Florida Bay Program & Abstracts

Joint Conference on the Science and Restoration of the Greater Everglades and Florida Bay Ecosystem

"From Kissimmee to the Keys"

April 13-18, 2003

Westin Innisbrook • Palm Harbor, Florida

Program Management Committee

Florida Bay and Adjacent Marine Systems
Science Program
www.aoml.noaa.gov/flbay/

Welcome to Florida Bay!

On behalf of the Florida Bay and Adjacent Marine Systems Program Management Committee (PMC), I welcome you to the fifth Florida Bay Science Conference. For the first time, the Florida Bay Science Conference is being held jointly with the Greater Everglades Ecosystem Restoration Conference.

As you know, the purpose of this joint conference is to provide a forum for physical, biological, and social scientists to share their knowledge and research results concerning restoration of the Greater Everglades and Florida Bay Ecosystem. Furthermore, this conference is designed to bring these scientists together with engineers, managers and regulators who are actively involved in all aspects of restoration. This week, we will all have the unique opportunity to interact with participants that work throughout the entire ecosystem, ***"from Kissimmee to the Keys".*** I encourage everyone to take the opportunity to meet new colleagues and learn about the entire ecosystem.

The following pages provide a background and overview of the Florida Bay segment of the conference. Please take a few moments to review this information and familiarize yourself with what is in store throughout the week. I would also like to thank Beth Miller-Tipton and her staff at the University of Florida/IFAS Office of Conferences and Institutes (OCI) for their tireless efforts to organize this conference. Their advice is truly appreciated.

Again, welcome to the conference, and please let me or any member of the OCI staff know if you need our assistance.

John H. Hunt
Co-Chair
Florida Bay PMC

<u>Conference Organizing Committee</u>

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Ms. Beth Miller-Tipton*,* Director, University of Florida/IFAS, Office of Conferences & Institutes (OCI), Building 639 Mowry Road, PO Box 110750, Gainesville, FL 32611; PH: (352) 392-5930; FAX: (352) 392-9734; Email: bmiller-tipton@mail.ifas.ufl.edu; WEB SITE: http://conference.ifas.ufl.edu

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Abstract Book Organization

Abstracts are divided by Question Number and are listed in alphabetical order by presenting author's last name, which appears in bold. This publication will also be available online after the conference at the following web site: **http://www.aoml.noaa.gov/flbay/abstracts.html**. Abstracts from all previous Florida Bay Science Conferences are also available through this site. For information about the Florida Bay Web Site, please contact DawnMarie Welcher at NOAA/AOML/OCD, 4301 Rickenbacker Causeway, Miami, FL 33149, PH: (305) 361-4388, FAX: (305) 361-4392, E-Mail: **welcher@aoml.noaa.gov**. Additional information on marine science and restoration can be obtained by contacting Florida Sea Grant, Florida Bay Education Office, 93911 Overseas Highway, Tavernier, FL 33070. PH 305-853-3592; FAX 305-853-3595.

Discussion Periods

As one of the primary purposes of the Florida Bay Science Conference is to promote the free exchange of technical information by scientists, discussion periods are scheduled at the end of each topical session to allow for questions and comments. Scientists working in the Bay should be available following each session to field questions and participate in discussion.

Presentation Format

The conference returns to its roots this year. Four sessions, each with seven or eight oral presentations, will be held based on the five central questions of the Florida Bay Strategic Science Plan. Additionally, a poster session centered around the central questions will be held. Please view our strategic plan at **http://www.aoml.noaa.gov/flbay**. Each session will be introduced by briefly reviewing the state of knowledge about each central question and introducing a suite of questions submitted by our Science Oversight Panel regarding each central question. These questions and the oral presentations will form the framework for the 45-minute discussion period at the end of each session.

Poster Session Information

Posters will be displayed throughout the conference by topical question as outlined in the agenda. **Poster displays MUST be set up and removed by the times indicated on the program agenda.** The conference is not responsible for the loss of or damage to poster displays not taken down by the specified time.

Conference History and Organization

The Florida Bay Science Conference provides an opportunity for scientists to exchange technical information, share that information with resource managers and other interested conference attendees, and establish collaborative partnerships. As in our past conferences, the sessions are organized around the five major questions that are recognized as central to understanding the problems affecting Florida Bay. Posters are organized similarly. The Florida Sea Grant College Program organized the first Florida Bay Science Conference in 1995 and successive conferences were held in 1998, 1999, and 2001.

Conference Objectives

The objectives of the Florida Bay Science Conference are to:

- Provide a forum for the advancement of knowledge regarding Florida Bay
- Synthesize results of research and model simulations
- Provide scientific information useful for restoration

Central Questions

On the advice of the Florida Bay Science Oversight Panel, the PMC has defined a series of core or central research questions to provide a framework for establishing program priorities. The five questions posed are discussed below in terms of the information and modeling needs considered critical for program success. All are tied to achieving a comprehensive knowledge of the Bay as a complex ecosystem that has undergone profound changes in its recent past.

Question 1: *How and at what rates do storms, changing freshwater flow, sea level rise, and the local evaporation/precipitation patterns influence circulation and salinity patterns within Florida Bay and outflows from the Bay to adjacent waters?*

Question 2: *What is the relative importance of the advection of exogenous nutrients, internal nutrient cycling including exchange between water column and sedimentary nutrient sources, and nitrogen fixation in determining the nutrient budget for Florida Bay?*

Question 3: *What regulates the onset, persistence and fate of planktonic algal blooms in Florida Bay?*

Question 4: *What are the causes and mechanisms for the observed changes in seagrass community of Florida Bay? What is the effect of changing salinity, light and nutrient regimes on this community?*

Question 5: *What is the relationship between environmental change, habitat change and the recruitment, growth, and survivorship of higher trophic level species?*

Research Team Leaders

The success of the Interagency Florida Bay and Adjacent Marine Systems Science Program depends largely on clear and regular communication and collaboration amongst the scientists working in the Bay. To promote this, the PMC has organized researchers and modelers into topical research teams. To date, teams have been formed in paleoecology, algal blooms, water quality/nutrient dynamics, circulation/hydrology, seagrass and benthic ecology, and higher trophic levels. Teams consist of formally appointed leaders, a PMC representative, and modelers and researchers working in the Bay and adjacent marine systems.

Question 1: Physical Sciences

Dr. Peter Ortner, PMC Representative, National Oceanic and Atmospheric Administration/ Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida

Dr. Thomas Lee, Co-chair, University of Miami, Rosenstiel School of Marine and Atmospheric Science, Miami, Florida

Dr. Elizabeth Johns, Co-chair, National Oceanic and Atmospheric Administration/ Atlantic Oceanographic and Meteorological Laboratory, Miami, Florida

Question 2: Nutrient Dynamics

Dr. Brian Keller, PMC Representative, Florida Keys National Marine Sanctuary, Marathon, Florida

Dr. Joseph Boyer, Co-chair, Southeast Environmental Research Center, Florida International University, Miami, Florida

Question 3: Algal Blooms

Dr. Douglas Morrison, PMC Representative, Everglades National Park, Key Largo, Florida

Dr. Edward J. Phlips, Co-chair, University of Florida, Institute of Food and Agricultural Sciences, Department of Fisheries and Aquatic Sciences, Gainesville, Florida

Dr. Gary Hitchcock, Co-chair, University of Miami, Rosenstiel School of Marine and Atmospheric Science, Miami, Florida

Question 4: Seagrass Ecology

Dr. Michael Robblee, PMC Representative, USGS – Biological Resources Division, Miami, Florida

Dr. Jay Zieman, Co-chair, University of Virginia, Department of Environmental Sciences, Charlottesville, Virginia

Dr. Michael Durako, Co-chair, The University of North Carolina at Wilmington, Center for Marine Science, Wilmington, North Carolina

Question 5: Higher Trophic Levels

Dr. John Lamkin, PMC Representative, Southeast Fisheries Science Center, National Oceanic and Atmospheric Administration and the National Marine Fisheries Service, Miami, Florida

Dr. Joan Browder, Co-chair, Southeast Fisheries Science Center, National Oceanic and Atmospheric Administration and the National Marine Fisheries Service, Miami, Florida

Program Management Committee (PMC)

To assure that the many individually funded scientific projects are integrated into a comprehensive program addressing key issues, a PMC was formed in 1994 and its membership expanded in 1998. The PMC consists of scientific program managers from:

- Miami-Dade County Department of Environmental Resources Management
- Florida Department of Environmental Protection
- Florida Fish and Wildlife Conservation Commission
- National Oceanic and Atmospheric Administration
  - Florida Keys National Marine Sanctuary
  - National Marine Fisheries Service
  - Office of Oceanic and Atmospheric Research
- National Park Service
  - Biscayne National Park
  - Everglades National Park
- South Florida Water Management District
- U.S. Army Corps of Engineers
- U.S. Environmental Protection Agency
- U.S. Fish and Wildlife Service
- U.S. Geological Survey
  - Biological Resources Division
  - Water Resources Division

Primary Functions of the PMC

The primary functions of the PMC are:

(a) Develop and implement a research strategy designed to merge scientific understanding of the Bay with management's decision making processes;

(b) Facilitate a consensus-based process for determining science needs and priorities;

(c) Promote funding of critical science needs;

(d) Develop and maintain an open and scientifically sound review process for evaluating research results and for advancing the program; and

(e) Communicate research results and program progress to management as well as the scientific and public community.

Relationship to Restoration Managers

One of the most important goals of the interagency science program is to provide scientific information and models that will enable natural resource managers to make responsible decisions based on sound science. The PMC provides this information through direct briefings, PMC participation in the larger components of the South Florida Ecosystem Restoration Initiative such as the Task Force, Working Group and Science Subgroup, CERP and by conducting the Florida Bay Conference.

Regional Context

Florida Bay is one component of the marine and coastal ecosystems of South Florida. Waters from the Gulf of Mexico and southwestern coastal Everglades influence the Western Bay, the Northern Bay receives the drainage from much of the adjacent mainland marsh, and the Eastern Bay abuts the populated Florida Keys. Bay water, in turn, flows through the Florida Keys channels out to the reef tract. The connectivity of these waters is obvious. Collaboration among federal and state agencies that share management responsibilities for these waters is required to effectively collect data and build tools essential for guiding restoration of the regional ecosystem.

Scientific Oversight Panel

It is vital to the Interagency Florida Bay and Adjacent Marine Systems Science Program that its projects, plans, and direction are carefully and continuously reviewed by an independent outside review panel of experts. The Florida Bay Science Oversight Panel has served this important function and participates in annual conferences by formally leading question and answer sessions and by providing the PMC a written report that critically reviews and recommends advancement and implementation of the Program. Additionally, it arranges ad hoc advisory panels of experts in specialized topical subjects to participate in workshops. To date, review workshops have included circulation modeling, water quality modeling, nutrient dynamics, seagrass ecology and higher trophic levels. The Oversight Panel consists of senior scientists with significant experience in major estuarine scientific programs, and its current membership includes:

Dr. William C. Boicourt, University of Maryland, Horn Point Laboratory, Center for Environmental Science, Cambridge, Maryland
- *Dr. Boicourt is Professor of Physical Oceanography and specializes in physical oceanographic processes including circulation of the continental shelf and estuaries.*

Dr. William Dennison, University of Maryland, Center for Environmental Studies, Cambridge, Maryland
- *Dr. Dennison is the Vice President for Science Applications at the University of Maryland, Center for Environmental Science. He is a marine ecologist, with a specialty in ecophysiology of marine plants, and has conducted coastal marine research in all of the world's oceans.*

Dr. John E. Hobbie **(Chair)**, The Ecosystem Center, Marine Biological Laboratory, Woods Hole, Massachusetts
- *Dr. Hobbie is a Co-Director of The Ecosystems Center and is a Coastal Microbial Ecologist specializing in biogeochemical cycles of large coastal and wetlands systems.*

Dr. Edward D. Houde, University of Maryland, Center for Environmental Science, Chesapeake Biological Laboratory, Solomons, Maryland
- *Dr. Houde is a professor at the University of Maryland, and specializes in fisheries science, management, ecology, larval fish ecology and resource assessment.*

Dr. Steven C. McCutcheon, Hydrologic and Environmental Engineering, Athens, Georgia
- *A member of the 1996 Bay Circulation and Water Quality Modeling Workshops and Co-Chair of the Model Evaluation Group, Dr. McCutcheon is a specialist in water quality issues, hydronamic modeling, sediment transport and hazardous waste management.*

Dr. Hans W. Paerl, University of North Carolina, Institute of Marine Sciences, Morehead City, North Carolina
- *Dr. Paerl is Kenan Professor of Marine and Environmental Sciences and his research includes nutrient cycling and production dynamics of aquatic ecosystems, environmental controls of algal production, and assessing the causes and consequences of eutrophication.*

Program Agenda

Sunday, April 13, 2003

3:00pm – 6:00pm	Conference Registration Opens [STIRLING HALL SALONS A, B & C] Florida Bay Poster Presenters set up Displays [EDINBURGH BALLROOM]
6:00pm – 7:00pm	Early Bird Social with Welcome Address and Overview by John Hunt [EDINBURGH BALLROOM]
7:00pm	Social Adjourns to "Unofficial Networking" in Bamboo's Restaurant

Monday, April 14, 2003

7:00am – 5:00pm	Conference Registration Office Open
7:00am – 8:00am	Early Morning Refreshments & Presenters put up Poster Displays [EDINBURGH BALLROOM]
8:00AM – 8:30PM	**FLORIDA BAY PLENARY SESSION: OVERVIEW [STIRLING BALLROOM EAST]**
8:00am – 8:10am	**Welcome and Introduction — *John Hunt***, PMC Co-Chair
8:10am – 8:30am	**Overview of the Status and Interactions of Florida Bay Science and Restoration — *David Rudnick*** and Dewey Worth, South Florida Water Management District, West Palm Beach, FL; *Erwin Wunderlich*, U.S. Army Corps of Engineers, Jacksonville, FL (p. 3)
8:30AM – 12:10PM	**FLORIDA BAY PLENARY SESSION ON QUESTION 1 (7 TALKS)**
8:30am – 8:45am	Introduction to Session and Initial Response to Panel Member Questions **PMC Team Leader: Peter Ortner**
8:45am – 9:05am	**Salinity History of Florida Bay: An Evaluation of Methods, Trends, and Causes — *T. M. Cronin***, *L. Wingard, J. H. Murray*, USGS Reston, VA; *G. Dwyer,* Duke University, Durham NC; *M. Robblee*, USGS, Miami, FL (p. 19)
9:05am – 9:25am	**Circulation and Exchange Processes within Florida Bay Interior Basins — *Thomas N. Lee*** and *Elizabeth Williams*, University of Miami, RSMAS, Miami, FL; *Elizabeth Johns* and *Ryan Smith,* NOAA/AOML, Miami, FL; *Nelson Melo,* Cooperative Institute for Marine and Atmospheric Studies, U. of Miami, Miami, FL (p. 26)
9:25am – 9:45am	**Selected Features of Florida Bay Circulation: Targets for Hydrodynamic Model Validation — *Ned P. Smith,*** Harbor Branch Oceanographic Institution, Fort Pierce, FL (p. 30)
9:45am – 10:05am	**Flows, Stages, and Salinities: How Accurate is the SICS Integrated Surface-Water/Ground-Water Flow and Transport Model? — *Christian Langevin***, *Eric Swain,* and *Melinda Wolfert,* U.S. Geological Survey, Center for Water and Restoration Studies, Miami, FL (p. 23)
10:05am – 10:25am	Refreshment Break in Poster Display Area [EDINBURGH BALLROOM]

Monday, April 14, 2003 (continued)

8:30AM – 12:10PM	FLORIDA BAY PLENARY SESSION ON QUESTION 1 (7 TALKS) (CONTINUED)
10:25am – 10:45am	**Florida Bay Hydrodynamic and Salinity Model Analysis — *J. M. Hamrick,*** Tetra Tech, Inc., Fairfax, VA and *M. Z. Moustafa,* South Florida Water Management District, West Palm Beach, FL (p. 22)
10:45am – 11:05am	**An Integrated Modeling System for Simulating Circulation and Water Quality in Florida Bay and Biscayne Bay — *Y. Peter Sheng*** *and Justin R. Davis,* Coastal and Oceanographic Engineering Program, University of Florida, Gainesville, FL (p. 29)
11:05am – 11:25am	**Establishing Minimum Flow Criteria for Florida Bay — *Joel VanArman*** and *David Swift,* South Florida Water Management District, West Palm Beach, FL (p. 33)
11:25am – 12:10pm	***Question 1*** **—** Detailed Discussion of Panel Member Questions and General Discussion Period on Question 1 Presentations
12:10pm – 1:30pm	Lunch on Own

1:30PM – 5:30PM	FLORIDA BAY PLENARY SESSION ON QUESTIONS 2 & 3 (8 TALKS) [STIRLING BALLROOM EAST]
1:30pm – 1:45pm	Introduction to Session and Initial Response to Panel Member Questions **PMC Team Leader: Brian Keller**
1:45pm – 2:05pm	**Connecting Florida Bay with The Upstream Landscape via the Florida Coastal Everglades LTER Program — *Daniel L. Childers***, Florida International University, Miami, FL (p. 81)
2:05pm – 2:25pm	**Stoichiometry of the Dissolved and Particulate Nutrient Pools, and Phytoplankton Uptake Rates, and Their Relationship with Phytoplankton Community Composition in Florida Bay — *Patricia M. Glibert,*** *Jeffrey Alexander* and *Marta Revilla,* University of Maryland Center for Environmental Science, Horn Point Laboratory, Cambridge, MD; *Cynthia A. Heil,* University of South Florida, St. Petersburg, FL; *Susan Murasko, David Hollander* and *Ana Hoare,* University of South Florida, St. Petersburg, FL (p. 115)
2:25pm – 2:45pm	**Phytoplankton and Bacterial Response to Inorganic and Organic Nutrient Enrichment and Alteration in Florida Bay: Results from Bioassay Enrichment Experiments — *Cynthia A. Heil,*** *Susan Murasko, David Hollander* and *Ana Hoare*, University of South Florida, St. Petersburg, FL; *Patricia M. Glibert, Marta Revilla* and *Jeffrey Alexander,* University of Maryland Center for Environmental Science, Horn Point Laboratory, Cambridge, MD (p. 117)
2:45pm – 3:05pm	**Internal Nutrient Cycling in Florida Bay: Denitrification, Nitrogen Fixation and the Role of Microalgae — *Jeffrey C. Cornwell,*** *W. Michael Kemp, Michael S. Owens, Jessica Davis* and *Eric Nagel,* University of Maryland Center for Environmental Science, Horn Point Laboratory, Cambridge MD (p. 83)

Monday, April 14, 2003 (continued)

1:30PM – 5:30PM	FLORIDA BAY PLENARY SESSION ON QUESTIONS 2 & 3 (8 TALKS) (CONTINUED)
3:05pm – 3:25pm	**Microbial Dynamics in Florida Bay: A New Paradigm for the Microbial Loop in Oligotrophic Marine Waters — *Joseph N. Boyer*** and *Susan K. Dailey*, Southeast Environmental Research Center, Florida International University, Miami, FL (p. 79)
3:25pm – 3:45pm	Refreshment Break in Poster Display Area [EDINBURGH BALLROOM]
3:45pm – 4:05pm	**Uncoupling Autotrophic and Heterotrophic Microbial Response to Increased DOM in Florida Bay — *Susan K. Dailey*** and *Joseph N. Boyer,* Southeast Environmental Research Center, Florida International University, Miami, FL (p. 113)
4:05pm – 4:25pm	**Temporal and Spatial Distribution of Nutrients and Salinity in Florida Bay Ground Water from 1994-2000 — *Christopher D. Reich*** and *Eugene A. Shinn*, US Geological Survey, St. Petersburg, FL (p. 85)
4:25pm – 4:45pm	**The Roles of Freshwater Discharge, Advective Processes and Silicon Cycling in the Development of Diatom Blooms in Coastal Waters of the Southwestern Florida Shelf and Northwestern Florida Bay (1999-2001) — *Jennifer L. Jurado,*** Broward County DPEP, Ft. Lauderdale, FL; *Gary L. Hitchcock*, University of Miami, Miami, FL; *Peter B. Ortner,* National Oceanographic and Atmospheric Administration, Miami, FL (p. 119)
4:45pm – 5:30pm	***Questions 2 and 3*** — Detailed Discussion of Panel Member Questions and General Discussion Period on Question 2 & 3 Presentations
5:30pm	General Session Concludes
6:30pm – 9:00pm	**Florida Bay Poster Session & Reception** *(Presenters to be stationed at their posters from 7:00pm – 8:30pm)* [EDINBURGH BALLROOM]

Tuesday, April 15, 2003

7:00am – 5:00am	Conference Registration Office Open [STIRLING HALL SALONS A, B & C]
7:00am – 8:00am	Early Morning Refreshments [EDINBURGH BALLROOM]
8:30am – 5:20pm	**Concurrent Sessions:** Greater Everglades Ecosystem Restoration (GEER) – *See detailed GEER Program Schedule*.
12:20pm – 1:30pm	Lunch on Own

Tuesday, April 15, 2003 (continued)

8:00AM – 12NOON	FLORIDA BAY PLENARY SESSION ON QUESTION 4 (8 TALKS) [Stirling Ballroom East]
8:00am – 8:15am	Introduction to Session and Initial Response to Panel Member Questions **PMC Team Leader: Michael Robblee**
8:15am – 8:35am	**Infection, Infestation, and Disease: Differential Impacts of *Labyrinthula* sp. on the Seagrass *Thalassia testudinum* (Banks ex König) in Florida Bay, USA — *Barbara A. Blakesley*,** *Donna M. Berns* and *Margaret O. Hall,* Florida Marine Research Institute, Florida Fish and Wildlife Conservation Commission, St. Petersburg, FL (p. 135)
8:35am – 8:55am	**The Effects of Sediment Toxicity on Florida Bay Turtle Grass: A Synthesis of Field Experiments (1990-2000) — *Paul Carlson*,** *Laura Yarbro, Brad Peterson* and *Alice Ketron,* Florida Fish and Wildlife Conservation Commission, Florida Marine Research Institute, St. Petersburg, FL (p. 138)
8:55am – 9:15am	**Meristem Anoxia and Sulfide Intrusion: A Mechanism for *Thalassia testudinum* Short Shoot Mortality in Florida Bay —** *Ole Pedersen, Jens Borum* and *Tina M. Greve,* University of Copenhagen, Hillerød, Denmark; ***Joseph C. Zieman*** and *Thomas A. Frankovich*, University of Virginia, Charlottesville, VA; *James W. Fourqurean,* Florida International University, Miami, FL (p. 152)
9:15am – 9:35am	**Multiple Stressor Effects on Seagrasses in FL Bay: A Mesocosm Research Approach — *Marguerite Koch*,** *Stephanie Schopmeyer* and *Claus Kyhn-Hansen,* Florida Atlantic University, Boca Raton, FL; *Chris Madden*, South Florida Water Management District, West Palm Beach, FL (p. 146)
9:35am – 9:55am	**Nitrogen Versus Phosphorus Limitation of Benthic Primary Production and the Role of Epiphyte Grazers in Florida Bay — *Thomas A. Frankovich,*** *Amy Willman* and *James W. Fourqurean,* Florida International University, Miami, FL; and *Kenneth L. Heck*, Dauphin Island Sea Lab and University of South Alabama, Dauphin Island, AL (p. 143)
9:55am – 10:15am	Refreshment Break in Poster Display Area [EDINBURGH BALLROOM]
10:15am – 10:35am	**The Response of Seagrass Distribution to Changing Water Quality: Predictive Models from Monitoring Data — *James W. Fourqurean*,** *Joseph N. Boyer* and *Bradley J. Peterson*, Department of Biological Sciences and Southeast Environmental Research Center, Florida International University, Miami, FL; *Michael J. Durako,* Center for Marine Science, University of North Carolina at Wilmington, Wilmington, NC; and *Lee N. Hefty,* Miami-Dade Department of Environmental Resources Management, Miami, FL (p. 140)

Tuesday, April 15, 2003 (continued)

8:00AM – 12NOON	**FLORIDA BAY PLENARY SESSION ON QUESTION 4 (8 TALKS) (CONTINUED)**
10:35am – 10:55am	**Use of a Dynamic, Mechanistic Simulation Model to Assess Ecology and Restoration of the Florida Bay Seagrass Community — *Christopher J. Madden*,** *Amanda McDonald* and *Stephen P. Kelly,* South Florida Water Management District, West Palm Beach, FL; Marguerite Koch, Florida Atlantic University, Boca Raton, FL (p. 148)
10:55am – 11:15am	**A Landscape Model of *Thalassia testudinum* Dynamics in Florida Bay** — ***T.M. Smith****, B. Wolfe, J. Zieman, K. McGlathery* and *E. Bricker*, Department of Environmental Sciences, University of Virginia, Charlottesville VA (p. 151)
11:15am – 12:noon	***Question 4* —** Detailed Discussion of Panel Member Questions and General Discussion Period on Question 4 Presentations
12:00pm – 1:30pm	Lunch on Own

1:30PM – 5:30PM	**FLORIDA BAY PLENARY SESSION ON QUESTION 5 (8 TALKS)**
1:30pm – 1:45pm	Introduction to Session and Initial Response to Panel Member Questions **PMC Team Leader: John Lamkin**
1:45pm – 2:05pm	**Potential Effects of the Diversion of Freshwater Flow from Taylor Slough to the C-111 Canal on the Salinity, Hydrology, Prey-Base Fish Community and Roseate Spoonbill Nesting Population of Northeastern Florida Bay — *Jerome J. Lorenz*,** National Audubon Society, Tavernier, FL (p. 206)
2:05pm – 2:25pm	**A Framework for Assessing Ecological Risks to the Roseate Spoonbill Related to Everglades Hydrologic Restoration Activities — *Steven M. Bartell,*** The Cadmus Group, Oak Ridge, TN; *Jerome J. Lorenz,* National Audubon Society, Tavernier, FL; *William K. Nuttle*, Ottawa, Ontario, Canada; *William B. Perry,* National Park Service, Homestead, FL (p. 193)
2:25pm – 2:45pm	**Postlarval Transport of Pink Shrimp into Florida Bay — *Maria M. Criales*** and *John Wang*, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL; *Joan A. Browder* and *Thomas Jackson*, NOAA Fisheries, Southeast Fisheries Science Center, Miami, FL; *Michael Robblee* and *Clinton Hittle*, U.S. Geological Survey, Water and Restoration Studies Center, Miami, FL (p. 196)
2:45pm – 3:05pm	**The Use of GAM Modeling Techniques to Evaluate the Effects of Freshwater Flow Into Florida Bay- Part 1- Forage Fish Models — *Darlene Johnson*** and *Joan Browder*, NOAA Fisheries, Miami, FL (p. 202)

Tuesday, April 15, 2003 (continued)

1:30PM – 5:30PM	FLORIDA BAY PLENARY SESSION ON QUESTION 5 (8 TALKS) (CONTINUED)
3:05pm – 3:25pm	**Use of Geochemical Tracers to Elucidate Life History Trajectories of Gray Snapper within South Florida's Marine Ecosystems —** *David L. Jones,* Univ. of Miami-RSMAS, Miami, FL; ***Monica R. Lara***, Univ. of Miami-RSMAS-CIMAS, Miami, FL; *John T. Lamkin*, NOAA-NMFS-SEFSC, Miami, FL (p. 204)
3:25pm – 3:45pm	Refreshment Break in Poster Display Area [EDINBURGH BALLROOM]
3:45pm – 4:05pm	**Mercury in Fish from Eastern Florida Bay — *David W. Evans*** and *Peter H. Crumley,* NOAA, Center for Coastal Fisheries and Habitat Research, Beaufort NC; *Darren Rumbold*, South Florida Water Management District, Fort Myers FL; *Sharon Niemczyk,* US Army Corps of Engineers, Palm Beach Gardens, FL (p. 199)
4:05pm – 4:25pm	**Using Bottlenose Dolphins as an Indicator Species in Florida Bay: Analyzing Habitat Use and Distribution Relative to Water Quality, Habitat and Fish Community — *Leigh G. Torres*** and *Andrew J. Read*, Duke University Marine Lab, Beaufort, NC; Laura Engleby, Dolphin Ecology Project, Key Largo, FL (p. 209)
4:25pm – 4:45pm	**Evaluating the Effect of Salinity on a Simulated American Crocodile (*Crocodylus acutus*) Population - *Paul M. Richards,*** Florida State University, Tallahassee, FL; *Wolf M. Mooij,* Netherlands Institute of Ecology, Nieuwersluis, The Netherlands; *Donald L. DeAngelis,* U.S. Geological Survey, Center for Water and Restoration Studies, University of Miami, Department of Biology, Coral Gables, FL USA (p. 207)
4:45pm – 5:30pm	***Question 5*** **—** Detailed Discussion of Panel Member Questions and General Discussion Period on Question 5 Presentations
5:30pm – 5:40pm	Florida Bay Wrap-up & Closing Remarks
5:40pm	FLORIDA BAY SEGMENT CONCLUDES
6:30pm – 9:00pm	**Joint Conference Networking Reception** [POOLSIDE AT LOCHNESS LAGOON]

Poster Directory

GENERAL — NOT LINKED TO A SPECIFIC QUESTION

1..........**Establishing Baseline Freshwater Flow to Florida Bay for Water Management —** ***Robin Bennett****, Chelsea Donovan, David Rudnick* and *Joel VanArman*, South Florida Water Management District, West Palm Beach, FL (p. 7)

3..........**A Decade of Mangrove Forest Change Following Hurricane Andrew —** ***Thomas J. Smith III***, U.S. Geological Survey, Center for Water and Restoration Studies, St. Petersburg, FL; *Kevin R.T. Whelan* and *Gordon H. Anderson*, U.S. Geological Survey, Center for Water and Restoration Studies, Miami, FL; *Christa L. Walker,* Dyncorp Systems & Solutions LLC, U.S. Geological Survey, Homestead, FL; *Jeffrey S. Dismukes,* ETI Professionals, Inc., USGS Center for Coastal and Watershed Studies, St. Petersburg, FL; *Thomas W. Doyle,* U.S. Geological Survey, National Wetlands Research Center, Lafayette, LA (p. 10)

2..........**Mangrove Die-Off in Florida Bay: A Recurring Natural Event? —** ***Thomas J. Smith III***, U.S. Geological Survey, Center for Water & Restoration Studies, St. Petersburg, FL; *Lenore Fahrig,* Carleton University, Ottawa, Ontario, Canada; *Paul W. Carlson,* Florida Marine Research Institute, St. Petersburg, FL; *Thomas V. Armentano,* South Florida Natural Resources Center, Everglades National Park, Homestead, FL; *Gina M. Peery,* ETI Professionals, Inc., St. Petersburg, FL (p. 14)

4..........**The Florida Bay and Florida Keys Feasibility Study: Update and Status —** ***Erwin J. Wunderlich,*** U.S. Army Corps of Engineers, Jacksonville, FL (p. 16)

QUESTION 1 — PHYSICAL PROCESSES

8..........**Spatial and Temporal Patterns of Salinity Simulated by the FATHOM Model Compared to Observed Salinity Data for the Period 1993 to 1999 —** ***B. J. Cosby*****,** Dept. of Environmental Sciences, University of Virginia, Charlottesville, VA; *J. W. Fourqurean,* Southeast Environmental Research Center, Florida International Univ., Miami, FL; *W. K. Nuttle,* Consultant, Ottawa, Ontario, Canada (p. 37)

9..........**Continuous Hydrologic Data in Florida Bay Channels —** ***Clinton Hittle*** and *Grant Poole*, U.S. Geological Survey, Center for Water and Restoration Studies, Miami, FL (p. 40)

10........**Estuarine Creek Responses to Extreme Hydrologic Events in Northeastern Florida Bay** — ***Clinton Hittle*****,** U.S. Geological Survey, Center for Water and Restoration Studies, Miami, FL (p. 42)

11........**New Interdisciplinary Oceanographic Observations in the Coastal Waters Adjacent to Florida Bay** — ***Elizabeth Johns****, Peter B. Ortner, Ryan H. Smith, Christopher R. Kelble, Shailer R. Cummings, Jr.* and *James C. Hendee*, NOAA, Atlantic Oceanographic and Meteorological Laboratory, Miami, FL; *Nelson Melo,* Cooperative Institute for Marine and Atmospheric Studies, U. of Miami, Miami, FL; *Thomas N. Lee* and *Elizabeth J. Williams*, U. of Miami, Rosenstiel School of Marine and Atmospheric Science, Miami, FL (p. 45)

QUESTION 1 — PHYSICAL PROCESSES (CONTINUED)

QUESTION 1 — PHYSICAL PROCESSES (CONTINUED)

QUESTION 2 — NUTRIENT DYNAMICS

QUESTION 2 — NUTRIENT DYNAMICS (CONTINUED)

QUESTION 3 — ALGAE BLOOMS

QUESTION 4 — SEAGRASS

Question 4 — Seagrass (continued)

Question 5 — Higher Trophic Levels

QUESTION 5 — HIGHER TROPHIC LEVELS (CONTINUED)

FLORIDA BAY ECOSYSTEM HISTORY

General -
Not Linked to Specific Question
Oral Abstracts

- Listed alphabetically by presenting author.
- Presenting author appears in **bold**.

Overview of the Status and Interactions of Florida Bay Science and Restoration

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For the past eight years, Florida Bay has been intensively monitored and researched for the purpose of understanding the causes of the ecosystem's perceived degradation and providing a scientific basis for ecosystem restoration. This scientific assessment is proceeding concurrently with implementation of the Comprehensive Everglades Restoration Plan (CERP). CERP is an eight billion dollar, multi-decadal effort to restore the greater Everglades ecosystem, including Florida Bay. Several ongoing CERP projects will change the flow of fresh water toward Florida Bay, with the expectation that these changes will restore both wetland and estuarine ecosystems. However, the analysis (in the "Restudy") that led to CERP authorization included only superficial analysis of Florida Bay due to time and data constraints imposed during the Restudy planning process. Consequently, no single CERP project or specific suite of projects was identified or recommended for implementation with a primary objective to restore Florida Bay.

This deficiency is being addressed through a supplement to the Restudy, CERP's Florida Bay and Florida Keys Feasibility Study (FKFBFS). The goal of this feasibility study is to evaluate Florida Bay and its connections to the Everglades, the Gulf of Mexico, and the Florida Keys marine ecosystem to determine the modifications that are needed to successfully restore water quality and ecological conditions of the Bay, while maintaining or improving these conditions in the Keys' marine ecosystem. Central components of the FBFKFS are: 1) definition and specification of restoration targets; 2) development of models (statistical or mechanistic) to evaluate ecosystem responses as a function of changes in the flux of fresh and salt water inputs ; 3) the specification of restoration alternatives; 4) evaluation of these alternatives with regard to Florida Bay and Keys responses; and 5) selection and optimization of a recommended plan.

The identification of FBFKFS restoration targets is currently underway. Unlike the Restudy, which depended heavily on the Natural Systems Model to hind-cast historical conditions, the FBFKFS will define targets using a combination of information derived from palaeoecological research, scientific literature, anecdotal history, and best professional judgment. This historic information is probably most robust (although imprecise) for salinity conditions. An important scaling consideration in this exercise is the historic change in the ratio of watershed area to estuarine area. While the intent of CERP is to restore all of Florida Bay to pre-drainage (pre-1900) conditions, this may not be realistic because half of the Everglades watershed has been developed and will not be restored as part of CERP. Hydrologic (and consequent ecological) restoration of the Bay could thus require conveyance of fresh water flows that could be excessive for the upstream wetlands without causing further degradation of the Everglades ecosystem and unrealistic, given demands for human consumption.

After defining restoration targets, the success of the FBFKFS depends upon our ability to accurately predict the effects of changing hydrologic and water quality conditions in the Everglades, as well as the effects of other potential changes, such as the removal of fill from passes in the Florida Keys. The FBFKFS will depend upon hydrodynamic, water quality, and ecological models for these predictions. These models will reflect our current understanding of the Bay's mechanistic relationships and the accuracy of these predictions will largely depend upon the sufficiency (quality and quantity) of data derived from the Florida Bay Science Program. Scopes of work for three physical models (for southern Everglades and mangrove zone hydrology, Atlantic and Gulf hydrodynamics, and Bay hydrodynamics) and a variety of linked water quality models are either in draft or have been completed. A dynamic seagrass model is currently under development and will be coupled with the Florida Bay water quality model. Specific characteristics of other biological models have yet to be defined.

Major ecological uncertainties that have been highlighted in recent reviews (including Hobbie et al. 2001 and Nixon et al. 2002) will persist through the duration of the FBFKFS. The consequences of these uncertainties on the predictions and recommendations of the FBFKFS will need to be explicitly addressed in the Final Study Report. One important uncertainty is our understanding of the effects of dissolved organic nutrient (particularly nitrogen) inputs from the Everglades on the Bay's algal bloom dynamics. Several research projects are now investigating this issue and are expected to quantify critical processes, leading to improvements in our conceptual and numerical models. Other major uncertainties include the relative importance of groundwater inputs to the bay in moderating salinity and as a nutrient source, causes of *Thalassia* mass mortality, and the effects of Florida Bay on the Keys' coral reef.

Any restoration project that is recommended by the FBFKFS for funding and implementation, must be implemented within a framework of adaptive assessment as already defined within the overall CERP program. This framework, which recognizes that our scientific understanding is never complete and that CERP will learn (and presumably become more effective) by concurrent restoration action and ecological study, is under development by RECOVER, a subgroup of CERP. RECOVER is responsible for system-wide monitoring and assessment for the duration of Everglades restoration. RECOVER has already developed a conceptual model of Florida Bay, defined preliminary performance measures (expectations and targets) for Bay restoration, and drafted a monitoring and assessment plan that defines a minimal set of monitoring parameters, a sampling design, and critical uncertainties to be researched. As such, RECOVER is a long-term conductor of Florida Bay science for Greater Everglades restoration.

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General - Not Linked to Specific Question Poster Abstracts

- Listed alphabetically by presenting author.
- Presenting author appears in **bold**.

Establishing Baseline Freshwater Flow to Florida Bay for Water Management

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Two assessments of the relationship between freshwater flow through the Everglades and the ecological status of Florida Bay are currently ongoing at the South Florida Water Management District (SFWMD). The first is a component of the Comprehensive Everglades Restoration Plan (CERP) – the definition of "Existing Legal Sources of water". This assessment establishes the baseline (pre-restoration, up to December 2000) input (timing and distribution) of water to Florida Bay and the extent to which this baseline delivery is beneficial to the ecosystem. The second assessment is derived from Florida legislation to define "minimum flows and levels" (MFLs) for "priority" water bodies and wetlands to ensure that water supply is sufficient to prevent "significant harm" to these systems.

For both assessments, it is necessary to establish relationships among water management discharges, watershed hydrologic conditions, freshwater flow into Florida Bay, salinity conditions in the Bay, and responses of aquatic resources (species of special interest and habitats). A simplifying assumption has been made that salinity levels and variations are the primary environmental parameter in Florida Bay that varies with freshwater flow and levels and also is a primary driver of biotic condition. Furthermore, for both assessments, it is desirable to accurately estimate the effect of changing watershed hydrologic conditions on salinity far from the coast. Since a validated hydrodynamic model is not yet available for Florida Bay, we employed a statistical approach to estimate hydrologic-salinity relationships. This analysis was limited to assess salinity conditions near the northern coast of Florida Bay and within Whitewater Bay.

For the Legal Water Sources assessment, we have taken the following approach: (1) determine relationships among upstream flow, stage, and Bay salinity regime (mean, range, frequency of a given magnitude); (2) identify key biological components that have demonstrated salinity tolerances or optima; and (3) describe the distribution, abundance, and other life-history attributes for biological components as a function of salinity regime for various areas of Florida Bay and Whitewater Bay. We developed regression models to evaluate flow-stage-salinity relationships. Salinity data were analyzed from eleven of Everglades National Park's (ENP) Marine Monitoring Network (MMN) stations. These near-shore stations are located in close proximity to freshwater outflows from the Everglades, and thus, are likely to be influenced by upstream water management. These salinity data were compared against stage data for 5 upstream wetland stations (P33, P37, EPS, TSB, and CP). Both stage and salinity were examined against flow data from canals discharging into the Shark Slough, Taylor Slough, and lower C-111 basins. Stage and flow were calculated for a variety of temporal periods (individual day, 30d moving average, and 30d moving average with 30, 45, and 60d lags). We also verified regression models by comparing predicted daily salinity with salinity measured by Florida International University (FIU) for the corresponding day (FIU data was independent from the MMN input data). In order to comply with a pre-CERP baseline definition, data from 2001-2002 were not included in our analyses.

Assessment of the salinity effects on Florida Bay biota was based on literature and unpublished information on the salinity tolerances and optima for several taxa. We selected a short list of species representing a range of trophic levels and habitat preferences (widgeongrass, shoalgrass, pink shrimp, spotted seatrout, American crocodile, roseate spoonbill). We examined habitat suitability for each species as a function of salinity regime at each site based on time-series plots and frequency distributions of salinity. Biotic response to salinity was also estimated during various climatic events that represented extremes for flows into the Bay (drought of 1989-1991, high water period of 1994-1995, and high variability of 1999). For each species, the effects of temporal variation of salinity during critical life cycle periods (e.g., spawning, nesting, and success of hatchlings/juveniles) were considered.

Salinity in Florida Bay and Whitewater Bay generally showed strongest correlation with upstream wetland stage, calculated as a 30d moving average value. Regression models (all $p<0.001$) were able to account for between 50-75% of the variability between stage and salinity, and from 41-81% of the relationship between upstream stage and flow from canal structures (flow relationship was also strongest when calculated as 30d moving average). Salinity from most eastern sites was best predicted by P37 stage, while western sites showed strongest correlation with stage at station P35. Salinity predictions for independent FIU data were strongest at sites in eastern FL Bay; mean difference was generally within the standard error of the FIU site-respective mean. Lowest R^2 values were calculated for north-central Florida Bay regression models. Relationships between flow and salinity were weaker than between stage and salinity.

Salinities occurring during the 1989-1991 drought were frequently outside the optimal ranges for the species we examined. Moreover, the unusually low salinities that occurred during the high water period of 1994-1995 provided a more beneficial habitat for crocodiles and spoonbill forage fish. These lower salinities also coincided with the eastward expansion of juvenile seatrout populations (Thayer et al. 1999). Furthermore, the salinities occurring in Little Madeira Bay during this high water period were close to the historical levels calculated by Bjork and Powell (1994). This suggests that, at least for the Taylor Slough system, such inflows could be beneficial for restoration. For the Legal Water Sources assessment, we tentatively conclude that baseline flows of freshwater to Florida Bay are beneficial to the ecosystem, especially if improvements can be made to the spatial distribution of these existing flows (in favor of the Taylor Slough basin).

The process of setting a MFL rule for Florida Bay is another important vehicle for resource protection and water supply planning. Florida Bay is designated as a MFL Priority Water Body and the MFL rule is due for adoption in 2005. As has been used for other SFWMD estuaries, a minimum flow (versus minimum level) will be the target for Florida Bay. A minimum flow is defined by Ch.373.042(1) F.S. as “the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area.” The definition of this point requires several steps, including (1) identifying resources and functions in the Bay, (2) selecting appropriate sensitive resources and functions, (3) determining technical relationships between inflow and resource functions, and (4) defining numeric criteria that reflect the threshold at which these resource functions have incurred “significant harm.” Significant harm is defined in Chapter 40E-8 F.S. as the degree of impact requiring more than two years for the water (or biological) resource to recover.

The development of MFL criteria for Florida Bay is underway and will be assisted by other ongoing efforts, including the assessment of Existing Legal Sources, development of a hydrodynamic model for the Florida Bay and Florida Keys Feasibility Study, and the definition of restoration targets based on this Study and other CERP projects.

The definition of Existing Legal Sources of water and the development of MFL criteria should not be viewed as end points in defining freshwater needs for Florida Bay. They are critical steps needed to protect existing resources from significant harm and establish baseline conditions, and thus are important processes *towards* a goal of restoration.

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A Decade of Mangrove Forest Change Following Hurricane Andrew

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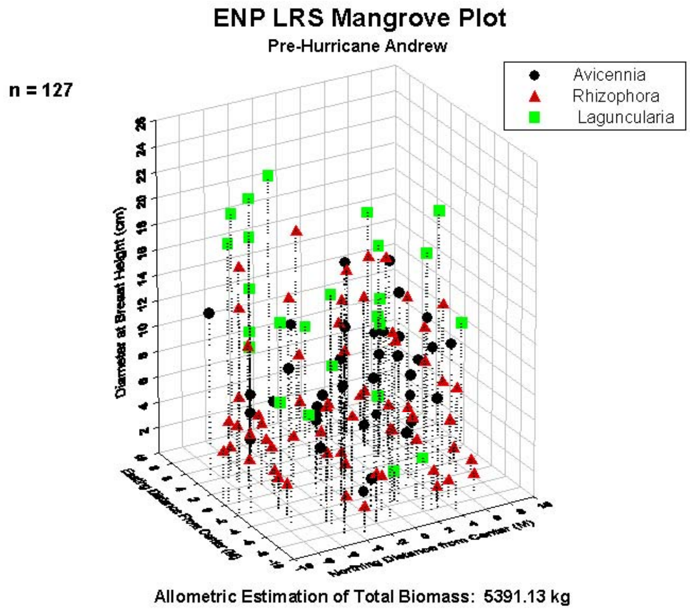
Hurricane Andrew crossed the southern Florida peninsula on the morning of August 24, 1992. Following the storm, the National Park Service conducted an "Environmental Damage Assessment" to gauge its' impacts on the natural resources of south Florida Park Service holdings. Although hurricanes had impacted 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, 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. Co-incident 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, 2).



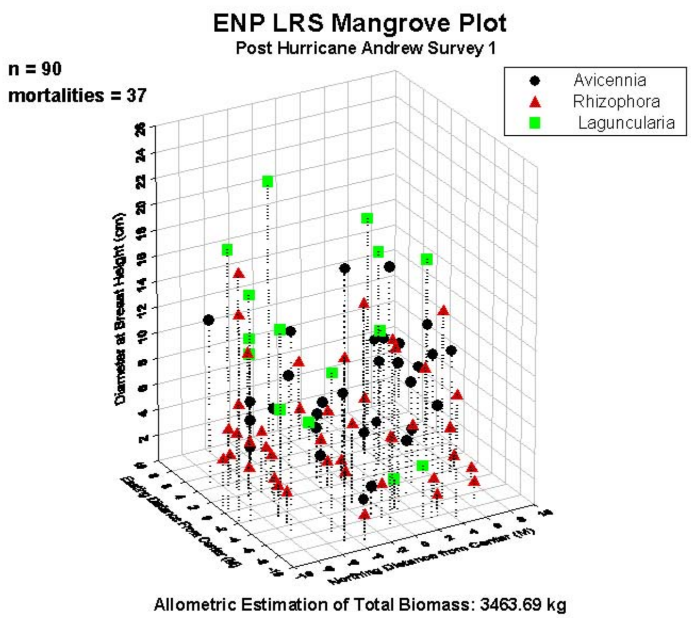
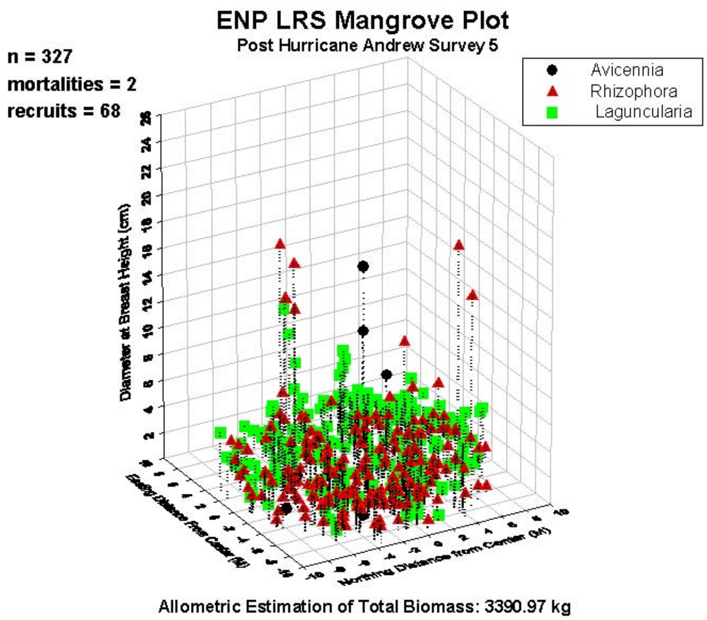


Figure 1. Illustrative data for the Lostmans Ranger Station plot. Results from the first surveys are shown. The top figure depicts the plot as it appeared prior to Hurricane Andrew and is based on a "reconstruction" from the initial sampling in October 1992. The lower figure is the "actual" state at the initial sampling.



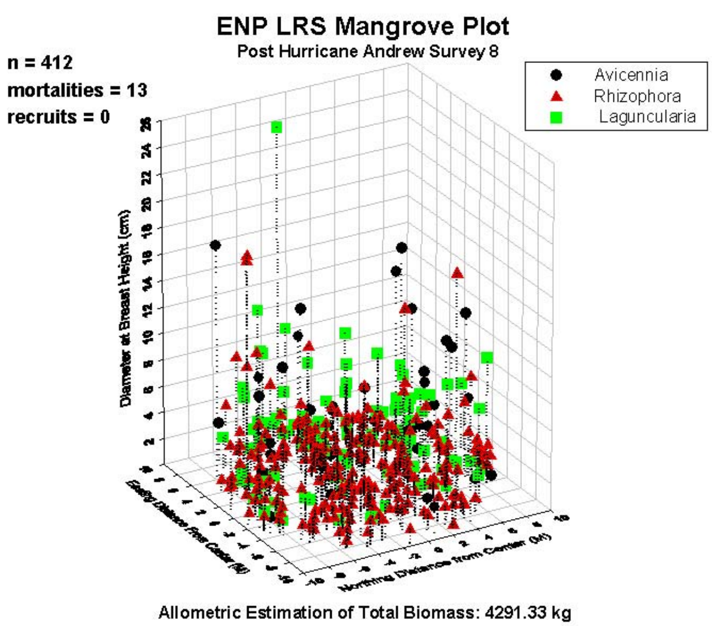


Figure 2. Subsequent surveys for the Lostmans Ranger Station plot. The situation in Jan 1995 is shown at top. Recruitment is well underway and consists of an even mix of *Rhizophora* and *Laguncularia*. The bottom figure shows 10 years after the hurricane, October 2002. *Rhizophora* has now come to dominate the pool of recruits and total biomass is beginning to exhibit an increasing trend.

Mortality is occurring at all sites. Sources of stem death have included: continuing mortality from damage initially induced by Hurricane Andrew, 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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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 plot's center. All stems >1.4m in height and $\leq$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* (Figure 1). A pulse of recruitment (new mangroves reaching 1.4m in height) was also measured at this location.

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, Figure 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.

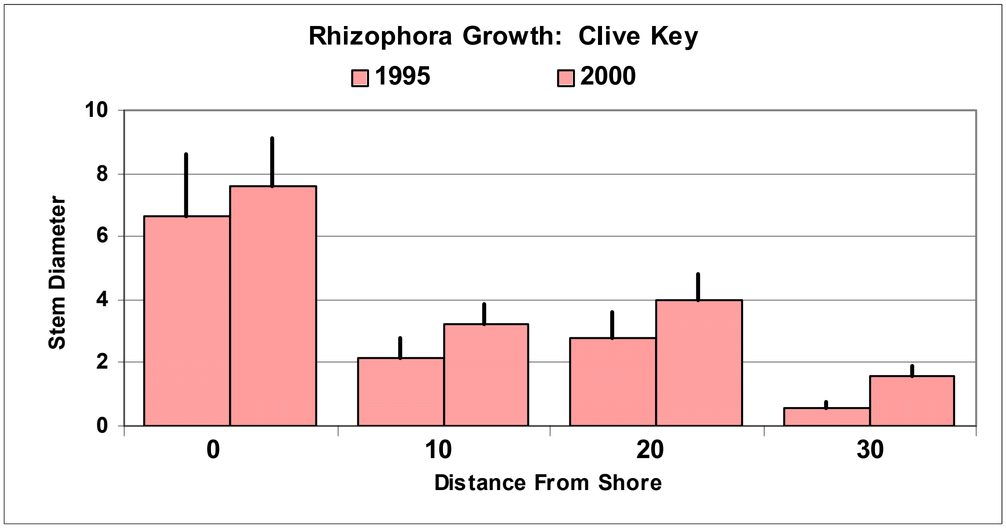

Figure 1. Increase in average stem diameter for *Rhizophora mangle* at Clive Key from 1995 to 2000.

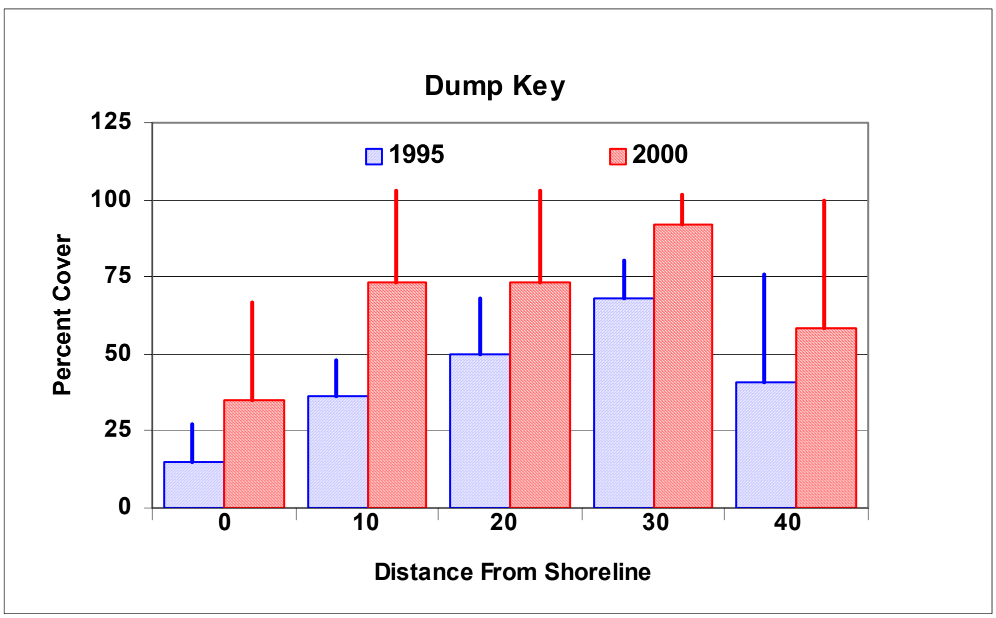

Figure 2. Increase in herbaceous vegetation cover at Dump Key from 1995 to 2000.

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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The Florida Bay and Florida Keys Feasibility Study: Update and Status

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The Florida Bay and Florida Keys Feasibility Study is the comprehensive evaluation of Florida Bay and its connections to the Everglades, the Gulf of Mexico and the Florida Keys marine ecosystem to determine the modifications that are needed to successfully restore water quality and ecological conditions of the Bay, while also improving these conditions in the Keys' marine ecosystem. An interagency team has been formed of federal, state, local, and tribal governments to participate in the completion of the Study.

Problems have been identified in the Study area to include a decline in seagrass; loggerhead sponge die off; presence of algal blooms; coral reef and reef species decline; decline of commercial and recreational fisheries; water inflow, salinity, circulation, and water quality effects not well understood; need balance in biodiversity; listed species need attention; and specific contaminants such as mercury need review. Data and information is being gathered in support of characterizing the problems and performance measures for the Study.

For purposes of performance measures and development of associated predictive capability, the Study area has been divided into 17 regions with differing environments. Performance measures have been identified to include submerged aquatic vegetation; physical characteristics such as salinity, light, and sediment; water quality characteristics such as chlorophyll, phosphorus, nitrogen, silicate; and higher trophic species such as sea trout, snook, forage fish community, lobster, roseate spoonbill, pink shrimp, and crocodile.

Preliminary alternatives being considered include specifying water boundary needs for the Study area; examining modifications to the specified Comprehensive Everglades Restoration Plan (CERP); reviewing Main Park Road and Ingram Highway plans; removing accumulated bottom sediment where blockages exist; reviewing the mangrove transition zone and dredge and fill blockages; reviewing creation of upland habitat; reviewing constructive ways to effect recreational improvements; stabilizing sediments; and reconnecting historic tidal connections.

The CERP Restoration Coordination and Verification (RECOVER) group, independent review personnel and the public will also review Study approaches. An Environmental Impact Statement (EIS) will be prepared and integrated into the completed Study.

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Question 1 - Physical Processes Oral Abstracts

- Listed alphabetically by presenting author.
- Presenting author appears in **bold**.

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 ~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.

Distinguishing natural salinity variability due to climate variability from changes caused by water diversion in the Everglades during the 20th century requires information on Florida Bay salinity history. 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. This study addresses 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:

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

where Mg/Ca represents the atomic ratio of Mg to Ca and $K_{D\text{-}me}$ 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 20th century decadal oscillations in salinity were related mainly to regional rainfall variability, which in turn was influenced by climate processes associated with interannual El Nino-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.

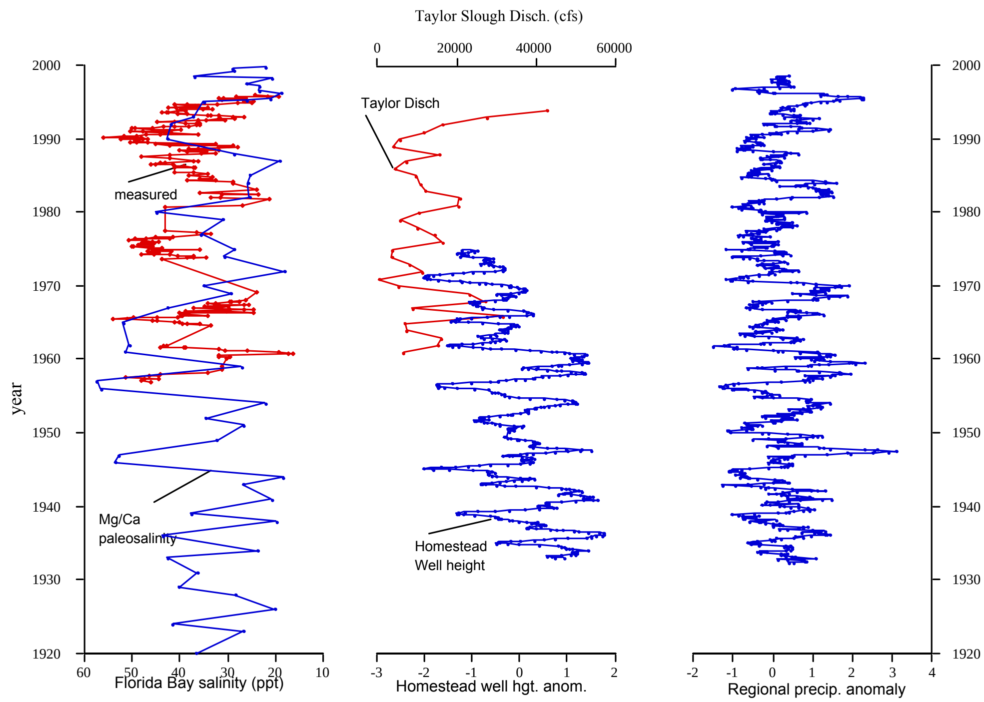

Figure 1. Comparison between paleosalinity and measured salinity (left), Homestead well level and Taylor discharge (center), and NOAA regional rainfall (right).

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

Table 1. Comparison between paleosalinity and instrumental of salinity minima and maxima

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 ~ -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 ~ 1993-1995, the 1980s, the late 1960s-early 1970s and ~ 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., ~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).

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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Florida Bay Hydrodynamic and Salinity Model Analysis

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A hydrodynamic, salinity, and temperature transport model of Florida Bay was developed. Model's performance was analyzed to evaluate the adequacy of field observations to support model calibration and verification and the feasibility of using the model for long-term management scenario simulations. The model was based on the Environmental Fluid Dynamics Code (EFDC), which has been extensively used for estuarine and coastal water applications. Model performance measures included harmonic analysis of water surface elevations, horizontal currents and time series, and correlation analyses of low frequency sea level, salinity and temperature.

The model grid domain included Florida Bay and extended westward into the Gulf of Mexico to 81.9^{o} latitude. The model was configured using NOAA and USGS bathymetry. Model forcing functions included, open boundary tidal and low frequency sea level, salinity, and temperature; spatially varying wind and atmospheric data for surface heat exchange prediction; and gauging estimates of inflows and corresponding salinity and temperature for canal, creek and river discharges along the northern land boundary of Florida Bay and the eastern land boundary of the Gulf of Mexico. Tidal and low frequency dynamic open boundary conditions were estimated using a variational inverse procedure which identified boundary conditions which resulted in a best fit, in the least squares sense, between model predicted and observed interior water surface elevation and current meter records. Salinity and temperature open boundary conditions were developed from monthly and higher resolution observation near the open boundary. Atmospheric conditions, including rainfall, air temperature, relative humidity, incident solar short wave radiation, and cloud cover were to specify thermal sources and sinks with the model predicting evaporation. The salinity transport forcing functions included open boundary conditions, rainfall, evaporation from the surface heat exchange prediction, and fresh and brackish water inflow form gauged canals, creeks and rivers entering Florida Bay and the southwest coast of the Gulf of Mexico. Model simulations covered a three year period from approximately mid 1997 to mid 2000.

Model performance with respect to water surface elevation, currents, and temperature were judged to be more than adequate for confidence in long-term prediction of these quantities. Using the observationally defined inflows and their associated observed salinity, the model tended to over predict salinity, particularly in the northeastern potion of Florida Bay. A simple data assimilation scheme was applied to estimate the additional distributed freshwater inflow that would be required to bring model predictions into agreement with observations. The results of estimation scheme indicate that a large quantity of un-gauged fresh water enters Florida Bay particularly during tropical storm events.

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

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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).

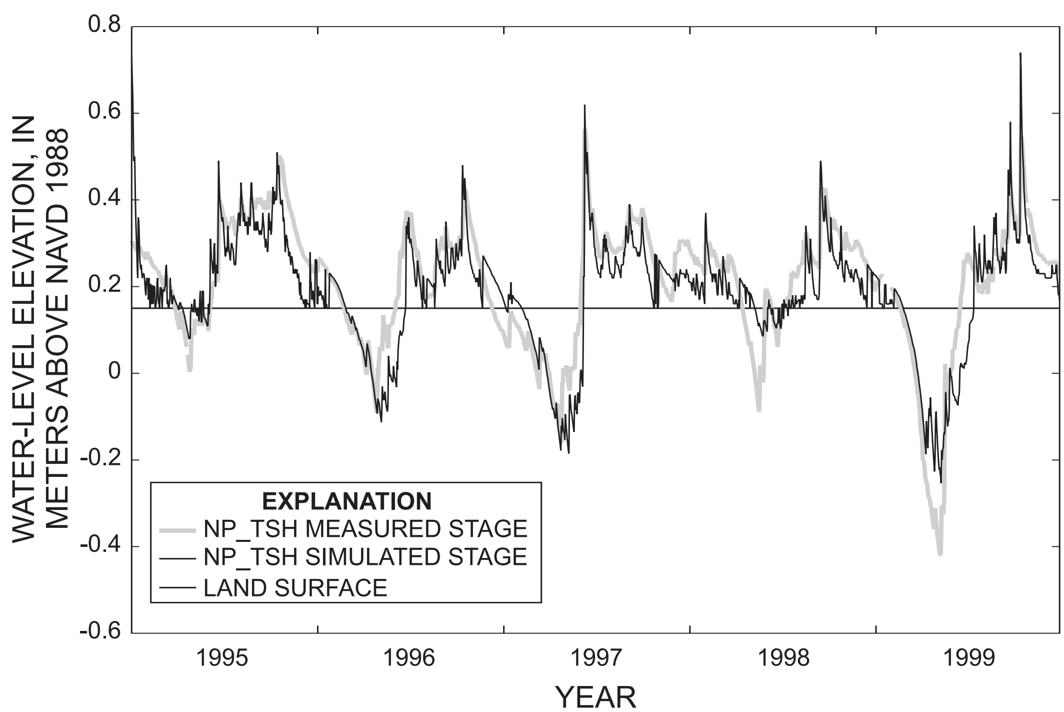

Figure 1. Measured and simulated stage at the TSH monitoring site, located in central Taylor Slough.

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.

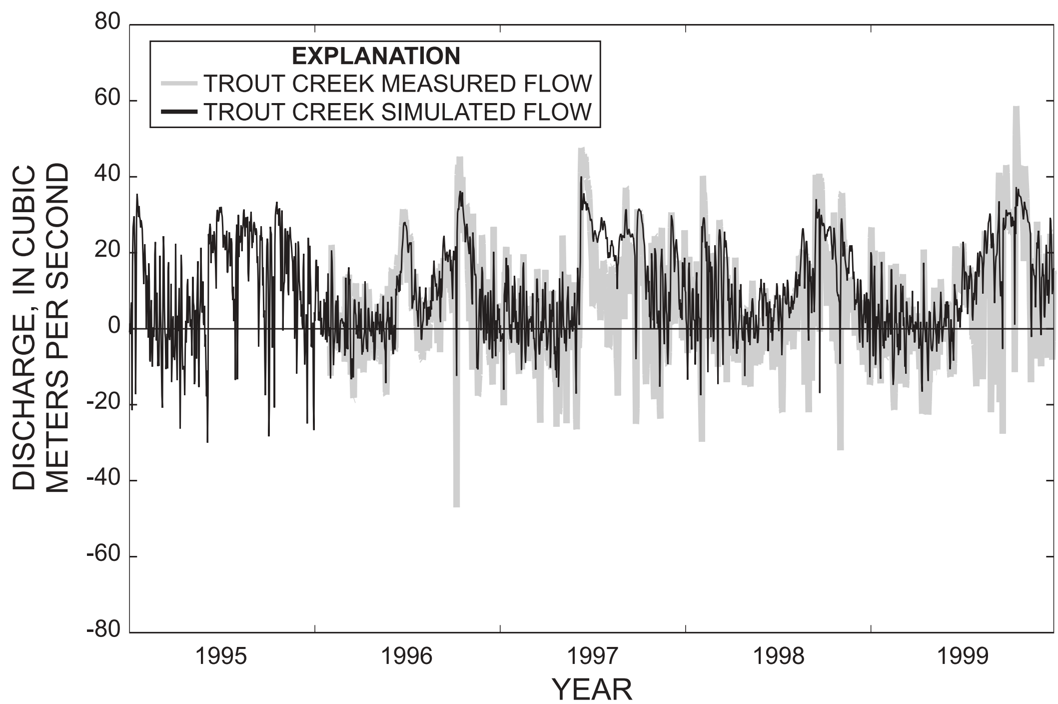

Figure 2. Measured and simulated discharge values for Trout Creek.

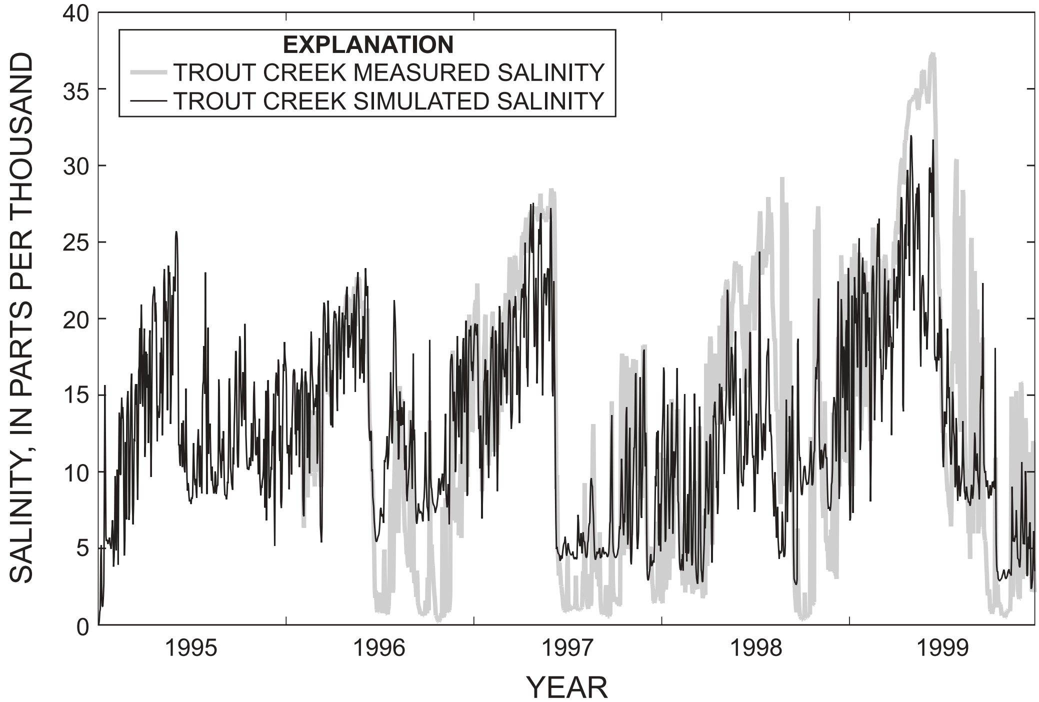

Figure 3. Measured and simulated salinity values for Trout Creek.

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.

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Circulation and Exchange Processes within Florida Bay Interior Basins

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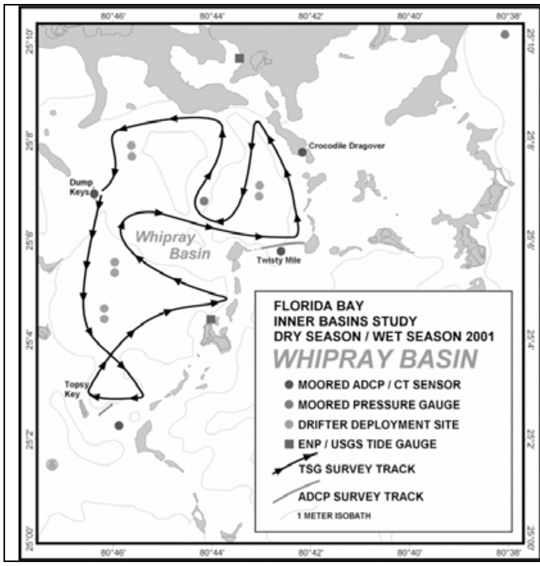
The goal of this study is to improve understanding of the circulation and exchange processes that regulate water properties and flushing rates of the interior basins of Florida Bay to aid evolution and application of predictive hydrodynamic models. At present it is not clear how proposed modifications in surface water delivery to Florida Bay will affect salinity variability within the Bay interior. However, it is generally agreed that large Bay salinity variations have significant impact on interior ecosystems, and possibly also with adjacent ecosystems of the shelf and Florida Keys National Marine Sanctuary (FKNMS) due to transport processes linking the regions. In April 2001 we began a new study to quantify the circulation and exchange rates influencing salinity variability in the eastern, central and western subregions of the Bay and their interactions with connecting regions.

Each basin is the focus of intense two month studies during wet and dry seasons. The observational program initially focused on Whipray Basin in the central region of the Bay and then most recently shifted to the Northeast Basin. Whipray was chosen for it is one of the most isolated basins, receives little fresh water runoff and develops hypersalinity conditions in the dry season with high turbidity levels and algal blooms. Our experimental approach was to directly measure the volume flows and salt transports into and out of the basins at the more significant flow connections, together with sea level variations and rapid basin surveys of temperature and salinity to directly compute the terms of the salt balance equation and estimate exchange rates. The shallow environments of Florida Bay required use of specialized equipment and techniques for moored time series measurements, small boat surveys and surface drifter trajectories. The experimental approach for Whipray is shown in Fig. 1. Sampling strategy consisted of a four mooring array deployed for two months over the dry and wet seasons in the flow passages, with bi-weekly ADCP transects, basin C/T/fluoresence surveys and drifter releases over 2-3 day periods for the season duration. A similar strategy was used for the Northeast Basin.

A total of 28 salinity surveys of Whipray basin were made over the dry and wet seasons from March 28 to Oct. 28, 2001. Salinity patterns show strong north/south salinity gradients in both seasons that reversed sign from positive in the dry season to negative in the wet season. Maximum salinities in the dry season reached 45 to 48 in the northwestern part of Whipray and even higher values near 50 were found on the bank in the Tin Can Channel region. During the wet season there appears to occur a general freshening over the entire basin, but with greater magnitude in the northern part where salinity's dropped to 25-30. Intrusions of lower salinity waters appear to enter the basin in the northeast and east via Mc Cormick Cr and Twisty section and from the northwest through the Tin Can Channel region. Drifter trajectories indicate a general basin-wide northwestward movement in the dry season and west to southwest movement in the fall. Basin average salinity was computed for each survey and is shown in Figure 2. The average salinity increased at a rate of approximately 4/mo during the dry season when rainfall and river discharge were negligible and evaporation maximum. During the wet season the basin average salinity decreased at a maximum rate of about 11.5/mo due to the combined influences of local rainfall, upland discharges and exchange with adjacent basins. The rapid rate of increase of basin average salinity during the dry season provides a rough estimate for the time scale of renewal of basin waters on the order of 6 months, using salt balance techniques. A similar renewal time estimate was previously made by Nuttle *et al*. (2000) using historical data.



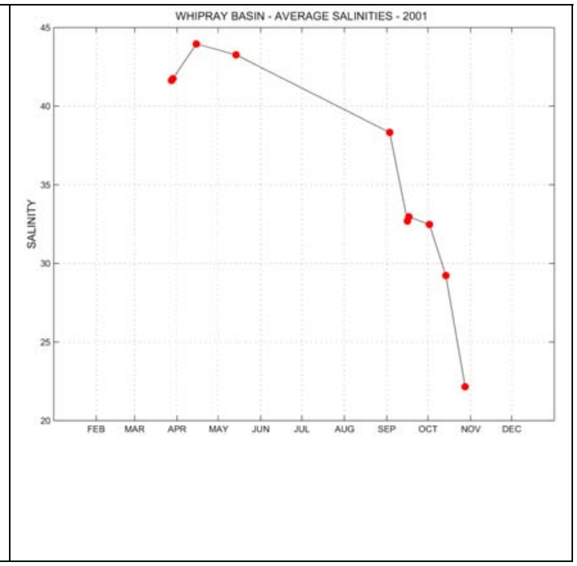


Fig. 1. Whipray sampling strategy

Fig. 2. Whipray average salinity 2001

Volume transports were measured with shipboard ADCP transects across the eastern opening to Whipray basin adjacent to Twisty Channel and across the southern opening of the basin adjacent to Topsy Key (Fig. 1). A total of 25 sets of transects were made at Twisty showing volume transports ranging +127 to –149 m3/s (+ is inflow and – outflow) for the 3 month wet season, and +44 to – 34 m3/s at Topsy from 27 transect sets. Mean flows from these data were +28 m3/s at Twisty and near zero at Topsy giving a mean inflow to Whipray of about 28 m3/s. However, these means are not reliable due to the scarcity of data and large variability observed, showing the importance of having time series measurements.

Shipboard volume transports were found to be linearly correlated to moored current records, accounting for 90% of the current variance and are used to derive volume transport time series for Twisty and Topsy sections. Volume transport time series were also derived for Dump and Crocodile Channels using moored current records with the cross-sectional areas. These transport time series show significant tidal and subtidal variations. Tidal fluctuations are primarily semi-diurnal at the eastern and western passages, but surprisingly there is a stronger diurnal variation through the southern passage (Topsy). Subtidal flows and sea level variability appear to be primarily responding to local wind forcing. Flows through the passages tend to be highly dependent upon the east-west wind component. East winds (toward west) cause inflows through Crocodile and Twisty and outflows through Dump and Topsy sections. The opposite occurs for west winds. In addition, flow through the southern passage (Topsy) is also dependent on the north-south wind component, ie north winds can cause outflow and south wind inflow. Surface drifters showed a similar response to east-west winds.

Means of the volume transports time series for the wet season were small. Inflows of 1.4 and 2.8 m3/s occurred through Crocodile and Twisty sections, respectively and outflows of 5 and 1 m3/s through Topsy and Dump sections, respectively. A very rough estimate of mean flow over the broad western bank adjacent to Whipray suggests an additional outflow on the order of 5 m3/s could have occurred. Using published estimates of mean wet season evaporation (9 m3/s) and precipitation (13 m3/s) for Whipray surface area requires a mean addition of river inflow at the northern boundary of 3 m3/s for a water volume balance. Our initial estimates of salt and water volume balances suggest a residence time for Whipray Basin of 6 to 11 months, which is in general agreement with previous estimates. These rough estimates will continue to be refined for the Science Conference and recent results from the Northeast Basin will be presented.

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An Integrated Modeling System for Simulating Circulation and Water Quality in Florida Bay and Biscayne Bay

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This paper presents an integrated modeling system, CH3D-IMS, based on the 3-D curvilinear grid circulation model CH3D and includes additional wave model, sediment transport model, water quality model, light attenuation model, and seagrass model. The CH3D model, originally developed by Sheng in 1986 and significantly enhanced at the University of Florida, has recently undergone major improvements to allow accurate and efficient simulation of circulation in complex estuarine and coastal environment such as Florida Bay. Four model aspects will be presented: (1)a robust algorithm for simulating wetting and drying of the shoreline and mudbanks in Florida Bay, (2)an accurate high-order advective scheme for simulating salinity and water quality transport, (3)parallel algorithm to allow efficient long-term simulations, and (4)coupling with a groundwater model. Example model simulations using the new modeling system will be compared with previous simulations using the earlier version of CH3D.

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Selected Features of Florida Bay Circulation: Targets for Hydrodynamic Model Validation

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Field studies conducted over the past five years have provided results that define many of the fundamental features of the movement of water into, through and out of Florida Bay. This paper draws from results of published and unpublished field studies to describe spatial patterns and to quantify local features of the circulation of the bay. In all cases, results can be compared with model simulations, and thus they serve as targets against which model simulations can be evaluated.

Harmonic analyses of water level records from Florida Bay (Smith 1997) provide amplitudes and phase angles of the principal tidal constituents that can be used to construct co-amplitude and co-phase charts. Co-amplitude charts show highest amplitudes for all principal tidal constituents in the northwest corner of the bay. M_2 amplitudes are just over 35 cm south of East Cape. S_2, K_1 and O_1 are 11, 15 and 12 cm. All tidal constituent amplitudes are less than 1 cm in the northeast corner of the bay. Co-phase charts indicate that M_2 waves enter primarily from the Gulf of Mexico and move eastward through the bay. M_2 waves travel at 5-10 km h^{-1} in the northwest part of the bay, then slow to a speed of 3-4 km h^{-1} as they move through the north-central part of the bay. Effects of Atlantic tides are restricted to areas near the tidal channels through which they enter from Hawk Channel.

Many observationss are site-specific, but even local measurements are helpful for model validation. Harmonic analyses of water level and current meter records from the same location quantify the tide-induced residual transport. Unpublished data from Flamingo Channel in northwest Florida Bay show maximum M_2 flood currents occurring 2 hours and 5 minutes before M_2 high water. Incorporating the local water depth and the amplitudes of the M_2 water level and current, one finds an M_2 transport of 1786 m^2 per tidal cycle. By integrating these values laterally across the width of Flamingo Channel ("calibrating" the channel), the total volume transport, in m^3 s^{-1}, could be determined and used for comparison with model simulations. The major tidal channels in the Upper and Middle Keys have been calibrated, and results are available for comparison. In Long Key Channel, the tide-induced residual transport is 28 m^3 s^{-1} (Smith 2002a). Observational results can be decomposed to quantify the role played by individual tidal constituents. For Long Key Channel, M_2 flood transport reaches 4915 m^3 s^{-1}, while ebb transport reaches 4583 m^3 s^{-1}. Over a complete tidal cycle, the net effect is 3.06×10^6 m^3 (Smith and Lee, in press), which is equivalent to 68.5 m^3 s^{-1} into Florida Bay. The long-term total transport through Long Key Channel, however, is from Florida Bay into Hawk Channel. Lee and Smith (2002) calculated a mean outflow of 280 m^3 s^{-1}, which was shown to be consistent with water levels 6 cm higher in western Florida Bay than in Hawk Channel. Even long-term transport values vary, however. In a nine-month study in 1997-97, Smith (2002a) calculated a mean outflow of approximately 390 m^3 s^{-1}.

Observations also provide information regarding how the bay responds to wind forcing. Spectral analysis of transport through Long Key Channel and Moser Channel indicates that wind stress is most efficient in forcing water into Florida Bay when the axis of the channel lies 55^o to the right of the wind stress vector (Smith 2002a). For those wind conditions, spectral analysis using Long

Key Channel data indicates that over time scales in excess of 3 days a ±1 dyne cm^{-2} variation in wind stress will produce a variation in transport of ±1300-1800 $m^3 s^{-1}$.

Combining results from field studies conducted in the central part of Florida Bay (Smith 2002b), a pattern of net outflow to the east, south and west defines a significant feature of the circulation. A one-year time series from Iron Pipe Channel, on the west side of Rabbit Key Basin, showed a net westward outflow of 12 cm s^{-1}. A one-year time series from Y Channel, through Nine Mile Bank along the south side of Rabbit Key Basin, showed a mean outflow of 6 cm s^{-1}. Data from Twin Key Basin, directly east of Rabbit Key Basin, show a net southward outflow of 18 cm s^{-1} through South Twin Key Channel, and an eastward outflow of 12 cm s^{-1} through a channel south of the Gopher Keys. Unpublished data suggest that part of the required inflow is a result of a southward flow from the north-central part of the bay. The divergent pattern in the central part of Florida Bay is a fundamental feature that should be reproduced by model simulations.

Two field studies conducted along the western boundary of the bay (assumed here to be the 81^o 05'W meridian) revealed regions of long-term net inflow and outflow. The boundary north of approximately 24^o 52'N appears in both field studies as a region of net inflow, while a net outflow occurs south of 24^o 52'N (Smith 2002b). Data from seven approximately equally-spaced locations provide information on the strength of tidal currents that exchange water between the bay and the eastern Gulf of Mexico (Smith 2002b). The amplitude of the east-west component of the M_2 tidal current decreases from approximately 34 cm s^{-1} at the northern end of the western boundary to 6-8 cm s^{-1} at the southern end. These observations should be useful for providing boundary conditions for the model or for verifying current speeds simulated along the 81^o 05'W meridian.

Current profiles obtained along the western boundary of Florida Bay (Smith 2000a) quantify vertical shear and are useful for selecting a single- or a multi-layer hydrodynamic model. At the northern end of the boundary, near-surface flow was southwestward, presumably in response to generally westward wind stress. In near-bottom layers at the same location the long-term net east-west flow was near zero. Further south along the boundary, near-surface and near-bottom flow patterns indicated minimal vertical shear. Resultant directions were nearly identical, while the magnitude of the resultant flow at the bottom of the water column was 81% of the magnitude in the near-surface layer.

Results of observational studies do not provide a complete picture of the regional flow field in and around Florida Bay. But they provide targets that are useful for model calibration and validation. Comparisons can include analog plots that superimpose simulated water levels or current speeds onto observations. But a thorough model validation should also include comparisons of identical analyses of observed and simulated variables. This includes comparisons of harmonic constants of observed and simulated water levels and current speeds, spectral analyses of observed and simulated currents with wind stress, and plots that identify regions of net inflow or outflow. With these comparisons, it is possible to quantify more precisely the accuracy with which physical processes in Florida Bay are being simulated.

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Establishing Minimum Flow Criteria for Florida Bay

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This report documents the process and methods that are underway by staff of the South Florida Water Management District (SFWMD) to develop technical criteria to define Minimum Flows and Levels (MFLs) for Florida Bay. Florida Bay includes the adjacent Taylor Slough and Shark River Slough watersheds within Everglades National Park that are the primary sources of freshwater surface inflow to the bay.

Section 373.042 (1), Florida Statutes (F.S.), defines the minimum level as the ". . . level of ground water within an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources of the area . . ." and the minimum flow as the ". . . limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area." Water resource functions protected under Chapter 373 are broad and include flood control, water quality protection, water supply and storage, fish and wildlife protection, navigation, and recreation. Passage of additional MFL legislation in 1997 added the requirements to consider changes and structural alterations, allow exclusions, and require development of a recovery strategy for water bodies that are not expected to meet the proposed criteria. During development of MFL criteria for the Florida Bay, a number of structural changes or alterations will be considered, along with the constraints such changes have placed on regional hydrology.

Surface water management and consumptive use permitting regulatory programs must prevent **harm** to the water resource. The hydrological criteria include level, duration, and frequency components and are used to define the amount of water that can be allocated from the resource. For purposes of establishing MFLs, **significant harm** is defined as loss of water resource functions that takes more than two years to recover, which result from a change in surface water or ground water hydrology. Water shortage declarations are designed to prevent **serious harm,** interpreted as long-term, irreversible, or permanent impacts, from occurring to water resources.

MFL criteria and definitions of significant harm will be developed based on the technical relationships of water resource functions to water levels or flows. The SFWMD is directed to use the best available information to establish a minimum flow or minimum level and define significant harm (Section 373.042, F.S.).
Florida Bay is an internationally recognized ecosystem due to its proximity to the Everglades, the largest subtropical wetland in the United States. MFL criteria and definition of significant harm for Florida Bay will be based on defining the amount of water needed to protect water resource functions of the system against significant harm. These water resource functions may include the following:

a. maintain desired salinity conditions within nearshore areas of Florida Bay
b. support freshwater, estuarine and marine ecosystems,
c. provide natural biological filtering and nutrient cycling,
d. provide dry season refugia for aquatic wildlife, and
e. prevent undesirable changes in seagrass vegetation and periodic algal blooms.

Water deliveries to Florida Bay depend directly on the flow of water through Everglades National Park from upstream areas, especially the Water Conservation Areas (WCA) and the

South Dade Conveyance System. Everglades water levels are managed based on regulation schedules in the WCAs and a rainfall based water delivery plan for Everglades National Park (ENP). A first step in the determination of MFLs for Florida Bay is to evaluate the effects of the MFL water level criteria that have already been established for ENP and the proposed restoration projects and water delivery criteria for Everglades National Park to determine what effects these deliveries will have on Florida Bay.

Minimum flow criteria for Florida Bay will be based on establishing quantitative relationships between the amount of water flow provided to the bay (or by inference, water levels in adjacent upland systems) and measured or measurable effects on water resources, including salinity, water quality, vegetation, fish and wildlife. The first steps in this analysis involve a review of available literature, historical water level, flow and salinity and ecological data, and data from mathematical water management, natural systems and hydrodynamic computer models that include Florida Bay. Impacts associated with significant harm in other estuaries in south Florida will also be examined to determine whether they can be applied to Florida Bay. Such effects include widespread and frequent loss of low-salinity habitat, frequency and extent of nuisance algal blooms, and widespread impacts to seagrasses, coastal vegetation communities or wildlife populations and that require more than two years for recovery to occur. Technical relationships for the Florida Bay will include analyses of the effects of water levels and flows on salinity, effects of salinity on plant and wildlife communities, and the occurrence of destructive events such as the dieoff of seagrasses, algal blooms and widespread changes in the distribution of critical habitats or salinity regimes, to the extent that these impacts can be linked to low freshwater inflow conditions

Florida Bay "no harm" standards will eventually be derived from model simulations for the year 2020 that include implementation of the features that are identified in the Florida Bay Feasibility Study as part of the Comprehensive Everglades Restoration Plan (CERP) to achieve restoration of the Bay. As restoration progresses, it is anticipated that the resource will improve and MFL criteria will need to be revised periodically to reflect the changing condition of the resource.

The SFWMD needs the assistance of the research community in two areas. The first is to determine which of the critical resources are most sensitive to the effects of freshwater inflow (i.e what is the MFL designed to protect?). By identifying and protecting the most sensitive resources, the assumption is made that other, less sensitive resources are also protected. The second need is to identify or develop quantitative relationships between freshwater inflow and resource impacts. This requires determination of a degree of resource impact that constitutes "significant harm" and determination of the minimum amount of water (defined in terms of flow rate or water level, duration or hydroperiod, and return frequency of exceedances) needed to prevent this condition from occurring.

Examples are provided to show how MFL criteria have been developed and applied by the SFWMD in other South Florida coastal systems.

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Question 1 -
Physical Processes
Poster Abstracts

- Listed alphabetically by presenting author.
- Presenting author appears in **bold**.

Spatial and Temporal Patterns of Salinity Simulated by the FATHOM Model Compared to Observed Salinity Data for the Period 1993 to 1999

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FATHOM is a dynamic, spatially explicit, mass-balance model designed to simulate the movement of water and solutes in Florida Bay in response to runoff, climate, tides and the topography of the bay. The model maintains a running account of the water and solute budgets in each of 43 well-mixed basins within the bay (Figure 1). The boundaries of these basins follow the banks that dissect the bay. The banks are the primary controls on mixing within the bay and the basins offer a natural framework for mass-balance accounting. We compare here the temporal and spatial patterns of salinity simulated by FATHOM with observed salinity data from the monitoring program conducted in Florida Bay by the Southeast Environmental Research Center (SERC). The SERC data base provides monthly salinity values in 24 FATHOM basins for the period 1993 to 1999. These data provide a robust test of the model's ability to simulate the temporal and spatial patterns of a conservative solute.

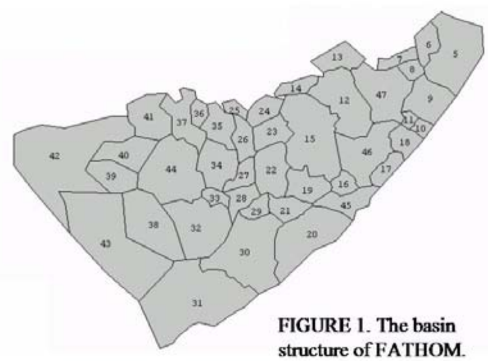

FIGURE 1. The basin structure of FATHOM.

Model Structure. The FATHOM model simulates exchange with the coastal ocean and mixing among the basins within the bay resulting from water fluxes driven across the shallow banks by differences in water surface elevation on either side of the banks. Manning's equation for friction flow in channels is used to calculate water velocity as a function of bank width, depth of flow and roughness of the bottom. At each time step, the model solves for uniform, hydraulic flow across each bank based on the depth**,** width, and frictional roughness of the bank and water levels in the upstream and downstream basins. Time steps are typically on the order of a few minutes so that tidally driven changes in water surface elevation can be resolved. Calculated velocities are used with the cross sectional areas of water on the banks to give water fluxes. Solute fluxes are then calculated from solute concentrations in the water on the bank.

Model Inputs. Observed rainfall data from the mainland and the Keys were used to establish time-series of rainfall inputs for four regions in the bay. An estimated average monthly pattern of evaporation was applied uniformly over the bay and repeated for each year of the simulation to set evaporation inputs. Along the Everglades coastline runoff inputs were based on observed discharges in Taylor Slough and the C-111 canal. This long time-series of runoff was distributed along the northeastern bay boundary using spatial patterns derived from a shorter period of observed creek discharge data. Hourly tide stages were applied along the Gulf and Atlantic boundaries of the model. Monthly changes in mean sea level at the boundaries and long-term trends in annual average sea-level are added to the tide data. The sea level data are derived from observations at Key West and within the bay. Observed salinity data were used to set the gulf and Atlantic boundary conditions for salinity. Bathymetry data were derived primarily from NOAA charts. The bottom roughness coefficient for Manning's equation was derived from flume studies conducted in the northwestern area of the bay.

Model Results. The simulations were performed with no refinement of the input data and no fine-tuning of model parameters beyond that described above. Time series of simulated and observed data for each basin (see examples in Figure 2) demonstrate that the "un-calibrated" model reliably reproduced most of the observed variations in salinity in the bay. Fits to observed data were generally best for basins in the western part of the bay and worst for the small bays immediately adjacent to the Everglades boundary.

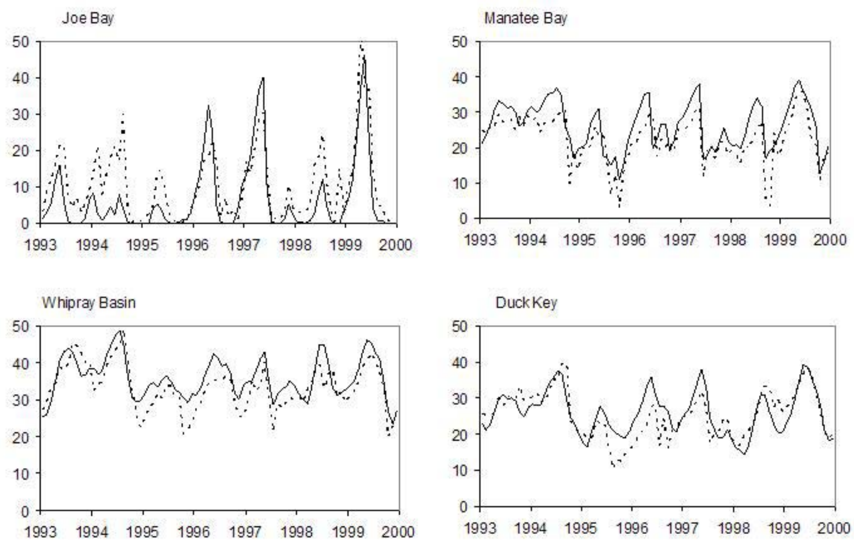

Figure 2. Examples of simulated (solid) and observed (dashed) salinity values for four basins for the period 1993 to 1999.

Discussion. There are a number of advantages in adopting a conceptually simple but process-based and physically constrained mass-balance framework for a model of Florida Bay. First, the work of the model, calculating velocities and fluxes of water, can be focused on those areas in the bay where the major controls on flow are operating, the banks and shoals. This leads to an efficient model. Second, the mass balance structure of the model required to track water levels in each basin makes it straightforward to add additional solutes to the structure. Third, the organizing units in the model (the basins and banks) have direct ecological significance and, in many cases, may be actual elements of ecological models, thus providing a ready link for coupling simulated physical and chemical responses to biological models. Fourth, the discrete nature of the framework means that model output is directly accessible in readily understood terms (e.g., colored maps of properties in each of the basins), and that sub-regions in the bay can be examined directly (e.g., time series data for individual basins) without the need for extensive post-processing of simulation results. A major disadvantage of the approach arises from the simplifying assumption that each basin is well-mixed. As a result, spatial details within individual basins are not resolved, and the temporal resolution of outputs for the basins (other than water levels) are limited to approximately daily average values. However, in light of the fact that observed data is frequently limited to one (or a at best a few) observations within each basin, the lack of spatial resolution within a basin seems not to be a disadvantage for many potential applications of the model. Similarly, the lack of extensive diel observations across the bay suggests that simulated values approximating daily averages may be sufficient for many model applications. Indeed, the current lack of high resolution (both spatial and temporal) observed data makes the testing and evaluation (and perhaps even the development) of more dis-aggregated models problematic at this time. Whether or not that may be the case, the examples presented here of FATHOM applied to the SERC salinity data (with no refinement of the input data or fine tuning of the model parameters) suggest that simpler, aggregated, process-oriented, mass-balance models are sufficiently robust to be useful for many quantitative and qualitative problems affecting Florida Bay.

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Continuous Hydrologic Data in Florida Bay Channels

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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).

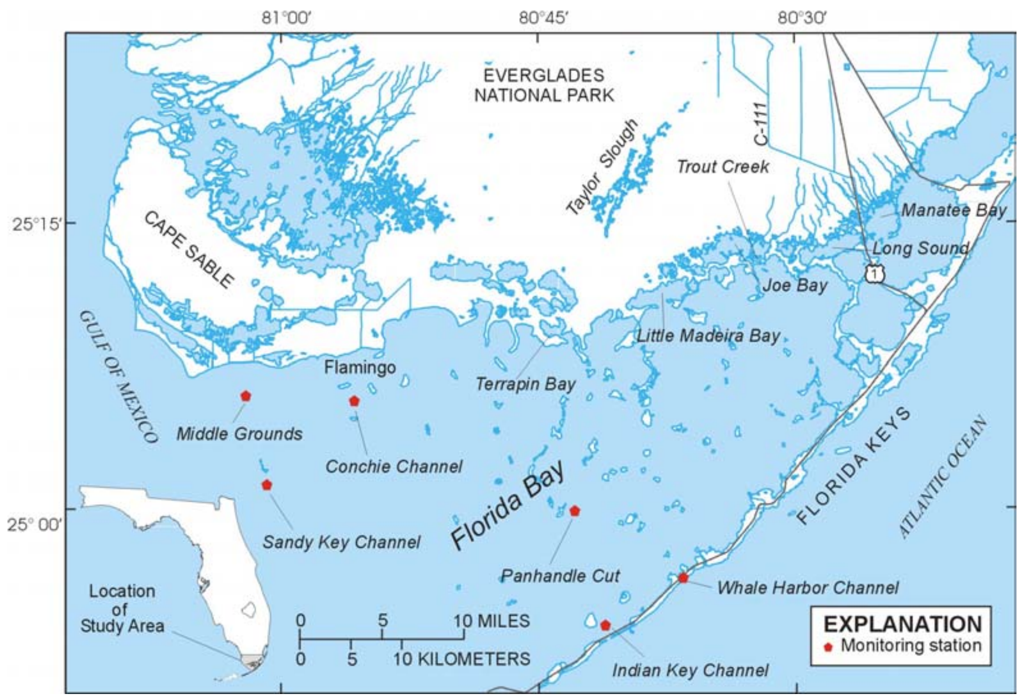

Figure 1. Location of Florida Bay monitoring stations.

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.

Figure 2. Helicopter based survey method.

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.

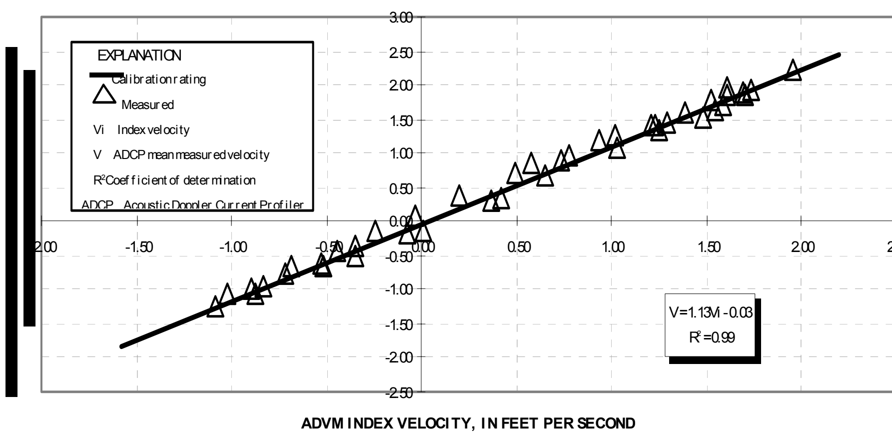

Figure 3. Velocity relation for the Whale Harbor monitoring station

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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Estuarine Creek Responses to Extreme Hydrologic Events in Northeastern Florida Bay

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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.

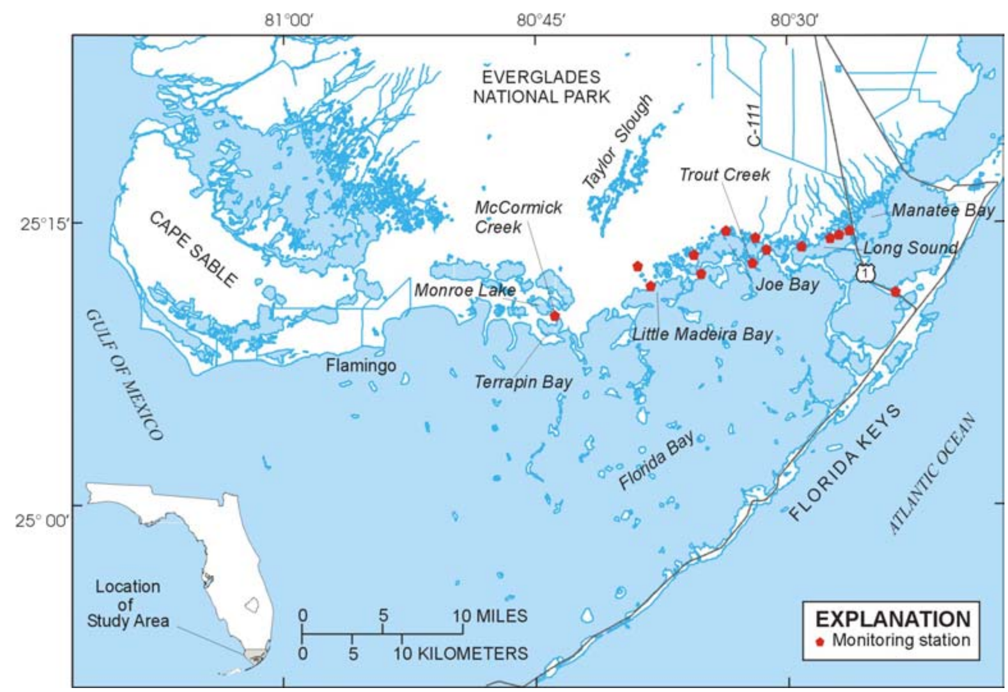

Figure 1. Location of Florida Bay monitoring stations.

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.

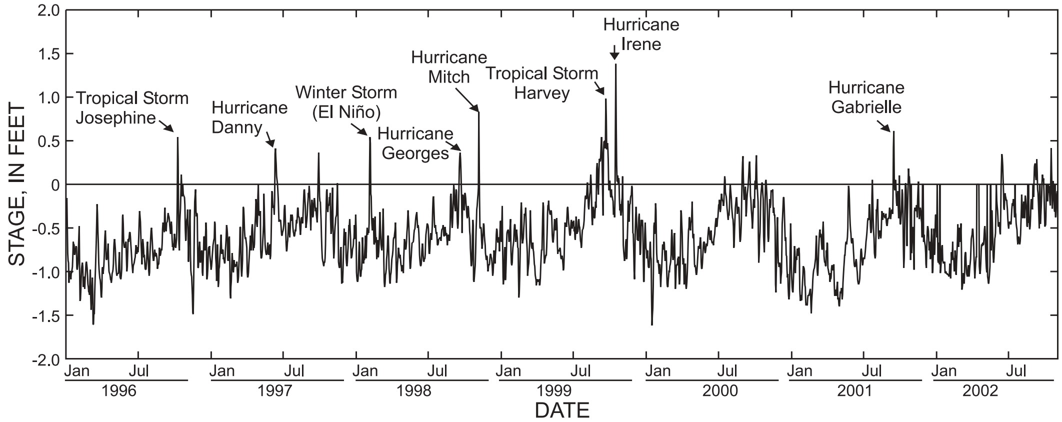

Figure 2. Daily mean values of stage for Trout Creek, 1996 – 2002.

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).

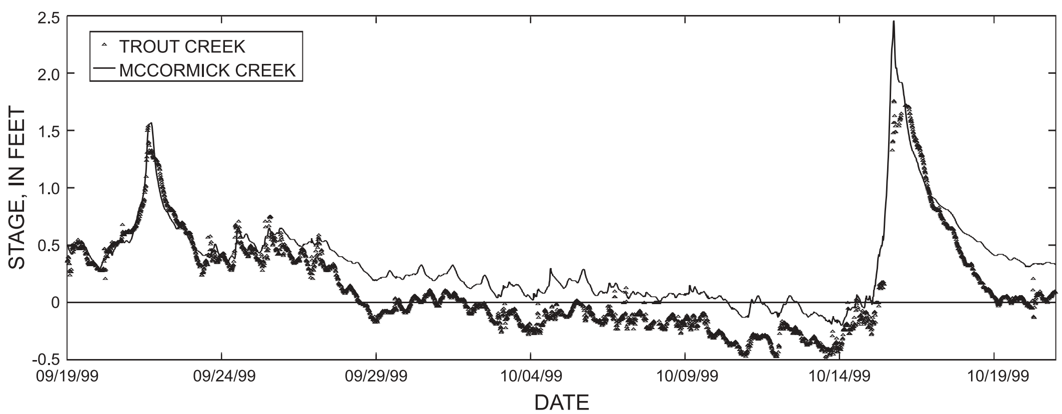

Figure 3. 15-minute interval stage values for McCormick and Trout Creek during Tropical Storm Harvey and Hurricane Irene.

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).

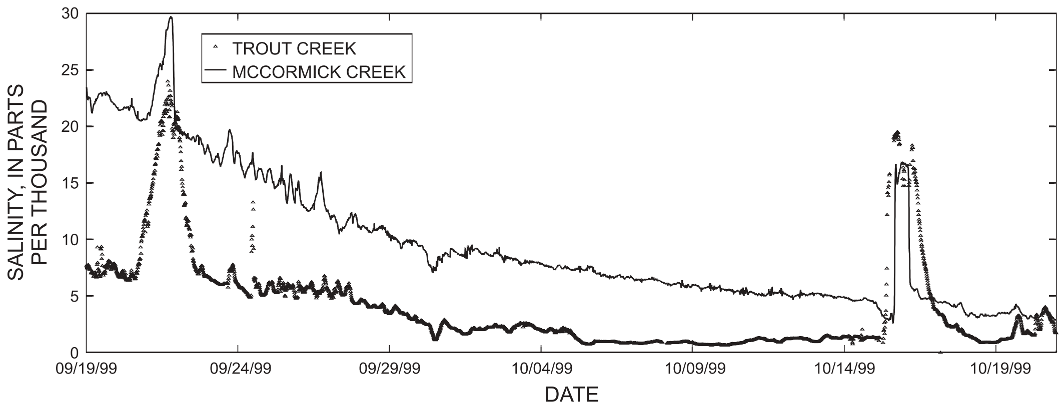

Figure 4. 15-minute interval salinity values for McCormick and Trout Creek during Tropical Storm Harvey and Hurricane Irene.

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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New Interdisciplinary Oceanographic Observations in the Coastal Waters Adjacent to Florida Bay

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As part of an ongoing, interdisciplinary study of Florida Bay and the adjacent coastal ecosystems of south Florida funded by NOAA's Coastal Ocean Program (COP), new observations are presently being made in the Florida Keys, the Dry Tortugas, and Biscayne Bay. Each of these new study areas has clear relevance to our efforts to understand the circulation affecting Florida Bay, either (1) by a direct connection in the case of the waters of the Florida Keys passages; (2) by a more remote oceanic linkage via large-scale currents and eddies in the case of the Dry Tortugas; or (3) by virtue of similarity of size, location, and physical forcing processes (allowing informative inter-comparison) in the case of Biscayne Bay. These new observations, described below, were begun in mid-2002 and it is hoped that they will become part of a south Florida coastal ocean monitoring system that will continue indefinitely, yielding invaluable long-term time series data sets relevant not only to Florida Bay but also to the management needs of the Florida Keys National Marine Sanctuary (FKNMS).

(1) The new work in the Florida Keys is focused on the goal of providing continuous observations of subtidal volume transport and water properties in the major passages between Florida Bay and the Atlantic Ocean. The project builds upon a previous study by Lee and Smith (*Cont. Shelf Res.,* 22, 1361-1377, 2002) in which it was shown, using volume transport measurements in the channels, bottom pressure instruments deployed at West Florida Bay and Tennessee Reef, and local CMAN station wind records, that subtidal transport variations through the passages are linearly correlated with cross-Key wind-driven sea level slopes. As shown in Figure 1, the mean transports through these passages were found to be –55 m^3/s each for Channels 2 and 5, -260 m^3/s for Long Key, and –370 m^3/s for the Seven-Mile Bridge, yielding a total volume transport of –740 m^3/s (where negative transports are directed from Florida Bay towards the Atlantic). With Lee and Smith (2002) having clearly established that the majority of the subtidal flow exchanges through the Long Key and Seven-Mile Bridge Channels, and furthermore having demonstrated the strong linear correlation between wind-driven sea level slope and volume transport, the next step was to find a way to use existing CMAN sea level

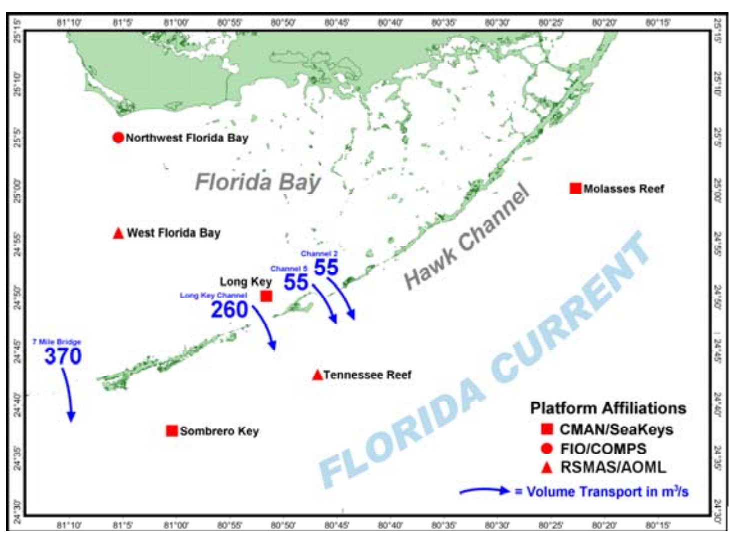

Figure 1. Volume transport through the Keys passages.

observations, available in near real-time (at www.ndbc.noaa.gov), to derive near real-time calibrated volume transports through these two major passages. These sea-level derived transports will be combined with data from conductivity, temperature, and optical instruments moored in the passages that will communicate their data back to our laboratory also in near real-time. The transport and water quality information will be provided on a Web site and will form the basis of a "smart" system which will notify interested scientists and resource managers of significant outflow events. In particular, such notification will allow us to rapidly stage event-response cruises to map outflow events as they impinge on the coral reef tract of the FKNMS, in order to assess the water quality and infer the ecological implications of the outflow from Florida Bay.

(2) The new work in the Dry Tortugas consists of a one day addition to the regular bimonthly schedule of the NOAA/COP funded interdisciplinary monitoring cruises aboard the University of Miami's research catamaran the *R/V F. G. Walton Smith*. The new Tortugas survey track is shown in Figure 2, and is designed to resolve the surrounding flow field and water properties of the Tortugas Ecological Reserve and its connections with the Gulf of Mexico, the Loop Current, and the quasi-permanent Tortugas Gyre. These cruises are conducted bimonthly and consist of hydrographic and biological-chemical observations over the area encompassing the Florida Keys, the Gulf of Mexico, and the southwest Florida shelf from Florida Bay to Charlotte Harbor. In addition to station data, continuous observations of temperature, salinity, chlorophyll, and turbidity are obtained along the ship track, and continuous upper water column currents are obtained using a hull-mounted ADCP. During the new Tortugas surveys, satellite-tracked surface drifters are often deployed in the vicinity of Riley's Hump (Fig. 2), known to be a critical snapper spawning area. These surveys have been conducted bimonthly since summer 2002, and preliminary results show that the circulation and water quality of the Tortugas must be examined in the broader oceanic context of the surrounding waters because the region is strongly affected by large-scale ocean currents such as the Loop Current and the Florida Current, and associated recirculating gyres.

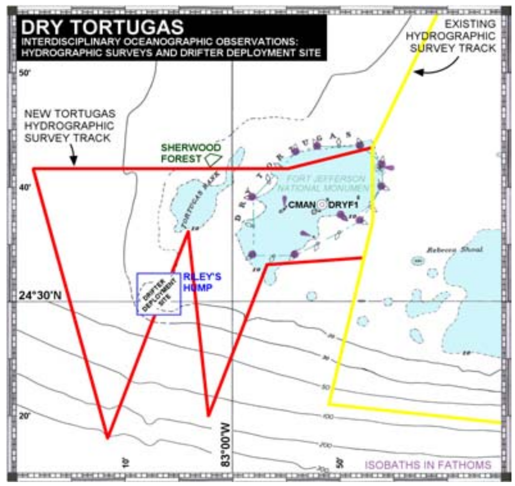

Figure 2. New Tortugas survey track and Riley's Hump drifter site.

(3) The new work in Biscayne Bay consists of a one day addition to the regular monthly two-day schedule of NOAA/COP funded Florida Bay monitoring cruises aboard the small research catamaran the *Virginia K.* The Florida Bay cruises have been conducted since the summer of 1998, with salinity/chlorophyll/turbidity maps posted regularly on the project Web site (at www.rsmas.miami.edu/flbay). The cruise track, shown in Figure 3, is designed to fully resolve the western side of Biscayne Bay by sampling the major canals and rivers

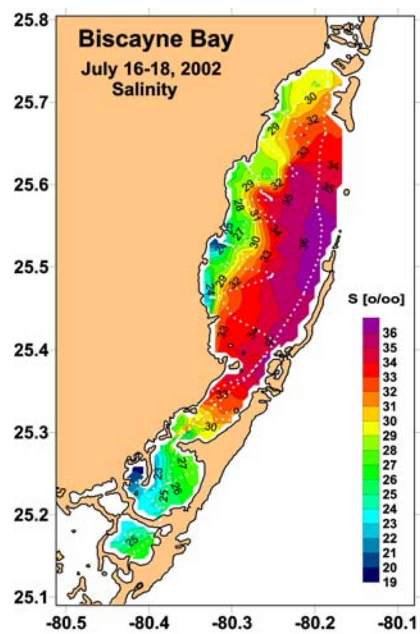

Figure 3. Typical monthly salinity survey of Biscayne Bay

discharging fresh water into the Bay. Biological and chemical samples are collected at a series of discrete stations along the cruise track. Because discharge through these canals is a function of water management decisions, additional Biscayne Bay event-response surveys may also be undertaken when major releases are made in response to flood protection concerns. These observations will eventually provide a time history of surface salinity and other parameters that will aid in our understanding of the circulation and water properties of Biscayne Bay and how the Bay responds to external forcing such as winds and storms, precipitation, evaporation, surface and ground water inputs, and exchanges with adjacent coastal waters.

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A Recent Study of the Light Environment in Florida Bay

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Light attenuation in marine ecosystems is of great importance to primary producers since light availability potentially limits the growth rates of both phytoplankton and seagrass. Chromophoric dissolved organic matter (CDOM), phytoplankton, tripton (inanimate particulate matter) and seawater itself are the major factors that influence light attenuation. These factors influence light attenuation via absorption and/or scattering of photons. In different ecosystems various combinations of these factors dominate the light regime. The light attenuation coefficient or K_t provides a useful way to quantify and compare the light regime in different regions. This coefficient can be further partitioned into partial light attenuation coefficients for each of the above factors.

Florida Bay is an area that has undergone numerous ecological changes over the past two decades. The most widely publicized of these was the mass seagrass die-off that began in 1987. Although the cause of this die-off is still unresolved it has been theorized that the die-off adversely affected the light regime of the Bay directly via resuspension of sediments and indirectly if greater nutrient availability led to increased phytoplankton biomass. The light environment of Florida Bay was studied intensely from August 1993 until September of 1994 by Phlips et al. 1995. However, not only has considerable time elapsed but since 1994 the Bay has significantly changed; in particular, the dense cyanobacterial bloom regularly observed in the central Bay in the early 1990's is not at present a dominant feature. While there have been some recent light measurements these have been of comparatively limited spatial extent and have not attempted to partition the factors contributing to attenuation. We here report the results of a spatially high resolution study of light attenuation and its components in Florida Bay including both the dry and wet seasons.

A total of eight cruises were conducted at approximately monthly intervals from July 2001 to March 2002 by the *R/V Virginia K* from NOAA's Atlantic Oceanographic and Meteorological Laboratory. Hydrographic data from the survey cruises are made available to the community via the world-wide web [www.aoml.noaa.gov/ocd/sferpm/surveymaps.html]. The Virginia K is equipped with a flow-through measurement system consisting of a Seabird model 21 thermosalinograph, a Japan Radio Corporation DGPS 200, a Seapoint CDOM fluorometer, a Seapoint chlorophyll *a* fluorometer, and a Wetlabs transmissometer. All data are recorded at seven-second intervals. In addition forty discrete stations were sampled each cruise for chlorophyll *a* (an estimator of phytoplankton abundance), Total Suspended Solids (TSS), and light attenuation (K_t).

Using the station data statistical models were generated to estimate chlorophyll *a*, tripton (a function of TSS and chlorophyll *a*), and, eventually K_t, from the underway measurements. To estimate chlorophyll *a* and tripton both non-linear and linear regression analyses were attempted using the five underway measurements as the independent variables. Linear regression models proved as efficient as non-linear models and multiple regression models were somewhat better than simple regression models. The models estimating chlorophyll *a* and tripton from underway measurements explained over eighty percent of the variance.

Two different approaches were employed to model K_t. The first was mechanistic and based upon partial light attenuation coefficients for each factor. The concentrations estimated from the underway measurements were multiplied by the specific absorption coefficient (SAC) for each variable (determined from the literature or in the case of tripton by difference). These partial attenuation coefficients were then summed to get an overall light attenuation coefficient. This model explained 74.9% of the variance in K_t. However, there are some *a priori* weaknesses in this approach that may result in an underestimation of the influence of phytoplankton pigments and an overestimation of the influence of tripton.

The second approach to modeling K_t was statistical (specifically multiple regression analysis). This relaxes some of the constraints of the previous model allowing the regression analysis to estimate "pseudo-SACs" for each factor. Some of these "pseudo-SACs" differed greatly from the previously employed SACs. However, these "pseudo-SACs" were in fact comparable to those calculated using a similar approach in Chesapeake Bay. Some differences are to be expected due to differences in phytoplankton species composition, CDOM chromophores, and the particle size and composition of suspended sediments.

While the multiple regression model was marginally more efficient, the two models predicted similar values. In fact, a 0.944 coefficient of determination was found when the results from the two models were regressed upon each other. The mechanistic model was then used to generate high-density maps of attenuation in the Bay from the underway data sets. The mean of these maps is shown in figure 1.

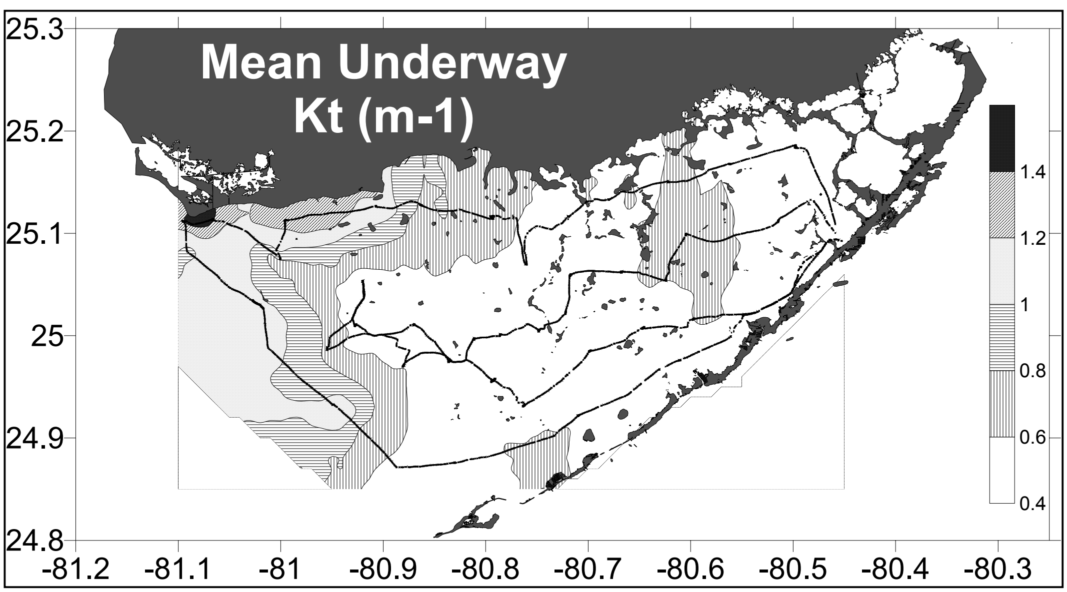

Figure 1. Plot of the mean light attenuation coefficient, K_t, estimated via the mechanistic model from the underway data sets.

The results of this analysis were then used to determine the sub-areas in the Bay where light-limitation is sufficient to limit phytoplankton primary production and seagrass growth. The light attenuation relationship generated, as well as the partial attenuation coefficients can be used in subsequent water quality models and for ground-truth of satellite remote sensing. NOAA/AOML expects to continue this monthly monitoring over the coming decades as CERP is implemented.

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On the Development of a Regional Hydrodynamic Model around Florida Bay and the Florida Keys

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A comprehensive, three-dimensional hydrodynamic model of the coastal seas adjacent to Florida Bay and the Florida Keys is under development (Figure 1). The study goal is to link the shallow coastal regions that encompass Florida Bay and the Florida Keys to adjacent oceanic and shelf flows that play an important role in the water circulation and exchange. The modeling strategy is to follow a nested and downscaling approach, where the regional model provides the link between coastal models of Florida Bay and the Florida Keys with a larger scale Atlantic Ocean and Gulf of Mexico hydrodynamic model. The regional model has an intermediate resolution (lying between the coarse resolution of the large scale model and the fine resolution of the coastal scale models) and it provides appropriate boundary conditions for the limited area models of the Florida Bay and Florida Keys regions. This approach ensures that the coastal models receive inputs from adjacent and remote sources, so that the calculated flows in the coastal areas of interest are realistic. Furthermore, the regional model provides downscaled fields of wind and heat and salt fluxes, that are the product of larger scale atmospheric models. These fields introduce the regional South Florida meteorological effects on the limited area coastal models.

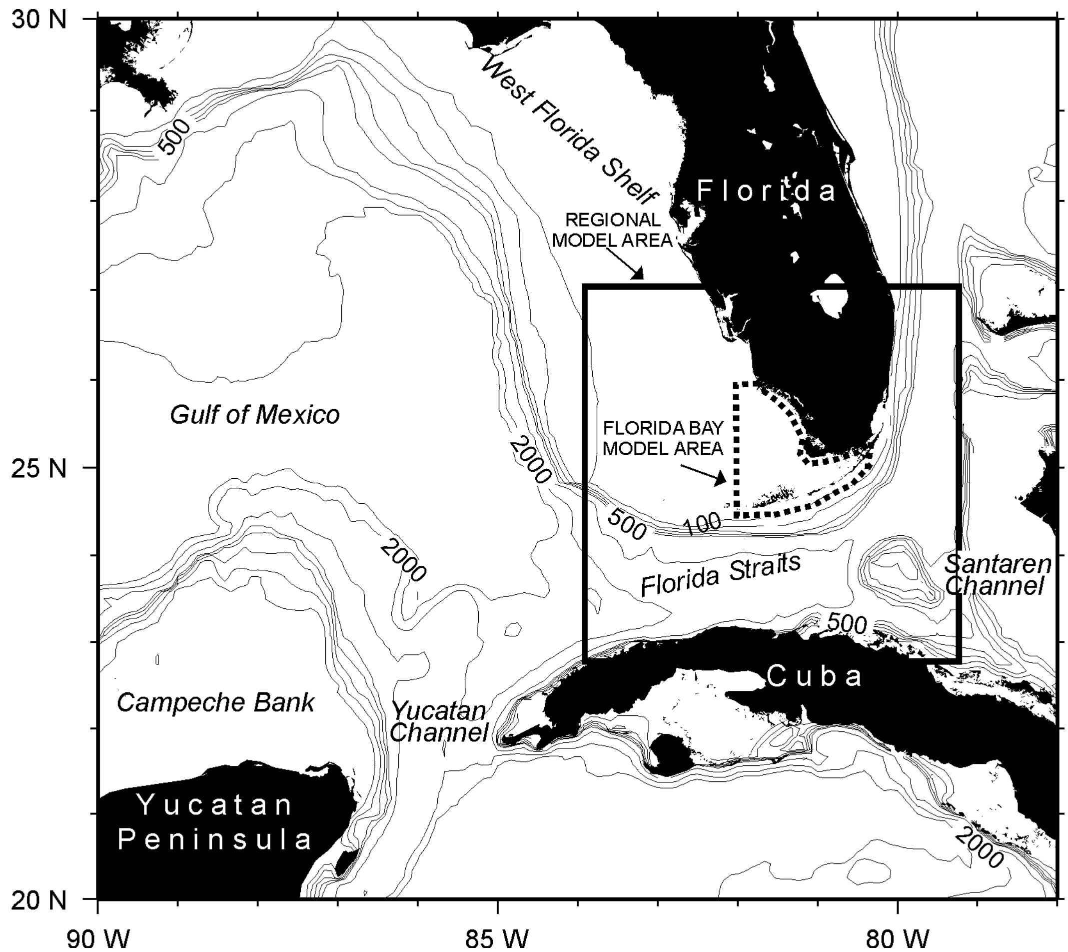

Figure 1: The seas adjacent to Florida Bay: Gulf of Mexico, West Florida shelf and Florida Straits; the thick rectangular frame marks the regional South Florida model area; the thick dashed line marks the inner Florida Bay model area.

The main objective of the study is to numerically simulate the key mechanisms that control the interaction between Florida Bay, the Florida Keys, the coastal waters of the adjacent shelf, and large-scale off-shore oceanic flows. The related processes have been identified through analysis of data from ongoing observational programs. Numerical simulations are being planned to test the data based hypotheses and determine which processes must be incorporated to successfully predict the transport rates and pathways of waters that exit Florida Bay toward environmentally sensitive areas such as the Florida Keys reef tract and the Dry Tortugas Ecological Reserve. An example is a process oriented numerical study on the net southward flow that couples the eastern Gulf and Atlantic coastal region of the Keys. This flow transports low-salinity discharges from rivers in the eastern Gulf and western Everglades around Cape Sable to western Florida Bay where they can interact with interior waters of the Bay as well as the Atlantic coastal waters of the Keys.

The regional hydrodynamic model is an implementation of the HYCOM (Hybrid Coordinate Ocean Model, http://panoramix.rsmas.miami.edu/hycom/), a finite-difference hybrid isopycnal/sigma/z-level model. This model has been developed on a hybrid vertical coordinate system, in order to overcome problems faced by traditional vertical coordinate choices (z-level, terrain-following sigma, isopycnic), that are not optimal everywhere in the ocean. HYCOM behaves like a conventional sigma model in very shallow and/or unstratified oceanic regions, like a z-level coordinate model in the mixed layer or other unstratified regions, and like an isopycnic-coordinate model in stratified regions. In doing so, the model combines the advantages of the different types of coordinates in optimally simulating coastal and open-ocean circulation features. Furthermore, depending on the application, HYCOM can be run in isopycnic, sigma or hybrid mode. This flexibility makes HYCOM an excellent choice for the current regional model development, as it can be easily coupled with a range of coastal Florida Bay and Florida Keys coastal models.

The South Florida regional HYCOM model is under development. It includes the southern part of the western Florida shelf and the Florida Straits on a 2-3 km resolution and it is being coupled with an existing large scale HYCOM model with 6-7 km resolution. The regional model encompasses the inner Florida Bay model domain (Figure 1) and it is thus suitable to provide boundary conditions for high resolution Florida Bay and Florida Keys coastal models. The regional South Florida model can perform suitable long term and event oriented simulations to compute and deliver all the necessary hydrodynamic parameters at the boundaries of the coastal models. This nested numerical approach ensures that simulations within Florida Bay and the Florida Keys are realistic, as they are sustained by interactive links to the adjacent large scale flows.

Preliminary results support the need for a nested modeling approach. The Loop Current and the Florida Current provide a mechanism for the connectivity of coastal waters around South Florida. This is a finding that is supported by the observations. Model results suggest that the summer period favors advection of low salinity waters from remote areas like the west Florida shelf and the Mississippi River toward Florida Bay and the Florida Keys. Supportive data from the summer of 1998 are presented.

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Salinity Simulation Models for North Florida Bay, Everglades National Park

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Everglades National Park, Homestead, FL

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This CESI project for Everglades National Park (ENP) developed salinity simulation models for north Florida Bay using statistical time series methods and available time series data. Daily data utilized included salinity, water levels in the Everglades, and Taylor Slough flows from the ENP Physical Monitoring Network; rainfall (several sources); South Florida Water Management District (SFWMD) C-111 canal flows; USGS creek flows, NOS tide elevations, and NWS wind. The period of record is October 1, 1994 through September 30, 2000.

Previous work by Marshall (2000) used monthly data to initially investigate the feasibility of time series models to simulate salinity variability. A primary objective of the current ENP CESI project is to evaluate and develop salinity simulation models for coupling with the output from the SFWMD 2X2 Watershed Model so that revised schemes for water delivery from the Everglades and the C-111 Canal to Florida Bay can be evaluated.

To begin the study, seasonal autoregressive integrated moving average (SARIMA) models for salinity at seven stations in Florida Bay and one on the west coast were investigated. SARIMA models are robust to the highly correlated components of the dataset. It was found that SARIMA models were best applied in one-step forward simulations, as shown by Figure 1 for Terrapin Bay at the end of this abstract. However, software and missing value limitations were found to limit the utilization of SARIMA models for coupling with the 2X2 Model.

As an alternative, preliminary multivariate linear regression (MLR) models for salinity were developed from the field data by adapting SARIMA model parameter identification techniques to linear regression methods. An example of the fit for one of the eight MLR models is presented as Figure 2. A summary of the R^2 and Mallow's Cp values for each of the preliminary models is presented as Table 1. As a proof-of-concept exercise, the preliminary MLR model for Little Madeira Bay was modified and then coupled with 2X2 Model output from a previous Restudy project to produce a salinity simulation for 30 years (Figure 3).

Table 1. Summary of MLR model R^2 and Mallow's Cp.

	joebay	ltmad	terbay	garbight	norriv	whip	butternut	duck
R2	0.76	0.92	0.92	0.96	0.82	0.99	0.95	0.97
Cp	13.5	5	15.8	7	9.6	11.2	6.6	11.5

This project has shown that MLR time series models can reasonably simulate salinity in Florida Bay from existing data, and has proven that statistical models can be coupled with 2X2 Model output for use as a salinity performance measure. Comparison of all plots of MLR model output to field data shows that additional work is needed to improve model fit, even though R^2 values are high. In the second year of this project (currently underway), MLR models will be optimized before being used with 2X2 Model output for revised water delivery scenarios to predict and evaluate changes to the existing salinity regime in Florida Bay.

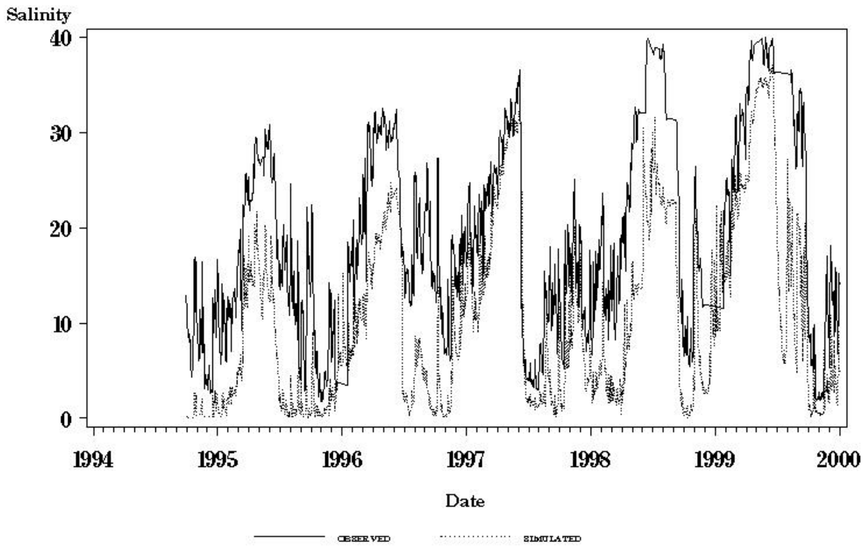

Figure 1. Comparison of SARIMA model output and observed data (one-step forward prediction) for Terrapin Bay (missing values have been filled).

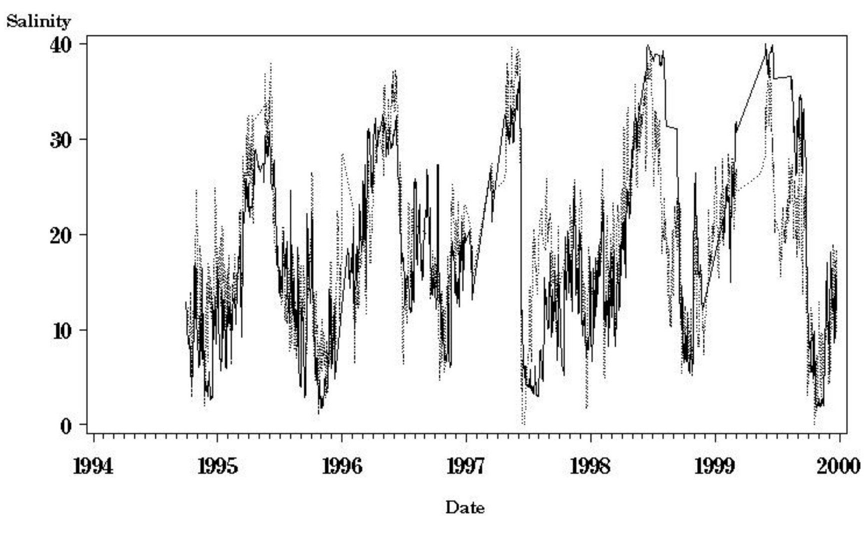

Figure 2. Comparison of multivariate linear regression (MLR) model output with observed data for Terrapin Bay.

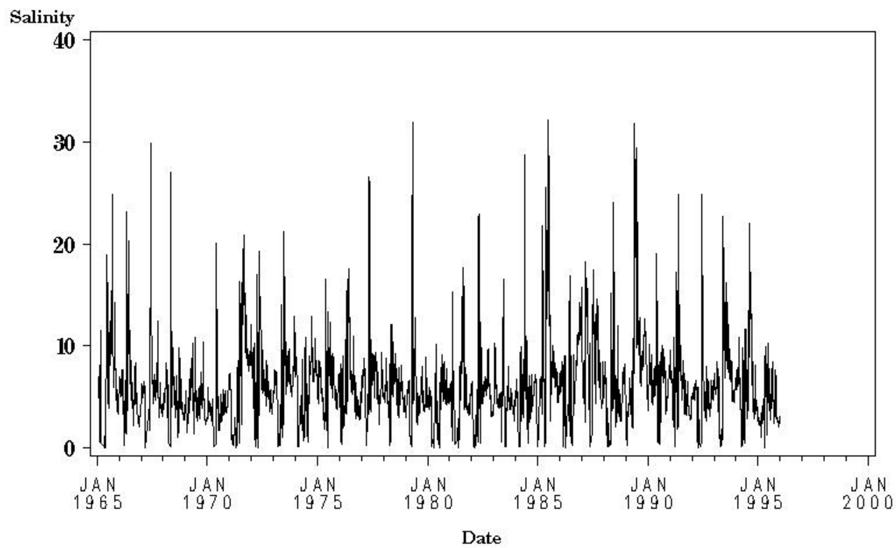

Figure 3. Simulation of salinity in Little Madeira Bay using 2X2 Natural System Model output and MLR salinity model.

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Florida Bay Shallow Water Surface Drifter

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In response to NOAA/COP funded research needs for high resolution Lagrangian analysis of Florida Bay interior basin flow fields, a shallow water drift buoy was designed and developed by AOML and RSMAS in Miami, Florida.

Primary design guidelines required a device capable of operating in water depths of one meter or less for up to a two week period. Small size was a factor both in minimizing windage at the surface and in aiding deployment and recovery efforts. The drifter would also require onboard GPS for accurate positioning. The need for a high resolution record of the drifter's track required GPS data to be logged onboard for post-recovery upload. However, in attempts to aid users in the drifter's recovery, a subset of these data would need to be transmitted to the users during deployment; this is handled by an onboard ARGOS transmitter.

Figure 1 - Shallow Water Surface Drifter

The hull is constructed of a 0.125 inch thick lexan, two-piece thermoformed shell in the general shape of a disc. The top is slightly domed and the bottom has molded fins in an attempt to couple the buoy to the water. Unfortunately, in the first Bay drift test the molded fins proved to be insufficient to keep windage to a minimum, so a "window shade" drogue has been incorporated with excellent results to improve coupling to the water (Figure 1).

The drogue is constructed of two crossed, flexible PVC sheets and is approximately 0.75 meters long. The shape of the buoy was analyzed to insure that it would be self-righting if turned over by a wave. When deployed, the hull floats with the top of the dome approximately 3 cm above the waterline. The dimensions of the hull are 33 cm in diameter by 15 cm high and the weight ready for deployment is less than 5 kg.

To derive high resolution currents, the position of the buoy must be determined frequently. A Motorola 12 channel GPS receiver is built into the electronics to collect this data. It computes 3 dimensional position information at pre-selected rates which are then stored in the buoy memory for later retrieval and subsequent data analysis. A relocation ARGOS satellite transmitter system is included in the electronics to recover the buoy at the end of each experiment. While the initial costs are relatively high, it is a proven system and provides unlimited geographical coverage. The ARGOS positions are used to get within the general vicinity of the buoy, and then a handheld ARGOS receiver on the boat is used to locate and retrieve the buoy.

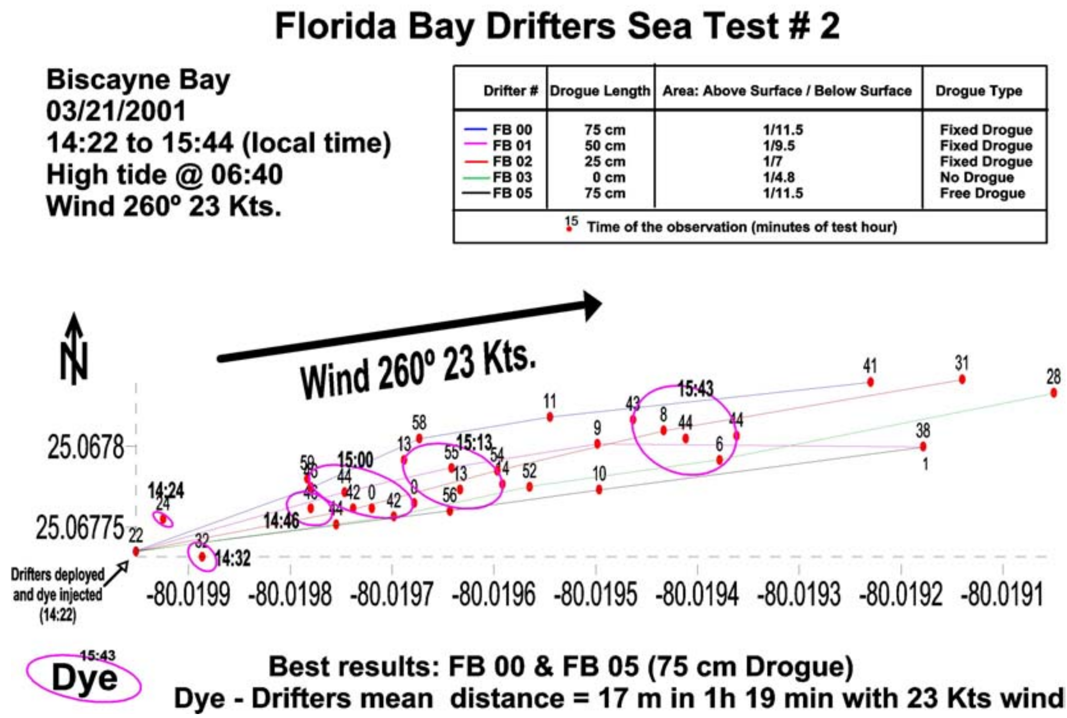

Figure 2 – Florida Bay surface drifter sea test

The operating procedures are very simple and very little training of field personnel is required. Typically, the buoy operating parameters are programmed through a waterproof serial port, and then the buoy is shut down until ready for deployment. Magnets are used to turn it off and on after sealing the hull. The transmissions are checked with the handheld receiver and then it is deployed. After retrieval, the GPS data is uploaded into a computer through the serial port.
Two "sea tests" were done to check the coupling of the drifter with the water. Five drifters with different drogue legs, and co-located patches of colored dye, were deployed in Biscayne Bay in a 23 knot wind. Although all of the drifters moved in the same direction as the dye patch, the drifters with 75 cm drogues had the best coupling with the water (Figure 2). The average difference between drifter speeds and dye patch speed was less than 1 cm/sec.

To date, a total of 68 drifter deployments have been used on eight cruises in Whipray Basin and the NE basin of Florida Bay (where the mean depth is 1.5 m) with excellent results (Figure 3). In the Bay the drifters generally move in the direction of the wind and display circulation patterns influenced by the basin configuration and topography.

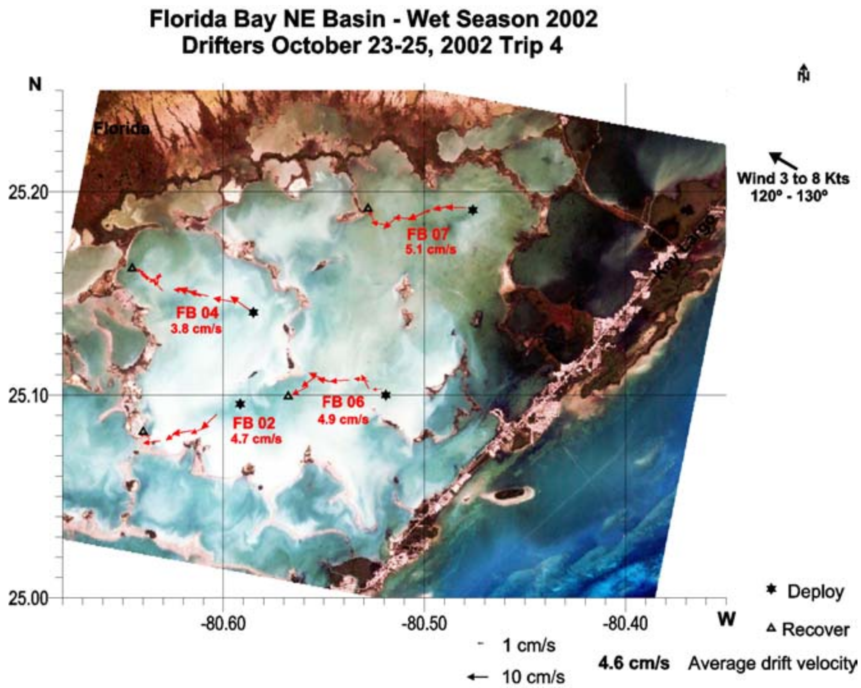

Figure 3 – Florida Bay inner basin surface drifter trajectories

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A Movie of Florida Bay Sea Level Response to Local Wind Forcing

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The response of sea level in the interior of Florida Bay to wind forcing during dry and wet seasons is shown with a computer-generated movie of subtidal sea level anomaly fields, combined with wind vectors from the Northwest Florida Bay COMPS station. Sea level records from the ENP Marine Monitoring Network, coastal gauge records from the USGS, and bottom pressure data from gauges deployed by RSMAS/AOML were filtered to remove tidal variations and then demeaned over the dry and wet seasons of 2001. The resulting sea level anomaly time series were optimally interpolated to produce sea level anomaly fields for Florida Bay every 12 hours, which were then combined in a continuous movie loop that also displays the subtidal wind vector on each scene. The movie shows Florida Bay sea level to be highly coherent and in-phase with local wind forcing. Largest sea level changes occur along the northern boundary where sea level rises (falls) of +/- 30 to 40 cm can occur with northward (southward) winds of 10 m/s. This response occurs as a direct setup (set-down) of sea level across the northern basins. Inter-basin coherency is high and sea level variations tend to be in-phase across the entire Bay. Prevailing winds from the southeast can also cause a setup of sea level along the northern boundary and a north to south sea level slope. Winds from the southwest and west cause sea level to rise to a greater extent in the northeast region of the Bay resulting in a positive sea level anomaly there. An example of the Bay's sea level set-up during northward winds is shown in Figure 1. The locations of the sea level stations are shown as +'s. The resolution available from the monitoring network is sufficient to suggest that there can be significant sea level slopes in individual basins associated with strong wind forcing, in addition to a wider-scale subregional response. The movie can also be used to aid in determining the deployment locations of additional sea level stations in order to enhance the spatial resolution of the sea level fields.

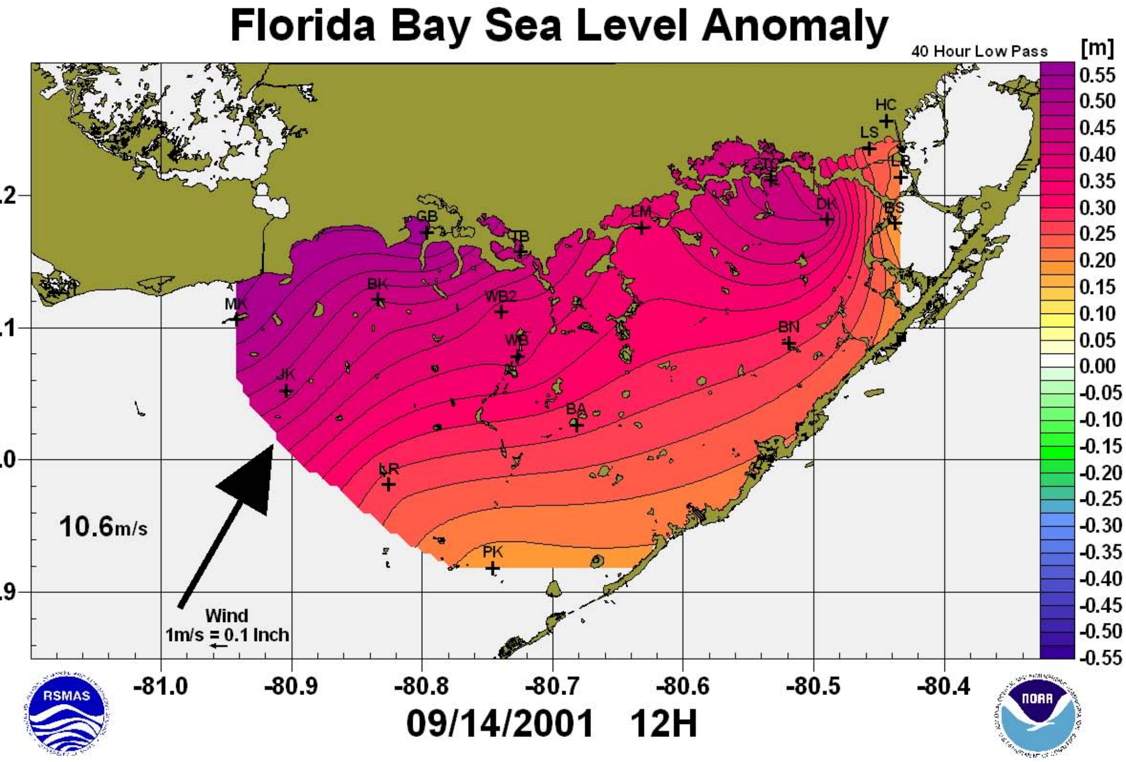

Figure 1. Scene from movie loop of Florida Bay sea response to local wind forcing showing sea level rise along the northern coastal boundary due to northward winds.

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Variation of Evaporation from Florida Bay

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Any attempt to evaluate the effects of hydrologic restoration on Florida Bay's ecosystem must also account for the natural variation in evaporation and rainfall over the Bay. The current goal for restoration will reduce direct runoff into the northeast portion of the Bay by about 35 percent, based on comparison of D13R to 95 Base scenarios. On the basis of an average year, the amount of fresh water entering directly from the Everglades is only a fraction of rainfall and evaporation, Figure 1. Seasonal and year-to-year variation in direct evaporation and rainfall overshadow the influence of runoff on salinity variation – a key characteristic that influences the distribution and composition of plant and animal communities (Nuttle et al. 2000). Therefore, patterns of rainfall and evaporation must be characterized well before we can evaluate the consequences of anticipated changes in Everglades' hydrology on the Florida Bay ecosystem.

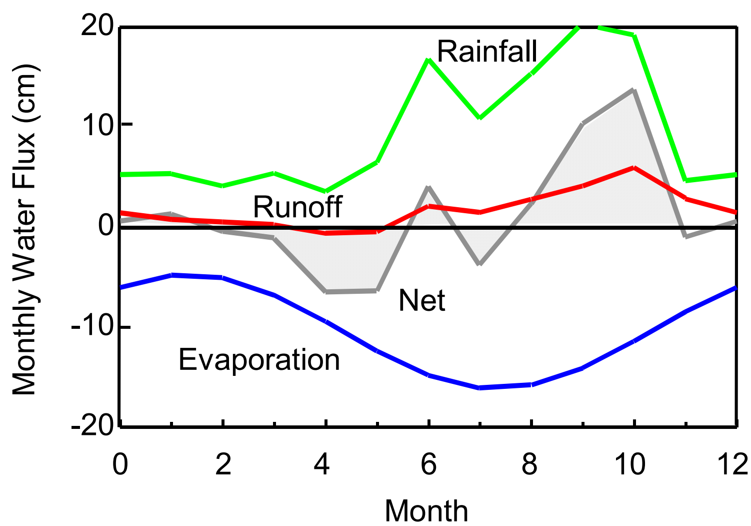

Figure 1: Evaporation is the largest single flux of freshwater in Florida Bay. Direct runoff into the northeastern portion of the Bay is a small component of the water balance, but it accounts for about a third of the net freshwater supply in late summer. Evaporation rates from box model.

This study characterizes variation of evaporation from Florida Bay over time and space. Little is known about this important component of the water balance, and the information that is available covers only a short period of time, i.e. Smith (2000), Pratt and Smith (1999). By comparison, fairly complete rainfall records exist for eight locations in the Bay spanning about ten years. This study employs several methods to estimate the average rate of evaporation from Florida Bay and characterize its variation. The Priestly-Taylor method estimates evaporation as a component of the thermal energy budget, and the Dalton Law method estimates evaporation as a vapor flux. Data on the energy balance and vapor flux were collected at platforms in the west (Rabbit Key) and the east (Butternut Key). Additional information on the spatial variation in the radiation budget was collected during two synoptic surveys, in June 2001 and in January 2002. Finally, a mass balance model for salinity was applied to estimate average monthly evaporation from an analysis of salinity, rainfall, and runoff data for the period 1993 through 1999.

Estimates of annual evaporation rates range between 125 cm to 169 cm, Table 1. The Priestly-Taylor method resulted in rates of 169 cm/yr for Rabbit and 163cm/yr for Butternut. Rates of 155 cm/yr for Rabbit and 133 cm/yr for Butternut were obtained using Dalton Law developed by Satori (2000). These annual rates of evaporation are about 30% higher than the box model estimate of 125 cm/yr, bay wide.

Table 1. Summary of Monthly Rainfall and Evaporation Rates in cm.

Month	Rabbit Vapor Flux	Rabbit Priestly-Taylor	Butternut Vapor Flux	Butternut Priestly-Taylor	Box Model
Jun 2001	16.8	21.01	6.22	19.98	14.81
Jul 2001	16.95	20.21	6.59*	6.11*	16.06
Aug 2001	17.33	19.96	13.77	15.8	15.80
Sep 2001	14.94	14.9	12.73	14.59	14.10
Oct 2001	12.6	16.4	12.14	12.27	11.42
Nov 2001	10.44	14.6	9.19	9.27	8.47
Dec 2001	9.25	10.3	9.18	8.46	6.05
Jan 2002	7.7	13.7	7.36	10.13	4.80
Feb 2002	9.68	11.1	9.84	10.14	5.06
Mar 2002	4.65	1.94	11.51	15.08	6.76
Apr 2002	16.4	9	17.05	20.51	9.44
May 2002	18.71	16.64	17.65	21.44	12.39
Total	155.45	169.76	133.22	163.79	125.24

*Data missing from 12 July to 7 August 2001

From analysis of salinity patterns for the period 1996 through 2001, we estimate annual evaporation to be 125 cm/yr, slightly less than combined input by rainfall and direct runoff. Results with the box model are most sensitive to uncertainty in estimated rainfall over the Bay, and to a lesser degree, uncertainty in estimated average water depth and freshwater runoff.

Evaporation varies seasonally, between 5-9 cm per month in the winter and 16-21 cm per month in the summer, coefficient of variation (c.v.) ~ 0.32. By comparison, variation in rainfall, c.v. 0.85, is larger and dominates the seasonal variation in net freshwater supply to the Bay's water column, Figure 1.

The seasonal pattern of evaporation estimated both by the box model and the Dalton Law method follows the seasonal pattern of thermal loading to the Bay's waters by solar radiation. This supports the hypothesis that solar radiation drives seasonal variation in evaporation, a finding that is consistent with the results obtained by German (2000) in his study of evaporation in the Everglades.

Components of the thermal radiation budgets measured at the two monitoring locations are similar, and there was little difference in monthly averaged values between two years of radiation measurements. The synoptic surveys found differences in albedo related to characteristics of the water column, similar to measurements reported previously by Stumpf et al.

(1999). However, it does not appear that this contributes to significant variation in the rate of evaporation.

The rate of evaporation over the extensive, shallow banks may be different than our estimates reported above. Neither our instrumented platforms nor the synoptic radiation survey characterize conditions over shallow, seasonally exposed banks. Although we expect that the radiation forcing over the banks will be the same as elsewhere, the different characteristics of the water column (shallow) and bottom (dense sea grass) might affect how outgoing heat flux is partitioned between long wave radiation, conduction, and evaporation.

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Florida Bay Standard Data Set

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Out of the past evaluation of hydrodynamic and water quality models of Florida Bay, the necessity arose for being able to judge model quality based on how each performs over a standard time frame with common input and target data. In addition, this data must capture the variations and characteristics of Florida Bay. In March, 2000, this necessity for a Standard Data Set was discussed at a Florida Bay workshop in Homestead, Florida. The results of that workshop were to establish the functions of the standard data set, to designate a period of record, and to determine the types of data to be obtained.

Functions of the Standard Data Set

1. Validate hydrodynamic and water quality models.
2. Define "normal", "wet", and "dry" water years.
3. Assemble data on water quality and hydrology needed to investigate linkages between Everglades hydrology and the surrounding coastal area.

Time Frame

10/94-9/00

Data Types

1. Oceanographic – Hydrography, Tides, Currents
2. Climate – Precipitation, Air Temperature, Dewpoint, Wind Direction and Speed, Solar Radiation, Pan Evaporation
3. Water Quality – Salinity, Water Temperature

Oceanographic, climate, and selected water quality data have been assembled from the various cooperating agencies that collect data in Florida Bay and Adjacent Marine Systems. This Standard Data Set, including metadata, can be accessed through the Florida Bay and Adjacent Marine Systems Science Program website: http://www.aoml.noaa.gov/flbay/.

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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)
$D_{\rho} = (Z_{cell}-Z_{elev})(\rho_{ave}-\rho_f) / \rho_f$
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)
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.

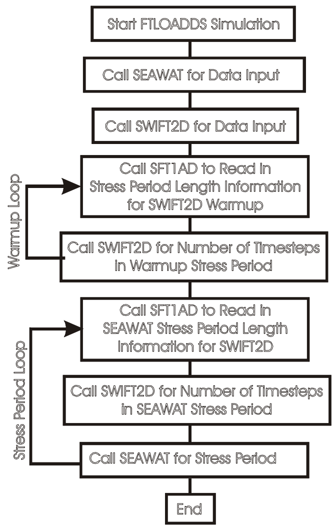

Figure 1. FTLOADDS flowchart.

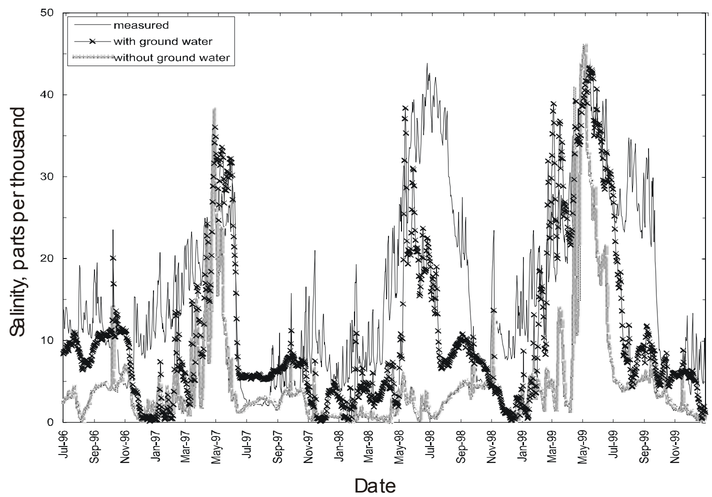

Figure 2. Salinity at McCormick Creek

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.

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Estimates of Evaporation Using Stable Isotopes in Florida Bay

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As the amount of freshwater entering Florida Bay directly from the Everglades is only a fractionation of amount derived from precipitation and lost through evaporation, knowledge of the variations in these parameters is important so that anticipated changes in the hydrological system of the Everglades can be evaluated. While precipitation can be directly measured using a variety of methods, the study of variations in evaporation is more enigmatic. We are investigating evaporation using a variety of different methods including evaporation pans, energy budget-Priestly-Taylor method, vapor-flux-Dalton Law Formula, a mass balance model of salinity, and a mass balance of the stable isotopes of oxygen and hydrogen.

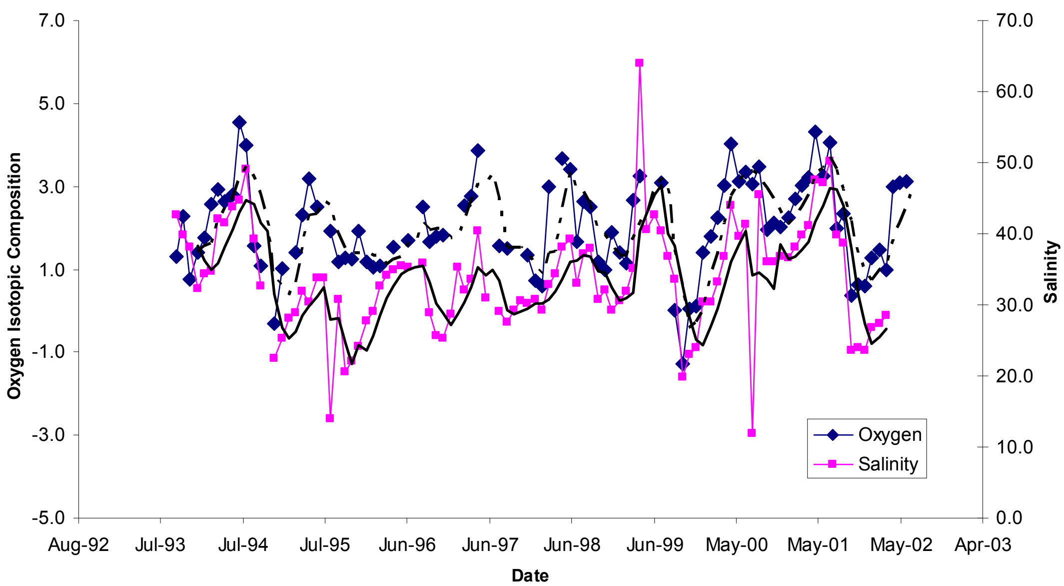

Figure 4:Monthly oxygen isotopic and salinity data (from FIU) for Whipray basin in Florida Bay between October 1993 and July 2002. The trend lines through the data represent four month running means of the data.

In this study we present the first results of a stable isotope (oxygen and hydrogen) mass balance approach applied to Whipray basin in central Florida Bay.

This basin has a mean $\delta^{18}O$ of +2 ‰ but varies seasonally between +5 and approximately 0 ‰ as a result of evaporation and dilution by runoff and rainfall. The stable H and O isotopic composition of a closed water body increases as a result of evaporation, eventually reaching a steady state value dependent upon the temperature, relative humidity and the isotopic composition of the atmosphere (Figure 2).

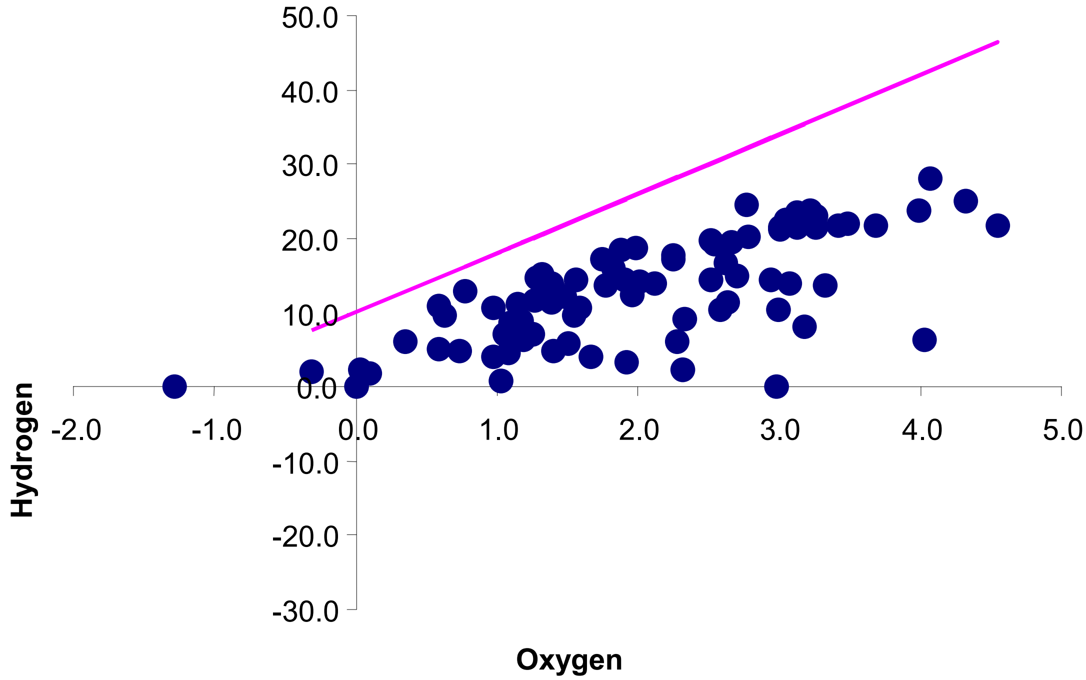

Figure 5: Relationship between the oxygen and hydrogen isotopic composition of waters from Whipray Basin between 1994 and 2003 (Figure 1) relative to the Meteoric Water Line (MWL). Deviations below the MWL indicate evaporation. Increasing deviation from the MWL reflects evaporation into environments of decreasing relative humidity.

As any basin within Florida Bay is dynamic, in order to model the evaporation of this basin using the stable oxygen isotopic composition of any particular month we need to know the isotopic composition of the inputs and estimate the approximate flux across the boundaries into adjacent boundaries. The isotopic composition of the adjacent boundaries can be taken as the values measured in adjacent basins, Rankin Lake to the west, Twin Key Basin to the South, Terrapin Bay to the east, and the Everglades to the north. Employing the equations outlined by Gonfiantini (Handbook of Environmental Isotope Geochemistry, Fritz and Fontes, 1986), we can attempt to estimate the fraction of water lost by evaporation (*x*) according to the following equation.

$$x = \delta s - \delta I / A - \delta s B = (\delta s - \delta I)(1 - h - \Delta\varepsilon)/(\delta s + 1)(\Delta\varepsilon + \varepsilon / \alpha) + h(\delta a - \delta s)$$

In this equation δs, δI, and δa represent the isotopic composition of the basin, the incoming water, and the atmospheric water vapor respectively. The terms A and B are related to the water balance in the area and are controlled by temperature and relative humidity, *h*= relative humidity, and $\Delta\varepsilon$= kinetic enrichment factor. In this presentation we present model solutions to this equation using various estimates of the isotopic composition of the input fluid and variations in temperature, relative humidity, and the isotopic composition of atmospheric water vapor.

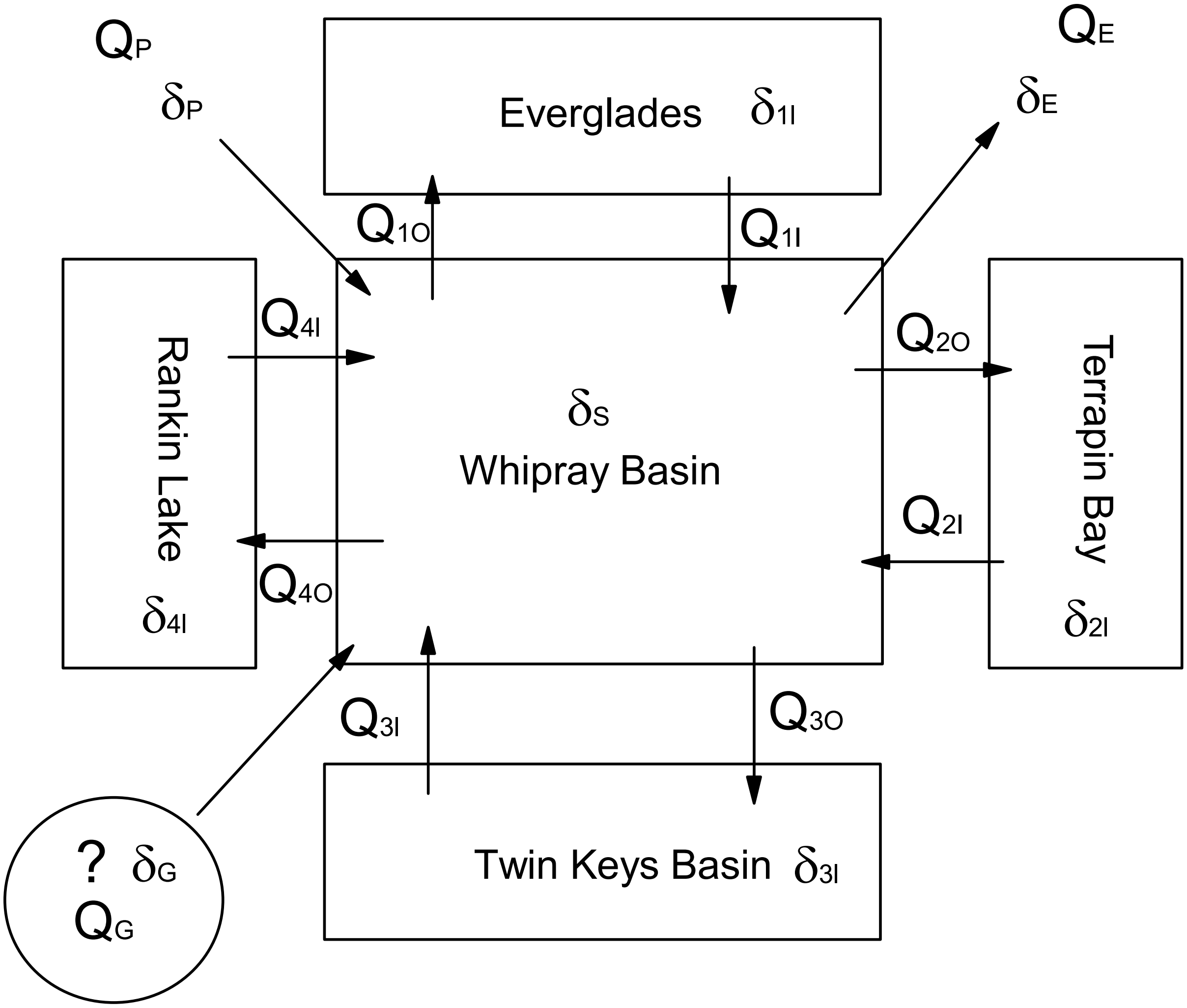

Figure 3: Schematic mass balance of water flow into and out of Whipray Basin with associated isotopic compositions. The values Q represent the fluxes into and out of Whipray Basin (Q_P=precipitation, Q_E=evaporation, and Q_G=potential groundwater input), while the δ values represent the isotopic compositions. A mass balance can be constructed using a combination of the fluxes, salinity, and stable O or H isotopic composition. Simplification of the mass balance yields the equation presented in this abstract.

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Mean and Seasonal Surface Current Patterns in South Florida Coastal Seas from Drifter Trajectories

***Elizabeth Williams**, Thomas Lee* and *Villy Kourafalou*
Rosenstiel School of Marine and Atmospheric Science, University of Miami

During the last seven years, over forty nearsurface CODE-type drifters have been released on bimonthly intervals in the Shark River Plume off the southwestern tip of the Florida mainland (25.35 N, 81.23 W). The drifter data have been employed to study the mean flows and the seasonal variability in the coastal seas adjacent to Florida Bay. The trajectories show that there is a strong link between the South Florida coastal waters (southwest Florida shelf, western Florida Bay, the Florida Keys coastal zone and the Dry Tortugas), as the preferred pathways generally follow a southeastward route through western Florida Bay and the passages between the Keys, then westward along the reef tract to the Tortugas. The route through western Florida Bay is driven primarily by local wind forcing and by a mean sea level slope between the Gulf of Mexico and the Atlantic. The westward route along the reef tract is induced by the prevailing westward component in the local wind and by recirculating gyres and eddies north of the Florida Current. A clear seasonal pattern in surface trajectories emerges with flow toward the southeast in winter/spring, northwest in summer, and southwest in fall. This pattern follows the seasonal cycle of local wind forcing. The most direct pathways to the Tortugas occur during the strong northeasterlies in fall, while the longest pathways to the Tortugas occur in summer, due to the southeasterlies that, although weak, effectively cause a northward surface drift reaching up to 27 N. However, multiple pathways can be seen in any season, reflecting the variability in wind forcing.

Wind and moored current measurements are employed to further elucidate the underlying shelf dynamics. It is found that seasonal changes in the regional wind forcing produce seasonal differences in the strength and variability of surface currents on the southwest Florida shelf that are similar to the seasonal changes shown by the drifters. Current amplitudes are greater in winter than in summer, following the enhanced wind stress. Moored currents are more southward in the fall, winter, and spring seasons, changing to northward in the summer, due to the shift of summer winds to southeasterly. An example of the winter/spring southeastward pathway is shown in Figure 1. The time series of drifter derived currents and wind from the Molasses CMAN station indicate a strong wind influence for the flow along the drifter tract (Figure 1). This is particularly evident in the v-component (north to south), partially due to flow alignment with the isobaths, but also in the u-component (east to west).

A simple multiple regression model was employed to analyze the relationship of the wind components to the drifter derived current components. A cubic spline was fitted to the drifter positions and interpolated to 6-hourly time intervals, followed by filtering of the tidal components. The current components were regressed separately against individual wind components and combined u- and v- wind components (multiple regression). The analysis was focused on the coastal areas which are not directly influenced by strong large-scale flows of the Loop Current and the Florida Current. We found that approximately 70 to 80% of the subtidal variance of drifter derived currents on the southwest Florida shelf and western Florida Bay is due to local wind forcing. Figure 2 displays the model computed currents versus the drifter derived currents for the period of the trajectory shown in Figure 1. The agreement is quite good, especially in the v-component, which has a high regression coefficient of 0.78. The residual current is also shown, as the difference between model and drifter currents. The residual current represents the part of the flow that cannot be attributed to the local wind forcing.

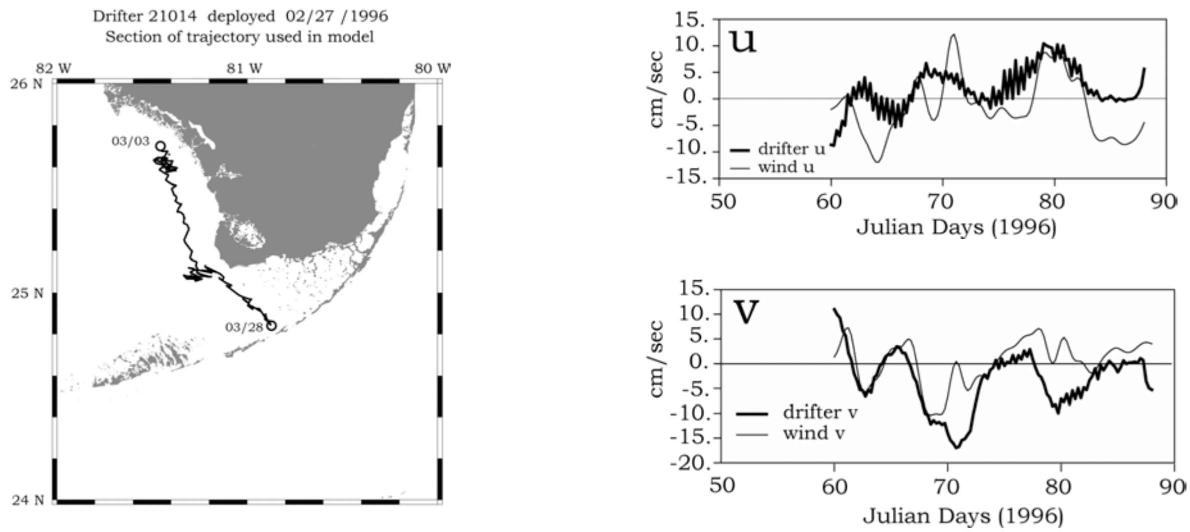

Figure 1: Time series of drifter derived currents from a sample trajectory (drifter 21014, left panel) and local wind: u-components (upper right panel) and v-components (lower right panel).

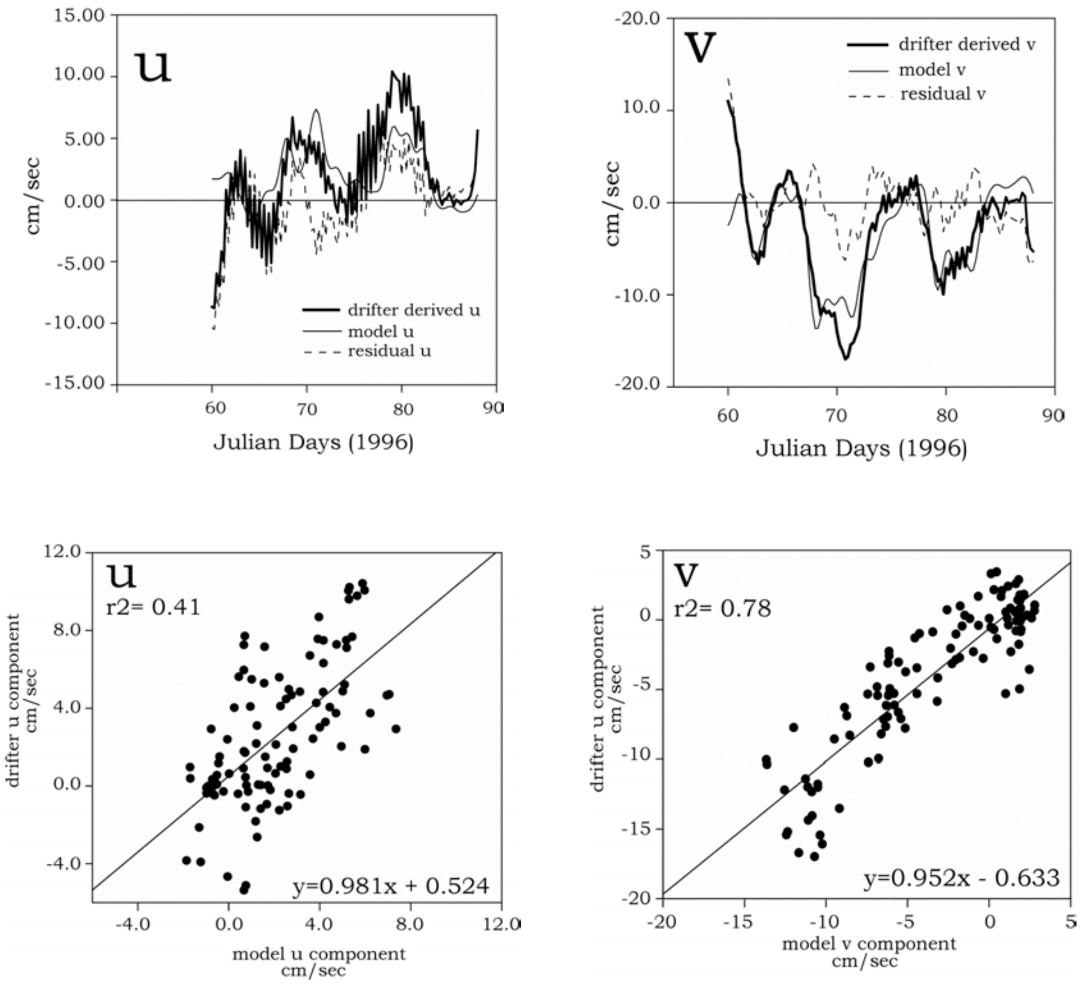

Figure 2: Upper panels: time series of currents derived from the drifter trajectory (thick solid line) and from the multiple regression model (thin solid line); the difference between the two time series (dashed line) is the residual flow (the part of the flow that is not driven by the local winds). Lower panels: Scatter plots and linear correlation between drifter and model currents.

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

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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. Acoustic Doppler Current Profiler (ADCP) measured discharge at East Highway Creek was related to the instantaneous discharge computed from 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).

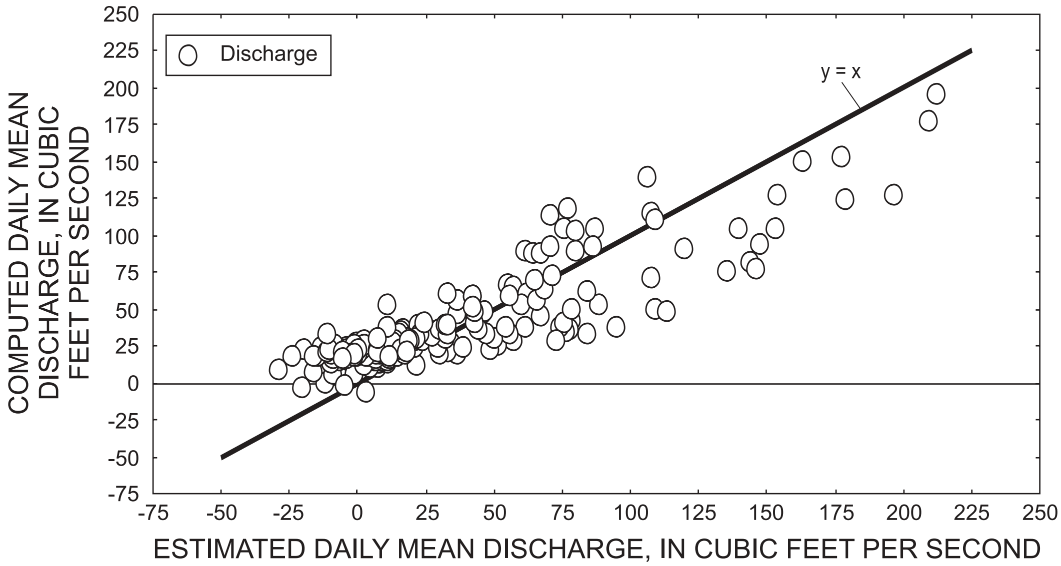

Figure 1. Scatter-plot of computed and estimated daily mean discharge at East Highway Creek including the line of equality.

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 since only five flow conditions have been measured. Improvements to the computed discharge record are possible with additional ADCP measurements at low flow conditions.

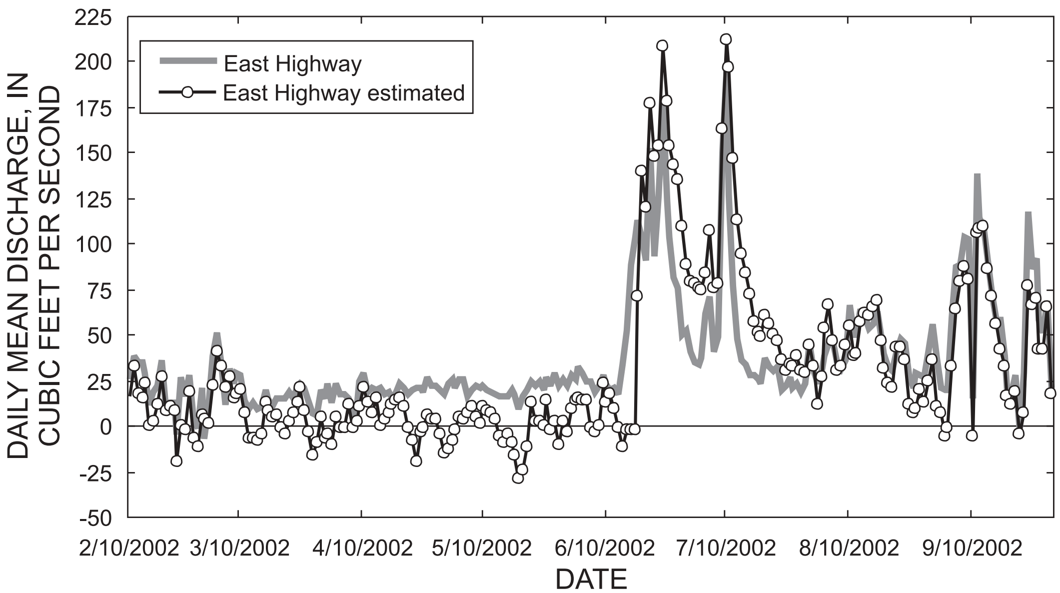

Figure 2. Time-series graph of computed and estimated daily mean discharge at East Highway Creek.

Hittle, C.D., Patino, Eduardo., and Zucker, Mark, 2001, Freshwater Flow from Estuarine Creeks into Northeastern Florida Bay: U.S. Geological Survey Water Resources Investigation Report 01-4164, 32 p.

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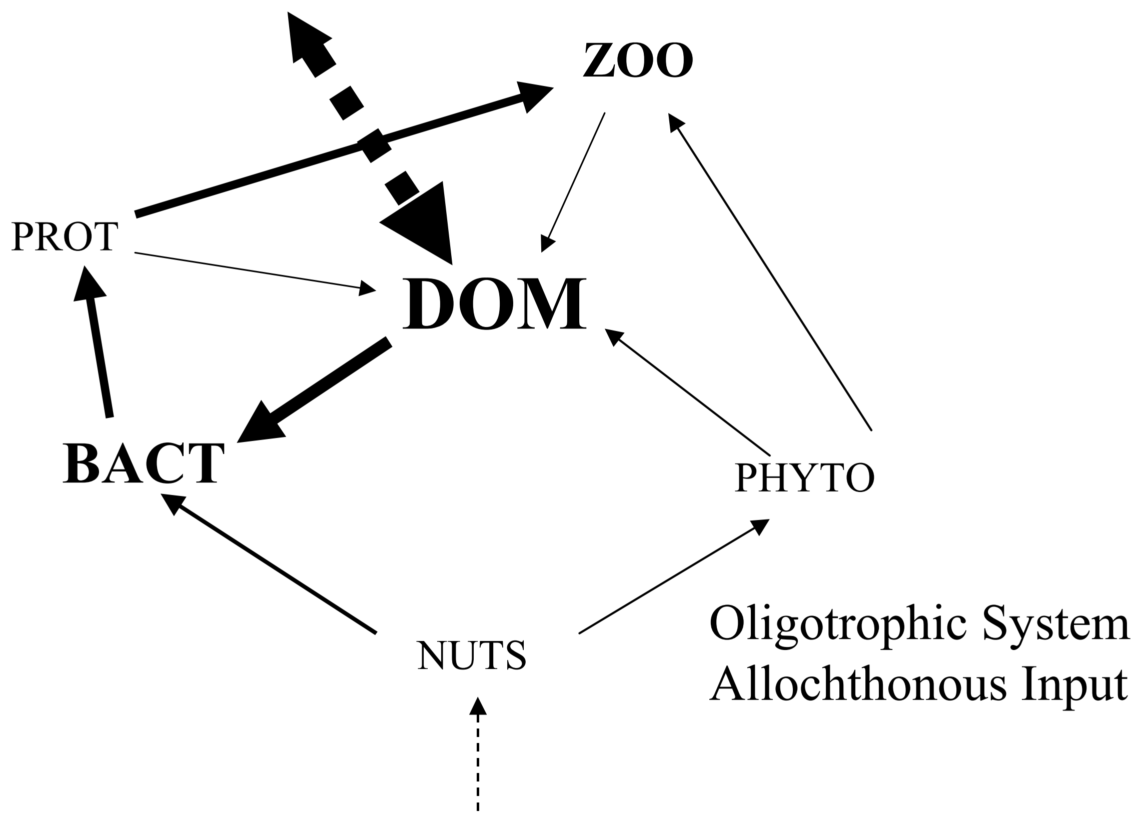
Question 2 - Nutrient Dynamics Oral Abstracts

- Listed alphabetically by presenting author.
- Presenting author appears in **bold**.

Microbial Dynamics in Florida Bay: A New Paradigm for the Microbial Loop in Oligotrophic Marine Waters

Joseph N. Boyer and *Susan K. Dailey*
Southeast Environmental Research Center, Florida International University, Miami, FL

Little is known of the contribution of bacteria to nutrient cycling and production in South Florida estuaries. In the classic marine microbial loop, the DOM produced by phytoplankton (authochthonous) is used by heterotrophic bacteria for growth and respiration. Their subsequent grazing by microheterotrophs has been shown to be an important alternative path to higher trophic levels in oligotrophic food webs. We were interested to see if terrestrial inputs of DOM from the Everglades and mangrove forests might be a significant source of bioavailable C to Florida Bay microbes, and if so, would this allochthonous subsidy act to uncouple the microbial loop from phytoplankton and result in the accumulation of recalcitrant DOC subject to advection.

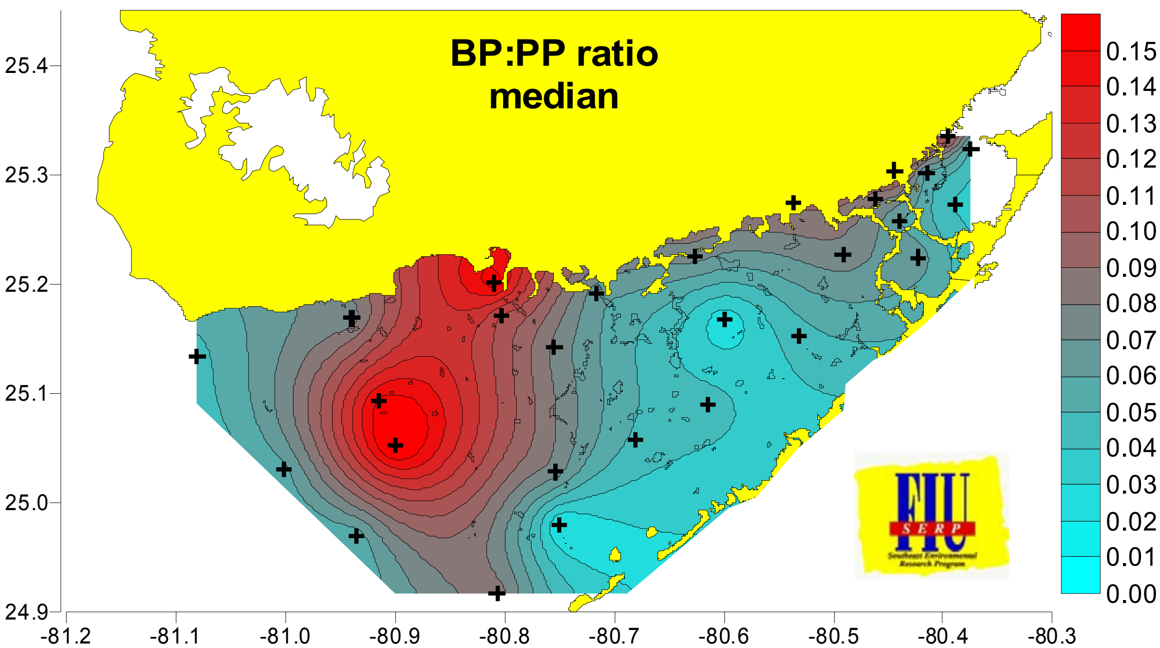


In addition to the C cycle, the microbial loop also may play a significant role in nutrient re-mineralization. Depending upon the C/N/P ratio of the parent DOM, N or P may be released to the water column upon DOM decomposition. Therefore, DOM composition and bioavailability may determine whether the microbial loop is a source or sink for nutrients in the ecosystem.

We found that only a small percentage of the DOM originating from Everglades marsh and mangroves is readily bioavailable (~15 %). Bacterial numbers (BACT) were lowest in the Eastern Bay and highest in the Central Bay with the Western Bay being intermediate. Bacterial production (BP) was also low (median 2 μg C l^{-1} d^{-1}) but showed a different spatial distribution, being high in both Central and Western Bay. Bacterial specific growth rates were also low overall (<0.5 d^{-1}) being highest in Western Bay while bacterial growth efficiencies ranged from 0.02 – 0.10 and were high in both Central and Western Bay.

Phytoplankton quantum yield (PP) in Florida Bay was low relative to other estuarine systems, as befits its oligotrophic nature. PP was highest in the Western Bay with lowest values in the east. BP was primarily associated with PP, which was in turn driven by the limiting nutrient - P. However, BP and bacterial numbers (BACT) covaried with DOM as well.

The median BP:PP ratio for Florida Bay was low (0.09) but ranged from 0.01-0.22. The spatial discontinuity between PP and BP meant that the BP:PP ratio was highest at the juncture of Central and Western Bays.



As this is an early foray into the microbial workings of Florida Bay, we want to emphasize the need for the parameterization of other aspects of the microbial loop such as microheterotroph and protest grazing rates as well as bioavailability estimates of other sources of DOM to the system (especially seagrass-derived). We conclude by saying that bacteria in Florida Bay are routinely co-limited by availability of labile carbon and that even the episodic loading of highly refractory DOM is important in driving the microbial loop.

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Connecting Florida Bay with the Upstream Landscape via the Florida Coastal Everglades LTER Program

Daniel L. Childers
Florida International University, Miami, FL

The Florida Coastal Everglades (FCE) LTER Program is currently completing its third year of this first 6-year round of NSF funding. In the first 3 years, the FCE program has grown to include over 40 Ph.D. level scientists and over 90 total personnel. A total of 12 institutions, agencies, and organizations are now affiliated with FCE. To varying degrees, all of these people are involved in the research I present here (and thus, rather than risk the wrath of a few whose names I might forget, I am hoping to diffuse the discontent across the entire group by including no co-authors!). The FCE LTER research program focuses on landscape-scale connectivity of the freshwater and coastal/estuarine systems of the Florida Everglades, and Florida Bay is a key component of our design. Our central idea is that: **Regional processes mediated by water flow control population and ecosystem level dynamics at any location within the coastal Everglades landscape. This phenomenon is best exemplified in the dynamics of an estuarine oligohaline zone where fresh water draining phosphorus-limited Everglades marshes mixes with water from the more nitrogen-limited coastal ocean.** The Everglades system is unique in many ways, including that the entire landscape is oligotrophic and phosphorus-limited and that the source of the limiting nutrient (P) is the Gulf of Mexico. Our estuaries are thus "upside-down" relative to other U.S. coastal systems, which receive [often bountiful supplies of] nutrients from upstream watersheds. We focus on the oligohaline zone because this is where water rich in organic matter—flowing from the freshwater Everglades marshes—meets relatively P-rich water from the Gulf of Mexico. Where this occurs, we have hypothesized a low-salinity peak in ecosystem productivity. Our experimental design follows this central hypothesis with two transects that track water flow, from canal inputs to the Gulf of Mexico. We hypothesize an oligohaline productivity peak along the Shark River Slough transect, because the freshwater Everglades and Gulf of Mexico are directly connected. Along the other transect, through the Southern Everglades and Florida Bay, we hypothesize no such productivity anomaly. Florida Bay is adept at sequestering P from the Gulf of Mexico before it can reach the oligohaline zone, which is nearly always located in the mangrove zone that separates Florida Bay from the freshwater Everglades.

The value of FCE research to Florida Bay biogeochemical questions and issues include: 1) the stability of consistent, long-term funding; 2) the built-in observational network, that is based on funding from agencies other than NSF, that runs from canal inputs to the GOM; 3) the ability to direct resources to basic questions of ecological process and biogeochemical detail, and; 4) the cross-disciplinary and cross-agenda collaborative environment that enhances scientific interactions and facilitates management decisions. In this presentation, I briefly describe the FCE LTER Program goals, hypotheses, and approaches as they apply to Florida Bay biogeochemical issues. I summarize the "state of our knowledge" about landscape connectivity in this system, particularly associated with: 1) nutrient loads; 2) freshwater inflow; 3) organic matter inputs and transformations, and; 4) salinity patterns through the freshwater-estuarine ecotone. FCE scientists are also working within Florida Bay itself, addressing important questions about nutrient cycling and organic matter production and transformations. I will synthesize these findings with our landscape connectivity information to demonstrate the scientific and management value of the FCE LTER Program. We hope that FCE research will become central to the science of Everglades and Florida Bay Restoration. The long-term changes that restoration will bring to our study system are key drivers behind our central hypothesis. At the same time, FCE scientists and students are involved in research efforts—both within and outside the bounds of the FCE program—that are critical to determining how to best conduct this restoration, and if the products of restoration are ecologically successful. In a very short time, we expect the FCE LTER Program to become a critical "hub" of Everglades science.

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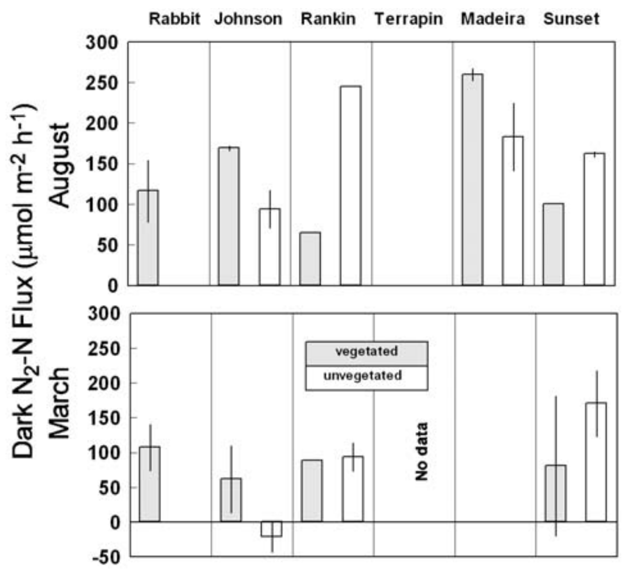
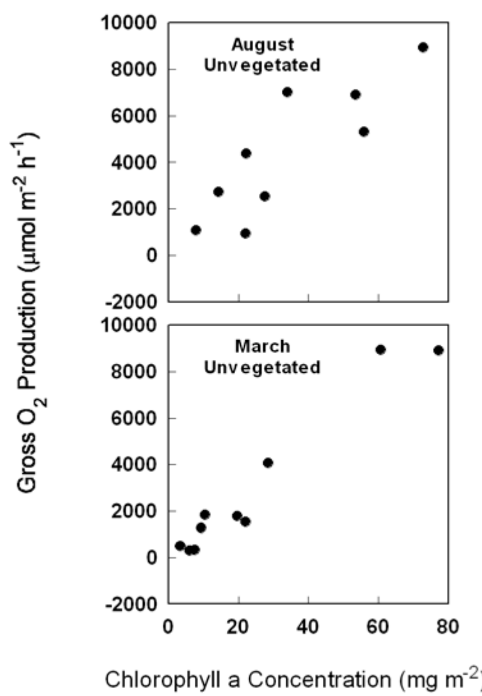
Internal Nutrient Cycling in Florida Bay: Denitrification, Nitrogen Fixation and the Role of Microalgae

Jeffrey C. Cornwell, *W. Michael Kemp, Michael S. Owens, Jessica Davis* and *Eric Nagel*
University of Maryland Center for Environmental Science, Horn Point Laboratory, Cambridge MD



Understanding of the impacts of restoration on biogeochemical processes and primary production in Florida Bay requires information on both external inputs of nutrients and internal cycling processes. Benthic nutrient recycling and primary production are particularly important in shallow systems such as Florida Bay, and these processes tend to regulate the exchange of nutrients and gases between the sediment and the water column. We have measured sediment-water exchanges using core incubations to determine the fluxes of NH_4^+, NO_3^-, soluble reactive P, N_2-N, O_2, DOC and DON. In addition, we have made estimates of N and P burial, nitrification, and N and P uptake by seagrasses and benthic microalgae.

Measured rates of denitrification (dark N_2 flux) were much higher than would be expected based on reported N loading rates to Florida Bay. In our first surveys, rates averaged 127 ± 87 µmol m^{-2} h^{-1} in August and 65 ± 82 µmol m^{-2} h^{-1} in March for all Bay sites. These rates are similar to values estimated for sediments in Chesapeake Bay and other eutrophic estuaries. We speculate that such high rates may be common in shallow tropical ecosystems like Florida Bay often characterized by severely limited phosphorus availability. Estimates of N fixation (gross N_2 fluxes in light) were large enough to balance denitrification in summer months. Ammonium fluxes across the sediment-water interface were much smaller, and generally directed into the sediments in the light and from the sediments in dark. We measured relative high biomass levels and photosynthetic rates for benthic microalgal communities at most Florida Bay sites.



Strong correlations between benthic chlorophyll-*a* and solute fluxes across the sediment water interface further suggest the importance of microphytobenthos. Estimated N budgets indicate that benthic algal uptake of N is one of the most important processes regulating N pools. Even in Rankin Bay, a major site of seagrass die-back, little ammonium and no nitrate escape from sediments to overlying water. Benthic algal assimilation and N_2 flux dominate the budget at this site. The absence of correlations between benthic community photosynthesis and respiration, however, suggest that are benthic algae are not the only important sources of organic matter fueling benthic respiration.

Nitrogen assimilation by the dominant seagrass, *Thalassia testudinum*, is an important term in the overall N budgets of the Bay. Seagrass uptake is, however, far more important in healthy beds like that at Rabbit Key than at dieback sites. Large pools of nitrogen are tied up in seagrass biomass, particularly for healthy beds. Seagrass nitrogen pools are sufficient to support measured rates of denitrification for more than three years at healthy sites. Although our current research in Florida Bay is addressing indirect effects of seagrasses on N cycling, the present study design was not geared to measure N fluxes in sediments with seagrass roots.

Our ongoing work is 1) refining our budge estimates for different Florida Bay basins, 2) examining the role of DOC and DON sediment-water exchange on N and C cycling, 3) experimentally examining the controls of sediment N fixation and 4) comparing biogeochemical gradients along bank to basin transects in healthy seagrass beds and in areas experiencing die-back.

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Temporal and Spatial Distribution of Nutrients and Salinity in Florida Bay Ground Water from 1994-2000

Christopher D. Reich and *Eugene A. Shinn*
US Geological Survey, St. Petersburg, FL

Quantifying sources of nutrients to Florida Bay, including a possible groundwater source, are critical to understanding the estuary's water quality issues. In order to examine nutrients in ground water, 33 monitoring wells at 25 sites throughout Florida Bay were sampled 10 times during the 6-year period between July 1994 and December 2000. Throughout this period, additional wells were installed and subsequently sampled to fill data gaps within Florida Bay. Wells were primarily sampled for specific conductance to ascertain the probability of ground water advecting into bay surface waters. In addition to specific conductance, groundwater samples were collected and analyzed for nutrients such as total phosphorus (TP), soluble reactive phosphorus (SRP), total nitrogen (TN), ammonium (NH_4), nitrate (NO_3), nitrite (NO_2), total organic carbon (TOC), and dissolved organic carbon (DOC). Surface waters were collected prior to groundwater sampling at each well site and analyzed for the same suite of nutrients.

The original objective was to determine if groundwater nutrient sources were originating from either a deep source (i.e., Floridan Aquifer) or from shallow recharge. Statistical analysis of the nutrient data do not support either a deep nutrient source or shallow recharge because there are poor correlations among specific conductance, depth, and nutrient species concentration (e.g., TN in Figure 1). However, there are temporal and spatial patterns of groundwater nutrients in Florida Bay. Figure 2 shows the spatial patterns of groundwater TN along four transects crossing different parts of Florida Bay. These data indicate that groundwater concentrations of TN in the central part of the bay, e.g., near Black Betsy Key (BBK), were higher (120-140 µM) than in other areas of the bay (50-115 µM). The BBK site also consistently had the highest groundwater specific conductance (mean = 62,000 µS/cm). Temporal analyses indicate that NH_4 and TN increased from 1994 to 1997 then decreased slightly in 1998 and began to rise again in 1999. TP increased slowly through the entire time period. A comparison of nutrient species in ground water to that of surface water was made showing distinct temporal trends. A strong correlation between groundwater and surface water {TP (r=0.98), NH_4 (r=0.82), TN (r=0.58) and specific conductance (r=0.65)} suggests that there is possibly some groundwater-surface water exchange. In a separate study, similar conclusions were made using environmental tracer data (Böhlke et al., 1999)

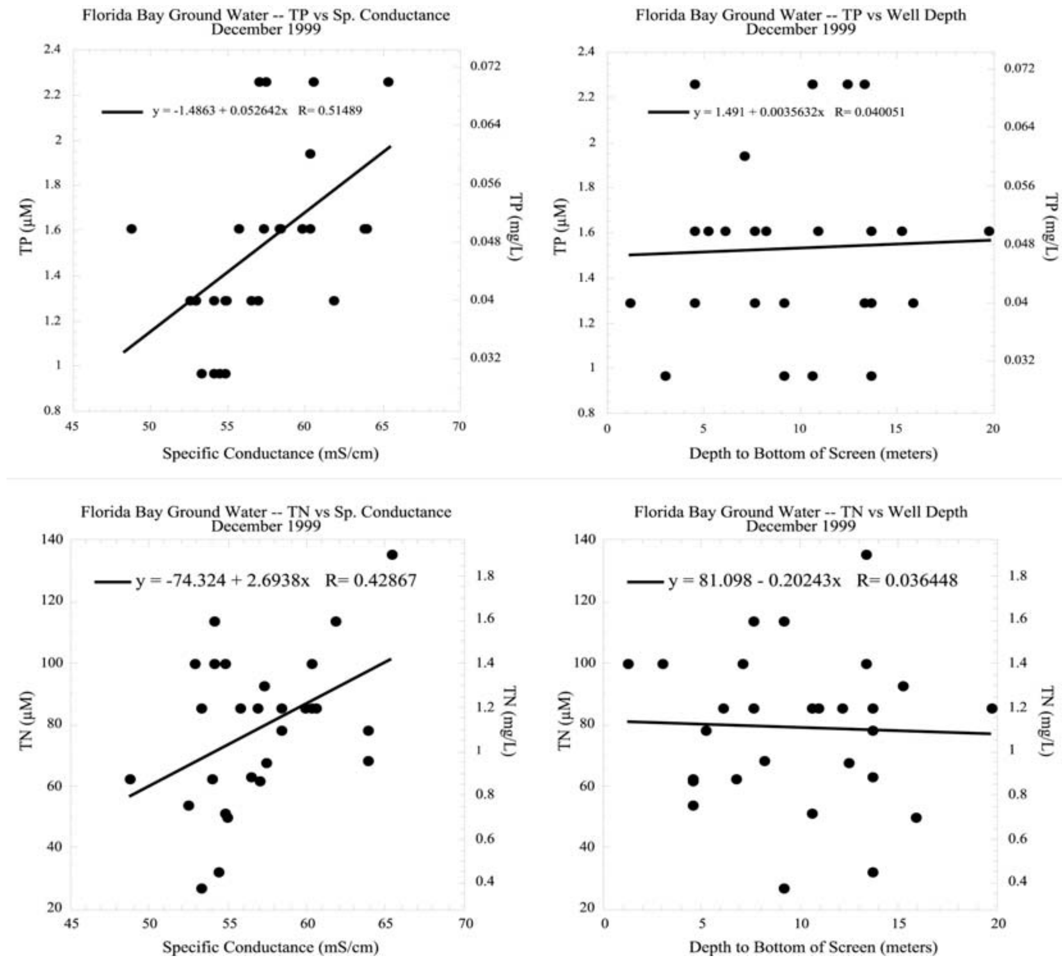

Figure 1. Plots of total phosphorus (TP) (top graphs) and total nitrogen (TN) (bottom graphs) versus specific conductance and depth to bottom of screen (below sea floor). December 1999 sampling was used as an example to demonstrate poor correlation between nutrient species and either specific conductance or depth.

In conclusion, there is a high potential for eutrophication of surface water by ground water because ground water is enriched 1-5X in NH_4, 1-7X in TP, and 1-2X in TOC. Groundwater-surface water exchange occurs in the bay along the Florida Keys as a result of tidal pumping and possibly along the southern shore of the Everglades because of the Everglades-FL Bay hydraulic gradient, but further hydrological testing needs to be conducted within the interior of the bay.

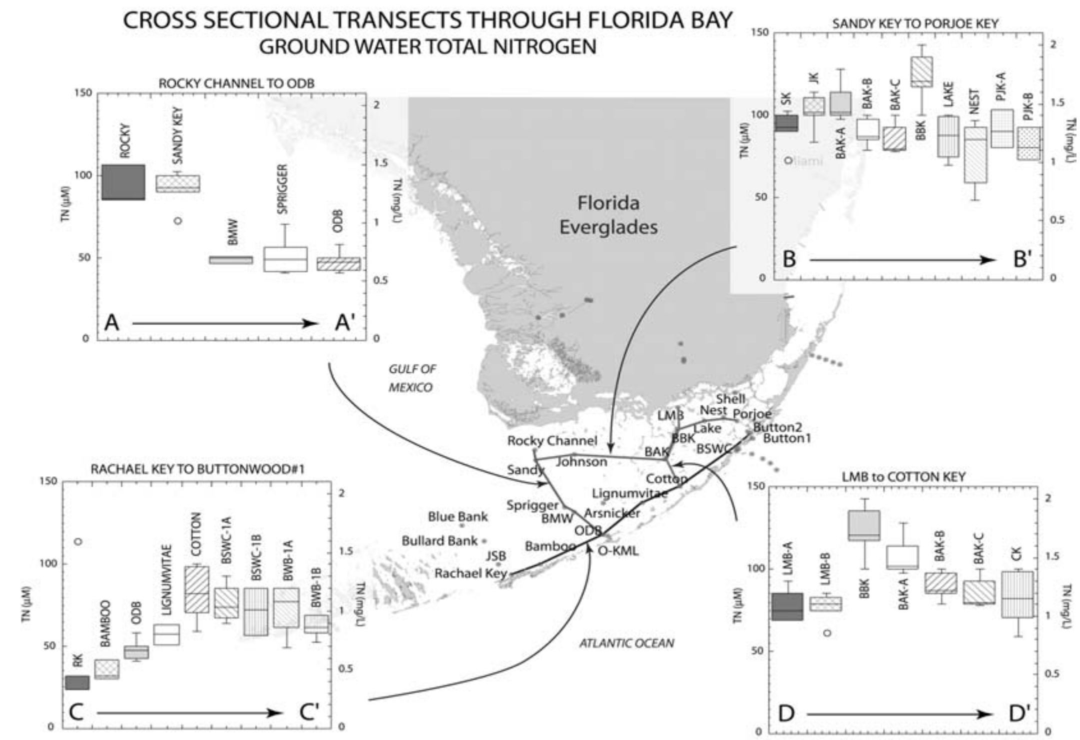

Figure 2. Spatial distribution of groundwater total nitrogen (TN) concentration along well transects in Florida Bay. Transects suggest that groundwater TN values are lower beneath the western part of the bay and increase toward the central and eastern areas.

Reference:

Böhlke, JK., Plummer, LN, Busenberg, E., Coplen, TB, Shinn, EA, and Schlosser, P, 1999, Origins, residence times, and nutrient sources of marine ground waters beneath the Florida Keys and nearby offshore area, USGS Open-File Report 99-181, p.2-3.

Contact Information: Christopher Reich, US Geological Survey, Center for Coastal and Watershed Studies, 600 Fourth Street South, St. Petersburg, FL 33701, Ph: 727-803-8747, Fax: 727-803-2032, Email: creich@usgs.gov

Question 2 -
Nutrient Dynamics
Poster Abstracts

- Listed alphabetically by presenting author.
- Presenting author appears in **bold**.

Mangrove Carbon Sequestration in the Florida Everglades

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Dan Childers
Department of Biological Sciences, Florida International University, Miami, FL

Mangrove forests represent one of the most geochemically and biologically active biomes (Twilley et al. 1992), yet at present no unified modeling framework exists to investigate processes governing carbon sequestration. Limited information is available to learn how mangrove forests respond to climate forcings and anthropogenic perturbations such as fresh water input dynamics. This research addresses the hypothesis that the carbon sequestration capability of the riverine mangrove ecosystem in south Florida is governed by rates of fresh water flows into the bay and abiotic forcings such as environmental irradiance, and temporal and spatial salinity gradients. The hypothesis is first evaluated through the application of coupled atmospheric-biospheric modeling systems.

We are developing a coupled atmospheric-biospheric modeling system to investigate trace gas exchange between the mangrove forest and overlying atmosphere. The model consists of a plant canopy radiative transfer module to describe solar and terrestrial irradiance disposition inside the forest, a module to quantify turbulent transport through the canopy, a plant biochemistry module to estimate carbon assimilation rates, and a component to evaluate soil respiration rates. The plant biochemistry module is based on the theory developed for terrestrial ecosystems (Baldocchi and Meyers 1998, Gu et al. 1999), but it incorporates physiological characteristics determined by our research group for riverine mangroves in Shark River Slough adjacent to Long-Term Ecological Research (FCE-LTER) site SRS-6. As input to the biochemical module, local physiological characteristics are considered including Rubisco, light limited carboxylation rates, nighttime respiration rates, and stomatal conductance to water vapor diffusion for red *(Rhizophora mangle)*, white (*Languncularia racemosa*), and black (*Avicennia germinans*) mangroves. To reflect the vertical gradients in both mangrove physiology and environmental state variables, the model represents the mangrove forest canopy as a conglomerate of layers. The net carbon exchange between the forest and overlying atmosphere is taken as the integral of the differences between photosynthetic gains and the respiratory losses.

Though the biophysical principles are essentially the same as those applied to terrestrial forest ecosystems, mangrove forests exhibit unique physiological attributes. For example, mangrove leaves exposed to direct sunlight throughout the day achieve maximum photosynthetic rates and stomatal conductance around 10:00 h local time. These optimum physiological responses occur much earlier than the time when the governing environmental variables attain their maximum daily values (Figure 1). As a working hypothesis, we propose that mangroves exhibit unique physiological responses to the local environment due to two coupled processes. First, as the atmospheric evaporative demand increases (as reflected in the high vapor pressure deficits, Figure 1D) mangroves need to reduce the stomatal conductance (Figure 1A) to conserve water. Mangroves must maintain low salt concentrations by either excluding salt in their xylem, as is the case with red mangroves, or ridding themselves of salt, as is the case with black mangroves. Second, mangrove leaves need to cope with exceedingly high radiational loadings. Because of the unique mangrove-water relations, evaporative cooling may not be the most effective mechanism to protect foliage from excessive radiational heating. Instead, the modulation of energy loading on the foliage may be accomplished through inclining leaf angle to reduce light interception. As an example, Figure 1A shows that leaf-level photosynthesis declines throughout the day in concert with increasing leaf temperature (Figure 1B).

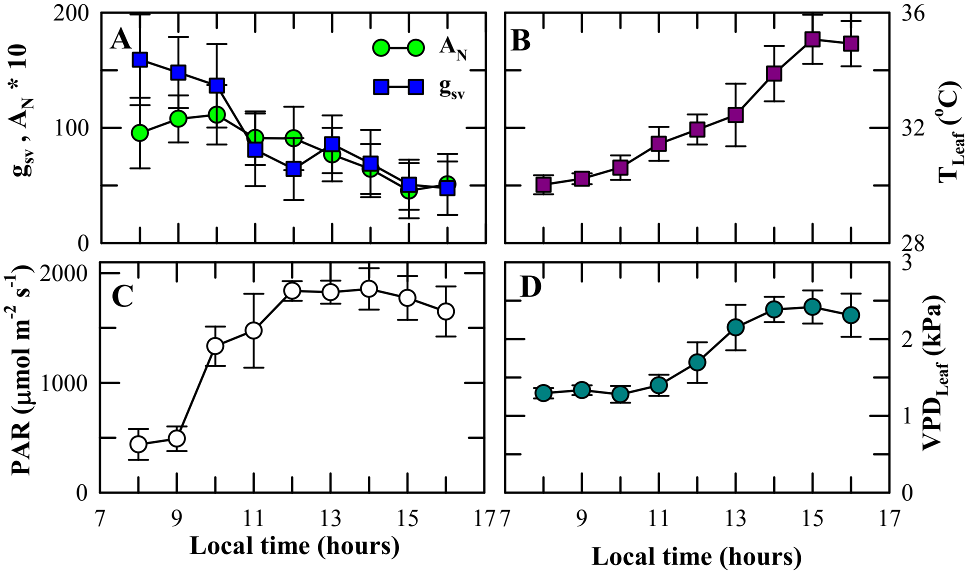

Figure 1. (A) Diurnal trends in net photosynthesis (A_N, in µmol (CO_2) m^{-2} s^{-1}), stomatal conductance to water vapor (g_{sv}, mmol (H_2O) m^{-2} s^{-1}). Figures B, C, and D illustrate the diurnal variations in foliage temperature, photosynthetically active irradiance (PAR), and vapor pressure deficit between mangrove leaves and atmosphere, respectively. Measurements were made on red mangrove leaves during 24 July 2001 at Key Largo, Florida.

To account for these unique mangrove-water relations, we have developed new stomatal conductance algorithms specific to the mangrove biome. Also, a new algorithm has been established to study the mangrove physiological responses to temperature. These mangrove-environment interactions are necessary to successfully investigate processes such as net carbon ecosystem exchange. In the presentation, we will provide evidence to support the conclusion that coupled atmospheric-biospheric modeling systems are important tools to assess the impacts of the Florida Everglades restoration project on the mangrove ecosystem.

Acknowledgements

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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 on-shore 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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The Distribution of Trace Metals in Florida Bay Sediments

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A study of the distribution of trace metals was made on surface sediments collected from 40 stations across Florida Bay in June, November and February (2000-2001) **(Figure 1)**. The concentrations of Sc, V, Ba, Cd, Cr, Co, Cu, Pb, Mn, Ni, Zn, Al and Mg were determined by ICP-MS, and the total Fe was determined by spectrophotometry. Organic carbon (OC), organic nitrogen (ON), and calcium carbonate ($CaCO_3$) were also measured.

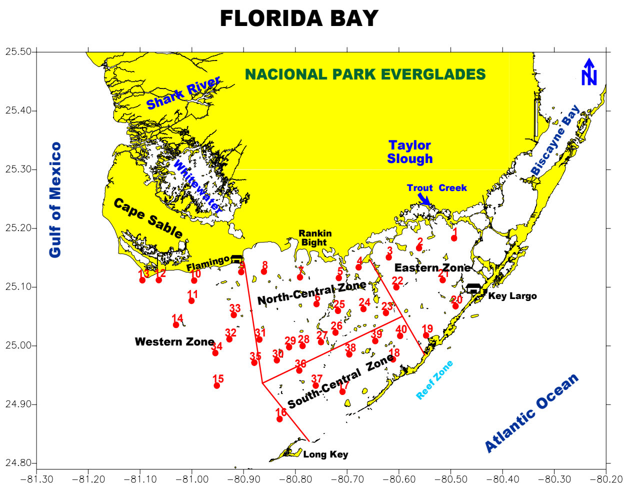

Figure 1. The stations and various zones sampled in Florida Bay

Florida Bay sediments are predominately $CaCO_3$ (65.9% - 92.5%). The highest value of OC (5.5%) and the lowest value of $CaCO_3$ (65.9%) were found in the Western zone, where colonies of seagrass are located. Most of the metals show a similar distribution pattern for the various months studied. The maximum metal concentrations were observed in the North-Central and Western zones of the bay, where the highest OC and the lowest $CaCO_3$ were found. The distribution of Cu is shown in **Figure 2.** Some metals (Ni, Zn, Cu, Cr, Pb and Ba) associated with petroleum use showed high concentrations at stations near the Tavernier marina. The Mn and Fe distributions were different than the other metals. Their concentrations gradually decreased from the North (Everglades) to the South (Florida Keys) **(Figure 3)**. The South-Central and Eastern zones show the lowest concentrations for all the metals, coinciding with high $CaCO_3$ and low OC. These low concentrations are influenced by the Key Channels, which exchange waters from the Atlantic and Gulf Stream that contain very low concentrations of dissolved trace metals.

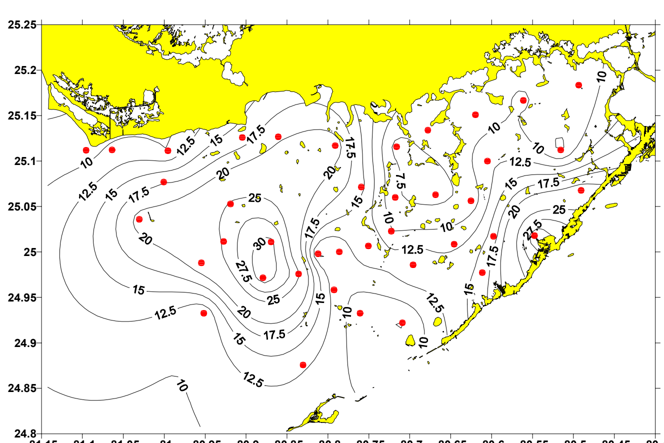

Figure 2. The distribution of Cu (nmol/g) in the sediments of Florida Bay (June 2000).

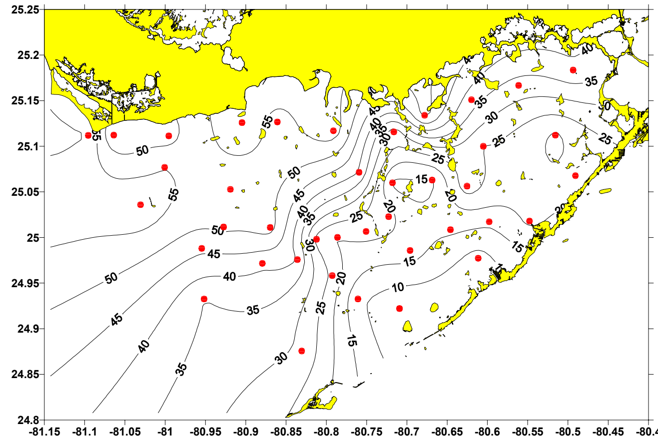

Figure 3. The distribution of Fe (µmol/g) in the sediments of Florida Bay (June 2000).

We found a strong correlation between most of the metals (V > Cu > Ni> Cr > Al > Co > Ba > Zn > Pb >Mg) and the percentage of OC in the sediments of Florida Bay. As an example, the vanadium correlation is shown in **Figure 4**. This direct correlation to OC is related to the areas having the same bottom type with seagrass and open mud, whereas the lower concentrations of the metals are in hard bottom-rich carbonate beds. Sc, Mn and Fe were the only metals studied that did not show a direct correlation with OC.

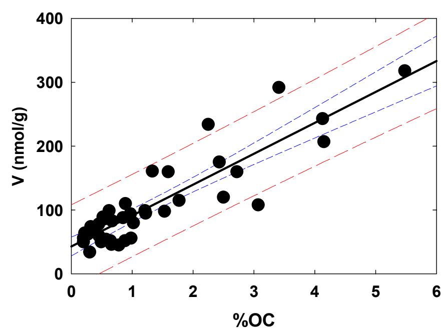

Figure 4. The linear regression of V versus the percentage of organic carbon.

All of the metals, except Mg, Mn and Co, show a strong correlation with Al and the fine fraction of the sediments (aluminosilicates) associated with river runoff. At station 19, Cu, Pb, Zn and Ba, showed a strong enrichment in June 2000 and February 2001 **(Figure 5).** The high concentrations of these metals at this station are due to anthropogenic sources at the Tavernier Marina and the drainage from the main highway (US1) on Tavernier Key.

In general, the concentrations of all the metals found in Florida Bay sediments are lower than most estuarine systems. Florida Bay is thus still a rather pristine estuary compared to most systems around the world.

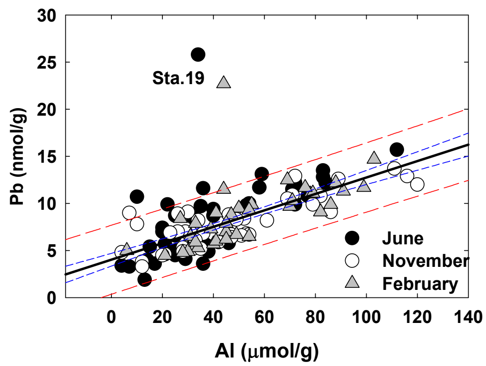

Figure 5. The linear regressions of Pb (nmol/g) and Zn (nmol/g) versus Al (μmol/g).

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Isotopic Fingerprinting of Nutrient Sources and Biological Sinks in Florida Bay: A Geochemical Tool for Evaluating Ecosystem Response to Changing Nutrient Inputs

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The stable isotopic measurements of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) in biological materials and dissolved species is a geochemical tool capable of tracing varying nutrient sources and their assimilation into biomass, delineating different biosynthetic pathways, and assessing trophic relationships among organisms within an ecosystems. The proposed re-establishment of surface flow through the Everglades is expected to change the amount, sources and ratios of dissolved nutrients (organic and inorganic) delivered to the bay potentially inducing an ecosystem response of changing structure and functions in both planktic and benthic habitats. As part of a NOAA-funded program, we have initiated a spatial and temporal study focused on determining the carbon and nitrogen isotopic composition of nutrient sources and their biological sinks (e.g., seagrass, algae, sediment) within the Everglade watershed and Florida Bay. The goal of this study is to develop isotopic tools that can monitor nutrient changes and evaluate ecosystem response associated with pending Everglade restoration.

The first of four sampling periods was conducted in November 2002. Waters, sediment cores, seagrass and other aquatic vegetation were collected at 6 geographically and ecologically unique sites within Florida Bay (Little Maderia Bay, Duck Key, Sunset Cove, Rankin Bight, Barnes Key, Rabbit Key), and a Gulf of Mexico influenced western Florida Bay site. In addition, two transects, one in the Everglades and the other along the bay/reef sides of Florida Keys, were also sampled for water, sediments, seagrass, and aquatic and terrestrial vegetation. Surface waters were filtered for particulate organic matter (POM) and filtrate, and then, as with sediments and vegetation samples, were immediately frozen for later stable isotope analysis. Initial efforts have focused on determining the carbon and nitrogen isotopic composition of POM, aquatic vegetation (particularly *Thalassia testudinum*), and surface sediment from the bay sites, and from the three Everglade watersheds (Canal 111, Taylor Slough, and Shark River Slough), representing the different source waters entering the bay.

Initial results indicate that the carbon and nitrogen isotopic composition of bay organics (the biological materials isolated from the water column (POM) and the benthic habitats, i.e. seagrass, and sedimentary organic matter) provides a sensitive indicator of local to regional changes in nutrient sources, and variations in carbon and nitrogen biosynthesis and cycling. Spatial trends in the isotopic composition of bay organics mimic the spatial variations in the nutrient stoichiometry (e.g. N/P) of bay waters. A pronounced 10‰ east-west gradient in $\delta^{15}N$ values and a distinct 15‰ north-south gradient in $\delta^{13}C$ values results in a well-defined northeast to southwest isotopic trend in organic materials that defines regional controls on nutrient sources, their availability, and their incorporation into biomass.

The range of $\delta^{15}N$ values for bay organics was extraordinarily large (10‰) with values ranging from 13‰ in the eastern portion of the bay (Duck Key, Sunset Cove, Little Madeira) to 3‰ in the western portion (Rabbit Key, Barnes Key, Gulf Station). This large range and systematic distribution in the $\delta^{15}N$ values of bay organics overlaps directly an observed 10‰ range and east-west gradient in $\delta^{15}N$ values for POM isolated from the three watersheds draining the Everglades. The range and spatial similarity in the $\delta^{15}N$ composition of organics between bay and Everglades samples is remarkable. This data infers that a wide array of natural (e.g., terrestrial, oceanic, and recycled) and anthropogenic (e.g. urban, sewage, agricultural) nutrient sources are being introduced into well-defined regions of the bay and that nutrient sources originating in the Everglades directly influence nitrogen cycling in bay waters and sediments. Furthermore, the spatial trends in the $\delta^{15}N$ values of bay organics from 14 to 4‰ reflect regional availability of nutrient and their control on the biogeochemical process of nitrogen assimilation (N_2 vs. NO_3) and recycling (e.g., denitrification, remineralization). For example, the isotopic data indicates an increase in the relative importance of nitrogen fixation by planktic and benthic algae in the western portion of the bay as waters become nitrogen-limited.

Carbon isotopic composition of bay organics display a strong north-south gradient of over 13‰ with values of –7 to -11‰ in the northern sites (Duck Key, Little Maderia, Rankin Bight) and more depleted values of –20‰ at more southern sites (Barnes Key, Rabbit Key , Gulf Station). This broad range of carbon isotopic compositions likely reflects the assimilation of different sources of carbon (HCO_3 vs. CO_2) during biosynthesis. Macrophytes, which are concentrated on the northern margin of the bay, preferentially utilize bicarbonate that is 8 – 12‰ enriched relative to carbon dioxide. The more depleted $\delta^{13}C$ values occur in the southern portion of the bay sites suggest the dominance of C_3 photosynthesizing algae (benthic and planktic) which selectively ultilize dissolved CO_2. $\delta^{13}C$ values of Everglade organics are depleted relative to bay samples with values between –21 and –33‰ indicating inputs from C_3 algae and terrestrial plants.

The nitrogen isotopic composition of seagrass species, *Thalassia testudinmu,* measured at our 6 bay sites are significantly different than those measured by Anderson and Fourqurean (in press) which focused on determining the inter-and intra-annual variations at two sites significantly westward of the bay interior. In our samples we observed a well-defined 9‰ gradient in the $\delta^{15}N$ of seagrass from 14‰ in the east to 5‰ at our westernmost site, similar to the isotopic range seen for all bay organics and for POM from the different the Everglades watersheds. In contrast, $\delta^{15}N$ values of *T. testudinum* sampled from the western margin of the bay were relatively depleted, showing a narrow range between –1.2 and 2‰ (Anderson and Fourqurean, in press) and exhibiting no overlap with our current measurement of *T. testudinum* in the bay proper. The differences in the $\delta^{15}N$ values between the two studies are significant. Our study focuses on the interior of the bay and may provide a truer representation of the nutrient dynamics and biogeochemical processes occurring throughout the bay, whereas Anderson and Fourqurean (in press) investigated sites at western edge of Florida Bay that reflect a greater gulf influence on nutrient dynamics. Efforts in the future will be directed at correlating variations in the health of seagrass beds to spatial and temporal variations in their nitrogen and carbon isotopic compositions.

Future work will also include spatial and temporal analyses of the isotopic composition of dissolved inorganic and organic nutrients (DIN, DIC, DON, DOC) to accompany ongoing isotopic determinations of the biological materials. Developing isotopic relationships between nutrient sources and biological materials will allow evaluation of the ecological response in the bay to changing nutrient inputs and biogeochemical cycling. Complementary work on the isotopic composition of bioassay experiments with nutrient enrichments and alterations will help define isotopic trends in organic materials resulting from changes in abundance and sources of nutrient inputs associated with the restoration of surface water flow through the Everglades. Finally, this research will incorporate isotopic analyses of organics in well-dated sediment cores from the 6 bay sites in order to evaluate the historical response of the bay ecosystem to documented changes in hydrologic conditions and nutrient cycling. The extensive analytical approach undertaken in this study promises a sensitive, cost-effective monitoring tool.

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Nitrogen Fixation in Microphytobenthos-Dominated Zones of Florida Bay

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Nitrogen cycling in Florida Bay is composed of a number of internal and external biogeochemical processes that govern the fate and availability of nitrogen within the system. Many recent studies have focused on the loading of nitrogen into Florida Bay from external sources in the development of a system-wide nitrogen cycling model. However, compared to external processes little is known about internal processes that also may introduce nitrogen to the system on more immediate spatial scales. Nitrogen fixation is one of these potentially important internal sources of bioavailable nitrogen to benthic environments in the basins of Florida Bay. Benthic systems in Florida Bay are generally dominated by dense stands of seagrass. However, with the recent advent of large areas of seagrass die-back, zones dominated by microphytobenthos have become more numerous and perhaps, of greater influence to the overall nitrogen cycling patterns in Florida Bay. In this research project we seek to measure rates of nitrogen fixation, create an annual profile of nitrogen fixation, and investigate abiotic controls on fixation in microphytobenthos-dominated zones at sites located throughout Florida Bay. Here we present measurements of nitrogen fixation rates in multiple basins as determined by the acetylene reduction and ^{15}N techniques. Preliminary results show fixation rates of 1-10 μmol N_2-N * m^{-2} * hr^{-1} which is of the same magnitude to external inputs from the atmosphere (through precipitation) and terrestrial sources.

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Chemical Characterization of Dissolved Organic Carbon and Dissolved Organic Nitrogen in the Florida Coastal Everglades: Preliminary Results

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The Everglades Restoration Project involves redistribution of water within the terrestrial ecosystem that will affect water entering the marine ecosystem. As a result, flow into Florida Bay is expected to increase and there is concern that increased nutrient loading will occur in the form of dissolved organic matter (DOM). Characterization of DOM can therefore be a valuable tool for understanding how changes in flow and thus DOM can affect ecosystem processes.

This study focuses on the molecular characterization of DOM from Florida Bay, and from Taylor Slough and the C-111 Basin in the northeast section of the Bay, as this is the Bay's main freshwater supply outside of rainfall. Detailed molecular characterization of DOM at 6 representative sites collected during the wet season (September 2002) will be presented. Results of several months of monitoring at 11 sites along two transects extending from the freshwater marshes of Taylor Slough and the C-111 Canal Basin through the mangrove fringe into and throughout Florida Bay will be presented as well.

In this study several approaches to chemical characterization were used to assess the source, bioavailability, and fate of DOM. Analytical techniques used for the characterization include pyrolysis-GC/MS, ^{13}C and ^{15}N NMR, gel electrophoresis, and LC/MS. The various techniques provide unique, complementary, and confirmatory information on the sources and fate of DOM. Representative examples of ^{13}C and ^{15}N NMR spectra of typical freshwater Taylor Slough and Florida Bay DOM samples are shown in Figure 1. The ^{13}C NMR spectrum allows observation of variations in relative intensities of different functional groups in relation to different sources and/or biogeochemical transformations. ^{13}C NMR spectra show that DOM in Florida Bay contain very low abundance of aliphatic and aromatic components but relatively high abundance of carbohydrates compared to Taylor Slough. Characterization using ^{15}N NMR spectroscopy indicates mostly proteinaceous material in the DON pool. Pyrolysis-GC/MS examines the fragmented chemical products of pyrolytic thermal degradation and allows reconstruction of source materials. Characterization of intact proteins through electrophoretic means was performed to gain insight into the role of proteins in the DON cycle. For additional DON characterization, total protein content is being determined by colorimetric methods on a monthly basis.

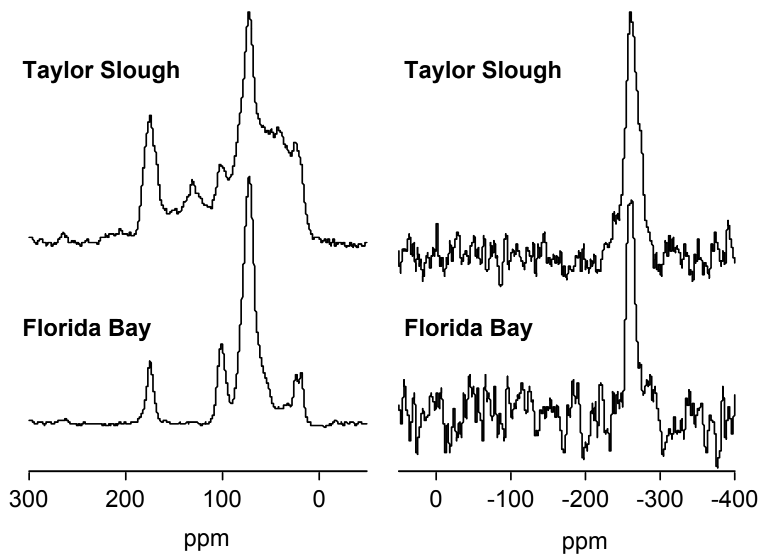

Fig. 1. Typical ^{13}C NMR and ^{15}N NMR spectra of HMWDOM (> 1 kDa) collected from Taylor Slough and Florida Bay.

In addition to the chemical characterization effort, monthly monitoring of water samples from the above-mentioned sites has been undertaken to assess seasonal variability in the DOM composition. Water quality parameters such as total nitrogen (TN), dissolved organic nitrogen (DON), dissolved organic matter (DOM), and other basic water quality parameters are being monitored for this purpose. Fluorescence measurements are also being recorded. In general, spectroscopic methods provide an assessment of terrestrially vs. marine derived DOM, an indication of organic carbon content, and estimate of the relative abundances of protein-like materials relative to humic material.

Monthly water samples were also examined for amounts of humic vs. non-humic substances. Non-humic substances are a class of compounds that include carbohydrates, proteins, fatty acids, and other low-molecular-weight organic substances. Humic substances form most of the organic matter of water and are largely the result of microbial transformation of higher plant material. Humic substances are dark-colored amorphous polymeric substances, whose compositions vary with the source materials and the state of degradation. The study of humic substances is warranted by their multiple chemical functions of biological importance.

Carbohydrates are an important potential energy source in aquatic environments. Information on carbohydrates can provide insight into the overall cycling of organic carbon. Total carbohydrates are being determined on a monthly basis. Further characterizations of carbohydrates in DOM have been performed to determine percent composition of individual sugars, and to use these in the assessment of DOM sources and transformations.

Finally, molecular weight distributions performed by gel filtration chromatography suggest differences in the chemical characteristics of DOM collected from Taylor Slough versus Florida Bay. Figure 2 is a typical elution chromatogram of water samples from these two sites, showing a higher weight distribution from Taylor Slough compared to Florida Bay.

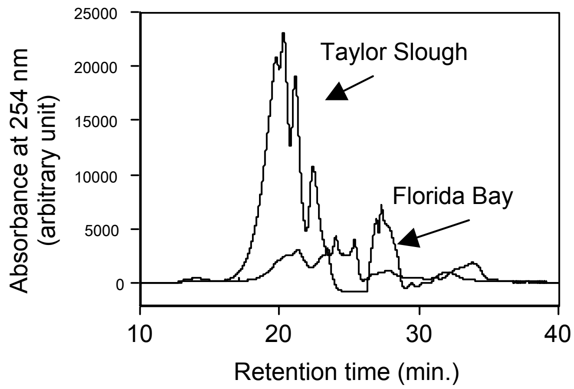

Fig. 2. Sample of elution curves of DOM collected from Taylor Slough and Florida Bay using a gel filtration chromatography.

Overall, the molecular characteristics of DOM in the Florida Coastal Everglades show clear differences between Everglades and Florida Bay samples. Optical and chemical characteristics suggest that much of the DOM in Florida Bay is of autochthonous origin.

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Bacterial Enumeration in Florida Bay Using Epifluorescent Microscopy

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Throughout the past 70 years, the freshwater that once passed through the Taylor and Shark sloughs has been diverted influencing not only the chemistry, but also turbidity, salinity and sediment material deposition. The Florida Everglades Restoration Project aims to re-establish the freshwater flow to these sloughs, which could impact the Florida Bay ecosystem. Although all aspects of the Bay may be affected, the microbial community structure of Florida Bay is of key importance. Long-term monitoring projects have identified trends pertaining to numerous facets including water quality, seasonal modeling, and unique theories regarding Florida Bay's microbial loop dynamics. Redirecting the flow patterns through the Everglades could change not only the amount, but the chemical composition of the dissolved organic material entering the Bay as well. The reaction by the microbial community, especially heterotrophic bacteria, to these changes must be monitored in order to form hypotheses regarding the impacts to higher trophic organisms and the health and stability of the Bay.

Seagrass communities and their associated epiphytes are an important source of utilizable DOC for bacteria in view of the fact that the oligotrophic nature of the Bay holds the phytoplankton production and biomass relatively low. Although models estimate that 10-50% of photosynthetically produced carbon is utilized by bacteria, the allochthonous dissolved organic material provided by the everglades is of critical importance to the Bay's microbial community. The freshwater entering Florida Bay via the Everglades is generally nutrient poor, but it is high in dissolved organic material (DOM), especially as dissolved organic carbon (DOC), which potentially fuels the bacterial aspects of Florida Bay's microbial loop. Although bacteria, like phytoplankton, are nutrient limited, they are able to take up nutrients faster, more efficiently, and in greater quantities than the phytoplankton. The microbial loop may play a significant role in Florida Bay's nutrient remineralization when utilizable nutrients are low. Heterotrophic and cyanobacteria liberate inorganic phosphorus via exudation of an extracellular enzyme measured as alkaline phosphatase activity (APA). Combining our analysis of bacterial enumeration, alkaline phosphatase activity, and water quality monitoring, with concurrent laboratory biodegredation experiments could elucidate the role of heterotrophic bacteria in Florida Bay's microbial loop.

There has been ongoing research on the C:N:P ratio of the DOM flowing into Florida Bay for several years. This ratio can determine whether nutrients are produced, consumed, or some combination of both by the loop. Our analysis involves the use of nucleic acid stains and epifluorescent microscopy to estimate bacterial cells l^{-1} of water throughout 28 sites in Florida Bay. These counts showed distinct seasonal patterns and produced an extensive database, which may be compared to future data accumulated as the restoration project continues.

Since September 2001, we have collected 250ml samples monthly from each of the 28 sites in sterile, lightproof bottles concurrently with those collected for the Water Quality Monitoring Program. Bottles were immediately stored on ice for transport to the lab where our laboratory enumeration analysis began within 24 hours of collection. From each site, a 10 ml aliquot was fixed with a final concentration of 2% formalin by volume. From this, 0.5ml was stained with the nucleic acid stain DAPI in a filtration tower for 20 minutes. After staining, the sample was vacuum filtered through a 0.2µm polycarbonate membrane filter, the tower rinsed with sterile water, and the filter affixed between a slide and cover slip. The slides were then viewed under 365 nm wavelength light and the fluorescing bacterial cells were counted within a 2000µm square grid. The totals from 10 randomly selected grids per slide were averaged and a cell count l^{-1} is calculated.

The past 14 months have provided a large data set that complements the 12-year Florida Bay database. Large spatial and temporal differences were observed among areas of the Bay. The highest cell counts came from the western Bay, and the lowest were shown to be in the eastern. Highest counts in each zone were typically associated with the fall (57% Sept. - Nov.) and to a lesser extent the spring (25% Apr.-May). Monthly low counts showed less seasonality but the majority of the low counts fell in the winter (36% Dec. – Feb.) and summer (29% June – Aug.). The range of bacterial cell counts across the sampling period was highest at site 19 (4.480245 $X10^6$ cells/l), and lowest at site 25 (5.89050 $X10^5$ cells/l). Site 15 was shown to have the greatest variance, while site 24 had the least. The coefficient of variation ranged from 21.8% to 97.9% but 49.4% was the average over 28 sites. Further analysis involving the comparison of the monthly water quality monitoring to bacterial counts will be investigated.

Other methods of enumeration are being compared to the epifluorescent direct count method presently used. A pilot study using a FACSort flow cytometer was conducted using the October 2002 Florida sampling. The data produced by the two methods were highly correlated (r^2 = 0.8071). We intend to use this technology to enumerate bacteria while investigating protist-bacteria relationships in Florida Bay. With further calibration, the adoption of flow cytometry will greatly reduce sample processing time and expedite proposed research regarding the grazing pressure on Florida Bay's bacteria. Understanding the role of protist grazing may provide a more complete picture of the factors controlling the Bay's bacterial dynamics and the transfer of materials and energy to higher trophic levels.

The primary objective regarding Florida Bay research has been to study the effects of the modification of overland flow through the everglades for agricultural demand and seasonal flooding control. The continued research on the microbial aspects of the Bay could be a powerful tool in assessing the impact of the restoration of the Everglades. Tying the Water Quality Monitoring Network data with our concurrent bacterial analysis may elucidate the mechanisms that control bacterial abundance across the Bay.

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Sedimentary Organic Matter Sources in Florida Bay as Revealed through Molecular Marker Analysis and Compound Specific Stable Isotope Measurements

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Tracing the origin of sedimentary organic matter in near-shore environments can be difficult due to mixed allochthonous and autochthonous sources. The use of biomass-specific molecular markers, as well as compound specific carbon isotope measurements, can aid in discerning mixed source assignments. This study was undertaken to assess organic matter sources in Florida Bay, using specific molecular markers for *Thalassia testudinum* and *Rhizophora mangle,* molecular marker proxies and compound specific carbon isotope measurements.

Florida Bay is a partially enclosed, sub-tropical estuary with mangrove islands, *Rhizophora mangle*, and dense meadows of *Thalassia testudinum* inter-dispersed throughout the bay. A transect of surface grab samples was collected from the Northeastern to Southwestern section of Florida Bay, and the solvent extractable organic matter fraction was characterized by GC/MS and GC-IR/MS. As mentioned earlier, the techniques used to trace organic matter sources to the sediments included a proxy developed by Ficken et al. (2000) along with compound specific stable isotopes and specific molecular markers for mangrove (β-amyrin) and seagrass (C_{25} ketone) vegetation.

The proxy used, P*aq*, takes advantage of the fact emergent and submerged vegetation has more mid chain length *n*-alkanes than longer chain *n*-alkanes. Table 1 shows the P*aq* values and compound specific carbon isotope values of *n*-alkanes obtained for the major biomass in Florida Bay and Everglades National Park. The P*aq* values for seagrass and mangroves are quite different as are the isotope numbers thus allowing for possible discrimination of these two sources. A more specific way to trace the inputs of seagrass and mangroves are to use compounds specific for each. Hernandez et al. (2001) found that C_{25} ketone (figure 1), was significantly more abundant in seagrass than in any of the other vegetation analyzed thus areas receiving more seagrass-derived OM would result in higher relative abundances of the C_{25} ketone. Similarly another molecular marker was used to trace mangrove-derived material (see figure1). The presence of β-amyrin would indicate mangrove sources due to this compounds specificity for this environment.

Preliminary results indicate a significant influence of mangrove derived organic matter on the composition of OM in seagrass beds, particularly in the Northeastern and central section of the bay, as seen by the presence of β-amyrin (figure 2). The compound specific stable carbon isotope values of the *n*-alkanes from the same site as in figure 1 also showed considerable terrestrial inputs of material. Data from the more seagrass dominated Southwestern section of the Bay presented neither molecular nor isotopic evidence for significant mangrove derived organic matter inputs. This data would seem to make sense due to the abundance of mangrove islands in the Northeastern and central part of Florida Bay and the possible organic matter transport of mangrove material from the mainland to these sites.

Plant	C23	C25	C27	C29	C31	P*aq*
Rhizophora mangle	-31.22	-31.64	-32.26	-31.92	-30.04	0.24
Cladium jamaicense	-31.15	-29.11	-32.13	-32.38	-33.66	0.13
Eleocharis cellulosa	-28.55	-31.06	-31.77	-33.99	-33.25	0.10
Ruppia maritima	-16.64	-16.84	-17.31	-17.52	-18.73	0.67
Chara sp.	-24.34	-26.30	-25.10	-25.06	N.D.	0.89
Utricularia sp.	-41.40	-41.87	-40.45	-39.10	-40.73	0.85
Periphyton	-32.25	-30.19	-30.00	-30.10	-28.52	0.45
Halophila decipiens	-17.21	-17.24	-17.11	-19.91	N.D.	0.90
Halodule wrightii	-14.78	-15.27	-15.56	-16.32	N.D.	0.99
Syringodium filiforme	-13.25	-13.14	-12.84	-15.81	N.D.	1.00
Thalassia testudinum	-14.87	-18.64	-19.50	-19.12	-19.12	0.93
Sargassum pteropleuron	n.m.	n.m.	n.m.	n.m.	n.m.	0.88
Caulerpa mexicana	n.m.	n.m.	n.m.	n.m.	n.m.	0.95
Penicillus capitatus	n.m.	n.m.	n.m.	n.m.	n.m.	0.95
Sediment						
TSPH 9 sed	-21.16	-24.10	-25.87	-28.42	-24.82	0.68
TSPH 10 sed	-16.21	-21.43	-24.66	-27.84	-22.62	0.63
TSPH 11 sed	-12.65	-12.55	-12.06	-18.76	N.D.	0.92
Trout Cove	n.m.	n.m.	n.m.	n.m.	n.m.	0.44
Bob Allen Key	n.m.	n.m.	n.m.	n.m.	n.m.	0.52
Russell Key	n.m.	n.m.	n.m.	n.m.	n.m.	0.58
Rabbit key	n.m.	n.m.	n.m.	n.m.	n.m.	0.70

Table 1: Compound Specific GC-IRMS and P*aq* data of vegetation and sediments.
n.m. = not measured; n.d. = not detected

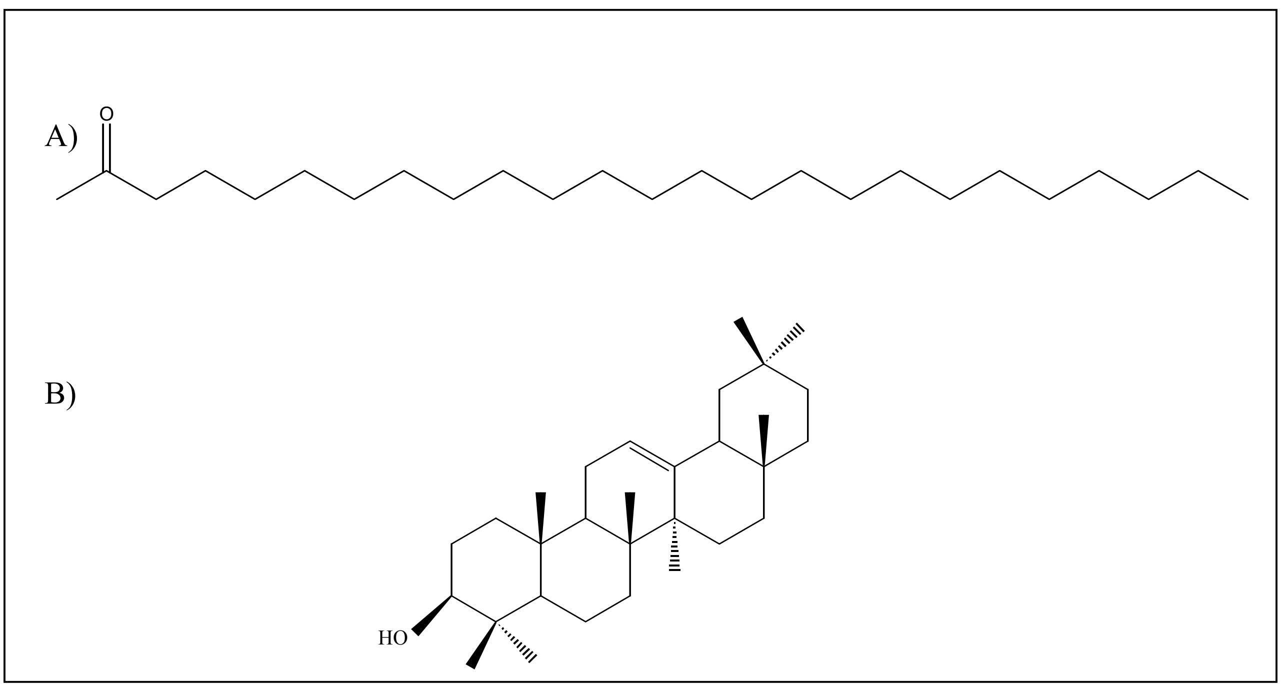

Figure 1: A) C_{25} Ketone molecular marker for seagrass. B) β-Amyrin molecular marker for mangrove input.

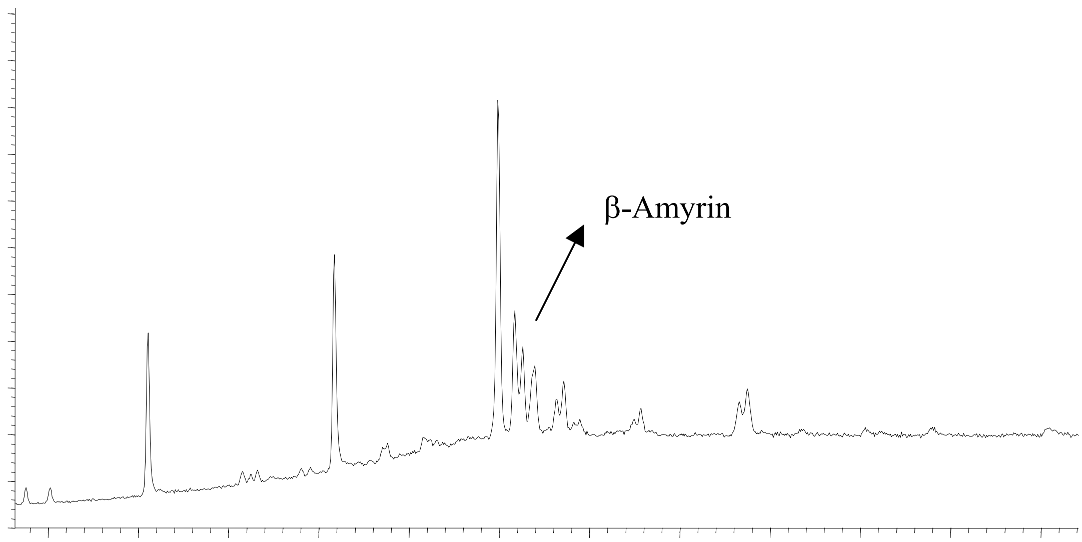

Figure 2: Chromatogram of the alcohol fraction from TSPH 9 showing the mangrove input molecular marker.

References:

Ficken, K.J., B.Li, D.L.Swain, G. Eglington, (2000). Organic Geochemistry, 31,pp. 745-749

Hernandez, M.E., R.Mead, M.C. Peralba, R.Jaffé, (2001). Organic Geochemistry.32, pp.21-32

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Surface Water Geochemical Surveys in Florida Bay

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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 (Figure 1). Carbon dioxide gas flux data were superimposed over bottom-type data to identify potential correlations between 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.

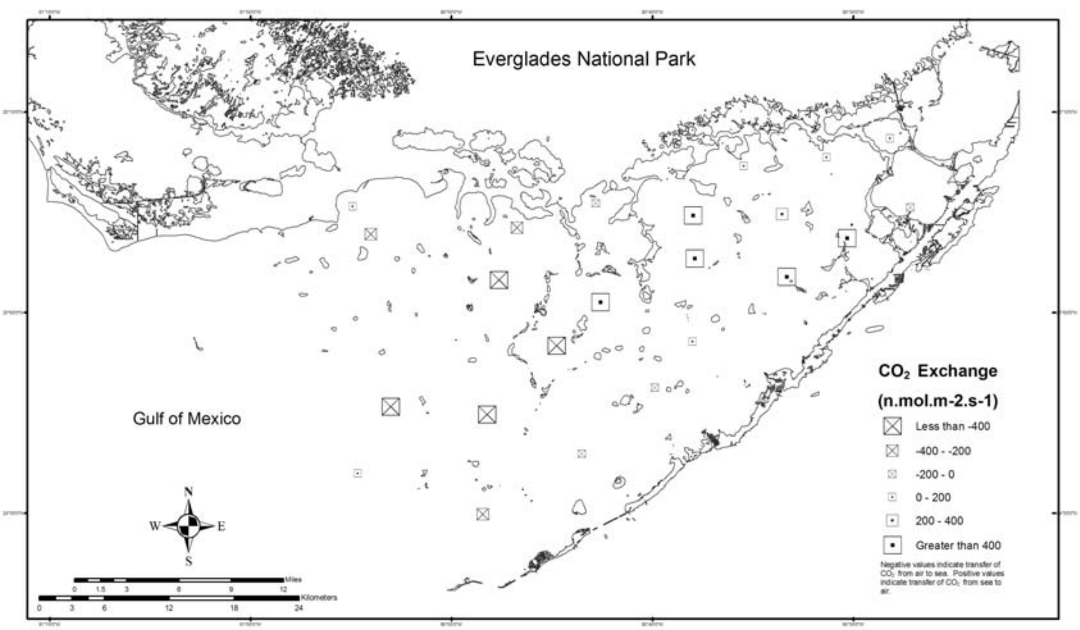

Figure 1. Example of Florida Bay air:sea carbon dioxide exchange data from April 2001. Boxes with and "x" indicate transfer of CO_2 from the air to surface waters. Boxes with a "•" indicate transfer of CO_2 from surface water to the air. Similar maps have been generated for salinity, temperature, pH,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

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Question 3 - Algae Blooms Oral Abstracts

- Listed alphabetically by presenting author.
- Presenting author appears in **bold**.

Uncoupling Autotrophic and Heterotrophic Microbial Response to Increased DOM in Florida Bay

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Distinguishing between autotrophic and heterotrophic contributions to microbial nutrient and carbon cycling is problematic. Intensive, extensive, and expensive experiments are required to simultaneously characterize microbial community structure and function. As a result, microbial loop interactions and the parameters contributing to microbial energy transfer are poorly understood in Florida Bay and in coastal systems in general. Discerning autotrophic and heterotrophic microbial dynamics in Florida Bay may contribute to our understanding of facilitation and progression of periodic plankton blooms.

We conducted a series of light and dark incubation experiments to concurrently distinguish between heterotrophic and autotrophic changes in microbial community structure and function with increased DOM availability. Taylor River is recognized as the primary terrigenous freshwater input and thus Everglades derived DOM source to Florida Bay. If planktonic bloom dynamics in the Bay are controlled by freshwater Everglades DOM inputs then we expected our greatest responses in microbial parameters and substrate use with DOM concentrated from Taylor River freshwater. We tested this hypothesis with water collected from Argyle Henry, a Florida Coastal Everglades LTER site and northernmost navigable creek-point in the Taylor Slough drainage basin.

Four sites in the central western and central eastern Bay were selected for study. Each of these locations has been characterized by relatively high CHLA concentrations and alkaline phosphatase activity (APA) through long term monitoring. Thus we expected the greatest response of DOM enrichment from these sites. We conducted five sets of ten-day bottle incubation experiments in August, October and December of 2001 and again in April and June of 2002. A control of untreated water, 1 and 10 uM addition of P and N, and a 2 times concentrate of DOM treatments were applied to water collected from each site for each of the experiments. Seventeen parameters of dissolved and total nutrients and microbial parameters were quantified for each incubation experiment and sampling.

Results from our combined incubation experiments in dark conditions of water from the four study sites consistently revealed a mean 2.2% loss in DOC concentrations in the light and 4% loss in the dark over the experiment interval. Mean loss of DOC in the DOC enrichment treatment revealed a mean 2.1% loss in the light and 8% in the dark. This difference between light and dark response may be associated with carbon production from plankton in the light treatment. These results indicate that Florida Bay DOC is highly degraded and recalcitrant and that the DOC from Arglye Henry was also relatively low in labile carbon.

Additions of DOM and inorganic nutrients yielded highly variable heterotrophic bacteria abundance and production across the study sites and between incubation experiments. In general, bacteria numbers and heterotrophic carbon fixation increased as a result of DOM additions and increased by an order of magnitude in the majority of incubations and across study sites.

Light incubations with DOM enrichment revealed less of a response in algal groups than the N and P additions. Inorganic nutrient additions responses were inconsistent among the fours sites and we observed a rapid depletion of inorganic nutrients. Following the uptake of nutrients with a lag period of 1-day, the green and cyanobacteria CHLA increased but was not persistent across the 10-day experiment interval. Brown algae comprised the bulk of CHLA measurements for all experiments.

Our results suggest that DOM enrichment alone does not contribute to short-term persistent increases in cyanobacteria, green, or brown algal groups. Heterotrophic bacteria and associated carbon cycling is definitively stimulated with DOM enrichments. When N and P are provided, short, intense periods of cyanobacteria and green algae growth occur but are not sustained after initial inorganic nutrient enrichment. Mineralization of inorganic nutrients by heterotrophic bacteria stimulated by DOM enrichment may be an important link in the onset of planktonic blooms. We are continuing incubations of Florida Bay water and examining the contributions of organic nitrogen to further elucidate planktonic dynamics in this critical coastal ecosytem.

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Stoichiometry of the Dissolved and Particulate Nutrient Pools, and Phytoplankton Uptake Rates, and Their Relationship with Phytoplankton Community Composition in Florida Bay

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The stoichiometric proportions of nutrient availability, and the proportions in which phytoplankton utilize those nutrients have been found to be useful in determining potential limitation of plankton productivity and biomass in subtropical coastal ecosystems. The alterations in the forms, sources, and ratios of nutrient inputs to Florida Bay that will likely result from the proposed Everglades Restoration project provide further justification for an assessment of the current status of nutrient stoichiometric relationships. As part of a NOAA-funded program, we have addressed the dissolved and particulate nutrient composition, rates of uptake of various inorganic and organic nutrients and their relationship with bacterial and phytoplankton biomass and phytoplankton community structure at 6 representative sites within Florida Bay.

The first of four planned field efforts was completed in November 2002 over a 10-day period, and preliminary analysis of these results indicates strong gradients in composition and in nutrient ratios. Samples were collected from sites within Florida Bay which encompassed a variety of geographical and environmental conditions: Little Madeira Bay, Duck Key, Sunset Cove, Rankin Bight, Barnes Key, Rabbit Key, and a Gulf of Mexico influenced western Florida Bay site. At each site, surface water was immediately returned to the Park Service laboratory and analyzed for a full suite of biological (e.g. chlorophyll *a*, pigment composition, bacterial and phytoplankton abundance), nutrient (dissolved inorganic and organic and particulate nutrients), isotopic ($\delta^{15}N$ and $\delta^{13}C$ particulate values) and rate (enzymatic and C, N, P and Si uptake) measurements.

During this sampling period, phytoplankton blooms were encountered at Barnes and Rabbit Keys, with chlorophyll *a* values ranging from ~2 - >8 $\mu g\ l^{-1}$. Zeaxanthin: chlorophyll *a* ratios suggest that these were blue-green algae. Wind-induced resuspension may have also contributed to elevated chlorophyll *a* at Barnes Key, as evidenced by the stable isotopic composition of the particulates. At all other stations, ambient chlorophyll *a* was <1 $\mu g\ l^{-1}$, with fucoxanthin dominating as the accessory pigment.

At all stations sampled, ambient inorganic nitrogen availability was <3 μg at N l^{-1}, with highest concentrations observed in the ammonium pool at Sunset Cove, Duck Key and Taylor Slough. A terrestrial source for this nutrient was apparent in the $\delta^{15}N$ of the particulate matter from these stations, with $\delta^{15}N$ values ≥ 10. Levels of inorganic nitrogen were <0.4 at Barnes and Rabbit Keys and at the Gulf station, and values of $\delta^{15}N$ of the particulate matter from those stations were significantly lower than the terrestrially influenced stations. Ratios of the ambient dissolved N:P nutrients were also substantially below Redfield ratios at Barnes and at the Gulf, and near Redfield proportions at Rabbit Key, adding further evidence of nitrogen limitation at these stations. Ratios of dissolved N:P were well in excess of Redfield proportions at the other sites, suggesting phosphorus limitation. No evidence of silica limitation was found at any site.

Direct measurements of uptake rates of nitrogen and phosphorus are consistent with these relationships. Highest uptake rates of nitrogen (based on short term assays of isotopically-labeled nitrogen compounds at varying concentrations) were found at Rabbit and Barnes Keys and at the Gulf station, whereas lowest nitrogen uptake rates were noted at Sunset Cove. All stations exhibited higher uptake rates of ammonium than of the other nitrogenous substrates tested, but all stations also demonstrated substantial uptake of organic nitrogen. Highest phosphorus uptake rates (based on short term substrate depletion of additions of varying concentration) were determined at Sunset Cove, Rankin Bight and Duck Key, and lowest at Rabbit Key and at the Gulf Station.

Further data analysis will permit an assessment of the elemental ratios of the particulate material from each station, and an assessment of the relationship between these ratios and those of their rates of uptake. Based on this preliminary view, phosphorus appears to be the predominant limiting nutrient at Sunset Cove and Duck Key, but nitrogen limitation appears to be the predominant limiting nutrient at Barnes Key and the Gulf station. Evidence of potential co-limitation by nitrogen and phosphorus is apparent at Rankin Bight, Little Madeira, and at Rabbit Key.

The pattern of a transition from phosphorus to nitrogen limitation found within Florida Bay differs from Moreton Bay, Australia, another subtropical system where comparative analyses have been done. Moreton Bay is a shallow, estuarine embayment heavily impacted by urban nutrients and aquaculture where significant seagrass die-offs have occurred. For that system, both biomass and productivity are characterized by limitation by nitrogen but not by phosphorus. That system also differs from Florida Bay in the dominant blooms that develop upon nutrient loading.

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Phytoplankton and Bacterial Response to Inorganic and Organic Nutrient Enrichment and Alteration in Florida Bay: Results from Bioassay Enrichment Experiments

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The proposed restoration of freshwater, surface-flow through the Florida Everglades is expected to alter the forms, sources, and ratios of nutrient inputs to Florida Bay. Of particular concern is the expected change in the availability and ratio of dissolved inorganic to dissolved organic nitrogen, as previous research in coastal oceans and estuaries has recognized that alteration in nitrogen cycling has the potential to promote selection and succession of phytoplankton species, change the distribution and magnitude of primary production and associated trophic levels, cause degradation of benthic habitats leading to mass mortality, and destroy recreational and commercial interests. As part of a NOAA-funded program, we addressed the nutrient composition and the potential for alternation in nutrient availability to impact plankton dynamics using short-term (48 hour) bioassay enrichment experiments in November 2002.

Water samples were collected from 6 geographically and ecologically unique sites within Florida Bay: Little Maderia Bay, Sunset Cove, Rankin Bight, Barnes Key, Rabbit Key, and a Gulf of Mexico influenced western Florida Bay site. Surface water samples from each site were immediately returned to the laboratory, and analyzed for a full suite of dissolved and particulate nutrients as well as phytoplankton (as chlorophyll *a*) and bacterial biomass. Water from each site was dispensed into duplicate 2 L carboys and enriched with ammonium (2 μg at N l^{-1}), organic nitrogen (a mixture of urea and amino acids at 2 μg at N l^{-1}), inorganic phosphate (2.0 μg at P l^{-1}), organic phosphate (2.0 μg at P l^{-1}), and humic acids (2 mg l^{-1}). A control with no additions was also maintained. All treatments were incubated under natural light and water temperature conditions and monitored over 48 hours.

Although ambient inorganic and organic phosphorus concentrations were low at all stations (<0.17 and <0.73 μM respectively), after 48 hours chlorophyll *a* in bioassays increased significantly ($P<0.05$) upon inorganic phosphorus enrichment only in the Sunset Cove and Little Madeira incubations, and increased with organic phosphorus enrichment only in the Little Madeira incubation. Although a phosphorus stimulus response was only evident only at these two stations, an increase in particulate P:Chl *a* ratios with both inorganic and organic phosphorus enrichment was observed within 24 hr at all stations, suggesting either luxury consumption and storage of both inorganic and organic phosphorus additions, or that a stimulation of the heterotrophic rather than the autotrophic community, occurred. In contrast, with the Rankin Bight bioassays, a significant increase in chlorophyll *a* was observed only upon the addition of dissolved organic nitrogen and at both Barnes Key and the Gulf stations with the ammonium addition. No significant stimulation in chlorophyll *a* was noted by any nutrient addition at Rabbit Key, indicating either nutrient sufficiency or simultaneous limitation by both nutrients.

Although increases in chlorophyll *a* varied with nitrogen and phosphorus additions in different locations in the Bay, physiological indices suggest that cells were poised to utilize any source of nitrogen or phosphorus that was supplied. Potential utilization of organic nitrogen and phosphorus were assessed in the bioassay experiments by measuring alkaline phosphatase and urease activity after 48 hrs. Both are inducible enzymes that allow cells to exploit organic sources of nutrient. Although enzyme levels varied from station to station, in general alkaline phosphatase activity increased upon additions of ammonium, organic nitrogen, and humic acids, whereas urease activity increased upon additions of phosphorus. Thus, these cells demonstrated the ability to utilize organic nitrogen and phosphorus when other cellular nutritional needs were met.

The response of the bacterial community to nutrient enrichment differed from that of the phytoplankton community at each station. With Sunset Cove and Rankin Bight incubations, there were no significant changes in bacterial abundance after 48 hour exposure to any of the added substrates. At Little Madeira, additions of ammonium, dissolved organic nitrogen and humic acids resulted in a significant ($P<0.05$) decrease in bacterial abundance, suggesting that a stimulation of bacterial grazers by nutrient additions occurred within 48 hrs. At Rabbit and Barnes Keys, inorganic phosphorus stimulated bacterial abundance, as did dissolved organic phosphorus at Barnes Key. Thus, the nutrients that stimulated production of phytoplankton biomass at each site were not the same as those that either stimulated or depressed bacterial levels, suggesting that different nutrients and processes regulate bacterial and phytoplankton biomass within Florida Bay, and that altered nutrient inputs may potentially act differentially upon bacteria and phytoplankton communities.

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The Roles of Freshwater Discharge, Advective Processes and Silicon Cycling in the Development of Diatom Blooms in Coastal Waters of the Southwestern Florida Shelf and Northwestern Florida Bay (1999-2001)

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Our research investigated the seasonal development of diatom blooms in coastal waters of the southwestern Florida shelf and northwestern Florida Bay during two years of contrasting rainfall (1999-2000). Spatial and temporal variability in the surface distributions of phytoplankton biomass were analyzed. Biogenic silica ($BSiO_2$) and netplankton chlorophyll *a* (>5µm size-fraction) served as indices of diatom biomass. We investigated the relationship between coastal freshwater discharge and phytoplankton biomass, and the role of advective processes in the transport of phytoplankton biomass and nutrients. The dynamics of diatom growth were analyzed and nutrients limiting the phytoplankton biomass were identified. External sources and internal supplies of silicic acid ($Si(OH)_4$) were compared and quantified. Silicon (Si) budgets were constructed to identify trends in the silicon cycle during three phases of a diatom bloom in northwestern Florida Bay and a conceptual model was developed to describe the evolution of the annual diatom blooms.

Initiation of the annual diatom bloom occurred between April and June as defined by a 2-fold increase in phytoplankton biomass above average background concentrations $<1\ \mu g\ l^{-1}$ chlorophyll *a* (Chl *a*) measured in nearshore waters of the southwestern Florida Shelf between Cape Romano and Cape Sable. The greatest increase in Chl *a* occurred near Middle Cape Sable, which was identified as the region of bloom initiation. Netplankton biomass near Middle Cape Sable responded to seasonal variability in Shark River discharge, with a rise in biomass that paralleled the increase in river discharge. This response suggests that the Shark River is an important nutrient source that influences the timing and location of the annual diatom bloom. However, interannual variability in the amount of freshwater discharge from the Shark River had less of an influence on the annual development of diatom blooms than seasonal variability in freshwater discharge. Despite a 3-fold difference measured between the maximum rates of Shark River discharge between 1999 and 2000, the maximum concentration of Chl *a* varied by <10% during the bloom's peak in October. Furthermore, during 2000 the shorter duration of enhanced discharge during the wet season did not result in a corresponding reduction in the duration of the annual diatom bloom.

Seasonal trends in alongshore advection, and longer retention times in nutrient-rich coastal waters were hypothesized to contribute to the annual development of diatom blooms in late spring. Between April and June, the period of bloom initiation, salinity distributions showed greater retention of low salinity water near the shore of Cape Sable, compared to winter and early spring. Currents measured at an ADCP located near the region of bloom initiation and development switched from net-southward to net-northward flow between April and June. During that time, current speeds were reduced. The trajectories of surface drifters released at the mouth of the Shark River also showed slower alongshore transport during late-spring and early-summer, compared to winter.

Nutrient fluxes out of the Shark River varied seasonally, with maximum fluxes measured during the fall when discharge was greatest. While the Shark River flux of nutrients was locally significant, the alongshore flux of dissolved inorganic nutrients frequently exceeded that supplied by the Shark River. However, combined riverine and alongshore fluxes of inorganic nutrients were less than estimated phytoplankton nutrient quotas, and were deemed to be incapable of satisfying the daily phytoplankton demand for nutrients. It was concluded that continued phytoplankton growth depended upon regenerated nutrients.

Regeneration of $Si(OH)_4$ was hypothesized to provide an important mechanism for maintaining diatom biomass in northwestern Florida Bay, where there was an inverse relationship between diatom biomass ($BSiO_2$) and $Si(OH)_4$ during the bloom peak in 1999. There was no clear seasonal trend in the benthic flux of $Si(OH)_4$ although there was a general pattern of lower fluxes of $Si(OH)_4$ with lower water temperature and, perhaps, salinity. Assuming an average depth of 2 meters for northwestern Florida Bay, the benthos provided 2.76 μmol Si l^{-1} day^{-1} to the overlying water column. In comparison, regeneration of $Si(OH)_4$ in the water column produced an average of 1.94 μmol Si l^{-1} day^{-1}. The flux of $Si(OH)_4$ across the northwestern boundary of Florida Bay could have supplied an additional 1 μmol Si l^{-1} day^{-1}. During the biomass maximum in summer and fall, the demand by diatoms for silicon (ca. 7 to 12 μmol Si l^{-1} day^{-1}) exceeded the rate of $Si(OH)_4$ supply (ca. 6 μmol Si l^{-1} day^{-1}).

While $(SiOH)_4$ was not identified as a primary nutrient limiting the production of netplankton biomass, the supply and availability of $Si(OH)_4$ were likely important factors influencing the dynamics of diatom blooms in northwestern Florida Bay. Silicon budgets were developed to constrain rates of silicon turnover during the evolution of an annual diatom bloom. During bloom initiation in spring, the pool of $Si(OH)_4$ was 2.5-times greater than that of $BSiO_2$ and the turnover time for each was ca. 2 days. During the period of bloom maintenance, summer and fall, the pool of $BSiO_2$ had doubled compared to spring, and the pool of $Si(OH)_4$ had begun to decline. The production of $BSiO_2$ was 4-times faster than the rate at which $Si(OH)_4$ was supplied to northwestern Florida Bay. During the fall diatom bloom, the pool and supply of $Si(OH)_4$ were balanced by the standing stock and production of $BSiO_2$, suggesting the system was in a steady state. At bloom termination in winter, the pool of $BSiO_2$ was ca. 5-times greater than the standing stock of $Si(OH)_4$ and concentrations of $Si(OH)_4$ had declined by ca. 85% compared to spring. At bloom termination, the rate of silica dissolution was 4-times greater than the rate of $BSiO_2$ production.

Termination of the diatom bloom in December is hypothesized, in part, to be the result of increased advection of phytoplankton cells out of coastal waters and northwestern Florida Bay. Isohalines in surface waters show a broad distribution of low salinity water along the inner shelf and into western Florida Bay between December and February. The trajectories of surface drifters released at the mouth of the Shark River generally show south and southeastward transport of coastal water during winter and spring. Analysis of coastal currents (T. Lee *et al.*) and alongshore fluxes of nutrients support this interpretation; the seasonal transition from north- to southward alongshore velocities occurred between October and December. During periods of strong southward advection, the flux of phytoplankton biomass out of the north was incapable of replacing biomass lost to the south. Reduced retention in nutrient-rich waters, and replacement of bloom concentrations with low-biomass waters from the north, are believed to have contributed to bloom termination.

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Question 3 - Algae Blooms Poster Abstracts

- Listed alphabetically by presenting author.
- Presenting author appears in **bold**.

Bloom in a Bottle: Experimental Derivation of the Mechanism for the Onset and Persistence of Phytoplankton Blooms in Florida Bay

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Florida Bay is characterized by shallow clear oligotrophic waters with a complex benthic community and typically low phytoplankton biomass. Florida Bay also periodically experiences extensive phytoplankton blooms that cannot be accurately explained by the current physical/chemical or nutrient limitation models. Previous research has shown that these blooms are unconventional in that their community structure is dominated by cyanobacteria instead of typical algae. There are significant physiological differences between these two organismal groups which may explain the prevalence of cyanobacteria blooms in the environmental regime of Florida Bay. Specifically, cyanobacteria differ from algae in both their ability to fix atmospheric nitrogen and their much higher cell-specific alkaline phosphatase activity (APA), an enzyme that cleaves organic P making it available for cellular uptake. These processes may give cyanobacteria an advantage over algae in the nutrient limited conditions of Florida Bay if in the presence of labile organic matter.

A dataset of over 12 years of Florida Bay monitoring indicates that low nutrient and high DOM conditions are especially prevalent in the central region of Florida Bay. This is also the region where most phytoplankton blooms are observed to begin. In this experiment we attempt to define and quantify the conditions and mechanisms resulting in cyanobacterial bloom development and persistence in Florida Bay.

In order to elucidate the mechanism for the onset and persistence of cyanobacteria blooms, we incubated Florida Bay water with enrichments of DOM and inorganic nutrients. Water was collected water from four long-monitored sites in Florida Bay, two sites in each Central (Sprigger Bank and Bob Allen Keys) and Eastern Bay (Joe Bay and Duck Key) zones. For each site, 3 treatments were tested under both light and dark conditions: control, N and P addition, and DOMx2 addition. The DOM for enrichments was obtained by concentrating water from Arglye Henry creek along the Taylor Slough River Basin by tangential flow fractionation filtration at a pore size of 1 kD. The incubations were conducted in 2.7 L polycarbonate bottles - both clear and covered in aluminum foil tape for dark incubations. All of the bottles were incubated in a lake on F.I.U. campus such that light and temperature were equivalent to ambient light and temperature in Florida Bay. Bottles were well-mixed via wave action in the lake. Samples were collected from the incubation bottles on 0, 1, 3, 6, and 10 days after treatment. These samples were analyzed for bacterial number by DAPI epifluorescent direct counts, bacterial production by ^{3}H-Thymidine uptake, a suite of chlorophyll-*a* and nutrient levels, and alkaline phosphatase activity (APA).

Analysis of the incubation experiments under light conditions indicated a trend for a peak in bacteria number, bacteria production, and Chl-*a* occurring in the N+P treatment bottles around day 6 of incubation. This peak corresponded to a near total depletion of inorganic nitrogen in the form of NO_3^-, NO_2^-, NH_4^+ in all light N+P treatments. It was also seen that all inorganic phosphorus in the form of SRP in these bottles was depleted rapidly, usually within 3 days. After the drop of SRP concentrations, a peak in APA was observed as was expected. Peak APA occurs on day 6 with the peak in production. This peak is seen in both central and eastern bay sites but was not seen in the control or DOMx2 treatments.

The day 6 bloom was not clearly perpetuated through day 10, possibly due to a lack of bioavailable N in the system. This indicates that a possible key factor for the persistence of blooms in Florida Bay is the concentration of bioavailable inorganic nitrogen in the system. It is possible that the organisms responsible for the day 6 bloom are capable of utilizing organic P via AP but lack the ability to fix a sufficient amount of N to sustain the bloom population. This theory is supported by the change in TIN:TP ratio. Due to the faculty of AP in utilizing TP, the TIN:TP ratio is a good indicator for nutrient limitation in a cyanobacteria population. We see an approximate 10 fold decrease in the TIN:TP ratio of the N+P light treatments as the system progresses towards N limitation. This ratio does not significantly change in the other light treatments. It is hence possible that the timing and composition of nutrient inputs before and during phytoplankton blooms is the key factor in their initiation and persistence.

DOC concentrations remained fairly constant across all sites and treatments, indicating two possibilities that a.) DOC is not a limiting factor for bacteria or phytoplankton populations in the area, or b.) the DOC is not bioavailable to the organisms involved in this system (i.e. DOC was aged and recalcitrant or some limiting nutrient was not presented). This has major implications in the fate of DOC from the Everglades and Florida Bay ecosystems and corresponding carbon budget models.

Analytical measurements from pulse amplitude modulated (PAM) fluorometry on sample Chl-*a* indicated a community shift in the bottle from a blue and brown dominated algal guild at day 3 to a green and/or brown Chl-*a* guild at day 6. A blue Chl-*a* signal is typical of cyanobacteria while a green signal is typical of marine algae and brown is characteristic of diatoms. These results are contrary to parallel experiment results indicating a green to blue community shift. More research must be done on the topic of cell-specific physiology of the community and additional substrate incubations to better understand these confounding signals in community shifts. Incubation experiments are being continued to examine the bioavailability and influence of organic nitrogen along freshwater-marine ecotones in Florida Coastal Everglades LTER sites that extend through Florida Bay. The results of the current experiment combined with continued research of alternate substrate bioavailability add to a growing base of understanding of the fate of DOM cycling in Florida Bay and coastal marine systems.

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Florida Bay Phytoplankton Community Structure and Algal Energetics Using PAM Fluorometry

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Florida Bay phytoplankton blooms have been dominated by cyanobacteria and are critical to the stability of community structure and function. Florida Bay has been characterized as an oligotrophic system with organic phosphorous and nitrogen controlling the nutrient pool. Cyanobacteria have an advantage over other algae because they contain a much higher cell-specific production of the enzyme alkaline phosphate, enabling them to utilize this organic phosphorus.

Phytoplankton community biomass as chlorophyll *a* (CHLA) has been estimated for the last 12 years by standard acetone extraction method as part of the SERC water quality-monitoring program. These data have been useful in providing an overall estimate of water column standing crop, yet do not yield information for the community structure of the major algal groups. To further distinguish structural and functional dynamics of the phytoplankton community we used Pulse Amplitude Modulated Fluorometry (PAM). PAM fluorometry can quickly discriminate the chlorophyll *a* content and quantify algal energetics, such as quantum yield and photosynthetic electron transport among three major groups of phytoplankton (cyanobacteria, greens, and browns). Phytoplankton community structure was examined to determine if there were spatial patterns or seasonal variation in Florida Bay. Data sets were analyzed from a sampling period between January 2001 and October 2002 and ranged across 28 sites in Florida Bay. These sites were further divided into three zones/regions: Central, Eastern and Western. The means of each major algal group (measured in $\mu g\ L^{-1}$) were calculated form all sites/zones and dates.

We compared the total CHLA data from PAM against the data collected using the standard acetone extraction method. The data set consisted of 617 observations from January 2001 to October 2002 at 28 sites in the bay. The result was a significant regression between the two methods ($r^2 = 0.728$, slope = 1).

Summary of mean CHLA values at each site revealed that the highest concentrations of both cyanobacteria and green algae were found in the Central zone, especially in Garfield Bight where the cyanobacteria mean = 1.32 $\mu g\ L^{-1}$ and Rankin Lake where the green algae mean = 0.28$\mu g\ L^{-1}$. Brown algae had the highest concentration (mean = 1.45$\mu g\ L^{-1}$) in the Western zone at East Cape. All three algae groups had the lowest values in the Eastern zone. We also observed CHLA values for each month and found that cyanobacteria and green algae had greater values in the wet season. Cyanobacteria mean = 0.74 $\mu g\ L^{-1}$ in July 2002 and green algae mean = 0.20$\mu g\ L^{-1}$ in August 2002. Contrary to cyanobacteria and green algal groups, brown algae abundance was characterized by high peaks in both the dry and wet season. Brown algae was more variable than either green or cyanobacteria across both sites and seasons and contributed the most to overall algal abundance in Florida Bay over the sampling period. Our results indicate a general progression of the algal community structure from low to high cyanobacteria and green algae biomass during the wet season with relatively little contribution of these two groups to overall algal biomass in Florida Bay during the dry season.

Algal community function was also examined using the PAM fluorometer. Here we report quantum yield sum as a surrogate for productivity and an instantaneous potential of production by the algal community. Algal energetics were investigated by averaging the quantum sum yields for each of the 28 sites. The pattern showed higher peaks at sites in the Central and Western zone, following the pattern in CHLA.

These overall findings may indicate seasonal and spatial differences in chlorophyll *a* concentrations, but PAM is a new technique in phytoplankton research and this data and information only summed a two-year data set. These data complement long-term, ongoing water column observations in Florida Bay by the Water Quality Monitoring network program and are the only information that concurrently characterize structure and function of the major algal groups. PAM research and the Florida Bay data set are also critical in the interpretation of concurrent experiments to determine the mechanisms and substrate uptake that promote the growth of cyanobacteria. Finally, PAM fluorometry has proven to be a rapid method of determining phytoplankton activity and may be comparable to the standard ^{14}C incubation method.

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Chemotaxomonic Assessment of Microalgal Communities in North-Central and Western Florida Bay

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This report relates to NOAA-SFERPM Question #3 (algal blooms) and explores pigment-based chemotaxonomy for the study of recurrent phytoplankton blooms in north central Florida Bay. Sampling was in the Snake-Rankin Bights through Whipray Basin and Flamingo to Sandy Key Basin / Cape Sable regions as these areas represent areas of cyanobacterial and diatom blooms, respectively. Study also included epiphyte productivity and community structure in north-central bay, specifically Snake and Whipray Basins.

The promise of *chemotaxonomy* derives from the fact that the various taxa of photosynthetic organisms evolved slightly different accessory pigments and dissection of natural pigment arrays allows one to discern the presence, absence and relative abundance of the contributory groups (*cf*. Millie *et al*., 1993).

Sample sites and sampling: 18 sites, covering Whipray Basin, Rankin Lake, Snake Bight, the Flamingo channel, Sandy Key Basin and nearshore / offshore Cape Sable were sampled monthly (09/00 – 09/02) for phytoplankton. Water samples for phytoplankton and epiphytes removed from surrogate (epiphytometer) or native seagrass (*Thalassis testudinum*) were filtered (Whatman GF/F), flash frozen in liquid nitrogen and later analyzed by HPLC-PDA as reported (Louda *et al*., 2002).

Epiphytes: We observed relatively straight forward growth rates which closely mimic natural seagrass epiphyte loads after 2-3 months, a reasonable lifespan for *Thalassia* shoots. The epiphytic communities are found to be vastly dominated (>90%, by CHL*a*) by diatoms, with minor abundances of dinoflagellates, cryptophytes and cyanobacteria. Total chlorophyll-*a* concentrations, a proxy for biomass, were found to range from 0.2 – 2.1 μg /cm^2 (1 mo.) to 0.4 – 6.6 μg / cm^2 (2 mos.). Growth curves (0, 1, 2 mos.) exhibited relatively smooth linear increases and the 2 month values usually mimicked values found on native *Thalassia testudinum*. The value of this method is 2 fold. First, time zero in growth profiles (productivity) is easily defined. Second, direct microscopic examination and epiphyte recovery are facile. Deployment of 'epiphytometers' in transects across and down suspected nutrient plumes is suggested here as an adaptive management monitoring tool.

Phytoplankton: Two areas of phytoplankton blooms are known in the Florida Bay area. First, in the central and north-central bay (Whipray Basin and environs), a low productivity ($\leq$ 1μg/L as CHL*a*) of a DIAT>DINO>CRYPTO >CYANO community was found throughout much of the year. This was punctuated, as seen in **Figure 1**, at certain times (11/00, 10/01,12/01, 01/02) by large increases in standing crop (4 - 15μg/L as CHL*a*) due almost entirely (>90%) to cyanobacteria. Tracking the increases in cyanobacteria spatially and temporally, it was found that the cyanobacterial bloom emerges from the mangrove transition zone and penetrates the bay. This shown by tracing salinity, total chlorophyll-*a* values, and chemotaxonomy, all of which change as one would expect for fresher cyanobacterial rich waters entering the saltier less productive waters of the north-central bay. That is, lower salinity (9-13 psu) highly productive (>20-40 μg CHL*a* / L) waters in and behind the mangrove fringe (*e.g.* the West Lake/ Long Lake/ Lungs / Garfield Bight region) enter the saltier bay and raise CHL*a* values in Snake Bight (S $\leq$

25psu, 13µg CHL*a* /L: 12/01) or Rankin Lake (S≤ 30psu, 15µg CHL*a* / L: 07/02). Similar influx has been found emanating from the Monroe Lake – Terrapin Bay region into extreme NE Whipray Basin (11/00, 10/01, 01/02, 07-08/02). This pattern was found to be repeated during several cyanobacterial influx episodes. Going on these and other observations, we propose that the cyanobacterial blooms of north-central Florida Bay are natural cyclic events that *may* gain severity in the face of additional nutrients in the bay. That is, rather than being a precursor to seagrass die-offs, we propose that the severe algal blooms which occurred around the times of the die-offs followed the initial release of nutrients and in so doing then added an extra stressor level for the perpetuation of the die-offs. This, I feel, is a small but important difference in the presently held dieoff scenario (bloom before dieoff initiation).

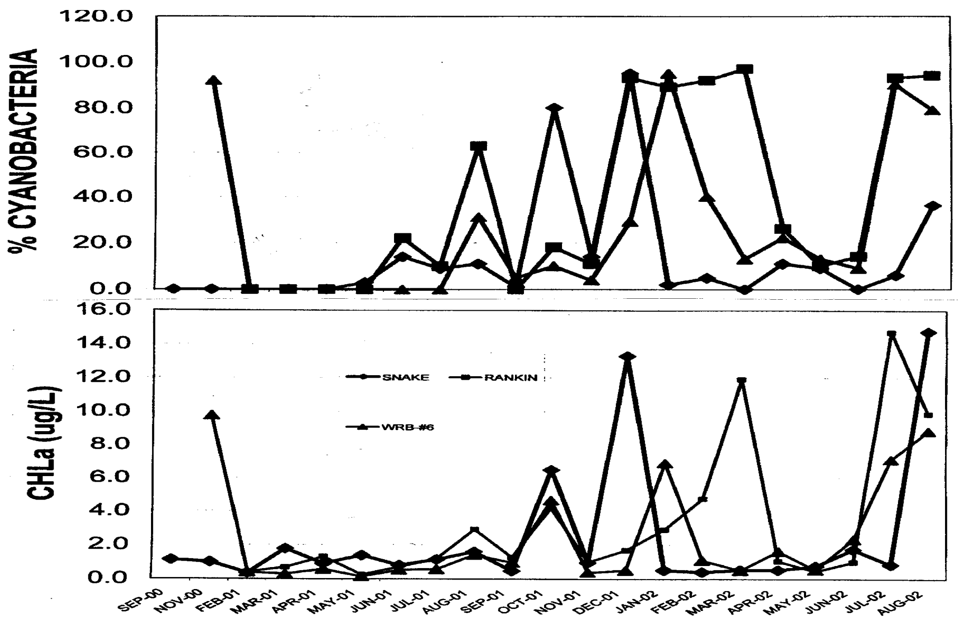

Figure 1: Total Chlorophyll-*a* (bottom) correlated to percent cyanobacteria (top) in 4 areas of north-central Florida Bay over a 2 year span.

The second bloom dynamic occurs in the western bay where annual diatom 'blooms' occur. Chemotaxonomy was able to reveal underlying separate cycles of chlorophyte and cryptophyte populations. These patterns are still being analyzed but, for now, it can be said that standing crops are moderate to high (2-7 CHL*a* / L) through out much of the year, with highs being in June, September and November-December of 2001. These were dominated by diatoms (65-85%) and lesser amounts (10-20%) of cryptophytes. Apparent increases (up to 55%), or concentration by loss of other taxa, of chlorophytes during February 2001 and January–February 2002, were noted. During the Summer months, CHL*a* was the lowest and cyanobacterial relative abundance was the highest (8-33%), due to a lack of diatom presence rather than an increase in cyanobacteria per se. Dinoflagellates, as signaled only by peridinin (gyroxanthin, indicator of *Karenia brevis* was not found) plus chlorophyll-*c*, never occurred at levels comprising more than about 10% of the total CHL*a* pool.

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Question 4 - Seagrass Oral Abstracts

- Listed alphabetically by presenting author.
- Presenting author appears in **bold**.

Infection, Infestation, and Disease: Differential Impacts of *Labyrinthula* sp. on the Seagrass *Thalassia testudinum* (Banks ex König) in Florida Bay, USA

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In the spring of 1995, concern over past acute seagrass die-offs of *Thalassia testudinum* in Florida Bay and continuing chronic seagrass losses there prompted the initiation of a large-scale monitoring effort of seagrass health. This study was done in conjunction with the Fisheries Habitat and Assessment Program (FHAP). Our work in Florida Bay from 1995 to 1999 on *Labyrinthula* sp. represents the first studies of the occurrence and distribution of this pathogenic slime net in the subtropical seagrass *T. testudinum* and its role in chronic and acute disease.

The field data focused our attention on the need to establish the role of *Labyrinthula* in both acute and chronic seagrass disease and mortality. Evaluation of that data, together with the results from concurrent laboratory studies of infection in both wild and cultured *Thalassia*, by *Labyrinthula* sp. provided insights on the impacts of the slime net in this seagrass in Florida Bay. Results from these studies first established the relationship between infection of this seagrass by the pathogen and the presence of necrotic lesions associated with disease. Another acute *Thalassia* die-off that occurred during the course of our study allowed us to determine that *Labyrinthula* sp. was not the primary pathogen involved in this acute event.

Historical parallels to this study include the impacts of infection by *L. zosterae* in the temperate eelgrass *Zostera marina* that were documented after massive seagrass die-offs along the coasts of northern Europe and North America in the 1930's and 1940's. A recurrence of this "wasting disease" in New England in the 1980's renewed interest in the pathogen and it's affects on seagrass. More recently, studies of *L. zosterae* in *Z. marina* in France raised questions as to what constitutes an infestation and what is truly a "disease" (Hily et al. 2002). The authors of that study found infection at all of their study sites and "infestation" during discrete time periods, but never detected adverse effects on seagrass beds such as changes in occurrence or distribution. It has been suggested that "disease" only occurs when the youngest blades on a short shoot become lesioned (Vergeer and den Hartog 1994, Hily et al. 2002).

Results from our study showed that increases in the occurrence and distribution of *Labyrinthula* sp. infection and associated lesions in *Thalassia* correspond with decreases in abundance and changes in the distribution of this seagrass. Baywide, the percent of microscopically verified infected *Thalassia* shoots increased 10-fold over the first 4 years of the study, while lesion prevalence and severity doubled. During this same time period, *Thalassia* cover abundance and short shoot density increased slightly baywide, but substantial localized *Thalassia* losses occurred in western and central Florida Bay.

We attributed localized chronic *Thalassia* losses to differential impacts of *Labyrinthula* sp. on its host. We propose that there may be a "threshold of disease" below which infected seagrass beds are not adversely affected (i.e. significant seagrass losses do not occur). Generally, we defined this "threshold of disease" in Florida Bay *Thalassia* as infection of approximately one quarter of the examined short shoots at a particular site. When a small percentage of shoots show *Labyrinthula* presence, they are merely "infected" as in Eagle, Calusa, Crane, and Madeira Basins (Table 1). "Infested" seagrass beds with slightly higher infection rates may be thinned, as has been observed in Blackwater, Twin, and Whipray Basins (Table 1). If the threshold is exceeded, the seagrass beds cannot outgrow the infection and chronic losses occur as in Rabbit, Johnson and Rankin Lake Basins (Table 1) and a true disease condition is present. We have also generally found a positive linear relationship between blade age and infection, with older blades being more severely lesioned than younger ones. However, when "infestation" and "disease" occur, the proportion of severely lesioned younger blades increases, with significantly greater lesion severity in "diseased" plants.

The "threshold of disease" can theoretically be shifted up or down depending on the ambient environmental conditions at the infection site. Some factors likely to influence the threshold are salinity, temperature, pathogen virulence, and host resistance. In basins where severe seagrass losses have already occurred from acute die-off (Rabbit, Johnson, Rankin Lake), *Labyrinthula* infection affects many of the shoots in the basin (Table 1) and causes seagrass mortality either directly or in conjunction with other stressors such as elevated sediment sulfide levels. We propose that, at these high infection levels, *Labyrinthula* can cause dramatic seagrass losses and may lead to the succession of *Thalassia* by *Halodule*. In Calusa, Crane, and Eagle Key Basins, infection levels remain low (Table 1), most likely due to relatively low-density seagrass beds. In basins where the average salinity periodically drops below 15‰ (Eagle and Madeira), infection levels remain low with occasional spikes in infection and lesion presence coinciding with, or following, elevated salinities. Usually, lesion severity in these cases remains low; this may be due to differences in virulence in different *Labyrinthula* species or strains. In Madeira Basin, seagrass densities are high enough to sustain *Labyrinthula* infection and transmission, but periodic low salinities control infection.

Basin	**Range of % Shoots Infected**	**Average % Shoots Infected**	**Average % Lesion Severity**
Eagle	0-3	"Infected" 1	0.1
Calusa	0-13	4	0.3
Crane	0-18	4	0.2
Madeira	0-22	7	0.5
Blackwater	0.9-22	"Infested" 9	0.9
Twin	0.7-28	11	0.8
Whipray	0-29	14	1.1
Rabbit	4-42	"Diseased" 24	1.7
Johnson	4-61	27	2.0
Rankin	1-59	35	2.5

Table 1. The range and average percent of shoots microscopically verified as infected, and the average percent lesion severity of all blades in the 10 study basins (1995-1999).

Several interacting factors, both biotic and abiotic, were identified which influenced the occurrence and distribution of *Labyrinthula* sp. in *Thalassia* within the Bay. These same factors, along with other as yet unidentified factors, influence the degree of impact of *Labyrinthula* sp. on its host *T. testudinum*. These impacts, both "beneficial" and detrimental, affect not only the spatial and temporal occurrence and distribution of *Thalassia* in Florida Bay, but also the overall health of these vitally important seagrass beds in one of the most extensive submarine seagrass meadows in the world.

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The Effects of Sediment Toxicity on Florida Bay Turtle Grass: A Synthesis of Field Experiments (1990-2000)

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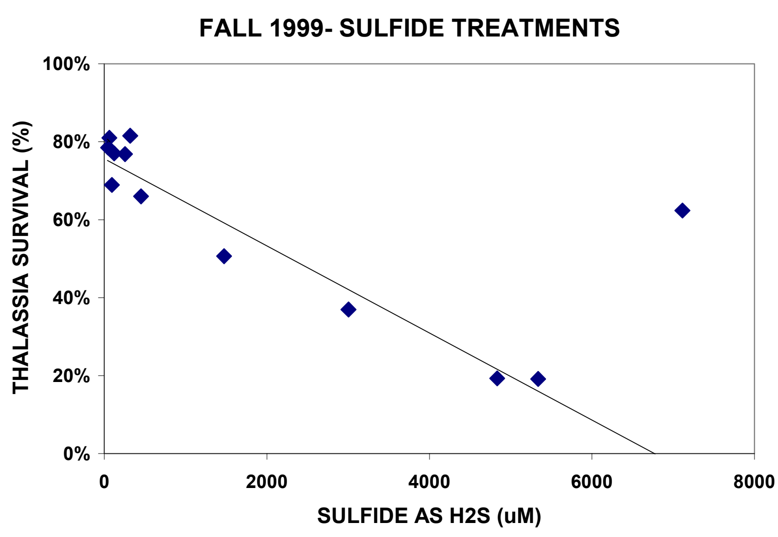
Between 1990 and 2000, we performed eight field experiments which tested the impact of porewater sulfide and ammonia concentrations on seagrasses in Florida Bay. The experiments were directed primarily toward turtle grass (*Thalassia testudinum*) because it was the species most affected by widespread die-off between 1987 and 1991. However, early experiments also tested the impact of elevated sediment concentrations on shoal grass (*Halodule wrightii*) and manatee grass (*Syringodium filiforme*). The objectives of this paper are to describe the dose-response relationship of sulfide toxicity for *Thalassia* growing *in situ* , the disparity between field and laboratory sulfide toxicity experiments, and the role of sulfide toxicity in Florida Bay seagrass die-off.

In each experiment, polyethylene sleeves (30 cm d. x 36 cm h.) were used to isolate columns of sediment in seagrass beds. Sediment chemistry within sleeves was manipulated by adding amendments to porous polyethylene tubes inside the sleeves. Varying amounts of glucose were added in different experiments to stimulate sulfate reducing bacteria and to elevate sediment sulfide concentrations. Sodium molybdate was added to serve as a competitive inhibitor for bacterial sulfate reduction, and potassium nitrate served to stimulate denitrifying bacteria, respectively. Both treatments effectively lowered porewater sulfide concentrations. Ammonium chloride was added in some experiments to test the toxicity of ammonia to *Thalassia*. Combined treatments of glucose and ammonia were also used in some experiments. Experiments were carried out in all four seasons.

In all experiments, elevated sulfide concentrations caused significant declines in *Thalassia* shoot survival, belowground biomass, shoot leaf area, blade width, and blade length. The negative relationship between shoot survival and sulfide concentration was generally linear (Figure 1, below), but the slope and coherence of the relationship varied among experiments. However, our results indicate lowered Thalassia survival even at 2 mM sulfide concentrations. The disparity between field and laboratory sulfide toxicity experiments might result from unusually low belowground:aboveground tissue ratios in laboratory experiments. Excised shoots used for laboratory experiments also have a limited life span and are vulnerable to artifacts associated with wound response. These data suggest that laboratory studies of sulfide toxicity are flawed and drastically overestimate sulfide tolerance of *Thalassia.*



Sodium molybdate and potassium nitrate amendments lowered porewater sulfide concentrations significantly (Table 1). Shoot leaf area, blades per shoot, and mean blade length were higher in nitrate and molybdate treatments than in glucose addition treatments. These results indicate that, even at sublethal concentrations, sulfide inhibits the growth of *Thalassia*.

Table 1: Effects of Sediment Amendments on Porewater Sulfide Concentrations and Thalassia morphology- Fall 2000. Data in each column with the same letter subscript are not significantly different.

Treatment	Porewater Sulfide	Shoot Leaf Area	Blades per Shoot	Mean Blade Length
Nitrate	136 d	26.6 a	3.1 a	10.6 ab
Molybdate	1120 d	27.1 a	2.8 ab	11.3 a
Outside control	320 d	22.8 ab	2.6 ab	11.3 a
Bucket control	3300 c	20.1 ab	2.5 ab	9.3 abc
Very low glucose	6880 a	15.5 b	2.2 b	8.9 bc
Low glucose	6020 ab	16.8 b	2.3 b	8.8 bc
High glucose	5020 b	16.1 b	2.3 b	8.3 c

The factor or factors responsible for the development of hypoxia, sulfide toxicity, and ensuing basin *Thalassia* mortality have not yet been identified. However, the recurrence of seagrass die-off at Barnes Key in 1999 casts doubt on the role of factors such as hyperthermia , hypersalinity, and lack of hurricanes suggested by Robblee et al. (1991) as possible causes of die-off episodes in 1988 through 1991. The new episode of die-off occurred under climatic conditions very different from the earlier event. The occurrence of die-off at Barnes Key, however, does support observations by Robblee et al. that anthropogenic factors probably did not contribute to seagrass mortality in Florida Bay because Barnes Key is far from mainland freshwater discharge points and well flushed by tides. Our experiments also indicate that ammonia and *Labyrinthula* are unlikely causes of primary die-off.

These results indicate that sulfide is a chronic stressor on *Thalassia* communities growing in carbonate sediments. It is also a by-product, and possibly a causal factor in basin seagrass mortality. As noted by Carlson et al. (1994), sulfide can be a primary cause of *Thalassia* die-off in one of two ways: 1) If physical or chemical factors change in a way that porewater sulfide concentrations increase suddenly, concentrations can exceed acute toxicity thresholds, or 2) Sulfide stress might also occur without changes in porewater sulfide concentrations if the oxygen balance of seagrasses is affected by decreased photosynthetic or oxygen transport capacity. In the absence of data or a mechanism to explain sudden increases in sediment porewater sulfide concentrations, we suggest that seagrass die-off events in Florida Bay have probably been initiated by the latter mechanism. Yarbro et al. (1989) proposed that chronic sulfide stress and shifts in the oxygen balance of *Thalassia* plants were involved in basin die-off, and more recent studies by Borum et al. (2001) support that hypothesis.

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The Response of Seagrass Distribution to Changing Water Quality: Predictive Models from Monitoring Data

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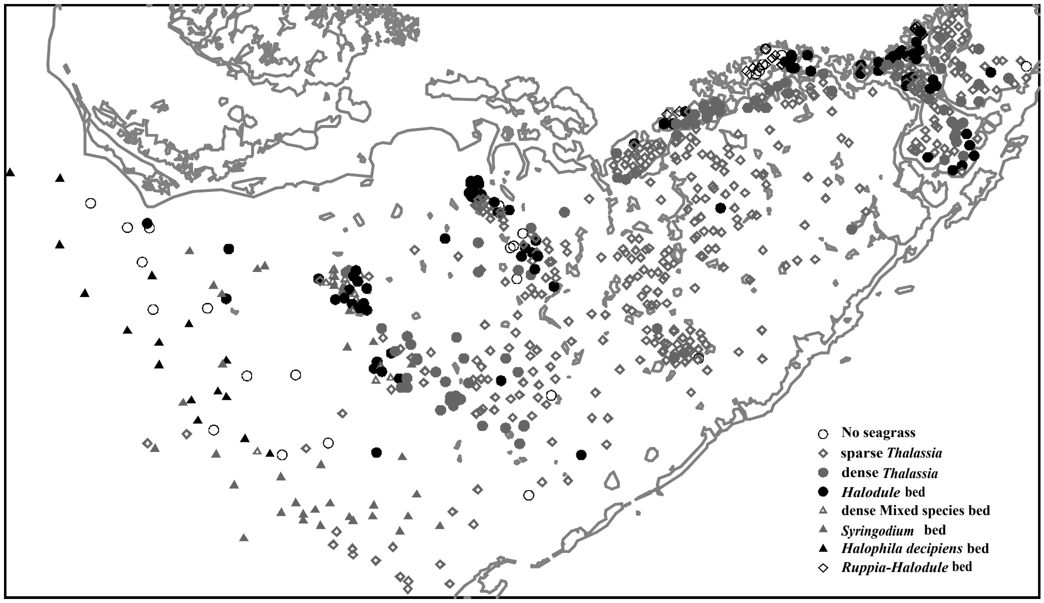
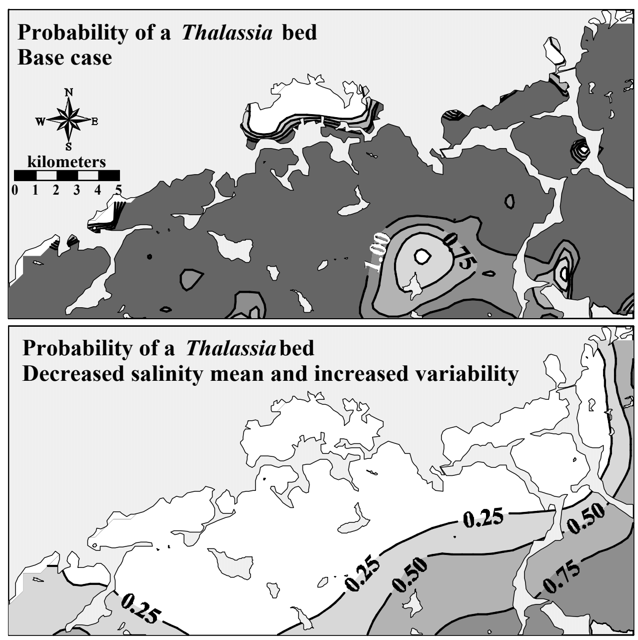
In order to deal with environmental change, resource managers require tools that will allow them to predict the response of ecological communities to alterations, both anthropogenic and natural, in the environment. Often, simulation models based on mechanistic descriptions of species' responses to environmental changes have been used to make such predictions, but the construction of these models requires extensive knowledge of physiological ecology and interspecific interactions. An alternative approach to simulation modeling is empirical statistical modeling, which uses data on spatial and temporal variability in both the environment and distribution of species or habitats to construct statistical models describing present relationships. These relationships may then be used extrapolate the ecological state under a changed environment. While such statistical models are constrained by the nature of the available data, they require much less knowledge of the biology and ecology of the target species and habitats to construct, and can be useful tools for both managers and ecologists in refining mechanistic simulation models.

Extensive data sets on water quality and seagrass distributions in Florida Bay have been assembled under complementary, but independent, monitoring programs. This work outlines a method for exploring the relationships between two such datasets. Seagrass species occurrence and abundance data were used to define 8 benthic habitat classes from 677 sampling locations in Florida Bay. By far the largest cluster contained 387 locations; the benthic community at these sites could be described as a sparse seagrass bed dominated by *Thalassia testudinum*, with occasional occurrence of *Syringodium filiforme* and *Halodule wrightii*. The mean Braun-Blanquet density of 2.1 at these locations indicates a *T. testudinum* cover of less than 25%, on average. The next-largest cover had 88 locations; these stations had a dense cover of *T. testudinum* (>75% cover) with some sparse *S. filiforme* and *H. wrightii* intermixed. Almost as common was a group of 85 stations dominated by sparse cover of *H. wrightii* with occasional *T. testudinum*. A group of 37 stations had a dense *S. filiforme* bed. At 19 locations, a dense mixed-species assemblage was observed, with no clear dominant species. At 16 of the sites, *Halophila decipiens* was the dominant seagrass in the community, and at the remaining 20 sites, the benthic community was dominated by a mixture of *Ruppia maritima* and *H. wrightii*.

Water quality data from 28 monitoring stations spread across the Bay were used to construct a discriminant function model that assigned a probability of a given benthic habitat class occurring for a given combination of water quality variables.



A discriminant function model using only mean salinity of a site correctly classified only 13.9% of the benthic habitat stations, and adding salinity variability led to a small but statistically significant increase in predictive ability, as did stepwise additions of $\%I_o$ and sediment depth. Adding the mean NO_3^-, TOC, NH_4^+ and TP as a group increased the accuracy of classification further, but adding information on the variability of these parameters did not increase the predictive ability of the model. The final discriminant function model correctly classified 56.7% of the benthic habitat stations, and the second-ranked predicted habitat classification was always biologically close to the actual habitat type . Not all benthic habitat classes were predicted with equal accuracy. The model was very successful in predicting the occurrence of *Halophila decipiens* (93.8% accuracy) and dense mixed species beds (84.2% accuracy), but was not successful in predicting the occurrence of benthic habitats with no seagrasses. For the sparse *Thalassia*, dense *Thalassia*, *Halodule*, *Syringodium* and *Ruppia-Halodule* communities, the most frequently-predicted habitat type corresponded to the actual habitat, and. For example, 66.1% of sparse *Thalassia* beds were correctly classified, but 16.8% were incorrectly classified as dense *Thalassia* beds. Very few mis-classifications were scored as *H. decipiens* beds or *Ruppia-Halodule* beds - two communities with very dissimilar habitat requirements



The model predicted that the distribution of benthic habitat types in Florida Bay would likely change if water quality and water delivery were changed by human engineering of freshwater discharge from the Everglades. Under a hypothetical scenario in which mean annual salinity was reduced by a factor of 2 and the variance in the salinity was increased (CV increased by a factor of 2), the discriminant model predicts the southern expansion of the *Ruppia-Halodule* community into Florida Bay and a retreat of *Thalassia*-dominated communities away from sources of freshwater runoff.

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Nitrogen Versus Phosphorus Limitation of Benthic Primary Production and the Role of Epiphyte Grazers in Florida Bay

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Restoration of the greater Everglades ecosystem will increase freshwater input to Florida Bay. Ecosystem health will be dependent upon the quality and quantity of that water. Recent evidence suggests that, depending on location, either nitrogen or phosphorus limitation exists for Florida Bay primary producers. Increased freshwater flow, as envisioned by the Restoration Plan, may increase loadings of both nitrogen and phosphorus into the Bay. The regional and temporal effects of these increased loadings on benthic primary production are a focus of this investigation. The grazing activities of indigenous epiphyte mesograzers may ameliorate some of the negative effects of increased nutrient loadings. The role of these associated consumer organisms as mitigating factors are a second focus of this investigation.

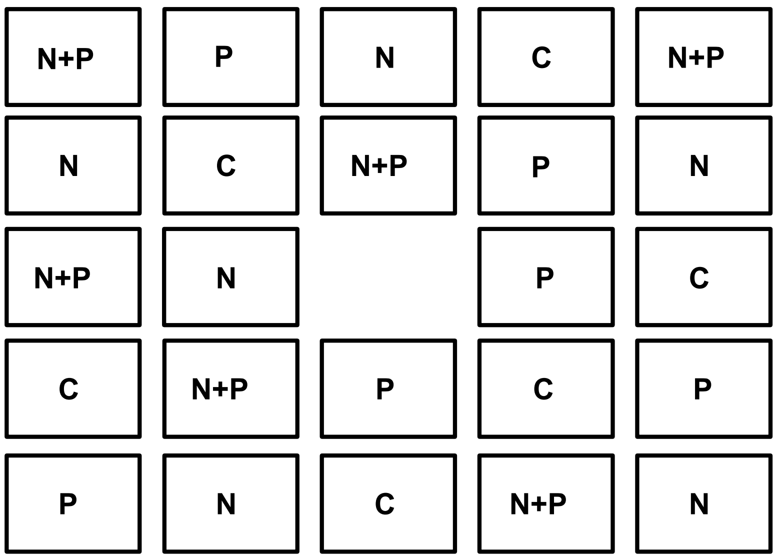

Figure 1. Schematic of 2 X 2 factorial design employed at each site. Individual plots are 0.25 m^{-2} and are separated by 1.5 meters. Treatments were assigned randomly within each column and row.

To determine nutrient limitation for benthic primary producers, and to assess the regional and temporal variability of N vs. P limitation, long-term replicated 2X2 factorial experiments (Figure 1) designed to assess the effects of nutrient additions (N, P, N + P) are being conducted at six sites within Florida Bay (Figure 2). Sites were selected in northeastern, central and western Florida Bay along an existing nutrient availability gradient (Fourqurean et al., 1993; Boyer et al., 1997). Slow-release nitrogen fertilizer (Poly-on, 38-0-0, Pursell Technologies) and phosphorus as granular phosphate rock (Multifos, IMC Phosphates) are being applied to the sediment surface at rates of 0.62 g N m^{-2} day^{-1} and 0.09 g P m^{-2} day^{-1}. The following response variables are being measured: seagrass biomass, productivity, Braun-Blanquet abundance, and leaf CNP, total epiphyte load, epiphyte chlorophyll-a, epiphyte accumulation rate, and benthic chlorophyll-a.

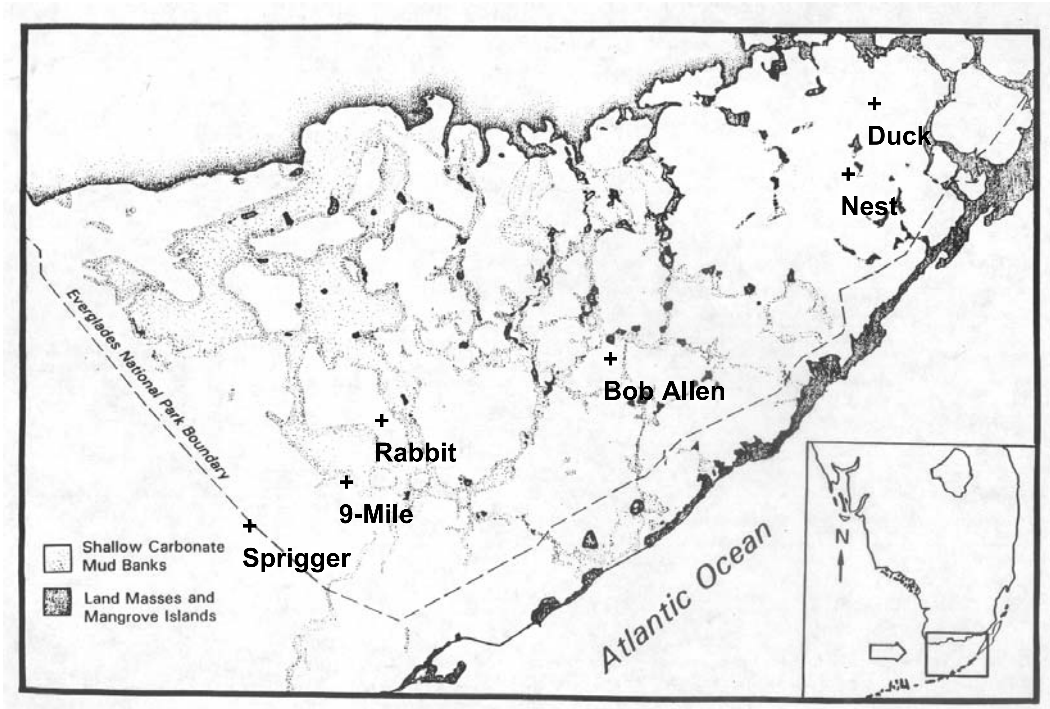

Figure 2. Location map of long-term fertilization sites. Chamber experiment conducted on banktop adjacent to Rabbit site.

To assess the role of epiphyte mesograzers under conditions of increased nutrient loadings, a series of short-term field mesocosm experiments are also being conducted. During August 2002, the abundances of 3 mesograzers (i.e., caridean shrimp - *Thor* and *Hippolyte* spp, the hermit crab *Paguristes tortugae*, and the gastropod *Turbo castanea*) and nutrient loading rates were manipulated inside acrylic chambers set within a *Thalassia testudinum* meadow. Nutrients were supplied to the water column within each chamber via slow-release fertilizer (Osmocote, 18-6-12). A two-way ANOVA design consisting of 3 levels of nutrient treatments and 8 levels of grazer treatments was employed. The 24 unique experimental treatments were replicated 3 times. The following response variables were measured: seagrass short-shoot biomass and leaf CNP, water-column nutrients, total epiphyte load, and epiphyte chlorophyll-a.

Preliminary Results - In October 2002, at the long-term fertilization sites, initial mean Braun-Blanquet *Thalassia testudinum* abundances measured on a scale from 0 to 5 ranged from 1.5 (Sprigger Bank) to 5.0 (Rabbit Key Basin). *Syringodium filiforme* was only abundant (BB = 3.1) at Sprigger Bank. Mean total epiphyte loads ranged from 0.22 mg dw cm^{-2} at Rabbit to 12.16 mg dw cm^{-2} at Bob Allen. Epiphyte chlorophyll-a ranged from 0.02 ug cm^{-2} at Rabbit to 2.63 ug cm^{-2} at Bob Allen.

Preliminary analyses of the 2002 chamber experiments indicate fertilized treatments, relative to unfertilized treatments, produced higher mean total epiphyte load, epiphyte chlorophyll-a, epiphyte autotrophic index, water-column chlorophyll-a, leaf nitrogen and phosphorus, water column dissolved inorganic nitrogen and soluble reactive phosphorus. Grazer treatments, relative to ungrazed treatments, produced higher mean total epiphyte load, epiphyte chlorophyll-a, epiphyte autotrophic index, water-column chlorophyll-a, and *Thalassia* short-shoot biomass.

Further results from the long-term fertilization experiment and statistical analyses from the 2002 chamber experiment will be presented.

Future Plans - The replicated nitrogen and phosphorus addition experiments will continue through summer 2005. The response of the epiphytic diatom species assemblages to the nutrient manipulations will also be assessed beginning in February 2003. Further mesocosm experiments will also be conducted in other areas of Florida Bay during different months to assess seasonality and the role of different indigenous grazer organisms.

This research is being supported by a CESI grant from Everglades National Park, Department of the Interior.

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Multiple Stressor Effects on Seagrasses in FL Bay: A Mesocosm Research Approach

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Although the South Florida rainy season can provide adequate fresh water flows to maintain mesohaline conditions in the Florida Bay estuary, a sub-tropical climate promotes frequent periods of drought and hypersaline conditions. A large-scale mesocosm facility was constructed at the FAU Gumbo Limbo Marine Lab (Boca Raton, FL) to experimentally define the upper levels of salinity tolerance for the dominant Florida Bay seagrasses (*Thalassia testudinum*, *Halodule wrightii*, and *Ruppia maritima*), using intact sediment cores in a highly controlled environment. In addition to establishing the upper levels of salinity tolerance for seagrasses in the Bay, the objective of the proposed study is to establish the relationship between hypersalinity tolerance and interactive stress variables, including high temperature, low light, and porewater sediment sulfide phytotoxicity. Results generated from the mesocosm experiments, and verified under field conditions, will be used to calibrate a Florida Bay seagrass simulation model. This model will be used to assess water management alternatives for Florida Bay Minimum Flows and Levels and CERP's Florida Bay and Keys Feasibility Study.

The mesocosm design (Fig. 1) includes 16 three-meter diameter X three-meter height fiberglass tanks equipped with 2 powersweeps, one for circulation at canopy height, and the other for surface to bottom circulation and continuous aeration. Each tank has a 1,000 Watt metal halide light with a detachable ballast delivering ~900 $\mu E\ m^{-2}\ s^{-1}$ light (PAR) to the water surface and ~650 $\mu E\ m^{-2}\ s^{-1}$ to the canopy. The tanks hold 500 L of recirculating coastal seawater and the facility has temperature-control, maintaining the tank water temperature between 25-28 ^{o}C. The large number of tanks provides the opportunity to evaluate a broad range of salinity levels.

Figure 1. Mesocosm design showing tanks and light fixtures in upper right.

In the initial hypersalinity experiment, conducted from August to November 2002, eight different salinity treatments were examined: 35, 40, 45, 50, 55, 60, 65, and 70 PSU in replicate. Intact sediment cores (15 cm diameter X 20 cm depth) of the three seagrass species were collected from Whipray Basin to Garfield Bight (northcentral Florida Bay) and transported in coolers to the mesocosms. In addition to intact sediment cores, a second set of experimental units was collected with at least one apical rhizome shoot and 4-5 live short shoots for each species. At least two rhizome segments were transplanted into tubs (30 cm X 10 cm) with field sediment. These two collection approaches were utilized to account for any differences in seagrass stress response due to cut rhizomes in intact cores, a situation more likely problematic in cores of *T. testudinum*. In summary, each of the 16 tanks contained 3 intact cores and 3 tubs of *T. testudinum*, *H. wrightii*, and *R. maritima*.

To simulate the in situ rates of salinity increase in the northcentral Bay, salinity levels were adjusted at a rate of one PSU per day. The experiment was run as a closed system with salts (Instant Ocean) or deionized water amended, as needed, based on evaporation rates. Coastal seawater was also added weekly to maintain nutrient levels in the tanks. Tank salinity and temperature were monitored daily, while light, oxygen, and nutrient samples were taken weekly. The biological response variables monitored weekly-included *T. testudinum* leaf elongation rates and live shoot counts for all species in both cores and tubs. Plants were at salinity treatment levels for a one-month period, the limit of extreme hypersalinity conditions in northcentral Florida Bay. After this time, leaf photosynthetic performance was determined by chlorophyll fluorescence or photosynthetic quantum yield using a Diving PAM (Pulse Amplitude Modulation). Once plants were harvested, they were separated into leaves, roots, and rhizomes and immediately frozen in liquid nitrogen. Tissue was freeze-dried for determination of adenylates (ATP, ADP, AMP), carbohydrates, and proline (an important osmolite in seagrasses) using HPLC. Prior to freeze-drying, a sub-sample of leaf tissue was frozen separately for determination of total osmolality on a vapor pressure osmometer.

The slow in situ rate of salinity increase (1 PSU d^{-1}) used in this study resulted in a highly linear response of total osmolality (mmol kg^{-1}) to salinity treatment level (PSU) for *T. testudinum* ($y = 166x + 1324$ $R^2 = 0.97$) and *H. wrightii* ($y = 193x + 1848$ $R^2 = 0.97$). Total osmolality was high across salinity treatments for *R. maritima* (2783 to 3731 mmol kg^{-1}) and no significant relationship was found between salinity level and osmolality ($y = 52x + 2967$ $R^2 = 0.19$). The ability of all three seagrass species to osmotically adjust to increased salinity at rates observed in the field is supported by the fact that even at 70 PSU, live shoots were observed in all species. This was true even though the 70 PSU treatment took 30 days to come up to treatment salinity, and was >40 PSU for 60 days. While no mass mortality of shoots was observed in any treatment and species, species tolerance to hypersalinity varied among seagrass species. Interestingly, *H. wrightii*, frequently found in mesohaline conditions, appeared to be the most salt tolerant, increasing shoot numbers under all hypersaline treatments including 70 PSU. Leaves in the 70 PSU treatments were, however, beginning to exhibit chlorosis, quantified by the lower quantum yield of photosynthesis, as measured by PAM fluorescence. Live shoot numbers were stable for *T. testudinum* up to 60 PSU, but declined in the 65 and 70 salinity treatments, consistent with declines in leaf elongation rates. These salinity levels of tolerance for *T. testudinum* are higher than those previously observed in our preliminary hydroponic experiments without osmotic adjustment (50 to 55 PSU), suggesting the importance of a slow rate of salinity increase to seagrass tolerance under hypersaline conditions. In conclusion, the three dominant Florida Bay seagrass species examined in this study are highly tolerant of hypersaline conditions under in situ rates of salinity increase. With subsequent experiments, we will further examine the effects of interactive stressors (high temperature, low light, and sulfide phytotoxicity) on this adaptive potential of seagrasses to hypersaline conditions in the Bay.

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Use of a Dynamic, Mechanistic Simulation Model to Assess Ecology and Restoration of the Florida Bay Seagrass Community

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A six-compartment dynamic simulation model was developed using STELLA software on a desktop computer. The model has been translated into MATLAB and FORTRAN for ease of incorporation into other models, such as hydrodynamic, and geochemical. The model, current spatially averaged, will form the kernel of a spatially explicit GIS-based landscape model. State variables include *Thalassia* above ground (TAG), and below ground (TBG) material, epiphytes (EPIPHYTE), Sediment Organic Carbon (OCS), Porewater Phosphate (PPW), Porewater Sulfide (SPW). The governing equation for *Thalassia* is:

$$T(t) = T(t - dt) + (Tps - Tmort - Tresp - T\,trans - Tsl) * dt$$

Where the *Thalassia* biomass (T) at time t equals previous biomass plus the sum of photosynthetic production minus mortality, respiratory, translocation and leaf sloughing losses. The model runs with a timestep of 3 hr, and a simulation length of 1 yr. During testing and calibration, the model is run for 3 or more years to achieve stability and reduce initialization errors. Under base case conditions, the model was stable for as long as 10 years. The model employs relationships between nutrient and light resource availability, primary productivity rates in *Thalassia* and epiphytes, and resulting uptake of nutrients from the sediment porewater and water column pools. Releases to porewater pools occur from decomposing plant material in the TAG, TBG and EPIPHYTE compartments.

Nutrient uptake of inorganic N and P is controlled by Michaelis Menten kinetics via separate functions for DIN and DIP. Half saturation parameters are derived from direct experimentation and literature values for *Thalassia* in subtropical systems. The sulfide effect function is an empirical relationship developed from mesocosm experiments on Florida Bay *Thalassia* under a range of H2S concentrations (Erskine and Koch 1999, Kemp 2001). Mesocosm experiments were also used to develop a salinity-productivity relationship for Florida Bay seagrasses (Koch 2001).

We are utilizing the calibrated Florida Bay model to determine the tolerance limits for the seagrass community to a variety of stresses, which occur either naturally or as a consequence of human activities. Data from mesocosm experiments on the effects of high salinity will be applied to the model to project how water management effects on the salinity regime will impact the plant community. The model is also being used to predict the mix of environmental factors required to sustain or restore the seagrass community via management of specific variables in the environment, particularly freshwater input, nutrient input and water transparency. An index indicating the status of nutrient and light limitation in the model was developed so that at any point in time the instantaneous level of nutrient or light stress is known. This is useful in determining the effects of seasonal or transitional stresses on the plants as well as the effects of synergistic phenomena that may be incurred in combination with salinity or temperature stresses.

In general, if light is sufficient, the plant will show signs of physiological stress when nutrients are limiting. We are correlating field measurements of stress via fluorescence (PAM) with the nutrient and light environments of the plants for incorporation into the model. Measurements were taken in the field to determine the level of stress of plants at five sites across a gradient of nutrient availability from Duck Key to Rankin Lake. Because Florida Bay waters are shallow and clear, it is generally accepted that it is nutrients that are limiting to plants in large parts of the Bay. Indeed, experiments have shown that additions of nutrients result in increased plant growth. However, the abundant growth of *Thalassia* in many parts of the Bay, such as Rabbit Key and Twin Key Basin, beg the question: what are the sources that provide nutrients in sufficient quantity to permit luxuriant plant growth beyond that expected based on available nutrient concentrations? Our model allows probing of this question by testing several hypotheses related to nutrient supply and availability. First, we are running the model using measured parameters of growth and tissue stoichiometry in the model to develop projections of nutrient demand. Then, we are constraining nutrient supply in the model from sources that are well documented- water column and sediment pools. The free terms such as recycling rate and abiotic processes are then being optimized to develop predictions of probable levels and supply rates. These results will then be followed up with targeted verification experiments.

In areas where seagrass growth is luxuriant, such as in Rabbit Key, and Barnes Sound, there are indications that light limitation by self-shading, even in very clear waters, may affect plant production. We are using the model to test this hypothesis and to quantify the light levels that may be deleterious to plant production. By manipulating the terms of the model to reflect expected changes in nutrient and light resources due to both natural and managed effects, we hope to predict the trajectory of the seagrass community in terms of biomass, distribution and species composition, as restoration continues.

We are also directing model development toward addressing effects of the interaction between seagrass plant morphology, bed configuration and ecological rate processes. The physical structure of the bed and of individual short shoots does affect the use of the resource environment. Light penetration through the canopy and self shading are determined by length, density and number of leaves on the short shoots; above to below ground biomass ratio determines the allocation of fixed carbon, and rates of lateral versus vertical propagation.

We have developed the following general rules set to selectively apply to the seagrass community in our model to test various hypotheses about how plant behavior and form affect ecological processes:

- In turbid environments, plants grow taller, and more widely spaced
- In highly sedimentary or resuspended environments, more biomass is invested in vertical rhizomes and in below ground material
- In nutrient poor environments, leaves are thinner
- In areas adjacent to bare areas, lateral growth is more rapid, decreasing with increasing adjacent biomass
- In areas with higher P, tissue concentrations of P are elevated and the uptake of P is greater.

The model was adapted to incorporate a subset of these rules as a heuristic exercise to determine the sensitivity of target variables biomass and production to environmental conditions that invoke these rules.

This model has proved to be an effective organizing framework for information about seagrasses in Florida Bay, demonstrating gaps in data and pointing to research needs. It is also a valuable tool for hypothesis testing and a predictive tool for testing management options.

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A Landscape Model of *Thalassia testudinum* Dynamics in Florida Bay

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We have developed a spatially explicit landscape model for examining the spatial and temporal dynamics of *Thalassia testudinum* within the Florida Bay ecosystem. The approach links a dynamic simulation model of seagrass productivity with a spatially explicit representation of the Florida Bay environment using a dynamic GIS. The seagrass model, developed by researchers at South Florida Water Management District and the University of Georgia, simulates photosynthesis, respiration, carbon allocation and mortality as spatially averaged processes over a defined area (e.g., 1 m^2), producing seagrass response to salinity, light, temperature and nutrient conditions over time. This model has been merged with a GIS database to generate spatially explicit prediction of seagrass status over time throughout the Bay.

ESRI's ARC software was used to create and combine GIS layers containing spatial data describing the physical environment of the Florida Bay (e.g., temperature, salinity, turbidity, nutrient status, sediment characteristics) to produce a final coverage containing a combined data set for the bay. The attribute table for this final coverage is then used as the parameter set for the seagrass model. At each time step during the simulation, the output data from the seagrass model are used to update the GIS coverage, representing a dynamic feedback between the model and GIS. This approach provides a seasonal dynamic of seagrass productivity and biomass for the Bay. Output data are exported into ArcView and joined into the attribute table to provide a graphic representation of the seasonal dynamics of seagrass across the bay.

This project is part of a larger collaborative effort to develop a combined process model of the Florida Bay seagrass, sediment and water column nutrient dynamics. The objective of the model is to test predictive scenarios of system behavior based on alternative management scenarios.

Meristem Anoxia and Sulfide Intrusion: A Mechanism for *Thalassia testudinum* Short Shoot Mortality in Florida Bay

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Seagrasses form dense populations in coastal waters in many parts of the world if substrate and light climate allows rooted plant growth. During the last decade, seagrasses of Northern Europe and North America have been observed to die-off during episodic events characterized by a combination of environmental stress factors including high temperature, high salinity, low light flux and/or low water column oxygen. In seagrasses, nighttime belowground aerobic respiration is supported by oxygen diffusing into the leaves from the surrounding water column and subsequently spreading via a well-developed aerenchyma to roots and rhizomes. Diel *in situ* measurements of meristematic oxygen pressure in *Thalassia testudinum* beds show that internal nighttime oxygen concentrations are closely coupled to the water column oxygen level rather than the photosynthetic history of the plant. Hence, if the lower water column is depleted from oxygen due to increased system respiration, anoxia may develop in the roots. This can subsequently lead to sulfide intrusion into the roots where gaseous sulfide may spread throughout the aerenchyma and poison the leaf meristems because sulfide is no longer oxidized to sulfate by root-mediated oxygen diffusing into the near rhizosphere.

As primary seagrass die-off in Florida Bay typically began in the fall, experiments investigating oxygen and sulfide dynamics within *Thalassia* beds were conducted in November of 2000 and October 2001. The studies took place in healthy *Thalassia* beds near Porjoe Key and in Rabbit Key Basin, and in very dense beds experiencing primary die-off in southern Twin Key Basin north of Barnes Key. Vertical profiles of oxygen and sulfide were measured with electrodes that profiled from 10 cm in the water column to 70 cm in the sediments. Diel meristematic oxygen and sulfide dynamics were measured using microelectrodes attached to 3-axis micromanipulating micrometers. The microelectrodes were inserted into the basal meristems to within 500 um of the center of the meristem. Power was supplied to the microelectrodes on a small boat moored immediately adjacent to the study sites. The output was fed to a lab on a houseboat moored on site and data was recorded continuously.

Vertical oxygen and sulfide profiles at Rabbit Key Basin at 21:00 revealed water column oxygen just below saturation. Oxygen declined rapidly within the sediment with hypoxic conditions down to 13 cm and anoxia below that. Sulfide levels were near zero within the *Thalassia* root and rhizome layer (0 -25 cm), but increased to 100 uM at 40-45 cm. In contrast, within the die-off affected beds at Barnes Key, the water-column became anoxic within 7 cm of the sediment surface and the sediments were completely anoxic with sulfide 3 cm below the sediment surface.

At all sites meristematic oxygen pressure showed typical diel patterns. Oxygen pressure declined with decreasing light in the late afternoon and reached minima just before dawn. At sunrise meristematic oxygen pressures rose rapidly reaching atmospheric oxygen pressures during mid to late morning. During nighttime, basal meristems at the die-off affected sites at Barnes went anoxic for as long as 5 hours. In contrast, the basal meristems at Porjoe Key experienced nighttime hypoxia but did not go anoxic.

Where primary seagrass die-off has occurred in Florida Bay, the seagrasses are characterized by extremely high density and biomass. In addition Florida Bay *T.* testudinum commonly has 85-90% of its total biomass in non-photosynthetic belowground tissue which exerts relatively large respiratory oxygen demands. Further the dense canopy of these beds and the decomposition of the accompanying dense litter layer greatly restricts nighttime replenishment of oxygen from the overlying water column. Florida Bay die-off events have primarily occurred in late summer and fall when solar irradiances and day lengths are declining. At the same time, water-column oxygen solubility is low and respiration rates are relatively high (both of which are in large part driven by temperature). When die-off was active, *Thalassia* short-shoots exhibited rotting meristems with a foul odor. The basal meristems are the most metabolically active portions of the short-shoot, and, in theory, would be the first area damaged by insufficient oxygen. All areas of Florida Bay that experienced the initial primary seagrass dieoff in the late 1980's and the recent instance of primary seagrass dieoff near Barnes Key showed these common characteristics. These spatial and temporal observations are consistent with a mechanism of oxygen depletion and sulfide intrusion at the basal meristem.

Environmental conditions that produce oxygen depletions (e.g., high salinity, high water temperatures, reduced circulation) may lead to meristem damage and thereby causing the observed die-offs within *Thalassia* beds.

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Question 4 - Seagrass Poster Abstracts

- Listed alphabetically by presenting author.
- Presenting author appears in **bold**.

Seagrass Distribution and Cover Abundance in Northeast Florida Bay 1996-2002

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The Miami-Dade County Department of Environmental Resources Management in cooperation with the South Florida Water Management District has maintained a routine submerged aquatic vegetation monitoring program in northeast Florida Bay since October 1993. The program was established to monitor for downstream affects associated with changes in water management practices in the east Everglades and Taylor Slough. The monitoring program has been modified over the last nine years to improve spatial coverage, standardize sampling methodologies, and to expand the study region. The focus of the study from 1996 to present has been to utilize a probabilistic stratified random sampling methodology similar to methods used by other seagrass researchers working in the Florida Bay ecosystem.

The study area includes ten basins in the region from Little Madeira Bay east to U.S. Highway 1, as well as Manatee Bay and Barnes Sound located east of U.S. 1. Sampling is conducted bimonthly at a total of 96 randomly selected stations located in the following twelve basins: Little Madeira Bay, immediately south of Little Madeira Bay, Alligator Bay, Davis Cove, Trout Cove, Joe Bay, Highway Creek, Little Blackwater Sound, Long Sound, Blackwater Sound, Manatee Bay, and Barnes Sound. At each station submerged aquatic vegetation cover was evaluated at four randomly placed $0.25m^2$ quadrats using a modified Braun-Blanquet Cover Abundance Scale (BBCA) (Table 1). When possible, additional measures of seagrass shoot and blade density were also collected. At each station physical water quality characteristics (i.e., temperature, pH, dissolved oxygen, oxidation-reduction potential, specific conductance, and salinity) and photosynthetic active radiation were recorded using a calibrated Hydrolab® multi-probe sonde, and a Li-Cor® integrating photometer, respectively.

The seagrass community in the study area is essentially composed of three species *Thalassia testudinum*, *Halodule wrightii*, and *Ruppia* maritima. *Halophila engelmannii* is also present, however, is very sparse and limited in distribution. Populations of the three major seagrass species have remained fairly stable across the study area throughout the duration of the monitoring program. *Thalassia testudinum* has been the most widely distributed and abundant seagrass in the study region. Annually, the presence of T. *testudinum*, throughout the entire study area, has ranged between 73.8% and 78.8% (Table 2), and the annual mean BBCA values have ranged from 1.72 to 2.33 (Table 3). The highest annual mean basin BBCA cover-abundance for *T. testudinum* within a basin was recorded in Manatee Bay, at 3.87, while the lowest was observed in Long Sound at 1.33. *H. wrightii* is also widely distributed, and has been present in all twelve basins throughout the reporting period. The annual mean presence of *H. wrightii* ranged from 58.8% to 70.2%, while the annual mean BBCA value ranged from 0.58 to 0.89 (Table 2 and Table 3). *R. maritima* was very sparsely distributed throughout the study period. Although it has been recorded in 8 basins, it is consistently found in only four of the twelve basins. The annual mean presence of *R. maritima* has ranged from 8.0% to 13.5%, while annual mean BBCA values have ranged from 0.04 to 0.14 (Table 2 and Table 3).

Table 1: Braun-Blanquet Cover-Abundance (Magnitude) Scale

BBCA VALUE	**OBSERVED % COVER**	**MEAN % COVER**	**RELATIVE ABUNDANCE**
5	> 75	87.5	ANY
4	50 to 75	62.5	ANY
3	25 to 50	37.5	ANY
2	5 to 25	15	ANY
1	< 5	2.5*	NUMEROUS
0.5	< 5	2.5*	LOW
0.1	< 5	2.5*	SOLITARY
0	ABSENT	0	ABSENT

* Represents an assigned value.

Table 2. Mean BBCA values per year for the total study area.

	1996	**1997***	**1998**	**1999**	**2000**	**2001**	**2002**
T. testudinum	1.72	2.02	2.26	2.33	2.07	2.14	2.07
H. wrightii	0.58	0.78	0.73	0.77	0.89	0.87	0.81
R. maritima	0.12	0.08	0.10	0.04	0.11	0.08	0.14

Table 3. Annual mean presence values.

	1996	1997*	1998	1999	2000	2001	2002
T. testudinum	73.8	75.7	78.8	78.7	74.5	75.2	76.5
H. wrightii	66.8	70.2	66.4	69.0	66.8	67.3	58.8
R. maritima	11.8	8.1	12.4	8.0	11.3	9.8	13.5

*Manatee Bay and Barnes Sound sites were added in October 1997.

Although the absolute value of presences and BBCA cover-abundance can vary significantly from basin to basin the values for a given basin have been relatively stable over time. Scale is an important consideration, as stability at the basin level masks changes occurring within the basins. Evaluation of data at the subbasin level has indicated significant changes within many of the basins. Most notable of these changes has been the decline of *T. testudinum* in the western portion of Little Madeira (Bacon et al. 2001). This decline was first observed in August of 1999 and the area begins at the mouth of Taylor River and extends out to the south and west. Within Little Madeira the mean annual BBCA cover-abundance of *T. testudinum* was significantly lower in 2000 and 2002 when compared to 1997-1999. This is in contrast to *T. testudinum* BBCA values for the four subasins, located in the western portion of the Little Madeira. In these subasins *T. testudinum* showed a decreased cover abundance from 2000-2002 when compared to 1996-1999. Following the decrease in *T. testudinum*, *H wrightii* increased in mean BBCA cover abundance, and this reflected in the basin wide mean 1.02 in 1999 to 1.28 in 2000 and in the western subbasins mean 1.45 in 1999 and 1.97 in 2000. *R. maritima* annual mean BBCA value increased for the entire basin, from 0.02 in 1999 to 0.13 in 2000, 0.06 in 2001, and 0.18 in 2002, while the western subbasins reflected a similar variation.

Additional investigations at the sub-basin level, have suggested localized and more dramatic changes in the seagrass community have occurred. Further analysis is being directed at analyzing these changes and their relationships with variations in temperature, salinity and light attenuation.

Reference:

Bacon, J.J., Hefty, L.N., Kemp, S.K., Shaw, F. Liddell, K., and Avila, C. (2001) Seagrass Distribution and Cover Abundance in Northeast Florida Bay. In 2001 Florida Bay and Adjacent Marine Systems Science Conference. pp. 145-148

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Below-ground Structure and Productivity of *Thalassia testudinum*: Root Component

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Thalassia testudinum is a species of seagrass critical to the ecologic function of Florida Bay. This species also affects the economic interests of South Florida. In terms of published scientific papers one of the understudied areas related to *Thalassia testudinum* is the investigation of below-ground processes. The study of below-ground structure and production is hindered by logistical difficulties which make viable estimates difficult to obtain. The inability to directly measure dynamic processes contributes to the error of these estimates. From a scientific standpoint this affects the ability to construct accurate ecological models. Since *Thalassia testudinum* is so prevalent in Florida Bay this information gap also affects the precision and effectiveness of ecologic and landscape models at all scales.

There are four major below-ground components of *Thalassia testudinum*. Lower leaves, short shoots, rhizome and roots. All four components were investigated in a study that ran from 2000 to 2002. The fieldwork took place at Rabbit Key Basin in Florida Bay. Long term monitoring of above-ground dynamics occurred during the summer months of 2000 and 2001. Monitoring consisted of repeated measurement of tagged individual plants. Sods, which included the tagged plants, were extracted. The plants were separated and structural measurements were completed in Charlottesville, Virginia. The data presented here will cover the investigation of the roots.

The roots of a Thalassia testudinum plant are tubular structures approximately 1 mm in diameter. Roots are attached to both the rhizome and the short shoot. A major difficulty in the study of roots is the selection bias. Longer roots are damaged or lost in the sod extraction and separation process. Therefore estimates of the average and maximum lengths are prone to underestimation. This selection bias also affects the estimates of the biomass ratios.

Roots on the rhizome were observed to be attached along a single axis on the underside of the runner. This oriented the growth of the root 180^o into the sediment depth. Live root material was found at depths more than 0.6 m below the foundation of the rhizosphere. This suggests an extended growth period for some of the population of roots. The early stages of root elongation appear to be in a steady state with rhizome elongation. The rate of root elongation was unique to individual plants. The population average was 0.85 cm of root elongation for every 1.0 cm of rhizome elongation, however the individual ratios were quite variable (sd=0.44).

Roots attached to the short shoots were always observed to be growing orthogonal to the direction of the rhizome runner. The primary attachment point was on the outside of the short shoot. This directed the growth of the root away from the rhizome. A small percentage (3.05%) of short shoots had root attachment points that were diametrically opposed to the outside attachment points. This means that root growth was still orthogonal to the rhizome, however, in these cases the root crossed the plane of the runner. The observation of in tact (root tip present), attached roots suggested three growth patterns. The first was steady state growth in relation to the number of scars on the short shoot. The second was terminal growth. This was observed when two or more roots of differing ages were observed to be approximately the same length. The third pattern observed was fast growing roots. These cases were classified by roots that had grown to lengths of up to 15 cm within 6-8 leaf plasticron intervals. This pattern of fast growth was supported by cases where older attached roots appeared to be in a steady state growth pattern and yet were shorter in length than the younger root.

The length and the weight of the roots were found to be strongly related (R^2=0.86). This relationship and the above mentioned growth patterns were combined to produce various productivity rates.

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Effect of *Thalassia testudinum* Dieback on Sediment Biogeochemical Processes in Florida Bay

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Thalassia testudinum communities have recently experienced an unprecedented dieback in Florida Bay. Although there is no evidence of dieback in some areas of the Bay (e.g., Rabbit Key), recent outbreaks of this phenomenon have been observed in other nearby areas (e.g., Barnes Key). This study examines the question of how nutrient cycling and related sediment biogeochemical processes may be affected by seagrass dieback. We addressed this research question by comparing sediment biogeochemical rates and nutrient pools in *T. testudinum* beds at stations along transects from shallow banks to deeper adjacent basins near Rabbit and Barnes Keys. Vertical profiles of nitrification (oxidation of ammonium to nitrate) activities and ammonification (ammonium recycling rates) were determined for sediments collected in healthy and dieback *T. testudinum* communities. We also measured diel changes in net fluxes of NH_4^+, NO_3^-, PO_4^{-3}, N_2, O_2, DON, and DOC between sediments/plants and overlying water using in intact vegetated sediment cores. Nitrification activities, which provide an index of coupled nitrification-denitrification rates, were consistently higher in the surface (0-3 cm) layer at all sites and at the depth of maximum root biomass (6-9 cm). Nitrification activities in sediments undergoing seagrass dieback were significantly lower (~1 nmol cm^{-3} d^{-1}) compared to measurements in adjacent healthy seagrass sediments (~6 nmol cm^{-3} d^{-1}). The reduction in nitrification activity in dieback areas suggests a parallel reduction in O_2 release from seagrass roots to surrounding sediments. It also coincided with a reduction in live belowground biomass in these areas. DOC and DON fluxes in healthy seagrass beds were closely tied to seagrass photosynthesis, as estimated by O_2 production. In dieback areas, DOC and DON fluxes were more variable. Overall, these observations suggest that dieback results in a transient increase in nutrient and DOC regeneration rates but a significant reduction in the ability of seagrass to oxidize the rhizosphere. This would lead to enhanced nutrient regeneration and decreased nitrogen removal from the system via coupled nitrification-denitrification.

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Seagrass Dynamics in Florida Bay 2000-2002: Links with Environmental Variability

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There is continuing concern regarding changes in the distribution and adundance of seagrasses within Florida Bay, especially in the context of proposed changes to the hydrodynamic conditions within the Bay associated with the Comprehensive Everglades Restoration Program (CERP). To fulfill this need to assess the effects of water management alterations associated with CERP on seagrass communities, we have been conducting the Fisheries Habitat Assessment Program (FHAP).

Sampling for FHAP is conducted twice per year, during spring and fall. Each of ten basins, representing a range of conditions and gradients in Florida Bay, are partitioned into approximately 30-35 tesselated hexagonal grid cells. Sampling-station locations are randomly chosen from within each cell. At each station, seagrass cover is visually quantified a modified Braun-Blanquet abundance scale. Seagrass distribution and abundance and changes in abundance are estimated using the geostatistical gridding method of kriging. Planar areas for each cover class are calculated and a dimension-less estimate of the total abundance of a species within a basin is then obtained by mutliplying the planar area for each cover class by the cover-class midpoint and adding the resulting values together. Using this "volume-slicing" approach, total Braun-Blanquet adundances for during spring FHAP sampling at the Bay and basin scales have been calculated since 1995 (Figures 1 and 2).

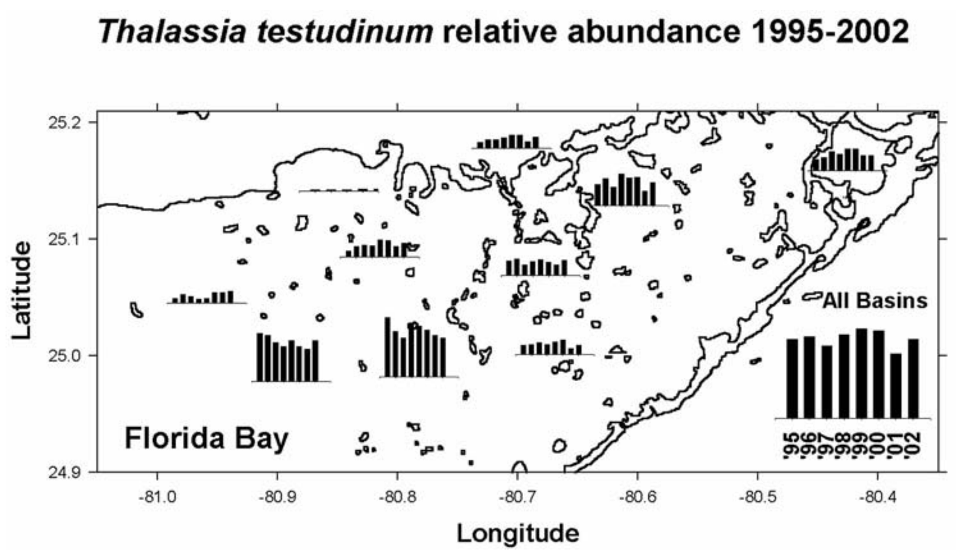

Figure 6. Changes in relative abundance of *Thalassia* from spring 1995 to spring 2002.

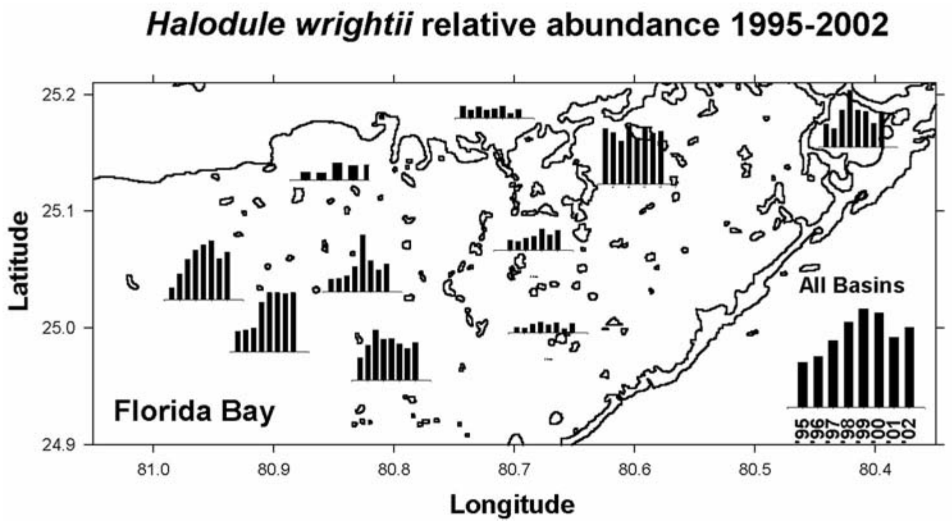

Figure 7. Changes in relative abundance of Halodule from spring 1995 to spring 2002.

In this presentation, we will primarily focus on FHAP data from 2000 to 2002. At the Bay scale, both *Thalassia* and *Halodule* BB abundances were reduced in spring 2001, compared with spring 2000 and 2002. In 2001, *Thalassia* had the lowest Bay-scale abundance we have measured since spring 1995 (Figure 1). The apparent declines in cover may have been the result of unusually low water temperatures during spring 2001 (Bay mean: 26.8 C for S01 vs 28.2 C for S00 and S02). The reduced temperatures may have resulted in reduced leaf growth, and thus, lower cover during our spring 2001 sampling. However, overall salinities were much higher in S01 (Bay mean: 40.2 psu for S01 vs 33.9 psu for S00 and 32.1 psu for S02), which may also have contributed to reduced growth and cover. Increases in estimated area of no *Thalassia* and *Halodule* cover in spring 2001 coupled with the lack of complete recovery in abundance by spring 2002 with the return of warmer water temperatures and lower salinities suggest that lower abundances in 2001 were the results of shoot mortality, in addition to reduced shoot leafiness. In contrast to the variation in temperature and salinity, water clarity has been almost identical for the last 3 years (Bay mean secchi depths: 166 cm for S00 vs 165 cm for S01 and 163.5 cm for S02), with the secchi disk visible on the bottom in almost 90% of the FHAP sites. Thus, light limitation does not seem to be a major factor in the recent changes.

During the spring 2001 sampling, we began measuring photosynthesis *in situ* using a Waltz Diving-PAM fluorometer. We hoped that this is non-destructive technique would provide a sensitive physiological indicator of *Thalassia*'s health. At each station, apparent photosynthetic quantum yield (=light-adapted) and maximum quantum yield (= dark-adapted) for four short-shoots were measured. Preliminary results from these measurements indicated that quantum yields exhibited significant diurnal variation and variation correlated with the ambient photosynthetic photon flux densities (PPFD), in addition to spatial variation. The multiple sources of variation have made interpretation of these initial results difficult. During spring 2002, PAM measurements were modified with the inclusion of Rapid Light Curves (RLC); measurements that should exhibit less diurnal variability than quantum yield measurements. We are currently analyzing these new data.

The recent FHAP data indicate a measureable link between environmental parameters and seagrass dynamics. Principal components analysis of shoot-specific and area-specific morphometric variation in *Thalassia* in the ten FHAP basins revealed basin clusters that correspond closely with the ‘zones of similar influence’ based on water-quality characteristics. The recent variations in seagrass abundance in Florida Bay, especially the declines in spring 2001, also reflect the influences of environmental factors on seagrass abundance. In addition, the lowest apparent reproductive effort for *Thalassia* for the recent past was observed in spring 2001. Reproductive short shoots were observed at only 8 stations in 6 basins during 2001, compared with 19, 26, and 22 stations in 7 basins for spring 1999, 2000, and 2002, respectively. Thus, not only are structural characteristics and abundance apparently reduced by ‘suboptimal’ environmental conditions, but reproductive effort (a source of future recruitment) may also be affected by environmental changes.

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Carbon and Nitrogen Stable Isotope Composition of Sedimentary Organic Matter from Florida Bay: Evidence of Historic Seagrass Distribution and Paleoproductivity

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The shallow marine waters of Florida Bay provide an ideal environment for seagrasses, which are the most common benthic community in the region. However, seagrass communities are susceptible to a variety of anthropogenic disturbances, particularly changes in water quality, and environmental conditions in Florida Bay have become a concern due to recent increases in salinity, algal bloom frequency, and seagrass mortality. These changes have been attributed to 20th century alterations in freshwater discharge from the Everglades to Florida Bay, deteriorated water quality, and changes in exchange between Florida Bay and the Atlantic Ocean. In order to better understand environmental change and impacts on the seagrass community over long time scales, sediment cores were collected in Summer 2002 from four locations in Florida Bay (Ninemile Bank, Bob Allen Bank, Russell Key, and Trout Creek) for multiple proxy analyses of seagrass abundance. All cores were collected to bedrock, with sediment depths ranging from 94 to 244 cm, potentially representing a 5000-year time series. ^{210}Pb dates for the Bob Allen Bank and Trout Creek cores indicate that the upper 30 and 50 cm of sediment represent the past 100 years, respectively. Basal peat evident in the Bob Allen Bank core has been constrained with ^{14}C-dating at between 2770 and 4190 b.p. Cores were sampled in 2-cm increments, representing an average of 2-10 years for bulk isotopic analysis of sediment organic content.

In two cores analyzed, Bob Allen Bank and Trout Creek, significant differences are evident in the carbon and nitrogen isotopic signatures both between sites and over time within site, with δ^{15}N values ranging between +3.2 and +7.6‰ and δ^{13}C between –24.3 and –8.6‰, both oscillating over time. These patterns may reflect changes and mixing in source material between terrestrial and estuarine organic matter, as terrestrial material is more depleted in terms of both ^{15}N and ^{13}C than estuarine organic matter due to differences in nutrient supply and recycling. Fluctuations in δ^{15}N and δ^{13}C signatures may also reflect changes in nutrient availability and primary production in the marine environment. Enrichment trends in nitrogen and carbon isotopic signatures may result from increases in productivity levels, limitation of carbon and/or nitrogen, or a combination of both factors, as changing production demand and nutrient supply influence processes of isotopic discrimination. Finally, there is evidence of decoupling between the carbon and nitrogen isotopic systems, although values throughout suggest that buried organic matter is predominantly seagrass-derived over time. Further bulk isotopic analyses of remaining cores, together with organic biomarker analyses, diatom and foraminiferal community analyses, and completion of age models for remaining cores will allow more definitive interpretation of the isotope patterns with implications to seagrass productivity levels over long time scales in Florida Bay.

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Responses of Benthic Primary Production to Nutrient Enrichment in the Upper Florida Keys

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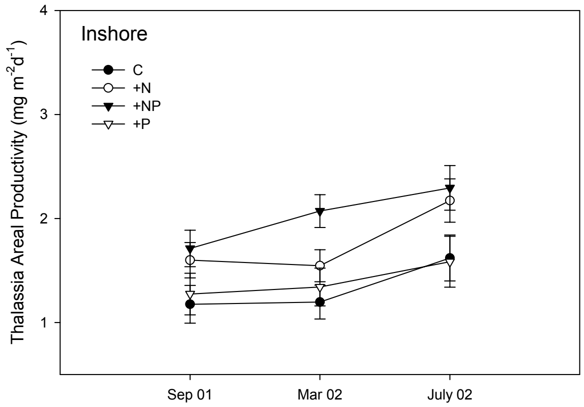
Eutrophication of some coastal systems has resulted in shifts of primary producer dominance, where slow-growing macrophytes such as seagrass and macroalgae are replaced by fast-growing microalgae. Stoichiometric analysis of seagrass tissue from the Florida Keys suggests a spatial pattern of nutrient limitation: benthic coastal communities may be phosphorus limited close to shore and nitrogen limited toward the offshore reef tract. This implies that benthic community responses to eutrophication may differ along a spatial gradient from nearshore to offshore habitats. A 14 month *in-situ* fertilization experiment was carried out to assess the consequences of coastal nutrient enrichment on benthic primary production and to determine the limiting nutrient of *Thalassia testudinum* growth in the oceanside waters of the upper Florida Keys.

A factorial (nitrogen, phosphorus) design was conducted at 6 sites that were divided into 2 groups, where each group represented the end points of the stoichiometric gradient: nearshore (< 1km from the shoreline) and offshore (< 2km inside the reef tract). At each site, 24 plots (0.5 m^2) were established in a 50 m x 50 m grid with 6 replicates of each treatment (N, P, N+P, Control), for a total of 144 experimental plots. Sediments were fertilized monthly. Nutrient loading rates of 0.77 N and 0.12 P g m^{-2} d^{-1} were based on current estimates of dominant nutrient sources in the Florida Keys. This experiment was analyzed using a mixed model ANOVA with a split-plot design and repeated measures. The experiment began in May 2001 and terminated in July 2002.

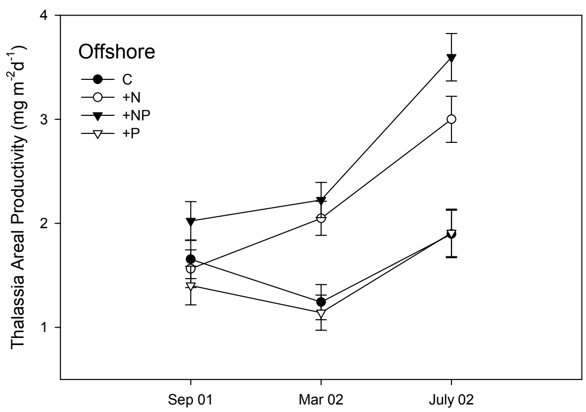
Sampling was conducted on those benthic species considered most sensitive to changes of nutrient availability in coastal marine systems: seagrass, macroalgae, epiphytes and sediment microalgae. The following response variables were determined every 4-5 months: Sediment nutrient and organic content, *Thalassia testudinum* abundance, morphology, biomass, leaf growth rates, leaf and rhizome nutrient content; macroalgae abundance; epiphyte total load and chlorophyll load; sediment microalgae abundance. *Syringodium filiforme* morphology, biomass and leaf nutrient content was analyzed at the end of the experiment.

The responses of benthic communities to nitrogen and phosphorus enrichment varied appreciably between nearshore and offshore habitats. There were significant increases in *T. testudinum* length, abundance, biomass and growth rates in response to N addition, but not P addition, at offshore sites. This suggests that *T. testudinum* in offshore habitats in the upper Florida Keys are nitrogen limited. Significant increases in abundance and biomass of non-seagrass primary producers were found exclusively at nearshore sites, and most often encountered with +NP treatments. Macroalgae abundance (rhizophytic calcareous greens) and total epiphyte loads increased with +NP at nearshore, but not offshore sites. Increases in autotrophic epiphyte loads and sediment microalgae abundance were also found only at nearshore sites.

The relative allocation of nitrogen and phosphorus to various seagrass system compartments (sediment, seagrass, algae, water column) was similar between nearshore and offshore sites. However, the net retention of added nutrients varied considerably based on nutrient and location. Although total system nitrogen doubled with nitrogen addition, less than 10 % of the added nitrogen was retained in that system. Phosphorus enrichment dramatically increased total system phosphorus and up to 82 % was retained in the system. The differences in nitrogen and phosphorus retention suggest that long-term phosphorus enrichment, unlike nitrogen enrichment, may be important as a driver of long-term community changes because most of the phosphorus is retained within the system, while much of the nitrogen is lost from the system. Nearshore systems may be particularly vulnerable to phosphorus enrichment because the retention efficiency of phosphorus at nearshore sites (82 %) was nearly twice that of offshore sites (49 %).



Seagrass leaf nutrient content increased at all sites with the addition of nutrients, although the magnitude of these responses varied by time and location. Increases in *T. testudinum* leaf N content were apparent quickly (3 months of fertilization), whereas significant increases in P content were not observed at nearshore and offshore sites until 10 months and 14 months of fertilization, respectively. Relative changes in seagrass leaf and rhizome elemental content support strong nitrogen-limitation of offshore seagrass, and suggest that phosphorus might be more limiting at nearshore sites.



Growth responses in this experiment did not consistently follow the nutrient content responses. Increases in *T. testudinum* leaf nutrient content, in the absence of a positive biomass or growth response, implies that nutrient availability in the study area was either insufficient to satisfy all plant metabolic demands for nitrogen and/or phosphorus, or that *T. testudinum* was efficient at luxury consumption.

This study demonstrated that eutrophication of the coastal waters of the Florida Keys has the potential to affect benthic communities. Taxa-specific responses to nutrient enrichment varied by location: macro- and micro-algae responded at nearshore sites while seagrass species responded at offshore sites. The increase in macroalgae and microalgae abundance at nearshore sites followed the predicted sequence of community responses during eutrophication. This experiment also demonstrated that seagrass communities in oceanside waters of the Florida Keys are indeed nutrient limited, but the nature of that limitation is different for nearshore and offshore sites. *Thalassia testudinum* responded to N+P addition at nearshore sites, and N addition at offshore sites. The largest increase in seagrass biomass and growth was found at offshore sites, demonstrating that the offshore *T. testudinum* is strongly nitrogen limited.

This investigation increases our ability to predict the effects of nutrient enrichment in seagrass communities and emphasizes the importance of nutrient supply in determining benthic community composition. The response of benthic communities in the oceanside waters of the upper Florida Keys to nitrogen and phosphorus enrichment varied significantly between the nearshore and offshore environment. Results may be used to model changes that anthropogenic eutrophication may cause in the subtropical coastal marine waters of the upper Florida Keys.

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Distribution and Abundance Patterns of Submerged Aquatic Vegetation in Response to Changing Salinity in the Mangrove Ecotone of Northeastern Florida Bay

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Within the mangrove ecotone of northeastern Florida Bay, historic flow and salinity patterns have been altered by the construction and operation of a series of canals known as the South Dade Conveyance System (SDCS). Changes in ecotonal salinity caused by operation of the SDCS have most likely altered the seasonal and inter-annual patterns of submerged aquatic vegetation (SAV). A routine surveying program was established in 1996 to determine any correlations between salinity and SAV distribution patterns and also to characterize seasonal patterns of SAV community structure. Surveying was conducted at 3 sites, located in the coastal wetlands of northeastern Florida Bay in the Taylor Slough/C-111 drainage area. At each site, 6 fixed stations along a salinity gradient, ending at Florida Bay were sampled approximately every 6 weeks. SAV were quantified using the point intercept percent cover method. Species abundance and community composition was determined by analyzing 12 randomly selected $0.25m^2$ quadrats at each station. Salinity, temperature, water depth, and water clarity were also measured at each station on day of sample.

SAV communities consisted of a variety of species ranging from freshwater marsh plants and algae to euryhaline seagrasses. Stations of similar mean salinity had similar assemblages of vegetation. Upstream stations (mean salinity ranging 3.5-8.6psu) consisted primarily of a mixed assemblage of *Utricularia sp*., *Najas marina*, *Chara hornemanii*, and *Ruppia maritima*. Downstream stations (mean salinity ranging 10.4-15.5psu) were dominated by *Halodule wrightii*, or a mixture of *Halodule* and *Ruppia*. Preliminary results indicate that there was a direct seasonal relationship between salinity fluctuation and die-back and re-growth of vegetation. SAV abundance at nearly all stations, excepting those near or in Florida Bay, appeared to indicate strong negative correlations with salinity. Relatively rapid increases in salinity on the wetlands at the onset of the dry season resulted in severe or complete die-off of vegetation. Recolonization and continued growth occurred with lowered salinities throughout the wet season. Since 1996, overall mean salinity at all stations has steadily increased. Over the same period, upstream stations dominated by freshwater plants and algae have proportionally decreased in total SAV abundance while downstream stations near or in Florida Bay have showed an opposite response. This downstream response may be explained by the continued expansion of *Halodule* and resulting displacement of lower salinity species. These preliminary analyses indicate that salinity may be the principal controlling factor in the submerged plant community and a trend towards a less stable salinity regime can negatively affect the composition of these communities in the ecotone.

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Thalassia Seedlings in Florida Bay: Can They Survive in Extreme Salinity Environments?

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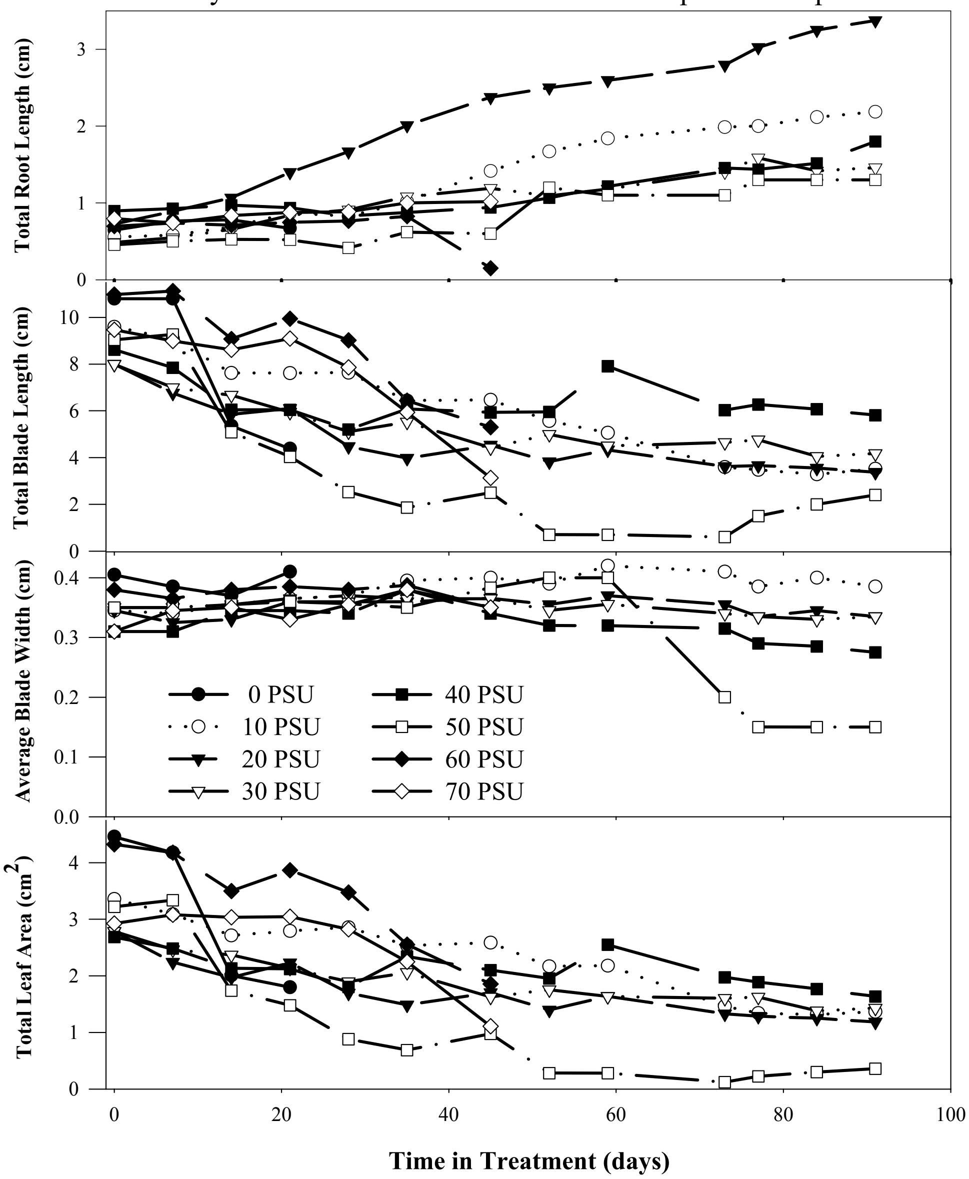
Although much research in Florida Bay has focused on how biotic and abiotic factors effect mature seagrasses, there is relatively little information on the effects of these factors on seedling dispersal, recruitment and survival. Seedlings may be critical to the re-establishment and sustainability of seagrass beds following stress exposure or die-off. To address the effects of stress on seagrass seedling establishment, we have initiated investigations on the effects of several environmental variables on seedling growth and development. Since the primary initial modification to the Florida Bay system in the Comprehensive Everglades Restoration Program (CERP) will be hydrological, salinity was the central focus of manipulation in this initial research. In this investigation we sought to quantify the effects of increased and reduced salinity (0-70 PSU) on the survival and development of *Thalassia testudinum* seedlings.

Thalassia seedlings were collected on August 13th, 2002 from the mangrove fringe on Little Rabbit Key in south-central Florida Bay and transported up to the Center for Marine Science, Wilmington, North Carolina. The seedlings were acclimated to 30°C, 29 PSU medium salt water for 24 h. Following acclimation, the seedlings were transferred to Magenta GA-7 flasks containing 200 ml of autoclaved Instant Ocean-based media at 0, 10, 20, 30, 40, 50, 60 and 70 PSU. Ten seedlings were chosen at random for each of the salinity treatments. The flasks were incubated at 24°C in a growth chamber under 12:12 light:dark photoperiod for three months. Weekly measurements were made of root number and lengths as well as blade number, lengths and widths from which total leaf area was calculated. Every four weeks, effective quantum yield and dark-adapted maximum quantum yield were measured using the Waltz Mini-PAM fluorometer. At the end of the experiment period, leaf osmolality was measured on the surviving seedlings using a Wescor VAPRO vapor pressure osmometer.

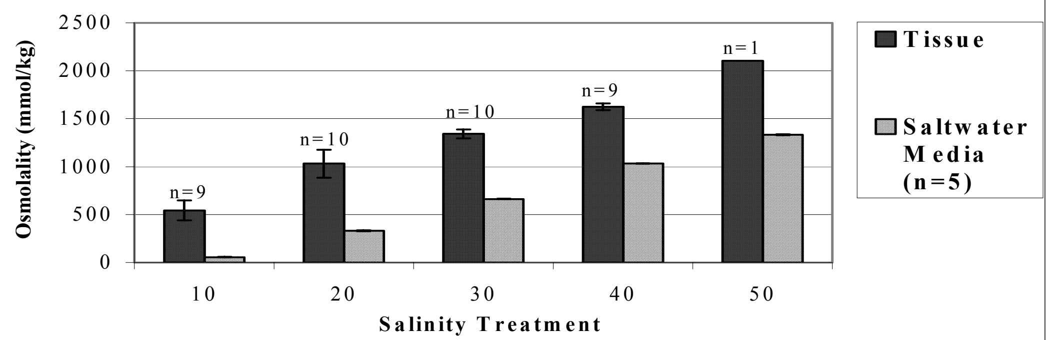
The extreme low- and high-salinity treatments had a negative impact on seedling survival after 3 weeks. All seedlings in 0 PSU media were dead after 25 days in the treatment. A dramatic decrease in survival by day 30 was also observed in the seedlings grown at 50, 60, and 70 PSU. The seedlings grown at 20, 30 and 40 PSU had a 100% survival over the experimental period. Morphometric characteristics (Fig. 1) showed a general trend in increasing total root length over time, with the greatest rate of increase in the 10 and 20 PSU treatments. Blade length and total leaf area decreased most drastically in the 0, 50, 60 and 70 PSU treatments. The general trend of decreased values over the course of the experiment was possibly the result of an experimental artifact associated with the free-floating conditions in which the seedlings were kept. Previous observations suggest that *Thalassia* seedlings exhibit better growth when rooted rather than free-floating as was the case in this experiment.

Fig.1. Average morphometric charactersitics of *Thalassia* seedlings grown at 8 salinity treatments measured over 3 month experimental period



The results from the PAM fluorometer measurements were inconclusive and no assumptions could be drawn from the data. The osmolality measurements on the other hand, showed significant trend in increased tissue osmolality for each of the more saline treatments. Upon comparison of tissue osmolality to saltwater osmolality, the tissue was distinctly hyperosmotic and maintained approximately the same value of hyperosmolality between each treatment (Fig. 2).

Fig. 2. Average Osmolality of Treatment Leaf Tissue and Plain Saltwater (mean del of 646 mmol/kg ±108)



These preliminary experimental data suggest that *Thalassia* seedling survival and development is negatively impacted in extreme salinity environments. It is possible that the cost of maintaining a hyperosmotic environment within the tissue is detrimental to plant tissue development and growth. Further studies will experimentally manipulate the treatment environment to examine the effects of incremental increases/decreases in salinity on seedling development. Oxygen electrodes will also be used to further investigate the impacts of extreme salinity on seedling physiology, particularly rates of respiration, as well more in depth use of the PAM flurorometer. Currently, data are being collected in an aquarium-scale experiment of a similar experimental design involving *Thalassia* seedlings growing in an aragonite shell-hash substrate. The data from this experiment, in conjunction with the flask-scale experiment, should more clearly define the potential contribution of seedlings to seagrass recovery in extreme salinity environments.

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Recent Changes in Macroalgal Distribution and Abundance in Florida Bay: An Initial Analysis of FHAP Macroalgal Data

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The Fisheries Habitat Assessment Program (FHAP), initiated in 1995, has produced an extensive database of distribution and abundance information regarding both seagrasses and macroalgae. To date, a thorough analysis of the macroalgal data has not been completed. The objective here is to provide an initial assessment of the abundance and distribution of three macroalgal species found in the Florida Bay.

Sampling for FHAP is conducted biannually, during spring and fall. Ten basins, chosen to represent a range of conditions and gradients in Florida Bay, have been partitioned into approximately 30-35 tesselated hexagonal grid cells. During each sample period, sampling station locations are randomly chosen from within each cell, for a total of about 330 stations. This type of sampling design results in systematic random sampling, it scales the sampling effort to the size of the basin, and it is well-suited for interpolation (i.e., kriging) and mapping of the data.

At each station, both seagrass and macroalgal cover is visually quantified within four, haphazardly-located 0.25m^2 quadrats using a modified Braun-Blanquet frequency/abundance scale, in which a value of .1 is solitary, .5 is sparse, 1 is numerous, but <5% cover, 2 is from 5-25% cover, 3 is 25-50% cover, 4 is 50-75% cover, and 5 is 75-100% cover. Seagrass and macroalgal distribution and abundance are estimated using a contouring and 3D mapping program (Surfer 8). The geostatystical gridding method of kriging is used to express the trends in the Braun-Blanquet data. A linear variogram model is used to calculate all grid node values. Planar areas for each cover class are calculated by the area differences among cut (positive) and fill (negative) volumes of the kriged grids using the grid volume command in Surfer. A dimension-less estimate of the total abundance of a species within a basin is then obtained by multiplying the planar area for each cover class by the cover class midpoint and adding the resulting values together.

A representative from each of the three major Divisions of algae has been chosen for this initial analysis. The abundance and distribution of *Batophora* (Chlorophyta), *Sargassum* (Phaeophyta), and the drift reds (primarily *Laurencia)* (Rhodophyta), in the spring of 1995, 1999, and 2002, have been computed using the methods described above.

In 1995, *Batophora* was observed in seven of the ten basins, in abundance ranging from sparse to numerous. In Johnson Key, Rabbit Key and Rankin Lake, the more north-western basins, no *Batophora* was found. *Sargassum* was observed in seven of the ten basins, ranging in abundance from sparse to numerous. No *Sargassum* was found in Johnson Key, Rabbit Key and Twin Key. Drift reds were found in abundances from sparse to numerous in all but one basin, Rabbit Key Basin.

In 1999, *Batophora* increased in both abundance and distribution, occurring in nine of the ten basins, Johnson Key being the only basin in which this genus was not found. *Sargassum*, however, decreased in abundance and distribution, occurring in sparse abundance in three of the ten basins. Eagle Key, Calusa Key, and Rankin Lake were the only basins in which this genus was observed. The drift reds were more widely distributed, occurring in all ten basins, and showed a significant shift in abundance to the more western basins, although the total relative abundance was slightly less than in 1995.

In 2002, *Batophora* exhibited a great increase in distribution, occurring in all ten basins in a greater abundance, though still having the least cover in Rankin Lake. *Sargassum* increased in distribution again, occurring in six of the ten basins. It was not observed in Blackwater Sound, Madeira Bay, Twin Key or Rabbit Key basins. The drift reds increased in abundance from 1999 to 2002 and maintained distribution throughout the ten FHAP basins.

Figure 1 shows a high variability of both abundance and distribution for each algae for each year in each individual basin, from Blackwater Sound, the eastern-most basin sampled, to Johnson Key Basin, the western-most basin sampled. Figure 2 clearly shows, at the Bay scale, that *Batophora* increased from 1995 to 1999 and from 1999 to 2002. *Sargassum* initially decreased from 1995 to 1999 but then increased to almost its original abundance in 2002. Drift Reds showed little change from 1995 to 1999 but increased from 1999 to 2002. The overall trend observed from both figures is a high variability in abundance at the basin scale but a general increase in macroalgal abundance at the Bay scale since 1995.

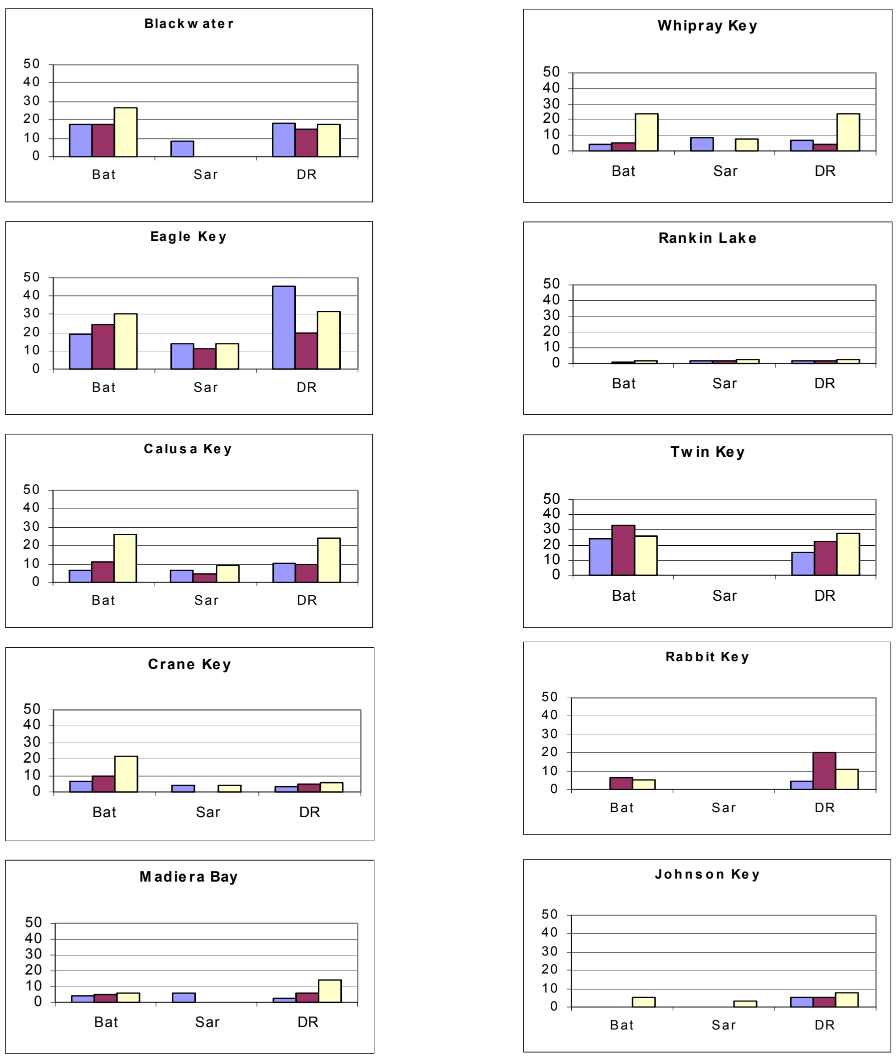

Figure 1. Relative total abundances (dimension-less, see methods) of Batophora, Sargassum, and the Drift Reds in each FHAP basin.

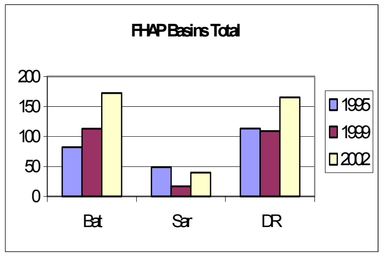

Figure 2. Relative total abundances of Batophora (Bat), Sargassum (Sar), and the Drift Reds (DR) in ten Florida Bay basins during spring 1995, 1999, and 2002.

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Historic, Current, and Future Seagrass Distribution in Florida Bay: Assessing the Impacts of Water Diversion and Everglades Restoration

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Current seagrass distribution and species composition in Florida Bay reflect decades of human impact on the hydrology of the Everglades and Florida Bay. Anecdotal observations indicate that, as a consequence of lower, and fluctuating, salinity in the past, seagrass distribution was more patchy along the northern portion of Florida Bay and turtle grass was much less abundant than it is today. Seagrass scientists and water managers anticipate that hydrologic restoration projects of the Comprehensive Everglades Restoration Plan will lower salinities in northern Florida Bay causing shifts in seagrass abundance and species composition similar to pre-management patterns.

To evaluate the effectiveness of the location, timing, and volume of water delivery through the Everglades, an historic benchmark for seagrass distribution in Florida Bay is needed. However, historic data on seagrass distribution in Florida Bay are limited. The first incidental data on seagrass distribution were collected by Durbin Tabb in the 1960's, but the first comprehensive characterization of seagrasses in Florida Bay was conducted by Zieman and Fourqurean in the early 1980's, long after altered hydrology had affected seagrass distribution. Some of the earliest aerial photos of Florida Bay were taken by USDA/ASCS in the 1940's, but coverage is limited to a few shoreline areas.

Historic Seagrass Analysis- A set of military aerial photos flown on November 1, 1945 might enable us to determine the distribution and patchiness of Florida Bay seagrasses prior to extensive hydrologic changes. Approximately 200 photos (1:24,000 scale) were taken on eight east-west flight lines covering most of the Bay (Figure 1). Water clarity was excellent, and seagrasses are discernible. The northernmost flight lines include the northern shoreline of the Bay, and the southernmost flight line runs through the Peterson and Arsenicker Keys. Over the next six months, we will evaluate image quality and potential for seagrass interpretation from these photos.

Current Seagrass Analysis - Current seagrass distribution, abundance and patchiness must also be measured to assess future changes in response to hydrologic changes in the system. Aerial photography has been hampered for several years by excessive turbidity in the Bay, the last complete coverage of the Bay was obtained in 1983. Photography was flown again in 1992 and 1994 but was hampered by poor water clarity in much of the Bay. Continuous light monitoring data suggest that water clarity has improved to the point that we can now fly seagrass aerial photography again over much of the Bay. FWCC will fly new photography at 1:24,000 scale in spring 2003, collecting 325 photos on 22 flight lines (Figure 3). Images will be scanned, georectified, and, utilizing relatively new digital image processing methodologies and auxiliary data, seagrass coverage will be mapped from the rectified imagery. Spatial analysis of patch metrics will be performed on the 2003 and 1945 photography with the ultimate goals of 1) analyzing historical changes in seagrass patch metrics and 2) developing methods to quantify future changes in seagrass distribution and patchiness.

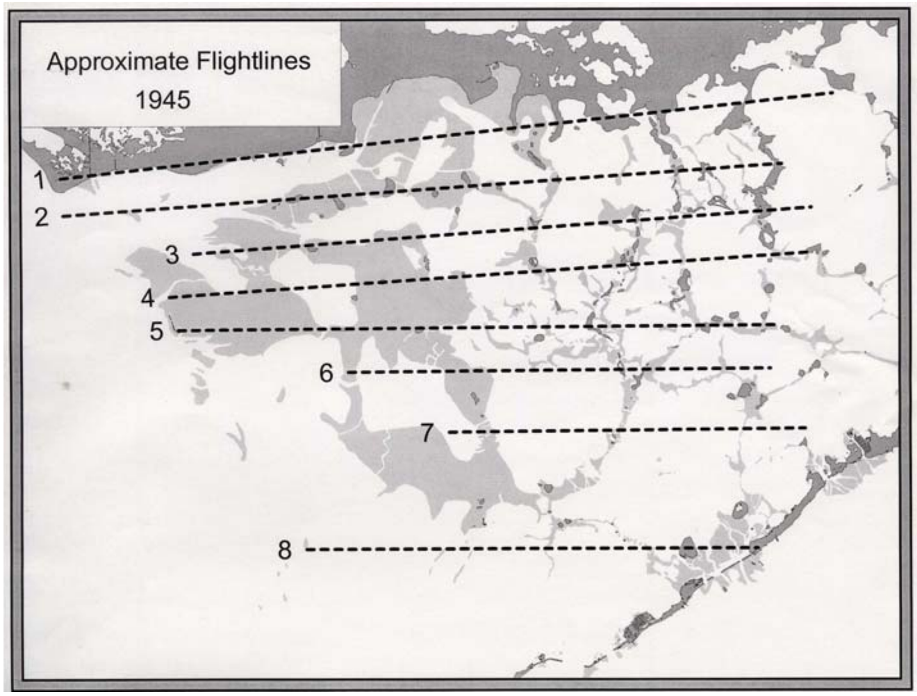

Figure 1: Flight lines for 1945 Florida Bay aerial photography.

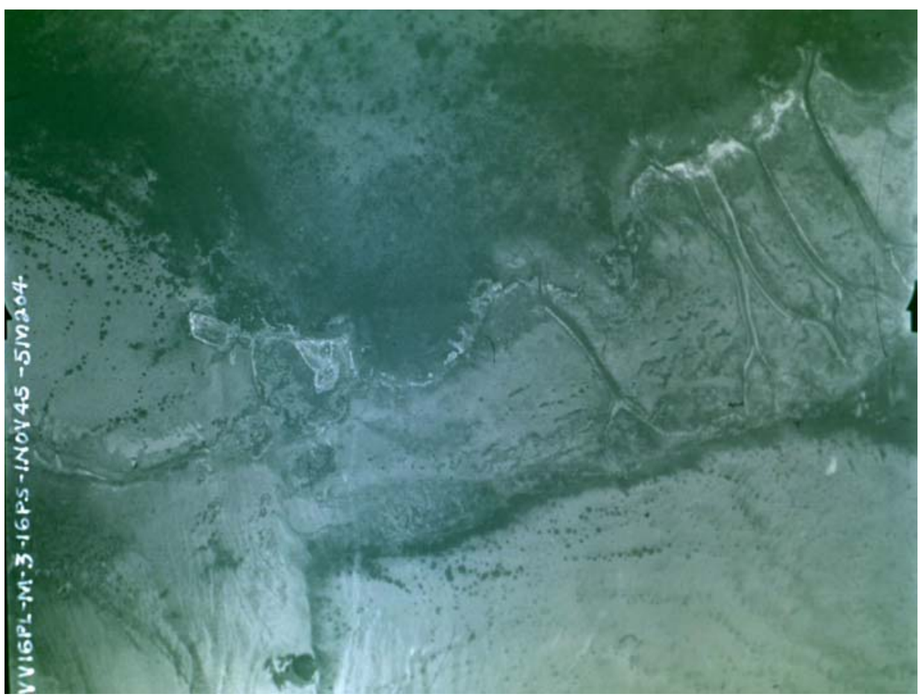

Figure 2: Detail of 1945 aerial photo of southern Twin Key Basin. Barnes Key is located at lower left center.

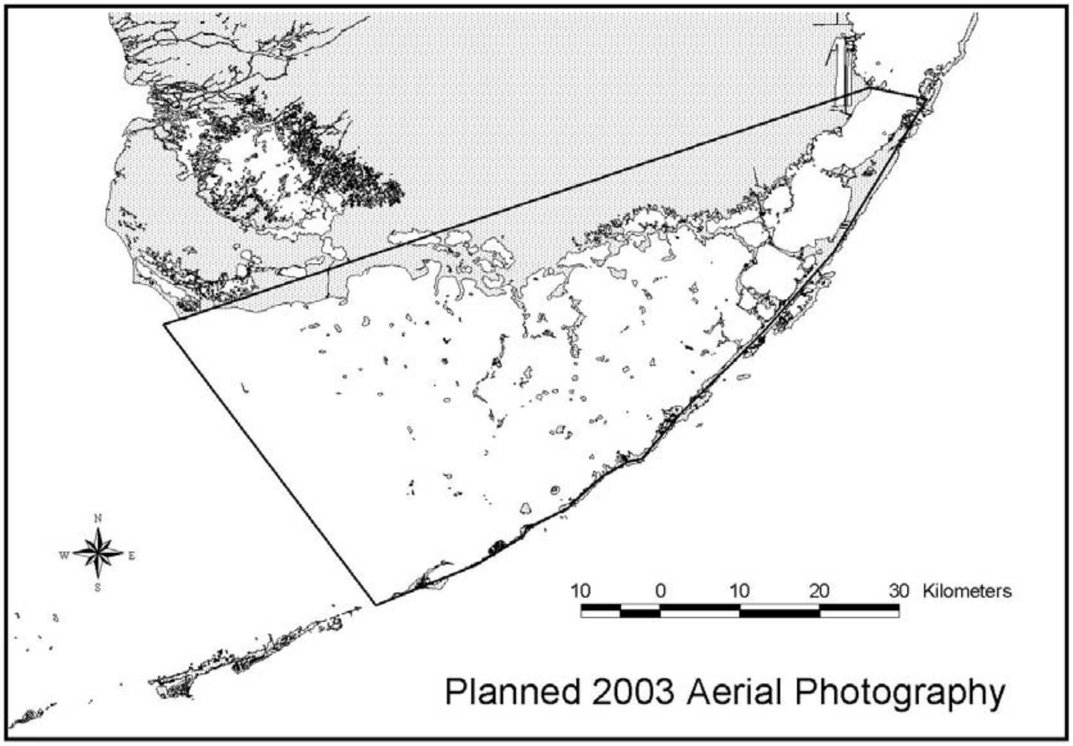

Figure 3: Study area boundaries for 2003 planned aerial photography.

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A Model of Seagrass Dynamics in Florida Bay: Evaluation and Application

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A mechanistic model of seagrass production in Florida Bay simulates seagrass and epiphyte growth as influenced by nutrient availability, light, sediment sulfide concentration, and salinity tolerance. Seagrass and epiphyte mortality and subsequent decomposition stimulate both sulfide production (a stress) and nutrient recycling (a benefit), which act as competing forces affecting seagrass production. Salinity, light regime and nutrient loading also affect the response of modeled seagrasses, epiphytes, and phytoplankton components. The model is solved numerically using a 4th order Runge-Kutta method and a step size of 3 hours (equal to 1/8 day). The goal is to couple this model with a water quality model to predict effects of large-scale management practices in Florida Bay on a spatially explicit landscape scale.

The model is initially parameterized for *Thalassia testudinum*. Intrinsic parameter values such as maximum growth rate and sulfide tolerance were determined from literature data and through targeted experiments. The model was calibrated to specific Florida Bay sites using environmental data collected from each site. Data include water column and sediment porewater nitrogen and phosphate, photosynthetically active radiation (PAR) above and below the water's surface, sediment sulfide levels, sediment organic matter, water temperature, and salinity. The model was initially forced with raw data to verify the accuracy of the model mechanisms, and then data from each site was analyzed for annual signals. These signals were then inserted as forcing functions in the predictive model. The model was used in hindcast mode for a period of five years and we tested results against historic seagrass biomass and nutrient concentration data at each site. Residuals between predicted and actual biomass were not statistically significant.

Sensitivity analyses were conducted on the model to evaluate the sources of uncertainty and the confidence of model output. Three approaches were used to evaluate the sensitivity of the model, the first being evaluation of sensitivity target response variables to forcing functions. Model output was analyzed to determine whether input signals were maintained, amplified, or damped and whether the output resulting from variable forcing functions differed significantly from those responding to constant forcings. The second approach was to introduce random variability into forcing signals to represent environmental stochasticity. The effect on the mean of the output (predicted value) and the variance of the output over multiple iterations was calculated. Our third approach was to apply a probability distribution to selected parameters to represent uncertainty in the parameter estimates.

Uncertainty analysis was used to assess the confidence of the model output assuming no environmental stochasticity. Parameters were treated singly, then in combination. Uncertainty around the parameters was assumed to be a normal random variable with mean of zero. Output variance relative to parameter variance indicates the strength of the model's dependence on the selected parameter. The probability density of the mean output is the confidence of the model predictions. The mean and variance of output variables determine the confidence interval of model predictions.

The model was used to simulate seagrass dynamics under different management scenarios for several basins in Florida Bay: Little Madeira Bay, Rankin Lake, Rabbit Key Basin, and Duck

Key. The scenarios we examined were increased and decreased salinity, increased and decreased phosphorous and nitrogen loads and changes in the subsurface light regime. These scenarios correspond to potential environmental responses to management practices being contemplated for Everglades and Florida Bay restoration. Increasing or decreasing the salinity out of optimal range resulted in reduced production, but not death, of *Thalassia* plants. The model shows that reductions in *Thalassia* density will provide opportunities for opportunistic pioneer species such as *Halodule*, and in the case of reduced salinities, increases in salinity-intolerant species, such *Ruppia* and the macro-alga *Chara*. Increased phosphorous load in the water column increased epiphyte productivity, producing an oscillation in seagrass biomass, and gradual reduction in below ground biomass. This condition led to an impairment of community resiliency- the ability to withstand and rebound from stress or conditions that cause temporary loss of above ground biomass. The model is currently being refined to enable quantitative analysis of the threshold at which nutrient introduction becomes problematic for the *Thalassia* community.

The model was also parameterized to describe *Halodule wrightii* dynamics. Since the data for *H. wrightii* parameters is less available, some of the parameters are adopted from similar species. Sensitivity analysis was conducted on these parameters to determine model uncertainty. The quantitative verification of model results was hindered by the lack of biomass data for *H. wrightii* in the absence of *T. testudinum*. This version of the model will later be refined and coupled with the *T. testudinum* model through experimentally determined interaction terms to simulate community dynamics, interspecific competition, community structure and succession.

Thus far, the model has been used only as a mean-field characterization of a seagrass bed. Bed morphology and density distribution are two areas of interest that are not directly addressed. By assigning relationships between biomass and canopy morphology or shoot density, we anticipate building into the model the ability to predict the effect of changing plant morphologies and seagrass bed densities on nutrient uptake, light availability, sediment resuspensibility, and ultimately, community survival.

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Macrophyte Benthic Communities and Groundwater Nutrient Dynamics in Biscayne Bay, Florida

Danielle Mir-Gonzalez and *Joseph N. Boyer*
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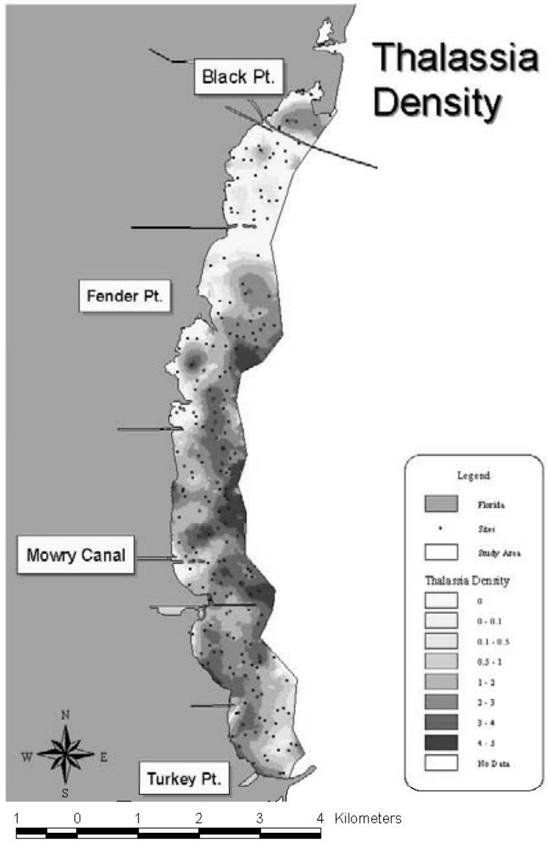
Most researchers agree that anthropogenic nutrient loading may affect the structure and function of benthic communities in shallow, marine systems. One important source of nutrient loading may be groundwater, especially in karstic limestone systems. The effects of groundwater on benthic vegetation are not well understood in estuarine areas and it may have a great impact on water quality. The presence of two landfills (old and new), and the large agricultural centers in southeast Miami pose a definite threat of groundwater quality, making this an interesting area to study.

Unlike the nearby estuary, Florida Bay, southern Biscayne Bay has very little background information on seagrass community structure and most of the published literature dates from the 1960's and 1970's. The distribution of *Thalassia testudinum* and other aquatic vegetation has been linked to groundwater discharges in Biscayne Bay (Kohout and Kolipinski 1967; Meeder et al. 1997).

This investigation is focused on the southwest region of Biscayne Bay, between Black Point and Turkey Point, and has found spatial variations of the nearshore (< 1 km) benthic macrophyte communities. Four transects consisting of four sites each were chosen based on the potential of groundwater and canal run-off nutrient concentrations. Seepage meters were installed along these transects to quantify potential nutrient loading of groundwater with distance from shore. We measured groundwater flow rates, nutrient concentrations in groundwater and surface water, and benthic community structure at each site.

Average seepage flux highs varied between transects (116 L m^{-2} day^{-1} to 13 L m^{-2} day^{-1}) during the months of August, October and December 2002. The highest flow rates were found near Mowry Canal 150 m offshore with Black Point having the second highest 300 m from shore. In general, the water obtained from seepage meters was significantly higher in phosphorus, total nitrogen, organic carbon, and ammonia (NH_4^+). Densities of *T. testudinum* plummet to zero in the Black Point vicinity. A "snap-shot" study done by Meeder & Boyer (2001) showed a similar pattern, where high levels of NH_4^+ concentrations at Black Point was correlated with an absence of *T. testudinum*. However, the nutrient levels may mask other factors that may be responsible for the decline such as salinity variations (Meeder, et. al, 2000). *Ruppia maritima* and *Chara sp*. were found where *T. testudinum* was absent. *Halodule wrightii* was the dominant species close to shore (<500 m) and in the Black Point area. The variations within the benthic macrophyte habitat will continue to be investigated in relation to nutrient availability, and groundwater inputs.



Surveyed March- May 2002

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An Assessment of Nearshore Benthic Communities of the Florida Keys

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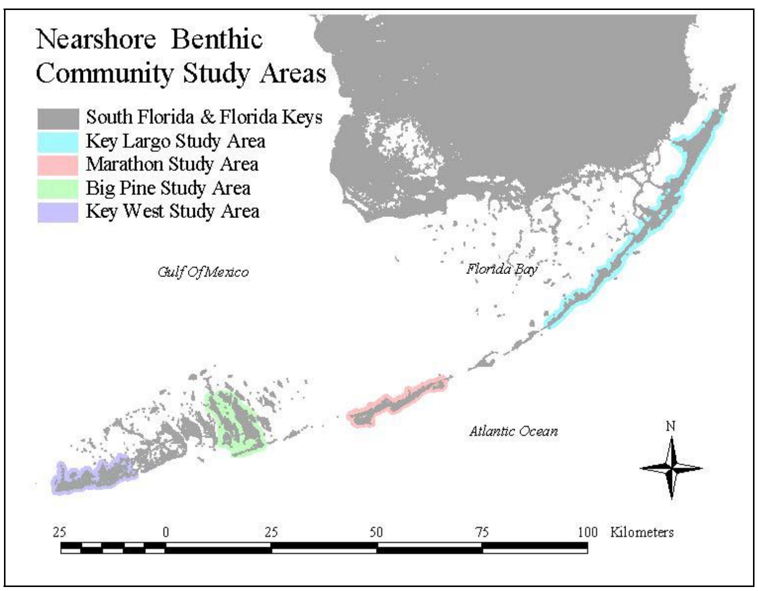
Understanding the causes of degradation to coastal marine ecosystems in the Florida Keys is a significant research and management challenge. An important aspect of this challenge is distinguishing between influences of natural environmental factors and anthropogenic factors on spatial and temporal variations in nearshore environments. Anthropogenic disturbance is often claimed to be the primary factor responsible for degradation of coastal marine ecosystems in the Florida Keys, however adequate scientific data are lacking that support this conclusion. Further, natural system variability caused by large storms, climatic shifts, and geologic history also contributes to changes within coastal marine ecosystems. Answers to the fundamental questions about causes of environmental changes in the Florida Keys remain elusive because few studies address ecosystem condition in different habitat types, at multiple scales, and over large spatial and temporal extents. Offshore coral reefs in the Florida Keys have received the most attention in terms of the numbers of studies conducted, but considerable debate still surrounds their condition. Interestingly, nearshore habitats, which are closest the potential sources of local anthropogenic disturbance and most likely to exhibit signs of anthropogenic disturbance, have been largely overlooked. In response to this oversight, a landscape scale investigation of nearshore (<1 km from shore) benthic communities of the Florida Keys was initiated.



Study areas included four regions within the Florida Keys: Key Largo, Marathon, Big Pine, and Key West. The study areas enabled sampling efforts to be distributed across the geographic extent of the keys while accounting for ecosystem variability. These four study areas were selected because they comprised the wide range of nearshore and terrestrial communities, as well as human populations, found in the Florida Keys. The study areas were characterized by a latitudinal extent of nearly 100 km and a longitudinal extent exceeding 160 km. Sampling efforts were concentrated in the nearshore zone for two reasons. First, little nearshore research has been conducted in the Florida Keys. The data collected extended existing offshore benthic survey and nutrient sampling programs to the nearshore environment. Second, if nutrients (including anthropogenically derived wastewater) are transported via groundwater or runoff in the Florida Keys, the nearshore zone is the one area where the effects may be detectable. However, it is known that excessive nutrient enrichment may only have localized effects in nearshore environments. Thus, sampling efforts within the study areas were distributed to include areas of heavy coastal development as well as undeveloped coastline. In addition, all sampling efforts were spatially intensive (on the order of 100s of meters) and concentrated close to the shoreline.

Part one of the investigation was designed to 1) document the current composition and distribution of nearshore benthic communities and 2) expose environmental factors (e.g. water depth, substrate type, sediment depth) affecting spatial variations in nearshore benthic communities. Benthic surveys were used to obtain comprehensive data on nearshore benthic community composition. A consensus classification of the community composition data resulted in eight nearshore benthic community classes; five classes represented seagrass communities, and the remaining three classes comprised hardbottom communities. The distribution of nearshore benthic community classes revealed spatially coherent variation of community composition within the study areas. There were also significant differences in the distribution of nearshore benthic community classes among study areas throughout the Florida Keys. Discriminant function analysis revealed that environmental factors could predict nearshore benthic community class membership with accuracies ranging from 25 to 50 percent.

Part two of the investigation was designed to evaluate relationships between human land use activity and the composition of nearshore benthic communities. In order to conduct the evaluation, models were developed that incorporated nearshore benthic survey data, natural environmental factors (water depth, substrate type, and sediment depth), and human land use activity (categorical land use data, quantitative nutrient loading data). GIS technology was used to calculate metrics that represented the influence of land use and nutrient loading on nearshore benthic habitats. The composition of nearshore benthic communities, represented by benthic taxa densities, was significantly influenced by proximity to land, water depth, substrate type and sediment depth. Many benthic taxa densities were also significantly influenced by human land use activity. However, these results varied tremendously, depending on which metric of human land use activity was used in the model.

Part three of the investigation was designed to describe spatial variations in the relative availability of nutrients in nearshore benthic environments. In addition, the relationship between nearshore nutrient availability and adjacent land use or nutrient loading was explored. Based upon the elemental content and ratios of the seagrass *Thalassia testudinum*, nearshore environments of the Florida Keys were characterized by low phosphorous availability. Nearly all response variables included in this investigation (seagrass, epiphyte, and sediment) exhibited significant spatial variation with respect to study area (Key Largo, Marathon, Big Pine, and Key West) and location (bayside or oceanside), but little significant spatial variation with respect to either distance from shore or land use.

Part four of the investigation was designed to characterize changes in nearshore benthic macrophytes to provide long-term perspective on historical changes in nearshore benthic communities. Specifically, the study was designed to 1) identify temporal variations in nearshore benthic macrophytes and 2) determine if these variations may be associated with land use in the Florida Keys. The analyses were conducted using four decades of black and white aerial photographs taken by the Florida Department of Transportation (FDOT). In general, nearshore benthic macrophyte communities in the Florida Keys displayed tremendous stability between 1959 and 1998; nearshore benthic macrophyte communities in the Florida Keys exhibited very slight positive changes overall. There were small, but significant differences in the amounts of change in nearshore benthic macrophytes among some of the five time steps (each step represented approximately 8 years). The nature of these small temporal changes in nearshore benthic macrophytes exhibited some spatial variation. The magnitude and direction of changes in benthic macrophytes were larger and more positive (net macrophyte increases) in the Key Largo and Marathon study areas but smaller and more negative (net macrophyte decreases) in the Big Pine and Key West study area changes. Human land use activity was shown to have little effect on changes in nearshore benthic macrophytes in the Florida Keys.

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Vertical Variations of Chlorophyll Concentration and C:N:P Ratio Along Leaves of *Thalassia testudinum* in Florida Bay: Modeling Implications.

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Seagrass photosynthesis is dependent upon the quantity of light absorbed by the leaves, which in turn is dependent on the concentration of chlorophyll in the leaves. The ability of seagrass to absorb light is determined by the sum of chlorophyll *a* and chlorophyll *b,* which are both present in seagrasses. The absorption spectrum of these two chlorophyll types differs to some extent. This indicates that the ratio of chlorophyll *a* to chlorophyll *b* influences the total amount of light absorbed. The ratio carbon to nitrogen and phosphorous (C:N:P ratio) in seagrass leaves is an indicator of nutrient availability. Given that Florida Bay is a P-limited system, lower amounts of P relative to C and N indicate a higher degree of nutrient limitation. In this study, chlorophyll contents and C:N:P ratios were compared along leaves of *Thalassia testudinum* to demonstrate how photosynthesis can vary vertically. Short shoots were removed from various geographic locations throughout Florida Bay. Locations included sites with varying light and nutrient availability. Each leaf was cut into 5 cm segments. Leaf segments were analyzed for chlorophyll content and percentage of carbon, nitrogen, and phosphorous. The vertical variation of chlorophyll concentration can be explained by leaf age. The highest chlorophyll concentrations are found at the bases of full grown leaves and the tips of young leaves. The lowest concentrations are found at the base of young leaves and the tips of the oldest leaves. C:N:P ratios also follow a pattern that suggests a decline with age of P relative to C and N. The concentration of total chlorophyll (chl *a* + chl *b*) and the ratio of chl *a* to chl *b* appears to be related to the quality of the light present at the location of the leaf sampling. Some seagrass modeling approaches utilize an average photosynthesis to irradiance relationship to drive photosynthesis. This averaging may introduce a significant degree of error into the models considering the vertical variation of the light absorption and nutrient availability coupled with the vertical variation of light availability. This study will explore the benefits of introducing this vertical component into the photosynthetic equation of seagrass models.

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Continuous Light Monitoring in Florida Bay: Interannual Variations and Light Availability to Seagrasses

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Continuous light monitoring, water quality, and epiphyte assessment in Florida Bay provide the framework for modeling the responses of seagrass communities to historical and anticipated changes in water clarity associated with recent changes and future management, respectively. At this time, we have collected four years of data (over 600,000 data records), and we can begin to see long-term as well as short-term temporal trends in the data. Furthermore, as the Comprehensive Everglades Restoration Plan (CERP) begins implementation, we see the utility of continuous light monitoring data to evaluate impacts of changed water management on Florida Bay.

Continuous light data have been collected at seven stations: Johnson Key, Rabbit Key, Rankin Lake, Little Madeira Bay, Long Sound, Butternut Key, and Peterson Key. Data collection began in November 1998 and continues at present. At each of these seven stations, we have installed Licor LI-1400 data loggers connected to two spherical, underwater light probes. The probes are PAR (photosynthetically-active radiation) sensors, which measure light with wavelengths from 400 nm to 700 nm. Their spherical shape integrates downwelling light and some bottom reflectance in much the same way that seagrass blades receive light form all directions. The probes are mounted on PVC staffs. In addition to measuring the amount of light available to seagrass and phytoplankton at the surface and at the bottom, the two probes enable us to calculate the diffuse attenuation coefficient for light in the water column. The logger records data from each probe every 15 minutes from 0530 h to 2100 h EST each day. Probes are cleaned, and data downloaded twice monthly.

In addition to the continuous bottom light data, we have summarized data by calculating several key parameters. Daily total PAR flux and peak mid-day PAR values, measured between 1100 h and 1300 h, have been calculated for each site using SAS (SAS Institute, 1988). We have also calculated the number of hours in each day when PAR values have exceeded 200 and 500 uE, respectively called Hsat 200 and Hsat 500. These parameters are based on the work of Dennison and Alberte (1985) who found that Zostera survival and growth were positively correlated with the number of hours each day when light exceeds the saturating light intensity for eelgrass, and they called the parameter Hsat. Our choice of two Hsat values, one based on 200 uE and the other on 500 uE, reflect the range of Hsat values which might be applied to seagrasses. Monthly averages have been calculated for all parameters.

We have also collected discrete water samples monthly at each monitoring site and 12 other sites scattered across Florida Bay for analysis of total suspended solids, turbidity, color and chlorophyll. For the first two years of the study, Thalassia shoots were collected monthly at each monitoring site and shoot morphometrics and epiphyte loading were measured on these samples.

All four measures of PAR—daily sum PAR, Hsat 200, Hsat 500 and mean mid-day PAR – varied significantly seasonally and among sites (Figure 1). Mean daily photon flux was generally higher at Butternut and Madeira than at Long Sound, Peterson Key or Rabbit Key. Peterson Key values have not been corrected for significant morning shading. Lowest photon fluxes occurred at Johnson Key and Rankin Lake. The seasonal pattern of daily photon flux was similar for all sites. Highest bottom light values occurred in the months of March, April and May of both 1999 and 2000. Lowest values occurred in the months of October through December. Low values coincided with seasonal insolation minima, but the maximum values in spring probably resulted form a combination of cool water (low phytoplankton growth rates), low rainfall and low cloud cover. Low light values in the fall also coincided with near maximal water temperatures. The lag between declining water temperatures and declining photoperiod in the fall is a potentially major factor contributing to historical and ongoing seagrass mortality.

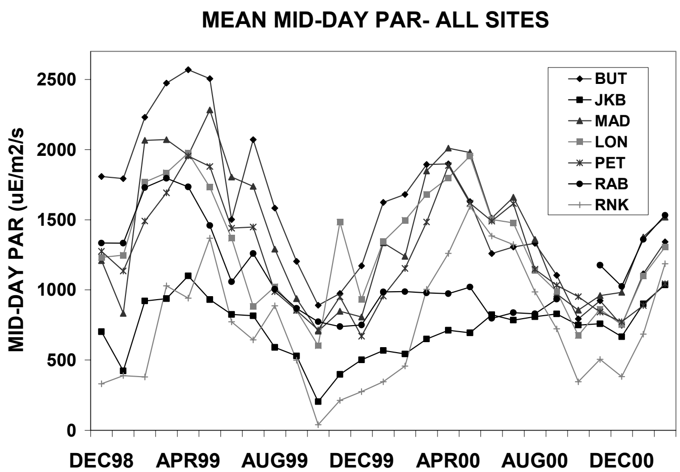

Figure 1. Average mid-day Photosynthetically-active radiation at seven Florida Bay sites.

Although Tropical Storm Harvey and Hurricane Irene did not physically disrupt or defoliate seagrass communities in fall 1999, the resultant drop in water clarity lasted for five months and had a significant impact on seagrass communities, especially in western Florida Bay (Figure 1).

With long-term data sets, subtle annual differences appear (Figure 2). Fall daily photon flux values fell between 1998 and 1999 and have shown successive increases in 2000, 2001 and 2002. In contrast, spring photon flux values declined each year since 1999, declining almost 30% over the three year period. With long–term data sets, the effect of climatic factors such as El Nino and drought years on the seasonal balance of light parameters might emerge. Their combined effects on seagrasses in Florida Bay might be considerable.

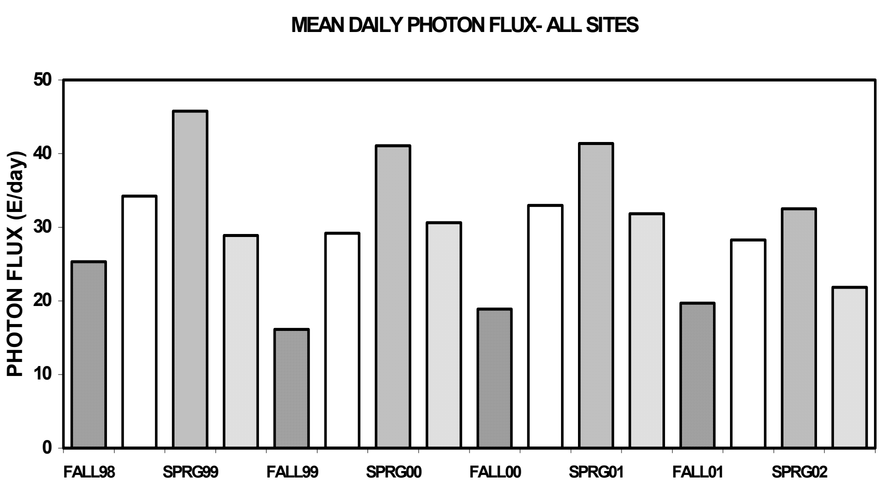

Figure 2. Daily photon flux averaged by season for all monitoring sites in Florida Bay.

We thank the following project staff: Paul Hunter, Jeff Absten, Alice Ketron, Herman Arnold, Braxton Davis, Kevin Madley, Brad Peterson, Jenny Davis and Manual Merello. The U.S Geological Survey and Everglades National Park provided financial and logistical support.

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Question 5 - Higher Trophic Levels Oral Abstracts

- Listed alphabetically by presenting author.
- Presenting author appears in **bold**.

A Framework for Assessing Ecological Risks to the Roseate Spoonbill Related to Everglades Hydrologic Restoration Activities

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We describe a risk-based framework for evaluating the effects of hydrologic restoration in the Everglades on roseate spoonbill nesting success in Florida Bay. Recognition that wading bird populations have declined by 90% motivates the present Everglades ecosystem restoration effort, and their recovery will be interpreted as an indicator of a restoration success. Changes in the roseate spoonbill population reflect an integrated response to subtle alterations in foraging habitat that are related to coastal hydropatterns (Figure 1) that are in turn driven by inland water supply and flood control operations. The quality of foraging habitat for spoonbills, as with other South Florida wading bird species, depends on (1) prey abundance, particularly small fishes, and (2) prey concentration resulting from the normal progression of dry-down in the coastal wetlands throughout the nesting season.

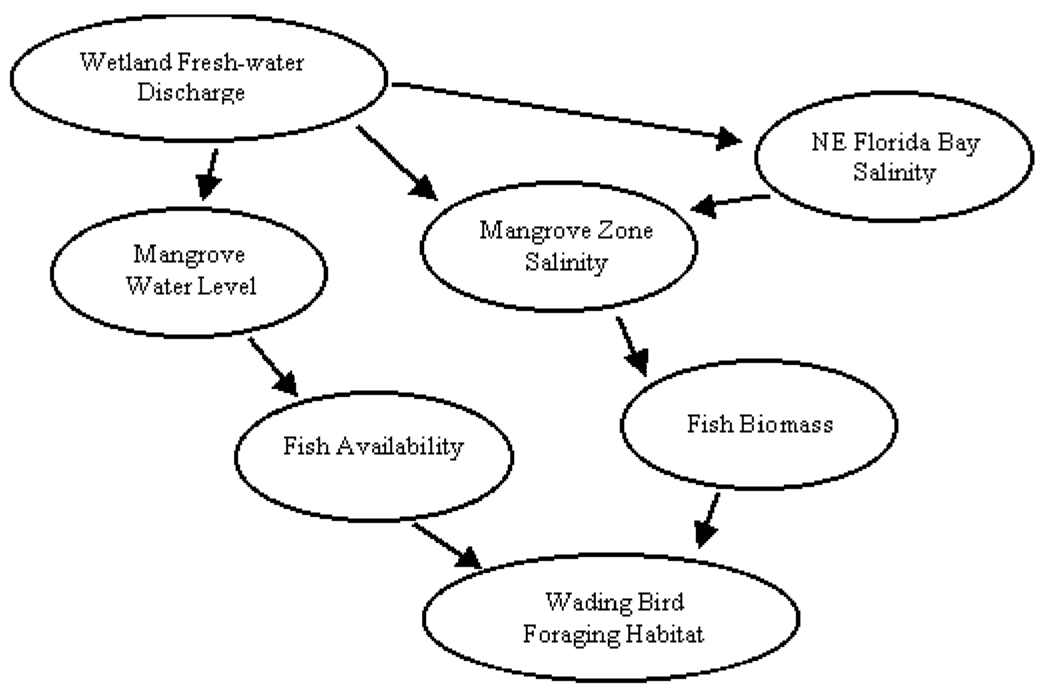

Figure 1: Conceptual model linking wetland freshwater discharge to the quality and quantity of foraging habitat for spoonbills.

Regional water management in South Florida (i.e. the Central and South Florida Project) has significantly altered historical hydropatterns that sustained coastal wetland and estuarine habitat in northeast Florida Bay. The resulting salinity regimes and altered hydropatterns have had a significant, long-term adverse effect on wildlife habitat, fishery nursery grounds, and estuarine fauna. Efforts underway to restore more natural hydropatterns in this area include the Mod Waters/C111 project and, on a longer timescale, the Comprehensive Everglades Restoration Plan. The challenge for managers is to develop methods for ecological assessment that facilitate comparison of alternative project designs or prescriptions of remedial actions that may exert their effects at different spatial and temporal scales.

The risk-based framework can be used to provide this assessment capability. Risk of adverse impacts to the spoonbill population arises from the critical importance of prey abundance and foraging habitat availability during nesting. The survival of recently fledged chicks appears to be greatly enhanced by hydropatterns that increase the amount and quality of foraging habitat. Quality foraging habitat depends on the size and location of feeding areas with water levels of $\leq$12 cm during nesting, from mid-November through March, and on salinity levels prior to the nesting season that favor higher levels of fish production.

Fundamental to implementing this approach for spoonbills are empirical relationships (1) between salinity antecedent to the nesting season and the abundance of fish prey and (2) between water level fluctuations during the nesting period and the quality and quantity of foraging habitats within 10-15 km of the nesting colonies. The quantity of freshwater in the coastal wetlands of the southeastern Everglades during the wet season strongly influences the production of forage fish consumed by spoonbills and other wading birds. Freshwater discharge exerts an immediate effect on salinity in the mangrove zone during the wet season and a delayed, longer-term effect during the rest of the year by modulating salinity in the downstream estuary. Timing of water delivery and rainfall influence prey availability during the nesting season by controlling wetland water levels.

The risk-based framework explicitly incorporates engineering, hydrological, and ecological sources of variability and uncertainty inherent to the analysis of complex ecological systems. Restoration project outcomes result in conditions that might increase, decrease, or not affect spoonbill foraging habitat. Other factors also affect the quantity and quality of foraging habitat and nesting success, for example weather, nest predation, and disease. Therefore, the potential impacts of proposed projects are estimated in probabilistic terms. Uncertainties are expressed as statistical distributions that describe the values of initial conditions, model parameters, and external forcing functions for each assessment. Monte Carlo methods are used to propagate these uncertainties and produce distributions of results, including maps of foraging habitat and estimates of spoonbill nesting success (i.e., chicks/nest).

The risk-based approach forecasts the response of spoonbill population size and viability based on the probable nesting success as affected by proposed water management plans for the Mod Water/C111 project and the CERP. Nesting success is related qualitatively to population viability using empirical rules: 0-1 chicks/nest implies a failed nesting and a future declining population, 1-1.25 chicks suggest moderate success and a quasi-equilibrium population, and >1.25 chicks indicate good nesting success and an increasing population. Subsequent modification of the risk-based framework might include a stage-based demographic population model that can be used to translate nesting success into projections of future spoonbill population sizes. Future expansion of this risk-based framework will similarly include other ecological indicators of Everglades restoration.

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Postlarval Transport of Pink Shrimp into Florida Bay

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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 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 (Figure 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 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% of the total variance in the east-west and north-south current data respectively in the onshore station and 97% and 30% 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

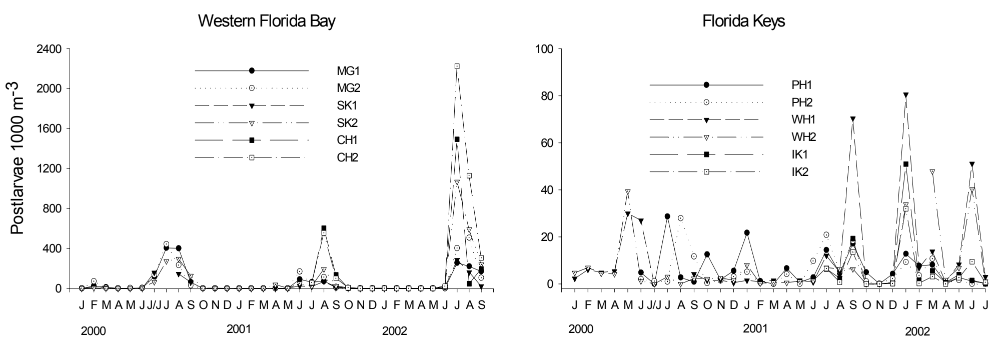

Figure 1. Densities of pink shrimp postlarvae at the two sampling sites

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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Mercury in Fish From Eastern Florida Bay

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Previous work during the period 1995 to 2000 has identified much of eastern Florida Bay as a region in which gamefish and forage fish have elevated mercury concentrations. Thirty-seven percent of spotted seatrout in this region contained more than Florida's no consumption advisory level of 1.5 $\mu g\ g^{-1}$ wet weight. Within this region, the transitional areas near Little Madeira and Joe Bays where freshwater enters the bay from the Everglades seemed to be the focus of highest concentrations. This has suggested that the Everglades, known to have a mercury problem, might be exporting mercury to Florida Bay. Freshwater diversions planned under the Comprehensive Everglades Restoration Plan (CERP) could worsen the mercury situation among Florida Bay fish which are consumed by piscivorous birds, reptiles, and mammals, putting wildlife as well as humans at risk.

Newer work has targeted the freshwater flow paths connecting the Everglades to northeastern Florida Bay as potential mercury sources to fish. Work reported separately by Rumbold *et al.* (these proceedings) describe patterns in the concentrations of mercury and methylmercury in water and sediments collected along two transects from the Everglades into Florida Bay through Little Madeira Bay and Joe Bay, respectively. We describe here the patterns of mercury in fish collected from these two transects.

A total of 562 fish samples have been analyzed for mercury. These include both gamefish (largemouth bass, peacock bass, red drum, spotted seatrout, snook, gray snapper, and jack crevalle) as well as intermediate sized and forage fish. Jack crevalle, which were extensively sampled, averaged more than 1.0 $\mu g\ g^{-1}$ wet weight, and exceeded the Florida no consumption advisory almost as frequently as spotted seatrout.

Along with work of Strom and Graves, there is no evidence of dramatic changes in mercury concentrations in these gamefish over the past decade, which contrasts with work in the central Everglades where the mercury in largemouth bass and other species seem to be declining. Forage fish are similar in lacking dramatic changes in mercury concentrations.

The pattern of summer seasonal maxima in methylmercury concentrations in water reported by Rumbold *et al.* (these proceedings) are mirrored by maxima in mercury concentrations in silversides (*Menidia* spp.), a fast growing pelagic forage fish. This linkage between methylmercury concentrations in water and mercury concentrations in this fish is strongest at sites within the mangrove transition zone and suggests that higher exposures to part of the food chain is translated to higher mercury bioaccumulation. This pattern is not observed in other species of forage fish for which we do not have adequate numbers of samples. Gamefish do not reveal such a seasonal pattern, and would not be expected to do so because of wider home ranges leading to spatial integration and slower growth and mercury cycling rates leading to temporal damping of the seasonal signal. There is some evidence of higher mercury concentrations in fish collected from the Taylor River/Little Madeira Bay transect than the C-111/Joe Bay/Trout Creek transect. Silversides, which were the only fish found across the wide salinity gradient, tended to have higher mercury concentrations at sites of lower salinity in the mangrove transition zone.

PERCENTAGE OF GAMEFISH IN EASTERN FLORIDA BAY OR ITS EVERGLADES DRAINAGE EXCEEDING FLORIDA'S ADVISORY CRITERIA				
	PRIOR WORK		CURRENT WORK	
	$\geq 0.5\ \mu g\ g^{-1}$	$\geq 1.5\ \mu g\ g^{-1}$	$\geq 0.5\ \mu g\ g^{-1}$	$\geq 1.5\ \mu g\ g^{-1}$
Spotted seatrout	97%	37%	100%	50%
Jack crevalle	70%	20%	92%	28%
Red drum	68%	5%	55%	9%
Gray snapper	21%	0%	29%	0%
Snook	89%	0%	44%	0%
Largemouth bass	----	----	59%	5%
Peacock bass	----	----	10%	0%

Analyses of stable carbon and nitrogen isotopes allows some characterization of the position of fish in the food web. They also define the relative importance of terrestrial/freshwater and estuarine sources of food to fish and, by inference, their mercury content which is largely derived from food. A plot of mercury concentrations in select species against their stable carbon isotope signatures indicates that freshwater fish (peacock bass, oscar, and mosquitofish) are characterized by a stable carbon isotope signature ($\delta^{13}C \leq -30$) characteristic of the Everglades, fish from the mangrove transition by intermediate values ($-30 \leq \delta^{13}C \leq -22$), and Florida Bay fish by lower values tending toward the isotope signature of seagrass or microalgal dominated food webs (*ca* $\delta^{13}C = -14$). This offers the possibility of testing the association of $\delta^{13}C$ with mercury concentrations in fish to infer the importance of an Everglades source of mercury. Given a strong Everglades source of mercury, mercury concentrations in any single species of fish should parallel the gradient in $\delta^{13}C$ values. This was not observed, and for jack crevalle we observed a pattern counter to this expectation.

Stable nitrogen isotope signatures can serve as a surrogate for trophic level. Gamefish have higher $\delta^{15}N$ values than forage fish and higher mercury concentrations, consistent with trophic biomagnification. Jack crevalle have higher $\delta^{15}N$ values and mercury concentrations than gray snapper, also confirming this expectation.. Among forage fish, pelagic-feeding anchovies and silversides have higher mercury concentrations than benthic feeding killifish and mojarra despite similar $\delta^{15}N$ values. This suggests different trophic pathways.

The absence of strong relationships between salinity or $\delta^{13}C$ values and mercury concentrations in fish suggests that a single source of mercury derived from Everglades runoff is inadequate to explain the complex patterns observed. A better understanding of food web linkages, fish movements between ecotones, and the biogeochemistry and bioavailability of mercury and methylmercury will be needed before the impact of altered freshwater flows during Everglades restoration can be predicted.

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The Use of GAM Modeling Techniques to Evaluate the Effects of Freshwater Flow Into Florida Bay- Part 1- Forage Fish Models

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An integrative database was assembled from three decades of forage fish studies conducted in Florida Bay. GAM models for 10 species of fish and pink shrimp were developed from this database. Samples were linked to other information: tidal amplitude, sea level, rainfall, freshwater discharge indices, wind, salinity, and habitat type (physical habitat, seagrass density, and seagrass type). The 11-species community selected for statistical models comprised 87% of the throw-trap samples by number for 1980's and 1990's. The group comprised 86% of the 1980's trawl data, 66% -89% of the 1990's trawl data, and 74% of the 1990's seine samples. During the 1970's, the 11-species group comprised 64% of the fauna sampled in the western bay, 92% in the central bay, and 39% in the eastern bay. A second database was prepared that combined ENP creel census data with environmental variables.

Freshwater flow was a significant model variable for all species, while month, seagrass density, seagrass type, and tidal amplitude were significant variables for 10 of the 11 species, followed by depth (9 species), habitat and temperature (8 species), and salinity and rainfall (7 species). Gear and wind (6 species), and sea level (5 species) were less important variables in predicting the abundances of forage species in the Bay.

All the resident species (except goldspotted killifish) and the pelagic species, bay anchovy (which spawns both offshore and inshore), showed a positive relationship with freshwater flow into the Bay. In contrast, the three species that spawned outside the Bay showed either a negative relationship with the previous month's freshwater flow that flattened out at higher flows (pinfish) or a negative/positive relationship to lagged freshwater flow.

Three species (bay anchovy, code goby, and gulf pipefish) were negatively correlated with salinity and two species (dwarf seahorse and mojarras) declined under hypersaline conditions. Pink shrimp and gulf toadfish showed a parabolic relationship to salinity peaking at 29 ppt and 32 ppt respectively. One species (code goby) was positively correlated with salinity. Predicted abundance of the two smallest species (rainwater killifish and goldspotted killifish) was highest at extreme conditions (low and high salinity) which suggests competitive exclusion or increased predation at moderate salinities.
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The density of two resident species (rainwater killifish and clown goby) was negatively related to rainfall, one resident species (code goby) was positively related to rainfall, and another resident species (goldspotted killifish) had a parabolic relationship with rainfall. Among the outside spawners, pinfish was positively correlated with rainfall (previous month), and mojarras were negatively correlated with lagged rainfall.

Two resident species (rainwater killifish and gulf pipefish) and the three offshore spawning species (pinfish, mojarras, and pink shrimp) were positively correlated with seagrass density. Predicted densities of gulf toadfish, dwarf seahorse, and goldspotted killifish were significantly higher at moderate seagrass densities. Densities of the pelagic bay anchovy were also significantly higher at moderate seagrass densities. Densities of the two gobies were highest in sparse seagrass. Increased densities of five species (gulf toadfish, dwarf seahorse, clown goby,

code goby, and bay anchovy) may have resulted from decreases in seagrass density due to seagrass die-off in the late 1980's. The models suggest that declines in seagrasses from moderate to sparse would result in increases in the two goby species, but declines in gulf toadfish and dwarf seahorse. The models predict that declines in dense seagrass would lead to declines in rainwater killifish, mojarras, pinfish, pink shrimp and gulf pipefish.

Seagrass type was important for all species but gulf toadfish, with significant higher densities in *Syringodium* (pinfish, dwarf seahorse, rainwater killifish), *Halodule* (pink shrimp, gulf pipefish, goldspotted killifish), mixed seagrass with *Thalassia* dominant (code goby), mixed seagrass with *Syringodium* dominant (mojarras, clown goby). The bay anchovy showed the strongest correlation to areas with no seagrass.

Densities of the three offshore spawners--pink shrimp, pinfish, mojarras were positively related to one or more physical parameters that may be indices of transport mechanisms for recruitment: tidal amplitude, sea level, and wind forcing. Densities of bay anchovy, a species that may spawn outside of the Bay as well as within it, also were positively related to these factors. In contrast, those species that spawned exclusively within the Bay and may be less dependent upon recruitment mechanisms showed less correlation with these factors.

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Use of Geochemical Tracers to Elucidate Life History Trajectories of Gray Snapper within South Florida's Marine Ecosystems

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The snappers inhabiting South Florida's marine ecosystems are a commercially, recreationally, and ecologically important group of higher trophic level carnivores. The larvae of a number of species are believed to settle in seagrass and mangrove habitats of Florida Bay where they spend their juvenile phase before migrating to the reef tract as young adults. Trace elements incorporated into the otoliths of fish during growth vary in composition and proportion depending on the environmental conditions fish were previously exposed to. Technological developments have recently become available to detect the microchemical constituents of fish otoliths and determine trace elemental signatures. These signatures can differ among stocks exposed to different water masses and environmental conditions allowing them to serve as natural tags for tracking fishes.

The elemental composition of otoliths extracted from juvenile gray snapper (*Lutjanus griseus*) collected in and around Florida Bay were examined using solution based Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) in order to determine the existence of a unique "Florida Bay Signature". Juvenile Gray snapper were obtained from waters in and around Florida Bay using a variety of collection gears from Jan-2001 to Aug-2002. Specimens were kept frozen until dissection of otoliths was performed. All dissection, cleaning, and drying of otoliths was performed under Class-100 clean room conditions using acid washed glass instruments and polyethylene storage capsules. Samples were transported to the Laboratory for Isotope and Trace Element Research (LITER) at Old Dominion University where they were decontaminated, weighted, and dissolved in acid. Samples were processed using a double focusing sector field Finnigan MAT Element-2 ICP-MS using internal and external standardization and method blanks.

The selection of elements to use as natural tags was based on their known occurrence in seawater and usefulness for stock discrimination in previous work. A suite of Rare Earth elements was included in the analysis since they lack biological activity and should more readily reflect environmental conditions in otolith chemistry. Additionally, Rare Earths are indicative of freshwater (riverine) input and anthropogenic effects. A total of 32 elements were targeted for analysis: Li, Na, Rb, Mg, Sr, Ba, Sc, Y, Lu, Cr, Mn, Fe, Cu, Zn, Cd, Hg, Pb, and P; a suite of rare earth elements (La, Ce, Pr, Nd, Sm, Gd, Tb, Dy, Ho, Er, Tm, Yb) and the actinoids Th and U.

Nonparametric (permutation-based) forms of MANOVA and Canonical Discriminant Analysis were used in the analysis of otolith trace elemental data in order to test for differences in elemental signatures within and among collection sites and across habitat types. Our results indicates a tentative "Florida Bay signature" can be defined by this technique, based primarily on the Rare Earth components of the elemental suite examined. This "Bay signature" allows high resolution spatial separation of collection sites, on the order of 10 km, with additional, significant variation attributed to habitat type.

Our ultimate goal is to employ multivariate pattern matching techniques comparing the juvenile portion of adult otoliths from the reef tract to our "Bay signature" in order to assess the proportion of adults on the Reef that used the Bay as a nursery habitat. The ability to reconstruct the environmental history of individual fish is a significant advancement in our ability to describe life histories and habitat requirements. These results are believed to offer new tools to fisheries managers and may have important implications regarding connectivity, establishment of marine protected areas, and designation of essential fish habitat.

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Potential Effects of the Diversion of Freshwater Flow from Taylor Slough to the C-111 Canal on the Salinity, Hydrology, Prey-Base Fish Community and Roseate Spoonbill Nesting Population of Northeastern Florida Bay

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The preponderance of scientific evidence clearly indicates that the Northeastern Basin of Florida Bay (defined as the basin south of Little Madeira Bay, Joe Bay and Long Sound and east of the Black Betsy Keys) has become more saline. The changes in freshwater flow to Florida Bay resulting from upstream water management practices has been implicated in the increased salinity regime and in many of the adverse ecological changes that occurred to the ecosystem in the 1980's and 1990's. Freshwater orignitating from either Taylor Slough or the C-111 Canal enters the Northeastern Basin via a broad swath of mangrove wetlands to the north. A currently accepted paradigm for restoring historically low salinity regimes of the Northeastern Basin is to move more fresh water across these wetlands, from both sources, and keep fresh water flowing from these wetlands into Florida Bay well into the dry season. I present evidence that re-establishing historic timing and distribution of freshwater flow may be as important, or more important, to achieving the goal of lower salinity than an increase in overall flow quantity.

Estimates of historic flow indicate that the vast majority of freshwater reached the Northeastern Basin via Taylor Slough and predominantly entered the Bay through creeks in Little Madeira Bay and western Joe Bay. Significant flow also arrived at the Northeastern Basin via the Transverse Glades Sloughs; however, these flows were relatively small compared to that of Taylor Slough. Today's water management practices have effectively reversed this situation, resulting in greatly reduced quantities of water flowing through Taylor Slough (compared to historic flows) and heavily augmented flows reaching the Long Sound area due to operation of the C-111 canal. Evidence is presented that suggests this redistribution of fresh water has resulted in increased and more variable salinity within the Northeastern Basin and the adjacent coastal wetlands. These salinity changes have been linked with lower secondary productivity in the prey-base fish community of these wetlands.

Finally, the redistribution of flow from Taylor Slough to the C-111 Canal appears to have resulted in higher and more variable water levels on the coastal wetlands during the dry season. I will attempt to show that the increased dry season water levels, coupled with the previously mentioned reduction in prey-base fishes, has lowered the quality of these wetlands as foraging habitat for Roseate Spoonbills. This reduction in foraging ground quality has manifested itself in lower nesting success in spoonbills and may explain the observed decline in nesting effort within the Northeastern Basin since the early 1980's. As with the salinity regime, a return to historic timing and distribution of freshwater flow would likely alleviate this situation.

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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 relationship 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.

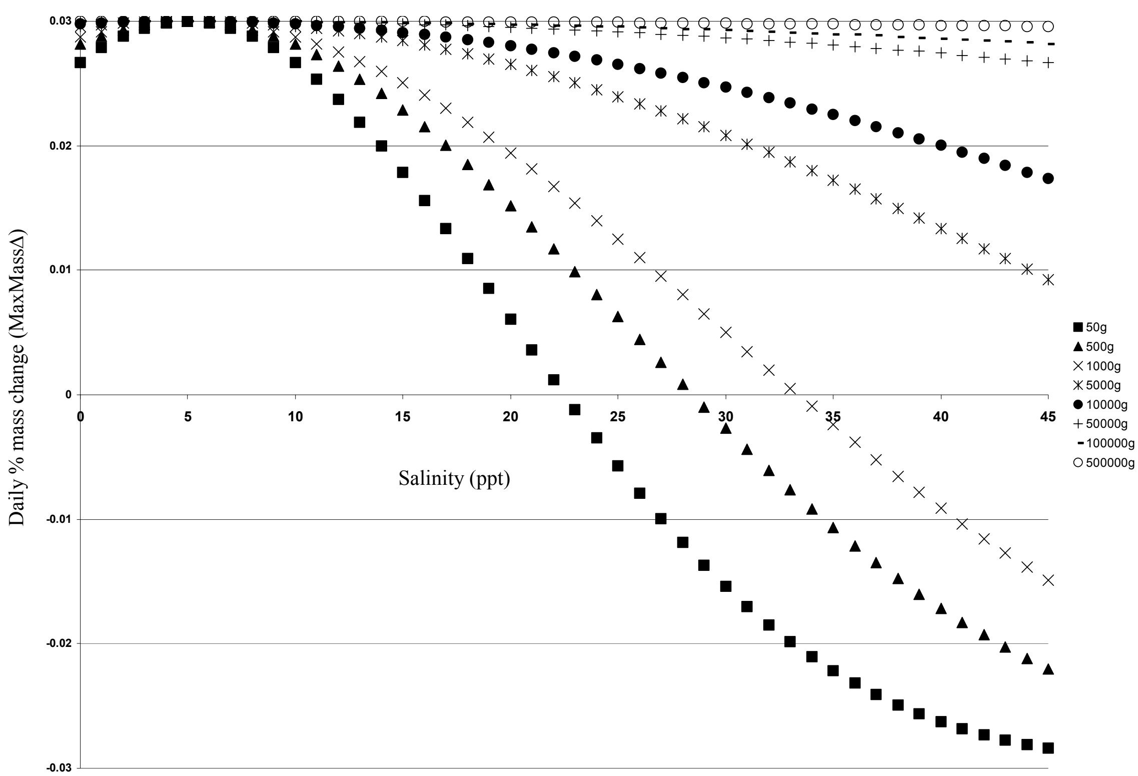

Figure 1: Daily percent change in mass (MaxMassΔ) as a function of salinity for model *C. acutus* from 50g to 500kg.

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% 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 3 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 3 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 3 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 it's 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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Using Bottlenose Dolphins as an Indicator Species in Florida Bay: Analyzing Habitat Use and Distribution Relative to Water Quality, Habitat and Fish Community

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Dolphin Ecology Project, Key Largo, FL

Background:
Our research is focused on the effects of habitat restoration on bottlenose dolphins in Florida Bay. Bottlenose dolphins range throughout Florida Bay and beyond, and their patterns of distribution reflect variation in various environmental parameters. We are particularly interested in the dynamics of dolphin predator-prey interactions in the context of habitat and water quality. As the first step in this research, we tested the hypothesis that dolphins occur and feed preferentially in habitats where prey densities are high. We have also examined whether or not variation in the density of potential prey is related to spatial variation in water quality and habitat type.

Methods:
We assessed dolphin distribution and habitat use in dedicated boat-based surveys throughout each basin of Florida Bay between June 15th and August 15th, 2002. The bay was divided up in five zones (Eastern, Central, Western, Gulf Transition and Atlantic Transition) based on similar environmental conditions (e.g. Thayer and Chester 1989, Sogard *et al*. 1989) and 6 bottom habitat types (seagrass, hardbottom, open mud, open sand, mud bank, mixed bottom type) based on the "Florida Bay Bottom Types" map created by the USGS in 1997 (Haley 1997). GPS waypoints were collected every five minutes and water quality parameters (salinity, temperature and clarity) were recorded every 30 minutes. Each area of the bay was surveyed twice throughout the summer to ensure equal survey effort in all habitats. At all sightings of dolphins, GPS location was recorded and water quality parameters measured. Photo-identification was conducted to determine group composition and site fidelity of individuals. Group size, the presence or absence of calves, and behavioral state were also noted.

To assess the fish community throughout Florida Bay, we used two fishing techniques: bottom trawls and gillnets. Demersal prey was sampled using a 3-m research otter trawl, towed at a speed of 4-5 knots for 3 minutes. The gillnet was comprised of 3 ¼ inch mesh and was set for 30 minutes. The locations of bottom trawls and gillnet sets were randomly generated, using GIS, to adequately sample the different habitat types and zones within Florida Bay. Fish were identified and measured before being released alive. Water quality was measured at each trawl and gillnet site. A total of 121 trawls and 26 gillnet sets were conducted during the summer of 2002. Trawling and gillnetting caught different species and size classes of fish, regardless of location.

All information was analyzed using Geographic Information Systems (GIS) software (Arc) to determine spatial relationships between (1) effort within habitat types and zones, (2) dolphin distribution and density, (3) water quality, (4) fish diversity and abundance and (5) dolphin behavior.

Results:

Bottlenose dolphins were distributed non-randomly among the various habitats of Florida Bay ($p < 0.001$, $\chi^2 = 235$, df = 5). Only 12% of Florida Bay is covered by mud habitats, but 33% of all sightings and 42% of all animals sighted in the Bay occurred in these habitats. In addition, the number of sightings ($p = 0.0002$, $\chi^2 = 22$, df = 4) and the number of dolphins ($p < 0.001$, $\chi^2 = 142$, df = 4) were distributed non-randomly in the five zones of the Bay. Very few dolphins were observed in the eastern and Atlantic transition zones (Figures 1 and 2). Only 1% of the eastern zone and less than 1% of the Atlantic transition zone is covered by mud. Spatial analysis revealed that dolphin sightings occurred most frequently in the northern part of the Central zone (Figure 1), but the actual density of dolphins (corrected for group size of each sighting) was greatest in the western part of the bay, particularly in the Gulf Transition zone and Western zone (Figure 2).

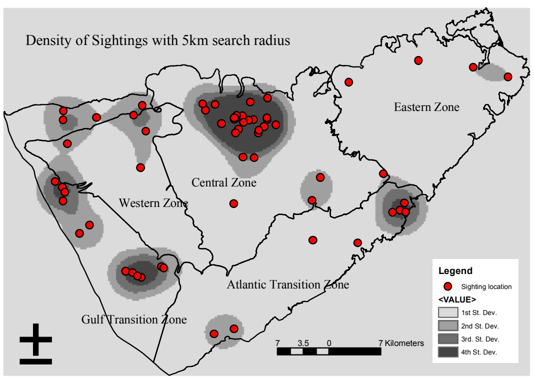

Figure 1.

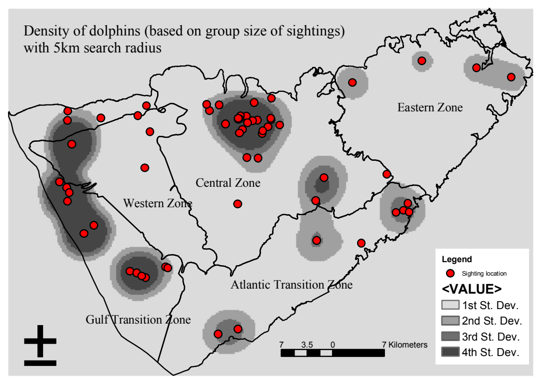

Figure 2.

Catch per unit effort (CPUE) of fish caught in trawls was related to the zone in which the trawl was conducted ($p < 0.001$, $\chi^2 = 34.5$, df = 4). The relationship between CPUE and bottom habitat type was not significant ($p = 0.103$, $\chi^2 = 7.7$, df= 4). CPUE of fish decreased significantly with depth ($p = 0.002$). (Analysis of CPUE compared to salinity and temperature has not been completed yet.) Total fish caught in gillnet sets was significantly related to both zone ($p < 0.01$, $\chi^2 = 13.3$, df = 4) and bottom habitat type ($p < 0.03$, $\chi^2 = 12.2$, df = 5).

Discussion:

Florida Bay is characterized by strong environmental gradients, particularly with regard to salinity, and a diversity of habitat types. In this environment, fish are patchily distributed, occurring in environments that are within their physiological tolerances and provide suitable habitat. Piscivorous predators, such as bottlenose dolphins, respond to the patchy distribution of prey by concentrating their foraging efforts in areas where prey are abundant. Due to their visibility, bottlenose dolphins are a good indicator of distribution or prey and, in turn, of the quality of the habitat and environment which support these fishes. By monitoring the habitat use and distribution ecology of bottlenose dolphins with synoptic sampling of the fish community and water quality, we quantified the response of bottlenose dolphins to environmental variation in Florida Bay to obtain a better understanding of the effects of environmental variability on upper trophic level predators throughout the Bay.

It is apparent from our preliminary examination of our data that the number of sightings, the number of dolphins and fish caught in both trawls and gillnets are related to zone and, less strongly, to bottom habitat type. We plan to conduct further analysis of dolphin distribution, abundance and behavior, as related to habitat type and the distribution of fish communities, to shed light on the spatial and temporal dynamics of dolphins and their prey in Florida Bay.

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Question 5 -
Higher Trophic Levels
Poster Abstracts

- Listed alphabetically by presenting author.
- Presenting author appears in **bold**.

The Pathological and Ecological Effects of a Herpes-like Virus in the Caribbean Spiny Lobster, *Panulirus argus*, from Florida

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In 1999, we discovered the first virus known to infect any species of lobster. HLV-PA is a pathogenic herpes-like virus that infects juvenile Caribbean spiny lobster, *Panulirus argus*, in the waters off south Florida (USA), and it alters the behavior and ecology of this species in fundamental ways. Gross signs of HLV-PA infection are lethargy, morbidity, cessation of molting, and discolored "milky" hemolymph that does not clot. HLV-PA infects the hemocyte cells of host lobsters, specifically the hylinocytes and semi-granulocytes, but not the granulocytes. When hemolymph from infected donors was injected into healthy juvenile lobsters 90% of the healthy individuals became infected within 80 days. In another set of laboratory trials, 40% of the juvenile lobsters that ingested conspecific tissue infected with HLV-PA developed the disease. In a third experiment wherein transmission by contact or waterborne means was tested, 63% of the lobsters <30 mm carapace length (CL), 33% of lobsters 30-40 mm CL and 10% of lobsters 40-50 mm CL were infected within 80 days.

In field surveys from 2000-2001, up to 40% of the juveniles at each of twelve sites (mean = 8%) had the disease. It is most prevalent (mean = 16%) among the smallest juveniles (i.e., < 20 mm CL), and thus far appears limited to juveniles. However, all of the surveys of disease prevalence are based on gross, visual signs of late stage infection, and are therefore conservative estimates. A diagnostic tool to assess infection at earlier stages is under development.

Field observations and laboratory experiments indicate that healthy juvenile lobsters avoid diseased conspecifics, which is only the second report of such behavior in any animal. The prevalence of the disease in wild lobster populations is not correlated with population density, even when lobsters were experimentally concentrated at sites with artificial shelters. An intriguing epidemiological twist is that commercial and recreational fishing activities for this economically valuable species potentially contribute to the spread of the pathogen.

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Regional Assessment of Hard-bottom Communities in the Florida Keys with an Emphasis on Lobster and Sponge Dynamics

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Background

Nearshore hard-bottom habitat is a ubiquitous feature of the shallow waters within the Florida Keys, yet remarkably little is known about their structure or ecological function, a fact highlighted in recent years by questions about the possible impact of environmental change and resource exploitation on these communities. During the past decade, hard-bottom communities in south-central Florida Bay were altered by widespread sponge die-offs. There are now concerns about the possible impact of Everglades restoration and salinity change on hard-bottom communities in this same region. The potential impact on spiny lobster nurseries are of particular concern because of the economic importance of this species in the region. In addition, the perceived over-exploitation of shallow water sponges by the commercial sponge fishery has prompted a call by some for the closure of the fishery. Resolution of this issue is hampered because there has been no stock assessment of sponges in the Florida Keys, the population dynamics for the pertinent species are largely unknown, and the effect of the fishery on commercial sponges and allied species in hard-bottom habitat have never been studied.

Objectives

Recently, we began a series of field studies, laboratory studies, and simulation modeling to better understand commercial sponge population dynamics, to determine the impact of the sponge fishery on sponge communities, and to examine the effect of salinity change on lobster, sponge, and octocoral survival in shallow hard-bottom habitat. Specifically, we seek to:

(1) Conduct the first in-depth, large-scale assessment of shallow hard-bottom community structure in the Florida Keys.

(2) Determine from repeated field measurements of tagged sponges at various sites throughout the Florida Keys the necessary site- and size-specific population dynamics information needed for the management and modeling of commercial sponge populations.

(3) Conduct field studies in concert with representatives of the fishing industry to determine the catch efficiency of sponge fishers and the by-catch associated with sponge harvesting.

(4) Conduct laboratory studies that experimentally test the tolerance of prominant hard-bottom-dwelling species (e.g., spiny lobster, five sponge species and two octocoral species) to different salinities, periods of exposure, and water temperatures.

(5) Incorporate new and existing information in a spatially-explicit simulation model to quantitatively compare the impact of potential management strategies on the sustainability of the sponge fishery and its impact on hard-bottom community structure in the FKNMS.

Objective 1: Hard-bottom Community Surveys

In the summer of 2002, we completed a comprehensive survey of the density of 60 different species of sponges, octocorals, corals, and macroinvertebrates at 135 shallow hard-bottom sites throughout the Florida Keys. Those data, which we are now analyzing, will be used to:

(a) characterize hard-bottom community types relative to GIS habitat designations

(b) determine if biogeographic provinces exist for hard-bottom in the Florida Keys

(c) ascertain an appropriate subset of sites suitable for long-term monitoring of hard-bottom in the region

(d) determine the current status of commercial sponge populations in the Florida Keys.

Objective 2: Sponge Population Dynamics
In the winter of 2002-2003, we established a dozen sites spanning the Florida Keys where we are monitoring the size-specific growth and reproductive status of three commercial sponge species: sheepswool sponge (*Hippospongia lachne*), yellow sponge (*Spongia barbara*), and glove sponge (*Spongia graminea*). At a subset of those sites we are also experimentally determining whether sponges that are disattached from the substrate continue to grow or can subsequently reattach to the bottom.

Objective 3: Fishery Impacts on Sponge Communities
These field experiments are planned for the summer of 2003.

Objective 4: Salinity Tolerance of Prominent Hard-bottom Species
In the summer of 2002, we completed a series of laboratory experiments in which we tested the salinity tolerance of three size classes of Caribbean spiny lobster (*Panulirus argus*), five species of sponge (loggerhead sponge – *Speciospongia vesparium*; vase sponge – *Ircinia campana*; branching candle sponge – *Ircinia sp*.; sheepswool sponge; golfball sponge – *Cinachyra alloclada*), and two species of octocoral (angular seawhip – *Pterogorgia anceps*; purple sea plume – *Pseudopterogorgia acerosa*) at typical winter and summer water temperature. The survival of these species were tested at four salinities (15 psu, 25 psu, 35 psu, 45 psu) at winter (18^{o}C) and summer (28^{o}C) water temperatures. The sponges and octocorals were subjected to two types of salinity stress in separate experiments. In one, salinities were altered from 35 psu then held constant for the remainder of the experiment, whereas in the other experiment the species only experienced the target salinity for 2 days before salinity returned to 35 psu. We also used laboratory assays to test whether juvenile spiny lobster movement changed in response to changing salinity. Our results indicate that octocorals were intolerant of salinity change. Although survival varied among sponge species, all sponges were generally intolerant of low (15 psu, 25 psu) or high (45 psu) salinity even for short periods of time (2 days), and especially at summer water temperatures. Only the smallest juvenile spiny lobster died in response to altered salinity in our experiments; the larger two size classes experienced no mortality after 6 weeks of exposure. However, larger juvenile lobsters respond to changing salinity by increasing their movement, but increased movement is not sustained at the most extreme salinities.

Objective 5: Modeling
We have completed the modeling of potential salinity impacts on spiny lobster, sponge, and octocoral populations in the Florida Keys. We simulated salinity conditions in the Florida Keys during an average year compared to an exceptionally dry or wet year using salinity conditions prevalent in the region during 1993 and 1995. Florida Bay experiences the most extreme salinities during wet and dry years and it is in these areas in our model where lobsters, sponges, and octocorals are most impacted. Sponge and octocoral populations in Florida Bay experienced mass die-offs in our model under extreme salinities. The impact of extreme salinity on juvenile lobsters was both direct (i.e., mortality or emigration in response to salinity) and indirect (i.e.,

loss of sponge shelter due to their mortality) and was projected to reduce lobster recruitment by 10-15%.

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The Use of GAM Modeling Techniques to Evaluate the Effects of Fresh-water Flow into Florida Bay-Part 2- Application of Models to Predict Community Composition in Extreme Wet and Extreme Dry Years

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An integrative database was assembled from three decades of forage fish studies conducted in Florida Bay and GAM models for 10 species and pink shrimp were developed from it. These 11 species models were used collectively as a community index to predict the densities of the forage community for the wet (August) and dry (April) seasons of an extreme wet (1995) and extreme dry year (1990) for each habitat of each basin of the bay. Areal coverage of each habitat of each basin was used to calculate abundance and biomass for the entire bay in each of time period. The approach allows a bay-wide assessment to be made based on changes in freshwater input and any resulting changes in salinity or seagrass. The project objective was to determine whether certain species densities or the combined 11-species density might serve as a performance measure to evaluate water management alternatives. We hind-casted densities for wet and dry seasons of a previous wet and dry year to evaluate the potential usefulness of the models as predictors (hydrologic and hydrodynamic model output was unavailable).

Models predicted that bay-wide abundance was seasonal and higher during wet seasons (August) than dry seasons (April). Predicted abundance of the 11 species was slightly higher in the wet year (1995) than the dry year (1990). The highest predicted abundance was during the wet season of the wet year (August 1995). The total predicted abundance in April 1995 (dry season, wet year) was 1.05 times higher than in April 1990 (dry season, dry year), and the total predicted abundance in August 1995 (wet season, wet year) was 1.07 times higher than in August 1990 (wet season, dry year).

Predicted response differed by species. The predicted bay abundance of *Lucania, Eucinostomus, Floridichthys,* and *Farfantepenaeus* was seasonal and was highest in August. Highest predicted numbers of *Lucania* were in August of the wet year, and highest predicted numbers of the other three species were in August of the dry year. Highest predicted numbers of *Microgobius, Gobiosoma, Anchoa, Syngnathus*, and *Hippocampus* occurred during the wettest period, August 1995. The predicted abundance of *Lagodon* was highest during the driest period, April 1990. The predicted abundance of *Opsanus* was highest during times of intermediate conditions: wet season/dry year followed by dry season/wet year.

On a Bay-wide basis, there were no major changes in predicted species composition among the four time periods. Four taxa were consistently dominant in terms of percent composition by number during all time periods: *Lucania, Farfantepenaeus, Anchoa*, and *Eucinostomus*. The relative importance of the individual species varied seasonally. *Eucinostomus* were more important in April than August. *Opsanus* and *Floridichthys* were most important in the driest period. Percent composition of *Syngnathus* was higher in both seasons of the wet year.

Patterns of density for the combined 11 species were similar across all habitats. When bay-wide total abundance was greatest (August 1995), basin habitat, followed by the mainland shoreline habitat, had the greatest predicted density, and bank habitat the lowest. Predicted densities were higher in August than April and in 1995 than in 1990 for both seasons. Individual species responses were habitat dependent. Predicted density was highest in basin and mainland shoreline habitats and lowest on banks. Highest predicted density of *Anchoa* was in channel habitat followed by basin habitats and lowest predicted density was on banks. *Eucinostomus* predicted densities were highest in island and mainland shoreline habitats and lowest in channel habitat. Predicted densities of *Farfantepenaeus* were highest in island shoreline and basin habitat and lowest in channels. *Floridichthys* predicted densities were highest on banks, mainland shorelines, and island shorelines and lowest in basins and channels. Predicted densities of *Gobiosoma* were highest in mainland shoreline habitat and lowest in island shoreline habitat. H*ippocampus* predicted densities were highest around island shorelines and lowest along mainland shorelines. Predicted densities of *Lagodon* were similar in all habitats with highest in basin and channel habitats. *Lucania* predicted densities were highest in basin and channel habitats and lowest on banks and island shorelines. Predicted densities of *Microgobius* were highest in channels and basins and lowest on banks and island shorelines. *Opsanus* predicted densities were highest in basin and channel habitats and lowest on banks. Predicted densities of *Syngnathus* were highest on bank and mainland shoreline habitats and lowest in channels and basins.

Predicted percent composition differed more on a habitat basis. In bank habitat (21% of bay area), the highest ranking dominants during the driest period were, in order, *Floridichthys, Eucinostomus*, *Lagodon*, and *Anchoa*, while the wettest period was characterized by *Eucinostomus*, *Floridichthys, Anchoa, Farfante-penaeus,* and *Syngnathus*. *Lucania, Anchoa,* and *Eucinostomus* were the predicted dominants in basin habitat (78% of bay area) in all periods. The importance of *Farfantepenaeus, Opsanus,* and *Floridichthys* varied among time periods. The first two species were more important in the dry season/wet year when *Floridichthys* predicted numbers were reduced.

A spatially averaged species evenness index, limited to our 11 species, was calculated from model predictions to compare dry (April) and wet (August) seasons of an extremely dry (1990) and extremely wet (1995) year. Predicted evenness for the wet year (0.75-0.77) was higher than predicted evenness for the dry year (0.62-0.71). Wet-season evenness was higher than dry-season evenness. Evenness was greater for wet-year predictions had a more even composition than dry-year predictions. Habitat was a major factor affecting species diversity. The basin habitat had the highest evenness and the bank habitat the lowest, which may indicate that the environment on banks is more stressful than that in basins. Salinity also affected evenness. A least square line of predictions suggested a negative correlation of evenness with salinity for the 11-species assemblage. Highest evenness was in the salinity range from 21-30 ppt followed by salinities less than 20 ppt. Lowest evenness was at the upper range, 51-60 ppt. These relationships are consistent with what may be expected for an estuarine fauna.

Predicted biomass was highest during the wet season of both years, but higher in the wet season of the dry year than that of the wet year. Biomass was dominated by three species (*Opsanus, Eucinostomus*, and *Lagodon*). *Opsanus* dominated biomass in all periods, except the driest when *Lagodon* dominated biomass. Predicted biomass of both *Opsanus* and *Eucinostomus* were higher in the wet season but higher in the dry than the wet year. *Lagodon* predicted biomass was higher in both seasons of the dry year. Predicted bay-wide percent composition of *Opsanus* was greater in the dry season in the wet than the dry year.

Predicted densities were highest during wet years in basins with the lowest salinities. Salinities ranged from 8 to 35 ppt in the wet year and from 28 to 60 ppt in the dry year. Predicted responses of species to salinity followed four general trends. Three species (*Farfantepenaeus, Gobiosoma,* and *Lagodon*) had a positive relationship to salinity at low salinities, optima approaching 30 ppt, and a negative response at high salinities. The predicted densities of three species (*Anchoa, Hippocampus,* and *Syngnathus*), decreased in relation to salinity in both years. Three species (*Floridichthys, Lucania,* and *Microgobius*) had a negative linear relationship in the wet year (at low salinities) and a near flat relationship in the dry year (high salinities). Two species (*Opsanus* and *Eucinostomus*) had a negative relationship at high salinities (dry year) and a flat relationship at lower salinities. High variability in predicted response suggests strong habitat influence.

Models suggest wet conditions produce a diverse and slightly more abundant estuarine forage community in Florida Bay but not greater biomass.

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The Use of GAM Modeling Techniques to Evaluate the Effects of Freshwater Flow Into Florida Bay- Part 3- Sport Fishes

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Everglades National Park creel census data (1985-1999) was used to develop models of nine species of sport fishes in Florida Bay to evaluate whether these data can be useful performance measures to evaluate the impact of freshwater flow and/or salinity on fishery resources of Florida Bay. Salinity maps were created for each of the areas, and fishery data were linked to the average monthly salinity of an area and indices of freshwater flow, rainfall, and wind. The fishery data came from three major areas, the northern bay, the western bay, and the southern bay. A review of the raw data indicated that the greatest number of fish was taken from the western bay, followed by the northern bay. Highest catch rates (catch/angler hour) for the combined nine selected fishes were in southern bay, followed by the western bay.

The species caught in the highest numbers were spotted seatrout, gray snapper, and crevalle jack. Highest catch/angler hour of spotted seatrout, gray snapper, and pinfish were from the southern bay, although highest catches of all three species were in the western bay. The western bay had both the highest catch/angler hour and the highest catches of snook and black drum. Sheepshead, crevalle jack, and red drum were taken at the highest catch/angler hour in the northern bay, but total catches of these species were highest in the western bay. Ladyfish were taken at the same catch/angler hour in all areas, but highest catches were in the western bay. Spotted seatrout was the species with highest catch rate in the western and northern bay areas. In the southern bay, gray snapper had a slightly higher catch rate than spotted seatrout. These results do not reflect fishery closures, although data used in model development were adjusted for closed periods of the snook, red drum, and spotted seatrout fisheries.

General additive models were constructed for spotted seatrout, red drum, snook, black drum, sheepshead, ladyfish, crevalle jack, and pinfish. Models were constructed with and without "year" as a categorical variable. The inclusion of year in the models provided an annual abundance index standardized for the effect of other independent variables. The exclusion of year as a variable in a second set of models allowed a clearer picture of the annually varying effects of salinity, rainfall, freshwater flow, and other environmental variables, especially those for which no spatial data were available. All models with year except for the one for snook had the higher r^2, suggesting that the year variable incorporated unknown factors that were not included in the models.

In the models without year, area, month, wind, and salinity were important to the same number of species as in the year model, but temperature (3 species), rainfall (7 species), and freshwater flow (7 species) were important to a greater number of species, suggesting that the year variable was not independent from these variables.

Snook and spotted seatrout did not show a significant relationship to monthly average salinity within an area. There was a negative relationship between gray snapper adjusted catch rates and salinity at the lower end of the salinity scale, changing to a positive relationship between gray snapper catch rates and salinity higher on the salinity scale. Predicted relationships with salinity may reflect catchability rather than abundance. Widespread hypersaline conditions may cause fish to concentrate in lower salinity nearshore locations where they are more vulnerable to fishing. Furthermore, the average salinity of a fishing area does not reflect salinity at which the fish were actually caught.

Yearly salinity patterns may be more important than the average bay salinity at time of capture. Highest model predicted standardized catch rates of spotted seatrout, red drum, snook, jack crevalle, ladyfish, and pinfish were in below-average-salinity years (average from 1985-1999 was 32.1 ppt), and highest standardized catch rates of sheepshead, and gray snapper were in higher-than-average years. Gray snapper highest catch rate was in a year close to average (32.1 ppt). Lowest model predicted standardized catch rates of red drum, sheepshead, and snook were in higher-than-average salinity years, and lowest standardized catch rates of black drum gray snapper, spotted seatrout, ladyfish, crevalle jack, and pinfish were in below-average-salinity years. There was not a large difference in annual Bay salinity between years of highest and lowest predicted abundance for some species (ladyfish, crevalle jack, gray snapper, and pinfish).

Catch rates of some gamefish species in any given year may be related to salinity and freshwater inputs of previous years rather than current years. Highest predicted catch rates of red drum, sheepshead, gray snapper, snook, pinfish, and spotted seatrout followed multi-years of higher than average freshwater inflows, whereas black drum, ladyfish, and crevalle jack highest catch rates followed multi-years of lower than average freshwater flow. Previous years' fresh water flow may influence the growth and survival of juvenile stages, and it is the abundance of juveniles one or more years previously that determines adult abundance of the current year. Four species (sheepshead, gray snapper, pinfish, and spotted seatrout) had both their highest and their lowest predicted catch rates following above average flow years. Spotted seatrout (an estuarine species) has been shown to occur in higher numbers in low salinity waters in fishery independent studies, so lower predicted catch rates during high flow years is inconsistent with what is known about this species. For most species examined, models suggest that salinity relationships were inconsistent with expected conditions for highest and lowest catch rates and what has been reported elsewhere for these species.

Individual fishing area models were developed for spotted seatrout. The models for the northern, western, and southern areas had a better model fit than the pooled model, which had fishing area as a categorical variable. In both spotted seatrout models (with and without year as a categorical variable) of the western bay, neither rainfall nor freshwater flow were significant factors. In the southern bay model, catch rates had a parabolic relationship with rainfall, but flow was not significant. Both rainfall and freshwater flow were significant in the northern bay, and peak catch rates were related parabolically to both. In spotted seatrout models without year as a categorical variable, catch rates were parabolically related to cumulative freshwater flow in the northern bay but negatively related to freshwater flow in the western bay. Seatrout catch rates were parabolically related to cumulative rainfall in the northern and southern bays but positively related to rainfall in the western bay. Area salinity was positively related to catches in the western bay model but was insignificant in other area models. The cumulative time period for rainfall and freshwater that correlated best with modeled fish catch rates differed among areas. The northern bay responded to the longest period, and the southern bay responded to the shortest.

In general, the index of area salinity was not a good predictor of creel catch rates of estuarine species, probably because the scale of the index is too coarse an approximation of the salinity at which fish were caught. Positive correlations with salinity and negative relationships to rainfall or freshwater flow for estuarine species may suggest that high salinity conditions in the Bay cause fish to concentrate in limited favorable areas where they are heavily exploited. Higher catch rates during these times may reflect increased catchability rather than increased abundance. Seasonal and long-term closings of red drum, snook, and spotted seatrout fisheries likely contributed to high predicted catch rates of the 1990's.

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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.

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 Bay's periphery. The strongest

apparent relationships 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*.

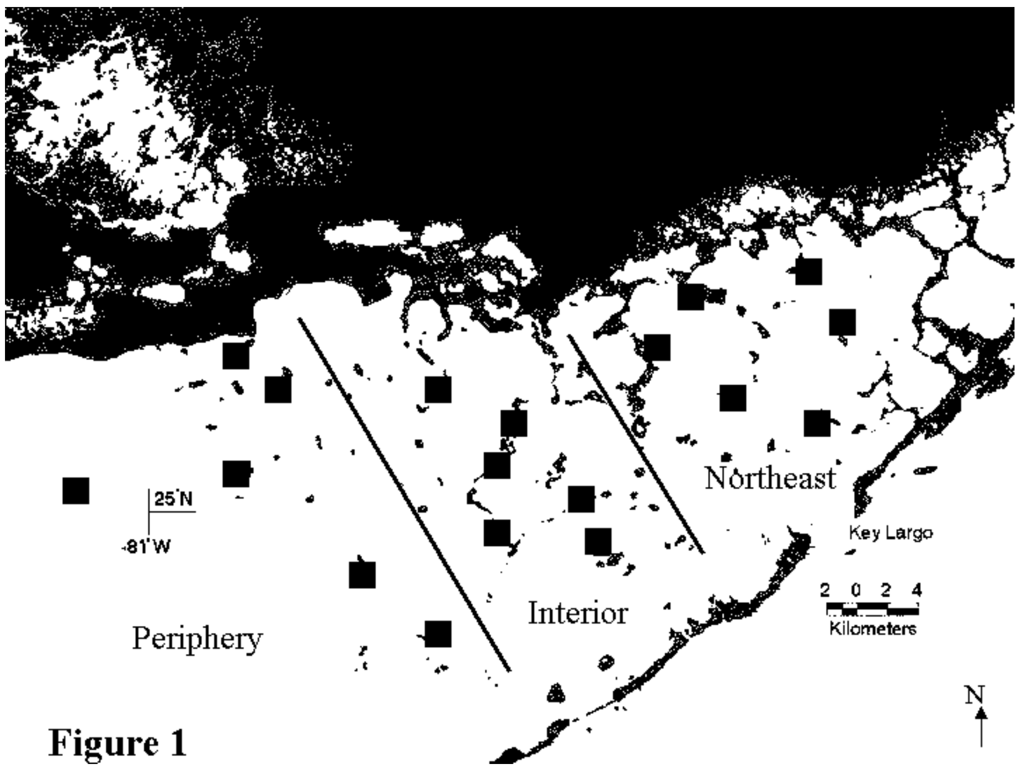

Figure 1

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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The Life Histories of Juvenile and Small Resident Fishes in Florida Bay

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An atlas is being prepared that will depict the life histories of approximately 70 fish species in Florida Bay, Everglades National Park. From the literature, information on the range, diet and reproduction will be presented. From data collected bi-monthly over six annual time periods, the spatial and temporal abundance of each species will be depicted on GIS generated maps. Also included for each species will be more detailed figures depicting the densities of each species by year, month and area, and length-frequency distributions to infer growth and recruitment. The following is an excerpt of a species account. Literature citations and figures mentioned in the text, with the exception of Figure 5.8, are not included in this abstract. From 1984 through 1998 the bay was divided into three strata (West, Central and East); from 1999 through 20001 into six subdivisions (Eastern, Northern, Atlantic, Central, Western and Gulf). For pelagic species as shown below, we included surface trawl data (taken only in 1984-1985) and otter trawl data (from 1984 through 2001).

Chapter 5: Family Engraulidae

Anchoa mitchilli (bay anchovy)
Range, Reproduction and Diet: The bay anchovy ranges from the Gulf of Maine to Florida, entire Gulf of Mexico and along the Caribbean coast to Belize. It is rare in the Yucatan, Gulf of Maine and Florida Keys and absent from the West Indies (Robins and Ray 1986, Leak and Houde 1987; Patillo et al. 1997). This species most likely constitutes the greatest biomass of ichthyofauna in the southeast and U. S. Gulf of Mexico (Pattillo et al. 1997).

In adjacent Biscayne Bay, bay anchovy eggs occurred throughout the year, but were most abundant in summer, and rare to absent during winter months (Jones et al. 1978; Houde and Lovdal 1984); whereas, in Tampa Bay, Florida spawning occurs when water temperatures reach 20^{o} C and ceases by November (Pattillo et al. 1997). Eggs, larvae and juveniles are pelagic, but bay anchovy dominate the lower portion of the water column relative to other zooplanktivorous fishes (Allen et al. 1995). Size at hatching is 1.8-2.7 mm TL, transformation to the juvenile stage begins at 16 mm SL and is complete by 22 mm SL. Males and females mature at lengths approximately 40 mm SL (Zastrow et al. 1991).

Carr and Adams (1973) reported that juvenile bay anchovy between 15-18 mm SL feed mainly on veligers (74% of stomach contents), followed by approximately equal amounts of copepods and eggs. Fish 20-23 mm SL fed on approximately equal amounts of veligers and copepods. Odum (1971) reported that bay anchovy <25 mm SL mainly consumed planktonic copepods and copepod larvae; whereas, larger juveniles and adults (31-62 mm SL) fed on a variety of small benthic crustaceans, particularly amphipods and mysids. Stomachs also contained harpactacoid copepods, ostracods, small mollusks, and small quantities of zooplankton and detritus.
Distribution and Abundance): In surface trawl collections in channels and basins in 1984-1985 (*n* = 590 bay anchovy) (Fig. 5.6), bay anchovy densities were significantly different between strata and months (Fig. 5.7). Highest densities were observed in May, lowest in January and July. Densities were highest in the West stratum. They were more commonly collected at channel

stations. Somewhat contrary to our findings, Sogard et al. (1987) reported significant differences in densities of bay anchovy between sites, with highest densities occurring at Eagle Key ("Northeast" site; our Eastern subdivision).

Considerable significant interannual variability was observed in the abundance of bay anchovy collected bi-monthly, by otter trawl in Florida Bay basins (Figs. 5.8 and 5.9), and because this species occurs in the lower water column (Allen et al. 1995), otter trawl densities probably are good estimators of the distribution and abundance of this species. This species (*n* = 9284) was uncommon in 1984-1985 and 2000-01, and to a lesser degree in 1998. Bay anchovy were very abundant in 1994-95 and 1996 following seagrass die-off, persistent turbidity, and phytoplankton blooms (Fourqurean and Robblee 1999). High densities during these periods might be due to their attraction to unvegetated bottoms and high turbidity (Patillo et al. 1997). Significant differences in densities were observed between strata and subdivisions, and months (Fig. 5.9). Monthly, highest densities were observed in November, lowest in July. From 1984-1998, bay anchovy were collected at highest densities in the Cental stratum with lower values in the East and West strata and from 1999-2001 highest densities in the Northern, Central and Gulf subdivisions. They were not collected in the Atlantic subdivision.

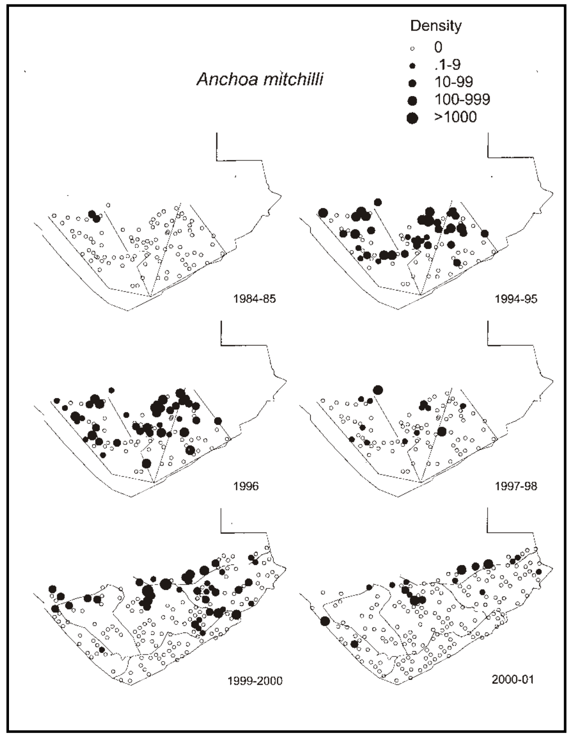

Figure 5.8. Densities of bay anchovy (*Anchoa mitchilli*) collected by otter trawl

Length-frequency Distributions: Based on length-frequency distributions spawning appeared to occur throughout the year in Florida Bay (Fig, 5.10). Growth of bay anchovy was difficult to discern from length-frequency distributions because of their protracted spawning period. In Biscayne Bay, bay anchovy (<14 mm SL) grow approximately 0.50 mm per day. During their first 49 days, Fives et al. (1986) reported exponential growth (approximately 4% per day) of anchovies collected near Beaufort, North Carolina. Fish spawned in spring could grow to maturity and spawn during their first summer. In Florida Bay, otter trawl collections were dominated by transforming juveniles (16-22 mm SL) and juveniles (22-40 mm SL).

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Fish and Shrimp in Relation to Seagrass Habitat Change in Johnson Key Basin, Western Florida Bay (1985 – 1995)

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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 a 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% 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.

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% in Johnson Key Basin (Figure 1A). Standing crop of *Halodule* increased by 24% 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% while seagrass fishes had declined by 81% (Figure 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 ^oC vs 24.9 ^oC, respectively).

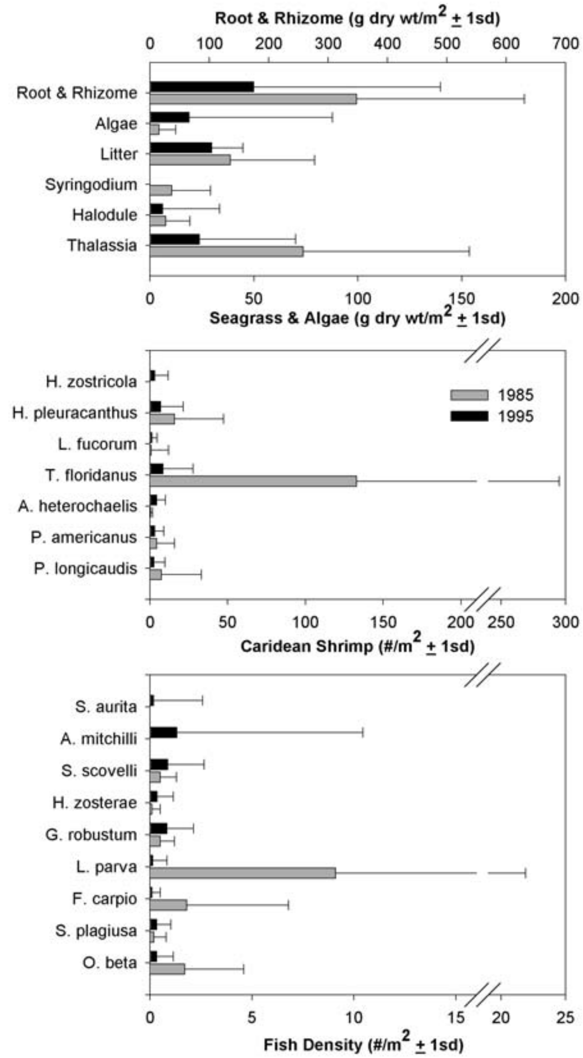

Figure 1. Comparison of habitat changes and associated caridean shrimp, and fish communities in Johnson Key Basin over the decade 1985 to 1995.

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% of individuals, January and May averaged, respectively). By 1995 these populations had declined to 3% and 27% 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% of fish collected. Five caridean shrimps, *Periclimenes americanus*, *Alpheus heterochaelis*, *Thor floridanus*, *Hippolyte plueracanthus*, and *Hippolyte zostericola*, accounted for 81% 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% of the variability among the original habitat variables was interpreted as a *Thalassia* gradient. *Halodule* is negatively correlated with *Thalassia* on PC1. PC2 (16%) was interpreted as a shallow water *Halodule* gradient. PC3 (12.4%) was interpreted as a *Syringodium* gradient. PC4 (10.4%) 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 relationship of pink shrimp size to seagrass habitat and individual species relationships with seagrass habitat will be presented.

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

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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 relationship 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 program). Concentrations of 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).

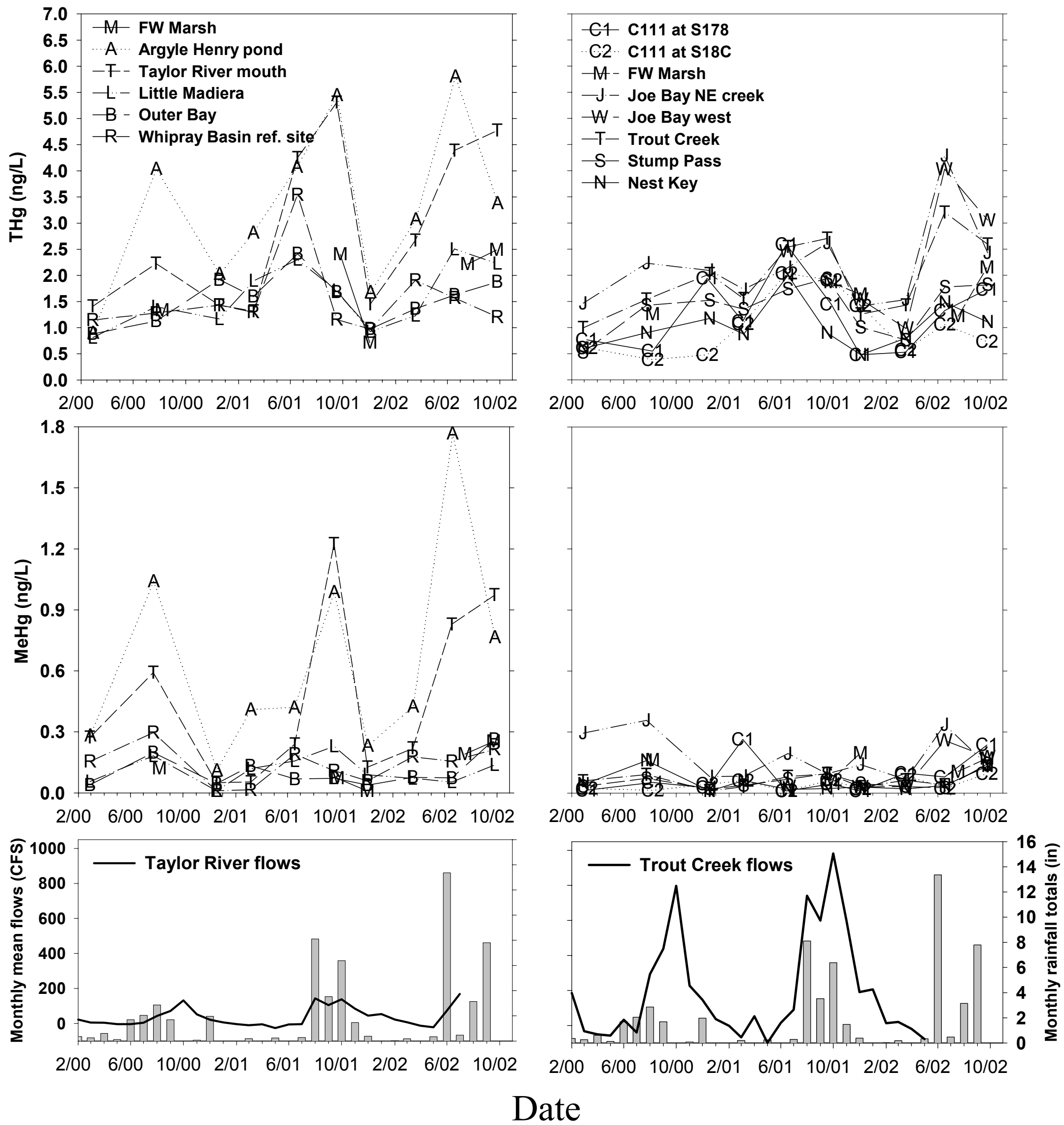

Fig. 1. Time series of total mercury (THg), methylmercury (MeHg), flows and rainfall (bars) measured along two transects into northeastern Florida Bay. Note, rainfall was recorded in Joe Bay and flows after 6/2002 not yet available.

On average, non-filterable or dissolved forms (<0.45 µm) accounted for 80% and 73% of the total THg and MeHg, respectively. MeHg constituted 8% of the non-filterable THg, but ranged up to 36% 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 concentrations of MeHg. Sediments collected from near Nest Key, for example, contained up to 1.8 ng MeHg/g, which constituted almost 8% 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 porewaters 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% to 11.2% 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 to understand the bay's MeHg problem 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's inflows for the restoration of the sport fishery and the protection of fish-eating wildlife in Florida Bay.

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Factors Affecting the Distribution of Two Gobies (*Microgobius gulosus, Gobiosoma robustum*) in Florida Bay, USA

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Densities of the code goby *Gobiosoma robustum* Ginsburg and clown goby *Microgobius gulosus* (Girard) vary across regions of Florida Bay. Although their distributions overlap to a limited degree, *G. robustum* is found in great abundance in the seagrass beds of the western and southern portion of the bay, where a strong Gulf of Mexico influence maintains salinities at a relatively constant level (35 – 40 ppt). Conversely, *M. gulosus* is most common in the north-eastern section of the bay that is influenced by freshwater inflow and generally is characterised by lower salinities. In this study, the effects of salinity, habitat complexity, competition, and susceptibility to predation were examined as possible factors underlying the distribution of these two species.

Acute salinity tolerance:
The premise of this study was to determine whether *M. gulosus* and *G. robustum* exhibited differential tolerance to acute salinity shifts, which may be related to their distributions within Florida Bay. Given that *M. gulosus* inhabits the north-eastern region of Florida Bay that is more likely to be exposed to rapid shifts in salinity than the less variable habitat over which *G. robustum* is distributed, it was hypothesized that *M. gulosus* would be more tolerant to salinity shifts. To test this hypothesis, acute (e.g., "plunge-type") salinity tolerance tests were performed with both species. There was no compelling evidence for differences in acute salinity tolerance over the 10-d experimental period, as both species showed significantly reduced survival at similar salinity levels.

Competition and habitat selection:
In Florida Bay, *G. robustum* is generally found in structurally complex habitats (e.g., seagrass beds), while *M. gulosus* is more often found in bare mud areas. To determine whether this habitat partitioning was an effect of interspecific competition, I conducted a series of laboratory experiments, in which each species was presented with structured (artificial seagrass) versus non-structured (bare sand) habitats and their frequency of choosing either habitat type was measured. Use of structured versus non-structured habitats were then examined when the two species were placed together in a mixed group. Finally, a predator (*Opsanus beta*) was placed in the experimental aquaria to determine how its presence influenced habitat selection. Both goby species selected grass over sand in allopatry; however, in sympatry, *M. gulosus* occupied sand more often when paired with *G. robustum* than when alone. *Gobiosoma robustum* appears to directly influence the habitat choice of *M. gulosus*: It seems that *M. gulosus* is pushed out of the structured habitat that is the preferred habitat of *G. robustum*. Thus, competition appears to modify habitat selection of these species when they occur in sympatry. Additionally, the presence of the toadfish was a sufficient stimulus to provoke both *M. gulosus* and *G. robustum* to increase their selection for sand.

Effects of salinity and competition on growth:
In this study, the relative influences of salinity and competition on growth of both goby species was evaluated in a laboratory experiment. Both species were grown in the lab over 27 d at two salinity levels (5 and 35 ppt), two food levels (low and high) and both with and without the presence of the other species. Both species exhibited greatest growth at the high food level and

the low (5 ppt) salinity. Neither species was affected by the presence of the other species, and there were no overall differences in growth between the two species. Thus, the competitive superiority of *G. robustum* over *M. gulosus* does not seem to confer an advantage relative to feeding success. Furthermore, as growth of *G. robustum* was greater at the lower salinity, it is clear that some factor other than salinity is restricting the bay-wide distribution of this species from north-eastern Florida Bay.

Habitat effects on susceptibility to predation:
To determine whether the presence of a structurally complex habitat mitigates predation for either species, a laboratory experiment was conducted in which gobies (1 per trial) were placed in aquaria containing either a) bare mud or b) bare mud + artificial seagrass substrate. The predator (*Opsanus beta*) was more successful preying upon *M. gulosus* than *G. robustum*, and there was no habitat (e.g., seagrass) effect. This was surprising, given that *M. gulosus* is a burrowing species that was expected to fare better than the non-burrowing *G. robustum*.

Based on the results of these experiments, the microhabitat distribution of *G. robustum* and *M. gulosus* in the Gulf-influenced (e.g., southern and western) regions of Florida Bay can be explained by the selection of *G. robustum* for structurally complex habitats (e.g., seagrass) and its competitive superiority over *M. gulosus*. However, the mechanisms underlying the distribution of these species in north-eastern Florida Bay is less clear. *G. robustum* was as tolerant to acute shifts in salinity as *M. gulosus*. Additionally, growth of *G. robustum* was not negatively affected by low salinities indicative of this region. Finally, *G. robustum* was less susceptible to predation than *M. gulosus* by *O. beta*, even in the absence of seagrass. Restriction of water movements by the anastomosing pattern of mudbanks in north-eastern Florida Bay may negatively affect larval recruitment of *G. robustum*. Alternately, it is possible that prey species utilised by *G. robustum* are not as abundant in the less-vegetated north-eastern Florida Bay as opposed to southern and western regions of Florida Bay.

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Monitoring a Sea Urchin Overgrazing Event in Outer Florida Bay

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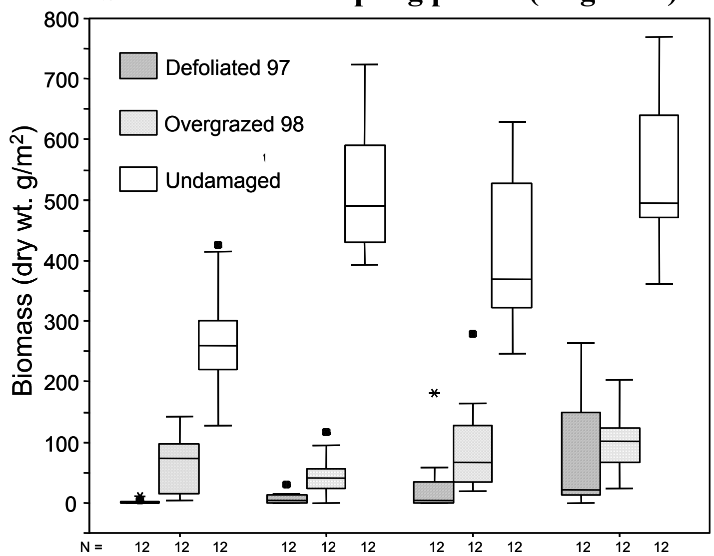
In August 1997, an extraordinarily dense aggregation of the variegated urchin, *Lytechinus variegatus* Lamark, was discovered within the extensive manatee grass (*Syringodium filiforme* Kützig) meadow in Outer Florida Bay, approximately 19 km north of Marathon, FL. By the time of its discovery, the aggregation had either completely defoliated or severely damaged approximately 9 km^2 of the meadow. When the damaged portion of the seagrass meadow was discovered in Florida Bay, the population dynamics of the urchin aggregation and the short-term impacts of their grazing on the seagrass and sediment were assessed. This work revealed that this urchin aggregation was composed of a single cohort that had consumed all of the above-ground seagrass biomass and damaged much of the below-ground seagrass biomass in an area estimated to be approximately 9 km^2, causing the depletion of the associated molluscan communities and the resuspension of fine-grained sediments. Because the event potentially posed the threat of additional larger-scale ecosystem perturbations, we continued periodic monitoring of urchins and the long-term impacts on the seagrass meadow.

We observed that the urchin cohort continued to damage the meadow through much of 1998, but by late that year, the formerly well-formed aggregation had clearly becoming more diffuse. The remnants of the urchin aggregation could still be detected in 1999, though the mean urchin density was approximately an order of magnitude lower than 1997. Yet, even at these lower densities, visual assessment by divers revealed continued decreases in seagrass biomass in the area of this aggregation, suggesting urchin abundance remained sufficient to damage the seagrass bed. Moreover, by late 1999 the size-frequency of the urchin population indicated that it was now composed not only of urchins from the cohort responsible for the overgrazing event, but also of smaller, presumably younger urchins. However, we could not assess if this younger cohort was present in numbers sufficient to cause prolonged damage to the meadow. Additionally, commercial spiny lobster fishermen reported unusually large numbers of *L. variegatus* within their traps located in nearby areas of the meadow.

Consequently, in 2000, we established additional monitoring sites and continued to evaluate urchin population dynamics and their effect on the seagrass bed. We also monitored the seagrass community within areas of the meadow that had previously undergone intense defoliation. We established sites in a spatially stratified manner according to the relative damage to the seagrass bed caused by the overgrazing event during 1997-98 and established four sites in the portion of the meadow that had been completely (or nearly) defoliated during September 1997 (hereto referred to as “Defoliated 97"), two in an area that urchin overgrazing had visibly reduced the seagrass biomass, but where sparse seagrass remained (“Overgrazed 98"), and two in an area that were undamaged by urchins (“Undamaged”). Each site was sampled during the winter (Dec - Feb) and summer (August - October) during both 2001 and 2002.

Our initial sampling conducted during December 2000 detected no unusually dense aggregations of urchins and no signs of continued overgrazing. Given the life span of *L. variegatus*, which has been estimated to be approximately four years, we concluded that a large portion of the urchin aggregation responsible for the overgrazing event of 1997-98 had perished through senescence by 2000, and that the abundance of urchins originating from subsequent cohorts were not present in densities sufficient to cause additional damage to the meadow. Seagrass biomass had increased at both Defoliated 97 and Overgrazed 98 sites from early 2001 to the summer of 2002, but remained greatly reduced compared to sites that had been not been impacted by urchin grazing (Figure 1).

Figure 1 **Boxplots comparing seagrass biomass at Defolatied 97, Overgrazed 98, and Undamaged sites from the Winter 2001 sampling period (Dec – Feb 2001) through the Summer 2002 sampling period (Aug 2002).**



Because the effects of urchin overgrazing on *S. filiforme* remains poorly understood we will continue to evaluate our monitoring sites annually and will be conducting manipulative field experiments to further evaluate the effect of urchin herbivory on this seagrass.

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The Long-Term Recovery of Sponge Populations in the Florida Keys, USA, Following A Widespread Mortality

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During 1992 and 1993, widespread sponge mortalities significantly impacted sponge populations in the Florida Keys, USA. The extent of the impacted areas was estimated to be approximately 1,000 km^2. The cause of the mortalities was attributed to cyanobacteria blooms. It was hypothesized that the sponge mortality resulted from clogging of the sponges' filter feeding mechanism, bloom toxicity, or perhaps lowered dissolved oxygen levels. However, the exact cause has not yet been documented.

The work described here was initiated in response to concerns regarding the ecological and fishery impacts resulting from increased commercial sponge (sponges of the genera *Hippospongia* and *Spongia*) harvesting effort in the late 1980s and early 1990s. Beginning in 1994, the work entered a second phase: documentation of the sponge mortality impact on sponge community biomass, and long-term evaluation of sponge community recovery. Data on the recovery of sponge populations in two areas has been collected on an annual basis from 1993 through 2002. Additional data has been collected within Everglades National Park.

Project data documented a highly significant decline in sponge numerical abundance, with an even more significant reduction (up to 90%) in sponge community volumetric biomass. However, the severity of the mortality varied significantly over the affected area. Sponges of the genera *Ircinia*, *Hippospongia* and *Spongia* appeared to be the most susceptible to the mortality. *Spheciospongia vesparia* appeared to be more resistant than many other species, but was completely eliminated throughout extensive areas. One species, *Cinachyra* sp., appeared to be particularly resistant.

As work has progressed, a more comprehensive description of the sponge fauna in the study area has been undertaken. Data are now collected for 30 sponge taxa and we have a reasonable complete description of the sponge fauna and relative abundance throughout the study area.

The 2002 data clearly document that significant sponge population recovery has occurred. However, recovery is not complete. Recovery is not uniform throughout the areas sampled, and several "important" species -- in terms of contribution to sponge community biomass -- have not exhibited significant recovery. Two species, *Spheciospongia vesparia* and *Ircinia campana*, accounted for approximately 70% of the sponge community biomass prior to the sponge mortalities. Significant recovery of *S. Vesparia* has been observed, but recovery has not been consistent throughout the affected area. No significant recovery of *I. campana* has been observed.

Project data, in general, documented recovery of commercial sponge species (*Hippospongia* and *Spongia*). Sponge harvesting activity has been observed in areas where commercial sponges had been previously eliminated. However, there has not been complete recovery throughout the study area.

It is now possible to identify several sponge species that are short-lived, and that widely fluctuate in abundance. In a sense, it may be impossible to say that these species have truly recovered because their abundance is probably constantly changing.

It is also now possible to follow the recovery of long-lived species that comprise the major portion of sponge biomass. With this information, it will be possible to truly evaluate sponge population recovery from a natural resource management perspective.

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Florida Bay Ecosystem History Poster Abstracts

- Listed alphabetically by presenting author.
- Presenting author appears in **bold**.

Evidence of Freshwater Influx into Rankin Basin, Central Florida Bay, Everglades National Park, prior to 1900

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Charles W. Holmes and *Eugene Shinn*
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Gary S. Dwyer
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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. Carlson, pers. comm.). 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.

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.

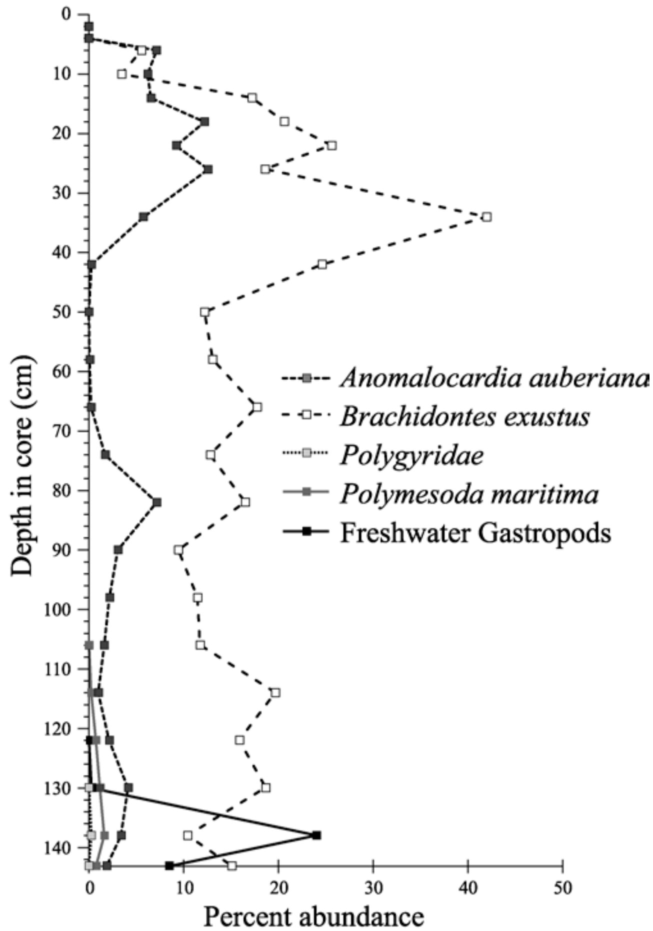

Figure 1. Percent abundance of key molluscan species from Rankin Core

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Molluscan Shells as Recorders of Environmental Change in South Florida

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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, ACOE 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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Florida Bay: A Historical Reconstruction

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Over a decade ago, beginning in late 1987 Florida Bay experienced a large and apparently unprecedented dieoff of *Thalassia testudinum*, culminating in the initial loss of over 20,000 ha of seagrasses, and significantly greater losses in the years following. Early losses were relatively easy to quantify, as the majority of waters for Florida Bay remained as clear as they were in 1987. As the dieoff progressed over several years, turbidity from the unprotected sediments, and plankton blooms, generated by the nutrients released from the decomposing seagrasses and exposed sediments, increased also. Maximum seagrass losses were estimated to go as high as 40,000 ha, but these are only estimates as the high turbidities precluded accurate surveys.

As the dieoff and its downstream effects intensified, spreading well into the Florida Keys National Marine Sanctuary, so did the realizations that this was a very large-scale, regional problem, and that much of the cause and hence the solutions lay upstream of the FKNMS and Florida Bay, in the Everglades. Another problem exists in defining what restoration is for Florida Bay.

To many people, the Florida Bay that is remembered fondly is the bay in the decade prior to the seagrass dieoff. This was a Florida Bay where much of the central and western bay possessed extremely clear water and the seagrasses, especially *Thalassia testudinum*, were dense and in near continuous monoculture.

One of the first scientists to attempt to characterize earlier times in Florida Bay was Durbin Tabb. Tabb et al. (1962) noted that "under hypersaline conditions (above 45-59 ppt) the turtle grass, *Thalassia testudinum* is adversely affected. The blades of the "grass" die back and thus expose the bottom muds. If high salinity periods persist for periods of 3-5 months the turtle grass cover of Florida Bay becomes reduced by defoliation so that wind scour reaches the marl muds and turbidity increases markedly. Such turbidity conditions further limit the numbers of species that may be found in the region beyond that already reduced by hypersalinity."

Tabb et al (1962) also noted that with salinities in the range of the more moderate range of 30-40 ppt, the seawater in western Florida Bay tended to become clearer, and that This would permit maximum growth and development of algae and marine grasses, which would further stabilize the bottom. Such conditions are favorable for angling and sightseeing, but are far different from the conditions that existed in the estuary prior to 1920, when the waters were stained by humic acids, organic particles and marl in suspension."

Knowledge of the historical Florida Bay is critical to the restoration of a stable and persistent ecosystem. Attempts to recreate an aesthetically pleasing but historically unstable ecosystem is simply resetting the clock for another round to the dieoffs that occurred in the 1987-91 period. Numerous lines of evidence will be developed to attempt to reconstruct the historical Florida Bay.

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