the vital rates and population structure for terrapins are poorly understood, we initiated an in-depth mark-recapture study within the Big Sable Creek system of Everglades National Park, southwest Florida. Short-term project goals are to characterize habitat use and movement patterns of individuals, and to estimate the size and geographic extent of the population. Long-term project goals are to compare the habitat use, demographic features, and genetic profiles of selected Atlantic and Gulf coast populations of the species.

To date, we have conducted three weeklong sampling trips to the Big Sable Creek system to capture, mark, and recapture terrapins. Captures of terrapins have been concentrated in the upper reaches of creeks in the system. On each sampling trip, we surveyed the named creeks and their navigable branches systematically for terrapins at AM and PM low tides. We used dip nets to capture turtles, with new moon tides providing the best conditions for capture success.

Over the course of the first year of our mark-recapture study, we marked the first 50 terrapins in November 2001, an additional 96 individuals in June / July 2002, and 64 new turtles in December 2002. Thus far we have recorded 210 unique individuals of which 104 are females and 106 are males, for a population sex ratio of 1:1.

Recapture locations have been clustered around capture sites, suggesting that terrapins display extreme site fidelity, even across seasons—recapture locations are often only meters away from original capture sites. Our current recapture rate is 32.4 percent. The summary recapture statistics together with the number of marked animals per sampling trip (Table 1) allow us to make initial estimates of population size.

Table 1. Mark-recapture summary statistics with Schnabel population estimate.

SAMPLING PERIOD	DATE	# MARKED	# RECAPTURED	SCHNABEL ESTIMATE
1	Nov. 2001	50	----	
2	June/July 2002	96	15	
3	Dec. 2002	64	53	N = 692

We used the Schnabel population estimator because it is appropriate for closed population studies with multiple mark and recapture periods. We assumed that every individual in the population has the same capture probability for a given sampling occasion, but that the capture probabilities can vary among sampling periods. We plan to update the population estimate after each of our next two sampling periods, scheduled for May and November 2003.

The Big Cape Sable terrapin population presently consists primarily of adult animals. Analysis of the age composition data revealed that 80 percent of females and 92 percent of males captured to date are in the adult life stage. We have recorded no females less than 5 years of age and no males less than 4 years of age, suggesting we have not encountered any juveniles during our surveys. Despite considerable and repeated efforts to sample as far up each creek as possible (to the limit of canoe penetration), we have not yet found young animals in the population.

We will continue to mark and recapture terrapins in the Big Sable Creek system throughout 2003. Additionally, we will study the movement of individual females by radiotracking 10 tagged individuals. We also hope to use satellite telemetry to better understand the movement of nesting females once they leave the Big Sable Creek system to find dry upland habitat suitable for egg-laying. Future analysis of microsatellites obtained from genetic samples will help to further define population structure and gene flow among individuals. These data will help to define the extent of a mangrove terrapin population and will delineate an ecologically and genetically relevant management unit for terrapin conservation.

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Environmental Fluctuation and Population Dynamics of Two Species of Freshwater Crayfish (*Procambarus* spp.) in the Florida Everglades

By A. Noble Hendrix[1], Joel Trexler[2], *and* William F. Loftus[3]

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Much effort has been directed by theoreticians to determine the response of species to environmental fluctuations by treating the physical environment as an unpredictable or stochastic factor. Applied ecologists have increasingly sought to understand and even replicate the periodicity of natural environmental fluctuation as a management tool to attain or restore "natural" ecological regimes. Thus, understanding the role of environmental fluctuation in promoting species coexistence, or facilitating the dominance of a single species, has gained additional urgency in natural resource management. Two species of crayfish have been identified from the freshwater habitats of the Everglades, the Everglades crayfish (*Procambarus alleni*) and slough crayfish (*P. fallax*). Crayfish burrow in periodic environments, and this behavior may provide a mechanism for persistence in dry periods. Everglades crayfish typically burrow during the dry season, and they have been collected from burrows throughout their range. Slough crayfish on the other hand have been captured largely from flooded habitats. The population dynamics of each species may therefore be uniquely affected by hydrology. Hendrix and Loftus (2000) found that species composition was a function of flooding duration in both spatial and temporal domains. Yet, the mechanisms responsible for these observations are unknown. Using field samples and a mesocosm experiment, we investigated how drought frequency affected mortality and recruitment rates of two coexisting crayfish species, and how these mechanisms shaped patterns of their density and relative abundance in the Everglades.

The time series data were obtained from crayfish collected at a short (site 50, inundated < 180 days per year), a long (site 06, inundated approximately 360 days per year) and an intermediate hydroperiod site (site 23 affected by shifts in hydromanagement in the 1950's) between 1985 and 1998. Species relative abundance was calculated from adult males and regressed against the number of years since drought (fig 1). Everglades crayfish were the dominant species soon after drought events (species ratio < 0.5), whereas slough crayfish were dominant at relatively longer times since drought. Crayfish relative abundance responded differently to flooding at each site. Namely, site 50 shifted from Everglades crayfish-dominated to slough crayfish-dominated communities quicker than the other two sites as the years since a drought increased.

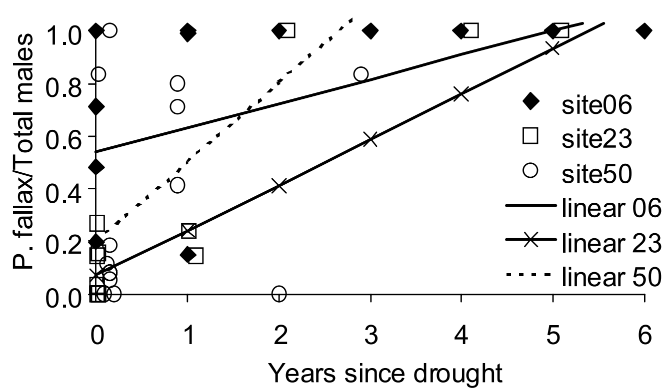

Figure 1. Species composition (slough crayfish males/total males) as a function of years since drought for sites 6, 23, and 50. Site 6 had the fewest drought events (N = 3), site 23 was intermediate (N = 5), and site 50 had the most droughts (N = 9) in a14-year time series from 1985-1998. Lines were fitted using logistic regression.

To examine the effect of drought on each species, we simulated a two-week dry-down event in mesocosm tanks. Each tank received six crayfish of a single species, which approximated average field densities of 1.91 m^{-2}. Tanks were checked three times weekly to measure water depth, feed crayfish dry commercial crustacean pellet food, estimate number of burrows, and collect mortalities. In mesocosm tanks, both species had higher survival in flooded tanks than in simulated drought events. Results of the experiment also suggested that relative survival was higher for slough crayfish in wet treatments, whereas survival of Everglades crayfish was higher in dry treatments. Everglades crayfish constructed more burrows in both treatments than slough crayfish.

We estimated stock recruitment relationships for each species by examining the log –log relationship between adults and juveniles in wet (flooded for the duration of the calendar year) and dry (dry at least three days) years. Everglades crayfish recruitment was affected by the hydrologic conditions in the spawning year (best fit model includes a greater intercept term for dry than wet years, fig. 2). Conversely, slough crayfish recruitment was not affected by wet versus dry year types (the best model to describe the slough crayfish stock-recruitment relationship had a common intercept for both years, fig. 2). Both models had a common slope. The log-log linear model used here was a log-transformed Ricker recruitment function. The intercept term was associated with the slope of the Ricker function near the origin, thus larger intercept terms had steeper slopes and higher recruitment at low densities of adults. Everglades crayfish had higher recruitment at low densities in dry years than slough crayfish, however recruitment at low densities was similar for both species in wet years. The slope term of this log-log linear model is the stock density at which recruitment is maximized. The slope of the slough crayfish stock-recruitment relationship was higher than the Everglades crayfish model (fig. 2), indicating that maximum recruitment may occur at higher adult densities for the slough crayfish.

Species coexistence may be facilitated by disturbance in some ecosystems. Two species with different, but overlapping, environmental tolerances may coexist when conditions regularly fluctuate through the optima of both taxa. In the Florida Everglades, two species of procambarid crayfish coexist and we investigated how their population dynamics were affected by drought frequency. Crayfish relative abundance was determined by local hydrological conditions. Everglades crayfish (Cambaridae; *Procambarus alleni*) were dominant when droughts were frequent, whereas slough crayfish (*P. fallax*) dominated when droughts were infrequent. Differential tolerances to drought frequency were manifested in species-specific vital rates. Everglades crayfish population dynamics were limited by low recruitment in flooded years, whereas slough crayfish population dynamics were regulated by low rates of survival through droughts as short as two weeks. Because the crayfish assemblage of the Florida Everglades is sensitive to drought frequency, hydromanagement of the region can alter species relative abundance.

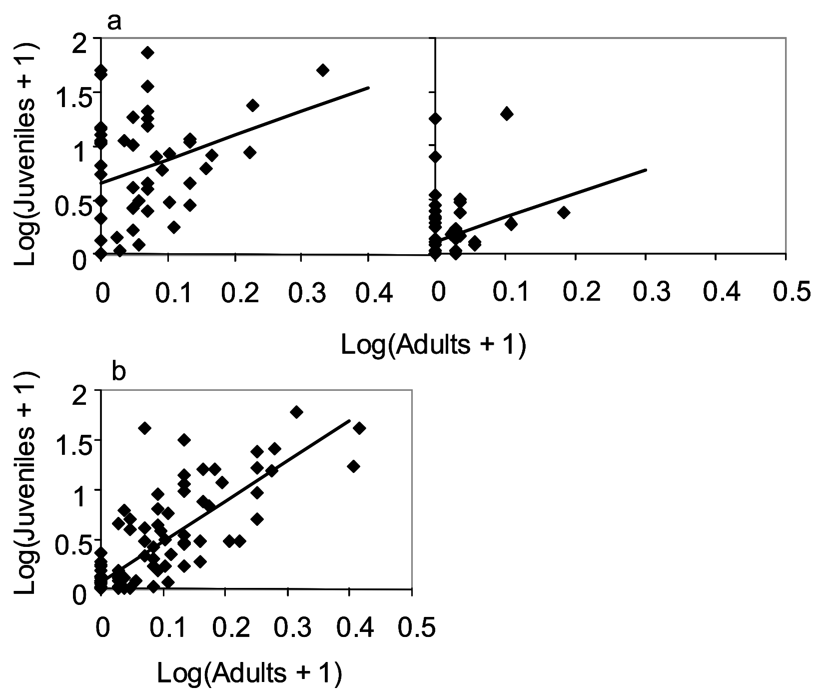

Figure 2. (a) Everglades crayfish stock-recruitment relationship. The estimated density of juveniles was analyzed in both wet and dry years. The best-fit model had similar slopes for wet and dry years, but significantly different intercept terms. (b) Slough crayfish stock-recruitment relationship. The estimated density of juveniles was analyzed in both wet and dry years. The best-fit model had a common slope for wet and dry years, and a common intercept term.

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Southern Biscayne Bay Nearshore Fish and Invertebrate Community Structure

By David Kieckbusch[1], Michael Robblee[1], André Daniels[1], Joan Browder[2], *and* Jeremy Hall[2]

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Loss and (or) degradation of coastal wetlands and nearshore estuarine habitats are long-term threats to ecological function and production of natural resources in Biscayne Bay. Because of its clear, shallow waters, Biscayne Bay's benthic community is a principal source of productivity and diversity. The seagrass/algae associated animal community, consisting of small forage fish, juvenile gamefish, and invertebrates such as pink shrimp, *Farfantepenaeus duorarum*, is particularly well developed in the shallow nearshore zone adjacent to the mainland and may be dependent upon freshwater inflow. The purpose of this study is to describe the spatial patterns of faunal community composition and species abundance in relation to salinity in the shallow, nearshore habitats of southern Biscayne Bay and ultimately to evaluate the influence of freshwater discharge on community structure.

A random stratified sampling design is being employed to characterize the spatial and temporal patterns of fish and invertebrate community structure in nearshore habitats and to facilitate a throw-trap/commercial roller trawl comparison in the adjacent deeper water commercial fishing zone. At present 54 randomly selected sampling sites, distributed on an areal basis among three salinity strata and an Elliot Key western shoreline control site, are being sampled bi-monthly. The three salinity strata are each subdivided into zones north and south of Black Point, while a subset of these sampling sites in deeper water are associated with the gear comparison.

A $1m^2$ throw-trap suitable for sampling across the full range of water depths observed in Biscayne Bay is being used to collect quantitative samples of fish and macroinvertebrates. A commercial shrimper, using a 4.4 m roller trawl, is sampling in water deeper than 1 m. Throw-trap and roller trawl sampling is coordinated to affect the gear comparison. All fishes and caridean and penaeid shrimp collected are identified, counted and sized as appropriate in the laboratory. Each throw-trap sample is associated with habitat quantitatively using a variety of techniques: visual, quadrat harvest, and Braun Blanquet. An emphasis in this study on coupling habitat (seagrass, algae, hardbottom) with fish and invertebrate community structure recognizes the importance of habitat, particularly seagrass habitat, in organizing benthic communities and to the nursery function of the bay.

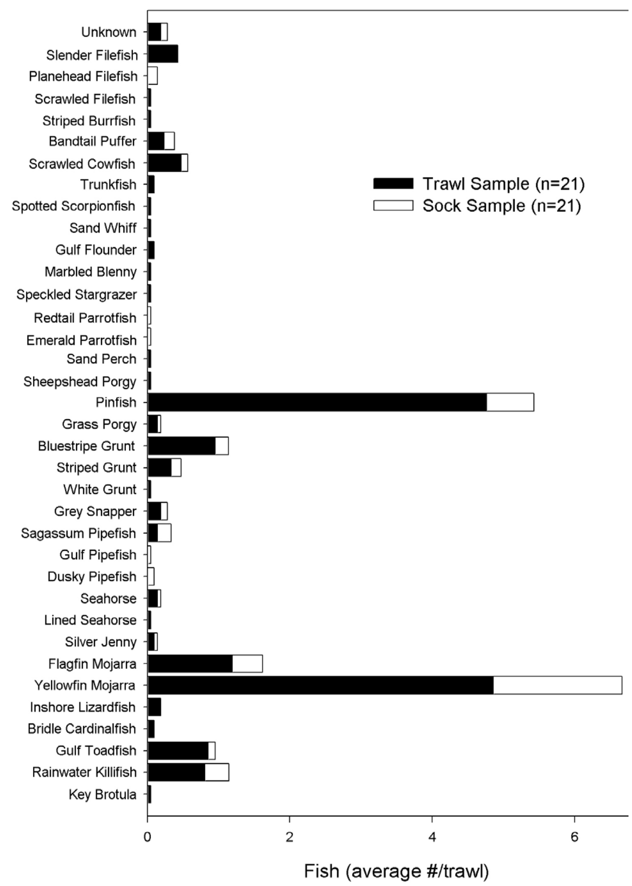

Figure 1. Comparison of the fish caught with the roller trawl versus the sock.

Sampling was initiated in the fall of 2002. Preliminary fish results are available characterizing the fish community in southern Biscayne Bay. Similar results are available for caridean shrimp and the pink shrimp. Figure 1 compares fish caught in the roller trawl net enclosed in a smaller mesh net referred to here as a sock. The sock captures fish and shrimp that might otherwise pass through the roller trawl net. Fish abundance in the collections was relatively low with averages/trawl of less than 8 for the most abundant species, *Lagodon rhomboides*, the pinfish, and the yellowfin mojarra, *Gerres cinereus*. Figure 2 compares fish caught with the throw-trap. The Elliot Key area serves as a potential control for the western shoreline of Biscayne Bay where changes in salinity patterns due to restoration of freshwater flow are expected. The fish fauna observed in Biscayne Bay is similar to that observed in western Florida Bay with the exception that parrotfish are present but absent in Florida Bay. With the exception that densities are lower the fish community along the western shore of Biscayne Bay, dominated by the rainwater killifish, *Lucania parva*, is typical of the seagrass associated fish community in Florida Bay.

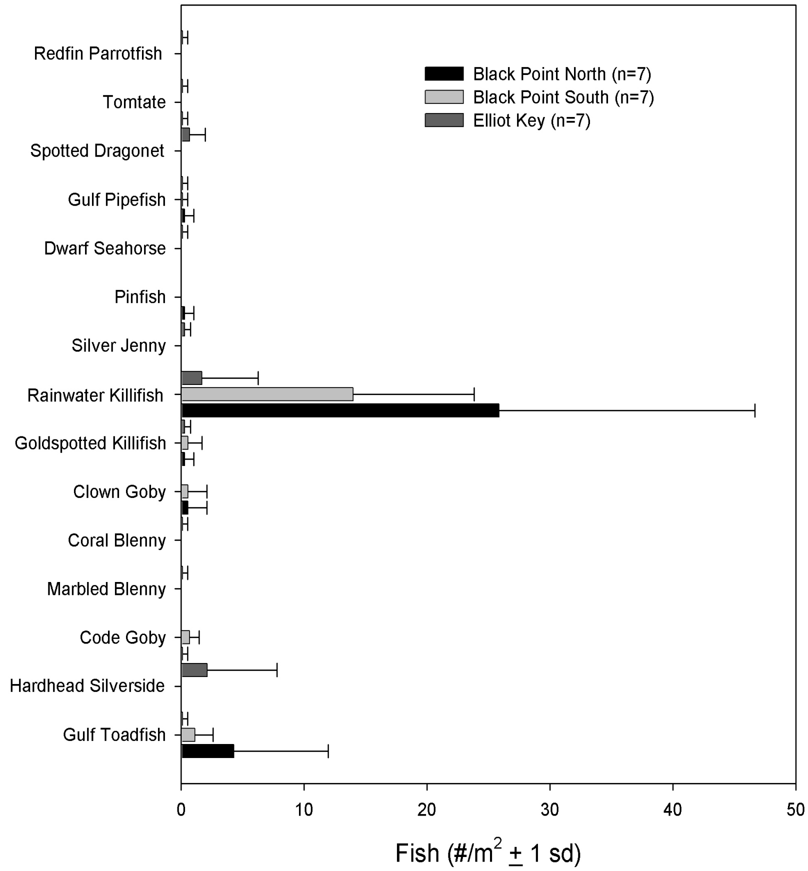

Figure 2. Comparison of the fish caught with the throw-trap north and south of Black Point and along the western shore of Elliot Key.

These results are preliminary. More detailed analyses focusing on evaluating the relationship of fish and invertebrates to salinity and habitat and comparing the throw-trap and roller trawl gears will be presented.

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Landscape Analysis of Gramminoid Habitats to Water Quality and Hydrology in Arthur R. Marshall Loxahatchee National Wildlife Refuge

By Wiley M. Kitchens

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The northernmost remnant of the intact Everglades habitat is located in the 57,235 ha (200 square mile area) of the Loxahatchee National Wildlife Refuge. Historically, this system was comprised of a spatially complex mosaic of wet prairies, saw grass stands, tree islands, alligator holes, and sloughs. However, upon completion of the extensive Army Corps of Engineers' Central and South Florida Project, the refuge began to experience large scale habitat conversions associated with altered hydroperiods and agriculturally derived pollution (i.e., contaminants and nutrients). This area has been subject to a rigidly imposed regime of water deliveries and severely degraded water quality as a result of the conversion of its primary watershed to agricultural land uses.

A multi-year interdisciplinary study (1986-91) was conducted to resolve the issues of hydrological alterations and nutrient loading impacts on this important piece of the Everglades system. As a result of altered hydrologic regimes and excessive nutrient loading, the vegetative habitats of the refuge have responded by conversion to massive monospecific stands of cattails in areas influenced by runoff waters. There has been a tendency to drown habitats in the south of the refuge and desiccate those of the north. This study defined gradients of nutrient addition effects and hydroperiods resulting from the management of water in the refuge. The study employed a community-level investigation of vegetative associations in response to the environmental gradients with a spatial characterization of the environmental variables in the GIS. We developed a spatial hydrological simulation model, a vegetative cover database from classified satellite imagery, a spatial coverage of water column/substrate nutrient concentrations, and landscape topography, all geo-spatially articulated in a GIS. Simultaneous studies of wading bird and forage fish distributions in response to habitat conditions were conducted to examine the influence of hydroperiod and water quality on wading birds and their prey base.

In order to spatially portray the various water depths and hydroperiods imposed on the wetlands and examine vegetative responses, a spatially articulate hydrological model was adapted from an existing model and applied very successfully to the area. The model incorporated approximately five hundred 1-km cells and was verified using field data. This capability provided a means hind-casting into the past and recreating the hydroperiod regimes for the past 16 yrs. Patterns of habitat use were influenced strongly by seasonal variation in water levels and decapod and fish assemblage structure varied among habitats. The bottom line results of the study were that there were indeed impacts and vegetative change resulting from hydrological alterations, but the principal agent responsible for the conversion of approximately 8,000 acres to cattail was principally phosphorus in the substrates proximal to agricultural inflows.

This work was an innovative approach for its time, employing a hierarchical approach spanning landscape level to community ecology level techniques with GIS technology. The study was however conducted approximately 15 years ago and needs to be upgraded with better imaging, modeling techniques, and community analysis techniques.

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Woody Debris in South Florida Mangrove Wetlands

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Volume of woody debris in forests provides an often overlooked, yet important, ecosystem service. The slow recovery, or decomposition, of woody debris following a major disturbance, such as a hurricane, has led to speculation that coarse woody debris serves to influence positively the long-term persistence and supply of nutrients in a forest ecosystem. Hence, immediately after a disturbance an acute flux of nutrients via litter and small woody debris fall occurs. This initial flux is followed by a gradual decrease in the supply of nutrients to some steady state whereby larger woody debris provides a source of nutrients during the ensuing forest recovery period when nutrients are most needed.

Woody debris is abundant in hurricane-prone forests. With a major hurricane impacting south Florida mangroves approximately every 20 years, carbon storage and nutrient retention may be influenced greatly by woody debris dynamics. In addition, woody debris can influence seedling regeneration in mangrove swamps by trapping propagules and enhancing seedling growth potential.

Here, we report on line-intercept woody debris surveys conducted in mangrove wetlands of south Florida 9-10 years after the passage of Hurricane Andrew (1992). The volume of woody debris for all sites combined was estimated at 67 $m3ha^{-1}$, and varied from 13 - 181 $m3ha^{-1}$ depending upon differences in forest height, storm circulation quadrant, and maximum model-generated wind velocities. The greatest amount of woody debris was found in the eyewall region of the hurricane, with a projected necromass of about 36 t ha^{-1}. Approximately half of the woody debris biomass was associated as small twigs and branches (fine woody debris) since much of the coarse woody debris > 7.5 cm was fairly well decomposed. Regressions of woody debris relative to forest height and maximum Hurricane Andrew windspeeds were developed so that woody debris can be added to existing ecological simulation models for the region. Including woody debris in model simulations may be important in accounting for a substantial amount of additional carbon within the system.

Cases of Caribbean mangrove tree mortality have been reported but have not included estimates of downed wood. Downed woody debris as a component of mangrove forest structure has been explored in two investigations from the old world tropics but have less relevance to neotropical mangrove swamps. This research provides those data for hurricane-prone regions of south Florida and provides the associated link to ecological simulation models.

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Recent Fish Introductions into Southern Florida Freshwaters, with Implications for the Greater Everglades Region

By William F. Loftus[1], Leo G. Nico[1], Jeffrey Kline[2], Sue A. Perry[2], *and* Joel C. Trexler[3]

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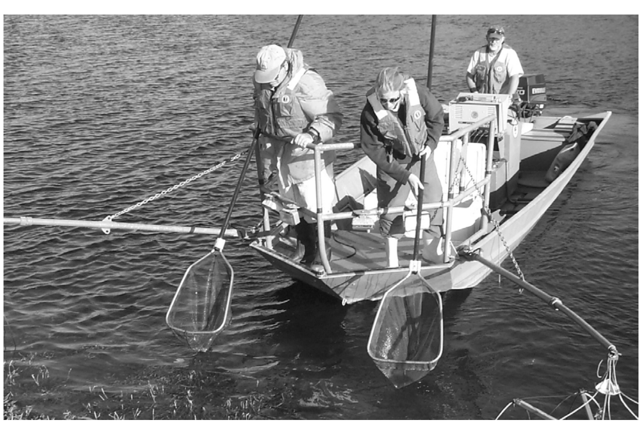
Much has been published about introduced fishes in Florida, particularly their ability to invade and potentially disrupt natural aquatic communities. Approximately 20 species have been recorded as establishing populations in the extreme southern part of the state, with many others having been collected without evidence of establishment. Recent papers have examined data collected in southern Florida to evaluate the distribution and relative abundance of introduced fishes across a variety of habitats. Two sampling programs in the Everglades provided systematically collected density information over a 20-year period, and documented the first local appearance of four introduced fishes based on their repeated absence in prior surveys. Freshwater canals, and natural tidal creeks surrounded by mangrove-dominated wetlands, held the largest introduced-fish populations in the southern Everglades region However, these combined studies reported fewer species of introduced fishes from the Everglades region when compared with studies conducted in canals along the developed Florida east coast, indicating that the most likely sites of introduction for most species is in those canals. Recent information on the appearance of additional species, and range expansions by established fishes, demonstrates that colonization of the Everglades region is continuing. The eight established species of introduced fishes known from the Everglades in the 1990s have since been joined by additional species. What are these fishes, how were they introduced, why are their ranges expanding, and what other species are likely to colonize the Everglades?

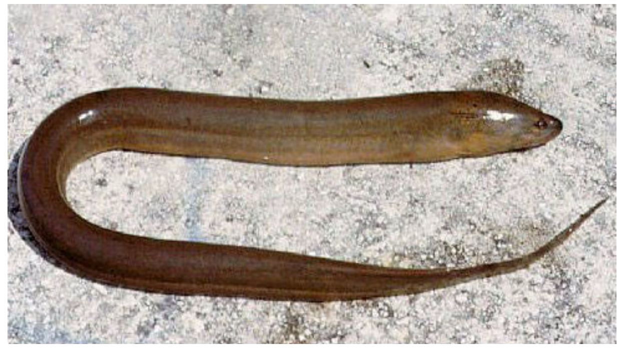
Pike killifish (Belonesox belizanus). L. G. Nico photo.

The native inland fish community of the Everglades region is comprised by about 35 temperate species with wider distributions in Florida and the southeast United States. Most previously introduced fishes in the Everglades were tropical in origin, illegally released, often from aquaria, and belonged to the family Cichlidae. One species each of livebearer and clariid catfish also were established there. Records indicate that most of those introduced species were released east of the Everglades and used the canal system to move into the Everglades system. Although many became widespread in the system, the majority did not achieve great numbers except in local situations. We hypothesize that a combination of cold winter temperatures and unfavorable habitat structure may have limited success in natural habitats by some previously established species.



Several widespread sampling programs employing electrofishing, trapping, and netting, and shorter-term research studies, continue to provide information on introduced species in the Everglades region. Those studies, and ongoing ichthyofaunal surveys of the Big Cypress NP and Biscayne NP, are continuing to collect data from canals, marshes, swamps, and detention areas. In recent years, several new species have been collected either in the Everglades or in canals that border the system. Although several are cichlids (jewelfish, banded severum, jaguar cichlid, peacock bass), others belong to families not formerly found in this region (Asian swamp eel, Homestead population, armored catfishes). In addition, other species are established in the canal system to the east, from which dispersal towards the Everglades is likely (Asian swamp eel – Miami population, snakehead, grass carp, various cichlids). While some of these recent introductions are probably aquarium releases, others appear to be illegal introductions for food or marketing purposes. Apart from the accidental release of blue tilapia from a Miami-Dade County aquaculture facility, this class of food-fish planting by amateurs is a novel vector for fish introduction.

Analysis of Everglades data collections found evidence for mainly local effects by introduced fishes, but the long-term effects of introductions, particularly with the continuing accumulation of species, are unclear. Experimental research into the biotic interactions of introduced fishes and native species is needed, as is modeling research to identify species that may pose problems if they were to be introduced. There should be emphasis placed on additional monitoring of under-sampled habitats such as canals. We also suggest that more efforts be made to educate the public about introduced species and in closing newly identified pathways for the introduction of additional species identified as potential threats.



Asian Swamp Eel (L.G. Nico Photo)

Although there have been no dramatic ecosystem effects such as extinctions or large-scale population declines in native species identified in southern Florida, we are uncertain that this condition will continue under the cumulative effects of future invasions or environmental change. What can be done to limit the numbers, spread and effects of introduced fishes? At present, there are few options available to deal with introduced fishes in the open habitats of southern Florida. Once a population has expanded beyond its point of introduction into the main canal system or into the Everglades marsh, nothing can be done to eliminate or even control them at this time. Control may be effective in local situations to meet specific management objectives. Even then, it will have to be a sustained effort because of the pool of recruits that exists in the canal reservoirs. Unlike the research and management funding used to find and deliver controls for plant or insect pests, there has been little funding applied to research into controls for fishes. Increased emphasis on finding innovative methods for dealing with fish invaders should be a priority. At present, the best way to prevent the continuing introduction of fishes may be through better public education. Design considerations should include consequences when planning pump stations, detention areas, new canals, and other constructs that will foster growth, dispersal, and delivery of non-native fishes, snails, and plants into natural wetland areas. Just "getting the water right" is not enough if it means the delivery of those waters will change the character of the Everglades biota.

Canals and structures bordering ENP.

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Fish Community Colonization Patterns in the Rocky Glades Wetlands of Southern Florida

By William F. Loftus[1], Robert M. Kobza[1], and Delissa Padilla[1], *and* Joel C. Trexler[2]

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As part of a larger effort to assess the role of aquatic refuges and subterranean habitats in system restoration, we began collecting baseline data on the ecology of constituent aquatic communities of the Rocky Glades in the wet season of 2000. The Rocky Glades is a threatened, short-hydroperiod habitat that remains intact structurally only within Everglades National Park (ENP), but even there its hydrology has been adversely affected by drainage. Pre-drainage accounts indicate that this region once had higher water levels that likely provided a richer habitat for aquatic species. Little has been published about the species composition of animals that survive below-ground through the dry season, their community patterns once above-ground, and their movements back into holes as water recedes in autumn. The highly eroded landscape offers dry-season refuge to aquatic animals in solution holes, which also allow them access to groundwater. As soon as rains flood the area in the early summer, fishes and invertebrates immediately appear on the wetland surface. We are investigating whether recolonization of the surface is a function of survival in local refuges, results from rapid, long-distance dispersal, or a combination of both.

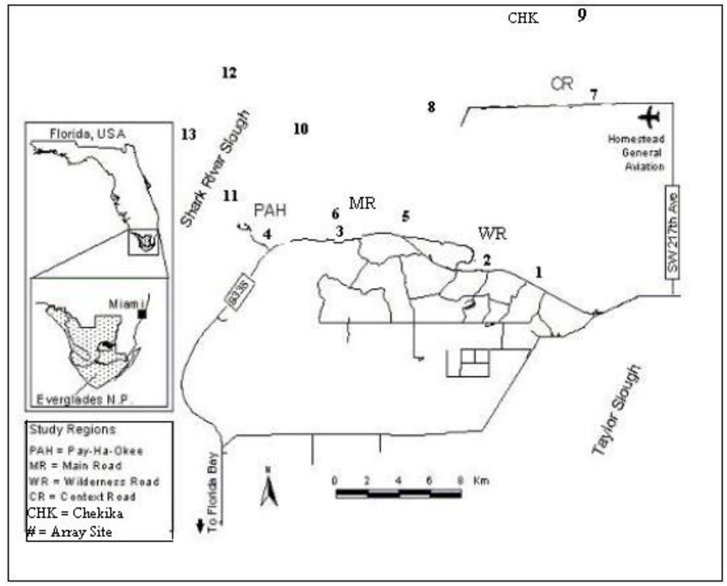

Figure 1. Drift-fence Arrays 1-13 in ENP.

In the early 1990s, we observed mass, early wet-season fish movements in the Rocky Glades, which sparked this study of the fish communities and dispersal. In the first project year, we tested methods designed to detect directional dispersal by using drift fences and funnel traps along a hydroperiod gradient. Several questions arose from these preliminary observations of dispersal in the Rocky Glades: How rapidly do different species appear in the arrays? Are the movement patterns of animals related to water flow? Do the animals disperse from the main sloughs to recolonize the Rocky Glades, or are the Rocky Glades acting as a source of animal colonists for the sloughs? Do roadways act as barriers to movement? How do composition, size-structure, and recruitment of aquatic animals change during the flooding period?

Figure 2. Trap retrieval at Array 4.

In 2000, we erected four x-shaped drift-fence arrays (Arrays 1 to 4: fig. 1), with 12 m wings made of black plastic cloth, along the main park road of ENP. The wings of the fences directed animals into traps that face the compass directions (fig. 2). When the wetlands flooded in June, we made daily collections for the first two weeks, reduced the frequency to twice weekly for three weeks, and to weekly collections until dry-down. We identified, weighed, and measured all animals in the lab. In 2001, a more spatially expansive study was implemented

The number of animals in each trap on a particular day seemed to be related to the water flow and depth, with the highest number taken during the highest flows. Most animals dispersed rapidly after the wetlands flooded. Preliminary assessments of the data indicated that the direction and degree of rheotaxy varied by species. Fishes and crayfish often reappeared in the traps on the same day that the wetlands flooded, supporting the case for local subterranean refuges. However the largest numbers of fishes appeared within two weeks of flooding (fig. 3). It remains unclear whether they may have been able to disperse for tens of kilometers across the heavily vegetated wetland landscape from Shark Slough and its estuarine creeks in that time. Hypotheses about dispersal patterns will be tested in 2003-2004 using methods such as stable isotope and otolith microchemistry analyses, and radio-tracking of larger species.

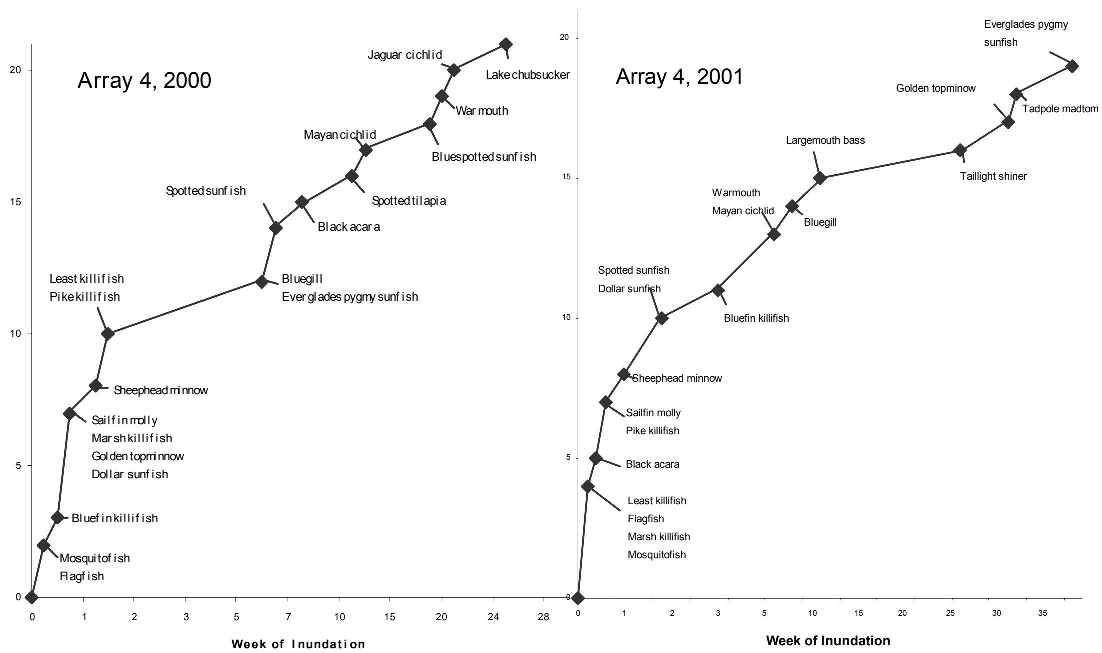

Figure 3. Appearance of fish species by week of sampling at Array 4 in 2000 and 2001.

Subsequent sampling provided data on community-succession patterns as new species appeared in the traps and relative abundances changed. Size-structure data have been used to document the onset of reproduction. Most fishes emerging onto the surface were adults that began reproducing within one or two weeks. Small juveniles appeared in the traps within a month of flooding.

The study of ecological interrelations between surface and subterranean habitats will help determine how human management has affected this region and what benefits can be anticipated by the restoration of natural hydrology. The temporal dynamics of the use of Rockland habitats in relation to hydrology have just begun to be described. This project will provide data important to simulation models, such as whether solution holes in the Rockland function as sources or sinks for fishes and how hydropattern affects trophic structure and the composition of aquatic animal communities in this landscape**.**

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Population Dynamics of the Snail Kite in Florida

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The snail kite (*Rostrhamus sociabilis plumbeus*) is an endangered raptor that inhabits flooded freshwater areas and shallow lakes in peninsular Florida and Cuba (Sykes 1984, Sykes et al., 1995). The historical range of the snail kite covered over 4,000 km^2 (2,480 mi^2) in Florida, including the panhandle region (Sykes et al., 1995), but is now restricted mainly to the watersheds of the Everglades, Lake Okeechobee, Loxahatchee Slough, the Kissimmee River, and the Upper St. Johns River. These habitats exhibit considerable variation in their physiographic and vegetative characteristics, and include graminoid marshes (wet prairies, sloughs), cypress swamps, lake littoral shorelines, and even some highly disturbed areas such as agricultural ditches or retention ponds (Bennetts and Kitchens, 1997). Three features that remain constant in the variety of selected habitats are the presence of apple snails, areas of sparsely distributed emergent vegetation (Sykes, 1983; 1987), and suitable nesting substrates, all of which are critical to the nesting and foraging success of the snail kite.

Snail kites are dietary specialists, feeding almost exclusively on one species of aquatic apple snail, *Pomacea paludosa* (Sykes, 1987; Sykes et al., 1995). The snail kite's survival depends on those hydrologic conditions that support these specific vegetative communities and subsequent apple snail availability in at least a subset of wetlands across the region each year (Bennetts et al., 2002). Wetland habitats throughout central and southern Florida are constantly fluctuating in response to climatic or managerial influences, resulting in a mosaic of hydrologic regimes.

The aim of the snail kite project is to monitor the response of the birds to those changes. This research essentially focuses on the most critical demographic parameters: survival, reproduction, recruitment and population growth rate (Bennetts et al., 1999; Dreitz et al., 2001; Bennetts et al., 2002; Dreitz et al., 2002). Because those demographic parameters are so heavily influenced by the behavior of the birds (i.e. their ability to move and select suitable habitats), movement studies constitute the other major aspect of the research. The objectives are twofold: First to evaluate the likelihood of biological hypotheses, which help understand the underlying mechanisms and processes driving the population dynamics of the kites; and second to provide reliable estimates of demographic parameters and movement probabilities, which are helpful for decision making using management models (see below). The statistical framework selected for parameter estimation is maximum likelihood estimation for its well recognized good statistical properties (Burnham and Anderson 1998). The empirical data consists of mark-resight and radio telemetry data.

The long-term data set already available offers the potential to investigate the effect of hydrological variations across time and space. Low water years have substantial effects on the number of nests detected, but do not seem to greatly affect nesting success (Dreitz et al. 2001), which suggest that when the hydrological conditions are unfavorable for kites, birds simply do not breed. Thus far there is no evidence for an effect of local drying event on adult survival, although this aspect needs to be investigated for juvenile. There is no strong evidence for a very substantial effect of a fairly widespread drought event (however, low in intensity) on adult survival (the 2000-2001 drought, fig. 1). In contrast the 2000-2001 drought considerably affected juvenile survival (fig. 1).

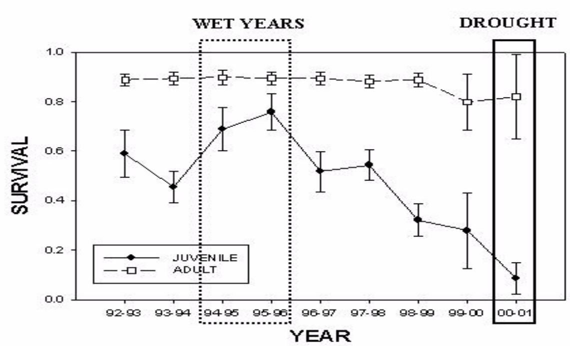

Figure 1. Survival estimates, for adult and juvenile (first year bird) snail kite in Florida between 1992 and 2001, the error bars correspond to the sampling error..

It was also interesting to note that it is during the wettest year that the highest estimates of juvenile survival were observed. Bennetts et al. (2002), explain this observation by suggesting that during high water year, more sites are likely to be suitable for foraging. Hence, during the dispersing period, when juveniles are most vulnerable, an increase in the surface area of suitable habitat, would reduce the chances of the dispersing juveniles encountering unsuitable habitat. An important point to make here is that the results provided in this abstract are preliminary. Those estimates will be refined by incorporating the 2003 field data. Nonetheless, the estimates that this analysis provides are already valuable for further modeling effort, in particular in the context of the Across Trophic Level Simulation System (ATLSS), which evaluates the effect of various hydrological regimes on the whole Everglades ecosystem (DeAngelis et al. 1998; DeAngelis et al. 2002). Indeed the present version of the spatially explicit individual-based kite model that will be incorporated into ATLSS (Mooij, Bennetts et al., 2002), is presently lacking robust estimates for survival during drought events.

Another aspect presently under investigation is the response of the bird in terms of movement. By combining radio telemetry and mark-resight data under a multistate modeling framework (Williams, Nichols et al., 2001), we intend to estimate yearly movement probabilities between critical habitats, and test biological hypotheses about the processes driving the long term movement patterns. This information together with some further investigation of within year movement patterns, should help improve the predictive performance (in particular the spatial component) of the spatially explicit individual based kite model.

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The Relationship of Seagrass-Associated Fish and Crustacean Communities to Habitat Gradients in Florida Bay

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Restoration of the Greater Everglades ecosystem will be multifaceted, but a large component of the program involves reestablishing a more natural hydrological regime. Downstream of the Everglades, changes in the quantity, timing, and distribution of freshwater flows entering Florida Bay will affect the resident biota. This project was designed to provide baseline data for one important faunal component of the Florida Bay ecosystem: seagrass-associated fish, caridean and penaeid shrimp, and portunid crabs. Seagrass beds are one of the most spatially extensive and important habitats in Florida Bay, and the extent, composition, and health of seagrass beds can definitely be affected by changes in freshwater inflow. Seagrass-associated faunal communities can be affected directly by salinity changes or indirectly by changes in the seagrass habitat. This study provides baseline data needed by managers to create models that can predict what will happen as a result of changes in freshwater delivery to Florida Bay and to evaluate the success of upstream restoration activities.

We used 1-m^2 throw-traps to collect seagrass-associated fauna at 18 sites distributed throughout Florida Bay. For analytical purposes, our sites can be grouped geographically (fig.1): 1) northeast—Black Betsy, Bob, Butternut, Deer, Eagle, and Nest Keys; 2) interior—Bob Allen, Buttonwood, Crab, Roscoe, Spy, and Whipray Keys; and 3) peripheral—Barnes, Joe Kemp, Johnson, Palm, Rabbit, and Sandy Keys. Three habitats (bank, basin, and near-key) were sampled at each site during wet (October) and dry seasons (April-May) from 1998 through 2000, yielding 360 bank samples, 360 basin samples, and 270 near-key samples. We identified 7,539 fish and 62,786 shrimp and crabs from these samples.

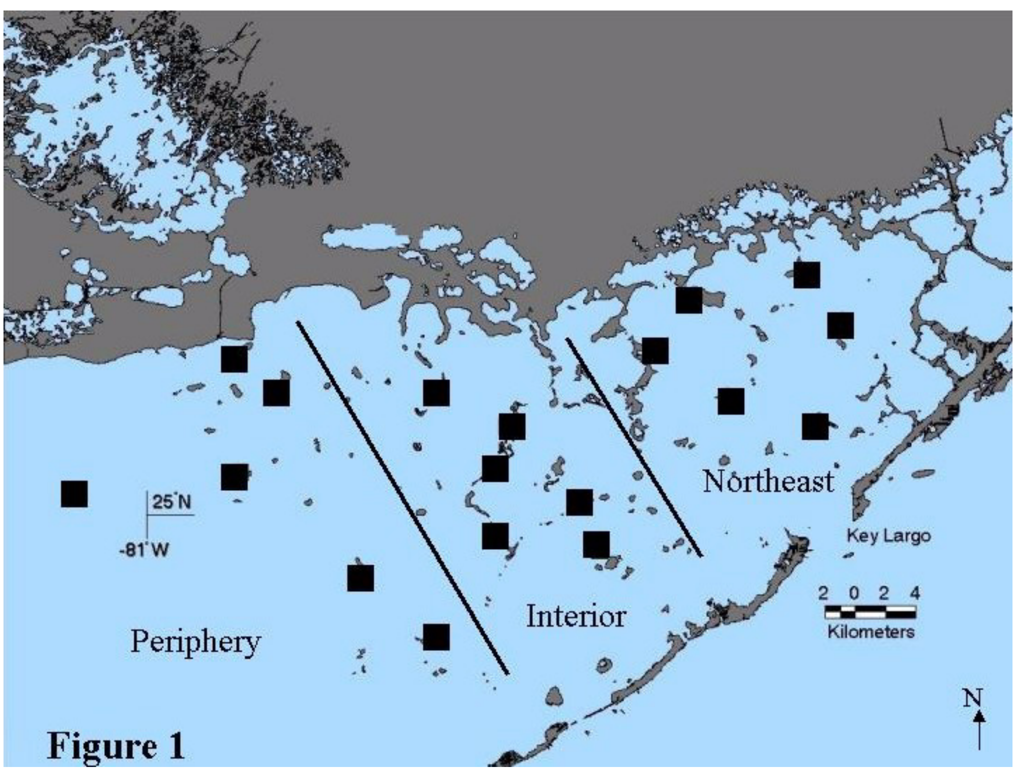

Figure 1

A gradient was apparent in both habitat features and biotic communities across the three regions (table 1). Northeastern sites had lower, more variable salinities; shallower sediments; less seagrass cover; and lower diversity and abundance of fish and crustaceans. Levels of these same parameters were often intermediate at interior sites and highest at peripheral sites.

The abundance patterns of the five dominant fish species were less consistent with this gradient than were the abundance patterns of the five dominant crustacean species. The abundance of only one fish species, *Lucania parva*, strictly followed the gradient of northeast<interior<periphery, and two fish species, *Floridichthys carpio* and *Opsanus beta*, were found at similar abundances in all three regions. *Anchoa mitchilli* and the sixth-ranked species, *Microgobius gulosus*, were both most abundant at northeastern and interior sites; both of these species are often found in the low-salinity portions of estuaries and are weakly associated (if at all) with seagrass. Among crustaceans, abundances of the top five species were all low in the northeast, moderate or high in the interior, and high on the periphery of the bay. The strongest apparent relation between abundance and salinity were observed for *Farfantepenaeus duorarum* and *Gobiosoma robustum.* Both of these species were essentially absent at salinities below 29 ppt but were among the most abundant species at higher salinities. Greater seagrass-bed development (i.e., greater density, leaf area, or diversity) was often accompanied by greater abundances of several species, including *F. duorarum*, *G. robustum, Thor floridanus*, and *O. beta*.

Table 1. Characterization of habitats and faunal communities in three regions within Florida Bay. Seagrass diversity is determined by the relative contribution of each of the species collected during this study to the overall abundance of seagrass in each region. Only the five most abundant fish and five most abundant crustacean species are included.

Parameter	Northeast	Interior	Periphery
Salinity	low	high	high
Salinity CV	high	low	low
Sediment Depth	low	moderate	high
Seagrass Shoots	low	moderate	high
Seagrass Biomass	low	moderate	high
Seagrass Diversity	low	moderate	high
Seagrass Canopy Height	low	moderate	high
Fish Abundance	low	moderate	high
Number of Fish Species	low	low	high
Lucania parva	low	moderate	high
Gobiosoma robustum	low	high	moderate
Floridichthys carpio	moderate	moderate	moderate
Opsanus beta	moderate	moderate	moderate
Anchoa mitchilli	high	high	low
Crustacean Abundance	low	moderate	high
Number of Crustacean Species	low	moderate	high
Thor floridanus	low	high	high
Hippolyte zostericola	low	moderate	high
Farfantepenaeus duorarum	low	moderate	high
Alpheus heterochaelis	low	high	high
Periclimenes americanus	low	moderate	high

Alterations in the pattern of freshwater inflow could affect most of the physical and biotic patterns which we observed in Florida Bay. The effects of these alterations on fauna will be species-specific. Our study provides data for predicting these changes prior to restoration and for documenting these changes after restoration.

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Status of the American Alligator (*Alligator mississippiensis*) in Southern Florida and its Role in Measuring Restoration Success in the Everglades

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The American Alligator (*Alligator mississippiensis*) was abundant in the pre-drainage Everglades. Alligators once occupied all wetland habitats in south Florida, from sinkholes and ponds in pinelands to mangrove estuaries during periods of freshwater discharge (Craighead, 1968; Simmons and Ogden, 1998). Nearly all aquatic life in the Everglades is affected by alligators (Beard, 1938). As a top predator in their ecosystem, alligators undergo an extraordinary change in body size, consuming different prey items as they grow (Mazzotti and Brandt, 1994). As ecosystem engineers, alligators create trails and holes that provide aquatic refugia during the dry season and concentrate food items for larger predators. Alligator nests provide elevated areas for nests of turtles and snakes, and for germination of plants less tolerant of flooding (Craighead, 1971; Kushlan and Kushlan, 1980; Enge et al., 2000). Alligator activity also keeps many small creeks in the freshwater mangrove zone, gator hole sites, and areas around tree islands from becoming overgrown with vegetation. It is possible the activity creates firebreaks that provide refuge to woody vegetation and various animal species (Craighead, 1968; Simmons and Ogden, 1998). The water present in holes during the dry season provides critical habitat for nesting female and juvenile alligators (Mazzotti, 1989; Kushlan and Jacobsen, 1990) and provides open water necessary for alligator mating (Garrick and Lang, 1975).

In Everglades National Park, the largest historical alligator populations occurred in broad marl prairies to the east and west of the ridge and slough habitats, and in the freshwater mangrove zone. Land development and water management practices have reduced the spatial extent and changed the hydropatterns of these habitats (Mazzotti and Brandt, 1994). As a result of these habitat alterations, alligators are now less numerous in the marl prairie, rocky glades, and mangrove fringe areas. For alligators, an important alteration was the construction of canals. Alligators initially displaced by development or drainage now reside in canals. The effects of artificial habitats such as canals on creation and maintenance of alligator holes had not been studied until recently. Everglades canals serve as alligator refugia throughout the Greater Everglades ecosystem. Adult alligator density (especially of males) is higher in canal habitats than in the natural marsh interior (FFWCC, unpub. data; Morea, 1999). The canals may provide suitable habitat for large alligators, but unlike alligator holes, they are not suitable for smaller alligators, smaller marsh fish, or foraging wading birds. Though this trend may be remedied by proper management practices, characteristics of alligator habitats have changed with the creation of canal systems now present in the Florida Everglades (Kushlan, 1974).

Restoration of hydrologic patterns and ecological function in the Everglades is now underway. The relations among dry season refuge, aquatic fauna, wading birds, and alligators have been identified as key uncertainties in the Comprehensive Everglades Restoration Plan (CERP; U.S. Army Corps of Engineers, 1999). Due to the alligator's ecological importance and known sensitivity to hydrology, salinity, habitat productivity, and total system productivity, the species was chosen as an indicator of restoration success. A number of biological attributes (relative density, relative body condition, nesting effort, and nesting success) can be measured, standardized methods for monitoring have been developed, and historical information exists for alligator populations in the Everglades. These attributes can be used to determine success at different spatial and temporal scales, and are instrumental for constructing ecological models used to predict restoration effects. The relative abundance of alligators is expected to increase as hydrologic conditions improve in over-drained marshes and freshwater tributaries. As canals are removed, densities of alligators in adjacent marshes and occupancy of alligator holes is expected to increase. As hydroperiods and depths approach more natural patterns, nesting success, alligator growth, and condition are all expected to increase in areas where they are currently below historic values.

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Fish Assemblages of Tidally Flooded Mangrove Forested Habitat Along a Salinity Gradient in Shark River

By Carole C. McIvor, Noah Silverman, Gary L. Hill, *and* Katie Kuss

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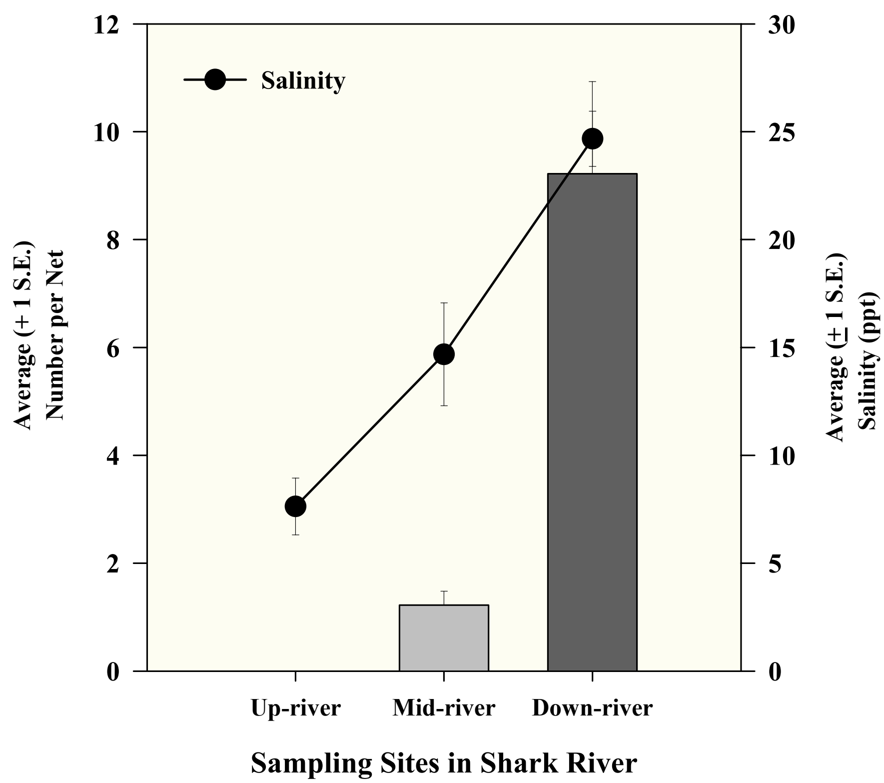
We have been sampling fishes that directly use tidally flooded mangrove forest habitat along Shark River for three years. We sample every other month using two passive sampling methods: 2 X 3 m^2 bottomless lift nets and 1 X 1.5 m block nets across the mouths of intertidal rivulets. Lift nets are located within the first 16 meters of fringing forests and yield density data; intertidal rivulet nets are located at the forest/river bank interface and yield CPUE (catch per unit effort) data as they drain an unknown and variable area. Sites are fixed, and located off Tarpon Bay upriver (S2), midway along the Harney River (S4), and downriver near the mouth of Shark River about 3 km upstream of Ponce de Leon Bay (S3).

The 18-month period January 2001 - June 30, 2002 is representative. We captured 25 fish species from 16 families on 8 sampling dates. Average catch per rivulet net was 13.8 fish; average density per lift net was 3.4 fish /6 m^2. Five families dominated the mangrove forest assemblage. Gobies (frillfin, crested), mojarras (silver jenny, tidewater mojarra), rivulins (mangrove rivulus), anchovies (bay anchovy) and killifishes made up 92 percent of the catch. Introduced species (walking catfishes, pike killifish, cichlids) were rare, as were juveniles of estuarine transient species that spawn offshore, e.g., gray snapper, pinfish, and mullets.

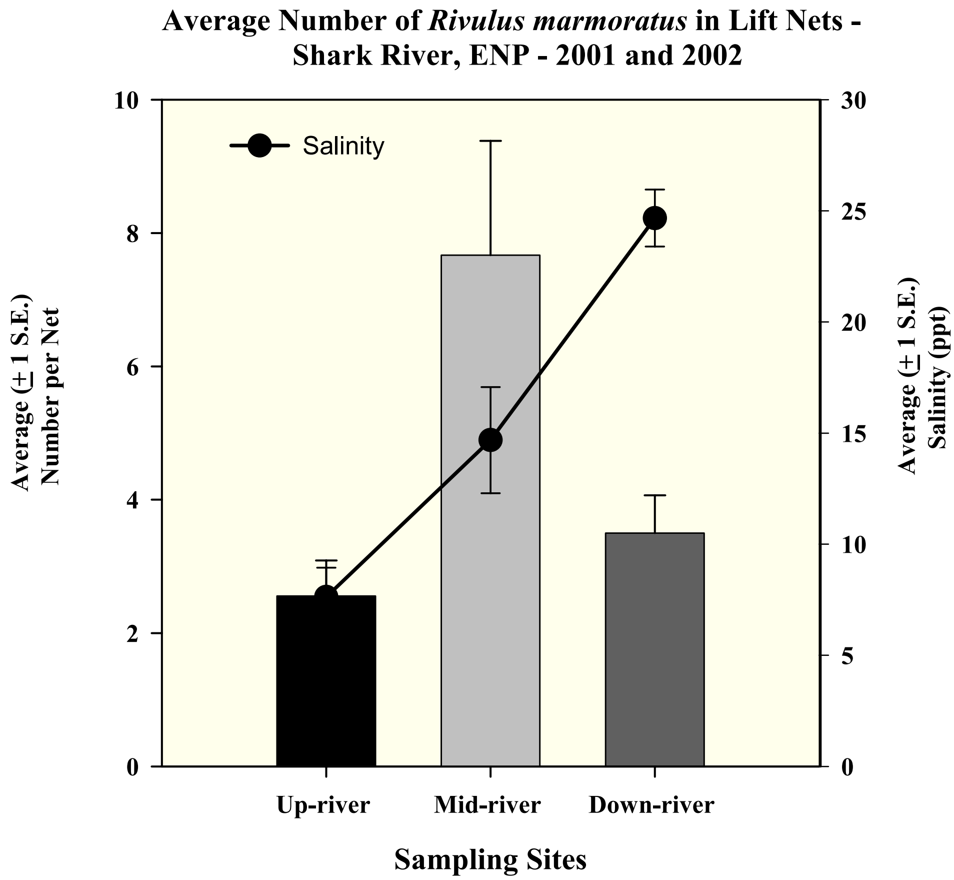
Frillfin goby (*Bathygobius soporator*) and mangrove rivulus (*Rivulus marmoratus*) were the most abundant species. Frillfin gobies appear to be best suited to higher salinities, showing a monotonic decline with decreasing salinity upstream in Shark River (fig 1). Mangrove rivulus, once considered a species of special concern in Florida, is common along the entire salinity gradient sampled (fig 2). This species is the most frequently captured species in our bottomless lift nets. Rather than being rare, it is actually a habitat specialist poorly captured by traditional sampling methods. Unlike other fish species, mangrove rivulus remains in the forest over low tide by a combination of aerial respiration and use of damp refuges, e.g., crab burrows, under wet leaves and wood. Although data analysis is incomplete, three trends are apparent in rivulus distribution along Shark River:

Average Number of *Bathygobius soporator* in Rivulet Nets, and Average Salinities at Sites in Shark River, ENP - 2001 and 2002



- Individuals tend to be smaller upriver.
- The greatest density occurs at the mid-river location.
- Rivulus have the highest condition factors downriver.

The relative abundance and distribution of these two common species (frillfin goby, mangrove rivulus) can be used as part of a larger monitoring effort to judge the effects of hydrological modifications made upstream in the catchment as part of restoration activities.



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Assessing the Consequence of Hurricane-Induced Conversion of Mangroves to Mudflats on Fish and Decapod Crustacean Assemblages in the Big Sable Creek Complex of Southwest Florida

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Hurricanes routinely cause damage to mangrove forests, generally by breaking and toppling trees. Normally forests recover through growth of new plants from seedling germination. For reasons that are not completely understood, the passage of two category 4-5 hurricanes across the Cape Sable peninsula in southwestern Florida (1935, 1960) resulted in permanent damage to some mangrove forests: adult trees were killed, sediments eroded, and no seedlings germinated. The net result was localized conversion of mangrove forests to unvegetated mudflats. Mangroves are generally considered to be critical nursery habitat to the juveniles of many species of estuarine transient fishes whose adults spawn offshore and whose young life history stages use mangrove environments. This project asks the question “What is the consequence of the conversion of mangrove to mudflat habitat on intertidal assemblages of fish and decapod crustaceans within the creeks in the Big Sable Creek complex?”

The Big Cape Sable Creek complex is located at the far downstream end of the Everglades restoration area, but is of interest because it naturally receives little freshwater inflow. The creek complex consists of six tidal creeks that are a mosaic of mangrove forest and mudflats (fig. 1): both habitats are inundated at high tide. Intertidal rivulets, i.e., drainage features smaller than first order creeks, also drain both habitats. Rivulets are depressions in the substrate up to 1 m deeper than the forest floor or mudflat around them. Rivulets fill earlier on flood tides and retain water later on ebb tides. Rivulets are “hotspots” for the entry and egress of fish and decapod crustaceans (shrimp, crabs) from intertidal habitats, and are a convenient location for sampling these animals with block nets (fig. 2) to compare the fish and decapod fauna leaving replicate forest and mudflat habitats.

Figure 1. Big Sable Creek complex. Intertidal mudflats show up in B&W photo as light gray openings in an otherwise continuous dark forest.

Figure 2. Permanent end posts either side of a routinely sampled intertidal rivulet: posts accommodate block net for capturing fish and crustaceans leaving the mangrove forest on an ebb tide.

We hypothesize that forested sites will be dominated by small benthic forage fishes (e.g., gobies, killifishes) that experience a lower risk of predation within complex intertidal vegetation. Alternatively, we expect deeper mudflat sites lacking vegetation to be dominated by two groups of fishes: water column schooling fishes (e.g., anchovies, silversides), and large roving predators (e.g., subadult snappers, catfishes), both of whose movements will be unimpeded by the structural complexity of stems and roots of mangrove trees.

The statistical design is a repeated measures ANOVA. The dependent variable is catch per unit effort (CPUE), the independent variable is habitat type: catch will be quantified as both numbers and biomass. We are sampling three replicate creeks, each with a forested and a mudflat site. The rivulet sites are fixed and drain an unknown area that varies with both tidal height and with location. Sampling will occur every 2 months for 12-18 months. A major challenge is defining either the area drained by each net, or the volume of water flowing through each net to refine our measurement of catch.

Species composition will be compared between habitat types using an ordination technique, multidimensional scaling (MDS), followed by analysis of similarity (ANOSIM) to ascertain statistical significance of species groupings. Very preliminary analysis of the first data collected in fall 2002 indicates compositional differences in the fish faunas of the two types of intertidal habitats.

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Projecting Future Population Dynamics of the Florida Snail Kite in Relation to Hydrology by Means of a Suite of Models

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The basic information for any model that projects future population dynamics should be good empirical studies. A large number of empirical studies have been done on the Florida Snail Kite. Such studies provide basic information on the biology of the species. They also provide the correlative relations between specific aspects of the snail kite life-history and behavior with the hydrology of the system. These relations form the building blocks of any hydrology-driven population-dynamical kite model.

Opinions differ on whether the best approach to modeling the life history of a population should be by means of a system-wide deterministic matrix model or, alternatively, a spatially-explicit stochastic individual-based model. We argue that rather than choosing among these two approaches, it is better to implement both concurrently. Next to the system-wide deterministic matrix model and the spatially-explicit stochastic individual-based model two other versions were implemented: a system-wide stochastic matrix model and a spatially explicit deterministic individual-based model. With these four tools in hand, we approached the challenge of making reliable projections of future population development of the snail kite under various hydrological scenarios.

Next to having a rigorous and transparent model structure, two issues are central to getting a reliable kite model: how to parameterize the model and how to set ranges of uncertainty to its output. The preferred statistical framework to solve both issues would be maximum likelihood estimation. In principle, the Maximum Likelihood Method provides a formal and rigorous approach to deal with the five sources of uncertainty: structural uncertainty, uncertainty in the hydrological input, uncertainty in the biological parameters, uncertainty due to demographic stochasticity, and finally uncertainty due to errors in the empirical data on basis of which the model is parameterized.

There is optimism that the kite model will be among the first applied population dynamical models that succeeds in disentangling and integrating these sources of uncertainty in a formal way. The current implementation of the model (Everkite 3.00), that has already been applied to evaluate hydrological scenarios and is ready to analyze new scenarios as they come, provides an excellent starting point for these new developments.

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Habitat Selection and Home Range of American Alligators in the Greater Everglades

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Regional development and water management practices have drastically altered the spatial extent and traditional hydropatterns of the Greater Everglades. Proposed restoration plans will dramatically affect the Everglades ecosystem. Alligators are a keystone species that have an important role in the trophic dynamics of the Everglades by engineering trails, "gator" holes and caves that are important refugia for many species of plants and animals (especially fish and amphibians) during the dry season. Canals (one focus of restoration plans) serve as refugia for alligators throughout the Everglades. Alligator life history patterns (including movement and habitat selection) are expected to change in response to restoration efforts.

For this study, the American alligator was selected (*Alligator mississippiensis*) as an indicator of the success of restoration efforts. The objective was to collect information that can be used in ecological models for predicting and evaluating alternatives of the Comprehensive Everglades Restoration Plan (CERP). The success of restoration efforts will rely on models such as the Across-Trophic Level System Simulation that require valid estimates of alligator response to habitat restoration.

Radio telemetry was used to examine habitat selection and home range of alligators in the Greater Everglades. The size and shape of home ranges as well as selection of cover types within home ranges reflect the quality and condition of available resources. As canals are removed and alligators move back into adjacent marsh habitat, we anticipate that resource selection (and ultimately demography) will depend on where the alligator is located in the Greater Everglades. Therefore, alligators were observed inthree contrasting Everglades habitats: marsh in Water Conservation Area 3A North (WCA), marsh in the Everglades National Park (ENP), and canals in both the WCA and ENP (Canal). Weekly locations for 66 alligators (WCA = 11, ENP = 22, Canal = 33 alligators) and intensive daily locations for 31 alligators (WCA = 6, ENP = 7, Canal = 18 alligators) were recorded in the 3 habitats. Weekly locations were recorded using aerial telemetry, while the daily locations were recorded using ground-based telemetry.

Home range for all alligators was estimated using a 95 percent daptive kernel model, which is a more robust and conservative estimate of home range size. However, we used a 100 percent. Minimum Convex Polygon (MCP) to estimate the proportion of habitat available to alligators in our examination of habitat selection. A 100 percent MCP included all habitats used by each alligator. We used compositional analysis to examine the selection of cover types with the 100 percent MCP. We examined seven cover types for the daily locations. The number of cover types was restricted by sample size. Cover types for daily locations included: 1) sawgrass (*Cladium jamaicense*), 2) emergent vegetation - including spikerush (*Eleocharis cellulosa*) and cattails (*Typha* spp.), 3) uplands - tree islands and shrub islands, 4) floating vegetation - mainly water lilies (*Nuphar* spp., and *Nymphaea* spp.), 5) open water - areas with little or no vegetation, 6) "gator" hole, and 7) canal. For weekly locations the same 7 cover types included in the daily locations were examined, but levee break, gator trail and airboat trail were added.

Mean home range was larger for alligators in canals (111.2 ± 27.1 ha, $\bar{x}$ ± SE) than either WCA (55.5 ± 17.7 ha) or ENP (79.7 ± 25.2 ha) marshes. There was no difference in home ranges for alligators in the marsh of WCA and ENP. Mean male home range (144.34 ± 22.3 ha) was larger than female home range (35.91 ± 16.76 ha).

Alligators frequently selected deeper water marsh in WCA (table 1) for both daily ($P < 0.05$) and weekly locations ($P < 0.001$). Floating vegetation was selected more than any other cover type for both daily and weekly locations. Weekly location data also indicated selection for emergent vegetation, levee breaks, and airboat trails that was greater than other cover types.

Alligators were frequently located in gator holes (table 1) in ENP during both daily ($P < 0.01$) and weekly locations ($P < 0.0001$). Daily locations also indicated a selection for emergent vegetation not observed for weekly locations. Spikerush and cattails often surround gator holes in ENP. More intensive daily locations were more likely to record locations in the surrounding emergent vegetation while alligators were using holes.

As expected, canal alligators strongly selected canals over all other cover types (table 1) for both daily ($P < 0.0001$) and weekly locations ($P < 0.0001$). The creation of canals in the Greater Everglades has influenced alligator movement and habitat selection. Canal alligators spend most of their time in canals and move greater distances (i.e., have larger, more linear home ranges) than alligators in WCA or ENP marshes. The response of alligators to the proposed removal of canals may depend on adjacent habitat. Alligators are able to restore abandoned alligator holes or create new holes in the peat dominated slough of ENP, but they may be drawn to deeper water marsh, such as found around floating vegetation or in levee breaks in the WCAs.

Table 1. Selection ratios (i.e., the ratio of the proportion of cover types used to the proportion of cover types available) for American alligators radiotracked in the Greater Everglades from November 1996 to August 1999 .

A. Daily Locations (n = 31 alligators)

	Saw-grass	Emer-gent	Upland	Floating	Open water	Gator hole	Canal
WCA	0.42	3.36	0.002	13.47	0.41	0.08	NA
ENP	0.27	9.57	1.17	0.001	0.01	7.41	NA

B. Weekly Locations (n = 66 alligators)

	Saw-grass	Emer-gent	Upland	Floating	Open water	Gator hole	Levee break	Gator trail	Airboat trail	Canal
WCA	0.21	3.24	0.001	3.47	1.20	0.07	2.58	0.63	2.33	NA
ENP	0.03	0.02	0.32	0.003	16.40	17.79	1.00	0.11	0.33	NA
Canal	0.03	0.98	0.01	0.02	0.20	0.35	0.20	0.05	0.09	3.90

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Movements and Habitat Requirements of Radio Tagged Manatees in Southwest Florida—Implications for Restoration Assessment

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A study on West Indian manatees (*Trichechus manatus*) in southwestern Florida is being conducted to determine the relative abundance, distribution, movements, and habitat use of manatees associated with coastal waters and rivers. As part of the study, an individual-based ATLSS model is being developed to predict manatee response to changes in hydrology caused by the Comprehensive Everglades Restoration Plan (CERP). A large proportion of the southwest Florida manatee population occurs throughout the Everglades National Park (ENP) and northwest into the Ten Thousand Islands (TTI). Ongoing research in this region shows that manatees make frequent movements up tidal creeks to obtain freshwater for drinking and to find thermal refugia during cold weather. Alteration of the freshwater and estuarine ecosystems associated with restoration of the Everglades and Southern Golden Gate Estates (SGGE) is likely to affect this manatee population. We hypothesize that manatee distribution, relative abundance, habitat use, and movement patterns will change because of altered water management regimes and resulting changes in near shore salinity. Aerial surveys and radio tracking tagged manatees provide valuable means of documenting the response of manatees to natural and human-induced fluctuations in freshwater inflow. This information, combined with water-quality data obtained from monitoring stations, is being incorporated into the manatee ATLSS model, which will be used to better understand and predict manatee response to different restoration scenarios. This project also fills a significant void in our knowledge of manatee ecology, as there is very little existing information on manatee population biology and habitat use in southwestern Florida. Recent advances in tracking technology have made this project logistically feasible and cost-effective.

Data from manatees radio tagged in the TTI documented the pre-restoration use of habitat by manatees within the region affected by the SGGE restoration. During the initial phase of this study, three captive, rehabilitated adult manatees were tagged and released in July 2000. Eight more wild manatees were captured and radio-tagged at Port of the Islands in February and March 2001. Two others tagged by Mote Marine Lab near Charlotte Harbor were moved into the Ten Thousand Islands during summer 2001. During January 2002, five more manatees were captured and radio-tagged at Port of the Islands, bringing the total number of manatees tagged and tracked in this study to 20 individuals.

We relied on several technologies to acquire geographic locations from tagged manatees. Most manatees were fitted with satellite-based Argos transmitters, which have a serviceable battery life of six months and provide locations along with data on temperature and transmitter activity. A location class (LC) designating the accuracy of each position is also recorded; quality locations include LC 1 <1000m, LC 2 <350m, and LC 3 <150m. Tagged manatees relayed an average of six quality locations per day, with a frequency of approximately two per day from each location class. In addition to the Argos satellite-monitored tags, we opportunistically attached a datalogging GPS tag to six manatees. The GPS tag provides locations which are much more accurate than the Argos data (approx. 30 m vs. 150 m) every 15-30 minutes, but the battery life expectancy is much shorter (8 weeks vs. 6 months). In combination, the Argos data provided region-wide, long-term coverage suitable for revealing general patterns of habitat use, while the GPS data showed fine details of travel pathways and time spent in specific areas. Newly developed Argos-linked GPS tags were recently deployed on individuals. This tag relays GPS locations as sensor data through the Argos satellite link, enabling detailed tracking data to be acquired remotely. All tagged manatees were periodically located and observed in the field using standard VHF tracking techniques. All location data were formatted using the SAS statistical software for error checking, analyses, and display in ArcView. Databases were correlated with temperature, salinity, and tidal data collected throughout the region.

From 2000 through July 2002, a total of 4,563 tracking days were recorded from 36 tag deployments on the 20 manatees. Two of the males traveled to areas more than 100 km north of the Ten Thousand Islands. Most remained within the study area, however, providing the first detailed movement data collected across seasons from wild manatees in the region. Warm season use areas for some individuals included seagrass beds off Cape Romano and the canals of Marco Island. Other manatees moved southeast into the northwest region of Everglades National Park, relying on inland creeks for fresh water. These data provide the first details on manatee use patterns in the TTI/ENP region.

Movement patterns for all individuals suggest a preference for foraging on seagrass beds in marine areas with brief trips to inland creeks and canals, which provide a source of fresh water. These inland trips, undertaken approximately four to eight times per month, reveal the reliance of these marine animals on accessible freshwater. Individual movements were linked to a network of travel corridors connecting seagrass beds and sources of freshwater, identified by manatee locations during GPS tag deployments. Movements were often rapid and direct. The deep canals at Port of the Islands provide access to freshwater at the spillway, as well as a passive thermal refuge for manatees during brief cold winter weather. Individual site fidelity for some manatees varied with season and calving events.

Feeding areas were documented within *Thalassia*, *Syringodium*, and *Halodule* seagrass beds along the outer islands. Spatial distribution of submerged aquatic vegetation, temporal fluctuations in freshwater areas, and bathymetry influenced movement and use patterns of manatees within the region. Salinity of inshore waters fluctuated with winter dry periods and summer rains. Abundance and species composition of submerged vegetation within inland bays may vary with these seasonal changes, thus influencing manatee feeding patterns. Additional studies are planned to assess manatee habitats including characterizing and mapping the distribution of submerged aquatic vegetation in areas used by tagged manatees for foraging.

Tracking data and field observations of tagged manatees revealed that the spatial distribution of submerged aquatic vegetation, availability of freshwater, and bathymetry influenced manatee movements and use patterns within the TTI and northern Everglades. Manatees routinely traveled from offshore seagrass beds to inland freshwater areas. We expect that altered water management regimes and resulting environmental changes may affect manatee habitat use and movement patterns within the region. These data are being integrated into the ATLSS model that will attempt to predict manatee responses to management actions.

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Inventory and Monitoring of the Amphibians and Reptiles of Biscayne National Park

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Declines in amphibian populations have been recognized worldwide over many regions and habitat types (Alford and Richards, 1999). No single cause for declines has been found, although acid precipitation, environmental contaminants, the introduction of exotic predators, disease agents, parasites, and the effects of ultraviolet radiation have been suggested. In fact, several factors may interact in such a manner as to threaten populations (Carey and Bryant 1995). A major factor in the loss of amphibian and reptile populations has been and continues to be the loss of habitat.

In response to concerns about the lack of basic knowledge of the amphibians and reptiles inhabiting Department of Interior (DOI) lands, inventory programs are being instituted nationwide. The Center for Water and Restoration Studies of the U.S. Geological Survey is conducting a reptile and amphibian inventory of Biscayne National Park (BISC) in cooperation with the Florida Cooperative Fish and Wildlife Research Unit. BISC is primarily an aquatic park with small islands and spans over 173,000 acres.

We have established 16 permanent inventory sites that are sampled on a monthly basis in BISC. During each sampling occasion, a 20m radius circular plot is searched using standard visual encounter survey (VES) techniques, and a 10-minute vocalization survey is conducted to detect calling anurans (frogs and toads). The locations of these sites were chosen randomly within habitat strata. Four of these sites (two in scrub habitat and two in mangrove habitat) are on the mainland portion of the park. Eight monthly sampled sites (three in scrub habitat, two in prairie habitat, and three in mangrove habitat) are on Elliott Key, the largest island in BISC. Two monthly sites (one in mangrove habitat and one in hammock) exist on both Sands Key and Boca Chita Key. In addition to the 16 monthly sites, we also have conducted surveys at six other random sites. These have all been in scrub and mangrove habitat sites on the mainland and on Elliott Key. Our goal is to continue to add random sites until all habitats on islands and the mainland have been surveyed.

Sampling for amphibians and reptiles in (BISC) began on May 2, 2002. As of November 30, 2002 a total of 22 sites have been surveyed during 76 sampling occasions. A total of 65 individuals of 12 species during VES surveys (table 1) and 7 species of anurans by vocalizations (table 2) have been observed.

Nine amphibian species have been detected in BISC, all anurans. Three of the nine amphibian species are introduced in south Florida: the greenhouse frog *(Eleutherodactylus planirostris)*, the Cuban treefrog (*Osteopilus septentrionalis*), and the marine toad *(Bufo marinus)*. These species have been detected on the islands and mainland of BISC. Five of the native amphibian species detected, the green treefrog (*Hyla cinerea*), the squirrel treefrog (*Hyla squirrella*), the leopard frog (*Rana sphenocephala*), the Florida cricket frog (*Acris* gryllus), and the pig frog (*Rana grylio*) have only been detected in mainland parts of the park. The narrowmouth toad (*Gastrophryne carolinensis*) is the only native frog detected on the islands to date.

Six species of reptiles, four lizards, and two snakes have been detected. Of the lizards, the brown anole (*Anolis sagrei*) and the tropical house gecko *(Hemidactylus mabouia)* are both introduced in south Florida. Tropical house geckoes are especially abundant on the buildings of Elliot Key. The green anole *(Anolis carolinensis)* and the Florida reef gecko *(Sphaerodactylus notatus)* are native to south Florida. The two snakes, the ringneck snake *(Diadophis punctatus)* and the Florida water snake (*Nerodia fasciata pictiventris*) are both native. Each of these has only been observed once.

Monthly sampling of the 16 permanent plots will continue through July 2003. In addition, random points throughout the park will be sampled. Each of these will be sampled at least twice during the study. We expect the number of species encountered to increase as this study continues, especially the number of reptiles.

Although the final inventory may include many species not encountered to date, the substantial constituency of exotic amphibian and reptiles inventoried in BISC during this study calls for some concern.

Table 1. Number of reptiles and amphibians counted during visual encounter surveys in Biscayne national Park during 2002

	Mainland	Elliott Key	Sands Key	Boca Chita Key
Hyla cinerea	3	0	0	0
*Osteopilus septentrionalis**	5	4	0	0
Rana sphenocephala	1	0	0	0
*Anolis sagrei**	2	25	2	5
Anolis carolinensis	0	0	1	0
Diadophis punctatus	1	0	0	0
*Bufo marinus**	0	0	0	0
*Eleutherodactylus planirostris**	0	9	2	1
Gastrophryne carolinensis	0	1	0	0
*Hemidactylus mabouia**	0	2	0	0
Nerodia fasciata pictiventris	0	1	0	0
Sphaerodactylus notatus	0	0	1	0

*These species have been introduced to BISC.

Table 2. Locations of anuran species detected during vocalization surveys in Biscayne National Park during 2002

	Mainland	Elliott Key	Sands Key	Boca Chita Key
Acris gryllus	X			
*Bufo marinus**	X		X	
*Eleutherodactylus planirostris**	X	X	X	X
Hyla cinerea	X			
Hyla squirrella	X			
*Osteopilus septentrionalis**	X	X		
Rana grylio	X			

*These species have been introduced to BISC.

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The Effects of the Cuban Treefrog (*Osteopilus septentrionalis*) on Native Treefrog Populations within Everglades National Park

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Native amphibian fauna throughout south Florida are currently threatened by the presence of an exotic competitor, the Cuban treefrog (*Osteopilus septentrionalis*) (fig. 1). First reported in the Florida Keys (Barbour, 1931), Cuban treefrogs expanded their range and were present in Everglades National Park as early as the 1950's (Meshaka, 2001). Cuban treefrogs compete with native treefrogs for breeding space and food sources.

Figure 1: Cuban Treefrog *(Osteopilus septentrionalis)* in Everglades National Park

In addition, Cuban treefrogs and their tadpoles are carnivorous and prey upon other frog species (Meshaka, 2001; Babbitt and Meshaka, 2000). Despite anecdotal evidence, no study has shown the extent to which Cuban treefrogs reduce populations of native hylids in natural areas. The goal of this study is to examine the direct effect Cuban treefrogs have on native treefrog populations within Everglades National Park. Native treefrogs studied included the Green (*Hyla cinerea*; Hci), and Squirrel (*Hyla squirella*; Hsq).

Population estimates for treefrogs were obtained through a mark-recapture study using PVC refugia. Five study plots were selected within Everglades National Park (2 mangrove and 3 pine rockland sites). Two of these sites are near disturbed areas, while all others are fairly remote. After initial population estimates were obtained, Cuban treefrogs were removed from sites to examine the recovery of native populations. Additionally, predation of hylids by Cuban treefrogs was quantified through stomach content analysis of removed animals.

To date, approximately 2,200 individual frogs have been included in this study. Preliminary results indicate Cuban treefrogs are more numerous in plots 501 and 101, which are located near disturbed areas, while remote sites contained larger populations of native species (fig. 2). Initial results indicate that native populations significantly increase as Cuban treefrogs are removed. The largest population increases occurred at sites where Cuban treefrogs were originally most dense (table 1). Preliminary analysis of stomach contents suggest that predation on hylid treefrogs is higher in mangrove than pine rockland sites.

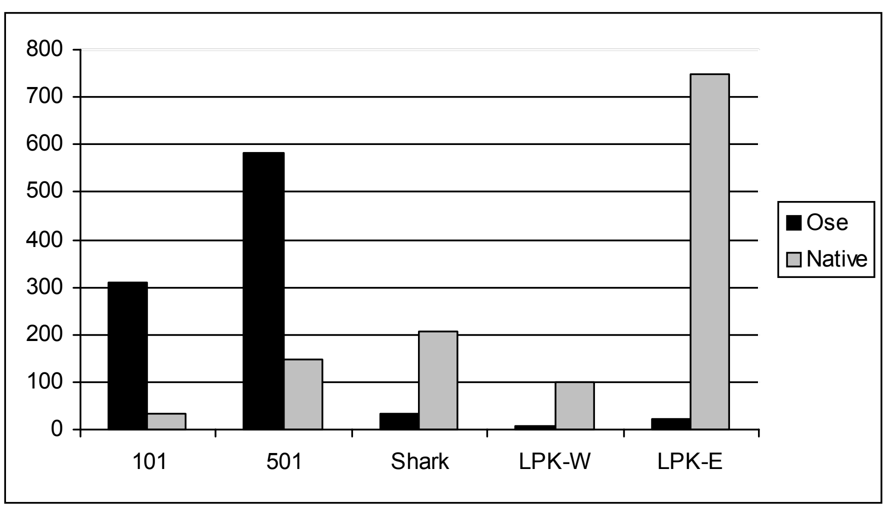

Figure 2. Total captures of Cuban (Ose) and native treefrogs in study plots within Everglades National Park from November 2000 to November 2002.

To adequately monitor the effects of Cuban treefrogs on native populations, this study will continue until Fall 2003. After completion, the results of this study may be used to identify factors that facilitate or obstruct dispersal of Cuban treefrogs into natural areas. In addition, this information will be incorporated into an ArcInfo model of the potential spread and impact of Cuban treefrogs on native species in protected areas. Data will be available to cooperating agencies and the public.

Table 1. Mean number of captures per visit of Cuban (Ose), Green (Hci) and Squirrel (Hsq) treefrogs before and after removal of Cuban treefrogs in sites 101 and 501 (* statistically significant)

Site and species	N (number visits) pre-removal	N (number visits) post-removal	Mean captures pre-removal	Mean captures post-removal
501-Ose	30	8	28.100 (± 5.497)	30.375 (± 5.928)
501-Hci *	30	8	1.533 (±0.328)*	19.500 (± 6.743)*
501-Hsq *	30	8	0.267 (± 0.117)*	1.500 (±0.886)*
101-Ose	29	7	15.414 (±3.260)	13.714 (±2.476)
101-Hci	29	7	1.517 (±0.411)	0.143 (±0.143)
101-Hsq *	29	7	0.379 (±0.104)*	3.571 (±1.343)*

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Impacts of Off-Road Vehicle Use on Wildlife in the Prairie Ecosystem of Big Cypress National Preserve

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The use of off-road vehicles (ORVs) has been a popular recreational activity in Big Cypress National Preserve (BCNP) for many years, and recently more than 2000 individuals per year have received ORV permits (National Park Service 2000). The repeated rutting of marl prairies due to ORV use has caused extensive damage to many areas within the preserve. A management plan has been implemented to mitigate this damage (National Park Service, 2000).

Although the degree of ORV use is well documented in the marl prairies of BCNP, the impact of ORVs on wildlife species is not well known. However, human recreation may result in alterations in behavior and reduce survival (Swarthout and Steid, 2001) or fitness (Parent and Weatherhead, 2000) of wildlife populations.

ORVs in the prairie habitats of BCNP may also have indirect effects on wildlife species. ORV use can impact the vegetation, hydrology, water quality, and soil structure of prairies (National Park Service, 2000). Duever et al. (1981) documented changes in plant species composition and abundance in prairies with high ORV use. The extent to which these environmental changes affect wildlife populations in the prairies of BCNP is poorly understood.

Amphibians and small mammals may be affected directly and indirectly by ORV use in prairies. Further, these animals are particularly suited for this study on the impacts of ORV use on wildlife because they are likely to spend their entire lives completely within or near the same homogenous prairie habitat. Also, they are easily sampled with traps and should occur in great enough abundance to allow the estimation of a variety of population parameters like abundance and survival using mark-recapture analysis.

We will investigate the effects of ORVs on amphibians and small mammals by using mark-recapture techniques to estimate population parameters at sites with varying degrees of ORV use. The two most important population parameters used in this study will be survival and abundance. Our efforts will focus on two groups of species: treefrogs that will be captured in PVC pipe refugia and rodents that will be captured with Sherman live traps.

Grids of 3.5cm PVC pipes will be erected in prairie habitat in BCNP. These pipes are very effective at capturing treefrogs (Boughton et al. 2000). Approximately 50 pipes will be used per site at as many as nine locations. These locations will be classified as having light, moderate, or heavy ORV use. Three replicate sites will be used for each category of ORV use.

PVC pipes will be examined for treefrogs once every two weeks. Captured animals will be carefully removed from the pipe to avoid harm. They will also be identified to species, age, and sex whenever possible, measured snout-to-vent (SVL) and massed using a Pesola™ hanging scale. Frogs will be marked using a commonly accepted toe-clipping scheme (Donnelly et al. 1994). Toes will be removed quickly with a pair of sharp scissors. No more than two toes per limb will be removed, and the first toe on any limb will not be removed. Scissors and other equipment will be cleaned with alcohol to avoid disease transmission. All methods used have been approved by the American Society of Ichthyologists and Herpetologists and the Society for the Study of Amphibians and Reptiles (http://www.asih.org/pubs/herpcoll.html). Each frog will be released as soon as possible after capture to minimize stress on the animal.

Mammals will be trapped and handled in a similar manner. Grids of Sherman live traps will be baited with rolled oats to capture rodent species. The grid design will allow us to calculate a density of the animals (Jones et al. 1996). Trapping will be conducted one week each month at each site. Each captured rodent will be identified to species, sex, and approximate age. The body length, tail length, and the mass of each captured animal will also be noted. Finally, each captured rodent will be uniquely marked with an individually numbered ear tag.

In addition to providing important information about ORV impacts on key wildlife species of the prairie habitat, these data will be used with hydrologic data to determine how hydrology affects these species. Specifically, changes in abundance and survival across seasonal hydrological gradients will be observed on sites stratified by ORV use. The presence, abundance, and behavior of the amphibian and small mammal species changes with the transition from dry season to wet season in this habitat will also be examined. Collectively, this information will be valuable for evaluating hydrologic and human-use impacts during Everglades restoration.

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Using Proportion of Area Occupied to Estimate Abundance of Amphibians in Everglades National Park and Big Cypress National Preserve

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Declines in amphibian populations have been documented for many regions and habitat types worldwide (Alford and Richards, 1999). No single cause for declines has been determined, and it seems likely that several factors interact to threaten populations (Carey and Bryant, 1995). In response to concerns about amphibian population declines, the Department of Interior (DOI) received funding from Congress to institute long-term surveys of the status and trends of amphibians on DOI lands. The U.S. Geological Survey has been conducting inventories of amphibian species in Everglades National Park (ENP) and Big Cypress National Preserve (BCNP) from 2000 to present.

Together ENP and BCNP comprise a contiguous protected area of more than 890,000 ha. This landscape, unique in the United States, contains a diverse array of different wetland and upland habitats. The amphibian fauna of the Everglades and Big Cypress region comprises 15 native species, all derived from temperate zone fauna, and three non-indigenous species from the tropics. Although historical and recent survey and inventory work on amphibians has been done on DOI lands in south Florida (Duellman and Schwartz, 1958, Meshaka et al., 2000), there is a need for a current inventory and estimate of the abundances of the amphibians of ENP and BCNP. This project uses data on detection of amphibian species after repeated sampling at a site to estimate the occupancy rate of various amphibian species (MacKenzie et al., 2002).

Sampling locations were chosen randomly throughout ENP and BCNP using a Geographic Information System (GIS), and all sampling was stratified by major habitat type. We divided the parks into six natural habitats: pineland, rocky glades, tropical hardwood hammock, mangrove forest, cypress dome, and freshwater slough. These habitat designations were based loosely on the vegetation classification scheme of Madden et al. (1999), and their map was used as the basis for site selection. We selected points at random within each of the major habitat types. Six of these sites in each habitat type at each park were used as monthly sampling locations. These were visited once within each calendar month for one year. Other random locations were sampled at least twice during times when they were accessible. A total of 118 sites in ENP and more than 75 sites in BCNP were sampled.

The primary method of sampling was a standard visual encounter survey (VES) technique combined with a 10-minute auditory survey for calling anurans (Heyer et al., 1994). Each sampling event lasted 30 minutes and all were conducted after dark. Each area searched was a 20-m radius circle (1,256 m^2 area) around the randomly chosen point. Each individual found was identified to species, sex, age, and snout-to-vent length. We measured the air temperature and relative humidity using a digital thermohygrometer. Cloud cover, wind speed, whether the plot was inundated with water, and water temperature (if applicable) were also noted.

Data were organized into capture history matrices where detection of species was denoted by a "1" for a given site and month. Non-detection of a species was denoted with a "0", and a "-" was used in cases where a site was not visited during a particular month. These data were analyzed using the program PRESENCE to calculate a proportion of sites occupied (PAO) by each species within each habitat (MacKenzie et al., 2002).

We observed 1,788 individual amphibians in ENP and more than 2000 in BCNP during VES surveys. Not all of the anurans were observed a sufficient number of times to allow calculation of proportion of sites occupied in ENP. Data collection and analysis for BCNP is still underway. For some of the more abundant anurans it was possible to estimate the site occupancy by habitat (table 1).

The results obtained for site occupancy may serve as a baseline for long term monitoring of amphibians in the national parks of south Florida. Estimating the total abundance of any of these species is practically impossible due to the large area involved and complicating variables like weather and phenology of amphibian behavior. However, by estimating the site occupancy rate of each species at randomly chosen sites within each habitat, it is possible to produce an estimate of the proportion of that habitat in which a species occurs. This number does not indicate the abundance of individuals, but it does permit estimates of the abundance of populations. This can serve as the basis for tracking changes in population abundance over time.

The sampling protocol developed here for these parks is considered appropriate for future monitoring of amphibians in the Everglades ecosystem. The methods are relatively inexpensive, and replication should be straightforward. Tracking changes in site occupancy over time will help identify trends in amphibian populations and serve as an early warning if any amphibian populations are truly declining in south Florida. Plans for future work include using PAO with hydrologic models of the Everglades ecosystem to predict how populations of species might react to hydrologic change. With estimates of the proportion of sites occupied by each species in amphibian assemblages in areas with different hydrology, it will be possible to predict how the assemblage will change during restoration. This will assist managers in assessment of proposed hydrological changes and restoration success.

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Table 1: Proportion of sites occupied by amphibian species by habitat in ENP.

Habitat	Acris gryllus	Bufo quercicus	Bufo terrestris	Gastrophryne carolinensis	Hyla cinerea	Hyla squirrella	Rana grylio	Rana sphenocephala
Pineland	0.63	1.00	1.00	0.64	0.95	0.94	0.33	0.38
Rocky Glades	0.84	0.60	0.21	0.46	0.99	0.61	0.90	1.00
Hammock	0.85	0.00	0.49	0.67	0.96	0.39	0.91	0.76
Cypress	0.84	0.00	0.00	0.66	0.90	0.97	0.78	0.68
Mangrove	0.00	0.00	0.47	0.40	0.49	0.53	0.27	0.35
Slough	1.00	0.00	0.39	0.28	1.00	0.24	1.00	0.76

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Evaluating the Effect of Salinity on a Simulated American Crocodile *(Crocodylus acutus)* Population

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Everglades restoration will alter the hydrology of the endangered American crocodile's *(Crocodylus acutus)* estuarine habitat of south Florida, affecting both water depth and salinity levels. Juvenile American crocodiles are thought to be sensitive to high salinity levels, suffering reduced mass, and potentially reduced survivorship and recruitment, thereby negatively impacting the population recovery. To answer the question of how the crocodile population will respond to alterations in hydrology we developed a spatially explicit individual based model designed to relate water levels, salinities, and dominant vegetation to crocodile distribution, abundance, population growth, individual growth, survival, nesting effort, and nesting success. The nature of the relation between salinity and growth was based on physiological measures in the lab that include only individuals smaller than 450 grams. The core of this model assumes that this relationship applies to the field, and to some extent, to individuals of all sizes (fig.1). Four different combinations of base parameterizations and initial population size were examined with sensitivity analyses and a factorial manipulation of model salinities, to evaluate the effects of each on population size, nest number, and survivorship of young of the year (YOY) crocodiles.

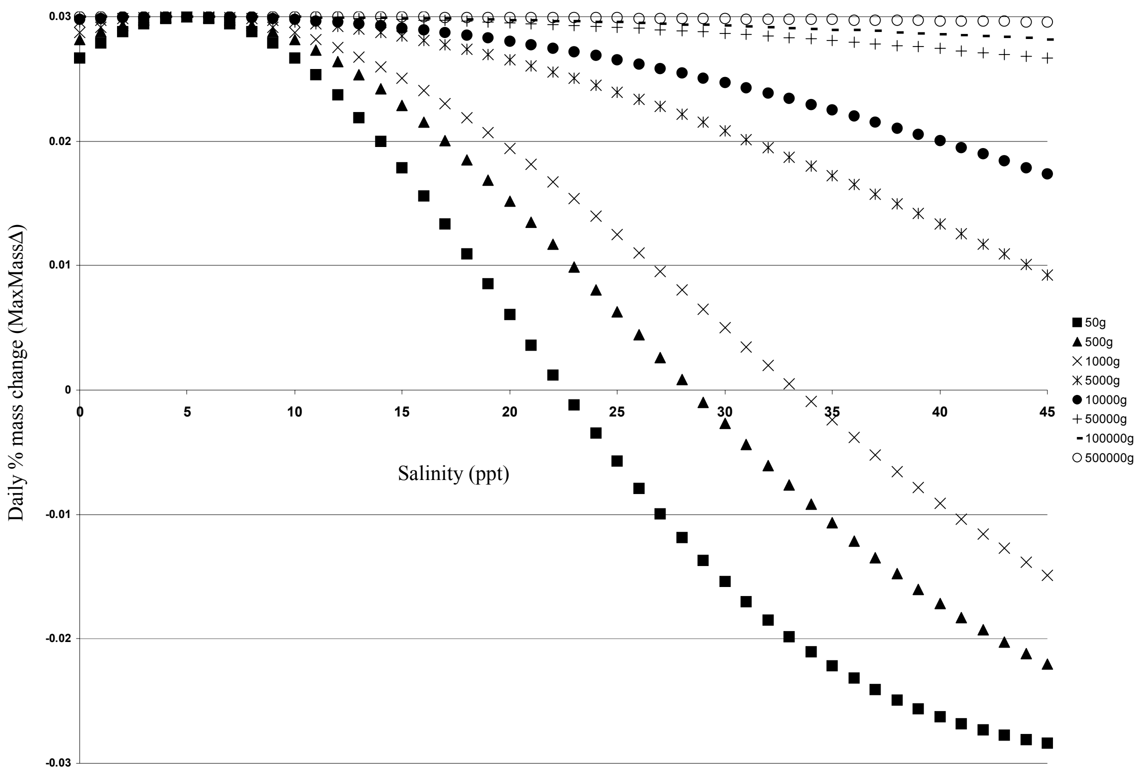

Figure 1. Daily percent change in mass (MaxMass) as a function of salinity for model *C. acutus* from 50g to 500kg.

Two types of sensitivity analysis were used, individual parameter perturbation (IPP) and uncertainty analysis. IPP examines the effect of small changes in individual parameter values on model output while holding all other parameters constant and uncertainty analysis examines the effect of random combinations of parameter values on model output. For IPP analysis we individually altered each nominal parameter by +/- 1 percent for continuous values and +/- 1 unit for integer values while holding all other parameters constant. For uncertainly analysis we employed the modified Latin hypercube parameter sampling method with 100 Monte Carlo simulations. Each continuous parameter was cut into 100 equidistant values within its range and each integer parameter was cut into 100 integer pieces within its range. From these sets we randomly selected parameters without replacement to construct the 100 parameter sets.

The rank ordering from the IPP analysis failed to give consistent rankings between populations. Because of this lack of consistency, for any output variable it is difficult to use these results to select a set of parameters that the model may be particularly sensitive to, independent of the population initial conditions or parameterization. In contrast, the uncertainty analysis consistently ranked parameters between populations, and therefore, it can inform us about parameters to concentrate on for further research and management.

Based on this result we conclude that to better understand *C. acutus* population dynamics, we suggest that research focus on survivorship and growth rate parameters, because these were ranked high by uncertainty analysis. The parameter with the largest effect on model output was survival of large individuals, which is not unusual for long-lived organisms. It may be difficult to measure survivorship for large individuals, but since it is consistently highly ranked as a parameter to which population size is sensitive, greater effort should be made to collect this sort of data.

To examine the model under possible management alternatives, we varied the application of salinity to the model in a fully crossed three way ANOVA. The model can alter timing of peak salinity, duration of salinity levels, and the spatial distribution of salinity ranges. Each of these factors were manipulated at three levels. Timing of the salinity peak was altered by one month (30 days), earlier and later than the base model value of day 144 (May 24). Salinity duration was compared at three levels, short, medium (base), and long. Regional salinity range values were also compared, raising these 5 ppt, and 10 ppt above base model runs.

Increasing regional salinity significantly reduced population size, nest number, and YOY survivorship in all base parameterizations. This effect was probably because at highest regional salinity treatment, even the lowest salinity habitats were at salinities for part of the year where small crocodiles would lose mass regardless of other conditions. Delaying the peak salinity level by one month, which placed it at the beginning of hatching season, significantly reduced the number of nests for only one parameterization. No other parameterizations were significantly affected by alterations in timing of peak salinity. Duration of salinity spread had no significant effect.

This model shows that research should focus on estimates of annual survivorship for large individuals. Similarly, conservation priority should be placed on reducing anthropogenic sources of mortality on large individuals, such as road mortality. Everglades restoration, through its effects on water flow to estuaries may benefit crocodile populations if increased freshwater flow reduces the chances that regional salinity levels exceed levels where small individuals lose mass.

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Fish and Shrimp in Relation to Seagrass Habitat Change in Johnson Key Basin, Western Florida Bay (1985—1995)

By Michael B. Robblee, *and* André Daniels

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In the fall of 1987, a widespread, rapid die-off of the dominant seagrass, *Thalassia testudinum*, began in dense seagrass habitats in western Florida Bay. Increasingly extensive and persistent turbidity and algal blooms, apparently linked to the loss of turtle grass, were associated with active seagrass die-off sites initially and have characterized western and central Florida Bay generally since 1991. In Johnson Key Basin denuded bottom was rapidly colonized by shoal grass, *Halodule wrightii*, following the loss of turtle grass. *Syringodium filiforme*, manatee grass had disappeared from the basin by 1995 possibly in response to reduced light availability.

In 1985, prior to seagrass die-off, thirty sampling stations had been established in Johnson Key Basin. Stations had been located generally with no *a priori* consideration of the seagrass habitat present and were evenly stratified among the principal seagrass macro-habitat types present in Florida Bay: bank, basin, and near key. These thirty stations were sampled on an approximately five-year interval (January 1985, May 1985; May 1989, January 1990; January 1995, and May 1995) providing the opportunity to observe fish and invertebrate community responses in numbers and species composition to change in seagrass habitat within the basin over the decade, 1985-1995. Quantitative animal samples of seagrass associated fish and invertebrates, including the pink shrimp, were collected using a 1m^2 throw-trap. The throw-trap operated over the full range of water depths occurring in Johnson Key Basin with a sampling efficiency estimated to exceed 95 percent for seagrass associated fish and invertebrates. Each animal sample was coupled with measurements estimating seagrass canopy structure and local environmental conditions: standing crops of seagrass and associated macroalgae, seagrass blade densities by species, sediment texture and organic content, water and sediment depth, compaction, salinity and temperature.

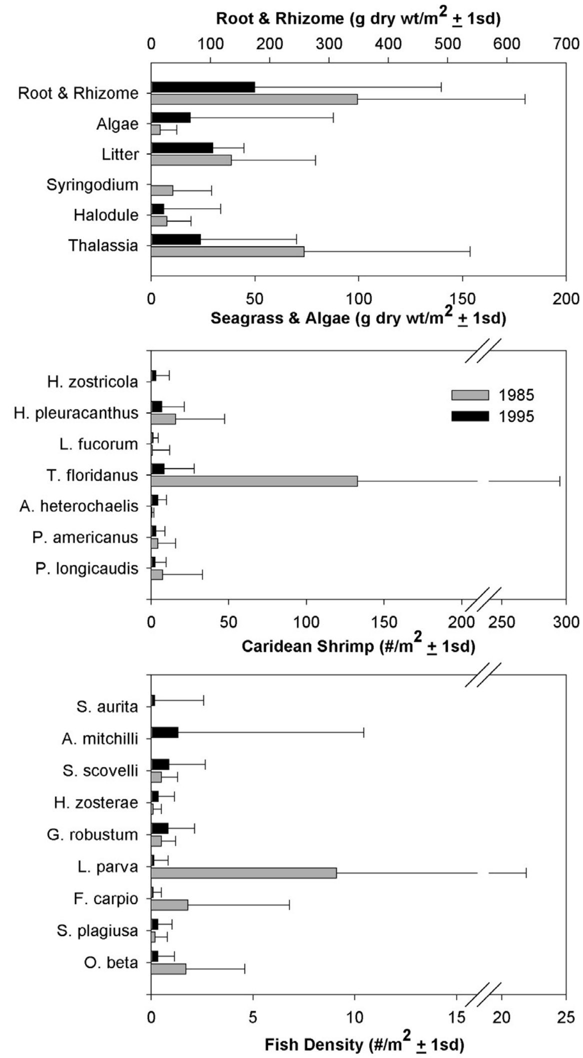

Figure 1. Comparison of habitat changes and associated caridean shrimp, and fish communities in Johnson Key Basin over the decade 1985 to 1995.

Unlike some areas in western Florida Bay, seagrass die-off in Johnson Key Basin was patchy with severe to no visible impacts among the thirty stations. Seagrass habitat change was most extensive between 1990 and 1995 when algal blooms were always present in the basin. The cumulative affect of seagrass loss and recovery and reduced water clarity between 1985 and 1995 was a shift away from a turtle grass dominated seagrass meadow to one exhibiting greater habitat heterogeneity. Over the decade the standing crop of *Thalassia* declined by 71 percent in Johnson Key Basin (fig. 1). Standing crop of *Halodule* increased by 24 percent.

Over the decade, the standing crop of *Thalassia* declined by 71 percent in Johnson Key Basin (fig. 1). Standing crop of *Halodule* increased by 24 percent in the basin. *Syringodium* had disappeared from the thirty stations sampled though it was reported as present in the basin. *Thalassia*, the dominant seagrass in 1985 at 17 stations in Johnson Key Basin was the dominant at only 9 in 1995. *Halodule,* present at 13 stations in 1985, was found at 18 by 1995. By 1995 bare sediment, not present as an appreciable habitat type in 1985, characterized the bottom in Johnson Key Basin at 4 of the thirty stations.

Faunal changes were observed accompanying these habitat changes. Comparing 1985 to 1995 the abundance (January and May averaged) of seagrass associated caridean shrimps had declined by about 65 percent while seagrass fishes had declined by 81 percent (fig.1). Densities of pink shrimp, *Farfantepenaeus duorarum*, in 1995 were half that observed in 1985, (1.9/m^2 vs 4.0/m^2, respectively). Salinity and water temperature conditions, during sampling in 1985 and 1995, did not differ appreciably (31.5‰ vs 28.4‰; 25 ^{o}C vs 24.9 ^{o}C, respectively).

The fish and shrimp communities changed dramatically over the decade in Johnson Key Basin. In 1985, the killifish, *Lucania parva* and the caridean shrimp, *Thor floridanus* dominated numerically (62 and 81 percent of individuals, January and May averaged, respectively). By 1995 these populations had declined to 3 percent and 27 percent of fish and caridean shrimp collected, respectively. Six fishes, *Anchoa mitchilli*, *Sardinella aurita*, *Achirus lineatus, Gobiosoma robustum*, and *Hippocampus zosterae.* were numerically more abundant in 1995 and accounted for 65 percent of fish collected. Five caridean shrimps, *Periclimenes americanus*, *Alpheus heterochaelis*, *Thor floridanus*, *Hippolyte plueracanthus*, and *Hippolyte zostericola*, accounted for 81 percent of the caridean shrimps collected in 1995.

A preliminary factor analysis (non-rotated PCA) was used to reduce 9 habitat variables to 4 interpretable components. PC1 accounting for 25.3 percent of the variability among the original habitat variables was interpreted as a *Thalassia* gradient. *Halodule* is negatively correlated with *Thalassia* on PC1. PC2 (16 percent) was interpreted as a shallow water *Halodule* gradient. PC3 (12.4 percent) was interpreted as a *Syringodium* gradient. PC4 (10.4 percent) was interpreted as a macro algal gradient. Interpretation of PC's 1-3 indicate *Thalassia* and *Syringodium* decline in abundance with time while *Halodule* increases over time.

Individual species and species groups relate to habitat differently in Johnson Key Basin. The pink shrimp, an abundant penaeid shrimp, is significantly correlated to PC2 and 3 indicating an affinity for shallow water shoal grass and manatee grass habitats. The killifish, *Lucania parva*, was significantly correlated to PC1 and 2. In Johnson Key basin this fish is associated with seagrass generally and is most abundant, as is the pink shrimp, in shallow water shoal grass habitats. The dominant caridean shrimp, *Thor floridanus*, is a ubiquitous species in the Johnson Key Basin grass beds, abundant in 1985 and scarce in 1995. It was positively associated with each of the 4 principal components.

More detailed analyses focusing on defining seagrass canopy and seagrass habitat change with time, the relation of pink shrimp size to seagrass habitat and individual species relation with seagrass habitat will be presented.

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The ATLSS American Alligator Population Model: Results from Restoration Alternatives

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The American alligator (*Alligator mississippiensis*) is a top consumer in south Florida that also physically influences the Everglades landscape through construction and maintenance of alligator holes and trails (Mazzotti and Brandt 1994). The existence of this species is important to the faunal and floral character of the Everglades as it has evolved. The U.S. Geological Survey (USGS) and its cooperators are using empirical data collection and model simulations to apply information on wildlife community patterns to the Everglades restoration process. The ATLSS (Across Trophic Levels System Simulation) project is a large-scale spatially explicit system of interacting landscape models of hydrologic processes, and plant and animal responses. ATLSS is designed to evaluate the effects of alternative water management plans on plant and animal abundance across the Greater Everglades Ecosystem. ATLSS requires an alligator population model to simulate the south Florida ecosystem under varying management strategies. The current project provides estimates of population parameters and modeling frameworks for an ATLSS American alligator population model (APM).

Current water management practices have resulted in a high and unpredictable rate of nest flooding. The natural predictability of the system has been lost (Kushlan and Jacobsen, 1990). Historically, alligators were abundant in prairie habitats of the eastern floodplain. Pre-drainage occupancy of deep- water central sloughs was relatively low. Marsh alligator densities are now highest in the central sloughs and canals (Kushlan and Jacobsen, 1990) and relatively low in the edge habitats. Modified hydrologic conditions might be expected to increase nesting effort, nesting success, and abundance of alligators in the aforementioned edge habitats. There may also be a corresponding increase in the number and occupancy of alligator holes that serve as drought refugia.

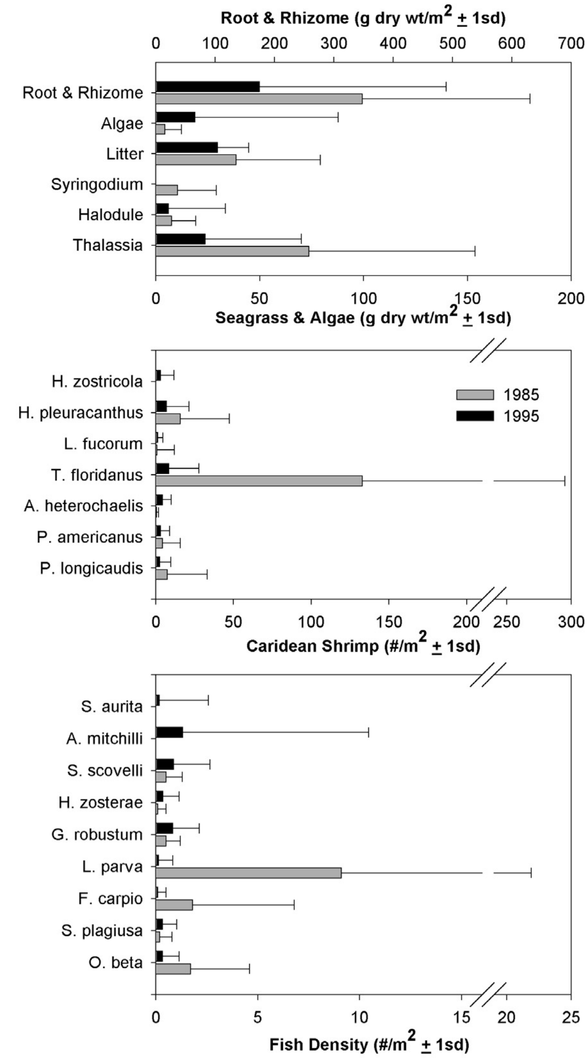

Figure 1. Comparison of habitat changes and associated caridean shrimp, and fish communities in Johnson Key Basin over the decade 1985 to 1995.

The Everglades is believed to be a harsh environment for alligators. Everglades alligators weigh less than alligators of the same length from other parts of their range (Jacobson and Kushlan 1989, Barr, 1997). In addition, maximum length is decreased, and sexual maturity is delayed (Kushlan and Jacobsen, 1990, Dalrymple, 1996). Jacobsen and Kushlan (1989) model for growth in the Everglades of south Florida suggests alligators reach a mere 1.26 meters in 10 years and require at least 18 years to reach sexual maturity. It is currently suspected that the reason for this reduced condition is a combination of low food availability and high temperatures (Jacobson and Kushlan, 1989, Dalrymple, 1996; Barr, 1997). Through the development of the APM, restoration alternatives will be evaluated and restoration performance measures will be assessed. By applying the APM to proposed restoration alternatives and predicting population responses, alternatives can be chosen that result in biotic characteristics that approximate historical conditions, and future research needs can be identified.

The APM uses water data from historical measurements, and alternatively simulated water data from the various restoration alternatives. Daily water levels were modeled by the South Florida Water Management District. The APM also obtains input from the ATLSS American alligator production index (API). Finally, the API model uses the water data in combination with the underlying topography and vegetation distribution to predict the probability that (1) a female alligator in a model cell will breed and construct a nest that year, (2) that the nest will not flood, and (3) that the habitat is favorable for nesting.

The core model component is a 3-D matrix that records the density of each stage of alligator in each 500x500m spatial location. The density matrix interacts with survival and condition matrices calculated for each time step based on water level, crowding, etc. To disperse alligators, a discrete spatial convolution method is used. The effect is similar to a "blur filter" used by many image-processing computer programs, and is a process that takes the contents of a cell and redistributes it according to a mathematical dispersal kernel. Dispersal kernels are sized according to the average dispersal distance of each alligator stage determined by field studies.

Output of the model is a 3-D alligator density matrix, with space along two axes (x and y), and the stage classes along the third axis (z). Also included in the matrix is a "running average" of the historical health and survival rates of each stage in each cell. This construct can easily be summed to obtain the total alligator population, or subsampled to verify agreement with field data. Instantaneous densities and local rates-of-change can be calculated from this model.

Using the historical calibration water dataset, which simulates actual hydropatterns from 1979-1995, the model output was compared to historical counts of alligators conducted along various airboat trails at night with a spotlight. Preliminary model results of overall alligator abundance along the airboat trails are within the maximum and minimum estimates derived from the surveys. Preliminary comparisons of base conditions (1995 and 2050) to alternatives (ALT D13R) suggest that conditions would improve, and populations of alligators would be reestablished in short hydroperiod wetlands such as the Rocky Glades in Everglades National Park (ENP). Habitats such as Shark River Slough in ENP that are projected to have increased water depths under proposed restoration alternatives are expected to maintain populations or experience slight declines. The results of these simulations agree with observations of crocodilian biologists working in the Everglades. Full model simulations and comparisons of base versus alternative scenarios are available for comment.

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Mangrove Die-Off in Florida Bay: A Recurring Natural Event?

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The phenomenon of "mangrove die-off" has been reported from Florida Bay periodically for decades. Botanical explorations of the Everglades, Florida Bay and the keys from the late 1800s and early 1900s by Small and others, reported salt barrens with standing dead stems on islands in the bay and along the northern mainland shoreline. Following the seagrass die-off in the bay in the 1980s, fishermen and scientists, reported a noticeable thinning of the mangroves on several bay islands and new interest was generated in mangrove die-off. Most recently Florida Bay-Watch reported renewed die-off in early 2001.

In the mid 1990s permanent vegetation plots were established at 11 sites (both island and mainland) in Florida Bay: Crocodile Point, Munroe Lake, North Dump Key, Roscoe Key, Samphire Key, Clive Key, Little Rabbit Key, Low Key, East Key, Little Butternut Key and Duck Key. At each site, two transects were established to overlay on a pre-existing network of sediment porewater sampling wells. Transects had been aligned to run from the shoreline into the interior salt barren at each location. The porewater well served as the center of the plot. All stems >1.4m in height and ≤3m from the center, were identified, measured for diameter at breast height (dbh), and mapped, using distance and bearing from the center. Stem density and basal area were calculated. Herbaceous vegetation and mangrove seedlings were sampled using three randomly placed 1m^2 quadrats within each plot. All species within the quadrat were recorded and the number of "hits" for each species on a 10x10 grid counted. This yielded a percent cover for each species. A subset of plots was resampled during the summers of 1999 and 2000. Change in a stem's dbh was used to calculate growth between the two samplings. Historical aerial photographs dating from 1927 were examined for each study location and the vegetation / cover was visually interpreted.

At almost all sites mangrove stem density decreased exponentially away from the shoreline. *Rhizophora* was most abundant towards the shore, with *Avicennia* dominant away from the shore. *Laguncularia* was seldom encountered. The number of living mangrove stems increased from the first to the second sampling. However, at many sites growth of individual mangrove stems is minimal. An exception was on Clive Key where significant growth occurred in all plots, particularly for *Rhizophora* (fig. 1). A pulse of recruitment (new mangroves reaching 1.4m in height) was also measured at this location.

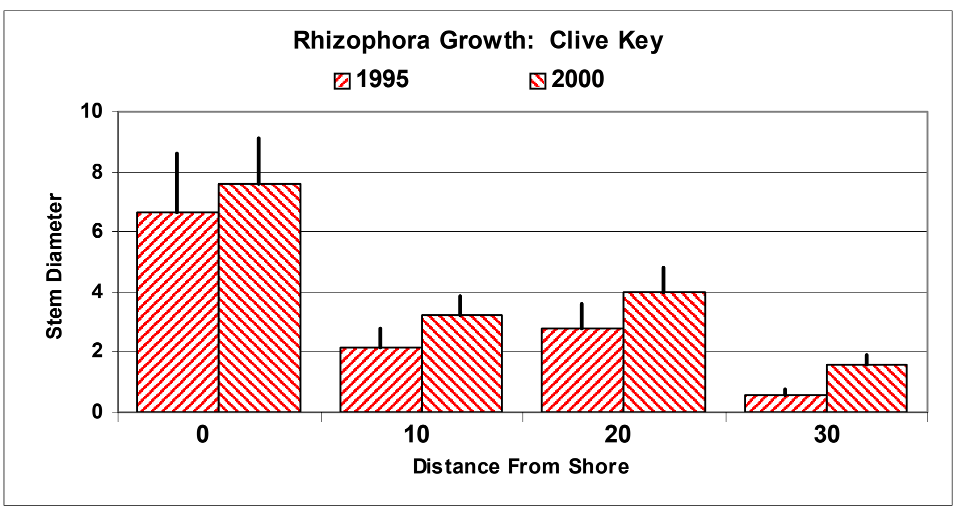

Figure 1. Increase in average stem diameter for *Rhizophora mangle* at Clive Key from 1995 to 2000.

Total cover of herbaceous vegetation changed dramatically over the short time period studied, with both increases and decreases observed. During the initial sampling in 1995, the interior portions of several sites were nearly devoid of vegetation, especially at Crocodile Point and North Dump Key. The tops of the porewater wells, which protruded above the sediment level, were easily seen. In 2000, these areas were covered with vegetation and the porewater wells obscured (to the point they were very difficult to find, fig. 2). Increase in herbaceous cover was due primarily to abundant growth by the succulents *Batis maritima*, *Salicornia virginica,* and *S. bigelovii* at the interior end of the transects. Herbaceous cover decreased shoreward at most locations, possibly due to increased growth of the mangrove canopy causing lower light at the forest floor.

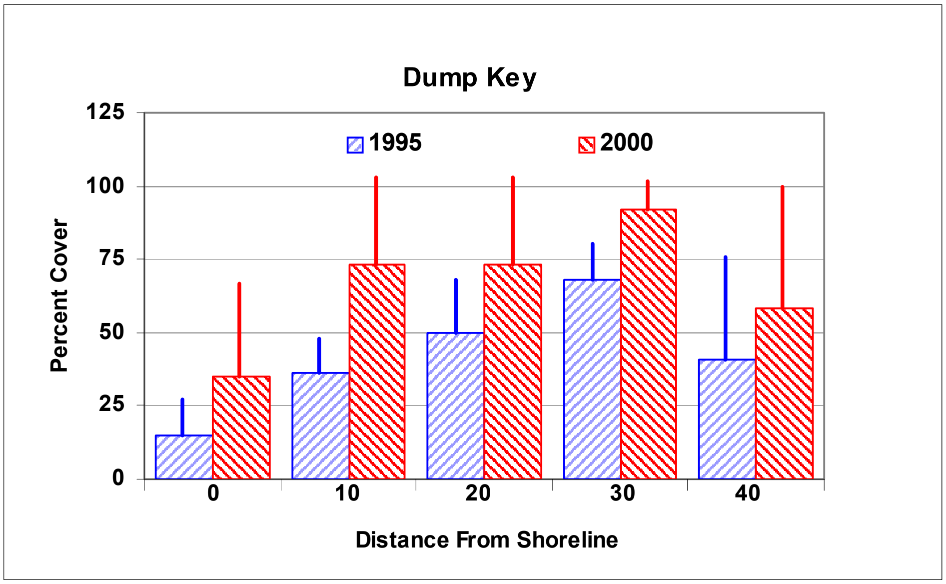

Figure 2. Increase in herbaceous vegetation cover at Dump Key from 1995 to 2000.

Interpretation of the aerial photographs revealed the presence of interior barren areas on numerous islands in Florida Bay in 1927, and their persistence through time. This record, combined with our short-term observations, highlight the dynamic nature of these coastal habitats and their ability to respond rapidly to short-term environmental change.

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A Decade of Mangrove Forest Change Following Hurricane Andrew

By Thomas J. Smith III[1], Kevin R.T. Whelan[2], Gordon H. Anderson[2], Christa L. Walker[3], Jeffrey S. Dismukes[4], *and* Thomas W. Doyle[5]

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Hurricane Andrew crossed the southern Florida Peninsula on the morning of August 24, 1992. Following the storm, the National Park Service conducted an Environmental Damage Assessment to gauge its impacts on the natural resources of south Florida Park Service holdings. Although hurricanes had impacted Park's lands, such as the Everglades, in the past, no systematic, permanent sampling scheme had ever been established to monitor long-term recovery (or lack of recovery) following catastrophic disturbance.

In October 1992, six large plots were established in the heavily damaged areas of mangrove forest on the southwest coast of the Everglades, along the Lostmans and Broad Rivers. The plot network was expanded during the next 24 months and now encompasses more than 20 permanent plots. Each plot is circular. For each stem >1.4 m in height, the distance and bearing from the stem to a permanent center stake was measured. The stem was identified to species and its diameter at breast height measured. The condition of each stem was recorded (alive or killed by Andrew). Each living stem was marked with an aluminum tree tag for future identification. Since establishment, each plot has been sampled from 6-9 times. During a resampling, all tagged stems were located and their dbh and condition recorded. Recruits (previously untagged stems now having grown to 1.4m in height) were identified, measured and mapped. Changes in condition of all stems were noted (e.g. mortality from various causes). Increases or decreases in biomass were calculated for individual stems based on allometric equations relating biomass to dbh. Total biomass was determined by summing individual changes and changes due to addition of recruits and losses from mortality. Coincident with the establishment of the permanent vegetation plot network, researchers from the USGS were constructing a network of hydrological monitoring stations in the southwest coastal Everglades. Each hydrology monitoring station has one or more vegetation plots nearby (but not all vegetation plots have an adjacent hydrology station).

The trajectory of vegetation change, growth, mortality and recruitment has been highly variable among plots. Indeed, most plots have followed unique patterns. The only overall pattern was the increase in stem density observed in all plots. The species that dominated recruitment varied, sometimes being *Rhizophora*, often *Laguncularia*, but never *Avicennia*. The rate of stem density increase varied among plots. After 10 years, Second Onion Bay had >1,900 stems, whereas Johnson Mound Creek had 325, about an order of magnitude difference. Individuals are continuing to recruit into the population at all plots except at Lostmans Ranger Station and Broad River Mid. The 10th year survey at both of these showed slight declines in stem density (figs. 1 and 2).

Mortality is occurring at all sites. Sources of stem death have included: continuing mortality from damage initially induced by Hurricane Andrew; and stems being killed by falling debris, lightning, wind-throw during winter cold fronts, freeze, fire and several smaller hurricanes since Andrew such as George, Harvey, Irene and Mitch. Stems in the smaller size classes are beginning to perish due to suppression (that is, being overtopped and heavily shaded by larger neighbors).

Growth by stems that survived Andrew or which have since recruited into the plots is difficult to explain. Productivity cannot be explained simply by sediment porewater nutrient concentrations, which are highly variable. Salinity and hydrologic parameters seem most promising to explain patterns of biomass increase following the catastrophic disturbance from Hurricane Andrew. Sampling of these plots will continue in order to monitor the effect of increasing freshwater inflow that will occur as a major component of the Everglades restoration.

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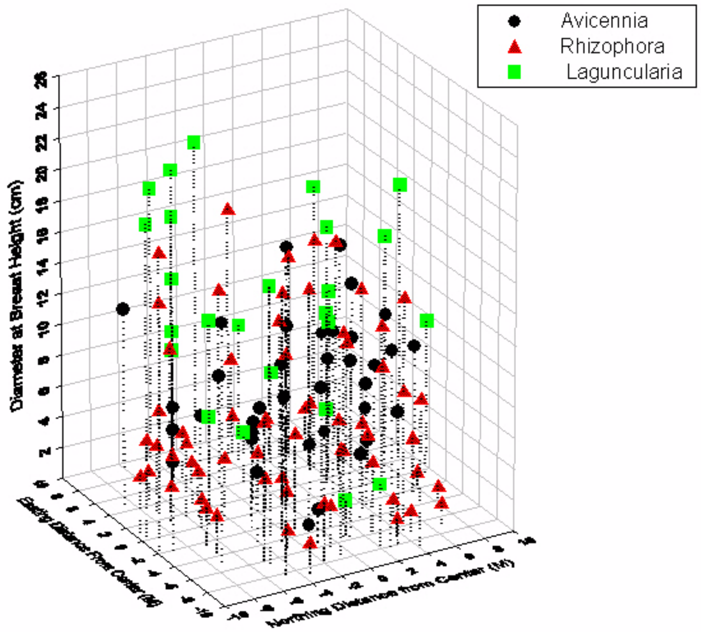
ENP LRS Mangrove Plot

Pre-Hurricane Andrew

n = 127

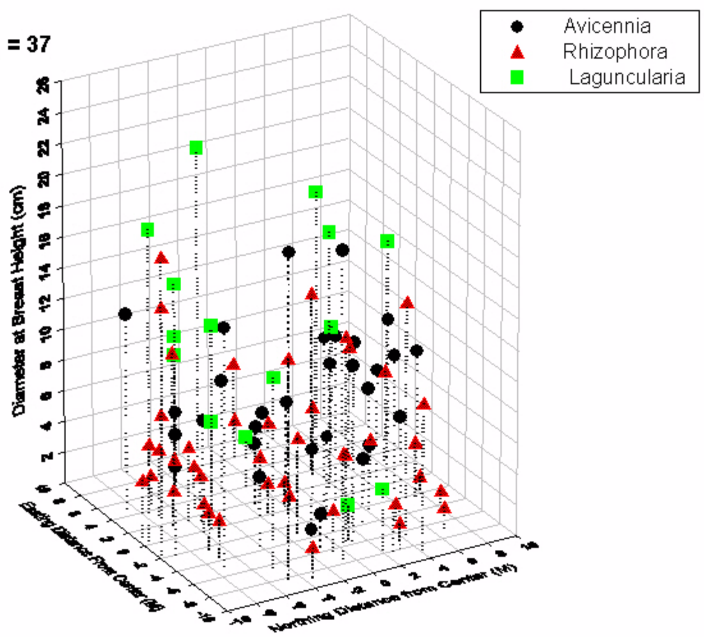


Allometric Estimation of Total Biomass: 5391.13 kg

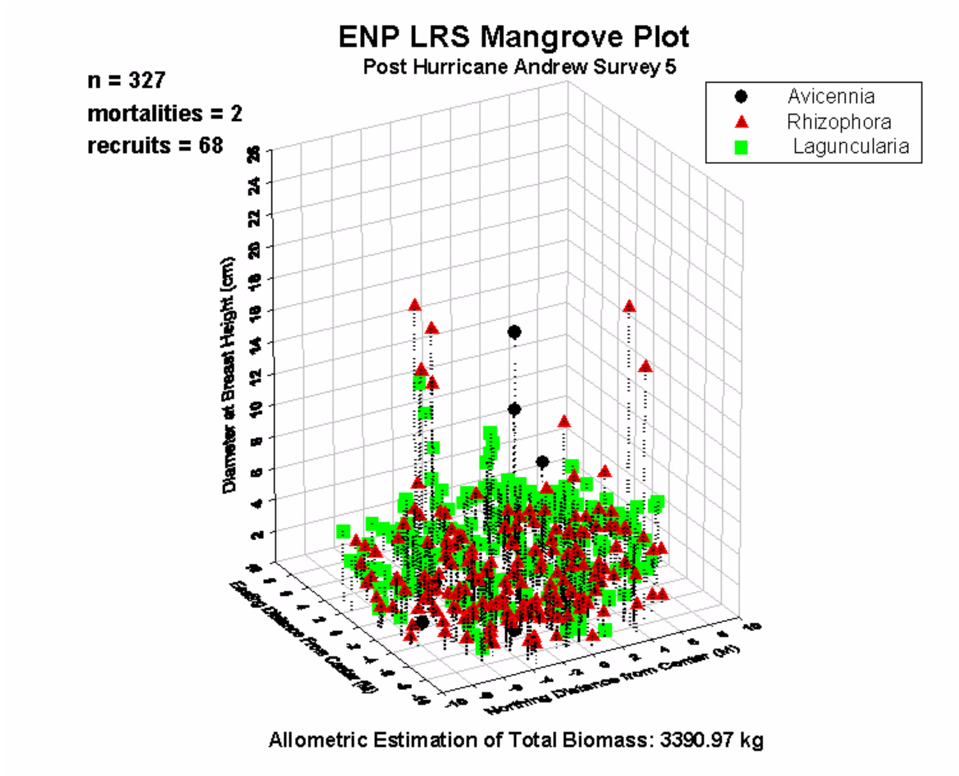
ENP LRS Mangrove Plot

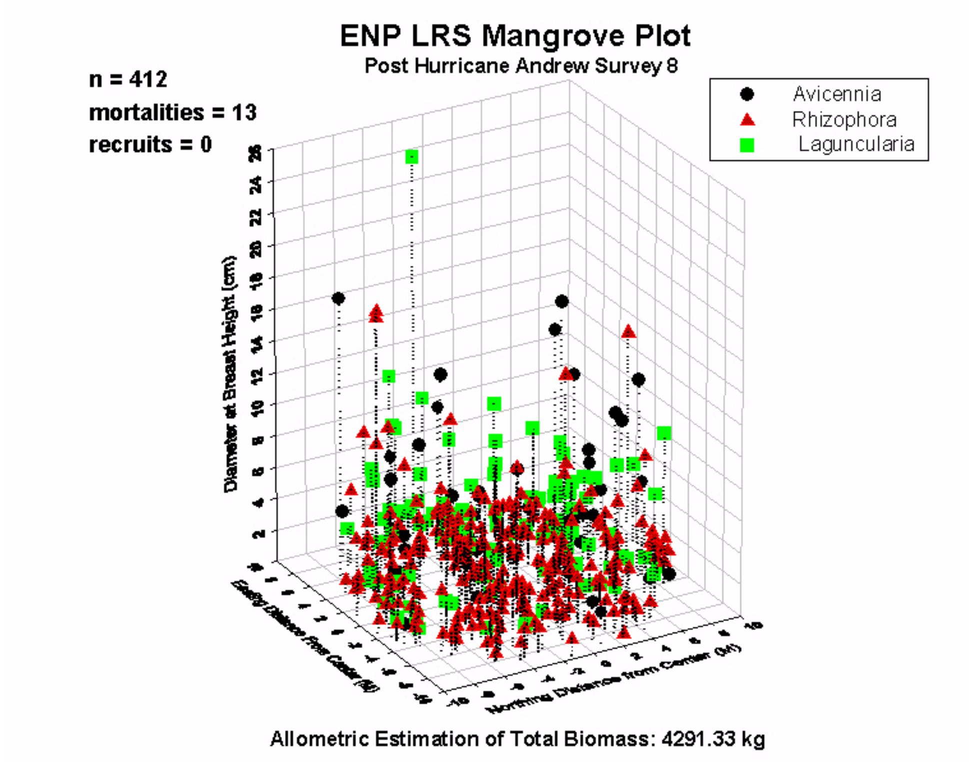
Post Hurricane Andrew Survey 1

n = 90
mortalities = 37



Allometric Estimation of Total Biomass: 3463.69 kg


ENP LRS Mangrove Plot
Post Hurricane Andrew Survey 5
n = 327
mortalities = 2
recruits = 68
Avicennia
Rhizophora
Laguncularia
Diameter at Breast Height (cm)
Northing Distance from Center (M)
Allometric Estimation of Total Biomass: 3390.97 kg


ENP LRS Mangrove Plot
Post Hurricane Andrew Survey 8
n = 412
mortalities = 13
recruits = 0
Avicennia
Rhizophora
Laguncularia
Diameter at Breast Height (cm)
Northing Distance from Center (M)
Allometric Estimation of Total Biomass: 4291.33 kg

Invasive Exotic Plant Management at the Arthur R. Marshall Loxahatchee National Wildlife Refuge, an Integrated Approach

By Allison G. Snow[1], William Thomas, Jr.[2], *and* Laura A. Brandt[2]

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Invasive exotic plants pose a severe threat to natural ecosystems worldwide including south Florida's unique and imperiled Everglades ecosystem. The sub-tropical climate, international commerce, and ornamental plant trade industry are factors, which significantly increase the susceptibility of Florida's habitats to invasion. The Everglades are already threatened by human encroachment, rampant development, and fragmentation of adjacent buffer lands. The Arthur R. Marshall Loxahatchee National Wildlife Refuge (the refuge) represents a unique remnant of the northern Everglades ecosystem, whose native species and ecological integrity are slowly yielding to the influx of invasive exotic plants. Old World climbing fern (*Lygodium microphyllum)* is decimating tree islands by smothering native vegetation, toppling trees, altering fire ecology, creating tangled mats capable of ensnaring wildlife, and preventing native species establishment. *Melaleuca quinquenervia* forms dense stands that are impenetrable to wildlife, alter hydrologic patterns, fire ecology, and native plant communities. In addition, other Florida Exotic Pest Plant Council Category I and II plant species occur with associated detrimental impacts to native plant communities and wildlife. In response to this threat, the refuge has developed a multi-faceted program incorporating detection, control, monitoring, and research, while working closely with other government and private organizations; a truly integrated pest plant management approach. The primary goals of this program are to reduce invasive plant populations to controllable levels where impacts to native plant communities and wildlife are minimized and to further understand the underlying causes and consequences of exotic plant invasions to native plant communities and wildlife.

To address the increasing populations of invasive exotic plants, a detection and treatment program was implemented. The refuge conducts Surveillance and Reconnaissance Flights (SRF) as the primary mode of detecting visible infestations of invasive exotic plants. These surveys are coordinated with the South Florida Water Management District (SFWMD) and the National Park Service (NPS) to ensure a consistent data set, providing complete coverage of invasive exotic plant infestations on the refuge as well as infestations on a regional level for all of south Florida. These SRF results are used to direct field operations by both private contractors who concentrate on heavier infestations over large acreages and refuge crews who concentrate on isolated populations and outliers. The preferred management strategy is to contain and treat small and (or) outlier populations. The most effective method to date for the most problematic species remains herbicides, which are applied using a variety of techniques. Refuge crews and volunteers deal with ancillary exotics on an individual basis. Along with conventional control methods, refuge staff are also active on the biological control front, working closely with the U.S. Department of Agriculture (USDA) to coordinate the release of insects such as the *Melaleuca* psyllid, a potential biocontrol agent for *Melaleuca quinquenervia*, and by implementing vegetation studies on *L. microphyllum* infested tree islands in collaboration with private parties such as the Institute for Regional Conservation (IRC) to provide baseline information on the impacts of *L. microphyllum* for future biological control releases. To combat aquatic invasive plants such as water lettuce (*Pistia stratiotes*) and water hyacinth (*Eichhornia crassipes*), the refuge collaborates with the SFWMD to ensure waterways are clear and navigable to maintain effective water flow and drainage and to ensure public recreational activities such as fishing and canoeing are not adversely impacted.

Areas that have undergone eradication efforts are monitored to document impact to and re-growth of the targeted invasive plant species and of surrounding native vegetation. These two parameters are then used to gauge the effectiveness of the treatment programs, improve efficiency, and provide modifications for future treatment protocols. This monitoring program includes establishing plots on islands where *Melaleuca* and *Lygodium* have been treated via ground-based herbicide applications. Though ground applications appear to be effective when performed correctly, they may not be cost efficient due to the severe infestations now occurring within all refuge habitats.
To evaluate an alternative control technique refuge staff, in cooperation with the SFWMD and University of Florida

(UF) scientists, are also examining the effectiveness of aerial application of two herbicides at two concentrations on two strand tree islands severely infested with *L. microphyllum*. In addition to monitoring post-treatment efforts, the refuge supports and facilitates several research projects on invasive plant species through cooperative efforts as well as through the issuance of Special Use Permits. Keeping with one of the primary functions of the National Wildlife Refuge system, refuge staff are examining an often-overlooked impact of invasive plant species; the toll these plants take on the wildlife. By studying the relationship between *L. microphyllum* infestations and vegetation and wildlife diversity, biologists hope to provide insight into the interactions between invasive exotic plants, native plant communities, and wildlife populations.

Research is also underway to develop tools to aid land managers in effective detection of invasive plant species as an alternative to the SRF. The SFWMD is conducting research to determine the feasibility of using IKONOS (satellite) data to detect infestations of *L. microphyllum*. Another crucial question for effective management is the ability to determine those areas at high risk of invasion as a result of exposure to an invasive seed/spore source. To address this concern, refuge staff are collaborating on yet another project to examine the distance *L. microphyllum* spores can be dispersed from existing infestations. By determining areas of highest spore deposition, refuge staff can concentrate their detection, control, and eradication efforts in areas most prone to invasion. This data set will have a dual function, also being integrated into a larger project conducted by USGS and the University of Tennessee (UT). This venture will incorporate current distribution maps, life history attributes of *L. microphyllum*, dispersal data, control mechanisms, and hydrology to develop a computer simulation model. This program will allow land managers to input parameters (current infestation coverage, funding for control, control method, and hydrological limitations) and view the potential outcome of different scenarios, thereby facilitating managerial decisions on the appropriate resources needed for efficient treatment and the type and location of treatments needed to achieve the most effective control to limit spread and invasion to new areas.

Early detection, treatment, and monitoring are critical components of a successful exotic plant management program. The refuge is aggressively addressing this problem, and is taking the necessary steps to monitor and reduce populations of invasive plants on the refuge while strengthening its efforts by collaborating with other private, local, and federal and state agencies including the SFWMD, USDA, Florida Department of Environmental Protection, UF, UT, USGS, Florida Atlantic University, and the IRC. Collaboration is essential; a variety of agencies throughout south Florida are battling invasive plants on a landscape level, encompassing a plethora of federal, state, local, and private buffer lands. By working together and with the help of volunteers, refuge staff are helping ensure the reduction of current exotic plant populations across south Florida.

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Clipping as a Substitute for Fire to Study Seasonal Fire Effects on Muhly Grass (*Muhlenbergia capillaris* var. *filipes*)

By James R. Snyder

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The Cape Sable seaside sparrow is a Federally listed endangered species whose range is almost entirely within Everglades National Park and Big Cypress National Preserve. Its preferred nesting habitat is the short-hydroperiod grassland known as marl or muhly (for *Muhlenbergia capillaris* var. *filipes*) prairie found on either side of the Shark River and Taylor Sloughs. Muhly is a perennial bunch grass with needle-like leaves generally less than one meter in height. Recent concerns about the survival of the Cape Sable seaside sparrow result from population declines attributed to prolonged flooding in the sparrow range west of Shark River Slough during the 1990's.

Muhly prairies can burn almost any time of the year. The area burned by wildfire is greatest during April, May, and June (Snyder, 1991), which is the peak of the Cape Sable seaside sparrow breeding season (Nott et al., 1998). Prescribed burning is recommended to prevent large wildfires from denuding significant portions of the critical habitat. It is often done during the cooler winter months because of more predictable and favorable burning conditions. Prescribed burning during the transition from dry to wet season, when fires normally burn the greatest area, is generally avoided because of potential control problems and because sparrows are nesting. While fire is a natural and necessary phenomenon in muhly prairies, the interaction of fire and flooding can have profound effects on vegetation structure and composition. Fire followed by flooding can result in high mortality of plants that normally resprout vigorously (Herndon et al., 1991).

We have proposed to address two related questions relevant to fire management and the endangered Cape Sable seaside sparrow: 1. How does season of burning effect the rate of recovery of muhly? 2. How does season of fire effect the ability of muhly to tolerate flooding? These questions will be addressed through two experiments, one in the field and one under more controlled conditions. Because experimental prescribed burns are relatively expensive to conduct and are difficult to apply consistently over time, the clipping of muhly plants was proposed as a substitute for fire. There is ample evidence that clipping and removal of litter can result in responses similar to those observed following fire (Hulbert, 1988). The results of a preliminary experiment intended to compare the response of muhly to clipping and burning are reported here.

The experiment was conducted in an area of muhly prairie burned by a wildfire that occurred on May 7, 2001, along U.S. 41 in Big Cypress National Preserve. On May 22, 20 burned muhly clumps were marked, about 50 m south of the road and within 20 m of the fire edge. The plants had resprouted about 10 cm since the fire. In the adjoining unburned area to the east 80 unburned muhly clumps were marked. Ten randomly selected clumps were clipped about 2 cm above the ground, matching the amount of grass that remained after burning. Groups of 10 randomly selected plants were clipped on five additional dates through July 12 to see if the seasonal timing of top removal affected plant response. Twenty marked plants were not clipped and served as controls. The heights of the tallest leaves in the marked muhly clumps in the burned area were recorded each time plants were clipped. By the latter part of June, there had been substantial rainfall and the ground was wet. At the last clipping date on July 12 there was standing water in low spots. The heights of a few plants clipped at different times were measured to compare rates of regrowth after clipping and burning.

Figures 1 and 2 show regrowth of the burned and clipped plants, respectively. The figures cannot be compared directly because the growth of plants burned on May 7 was observed for up to 66 days; whereas, plants were clipped at various times up to 51 days before July 12. Therefore, the period during which leaf growth was observed differed in the two situations. The closest comparison is between plants clipped 15 days after the fire, which were slightly under 60 cm tall 50 days after clipping, to burned plants, which were slightly over 60 cm tall 50 days after burning. It therefore appears that growth is similar, but that burned plants may resprout more vigorously than clipped plants. It is possible that the ash fertilizes the grass after burning and enhances regrowth.

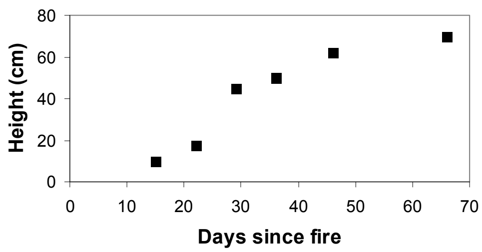

Figure 1. Approximate heights of tallest leaves resprouting from muhly clumps burned on May 7, 2001.

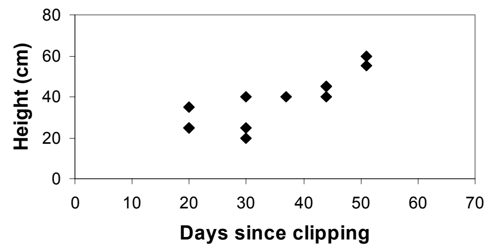

Figure 2. Heights (on July12, 2001) of tallest resprouting leaves from several clipped plants.

In October, the number of flowering culms in each clump was counted. In the unburned area, the 20 unclipped plants had no flowering culms. This was considered likely because flowering is seldom observed in muhly that has not recently burned. In the burned area the plants showed substantial flowering. Only 17 of the 20 plants originally marked in the burned area were relocated and they had a mean of 6.5 flowering culms per plant, with a range of 0 (2 plants) to 15 culms per plant. In contrast, a single flowering culm was found on a plant clipped on June 22; the other 59 clipped plants had no flowers. Therefore, the conclusion drawn is that clipping as done in this experiment is not an adequate substitute for fire, even though vegetative regrowth was similar between burned and clipped plants.

A few possible reasons that flowering is not stimulated by clipping include the lack of a nutrient pulse, excess residual litter, or a lack of stimulation to belowground parts by heat. Even though a 2-cm stubble is left after a fire, the tissues above ground are undoubtedly dead. This is not the case with clipped plants.

As a consequence of this preliminary study, a method to burn individual muhly clumps in the field relatively easily and safely has been developed. Experimental burning treatments addressing the issue of season of burning and the response of muhly will begin in January 2003 and continue through the early part of the wet season.

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Modeling Manatee Response to Restoration in the Everglades and Ten Thousand Islands

By Bradley M. Stith, Jim Reid, Dean Easton, *and* Susan Butler

USGS, Center for Aquatic Resources Studies, Sirenia Project, Gainesville, FL., USA

The coastal waters of southwest Florida harbor nearly a third of the Florida population of the Federally listed West Indian manatee (*Trichechus manatus*). A large proportion of this population occurs within the Everglades National Park (ENP) and the Ten Thousand Islands (TTI), yet only limited information is available from this remote region. Aerial surveys conducted by ENP personnel in the early 1990s revealed heavy use of both inshore and offshore areas during most of the year. Manatees feed almost exclusively on submerged aquatic vegetation (SAV), and most individuals show a strong preference for marine seagrasses. Bcause manatees lack the ability to drink saltwater (mariposia), they need to drink freshwater periodically. Thus, manatees depend on resources in marine, estuarine, and freshwater zones, making them excellent indicators of the health and restoration success across all of these zones.

A primary goal of this research is to develop an individual-based ATLSS model to simulate manatee response to changes in hydrology caused by the Comprehensive Everglades Restoration Plan (CERP). In support of this goal we have analyzed manatee telemetry data from the study area to parameterize and calibrate the model. We have also conducted aerial surveys in the TTI region to provide information on the distribution and abundance of manatees that could be used to validate the model.

Analysis of Telemetry Data

Data was analyzed from 20 tagged animals between June 2000 and July 2002, representing 4,563 manatee tracking days. The attached Argos transmitters were programmed to fix at least one location during four time-windows each day, when satellite overpass geometry was optimal. The actual number and accuracy of fixes obtained varied due to animal behavior or equipment performance. Filtering out all points with poor spatial accuracy resulted in 12,600 fixes, a decrease of 31 percent over what could be obtained under optimal conditions. We also deployed GPS tags for 104 manatee days; these tags were programmed to obtain fixes at 15- or 20-minute intervals.

The Argos telemetry data provided valuable information on coarse-scale patterns of manatee behavior that were incorporated into the ATLSS model. We classified the landscape into four simple aquatic zones: offshore, travel corridors, inshore bays, and inland riverine systems or canals. We used a GIS overlay analysis to determine the aquatic zone for each telemetry point. Most manatees showed a consistent pattern of feeding on marine seagrass beds in offshore zones for a period of several days, followed by large movements of 5 to 20 km or more up rivers and canals, presumably to obtain freshwater. Several animals also made heavy use of inshore bays where they could feed on a suite of SAV different from the offshore areas. The home ranges of all animals incorporated one or more inland sites which supply freshwater, as well as offshore areas that provide food resources.

Comparison of the number of inland forays made during wet versus dry season showed a slightly higher number during the dry season, but the difference was not significant. Manatees made inland forays in the wet season, even when freshwater was available at the mouth of rivers or canals. During periods of significant cold weather, manatees greatly decreased their use of offshore areas and increased their use of inshore locations with favorable thermal buffering (typically deeper sections of canals, rivers, and inshore holes).

GPS data provided valuable fine-scale information on manatee behavior, which could not be obtained from the Argos data. Distribution of movement rates between GPS points fitted an inverse distribution, with a mean and mode well below 1 km/hour, and maximum speeds approaching 3 km/hour. Directionality of movement was highly biased towards small turn angles, and the GPS data provided precise movement pathways through the complex aquatic landscape in TTI and ENP.

The telemetry data provided valuable information needed to parameterize and structure the ATLSS model. The broad movement patterns provided by the Argos data were nicely complemented by the detailed data provided by the GPS tags.

Model Structure

The manatee ATLSS model is being developed in C++ using object-oriented techniques. The model is individual-based, spatially-explicit, and simulates the movements of individuals on a raster image (20-m cell size) of southwest Florida. A network data structure of arcs and nodes is used to direct the movement of manatees in an efficient manner. This network structure was developed from telemetry locations and aerial survey data, and consists of nodes representing primary drinking areas, feeding areas, and thermal sheltering areas, connected by travel paths represented as arcs. Standard algorithms from graph theory are used to access and query this network structure.

Home range allocation—Each manatee is allocated a portion of the total network that includes one or more freshwater sites and offshore seagrass beds. The initial network portion allocated to each manatee at the start of a simulation is drawn from a distribution of home range sizes and geographic positions along the coast as determined from telemetry data. Manatees born after the creation of the initial cohort inherit their mother's network, to reflect maternal transmission of home range.

Movement rules—Manatees move on a network of nodes representing destination sites for feeding, drinking, and thermal sheltering, all connected by arcs representing travel corridors. Low water depths limit the movement of manatees along some portions of the network. Manatees can shift their home range to different parts of the total network if freshwater or seagrass becomes unavailable within their subset of the network.

Incorporation of environmental variables—Salinities, temperature, and water depth are modeled only along this network, rather than across the entire grid, to increase computational efficiency. Until linkages exist to hydrologic models such as TIME, we are relying on simple surrogate models that simulate observed patterns and possible restoration scenarios.

Manatee behavioral state switching—A Markov Chain approach is used to simulate the transition of manatees into different behavioral states that drive the movement patterns of each individual. Only a few, simple behavioral states (feeding, drinking, traveling, resting) inferred from the telemetry data are modeled. Transition probabilities were developed from the telemetry data and from previous research on manatee time budgets in other areas.

Manatee learning—Several simple learning modules simulate freshwater site switching by manatees. These modules determine how quickly manatees shift their use of different parts of the network in response to positive or negative reinforcement in the availability of freshwater at sites within the home range of each manatee. The simplest algorithm, the real-time linear operator model, assumes that animals maintain an estimate of resource availability at time *t*, which is incremented or decremented during each time step, depending on whether the resource was found or not.

Key assumptions—A key component of the model is the manatee-learning module, which determines how quickly manatees shift their use of different parts of the network in response to positive or negative reinforcement in the availability of a critical resource. Sensitivity analyses will be used to evaluate the importance of different assumptions and uncertainty associated with poorly understood parameters. As additional telemetry data are collected, the model will be refined to incorporate new insights from these data. Radiotracking and aerial surveys will provide an important means of monitoring manatee response to natural environmental fluctuations and human-induced alterations associated with restoration activities.

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Abundance and Diet of *Rana grylio* Across South Florida Wetlands

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Federal and state agencies are attempting to project the impact of hydrologic restoration on the Everglades ecosystem. Current modeling efforts have focused on primary producers (e.g. macrophytes and periphyton) or organisms of higher trophic levels (e.g. panther, deer, birds). Amphibians are a vital intermediate link within the Everglades food web (ATLSS 1997, Ligas 1960). Even though amphibians are known to comprise a large portion of the faunal biomass within wetland systems, they remain underrepresented in restoration efforts (Burton and Likens, 1975). The biphasic lifecycle of pigfrogs (*Rana grylio*) makes them extremely sensitive to hydrologic change. Unfortunately, little is known about their abundance, ecology, and importance to the greater Everglades ecosystem. This study investigated temporal changes in *Rana grylio* abundance and diet in south Florida wetlands from August 2000 to September 2002. The goal of this study was to link changes in hydrology to the abundance and condition of this species throughout south Florida wetlands.

A total of 551 one kilometer transects were surveyed at night via airboat to compare the monthly abundance of *R. grylio* across large areas of Water Conservation Areas 3A, 3B, and Everglades National Park (ENP). Abundance estimates were calculated using a double-observer approach (Nichols et. Al, 2000). Capture-recapture techniques were used within three one-hectare plots at each site in order to estimate abundance and growth parameters on a smaller scale. We collected 684 frogs from throughout the study areas from 1999-2002 to examine stomach content among sites. A drought occurred during 2001, which allowed us to assess how this species responds to a severe prolonged dry-down.

Stomach contents were greatest during the mid to late dry season at all three sites (fig. 1). Frogs in 3A had less food in their stomachs than those in either 3B or ENP. Growth was highest from December to March. Frogs were most abundant from March through September (fig. 2). Recruitment of metamorphs appears to peak from July through September. It appears that as water levels decrease, food may become more available to the frogs, allowing them to grow or invest in reproduction during this time. The study sites in WCA 3A rarely dried down. These frogs rarely contained fat bodies or food in their stomachs; this may be due to prolonged flooding in this area. Frogs are both smaller and more abundant in WCA 3A than in ENP or WCA 3B. This is probably due to a combination of both frog harvesting and high water throughout the year. Final results including models of the effects of hydrology on this species will be available in Fall 2003.

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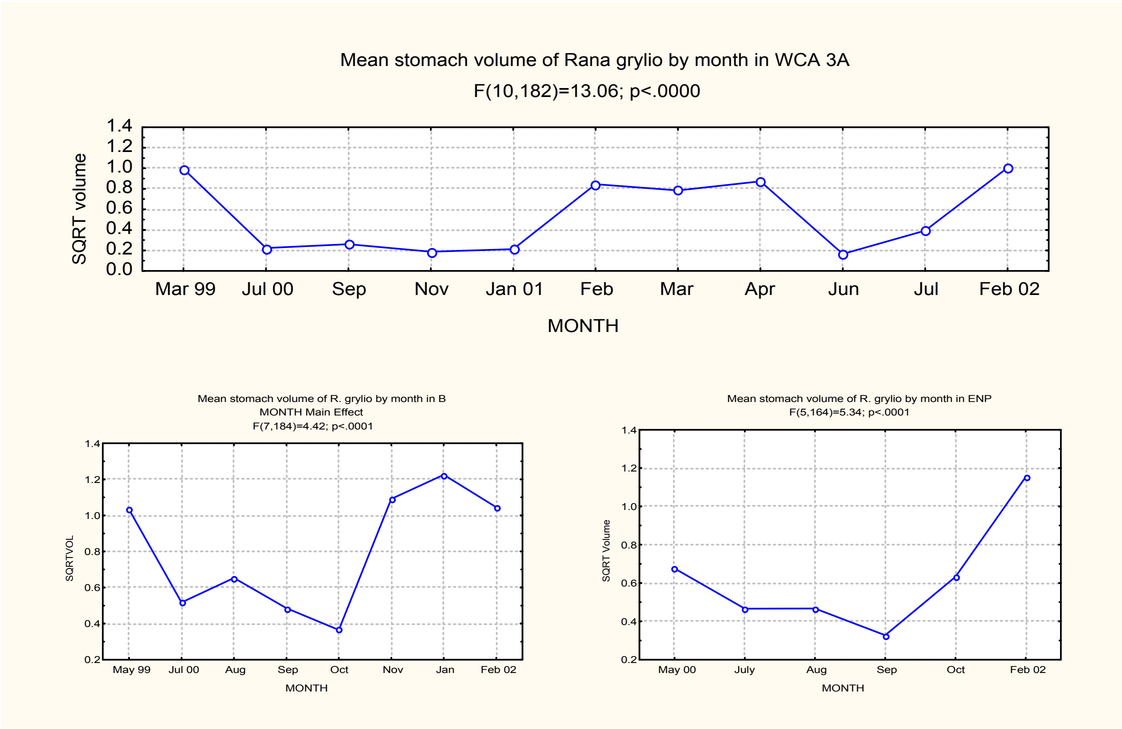

Figure 1. Mean total stomach volume of *Rana grylio* from three study sites in the Everglades during 2001-2002.

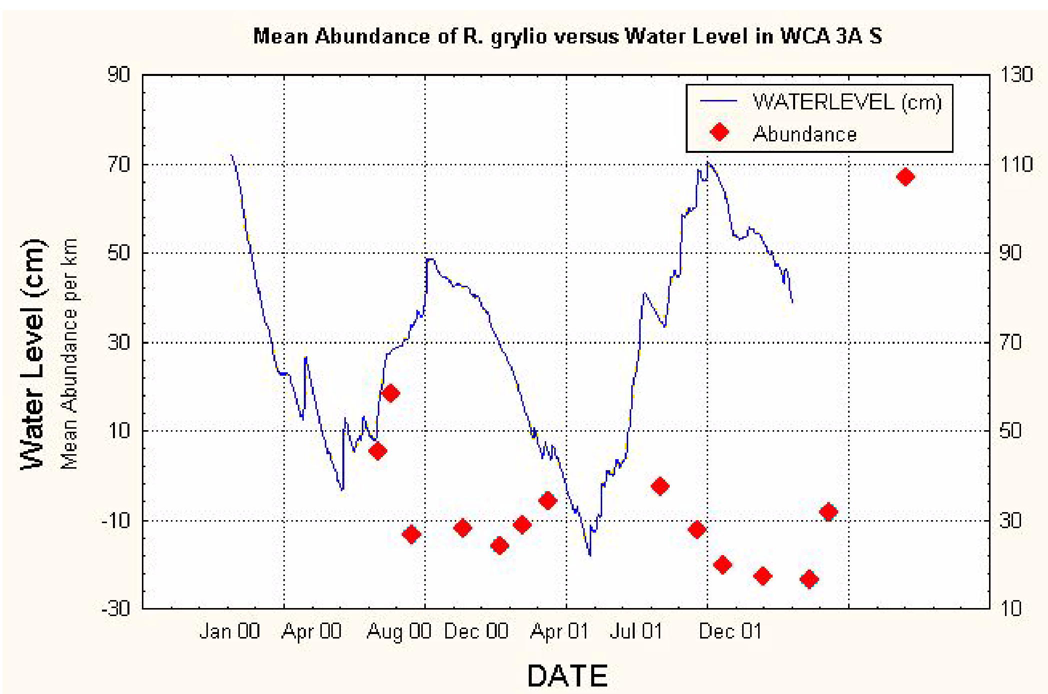

Figure 2. Mean abundance (animals/km) of *Rana grylio* from Water Conservation Area 3A.

Short-Term Dynamics of Vegetation Change Across a Mangrove—Marsh Ecotone in the Southwest Coastal Everglades: Storms, Sea-Level, Fire, and Freeze

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Understanding the potential impacts of Global Climate Change, such as sea-level rise, on the newly initiated Comprehensive Everglades Restoration Plan (CERP) are crucial to its success. The position of the mangrove-marsh ecotone (MME) is known to have changed through time at several locations in coastal Everglades and Florida Keys. Shifts in the upstream position of the MME have been suggested as a means of monitoring sea-level impacts and to serve as an indicator of global climate change in places such as Australia and Southeast Asia.

The ecology of a MME has been examined in detail for over seven years. The site is located along the Harney River, in Everglades National Park. We established a transect across the MME, which spans a distance of >350 m running from a tall mangrove forest at the river bank, into a sawgrass dominated plain. Five sediment porewater sampling sites are located along the transect. At each porewater site there are six porewater sippers, three at 30 cm depth and three at 60cm depth. These sippers were sampled weekly for the first year (1997) and then bi-weekly thereafter. Porewater for nutrient analyses was collected at infrequent intervals. Permanent plots for measuring changes in the mangrove forest canopy and in the abundance of mangrove seedlings were established in 1998 and have been sampled yearly. An experiment was established to examine the impacts of a marsh fire on the subsequent establishment and growth of mangrove seedlings. Change in the position of this ecotone since 1927 has been determined by the analysis of aerial photographs.

The river edge is dominated by tall mangrove forests, particularly *Rhizophora mangle* and L*aguncularia racemosa*. *Avicennia germinans* is present in low numbers over the first 200 m of the transect (fig. 1). Forest height and average stem size decrease inland. Both *Rhizophora* and *Avicennia* disappear from the inland areas of the transect, leaving *Laguncularia* as the only mangrove species where the forest gives way to a marsh dominated by sawgrass *(Cladium jamaicense)*.

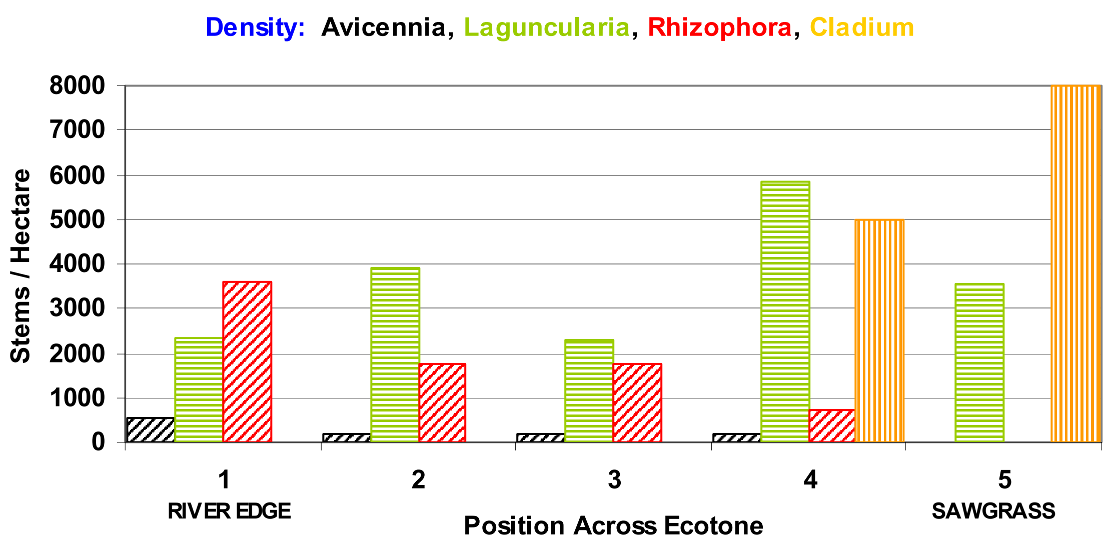

Figure 1. Stem density for the dominant species across the Harney River mangrove marsh ecotone transect (multiply *Cladium* by 100).

Long term change in the position of the ecotone has occurred. In 1927 the MME was approximately 100 m from the river bank. By 1994, the MME was 350 m from the river bank, an inland shift of approximately 250 m, a distance readily measurable on the photographs. Stumps of the Cabbage Palm (*Sabal palmetto*) can be found inside of the current mangrove forest and provides strong evidence for a change in the vegetation. Our physical data indicate that this transect, located on a large coastal island, is disconnected from upstream hydrologic signals. We thus feel that the movement of this ecotone over the past 70 years is related to a rise in sea level.

Gross sediment nutrient concentrations vary significantly from river edge to interior marsh. Total nitrogen increases from just over 1 ppm (mg per gm wet sediment) in the riverine mangrove forest to more than 2 ppm in the sawgrass. The trend for phosphorus is the reverse. Sediment P is highest in the riverine forest (1.2 ppm) and least in the sawgrass (0.4 ppm).

Tree mortality has been observed from a variety of sources over seven years including: wind (from both hurricanes and winter cold fronts), freezing temperatures, fire and lightning (fig. 2). Freezes and fires are more likely to affect stems at the ecotone. Both fires and freezes "top killed" numerous individuals of *Laguncularia* along the ecotone. This species stump sprouts readily. The frequent occurrence of fires and freezes may account to the large number of *Laguncularia* that are multi-stemmed.

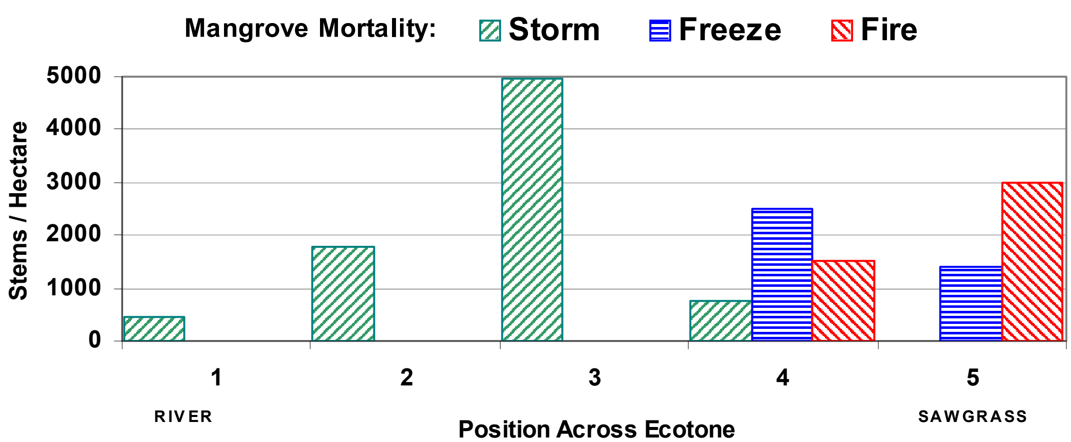

Figure 2. Causes of short term mortality along the Harney River transect. Storm related mortality is common near the river edge and in the interior forest. Freeze and fire are the major mortality factors at the mangrove – marsh ecotone.

In terms of fire impacts, the preliminary results from our seedling transplant experiment are interesting. We hypothesized that seedlings planted into a recently burned sawgrass marsh would have higher survival rates than ones planted under an unburned sawgrass canopy. For all three mangroves, however, the reverse was true. Individuals in the unburned marsh had greater survival. The largest effect, however, was among species. *Avicennia*, in both burned and unburned marshes, died rapidly, whereas 45 percent or more of both *Laguncularia* and *Rhizophora* survived for at least 200 days.

Results of this study indicate the mangrove-marsh ecotone is a dynamic component of landscape, capable of changing and being changed over relatively short time periods. Mangrove -marsh ecotones at more upstream locations in the Everglades ecosystem will be useful locations at which to monitor the effects of increasing freshwater inflow.

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Characteristics of Lightning Gaps in the Mangrove Forests of Everglades National Park

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Lightning gaps have been identified as a common disturbance in mangroves throughout the world. Lightning created canopy gaps are abundant in the mangrove forests of Florida. An average 9,900 cloud to ground strikes occur annually in Florida, the highest level found in the United States. The dynamics of Florida mangrove systems may result from the interactions of small-scale lightning gaps, large-scale hurricane disturbances, and sea-level rise. In addition to these ecosystem forcing functions is the Greater Everglades restoration effort, known as the Comprehensive Everglades Restoration Plan (CERP). CERP will greatly influence hydrological flow through much of the 100,000 ha of mangroves in south Florida. Clearly, to understand how the mangrove ecosystems may change in response to restoration it is important to determine how these mangrove ecosystems respond to small- and large-scale disturbance along with sea-level rise.

The goal of this project is to characterize the role of lightning generated gaps within south Florida mangrove ecosystems. This is being accomplished by: following short-term changes in community level and environmental processes; evaluating community characteristics in a time series of gaps along a known salinity gradient; and appraising the regional signal for mangrove gap dynamics. Here we present findings of 39 gaps from the general region for canopy and expanded gap size and direction of orientation. Additionally, we present initial findings of habitat characteristics for six gaps of differing successional age located in the lower Shark River Region.

The mean canopy gap area was 212 m^2 and the expanded gap was 299 m^2 for the general gap survey. Gaps were slightly elliptical in shape with an average eccentricity of 1.28. There was a preferential directional bias to the longest axis of the gaps. However, there was no evidence of wind extensions to the gaps. Thirty-three percent of the variation in gap size was explained by average surrounding canopy height.

To understand the successional process it is important to determine a relative age of the recovering gap. The aging of tropical gaps has been a problem in a number of environments. Here we have developed a hypothetical relative aging of gaps based on the ratio of the coarse woody debris of the gap compared to the average of coarse woody debris amount for the study island. The average coarse woody debris was 52.52 tons ha^{-1} for the study island. The gap coarse woody debris varied from 16.7 to 182 tons ha^{-1}. There is a linear relationship between relative gap age and the amount of coarse woody debris present with older gaps having a higher ratio of coarse woody debris relative to younger gaps (fig. 1).

It appears that roots within the lightning created gaps die as a consequence of above ground tree mortality and possibly from the lightning itself. Root death causes the physical properties of the sediment to differ from the surrounding forest type. We assessed sediment parameters for six gaps of different successional age and found that compaction is significantly lower in gaps (0.094 kg/cm^2) and higher in the surrounding closed canopy forest (0.124 kg/cm^2). The same was true for sediment shear strength (gap mean = 7.4 kg/cm^2 and forest mean = 8.8 kg/cm^2). Shear strength and soil compaction taken together indicates soil cohesiveness. There is a linear relation between these parameters and our data supports this linear relation; however, all samples from gaps are consistently grouped towards lower end of this relation (fig. 2). Sediment shear strength and compaction are usually correlated with bulk density, however, our study does not support this finding. In addition, there was no difference in sediment bulk density between gaps and the surrounding forest. There are plans to extend this type of investigation of lightning gaps to the mid-stream and upstream areas of the Shark River Region. In this way we will investigate the effect of salinity on the recovery process.

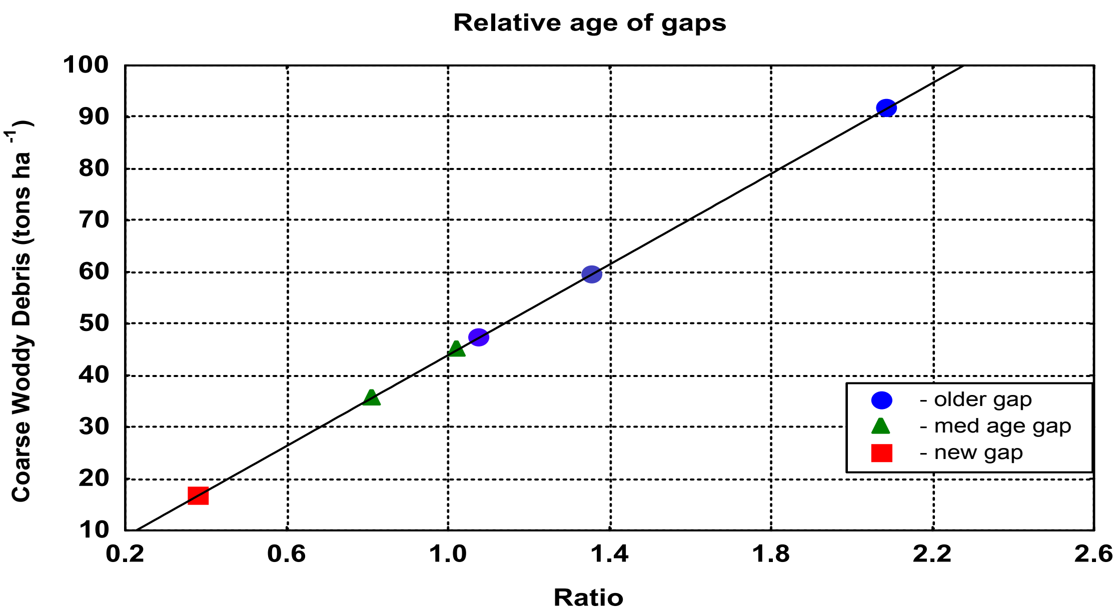

Figure 1. Hypothesized relation between gap age and the amount of coarse woody debris.

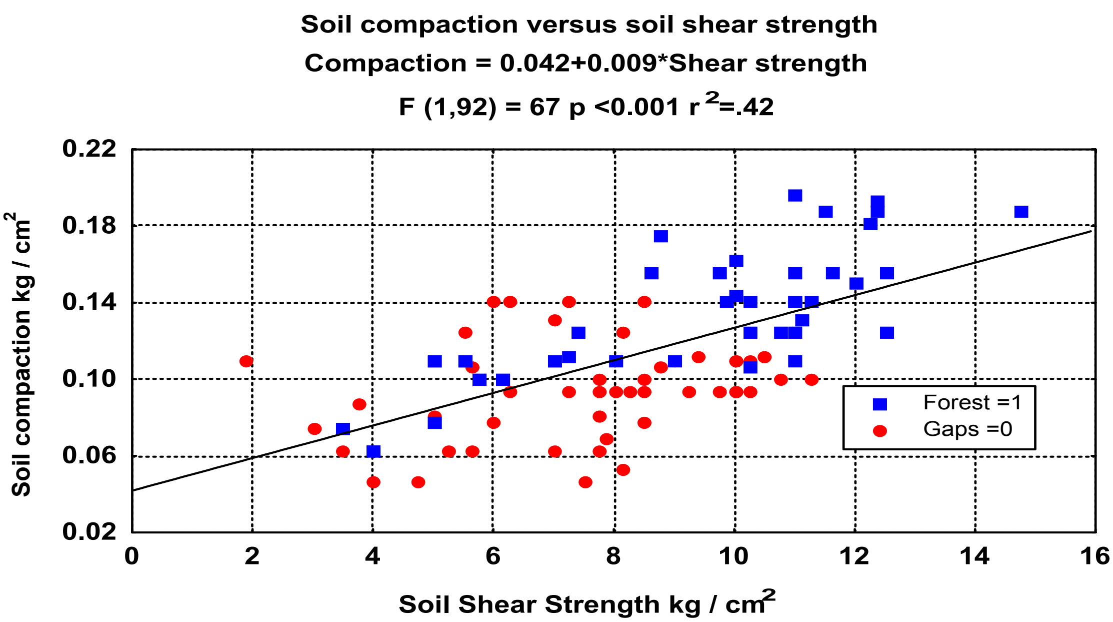

Figure 2. Relation between soil compaction and soil shear strength for mangrove forested sites (squares) and gap sites (diamonds).

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Poster, Ecology and Ecological Modeling

Ecosystem History of Central Biscayne Bay Based on Sediment Core Analyses

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During the last century, Biscayne Bay has been greatly affected by anthropogenic alteration of the environment through urbanization of the Miami/Dade County area and alteration of natural freshwater flow. Changes in the sources, timing, delivery, and quality of freshwater flow into the Bay have altered shoreline and sub-aquatic vegetation to unknown degrees. Land management agencies that focus on the restoration of natural flow of freshwater into Biscayne and Florida Bays can benefit from paleoecological and geochemical analyses documenting the impacts of past changes in freshwater input.

To establish targets and performance measures for restoration, research is being undertaken to determine pre-alteration baseline conditions and natural variation within the system. The USGS, in conjunction with South Florida Water Management District, Biscayne National Park, Duke University, Southern Illinois University, and University of Miami, is examining the natural patterns and causes of temporal change in salinity, water quality, vegetation, and benthic fauna in Biscayne Bay over the last 100-300 years.

The current studies extend prior knowledge of Biscayne Bay environmental history by obtaining cores from new sites, obtaining series of radiocarbon dates, evaluating lead-210 dating of Biscayne Bay sediments, utilizing multiple paleoenvironmental proxies, and applying quantitative methods of faunal and geochemical analyses. These analyses build on an expanding methodology utilized in research conducted in Florida Bay (1995 – ongoing) and Biscayne Bay (1996-2000) (Brewster-Wingard, et al, 2001; Cronin, et al., 2001; Dwyer and Cronin, 2001; Holmes, et al, 2001; Ishman, 1998).

Three sets of replicate cores were collected in March 2002 from sites in central Biscayne Bay, Featherbed Bank, and an unnamed bank [herein referred to as No Name Bank, equivalent to Black Shoal of Wanless (1969)] (fig. 1), and southern Biscayne Bay at Card Bank. Analyses of the two cores from central Biscayne are nearly complete. A preliminary age model using lead-210 geochronology places the base of the 2002 Featherbed Bank Core at 1741 and the base of No Name Core at 1874. Age models developed from radiocarbon and lead-210 dating of the 1997 and 2002 cores indicate mean sedimentation rates for Card, Featherbed, and No Name Banks were 0.25 cm yr^{-1}, 0.85 cm yr^{-1} and 1.22 cm yr^{-1}, respectively. The Card, Featherbed, and No Name cores yield paleoecological and geochemical records spanning the past 900, 500, and 150 years, respectively.

Analyses of fossil ostracode and molluscan faunal assemblages indicate a major shift in benthic communities in both central and southern Biscayne Bay during the late 1500's through 1600's, when epiphytal species indicative of seagrass (*Thalassia*) habitats became abundant. Moreover, there is preliminary evidence that a decline in seagrass-dwelling epiphytal species, unprecedented in the past 400 years, occurred at both No Name and Featherbed Banks during the mid-20^{th} century. It is unclear what caused this decline; however, it may be due to changes in mean salinity, increased turbidity, nutrient influx, or other factors.

Ostracode shell magnesium to calcium (Mg/Ca) ratios, a proxy for salinity, indicate considerable short-term variability in Mg/Ca at No Name Bank during the past 150 years (fig. 2). The paleosalinity patterns are generally similar to those observed at Featherbed Bank and from Russell Bank in Florida Bay.

Compilation of the data from the 2002 cores will provide additional data on the timing and causes of salinity variability and its relation to benthic faunal variability and benthic habitats. Comparisons will be made to cores collected in Biscayne Bay between 1996-99, to determine trends in salinity, subaquatic vegetation, and shoreline vegetation for Biscayne Bay. A comparison to Florida Bay cores will provide information on ecosystem-wide changes. These data will provide the essential data necessary to establish performance criteria and restoration targets for CERP (Comprehensive Everglades Restoration Plan) and the agencies responsible for implementing CERP.

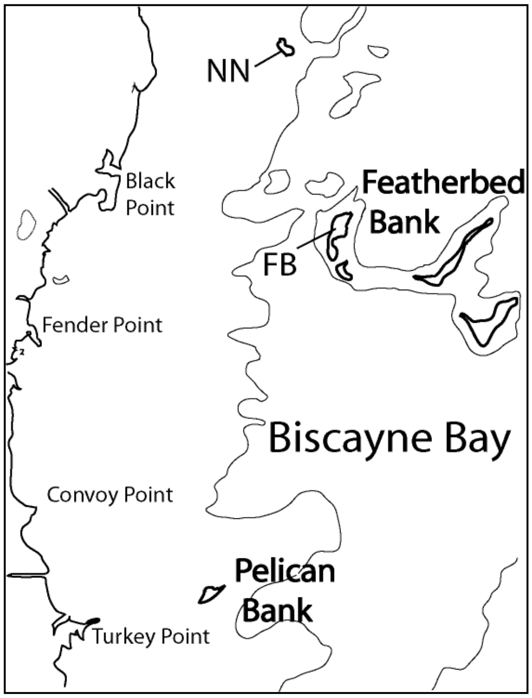

Figure 1. Map showing core locations in central Biscayne Bay. NN, No Name Core. FB, Featherbed Core.

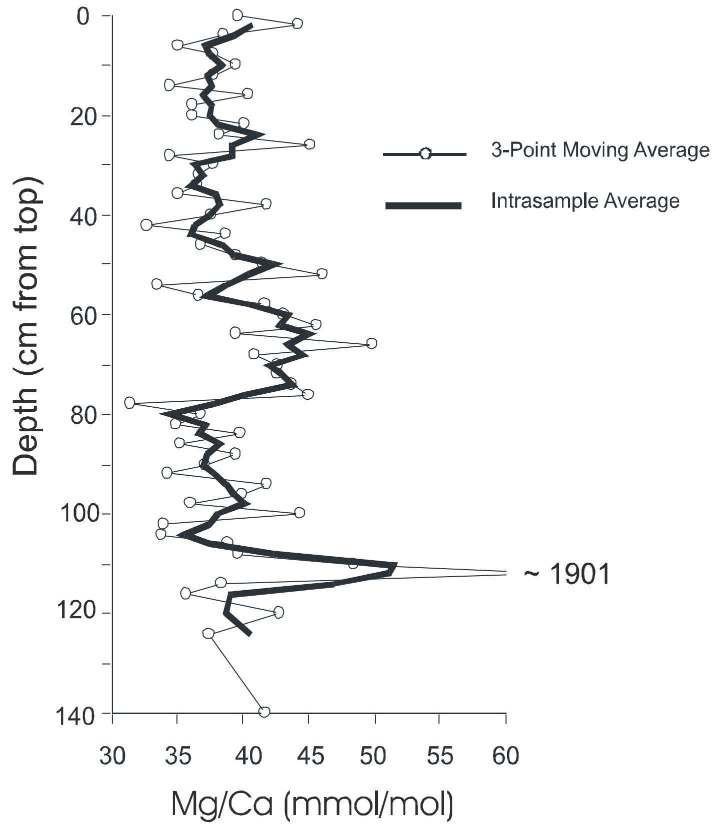

Figure 2. Ostracode Mg/Ca ratios from No Name Bank Core, Biscayne Bay.

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Evidence of Freshwater Influx into Rankin Basin, Central Florida Bay, Everglades National Park, Prior to 1900

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Preliminary data from analyses of a core (GLBW601-RL1) taken in Rankin Basin in June 2001 indicate significant environmental changes have occurred at the site over the last two centuries. The core was collected at a site of documented seagrass die-off in 1987-1988 (P.R. Carlson, Florida Marine Research Institute; written communication, 2001). The purpose of the core collection was to document the long-term sequences of events leading up to the die-off event. Analyses have been conducted to examine faunal changes in the ostracodes and mollusks, biochemistry of the ostracode shells, geochemical changes in the sediment, and the influx of atmospheric dust. The faunal assemblage analyses provide information on the salinity and benthic habitat at the site. These data, when compiled, will provide a means to test hypotheses of cause and effect in seagrass die-off, and will illustrate decadal-scale patterns of change that may contribute to die-off events.

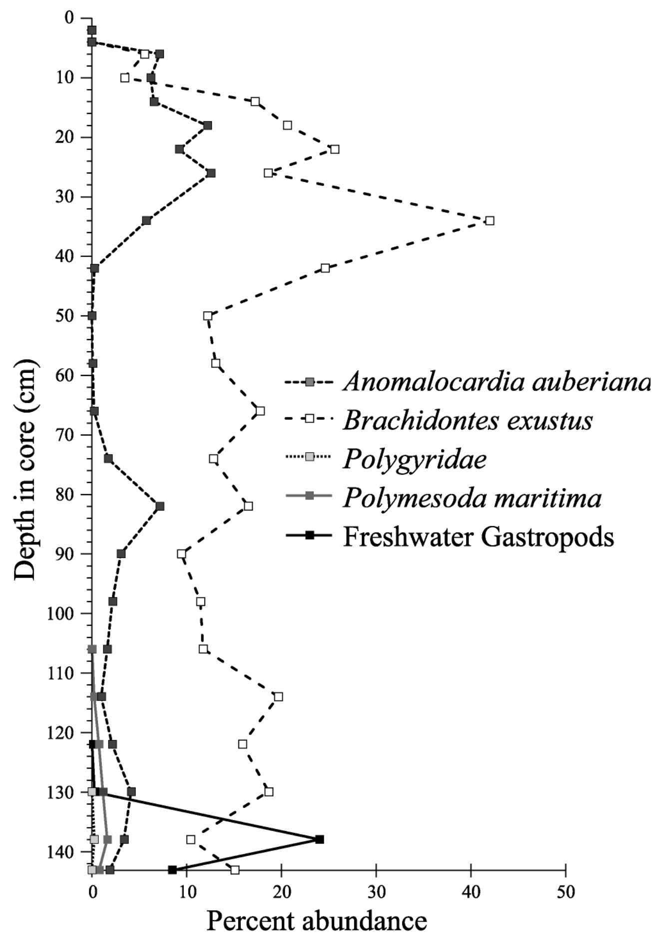

Figure 1. Percent abundance of key molluscan species from Rankin Core

The molluscan faunal analyses show two important results. First, at some point prior to 1900, a significant influx of freshwater occurred in Rankin Basin. Second, immediately prior to the documented seagrass die-off, the mollusks indicate an increase in the amplitude of salinity fluctuations. Figure 1 shows freshwater mollusks present in the lowest 20 cm of the core, reaching a high of 24 percent of the molluscan fauna at 138 cm. Small percentages of terrestrial gastropods (Polygyridae) and a clam, *Polymesoda maritima,* also are present in this segment of the core. *Polymesoda maritima* is found in oligohaline to lower mesohaline waters (5-12 ppt), so it is an indicator of reduced salinities. This assemblage is similar to that seen in the lowest portions of a core from Taylor Creek. At approximately 50 cm in the Rankin core a significant increase occurs in *Brachidontes exustus* and *Anomalocardia auberiana*, two species that tolerate fluctuations in salinity; these species are typical of the Northern Transition Zone of Florida Bay. When the geochronology of the Rankin core is complete, these changes can be placed into temporal context and compared to natural and anthropogenic events affecting Florida Bay.

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Molluscan Shells as Recorders of Environmental Change in South Florida

By G.L. Wingard, R. Stamm, *and* J.B. Murray

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The most critical issue in the Comprehensive Everglades Restoration Plan (CERP) is to restore more natural patterns of freshwater flow through the terrestrial ecosystem and into the estuaries and coastal areas. In order to recreate natural freshwater flow patterns, it is essential to understand the natural patterns of variation prior to significant human alteration of the system and the natural sources of water. Seasonality of water delivery is especially critical because the reproductive cycles of many of the organisms within the environment are tied to these seasonal patterns of flow. A number of studies have documented the utility of mollusks as indicators of environmental change (Dodd and Crisp, 1982; Dettman, et al., 1999; Rodriguez, et al. 2001; Surge, et al., 2001) and the term sclerochronology has been applied to this type of research (Schöne, et al., 2002). Current U.S. Geological Survey research is applying this methodology to determining historical salinity patterns and sources of freshwater influx in Florida Bay.

Mollusks grow incrementally, secreting calcium carbonate layers that preserve information about the water at the time of secretion. Analyses of the individual growth bands of mollusks allow detailed comparisons of seasonal change over time. Shells analyzed from radiometrically-dated sediment cores taken throughout the region allow reconstruction of seasonal salinity variations and freshwater sources in the past, prior to significant human alteration of the system. These data will provide the resource managers (SFWMD, USACE, and ENP) with restoration targets and performance measures that will allow them to "get the water right."

Significant progress has been made on developing sclerochronology for application to south Florida ecosystem restoration by means of three discrete types of experiments: 1) growth studies on selected molluscan organisms; 2) salinity tolerance experiments and calibration of shell chemistry to water chemistry (both in the lab and in the field); and 3) testing of instrumentation for conducting analyses. Determining an accurate growth rate is important because the timing of seasonal changes in the estuaries is critical to ecosystem health. In order to use mollusk shells for determining these seasonal changes, it is essential to understand average growth rate and the timing of growth. For example, if growth only occurs during certain seasons, then the mollusk will not capture the full spectrum of seasonal salinity changes. Previously, determination of growth rates was only assumed or measured. Currently, we have focused our experiments and analyses on *Chione cancellata*. *Chione* was selected as the initial test organism for several reasons: 1) the thickness of the shell makes sectioning and analyses of individual layers easier; 2) early salinity tolerance experiments have demonstrated that this clam will survive in a wide range of salinities (10-68 ppt); and 3) field evidence suggests it is one of the longer lived (3-7 years) molluscs present in Florida Bay.

Growth experiments, salinity tolerances, and calibration studies are conducted both in the field and in the lab. Tanks are set up in the lab and maintained at specific salinities (15, 25, 35, and 45 ppt). Animals are removed periodically and digitally photographed to determine growth, water is tested daily, and water samples are removed weekly for analysis and calibration to the shell chemistry. Mortality is checked daily, and shells are removed and frozen immediately to be preserved for biochemical analyses. Additional experiments on salinity extremes and survivability have been conducted by increasing the salinity to 65 ppt. In the field, habitats are located close to water monitoring stations so data on water chemistry can be obtained. Animals are collected, tagged, digitally photographed, and placed in the habitat. Habitats are checked approximately every 90 days, and dead specimens are removed, saved for analysis, and replaced with a newly tagged and photographed specimen; live specimens are photographed and returned to the habitat.

Four instruments have been tested for analyzing the individual growth layers of mollusks: (1) SHRIMP—Sensitive High Resolution Ion Microprobe; (2) Cameca 4F SIMS – Secondary Ionization Mass Spectrometer; (3) LA-ICP-MS – Laser Ablation Inductively Coupled Plasma Mass Spectrometry; and (4) JEOL Electron Microprobe with multi-wavelength dispersive spectrometers (WDS). The same specimens of *Chione* have been analyzed on these instruments allowing for comparison. A specimen from the mouth of Little Madeira Bay (FB8-1) has been analyzed on the LA-ICP-MS, the JEOL, and the SHRIMP for Mg/Ca ratios. The similar results from all three instruments indicate that the techniques are comparable. A specimen from Bob Allen mudbank in central Florida Bay also was analyzed for Mg/Ca and for Sr/Ca on the LA-ICP-MS and the JEOL. The trends on the two machines are nearly identical as noted for specimen FB8-1. In addition, the Mg/Ca and Sr/Ca trends are parallel. Sr/Ca is primarily dependent upon salinity. Mg/Ca, however, depends on temperature and salinity, but it has been argued that in sub-tropical to tropical environments Mg/Ca primarily reflects salinity. Analyzing both ratios provides reassurance that salinity – the critical variable for this project – is the variable being measured.

After completing these analyses, it has been determined that there is no single best instrument. Each instrument is capable of detecting differences in Mg/Ca ratios in different areas of the *Chione* shells, and parallel trends in Mg/Ca and Sr/Ca indicate salinity is the primary controlling variable on Mg/Ca. Each instrument tested potentially has application to specific aspects of this study. The SHRIMP, JEOL, and LA-ICP-MS all produce comparable results for Mg/Ca ratios. The SHRIMP is the most expensive and least accessible, but the most accurate. The JEOL is the least expensive and the most accessible, but the least accurate. The Cameca is currently the only choice for isotopic analyses, except for micromilling, which we have not tested. The Cameca may be suitable for Mg/Ca analyses as well, but we have not adequately tested this capability. The next step is to complete testing of the Cameca using Woods Hole Oceanographic Institute instruments. Woods Hole is preferred because (1) they have machines that can do both isotopic and elemental analyses and (2) they work with biogenic carbonate materials and thus have the expertise to contribute to the interpretation of the resulting data.

Assuming the results on the Woods Hole machine are comparable to the other tested instruments, the plan is to begin detailed analyses of *Chione* from the experimental tanks and habitats early in Spring 2003, in order to calibrate shell chemistry to water chemistry. These tests will be followed up with analyses of *Chione* shells from cores collected throughout Florida Bay to determine historical seasonal patterns of salinity change. Salinity estimates derived from molluscan sclerochronology will be compiled with standard paleoecologic faunal and floral analyses of the cores and with Mg/Ca analyses of ostracode shells (see Cronin, et al. abstract, this volume). Combined, these biochemical and paleoecologic analyses of cores will provide an accurate picture of the patterns of salinity change in Florida Bay over the last 100-200 years.

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Patterns of Movement of Florida Gar (Lepisosteus platyrhincus) in the Everglades Revealed by Radio Telemetry

By Lawrence F. Wolski[1], Joel C. Trexler[1], Jason Knouft[2], Carl Ruetz III3[2], *and* William F. Loftus[4]

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To build credible simulation models for the Everglades fish community for use in the restoration process, information on fish movement patterns and habitat use is a critical need. In this pilot project, we are testing the feasibility of using implanted radio transmitters to trace the movements of Florida gar across the open Everglades landscape. Beginning in March 2002, we monitored the movements of Florida gar (fig. 1) in the Everglades Wildlife Management Area, Conservation Area No. 3A (WCA-3A). An initial group of 20 was monitored from March to July and monitoring of the second group of 20 began in August and is ongoing. We collected gar using standard electrofishing techniques from an airboat, weighing and measuring each gar as it was collected. Fish were anesthetized in a solution of MS-222 for surgical implantation of transmitters (SB-2, Holohil Systems, Ltd.). Transmitters were inserted into the body cavity of the gar through a ventral incision posterior to the pelvic girdle, which was closed with three to five sutures and SuperGlue (fig. 2). The transmitter size maximizes the range and lifespan of the transmitter but cause no harm or mechanical interference to the fish. Each fish was released at the point from which it was captured and was monitored for the lifetime of the transmitter (approximately 3 months for the first group of fish). We captured the fish in two widely separated areas of WCA-3A, one short-hydroperiod area to the west (site 3; 26.014 N, 80.82 W), and a second, longer hydroperiod area in central 3-A (site 1; 25.86 N, 80.73 W). We tracked the gar using a Wildlife Systems receiver from an airboat. Fish that were unable to be located from the airboat were tracked by helicopter or airplane.

Figure 1. The Florida gar, *Lepisosteus platyrhincus*.

We tracked gar from the first group an average of 52 days between transmitter insertion to the time of last field record (Max. = 128, Min. = 1). Fish tracked at site 1 were monitored for an average of 50.5 days (Max. = 128, Min. = 3) and moved an average of 2.62 kilometers from the point of release (Max. = 7.339, Min. = 0.010). The majority of fish moving long distances swam to the southeast (fig. 3). At site 3, the shorter hydroperiod site, the average tracking duration was nearly the same (54.8 days), but the average distance travelled was much less (0.913 km; Max = 2.96, Min. = 0.004). There was no trend in the direction of movements at that site, in contrast to the fish marked at site 1. This difference in movement may be related to local hydrology. At site 3, the gar travelled the greatestdistances during the periods of March 12–24 and June 16– July 1. Water depth at site 3 dropped substantially between March 24 and June 16 as the dry season progressed. Between May 6 and June 14, site 3 was unreachable because of low water levels. There was also a decrease in the distance per day travelled during this period (fig, 4), which was probably related to the declining water depths.

Figure 2: Ventral surface of gar after insertion of transmitter.

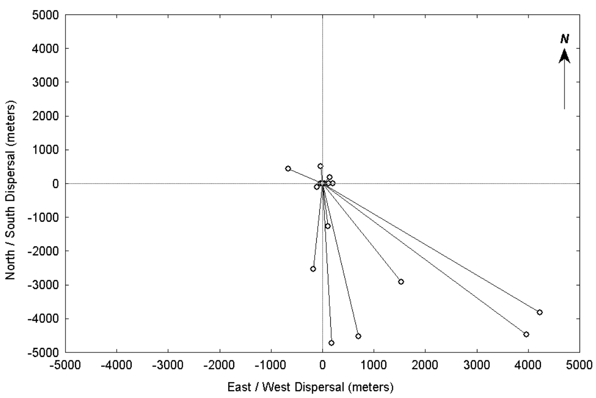

Figure 3. Gar dispersal from release point at Site 1.

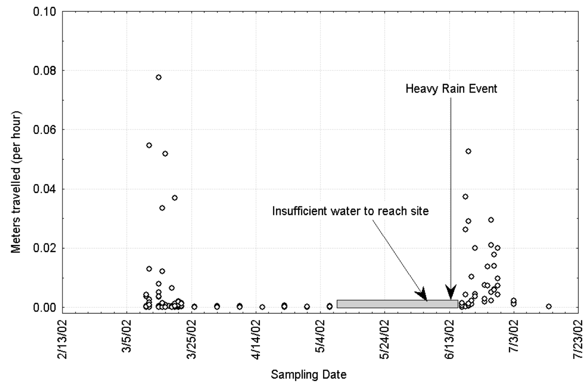

Figure 4. Distance traveled per hour for gar at Site 3.

We are presently monitoring a second group of gar at sites 1 and 3 that were tagged at the height of the 2002 wet season. We are tracking 14 individuals, of which four have moved beyond the range of our equipment. We believe this is a result of the deep, wet-season water depths that enable the gar to move longer distances than in the dry season.

In addition to long-term monitoring of the gar, we collected intensive diel movement and habitat-use data at both study sites by locating all fish at each site every 2 hours during a 24-hour period. As of November 2002, two diel studies have been completed from site 1 and two from site 3. Both diurnal sampling events from site 1 involved the most recent group of tagged gar, while at site 3, we collected one diurnal data set from each group. Preliminary analysis indicates that for 3 of the 4 tracks, there was no directional pattern to the movement of gar and no change between day and night movements. However, in one case (site 3, Group 1) the fish became more active at night and traveled longer distances. This coincided with shallow water depths at site 3; gar were found in alligator holes and deeper areas of the marsh during the day, moving into shallower areas during the night. This variation indicates that hydroperiod, and weekly variation in water depth at a particular site, play an integral role in the movement of gar. This study demonstrates the feasibility and effectiveness of using radio transmitters to describe movement patterns of large, mobile fishes across the wetland landscape. By collecting and analyzing movement data, we aim to develop a deeper understanding of survival, dispersal, and habitat use by these and other aquatic predators in the Everglades. This research was funded by a cooperative agreement between the U. S. Geological Survey and FIU, under the CESI initiative (CA 1445-CA09-95-0112, Sub-agreement No. 1). Mention of specific manufacturers does not imply endorsement.

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Body Condition Analysis for the American Alligator for Use in Everglades Restoration

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The American alligator (*Alligator mississippiensis*) is an integral part of the Everglades ecosystem. They effect and are affected by the landscape and changes in hydrology, which makes them an excellent organism to use in evaluating current Everglades restoration efforts. Information on alligators (census data, capture or morphometric data, blood chemistry, and reproduction statistics) has been collected in the Everglades since the 1950's. Available historical information includes a suite of life history characteristics and population parameters (health and condition, nesting effort, growth rate and survival, and density) that are useful for evaluating restoration. However, some life history traits (e.g. absolute density and survival) are difficult to accurately measure and can require decades of data to detect trends. In contrast, body condition can be measured using indices and requires less data to begin an analysis. If used properly, condition can be a useful monitoring tool to assess the health of a population and thus the health of its ecosystem. This project evaluated morphometric measurements taken for the American alligator, available condition indices and, using a stepwise process, recommends an appropriate index for use in ecological applications such as Everglades restoration.

Condition indices have been used to analyze the fitness of animal populations for the last 50 years. However, the indices are complex and can be used inappropriately if one is unfamiliar with the constraints. For example, condition for crocodilians has been calculated numerous times using Relative K (length/volume ratio), developed for fisheries in 1951 (LeCren 1951). Relative K is useful for comparing the condition of a population over time, but not appropriate among populations.

Alligators were captured during March, April, and October from 1999 to 2002 by a multi-agency team that consisted of members from U.S. Fish and Wildlife Service, U.S. Geological Survey, University of Florida, and the Florida Fish and Wildlife Conservation Commission. Study areas were A.R.M. Loxahatchee NWR (LNWR, 1 site), Water Conservation Areas 2 (WCA2, 1 site) and 3A (WCA3A, 2 sites), and Everglades National Park (ENP, 2 sites: ENP-SS Shark River Slough, ENP-EST Estuaries). Animals were captured from all study areas in marsh habitats only.

We analyzed morphometric measurements of the captured animals to determine which are measured most accurately and are appropriate for condition analyses. Condition indices are functions of a body length indicator and a volumetric measurement, and are only as accurate as the measurement used. Head length (HL), snout-vent length (SVL) and total length (TL) are suitable for body length indicators and tail girth (TG), neck girth (NG), chest girth (CG), and mass can all be used as volumetric measurements. We then compared four condition indices and two models of volume/length relations for their ability to distinguish between populations with known qualitative condition differences. Condition indices were Fulton's K, Relative K, a simple length/volume ratio, and relative mass. We also modeled volume/length with a residual index and ANCOVA.

It was determined through ANOVA/LSD analysis of the condition indices that the HL/Mass combination of Fulton's K and the SVL/Mass combination of ANCOVA were best able to distinguish differences in condition between areas of the Everglades. ANCOVA is best for determining temporal differences between populations. However, it cannot be used to compare differences across populations, unless strict assumptions can be met. HL/Mass Fulton's K can be used to spatially compare populations of the American alligator, and is suggested by this study as the best condition factor to use for that purpose.

Condition is a very fluid measurement. Water management practices and rainfall can dramatically change condition of animals in a relatively short amount of time, because so many aspects of their life history (feeding, courtship, and nesting) depend on seasonally fluctuating water levels. In this study, we found that ENP-SS alligators had the highest condition (fig. 1), but Dalrymple (1996) and Barr (1997) observed Shark Slough alligators to be in very poor condition only five or six years earlier. Water levels were high during capture periods for these earlier studies, possibly affecting food availability.

Because the alligator's life history is so closely linked to hydropattern, body condition can reflect the impacts of changes in hydrology. The condition indicies recommended here should provide a monitoring tool of alligator population health for the current restoration process.

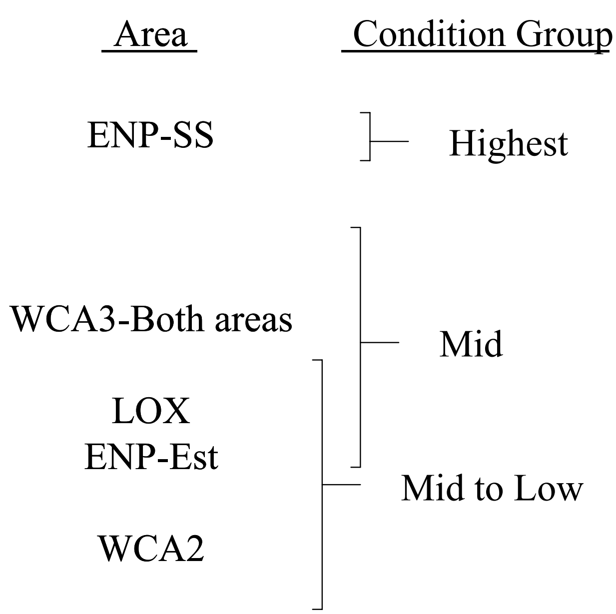

Figure 1. Hierarchy of body condition of alligators in several study sites in the Everglades of south Florida from 1999-2002 using a Fulton's K analysis (n = 395). Brackets indicate condition does not differ significantly within that group.

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LeCren, E. D. 1951. The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). Journal of Animal Ecology 20(2): 201-219.

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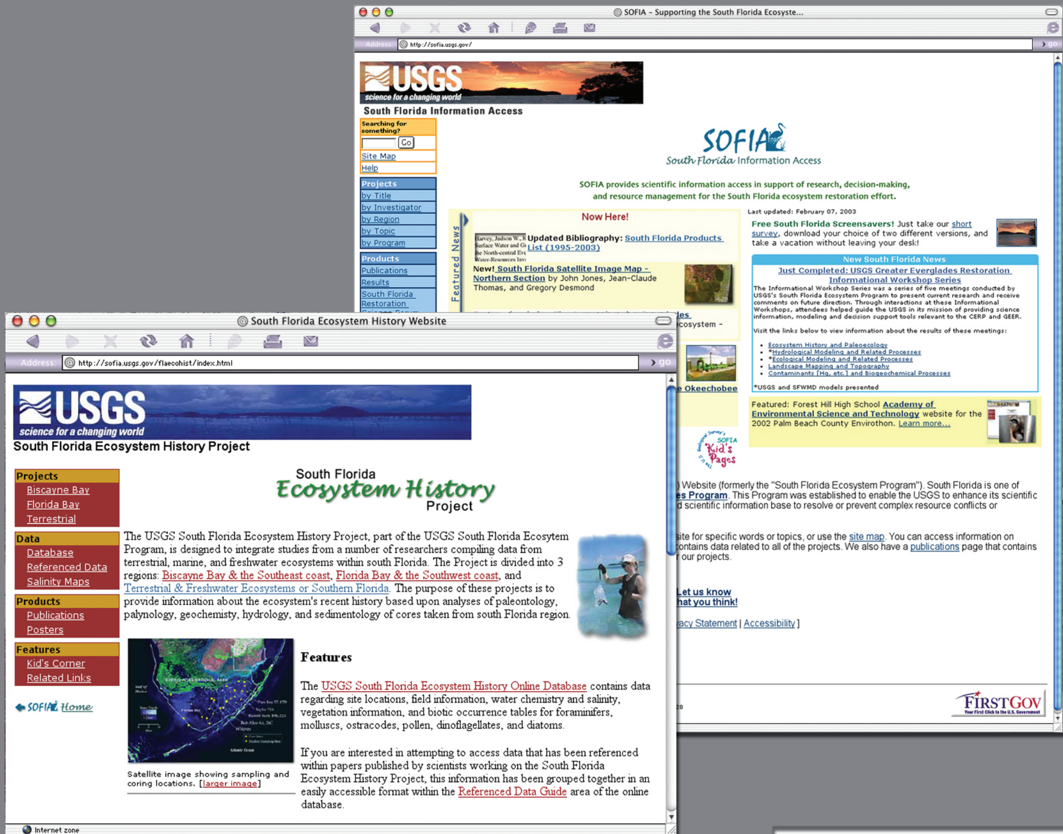

Section IV

Information Systems

Contents

Section IV: Information Systems

Development of Digital Aerial Photography Archives for the Greater Everglades of South Florida

By Peter R. Briere[1], Thomas J. Smith III[2], Ann M. Foster[3], Alisa W. Coffin[4], Ken Rutchey[5], John W. Jones[6], Carson Van Arsdall[6], *and* William B. Perry[7]

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Currently, a restoration effort, guided by the Comprehensive Everglades Restoration Plan (CERP), is underway in central and southern Florida. A basis for the restoration must be a clear understanding of pre-management wetland characteristics in order to establish a gauge for future performance and impacts of CERP. An increase in studies related to pre-management wetland characteristics has resulted in an increased demand for historical data from the Greater Everglades region. Aerial photographs provide one form of historical data documenting past effects of flood protection and water supply management measures on south Florida ecosystems.

More than 25,000 historical aerial photographs of the Everglades and south Florida, some flown as early as the mid 1920's, are known to currently exist in print or negative form at various locations. This estimate only includes photographs whose physical location is known and accessible, many of which are temporarily situated at the USGS Gainesville facility. The USGS Florida Integrated Science Center (FISC), in collaboration with USGS Eastern Region Geography, processed some of these photographs in 2001 and 2002 (see fig.1). The primary goals of this project were to (1) catalog available photographs in a database, (2) convert these print and negatives to digital form, (3) make the digital files readily accessible via publication, and (4) orthorectify the files for future spatial data analyses.

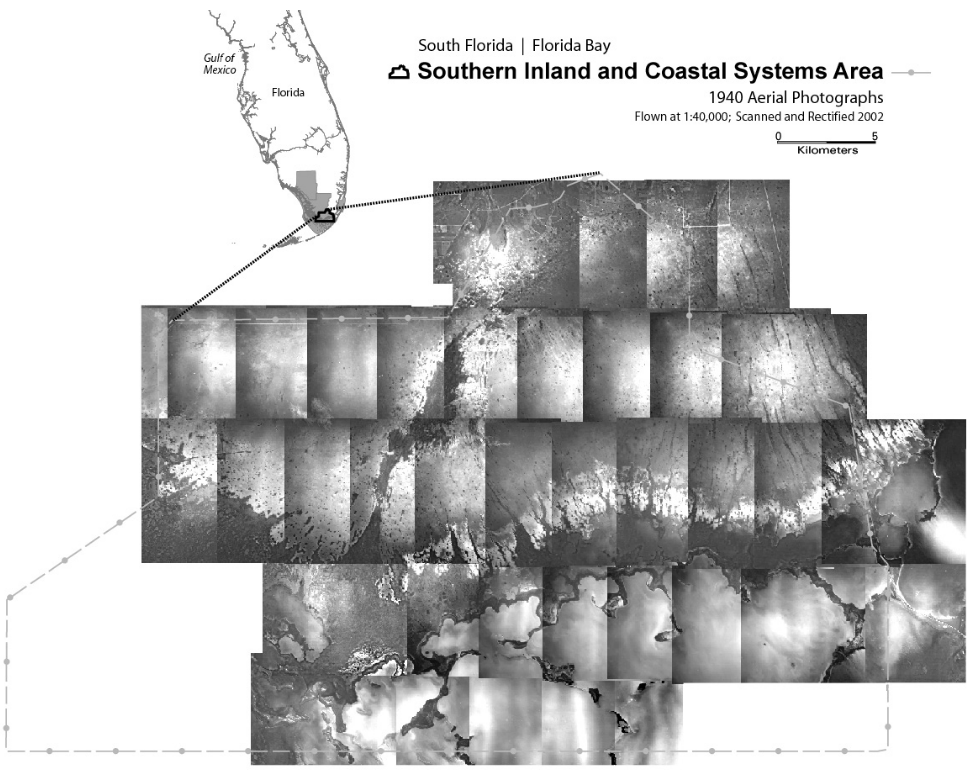

Figure 1. Example of 1940 Rectified Imagery, south Florida and Florida Bay.

To date, this effort has produced one USGS Open-File Report on CD-ROM with rectified 1927 topographic sheets (t-sheets). Other Open-File Reports containing digital files of 1940 and 1987 aerial photography are currently in review. Another report with 1964 aerial photography is being prepared. Over 8,000 entries have been added to the database, documenting quality and quantity of available photographs. More than 2,000 photographs have been scanned at 800 dots per inch (dpi) or close to 31.75 microns. Thousands more photos have been scanned at 300 dpi to generate mosaics that establish flight information. The mosaics and flight lines will also facilitate future orthorectification and are used for publication purposes.

Another related product resulted from the conversion of 820 digital ortho quarter quads (DOQQs) to 54 south Florida basemaps extending from Lake Okeechobee to Florida Bay. These basemaps are 2-meter resolution mosaics in contrast to the 1-meter DOQQs. Using 2m basemaps makes storage and retrieval more efficient compared to the DOQQs, and thus reduces the time necessary for orthorectification. Each basemap is a mosaic of 8-16 DOQQs derived from aerial photography flown in 1994.

The aerial photographs, converted to digital files and published so far, represent a segment of the existing prints and negatives available. Many aerial flights covered portions of the south Florida area and these photographs remain in analog form. A small technical staff of 1-3 may require 4-12 years of full-time effort to convert the remaining photographs to orthorectified and published form given current available hardware and software capabilities. This assumes future storage needs will be accounted for. An associated project will make all the digital images and linked attribute databases available via the Internet.

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Creation of a Geodatabase of the Digital Aerial Photography Archives for the Greater Everglades of South Florida and the Southern Inland and Coastal System

By Alisa W. Coffin[1], Heather Henkel[2], Heather Mounts[3], Peter R. Briere[4], Ann M. Foster[5], Thomas J. Smith[2], *and* Robert R. Wertz[2]

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The project to create a digital archive of historical aerial photographs for the Greater Everglades is an important first step in the development of an understanding of the pre-drainage vegetation in the south Florida landscape. This knowledge is essential in the development of “endpoints, restoration goals and performance measures to gauge restoration success” (Smith and Foster, 2002). Work on the digital archive has progressed with the creation of two open file reports publishing maps from 1927–35 and imagery from 1940 (Smith and others, 2002; in press). In addition to these two sets, scanning of photographs dating from 1952 and 1987 has progressed, with an open file report of the 1987 set due to be published in the near future.

Concurrent with the development of the digital archive, information about the photography was recorded in a relational database using Microsoft Access. The data recorded included information on the flight, the photography, the scanning process and detailed information on each individual photograph.

After scanning the photography, georeferenced mosaics of the flight lines were constructed indicating the general locations of the photography. From these mosaics, approximate center points of each photograph were recorded in the database, thereby providing general locations to which the photographic metadata could be linked (fig. 1). The utility of linking the metadata with physical locations became readily apparent. It would be even more useful if the metadata about the photograph could be linked to each georeferenced raster image in the archive.

It has always been the intention of the digital archives project to create georeferenced imagery of the south Florida photography. However, in order for the imagery to be useful as a tool, it must be integrated into a geographic information system (GIS). This presents a challenge to users because, as individual files, the raster images are very large thus limiting their use to small study areas, and effectively restricting their use in landscape-scale analyses. The challenge of incorporating raster images with large file sizes (for example, 160 MB) into a geographic information system is resolved in the ArcGIS geodatabase system using ArcSDE and Oracle database management software.

To test the geodatabase system as it applies to the Digital Aerial Photography Archives for the Greater Everglades of south Florida, a limited area

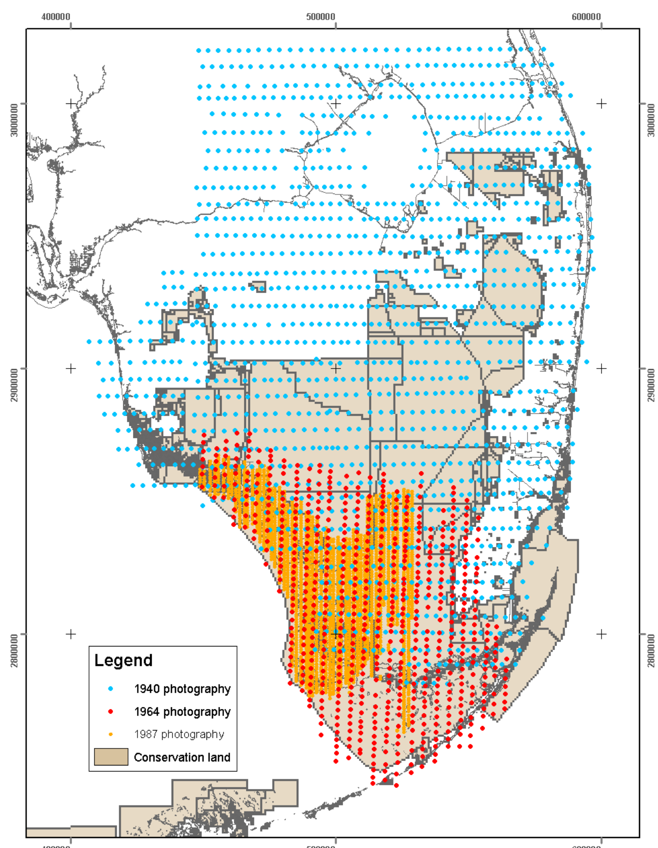

Figure 1. Map showing approximate center points of photography in the Digital Aerial Photography Archives for the Greater Everglades.

was selected as a pilot project. The project consists of a geodatabase that includes georeferenced raster imagery from 1940, 1964, and 1987 incorporated with tables of detailed information about the photographs. It also includes vector files and raster imagery of the T-sheets that are based on a 1927 aerial photographic survey (Smith and others, 2002). The selected area corresponds to the Southern Inland and Coastal System (Area 6) of the Everglades. The geodatabase is part of the South Florida Information Access (SOFIA) clearinghouse and can be searched and used free of charge by accessing the SOFIA web address (http://sofia.usgs.gov/exchange/).

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Poster, Information Systems

Data in the Key of ZZZ: Development of a Network to Establish Vertical Reference Datum for Research Stations in the Southwest Coastal Everglades

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Some of the most remote locations in all of the National Park Service system in the lower 48 states are located in the southwestern, coastal areas of Everglades National Park. Highland Point lies on the coast between the mouths of the Lostmans and Broad Rivers and is more than 40km from the nearest trail-head. This mangrove and marsh dominated coastal wilderness is at the southern end of the Everglades, where the "River of Grass" meets the Gulf of Mexico. It encompasses over a third of the Park's total acreage.

As the Comprehensive Everglades Restoration Plan (CERP) is implemented, questions have arisen related to monitoring restoration success in this region. Since 1996 the USGS/BRD has established and maintained a network of study sites for sampling hydrology, sediments and vegetation (fig 1). Benchmarks were established and set to a relative datum at a total of 13 hydrological stations. This network of benchmarks has been used as a starting point to develop a broader survey of vertical elevation. Thirteen of the benchmarks have been installed by driving a pipe to refusal, capping it, and setting the mark with cement to maintain a stationary point of occupation that is separate from the wooden platforms constructed for fieldwork measurements. Ten other control locations are temporary locations consisting of a PK nail hammered into the top of a hydrologic station platform with the assumption that the platform remains stable through time.

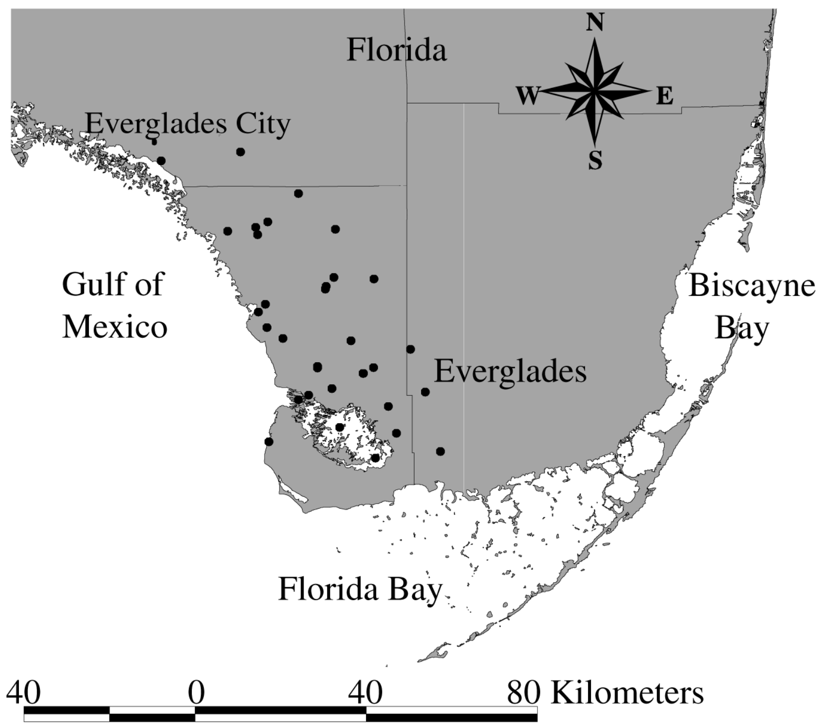

Figure 1. Graphic of south Florida displaying locations where benchmarks have been occupied to date for determination of the "key of Z."

The elevation factor Z is the critical variable for much of the work in the Everglades as well as Florida Bay and the Florida Keys Reef Tract. An accurate reliable key of Z is needed to convert field measurements into metrics that are cross-comparable. It also serves to satisfy the vertical variable in flow models. Essentially, an accurate elevation will become an established pivot point for data comparison among the scientific studies of various disciplines such as biology, water, remote sensing, and geology that are underway within the Everglades.

An accurate elevation for the Everglades portion currently exists for only one site of this network. To begin to bridge this gap, annual surveys have begun starting in June 2000 with long-term, repetitive occupation time from 8 hours to 24 hours upon selected benchmarks. These surveys are tied to the closest National Geodetic Survey (NGS) sites available having the best vertical control published. These sites include FLGPS Thompson, FLGPS GEB, and

Tidal 8724948EH7. The surveys will begin to establish a strong reliable network for the original 13 stations. High precision Ashtech GPS receivers and antennas are the instruments used for receiving the L1 and L2 signals from the satellite constellation which are then post processed to obtain the horizontal and vertical (XYZ) information for each benchmark. Thirty-four stations in total have been occupied in the last two years three of, which are NGS control points that will be the tie to the National Geodetic Survey's network.

Because technology is rapidly improving and this elevation survey is relatively young, the post processing method has been carried out using three different methods. The first method uses PNAV post processing software. This software calculates vectors between locations and based upon the repetition of vectors and their quality, it calculates coordinates for the location. The second method is Automated Gipsy by the Jet Propulsion Lab. This method can be applied when a location cannot be tied into an established network like an NGS location. Submission of long occupation times to Automated Gipsy will produce a location in an ITRF## format which can be transformed into NAVD88. The third method utilizes OPUS (Online Positioning User Service) located on the NGS website. This method requires submittal of a GPS file and OPUS determines the three best CORS stations (Continuously Operating Reference Station) for processing the location of the submitted file. Both OPUS and Automated Gipsy are automated and require minimal file preparation, whereas, PNAV is controlled solely by the user allowing choice selections of vector inclusion and exclusion to maintain accurate results.

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POSTER, Other Coastal Ecosystems

The South Florida Information Access (SOFIA) Website

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The south Florida ecosystem, encompassing the Kissimmee River Valley, Everglades, Florida Bay, urban areas, developed agricultural areas, rangelands, and wetlands, has been altered greatly over the past 100 years. Resource managers, Federal, State, and local agencies, and other groups are seeking to reverse environmentally damaging actions taken during that period. The U. S. Geological Survey (USGS) began a research program in support of the restoration of the Everglades and south Florida ecosystem in 1995. USGS personnel have been conducting research projects designed to provide sound scientific information upon which resource managers can base their decisions. The USGS also has recognized the need for a central site to provide all interested parties with information from this research and access to these data. The South Florida Information Access web site (SOFIA) was created as a 'one-stop-shopping' access point for research on south Florida. All USGS South Florida Place-Based Studies research projects, ranging from mercury contamination in the Everglades to coral reef decline, are online at this site. The site provides project descriptions, proposals, publications, data (through our data exchange site), presentations, and contact information, as well as general interest items, such as photographs and posters. The SOFIA site also is a portal through which you can access our extensive database and internet map server (IMS).

The SOFIA site has grown tremendously since its initial development in 1996. The site increased from fewer than 100 pages in 1996 to over 3,600 webpages in 2002. The site also contains over 250 publications: circulars, fact sheets, open file reports, lectures, papers, posters, and reports. Included are not only publications created by the south Florida program, but historical documents dating to the early 1970’s as well. This effort involves locating and digitally scanning historical documents from all disciplines. By 2003 we will have an extended search interface to our publications that will allow users to customize their searches based on a variety of parameters.

Within the last year, we have enhanced our data exchange site and added new sections to the site, including the ability to view projects by topic, region, scientists, or program. The data exchange site includes a variety of data, including hydrology, biology, ecology, mapping, and chemistry. We also maintain a robust metadata collection that is FGDC-compliant and acts as a member-node of the National Spatial Data Infrastructure (NSDI).

Figure 1. SOFIA’s current publications interface (2002).

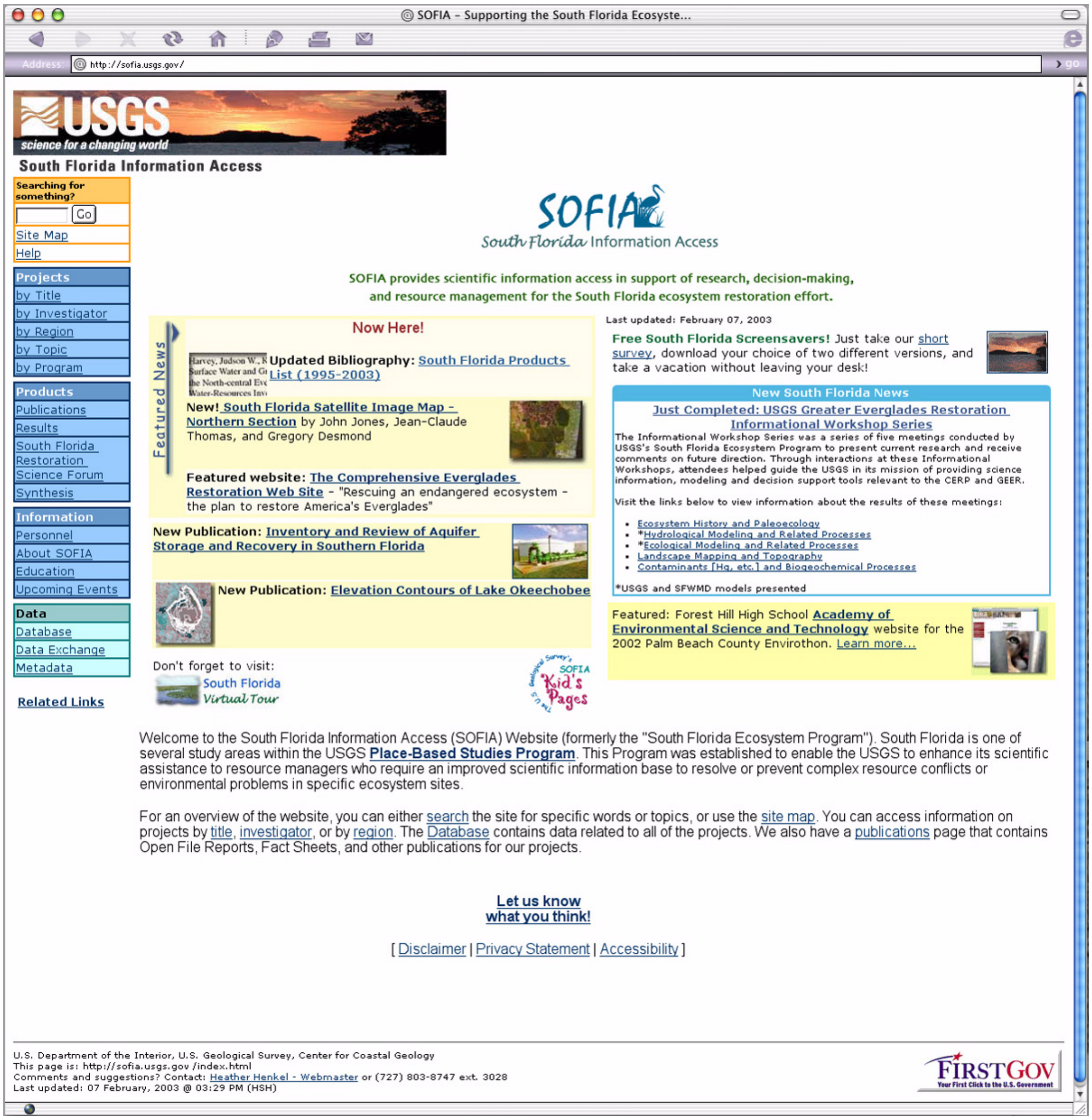

Figure 2. South Florida Information Access (SOFIA) homepage.

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The South Florida Satellite Image Map Series: A Tool for Research, Monitoring, and Education

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Satellite image maps provide an empirical foundation for the study of the temporally dynamic and spatially complex nature of Everglades land surfaces. They help laboratory and field scientists plan instrument placement and field experiments. They provide spatial context for the interpretation of data related to Everglades research, modeling, and restoration activities. They constitute baseline data for Everglades monitoring. Several satellite image maps covering the region south of Lake Okeechobee have been distributed as USGS Miscellaneous Investigations Series publications (Jones and Thomas, 2001; Thomas and Jones, 2002). Each map (for example, fig. 1) covers the largest area possible given high-quality, mass-printing limitations for 1:100,000 scale National Mapping Accuracy Standards. Every map was designed to meet a variety of needs. For example, the first publication (fig. 2) was constructed with both scientists and the general public in mind. Driven by research requirements, the boundaries of the western sheet encompass a focus area for hydrologic modeling. The eastern sheet allows the general public to view the urban development of the Atlantic Coast adjacent to the Everglades wetlands and contains descriptions of map development and interpretation in terms that can be understood by a broad spectrum of readers. Together, these two parts serve as an intuitive backdrop for discussion of important environmental, economic, and social issues. They allow viewers to understand some of the interrelations among Everglades wetland condition and agricultural, industrial, and residential activities. Some environmental features like the impact of fires and the status of nutrient removal areas are obvious (fig. 1). Others require closer image map inspection. For example, visual comparison of the first and third maps in the series uncovers subtle, high frequency variations. Their source images were collected only 9 days apart (that is, 2/5/00 and 1/27/00, respectively). However, water level data recorded in an area of image overlap show that water levels dropped approximately 8 cm over that short period (fig. 3), creating impacts that are detected with careful examination of full-resolution renditions of the image maps.

Figure 1. A thumbnail view of the Northern Everglades image map in the series of 1:100,000 scale image maps distributed in both printed and digital forms as part of the USGS Miscellaneous Investigations Series.

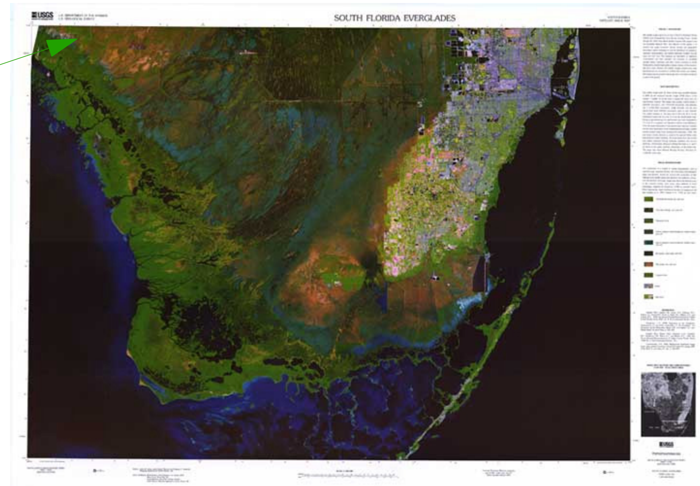

Figure 2. A mosaic of the two southern Everglades image maps in the series. While this area is printed on two 1:100,000 scale maps, the maps were combined before digital distribution.

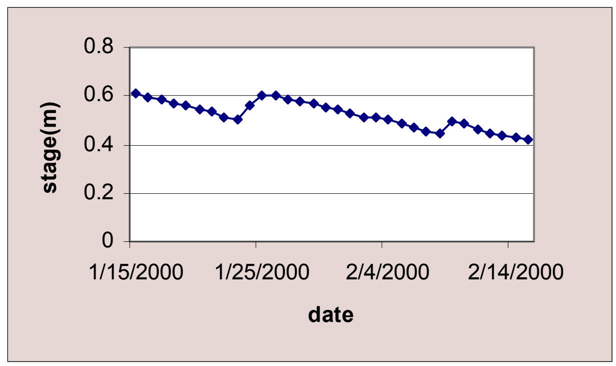

Figure 3. Recorded stage for one Big Cypress National Preserve station number 8.

The creation of such information-rich satellite image maps required a great deal of research and forethought. Multivariate statistical analysis was combined with the knowledge of remote sensing physics to select a combination of satellite measurements that yields desired colors, minimizes adverse impacts of the Earth's atmosphere on image clarity, and maximizes contrasts and information content. Image colors change as the data are transferred from digital to paper formats. Therefore, previous experience and repeated trials were used to further digitally manipulate the data to produce visually appealing, easily interpreted colors across all final image maps. Project research also developed a mathematical procedure to sharpen urban and other features by merging multiple satellite image data sets. To make the image maps as useful as possible in the field, the classroom, and the conference room, they have been made widely available in a variety of formats. Printed maps can be obtained at low cost through the U.S. Geological Survey Earth Science Information Center (1-888-ASK-USGS). In addition, following Library of Congress policies, printed image maps were scanned with sufficient resolution to reproduce them to scale without loss of information. Also, these output files were sub-sampled for other uses. Finally, one file for each map was converted to Geotiff format for use in Geographic Information Systems. Each map has been featured on the South Florida Information Access website upon publication, where all digital files are freely available (http://sofia.usgs.gov).

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South Florida Information Access System (SOFIA)

By Roy S. Sonenshein

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The South Florida Information Access (SOFIA) system was created by the U.S. Geological Survey (USGS) in 1995. Its mission is to provide easy access to information about research projects and products generated as part of the USGS South Florida Placed-Based Studies (PBS) and other Federal, state, and local science providers. SOFIA provides this service by integrating information systems and tools enabling efficient storage, organization, and search and retrieval of scientific information about the south Florida ecosystem.

A principal objective of the USGS South Florida PBS is to assist resource managers who require an improved scientific information base to resolve or prevent complex resource conflicts or environmental problems in southern Florida. SOFIA is an integral element of this program and is a primary resource for providing the USGS scientific information to resource managers and scientists working to preserve and restore the south Florida ecosystem. SOFIA was designed to benefit three major user groups: USGS program managers and scientists working with the South Florida PBS, managers and scientists working for other organizations involved with Everglades restoration, and members of the public interested in USGS research and/or the science behind the Everglades restoration effort. Program managers and scientists working within the South Florida PBS use the SOFIA website in various ways: (1) coordination and sharing of scientific research information; (2) access to announcements and registration links for upcoming workshops, conferences, and seminars; (3) monitoring of current ecosystem conditions through the real-time data pages; and (4) access to synthesis of topic-specific research results to benefit from lessons learned and avoid duplication of effort.

The users of the SOFIA site have a variety of interests and informational needs. Information is provided at many levels of detail, catering to users from a wide range of technical understanding. The general public uses the site to understand the problems and research behind Everglades restoration. The site provides information for children and adults, including summaries already adapted for use in classroom, museum, and other public venues, as wells as for journalists, government, and non-government organizations. SOFIA is used by stakeholders who follow USGS activities in the community and outdoorsmen to track research as well as monitor real-time conditions in planning activities.

SOFIA is an evolving and dynamic system that builds on the ever-increasing sophistication of new information technology. The current architecture consists of three tiers. The top tier is the web browser; the middle tier is the web server with business logic, and static web pages and data files; and the bottom tier is the SOFIA database. A map server using geographic information system (GIS) technology is being developed to provide a map-based interface to the database and the website.

Data is served by three mechanisms on the SOFIA website. The Data Exchange (URL http://sofia.usgs.gov/exchange/) provides access to files organized by project. The projects are further organized using six primary themes: biology, chemistry, ecology, geology, hydrology, and mapping. Data are stored in various file formats, such as ASCII text files, spreadsheets, and databases. For each data set, additional information is provided, including a description of the method of data collection, an explanation of the data file format, and a listing and a map of the data collection locations. The Data Exchange provides an efficient means of providing data to users who are familiar with a project and would like to obtain the project data sets.

The second mechanism of serving data is through a web interface (URL http://www.envirobase.usgs.gov) to an SQL-based database. The SOFIA database is currently being developed using PostgeSQL 7.2 as the database engine. The web interface is being developed using PHP, a server-side scripting language developed for the web. The database consists of over 50 tables, providing a means of storing the data and associated metadata. Included in the tables are the data values as well as information about methods of data collection, data-collection locations, and associated projects, publications, and photographs. Many of the database objects provide links to related information on the SOFIA website.

The third mechanism of serving data is through a web-based map server. The map server, which is being developed using ArcIMS software, will provide a means of accessing information stored in the SOFIA database and the SOFIA data exchange website through a geospatial query. The spatial data will be served using the ArcSDE software, which provides a mechanism for storing spatial data in a relational database. The spatial database will contain point data sets showing data-collection locations presented on the SOFIA website, published maps, such as bathymetric contours, geologic surfaces, and vegetation grids, as well as background data sets, such as political boundaries, hydrography, and roads. The map server will provide access to related information stored on the SOFIA website and in the SOFIA database.

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Metadata for the U.S. Geological Survey Greater Everglades Place-Based Studies

By Jo Anne Stapleton

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The south Florida ecosystem, encompassing Everglades National Park, urban areas on the coast, intensely developed agricultural areas, rangelands, and wetlands, has been altered greatly over the last 100 years. In 1995, the U.S. Geological Survey (USGS) began a research program in support of the restoration of the Everglades and south Florida ecosystem. Early in the program, the need for information to document the projects and later the resulting datasets was recognized. Metadata allow for the documentation and discovery of data. They also provide lasting information about the data in the event the data producer is no longer available. Use of standardized terminology facilitates searches for data by all users.

In 1994, Executive Order 12906 was issued, which mandated that digital data produced by a Federal agency be documented with metadata specified by the Federal Geographic Data Committee (FGDC) Content Standards for Digital Geospatial Metadata. Members of the South Florida Information Access (SOFIA) metadata team conducted a survey of the project chiefs on the usefulness of metadata and their willingness to provide FGDC-compliant metadata for their projects and datasets. The overwhelming majority of the respondents agreed that metadata were very important, but funds and personnel were needed to create the metadata. Furthermore, most of them felt that the FGDC standard was confusing and cumbersome to use. The survey results led to the decision to create a metadata team for generating the required metadata. This would result in more consistent metadata, and the scientists would not have to become familiar with the FGDC standard to document only one or two projects or datasets a year.

The initial metadata records were created by interviewing the project chiefs and using their project proposals to fill in the elements in the FGDC standard. The project chiefs then reviewed the resulting records and the team made the indicated changes or corrections. The records were then posted on the SOFIA web site and indexed for searching on the FGDC National Spatial Data Infrastructure (NSDI) node as the south Florida Ecosystem database.

Several methods have been used to create the FGDC metadata records. Initially, a template was created using a word processing program. The required FGDC elements were populated, and the file was output in ASCII text format. For the last several years, the commercial software program Spatial Metadata Management System (SMMS) has been used. SMMS is currently a product of the Intergraph Corporation. This program is not perfect but is a great improvement over the word processing template. Output from this program is also in ASCII text for input to the USGS program “mp,” which is used to parse the metadata records for conformance with the correct parent-child relationships for FGDC metadata. This program also allows output of the records in various formats, such as the outline or standard FGDC format, a question and answer format that uses “plain English” statements for the metadata information, SGML to index the records for the FGDC NSDI node, ASCII text, XML, and several other formats not used on SOFIA. Other options for creating metadata include USGS in-house software XTME for UNIX-based systems and TKME for Windows-based systems. Metadata created from a word processing template must be run through preparser software “cns,” also from the USGS. This program formats ASCII text files into the outline format for input to mp.

Current work on the metadata involves updating the project records and creating records for all the datasets available on the Data Exchange pages on SOFIA. Information to update the metadata is being gleaned from project annual summaries, proposals, work plans, and published reports, such as USGS Open-File Reports, Water Resources Investigations Reports, fact sheets, conference abstracts, and journal papers. The updated records are sent to the project chiefs for review. Recently, the SOFIA program manager decided to document types of data rather than individual datasets. This necessitates combining records already on SOFIA into one record for each type of data collected by a project chief. It also will reduce the number of metadata records to be maintained. The plan is to have all fiscal year (FY) 2003 projects documented with FGDC-compliant metadata by the GEER conference in April

2003. By the end of the fiscal year, the data sets for FY03 will also have current FGDC metadata records. Metadata for projects and datasets that have been completed also will be updated but at a lower priority. Another lower priority goal is to document relevant historical datasets with metadata to enhance the ability to do time-series studies for the Everglades area. Links will be provided to other organizations' metadata applicable to the Everglades restoration effort.

Undocumented data are of little use other than to the collector. Information about the data must be available to ensure its future use. The FGDC metadata standard provides standardized element names and information. This allows potential users to search for and evaluate the data for their use. It also preserves the usefulness of the data if the original data collector leaves the organization. Data generated by the USGS as part of the research into the Everglades restoration effort need to be available to other researchers in the future and will enhance data collection efficiency. Documenting projects and datasets with proper metadata can help prevent duplication in data collection.

Information on XTME, TKME, cns, and mp can be found at http://geology.usgs.gov/tools/metadata/.

An explanation of Metadata in plain language can be found at http://geology.usgs.gov/tools/metadata/tools/doc/ctc/.

The FGDC metadata standard is available at http://www.fgdc.gov/metadata/contstan.html.

Information on SMMS is available at http://www.intergraph.com/gis/smms/.

The metadata for the USGS Place-Based Studies research in south Florida are on the SOFIA Web site at http://sofia.usgs.gov/.

Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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Section V

Fact Sheets and Flyers

Contents

Section V: Fact Sheets and Flyers

Fact Sheets and Flyers Produced under the Greater Everglades Science Program: Place-Based Studies Initiative

By Heather S. Henkel[1], Arturo E. Torres[2], G. Ronnie Best[3], Aaron L. Higer[4], *and* Robert Mooney[5]

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The Greater Everglades Science Program: Place-Based Studies Initiative has produced a total of about 475 publications (see Section V- Bibliography in this volume) during the period 1995-2002. Among this total, 85 Fact Sheets and Flyers have been produced to summarize some of the major accomplishments of the Greater Everglades Science Program. The Fact Sheets and Flyers are organized according to the restoration objectives of the South Florida Ecosystem Restoration Task Force: (1) **Getting the Water Quantity Right**, (2) **Getting the Water Quality Right**, (3) **Preserving Natural Habitats and Species,** and (4) **Information Availability.**

The history of the USGS Greater Everglades Science Program: Place-Based Studies Initiative is summarized in the three Fact Sheets listed below. This program, developed by USGS scientist Aaron L. Higer in 1995, was initially known as the South Florida Ecosystem Program. Upon Higer's retirement in 2000, USGS scientist Dr. G. Ronnie Best has served as coordinator of the Greater Everglades Science Program.

1. USGS and The Everglades Ecosystems http://www.fcsc.usgs.gov/Fact_Sheets/everglades.pdf
2. USGS Science for Restoration of South Florida: The South Florida Ecosystem Program (FS-61-99) http://sofia.usgs.gov/publications/fs/61-99
3. South Florida Ecosystem Program (FS-134-95) http://sofia.usgs.gov/publications/fs/134-95

GETTING THE WATER QUANTITY RIGHT—The 18 Fact Sheets listed below provide a general description on establishing the volume, quantity, timing and distribution of surface and ground waters to approximate pre-and development conditions.

1. Comparison of the South Florida Natural System Model with Pre-canal Everglades Hydrology Estimated from Historical Sources (FS-187-96) / http://sofia.usgs.gov/publications/fs/187-96
2. Coupling Models for Canal and Wetland Interactions in the South Florida Ecosystem (FS-139-96) http://sofia.usgs.gov/publications/fs/139-96
3. Examining Freshwater-Saltwater Interface Processes with Four Radium Isotopes (FS-065-99) http://sofia.usgs.gov/publications/fs/65-99
4. Freshwater Discharge to Florida Bay (FS-135-96) http://sofia.usgs.gov/publications/fs/135-96
5. Gauging Flows in Northeastern Florida Bay (FS-130-96) http://sofia.usgs.gov/publications/fs/130-96
6. Geophysical Mapping of Freshwater/Saltwater Interface (FS-173-96) http://sofia.usgs.gov/publications/fs/173-96
7. Ground-Water Discharge to Biscayne Bay (FS-131-96) http://sofia.usgs.gov/publications/fs/131-96
8. Hydrogeology of the Surficial Aquifer System in Southwest Florida (FS-158-96) http://sofia.usgs.gov/publications/fs/158-96

9. Internal Surface Water Flows (FS-175-96) http://sofia.usgs.gov/publications/fs/175-96

. An Investigation of the Interrelation of Everglades Hydrology and Florida Bay Dynamics to Ecosystem Processes in South Florida (FS-049-01) http://sofia.usgs.gov/publications/fs/49-01

10. Magnitude and Distribution of Flows into Northeastern Florida Bay (FS-030-00) http://sofia.usgs.gov/publications/fs/030-00

11. Quantifying Freshwater Discharge for Coastal Hydraulic Structures in Eastern Dade County, Florida (FS-123-96) http://sofia.usgs.gov/publications/fs/123-96

12. Regional Evaluation of Evapotranspiration in the Everglades (FS-168-96) http://sofia.usgs.gov/publications/fs/168-96

13. Review and Evaluation of a Model for Simulating the Natural Hydrology of South Florida (FS-180-96) http://sofia.usgs.gov/publications/fs/180-96

14. Seepage Beneath Levee 30 in Northern Dade County (FS-132-96) http://sofia.usgs.gov/publications/fs/132-96

15. The Tides and Inflows in the Mangroves of the Everglades (TIME) Interdisciplinary Project of the South Florida Ecosystem Program (FS-031-01) http://water.usgs.gov/pubs/FS/fs-031-01

16. Vegetation Affects Water Movement in the Florida Everglades (FS-147-96) http://sofia.usgs.gov/publications/fs/147-96

17. Vertical Exchange of Ground Water and Surface Water in the Florida Everglades (FS-169-96) http://sofia.usgs.gov/publications/fs/169-96

GETTING THE WATER QUALITY RIGHT—The 17 Fact Sheets and Flyers listed below provide a general description on reducing or eliminating pollutants and other undesirable substances from the water.

1. Geochronology of Terrestrial Sediments: South Florida ttp://sofia.usgs.gov/publications/fs/sed_geochron
2. Interactions of Mercury with Dissolved Organic Carbon in the Florida Everglades (FS-186-96) http://sofia.usgs.gov/publications/fs/186-96/
3. Mercury and Periphyton in the South Florida Ecosystem (FS-184-96) http://sofia.usgs.gov/publications/fs/184-96
4. Mercury Contamination of Aquatic Ecosystems (FS-216-95) http://water.usgs.gov/wid/FS_216-95/FS_216-95.html
5. Mercury Studies in the Florida Everglades (FS-166-96) http://sofia.usgs.gov/publications/fs/166-96
6. Methodology for the Determination of Nutrient Loads to East Coast Canals (FS-129-96) http://sofia.usgs.gov/publications/fs/129-96
7. Methyl-Mercury Degradation in Florida Everglades Peat-Sediment http://sofia.usgs.gov/publications/fs/bactdem
8. Remote Sensing of Turbidity and Sedimentation http://sofia.usgs.gov/publications/fs/sed_turbidity
9. Sedimentation, Sea-Level Rise, and Circulation in Florida Bay (FS-156-96) http://sofia.usgs.gov/publications/fs/156-96
10. Short-Lived Isotopic Chronometers (FS-73-98) http://sofia.usgs.gov/publications/fs/73-98
11. South Florida Ecosystems: Changes Through Time (FS-171-95) http://sofia.usgs.gov/publications/fs/171-95

12. South Florida Wetlands Ecosystem: Biogeochemical Processes in Peat http://sofia.usgs.gov/publications/fs/wetland_seds
13. South Florida ecosystems – The Role of Peat in the Cycling of Metals (FS-161-96) http://sofia.usgs.gov/publications/fs/161-96/
14. Summary of Data from Onsite and Laboratory Analyses of Surface Water and Marsh Porewater from South Florida Water Management District Water Conservation Areas, The Everglades, South Florida, March 1995 http://sofia.usgs.gov/publications/fs/merc_carbon
15. Taylor Slough and Eastern Florida Bay: Geochemical Studies in Support of Ecosystem Restoration in South Florida http://sofia.usgs.gov/publications/fs/taylor_slough
16. Water Flows and Nutrient Loads to the Southwest Coast of Florida (FS-179-96) http://sofia.usgs.gov/publications/fs/179-96
17. Water-quality assessment of southern Florida-wastewater discharges and runoff (FS-032-98) http://fl.water.usgs.gov/Abstracts/fs032-98_marella.html

PRESERVING NATURAL HABITATS AND SPECIES—The 40 Fact Sheets and Flyers listed below provide a general description on providing the needs of the diverse flora and fauna of this ecologically unique area

1. Across-Trophic-Level-System Simulation (ATLSS) Program http://www.fcsc.usgs.gov/atlssflier.pdf
2. ATLSS High Resolution Topography and Hydrology Model http://fl.water.usgs.gov/cesi/ddl_highresmodeling_proj.htm
3. ATLSS PanTrack Tool Enables Visualization of Florida Panther Movements http://fl.water.usgs.gov/cesi/ddl_pantrack_proj.htm
4. American Alligator Population Ecology http://www.fcsc.usgs.gov/Fact_Sheets/riceflierv2.pdf
5. Amphibian Inventory of Everglades National Park and Big Cypress National Preserve http://www.fcsc.usgs.gov/posters/Everglades/Amph_ENP_and_BICY/amph_enp_and_bicy.html
6. Amphibian Inventory of the National Parks of South Florida and the Virgin Islands http://www.fcsc.usgs.gov/posters/Everglades/Amph_Virgin_Islands/amph_virgin_islands.html
7. An Assessment of Potential Contaminant Effects on Freshwater Mussels in the South Florida Ecosystem http://www.fcsc.usgs.gov/posters/Ecotoxicology/Contaminants_Effect_Mussels/contaminants_effect_mussels.html
8. Compilation of America Alligator Data Sets in South Florida for Restoration Needs http://fl.water.usgs.gov/cesi/rkg_americanalligator_proj.htm
9. Corals Record the Water Runoff History of South Florida http://sofia.usgs.gov/publications/fs/139-96
10. Dispersal and Successional Patterns of the Fish Community of the Rocky Glades of Southern Florida http://www.fcsc.usgs.gov/posters/Everglades/Rocky_Glades/rocky_glades.html
11. Ecosystem History of Biscayne Bay and the Southeast Coast (FS-145-96) http://sofia.usgs.gov/publications/fs/145-96
12. Ecosystem History of Florida Bay (FS-144-96) http://sofia.usgs.gov/publications/fs/144-96
13. Ecosystem History: Terrestrial and Fresh-water Ecosystems of Southern Florida (FS-146-96) http://sofia.usgs.gov/publications/fs/146-96
14. Ecotoxicology Program - Florida Caribbean Science Center http://www.fcsc.usgs.gov/EcotoxProgBrochure.pdf
15. Effects of the Nonindigenous Treefrog, Osteopilus septentrionalis, on Native Hylids in Protected Areas of South Florida http://www.fcsc.usgs.gov/posters/Everglades/Cuban_Treefrog/cuban_treefrog.html

16. Empirical and Modeling Studies in Support of Florida Bay Ecosystem Restorationhttp://www.fcsc.usgs.gov/Fact_Sheets/robblee.pdf
17. Everglades Ecosystem Restoration - Florida Apple Snail
http://www.fcsc.usgs.gov/Fact_Sheets/apple_snail.pdf
18. Fire Ecology of South Florida Pinelands
http://www.fcsc.usgs.gov/Fact_Sheets/snyderflier.pdf
19. Florida Caribbean Science Center: Restoration Ecology Branch: Major Research Areas And Initiatives
http://sofia.usgs.gov/publications/fs/res_eco/
20. Home Range and Movement of Alligators in the Everglades
http://www.fcsc.usgs.gov/posters/Everglades/Home_Range_Alligators/home_range_alligators.html
21. Influence of Hydrology on Life-History Parameters of Common Freshwater Fishes from Southern Florida
http://fl.water.usgs.gov/cesi/lwf_influence_proj.htm
22. Life History Parameters and Population Dynamics of Freshwater Fishes of South Florida Canal Systems
http://www.fcsc.usgs.gov/posters/Everglades/Fish_Life_History/fish_life_history.html
23. Mangrove prop-root habitat as essential fish habitat in northeastern Florida Bay
http://www.fcsc.usgs.gov/posters/Coastal_Ecology/Mangrove_prop_root/mangrove_prop_root.html
24. Modeling Alligator Production Probabilities in the Everglades
http://www.fcsc.usgs.gov/posters/Everglades/Alligator_Production/alligator_production.html
25. Modeling Fish Population and Biomass on the Everglades Landscape (ALFISH)
http://fl.water.usgs.gov/cesi/ddl_modelingfish_proj.htm
26. Modeling Hurricane Effects on Mangrove Ecosystems (FS-095-97)
http://sofia.usgs.gov/sfrsf/rooms/coastal/hurrfs.html
27. Modern and Historical Bathymetry of Florida Bay (FS-096-98)
http://sofia.usgs.gov/publications/fs/96-98/print.html
28. Nonindigenous Fishes of Florida, With a Focus on South Florida
http://www.fcsc.usgs.gov/posters/Nonindigenous/Nonind_Fish_of_Florida/nonind_fish_of_florida.html
29. Nonindigenous Species Introduced into South Florida
http://www.fcsc.usgs.gov/posters/Nonindigenous/Nonind_Species_Introduced/nonind_species_introduced.html
30. SIMSPAR Model Simulates the Impact of Hydrology on the Cape Sable Seaside Sparrow
http://fl.water.usgs.gov/cesi/ddl_simspar_proj.htm
31. Sirenia Project: Manatee Ecology and Population Biology
http://www.fcsc.usgs.gov/manateeecology.pdf
32. Studies of aquatic community structure and dynamics in the seasonally variable wetlands of southern Florida
http://www.fcsc.usgs.gov/Fact_Sheets/loftus.pdf
33. Studies Supporting Restoration of Mangrove Habitat in Everglades National Park: Faunal Component
http://www.fcsc.usgs.gov/Fact_Sheets/mcivor.pdf
34. The Swamp Eel: A New Invasive Fish
http://sofia.usgs.gov/publications/fs/swampeel/
35. The Effects of Canals on Alligators in the Everglades
http://www.fcsc.usgs.gov/posters/Everglades/Effects_of_Canals/effects_of_canals.html
36. The Effects of Harvest on Pig Frog Populations from the Everglades
http://www.fcsc.usgs.gov/posters/Everglades/Pig_Frog_Populations/pig_frog_populations.html
37. Thermoregulation of the American Alligator in the Everglades
http://www.fcsc.usgs.gov/posters/Everglades/Alligator_Thermoregulation/alligator_thermoregulation.html

38. Vegetation and Hydrology of Land-Margin Ecosystems
http://www.fcsc.usgs.gov/Fact_Sheets/smithflierv2.pdf
39. U.S. Coral Reefs - Imperiled National Treasures (FS-25-02)
http://geopubs.wr.usgs.gov/fact-sheet/fs025-02
40. Using Proportion of Area Occupied to Estimate Abundance of Amphibian Species in Everglades National Park
http://www.fcsc.usgs.gov/posters/Everglades/Amph_PAO/amph_pao.html

INFORMATION AVAILABILITY—The 7 Fact Sheets and Flyers listed below provide a general description on exchanging information regarding programs, projects, and activities to promote ecosystem restoration and maintenance - through South Florida Information Access (SOFIA)

1. Color Infrared Digital Orthophoto Quadrangles for the South Florida Ecosystem Area (FS-163-96)
http://sofia.usgs.gov/publications/fs/163-96
2. Florida Cooperative Mapping Project
http://sofia.usgs.gov/publications/fs/flcoopmap/
3. A GIS Interface for Environmental System Analysis: Application to the South Florida Ecosystem (FS-193-97)
http://sofia.usgs.gov/publications/fs/193-97
4. Reflectance Calibrated Digital Mulitspectral Video: A Test-Bed for High Spectral and Spatial Resolution Remote Sensing http://sofia.usgs.gov/publications/fs/remote_sens
5. South Florida Ecosystem Program Ecosystem Database Development (FS-174-96)
http://sofia.usgs.gov/publications/fs/174-96/
6. South Florida High-Accuracy Elevation Data Collection Project (FS-162-96)
http://sofia.usgs.gov/publications/fs/162-96
7. Web Site Fact Sheet (FS-155-96)
http://sofia.usgs.gov/publications/fs/155-96/

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