Linking Hydrologic Modeling and Ecologic Modeling: An Application of Adaptive Ecosystem Management in the Everglades Mangrove Zone of Florida Bay

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Abstract: The Across Trophic Levels System Simulator (ATLSS) is a suite of ecological models designed to assess the impact of changes in hydrology on biotic components of the southern Florida ecosystem. ATLSS implements a multimodeling approach that utilizes process models for lower trophic levels, structured population models for middle trophic levels (fish and macroinvertebrates), and individual-based models for large consumers. ATLSS requires hydrologic input to assess the effects of alternative proposed restoration scenarios on trophic structure. An ATLSS model (ALFISH) for functional fish groups in freshwater marshes in the Everglades of southern Florida has been extended to create a new model (ALFISHES) to evaluate the spatial and temporal patterns of fish density in the resident fish community of the Everglades mangrove zone of Florida Bay. The ALFISHES model combines field data assessing the impact of salinity on fish biomass with hydrologic data from the Southern Inland and Coastal System (SICS) model. The estuarine landscape is represented by a grid of 500 $\times$ 500-meter cells across the coastal areas of the Florida Bay. Each cell is divided into two habitat types; flats, which are flooded during the wet season, and creeks, which remain wet and serve as refugia during the dry season. Daily predictions of water level and salinity are obtained from the SICS model output, which is resampled at the 500-meter spatial resolution of the ALFISHES model. The model output may be used to assess the impact of changes in hydrology on fish biomass and its availability to wading bird and other consumer populations. With the development of restoration scenario capabilities in the SICS model, the SICS/ALFISHES coupling should prove an effective tool for evaluating the potential impact of water management policies on the wading bird population in the Everglades mangrove zone.

Keywords: Everglades; Spatially explicit model; mangrove zone; Fish; Scenario evaluation

1 INTRODUCTION

Wading birds have long been a predominant feature of the Everglades mangrove zone of Florida Bay. In particular, the Roseate Spoonbill (*Ajaia ajaja*), a key indicator species due to its strong site fidelity [Lorenz, 2000], has been in decline in recent years. It has been proposed [Lorenz et al., 2002] that changes in the natural pattern of water delivery from the freshwater marshes to the mangrove zone have played a significant role in the decline of the local Roseate Spoonbill population, due to reduced availability of local estuarine fish, its primary food source.

Directly or indirectly, small estuarine fish are an important food source for many wading birds, crocodiles, and large predatory fish in the southern Everglades mangrove zone. Changes in hydrology upstream have increased salinity and altered flooding regimes. A study of the impact of hydrology on the community of small mangrove fish in Taylor Slough and C-111 basins [Lorenz, 1999] suggests these changes may have altered the composition of the resident fish community and affected the relative availability of prey base fish. Thus the ability to link the predicted hydrology to the ecological response of fish populations is an important part of evaluating the effectiveness of water-delivery schemes.

The U. S. Geological Survey has developed two separate models applicable to the southern Everglades. The Southern Inland and Coastal System (SICS) model [Swain, 1999; Swain et al., 2004] is a hydrodynamic surface-water flow model modified for wetlands application and recently coupled to a ground-water model to account for leakage and salinity transfer. The Across Trophic Levels System Simulator (ATLSS) is a suite of ecological models designed to assess the impact of changes in hydrology on biotic components of the southern Florida landscape [DeAngelis et al., 1998; DeAngelis et al., 2002]. Both SICS and ATLSS are essential parts of restoration planning in South Florida.

ATLSS implements a multimodeling approach that utilizes process models for lower trophic levels, structured population models for functional groups of fish and macroinvertebrates, and individual-based models for large consumers. To simulate the dynamics of the estuarine fish community, an existing ATLSS model (ALFISH version 5.0.0) for functional fish groups in freshwater marshes in the Everglades (multicolored areas in Figure 1) was extended to create a new model (ALFISHES) [Cline and Swain, 2002] to evaluate the spatial and temporal patterns of fish density in the Everglades mangrove zone of Florida Bay.

ALFISHES requires input from a hydrologic model to assess the effects of alternative proposed restoration scenarios on trophic structure. The areal distribution of water depths and salinity computed by SICS is used to drive the various components of ALFISHES. This information represents the most complete application to date of the hydrodynamic and transport equations to represent the wetland flow and salinity movement in the coastal area of the southern Everglades.

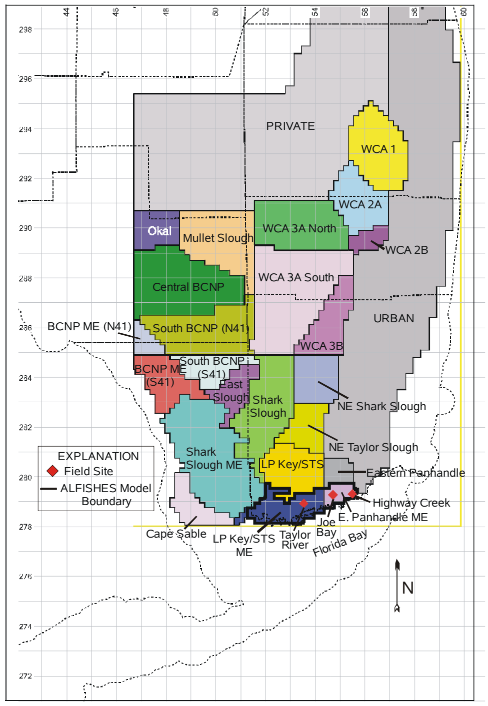

Figure 1: **Subregions for Fish Model with ALFISHES Study Area (ME: Mangrove Estuary; STS: South Taylor Slough) and Field Sites (from left to right: TR, JB, HC)**

2 MODEL DESCRIPTION AND SOLUTION METHODS

The restoration of the South Florida Everglades ecosystems requires linking landscape changes associated with environmental management with changes in key biotic components of the landscape [DeAngelis et al., 2002]. The management process involves developing scenarios of landscape change, developing and applying a suite of hydrologic and ecological models to project the impact of different scenarios on the Everglades ecosystem, and applying a decision framework analyze model output and evaluate management alternatives (see Figure 2).

ALFISHES is designed to utilize the ATLSS modeling infrastructure to implement individual model components and to integrate these components into a single framework. The ATLSS modeling framework combines functionality associated with traditional Geographic Information System (GIS) software with an agent-based modeling approach [Duke-Sylvester and Gross, 2002].

The fish model landscape consists of multiple grid layers including static layers such as vegetation

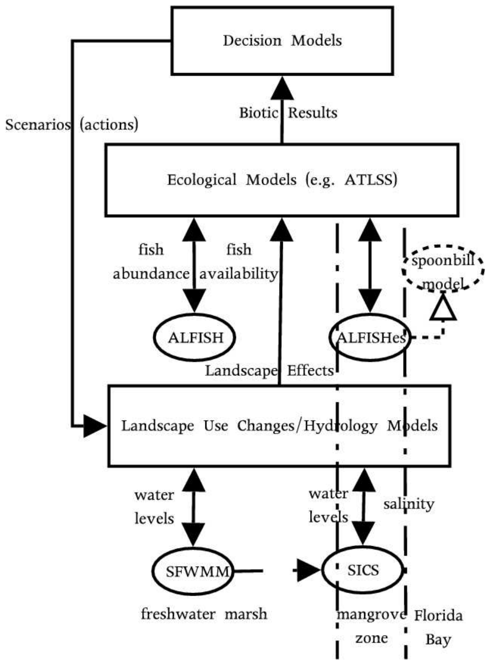

Figure 2: **Decision Process for Ecosystem Restoration (adapted from [DeAngelis et al., 2002; Pearlstine et al., 2004]).**

types and topography, combined with dynamic layers such as hydrology and fish biomass. The ATLSS C++ landscape classes [Duke-Sylvester and Gross, 2002], which provide a common interface for manipulating spatial data, are the primary means of communicating spatial information between different model agents. ALFISHES consist of the following components:

- hydrology component: spatially-explicit time series of water depth and salinity
- landscape component: distribution of marsh or mangrove habitat within a single landscape cell
- lower trophic level components: food base for small fish
- fish component: fish population model

The following subsections describe SICS and the ALFISHES model components in more detail.

2.1 The Hydrology: the SICS Numerical Model

The Southern Inland and Coastal Systems (SICS) model is used to represent the hydrology of the

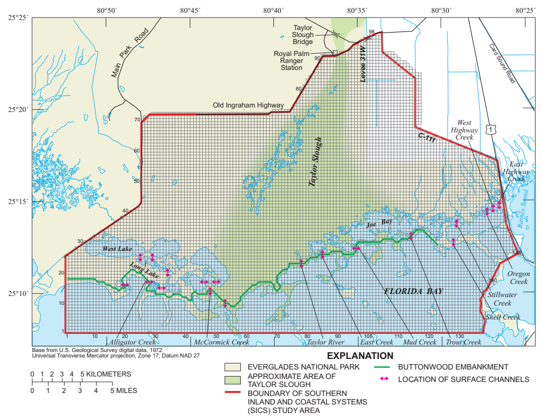

Figure 3: **Southern Inland and Coastal Systems (SICS) study area with 305 meter square grid overlay (USGS, U.S. Geological Survey; NPS, National Park Service; SFWMD South Florida Water Management District).**

model area (Swain and others, 2003). SICS utilizes a two-dimensional, dynamic surface-water model, called SWIFT2D, coupled to a three-dimensional ground-water model, called SEAWAT. This coupled model has several features which allow it to produce an advanced simulation. Both the surface-water and ground-water models simulate salinity transport and the effects on fluid density. The formulations have been modified to account for wind forcing, coastal creek flows, evapotranspiration, and leakage between the surface-water and ground-water. The model area is discretized into a 305 meter square grid as shown in figure 3. The surface-water model operates on a timestep of 7.5 minutes and the ground-water model has a 1 day timestep. A simulation period of 7-years, 1996-2002 inclusive, has been developed and verified. For the purpose of supplying data for ecological models, 1 day averaged values are output from the simulation.

In order to utilize the SICS model to analyze possible changes to the system resulting from ecosystem restoration scenarios, it is necessary to modify the boundaries of the SICS model to reflect regional changes to the south Florida hydrologic system. The boundaries of the SICS model are shown in figure 4. The boundary modifications are accomplished by utilizing results from the South Florida Water Management Model (SFWMM) which represent the modifications to the hydrologic system proposed for restoration purposes. The SFWMM is a much coarser model and uses a 2 mile by 2 mile grid size. Analysis of the SFWMM indicates that the produced water-levels are more accurate than the discharges, thus the water-levels produced on

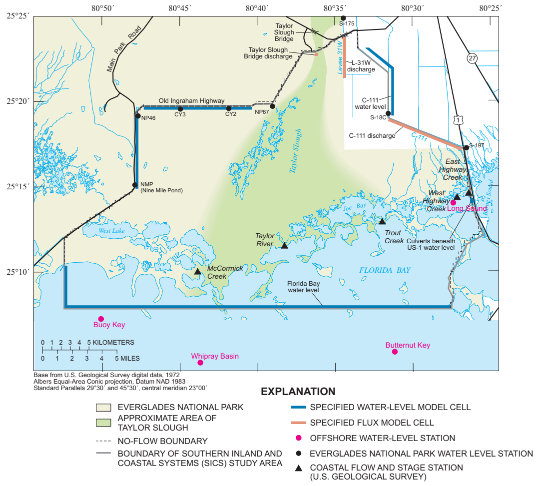

Figure 4: **Southern Inland and Coastal Systems (SICS) study area and selected data-collection sites. (USGS, U.S. Geological Survey; NPS is National Park Service).**

the 2 $\times$ 2 mile SFWMM grids are interpolated to develop new boundary data for the SICS model (see Figure 5).

Replacing the SICS model field-data-produced boundaries with interpolated water-level values from the SFWMM model for the base case, produces very similar results. This indicates that using the SFWMM boundaries is a valid approach. Several different restoration scenarios are to be tested in this manner. A primary scenario is referred to as D13R, which describes hydrologic conditions that are expected to exist in the year 2050 if the Comprehensive Everglades Restoration Plan (CERP) is implemented. This plan involves removal of canal sections and new hydraulic control structures and operating rules.

2.2 The Landscape Fish Model: ALFISHES

The model components of ALFISHES are designed to incorporate the impact of local hydrologic conditions, including salinity levels, on fish population dynamics. The basic model architecture and behavior is derived from ALFISH. ALFISHES is designed to mimic the behavior of the ALFISH in the freshwater marsh habitat in the northern edge of the SICS/ALFISHES modeling area. Since the ALFISHES modeling area straddles a dynamic salinity gradient that characterizes the estuarine ecotone between the Everglades freshwater marshes and Florida Bay, salinity plays a significant role in model dynamics. Along the gradient from freshwa-

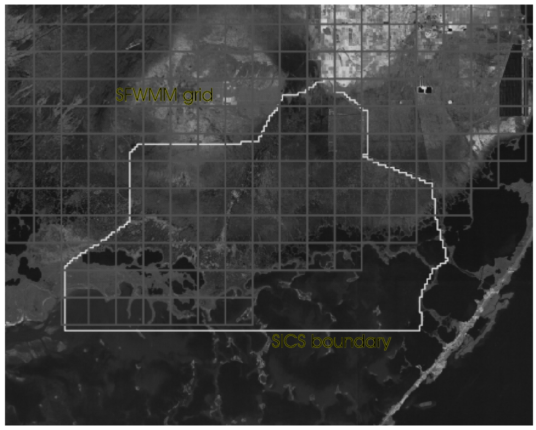

Figure 5: **Southern Inland and Coastal Systems (SICS) study area with the SFWMM 2 $\times$ 2 mile grid overlay. (USGS, U.S. Geological Survey; NPS is National Park Service).**

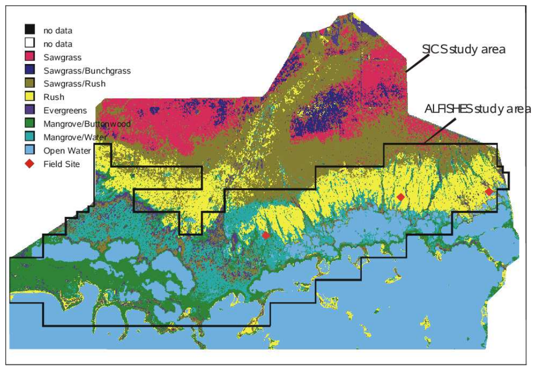

Figure 6: **SICS vegetation map (adapted from [Carter et al., 1999] with the SICS and ALFISHES study areas.**

ter marsh to the estuarine mangrove zone, increasing salinity is associated with changes in the composition of the habitat structure, the lower trophic level, and the small fish community.

The Hydrology: Linking SICS and ALFISHES to Model Dynamics. ALFISHES requires input from a hydrologic model, such as SICS, that includes salinity. In order to process hydrologic output for ALFISHES, output from SICS simulations representing different water management scenarios is archived. A collection of programs utilizing the ATLSS landscape library was developed to resample the SICS output at the 500-meter spatial resolution of the ALFISHES model and build spatial data sets representing the time series of water depths and salinity in the model area. These spatial data sets are used as input for the ALFISHES model.

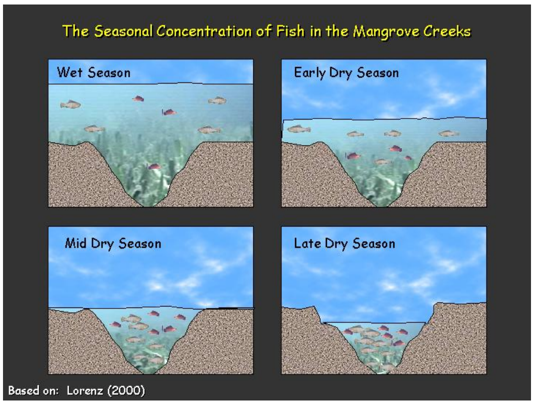

Figure 7: **Hydrology of dwarf mangrove creek habitat. (adapted from Lorenz [2000])**

The mangrove zone landscape model is based on data collected at field sites [Lorenz, 1999] and the static SICS vegetation map [Carter et al., 1999] (see Figure 6). Each cell in the model landscape represents a 500 $\times$500-m cross-section of the Everglades mangrove zone. The impact of hydrology in the single cell fish model of DeAngelis et al. [1997] was captured by dividing the habitat within the cell into three parts: marsh, pond, and solution holes. The marsh areas reflood periodically, while the ponds and solution holes serve as refugia during periods of low water.

The field sites are located in dwarf mangrove (*Rhizophora mangle*) habitat and are characterized by deep creeks surrounded by flats that are flooded seasonally [Lorenz, 1999]. When the sites flood, the fish spread across the flats. The fish either retreat to refugia (in this case, creeks), or retreat to neighboring spatial cells, or die, if the cell dries out (Figure 7).

3 MODEL ARCHITECTURE AND IMPLEMENTATION

The ATLSS model components are agent-based and use a library of C++ landscape classes to model landscape and hydrologic data [Duke-Sylvester and Gross, 2002]. The ATLSS landscape class library provides common interface for manipulating spatial data, a generic IODevice class for managing data input and output, a generic Metadata class for describing spatial data and other basic data types, and support for manipulating time series of spatial datasets. More details about the ATLSS approach are available at http://atlss.org/.

ALFISHES (see Figure 8) incorporates some additional features not provided by the original ATLSS framework: support for XML (eXensible Markup Language)-base metadata, abstract interfaces for generic components (e.g. a generic hydrologic model interface), support for a model repository allowing dynamic loading of model components specified by metadata, and a CORBA-based client-server implementation that combines a Java-based GUI (Graphical User Interface) for visualizing spatial data, a C++-based simulation server.

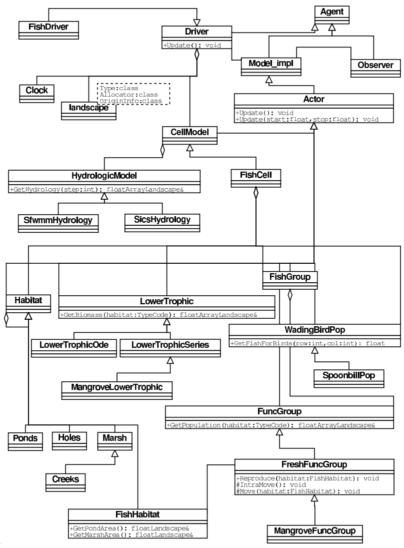

Figure 8: **Classes of the ALFISHES model**

These additional features are provided by SimApp [Cline et al., 2000], a CORBA-based framework for spatially-explicit ecological simulations. SimApp is an object-oriented framework for spatially-explicit modeling that combines support for implementing a suite of meta-models in a distributed computing environment via XML and CORBA. This approach allows for a more modular and scalable computing approach that supports using different applications in concert for data visualization, data analysis, and model computation.

4 CONCLUSIONS AND FUTURE WORK

Prior to the coupling of SICS and ALFISHES, the Everglades mangrove zone had been excluded from the ATLSS modeling work in support of CERP. With the incorporation of different water management scenarios from the SFWMM into the boundary conditions for SICS, the combination of SICS and ALFISHES may provide a platform for establishing the link between water management and the viability of key indicator species such as spoonbills.

The ability to produce reliable projections of both fish abundances and fish availability during the spoonbill nesting season remains a primary objective of the modeling effort. The hydrologic and landscape components developed for ALFISHES may be used to facilitate development or refinement of other models of wildlife populations in the Everglades mangrove zone such as the American crocodile (*Crocodylus acutus*).

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