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The Tides and Inflows in the Mangroves of the Everglades (TIME) Interdisciplinary Project of the South Florida Ecosystem Program

The U. S. Geological Survey (USGS) has a prominent role in the Federal Government's comprehensive restoration plan for the south Florida ecosystem encompassing the Everglades—the largest remaining subtropical wilderness in the continental United States. USGS scientists, in collaboration with researchers from the National Park Service (NPS), other governmental agencies, and academia, are providing scientific information to land and resource managers for planning, executing, and evaluating restoration actions. One major thrust of the restoration effort is to restore the natural functioning of the ecosystem to predrainage conditions, an objective that requires knowledge of the hydrologic and hydraulic factors that affect the flow of water. A vast network of interlaced canals, rimmed with levees and fitted with hydraulic control structures, and highways, built on elevated embankments lined by borrow ditches and undercut by culverts, now act to control and direct the flow of water through the shallow low-gradient wetlands. As water flows south from Lake Okeechobee past the city of Miami and through Everglades National Park (ENP), it is diminished by canal diversions, augmented by seasonably variable precipitation, and depleted through evapotranspiration. Along its path, the shallow flowing water, referred to as sheet flow, interacts with surficial aquifers and is subject to the resistance effects of variably dense vegetation and forcing effects of winds. New scientific investigations are providing additional insight into the hydrologic and hydraulic processes governing the flow, and recent data-collection efforts are supplying more comprehensive data describing the flow behavior, both of which are benefiting development of improved numerical models to evaluate and restore the natural functioning of the ecosystem.

INTRODUCTION

A critical goal of Comprehensive Everglades Restoration Plan (CERP) (http://www.evergladesplan.org/) is to restore and preserve the hydrology of the predrainage ecosystem to provide ecological conditions that are consistent with habitat requirements. This objective is particularly problematic in the mangrove ecotone comprising the interface of the Everglades wetlands with the Gulf of Mexico and Florida Bay. This transition zone between the freshwater-wetland and coastal-marine ecosystems provides nesting habitat and is a primary productivity area for the food web of numerous endangered species. In order to correctly and properly evaluate flow conditions within the mangrove ecotone, neither hydrologic processes affecting flows in the wetlands nor dynamic forces driving flows in the connecting coastal systems can be ignored. An investigation into the interacting effects of freshwater inflows and coastal driving forces in and along the mangrove ecotone of southern Florida within Everglades National Park (fig. 1) is being undertaken in the Tides and Inflows in the Mangroves of the Everglades (TIME) project of the USGS South Florida Ecosystem Program. The goals of the TIME project are to provide new scientific insight, additional quantitative information, more comprehensive data, and a refined hydrodynamic model to help guide and assess restoration and management decisions for this critical ecosystem.

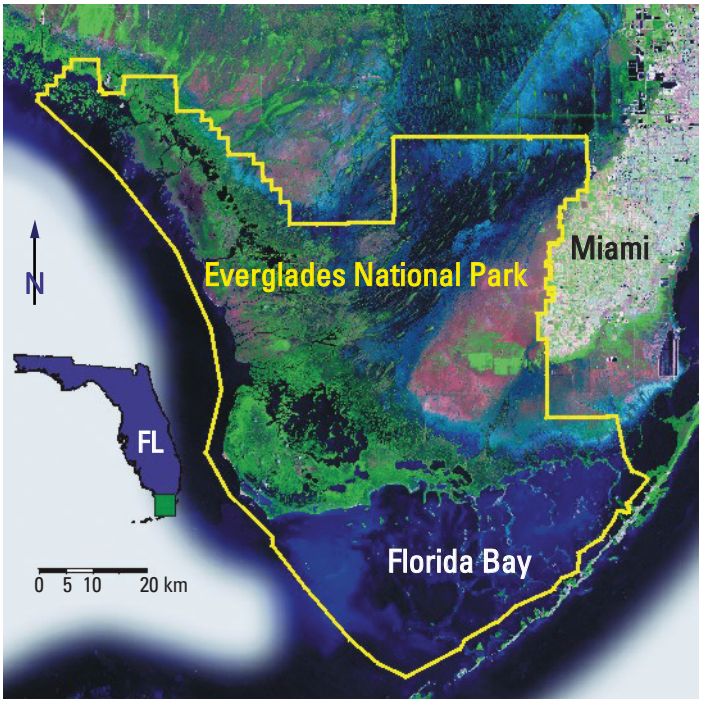

Figure 1. Satellite image of south Florida covering Everglades National Park, 1:500,000 scale.

The TIME project and model will help address several key questions pertaining to restoration actions and management decisions.

- How do the Everglades freshwater-wetland and coastal-marine ecosystems respond concurrently, both hydrologically and ecologically, to regulation of inflow?
- Will upland restoration actions affect the transformation of freshwater wetlands to brackish and marine marshes and subsequently to mangrove marsh ecotones?
- How will changes in inflows act in concert with predicted increases in sea level to affect migration of the freshwater/saltwater interface within the surface and subsurface flow systems?
- What key factors influence salt concentrations in the coastal mixing zone and how do these factors interact to affect wildlife habitat areas?
- How will external dynamic forcing factors, such as sea level rise or meteorological effects, adversely affect upland regulatory plans?
- What concurrent changes in wetland hydroperiods and coastal salinities are likely to occur in response to various proposed restoration and management plans?

PROJECT OBJECTIVES

The primary objectives of the TIME project are to develop, implement, and use a mathematical model to study the interaction of overland sheet flow and dynamic tidal forces, including flow exchanges and salin-

ity fluxes between the surface- and ground-water systems, in the mangrove-dominated transition zone between the Everglades wetlands and adjacent coastal-marine ecosystems. The scope of the project is:

1) to investigate hydrologic processes in the wetlands and dynamic forces in the mangrove ecotone to develop additional scientific insight into the behavior of these ecosystems individually and into their complex interaction,
2) to translate any newly gained knowledge of processes and forces into improved empirical expressions and mathematical equations defining the ecosystems,
3) to transform these mathematical representations into numerical algorithms for integration into simulation models,
4) to develop a coupling between two existing fully developed models, a two-dimensional surface-water flow/transport model and a three-dimensional ground-water flow model with a salt transport component,
5) to implement the coupled model to the transition zone of the Everglades using existing and newly collected data to define ecosystem properties,
6) to calibrate and verify the coupled model using field-collected water-level, flow, and salinity data,
7) to use the model to investigate and quantify the interrelation of freshwater and saltwater flows in response to temporal and spatial variations in inflows and sea level, and
8) to document the model development and implementation as well as any findings that are critical for restoration and management of the Everglades ecosystem.

PROJECT OVERVIEW

The TIME project, which began in October 1999, is utilizing findings and results from a number of individual projects conducted by scientists from all disciplinary divisions (Biological Resources, Geologic, National Mapping and Water Resources) of the USGS within its South Florida Ecosystem Program. Scientists in the Water Resources Division (WRD) are evaluating hydrologic processes and hydraulic forces, including vegetative resistance, evapotranspiration mechanisms, wind effects, ground-water/surface-water exchanges, and canal/wetland interactions, to provide critically needed empirical coefficients, process descriptions, and equation formulations. Geologic Division scientists are investigating the historical effects of hydrologic changes in the freshwater wetlands to isolate anthropogenic influences and the impacts of sea-level rise on coastal marine ecosystems. Project efforts within the National Mapping Division (NMD) are providing measurements of land-surface elevations that define topographic gradients in the wetlands and that quantify the relief of unique terrain features, such as the Buttonwood Embankment along the mangrove fringe of Florida Bay. A major effort by collaborating WRD and NMD scientists is presently underway to sample, classify, and map the wetland vegetation to provide detailed information on species composition, plant characteristics, vegetative structure, and biomass for quantification of correlated hydrologic processes. A joint effort between WRD and Biological Resources Division (BRD) scientists is directed at integrating hydrological and ecological findings at resolution scales consistent with species model developments. The primary focus of these collaborations is directed toward extension of the present suite of models within the Across Trophic Level Simulation System (ATLSS) (http://www.atlss.org/), used extensively in development of CERP (Comiskey and Gross, 2000), to include estuarine species (DeAngelis, 2000). TIME model results that define, for example, salinity changes in threatened estuarine habitat areas will be provided to further development of species models, including, initially, estuarine fish (Cline and others, 2000; McIvor and Whaley, 2000), crocodiles (Mazzotti and others, 2000), and wading birds. Projects supporting the TIME model development effort within the USGS South Florida Ecosystem Program as well as others of related scientific interest, are described in abstracts published in Eggleston and others (2000) and in Fact Sheets available at the USGS South Florida Information Access (SOFIA) (http://sofia.usgs.gov/) Web site.

For specific development of the TIME model, an existing, generic, two-dimensional surface-water flow and transport model is being coupled to a fully developed, generic, three-dimensional variable-density ground-water flow and solute-transport model. Upon completion of the model coupling and implementation to the TIME domain, the surface- and ground-water flow and salt transport model will facilitate the simulation of flow and salinity conditions in, and mixing between, the surface and sub-surface flow systems. The TIME model domain has an eastern boundary at the L-31N, L-31W, and C-111 canals, a southern boundary across northern Florida Bay from Key Largo to Cape Sable; a western boundary along the Gulf coast from Cape Sable to Everglades City; and a northern boundary along Tamiami Trail as shown in figure 2, thereby enabling direct and concurrent simulation of coastal driving forces and freshwater inflows into ENP.

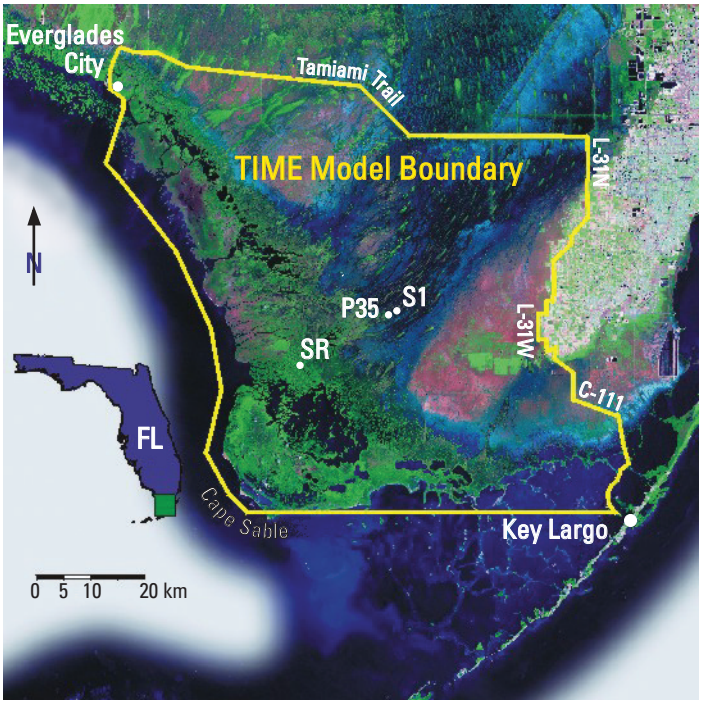

Figure 2. Satellite image showing TIME model boundary, 1:500,000 scale. (SR, P35, and S1 represent the locations of USGS/WRD, NPS/ENP, and USGS/BRD water-level gages, respectively, in Shark River and Shark River Slough.)

Spatial data sets describing the physical properties of the ecosystem, and time-series data depicting flow and salinity conditions along the model boundaries and within its interior domain, are being collected and(or) compiled to implement the model. A preliminary land-surface elevation grid of the eastern part of the TIME model domain within Dade County, interpolated from helicopter survey data collected at 400-meter intervals using differential GPS technology, is shown in figure 3. Contours of the gridded data (fig. 4) illustrate the shallow land-surface gradient within the wetlands. The model grid of 500-meter square cells is being updated and extended continually as new data become available

from the ongoing NMD mapping effort. Companion grids depicting vegetation characteristics and aquifer properties are also under development.

Sets of time-series data quantifying surface-water levels, ground-water heads, flow velocities, structure discharges, tidal fluctuations, salt concentrations, rainfall events, and meteorological conditions are being collected and(or) compiled to implement the model. Data collected by the USGS, NPS, U.S. Army Corps of Engineers, National Oceanic and Atmospheric Administration, and the South Florida Water Management District are being compiled and used. A database system, developed specifically to facilitate management of the time-series data for use in the model, can be accessed to view and download the data via the Internet—see "Time Data" page of the TIME (http://time.er.usgs.gov/) Web site. A sample plot of water-level data, obtained from three hydrologic monitoring stations (identified as sites SR, P35, and S1 in figure 2) and being used to implement and calibrate the model, is shown in figure 5 to illustrate the diminishing effect of tide through the mangrove marsh ecotone of lower Shark River Slough. Data collected within the USGS South Florida Ecosystem Program in support of the TIME project are available for downloading from the SOFIA Web site. Flow and salinity data and model results are posted for downloading on the TIME and SOFIA Web sites as they become available for the benefit of related restoration investigations such as the Florida Coastal Everglades Long Term Ecological Research (LTER) project (Childers and others, 2000), http://fcelter.fiu.edu/.

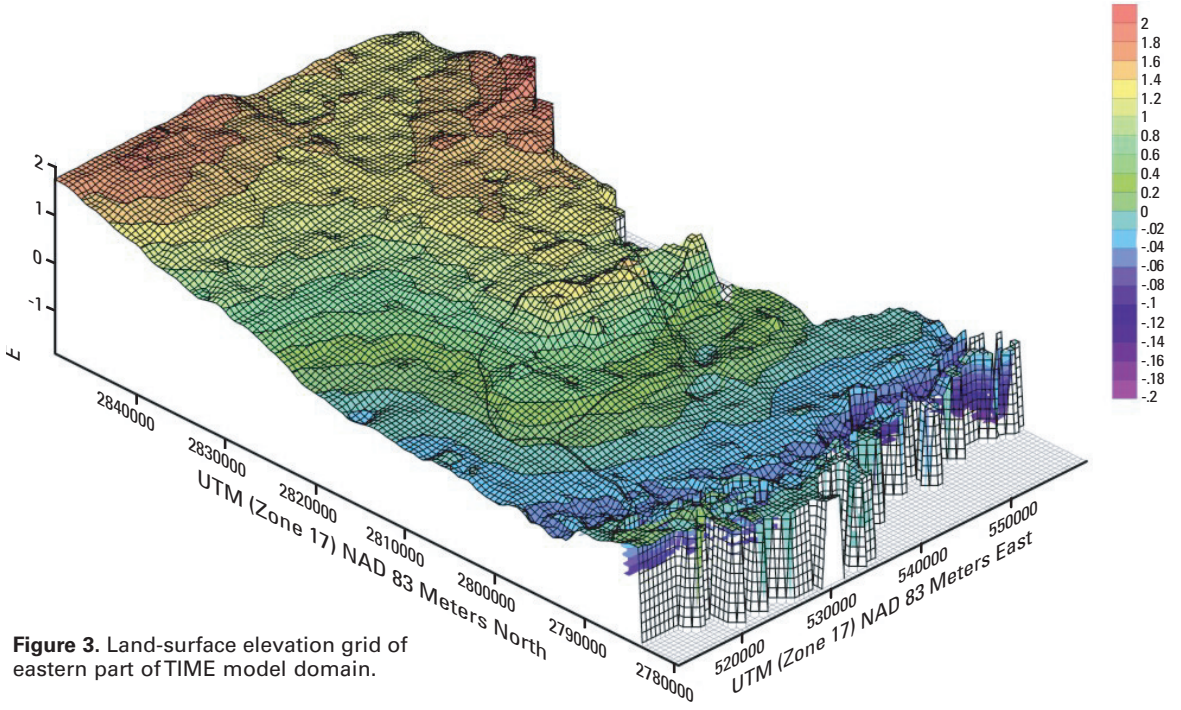

Figure 3. Land-surface elevation grid of eastern part of TIME model domain.

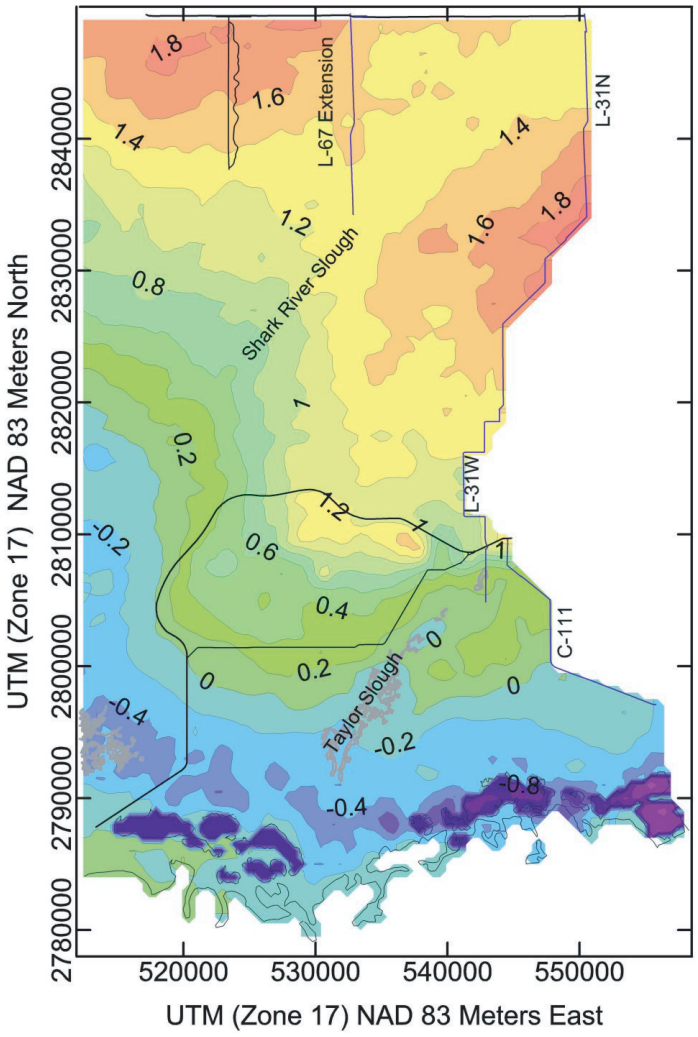

Figure 4. Land-surface elevation contours of eastern part of TIME model grid.

SUMMARY

Upon planned completion of the TIME project, it is anticipated that a sound, physically based, fine-resolution (500 meters) flow/transport model, consistent with individual species models of the ATLSS program, will be available for use as an evaluation and management tool to study and assess the ecological response of the mangrove marsh ecotone of ENP to upland regulatory decisions. Analyses of numerical model simulations for varied inflows and forcing mechanisms should enable cause-and-effect relationships of ecosystem functions and sustainability to be investigated and identified to help guide and evaluate restoration actions. Upon full implementation and final calibration of the TIME model, any implications on restoration decisions and actions resulting from the combined effects of hydrologic processes on flows in the wetlands and dynamic forces affecting flows and salinity conditions in the adjoining coastal marine ecosystems will be demonstrated through numerical simulations conducted using the model. Interim results and findings from the ongoing TIME project are being reported intermittently at the TIME Web site as the project progresses.

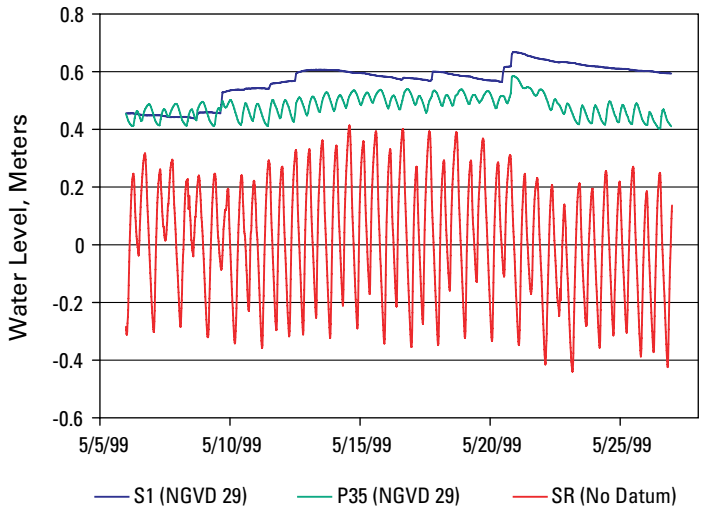

Figure 5. Water levels recorded in Shark River (SR) and Shark River Slough (P35 and S1). (P35 data collected by NPS/ENP, S1 data collected by USGS/BRD Land Margin Ecosystem Program, and SR data collected by USGS/WRD Water Flows and Nutrient Fluxes to Southwest Coast Project.)

COLLABORATING PROJECTS

Projects and the principal investigators contributing to the TIME effort are as follows:

Biological Resources Division:

Across Trophic Level System Simulation—D.L. DeAngelis
Changes in Marsh/Mangrove Ecotone over Time—A. Foster
Manatee Ecology and Population Biology—L.W. Lefebvre
Submerged Aquatic Vegetation and Fauna—C.C. McIvor
Salinity Patterns in Florida Bay: A Synthesis—M.B. Robblee, R.B. Halley, and D. Smith
Land Margin Ecosystem Program—T.J. Smith III

Geologic Division:

Geophysical Studies of the Southwest Florida Coast—D.V. Fitterman
Sedimentation, Sea-Level Rise, and Circulation in Florida Bay—R.B. Halley
High-Resolution Bathymetry of Florida Bay—M.E. Hansen
Ecosystem History: Terrestrial and Fresh-Water Ecosystems of Southern Florida—D.A. Willard
Development of Everglades Tree Islands—D.A. Willard

National Mapping Division:

High Accuracy Elevation Data Collection—G.B. Desmond
Land Characteristics from Remote Sensing—J.W. Jones

Water Resources Division:

Regional Evaluation of Evapotranspiration in the Everglades—E.R. German
Groundwater/Surface-Water Exchange Fluxes—J.W. Harvey and J. Choi
Vegetative Resistance to Flow—H.L. Jenter and N.B. Rybicki
Effect of Wind on Surface Water Flows—H.L. Jenter
Canal and Wetland Flow/Transport Interaction—R.W. Schaffranek
Freshwater Flows into Northeastern Florida Bay—C.D. Hittle and E. Patino
Water Flows and Nutrient Fluxes to Southwest Coast—V.A. Levesque
Southwest Coastal and Wetland Systems Monitoring—E. Patino
TIME Model Development—C.D. Langevin, E.D. Swain, K. Kotun, H.L. Jenter, and R.W. Schaffranek

References

Childers, D.L., Boyer, J., Fourqurean, J., Jaffe, R., Jones, R., Trexler, J., Anderson, W., Gaiser, E., Meeder, J., Richards, J., Ross, M., Scinto, L., Chambers, R., McIvor, C., Sklar, F., and Twilley, R., 2000, Regional controls of population and ecosystem dynamics in an oligotrophic wetland-dominated coastal landscape— introducing a new long term ecological research (LTER) project in the coastal Everglades, *in* Proceedings of the Greater Everglades Ecosystem Restoration (GEER) Science Conference, December 11–15, 2000, Naples, Fla., p. 68–69.

Cline, J.C., Lorenz, J., and DeAngelis, D.L., 2000, ALFISHES: A size-structured and spatially-explicit model for predicting the impact of hydrology on the resident fishes of the Everglades mangrove zone of Florida Bay, *in* Proceedings of the Greater Everglades Ecosystem Restoration (GEER) Science Conference, December 11–15, 2000, Naples, Fla., p. 70.

Comiskey, E.J., and Gross, L.J., 2000, Spatially-explicit species index models in application to Everglades restoration, *in* Proceedings of the Greater Everglades Ecosystem Restoration (GEER) Science Conference, December 11–15, 2000, Naples, Fla., p. 384.

DeAngelis, D.L., 2000, Across trophic level systems simulation (ATLSS) program, *in* Proceedings of the Greater Everglades Ecosystem Restoration (GEER) Science Conference, December 11–15, 2000, Naples, Fla., p. 77–78.

Eggleston, J.R., Embry, T.L., Mooney, R.H., Wedderburn, L., Goodwin, C.R., Henkel, H.S., Pegram, K.M., and Enright, T.J., (compilers), 2000, U.S. Geological Survey Program on the South Florida Ecosystem: 2000 Proceedings: Presentations made at the Greater Everglades Ecosystem Restoration (GEER) Conference, December 11–15, 2000, Naples, Fla., U.S. Geological Survey Open-File Report 00–449, 246 p.

Mazzotti, F.J., Cherkiss, M.S., Moller, M., Kovac, S., and Brandt, L.A., 2000, Ecology and conservation of the American crocodile in Florida, *in* Proceedings of the Greater Everglades Ecosystem Restoration (GEER) Science Conference, December 11–15, 2000, Naples, Fla., p. 231–232.

McIvor, C.C., and Whaley, S., 2000, Patterns in the distribution and abundance of mangrove-associated fishes and crustaceans along a salinity gradient in Shark River, Everglades National Park, *in* Proceedings of the Greater Everglades Ecosystem Restoration (GEER) Science Conference, December 11–15, 2000, Naples, Fla., p. 123–124.

For more information contact:
Raymond W. Schaffranek
U.S. Geological Survey
12201 Sunrise Valley Dr.
National Center, Mail Stop 430
Reston VA 20192
(703) 648-5891 (voice); (703) 648-5484 (fax); rws@usgs.gov (E-mail)

Or visit the TIME project Web site at http://time.er.usgs.gov/.

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