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LINKAGE OF HYDROLOGIC AND ECOLOGICAL MODELS: SICS AND ALFISHES

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Abstract: The U. S. Geological Survey has developed two separate models applicable to the southern Everglades. The Southern Inland and Coastal System (SICS) model is a hydrodynamic surface-water model modified for wetlands application, and was 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 that are 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 the 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. Prior to the development of ALFISHES, the estuarine interface had been excluded from ATLSS due to the lack of reliable hydrologic information.

The ALFISHES model combines field data assessing the impact of salinity on fish biomass with hydrologic data from the SICS model. The estuarine landscape is represented by a grid of 500 x 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 fish spread out into the flats during flooded conditions. As the dry season approaches, cells dry out and the fish either retreat by moving into creeks, move to other spatial cells, or die if their cell dries out. The ALFISHES model incorporates an assumption based on field data that the productivity, expressed as the amount of lower trophic level biomass, is inversely correlated with salinity. 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.

Calibration of the SICS/ALFISHES linkage requires hydrologic and ecological data sampled from the landscape. The primary means of evaluating the linkage is the comparison with hydrologic and drop-net data collected at three field sites in the Florida Bay mangrove zone. Both SICS and ALFISHES are evolving as data and calibration

information becomes available for each. This makes their linkage change iteratively. 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 on the wading bird population in the Everglades mangrove zone.

INTRODUCTION

Wading birds have long been a predominent 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 (J. Lorenz, National Audubon Society, oral commun., 2000), has been in decline in recent years. It has been proposed (Lorenz et. al., 2000) 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. Small estuarine fish are an important food source, directly or indirectly, for many wading birds, crocodiles, and large predatory fish in the southern Everglades mangrove zone of Florida Bay. Changes in hydrology upstream have increased salinity and altered flooding regimes. A recent study of the impact of hydrology on the community of small mangrove fish in Taylor Slough and C-111 basins (Lorenz, 1997; 1999) suggests these changes may have altered the composition of the resident fish community and affected the relative availability of prey base fish. The ability to link the predicted hydrology to the ecological response, such as fish population 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 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 that are designed to assess the impact of changes in hydrology on biotic components of the southern Florida landscape (DeAngelis et. al., 1998).

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, a model of functional fish groups was developed within the ATLSS modeling framework. 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) 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 water depth and salinity information computed by SICS 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. The areal distribution of water depths and salinity computed by SICS is used to drive the various components of ALFISHES.

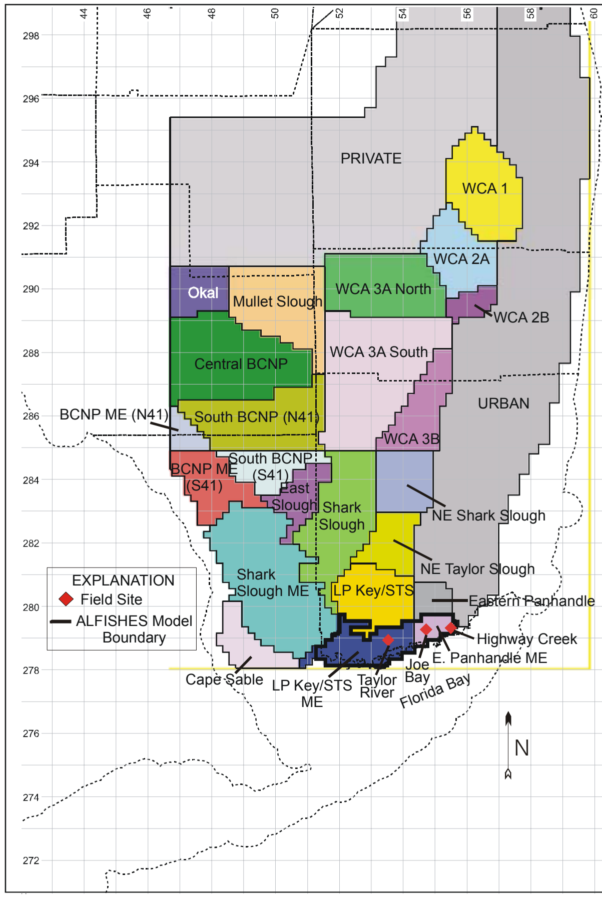

Figure 1: Subregions for ALFISHES and Study Area and Location of Field Sites (WCA, Water Conservation Area; BCNP, Big Cypress Natural Preserve; LPK, Long Pine Key; STS, South Taylor Slough; ME, Mangrove Estuary

The primary objective of the ALFISHES model is to provide a tool for assessing the impact of hydrology on fish of the Everglades mangrove zone of Florida Bay and ultimately, the impact of hydrology on wading birds and crocodiles. By using the SICS numerical model to represent water-management scenarios, the impact of different scenarios on wildlife populations may be evaluated. The model also provides a generic framework that allows for the input of static and dynamic landscape features imported from a geographical information system (GIS) or other spatial models of physical features. The landscape model structure may be readily reused for other ecological models in the mangrove zone.

MODEL DESCRIPTION AND SOLUTION METHODS

SICS numerical model: The SICS model is a hydrologic model that evolved from a two-dimensional hydrodynamic surface-water model to a coupled surface-water/ground-water model with salinity transport. Surface water is represented by the SWIFT2D dynamic-wave code. This code was originally designed to represent transient two-dimensional flow in water bodies while accounting for wind forcing, lateral boundaries, point inflows, and the transport of conservative and nonconservative constituents. Modifications were made to account for rainfall and evapotranspiration volumes and their effects on constituent concentration. The effects of ground-water interactions were significant enough to require a coupling of SWIFT2D to the three-dimensional variable-density ground-water code SEAWAT that also models salinity transport. With leakage between the surface-water and ground-water systems accounted for, the ability to simulate the hydrologic system was greatly improved, especially in representing coastal salinities.

The SICS model is constructed using a 305 x 305-meter finite-difference grid for the surface-water and ground-water models. Water level and salinity are computed for each cell; flow between cells also is computed. It is necessary to spatially interpolate these values to input them into the 500 x 500-meter ALFISHES model grid. The surface-water model generates data at a 7.5-minute interval, which must be averaged to compute the daily data used for ALFISHES.

Boundary conditions for the SICS model must contain salinity information, as well as water-level or discharge data, to define the hydrodynamic driving forces. The southern boundary is defined by water levels in Florida Bay (Figure 2). Monitoring stations in the bay also help to define the salinity along this boundary. Northern boundaries are primarily defined by discharge values, and their salinities are normally considered to be negligible. The boundary conditions in the SICS model have a substantial effect on the model's hydrologic output and the effects on ALFISHES.

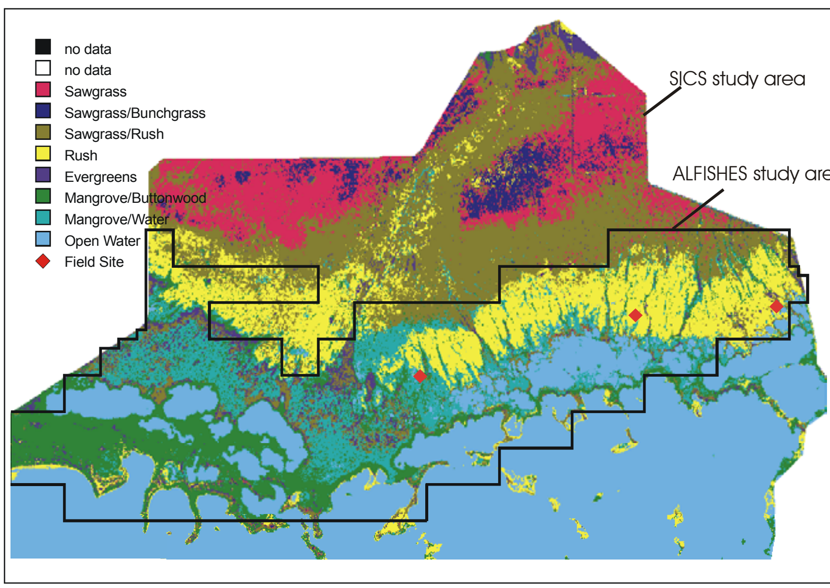

Figure 2: SICS Vegetation map (adapted from Carter et al., 1999) with the SICS and ALFISHES study areas

The SICS model has the capability to represent potential restoration scenarios and their impact on relevant hydrologic parameters. The scenarios of interest involve variations in the operations of control structures that regulate flows into the SICS area and the addition or removal of control structures and canals. Most of these proposed changes occur outside the SICS study area. In order to use the SICS model to represent these changes, the regional South Florida Water Management Model (SFWMM) is used to generate SICS boundary conditions. The SFWMM, developed by the South Florida Water Management District (SFWMD), simulates the hydrology of the southern Florida peninsula on a larger scale, using 3.2 x 3.2-km grid cells. The operational scenarios are simulated in the SFWMM and boundary conditions generated for the SICS model. In this way, SICS can represent hydrologic change on a smaller scale and with more complex equations than the SFWMM. This adds versatility to the SICS/ALFISHES coupling, and makes more accurate scenario testing possible.

ALFISHES landscape fish model: The structure of the ALFISHES model is derived from an earlier model (ALFISH version 5.0.0) for functional fish groups in the freshwater marshes of the Florida Everglades (Gaff et al., 2000). ALFISH extends a single cell fish model of DeAngelis et al. (1997) to model the entire marsh landscape as 500 x 500-meter spatial cells on a grid overlaying the 40,000 km^2 Everglades freshwater drainage basin from Lake Okeechobee south to Florida Bay. The multiple grid layers of the model include static layers, such as vegetation types and topography, combined with dynamic layers such as hydrology and fish biomass. The ALFISH model was developed to incorporate spatially explicit hydrologic data from the SFWMM and has been used to evaluate alternative water-management scenarios of the Florida Everglades region.

Linking SICS and ALFISHES to Model System Dynamics: The SICS model region encompasses the coastal and offshore areas of Everglades National Park and Florida Bay (figures 1 and 2). The ALFISHES model landscape represents the intersection between two subregions, E. Panhandle ME and LPK/STS ME, that are associated with the mangrove zone north of Florida Bay and the SICS modeling region (Figure 2). Daily snapshots of water depth and salinity for each cell are generated by SICS for input into ALFISHES. Spatial interpolation methods provided by the ATLSS landscape classes (Duke-Sylvester and Gross, 2002) were used to map these hydrologic data into the 500 x 500 meter ALFISHES model grid.

The dynamics of the Everglades landscape is characterized by periodic dry-downs and refloodings. 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 ALFISH model applies this habitat structure to the entire landscape, although the solution holes are omitted from the current version of that model due to lack of sufficient data. The typography of the marsh area of each cell is defined by an average hypsograph, which determines the fraction of marsh area flooded for a given water depth (Gaff et al., 2000).

The ALFISHES model landscape includes a new spatial cell type that models the mangrove estuarine landscape. The field sites associated with this modeling effort are located in dwarf mangrove (*Rhizophora mangle*) habitat, characterized by deep creeks surrounded by flats that are flooded seasonally (Lorenz, 1997; 1999). As in freshwater marsh habitat, fish spread across the flats when the region is flooded and either retreat to refugia (in this case, creeks), retreat to neighboring spatial cells, or die if the cell dries out (Figure 3).

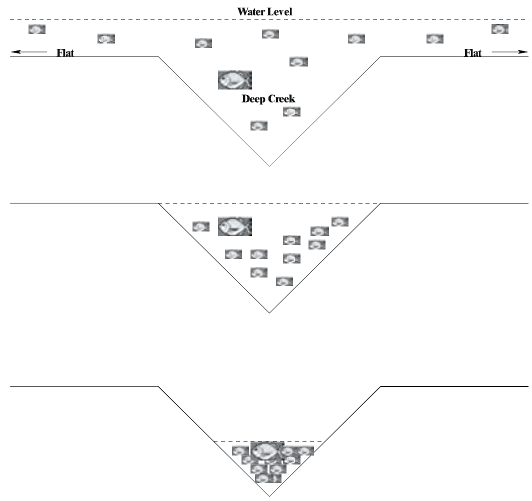

Figure 3: Hydrology of Dwarf Mangrove Creek Habitat

A hypsograph for mangrove habitat was generated by establishing the relation between vegetation type and relative elevation. The habitat at each field site was classified into one of four different types: high flats, flats, high creek, and creek. An elevation map in which each habitat type is associated with a relative elevation was generated for each of the study sites by combining analysis of aerial photos and ground surveys of field sites. To apply this hypsograph to the entire mangrove landscape, the habitat types identified in the field study were mapped to vegetation categories supplied by the static SICS vegetation data (Carter et al., 1999) (figure 2), which is an aggregated reclassification of the Florida gap analysis project (Scott et al., 1993, U. S. Geological Survey, 1997) vegetation map. The vegetation data, which have 30-m resolution, are used to compute the percent of each habitat type within each landscape cell.

The parameters and methods associated with fish movement, mortality, and reproduction are unchanged from the original ALFISH model. Due to the lack of information, the large fish group is currently not included in ALFISHES simulation scenarios. The species composition of the large fish guild in the mangrove zone is different from that of the freshwater marshes, and the large piscivorous fish that frequent the tidal creeks in the mangrove zone tend to be more mobile than their freshwater counterparts (J. Lorenz, National Audubon Society, oral communication, 2000). Future versions of ALFISHES may incorporate the large fish group, as well as fish movement and mortality as a function of salinity.

Another factor that influences fish density is the availability of food resources from lower trophic level resources. One weakness of the ALFISH model (version 3.1.7) used for the Central and South Florida Comprehensive Project Review Study is that the lower trophic level resources are held constant independent of hydrology, habitat type, spatial location, or time of year. More recent versions of the ALFISH model assume that lower trophic level biomass varies seasonally and depends on habitat type. Preliminary runs of the ALFISHES model suggest that a more complicated water-driven lower trophic model calibrated for the mangrove zone may be more appropriate.

ALFISHES program structure: The primary inputs into the ALFISH and ALFISHES models are the landscape typography, hydrologic data, and lower trophic level biomass. Both models use the ATLSS multimodeling framework, which consists of a collection of model subcomponents. 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). Because the landscape structure for a particular ATLSS model scenario is well defined and landscape objects are the primary means of communicating spatial information between different model agents, different implementations of a particular submodel, such as the lower trophic level model, may be used without changing the structure of the simulation. Therefore, the effect of different modeling approaches, from simple process models to highly detailed individual-based models, on model effectiveness may be evaluated within the same framework.

The ALFISHES model inherits the basic program structure, parameters, and agent classes used in the ALFISH model (Gaff et al. (2000) for a detailed description). ALFISHES adds generic agent classes and additional derived subclasses to construct an object-oriented framework that partitions the model system into a hierarchical collection of components (Figure 4). Each model agent is responsible for a specific aspect of the simulation. Table 1 summarizes the agent class used in ALFISHES.

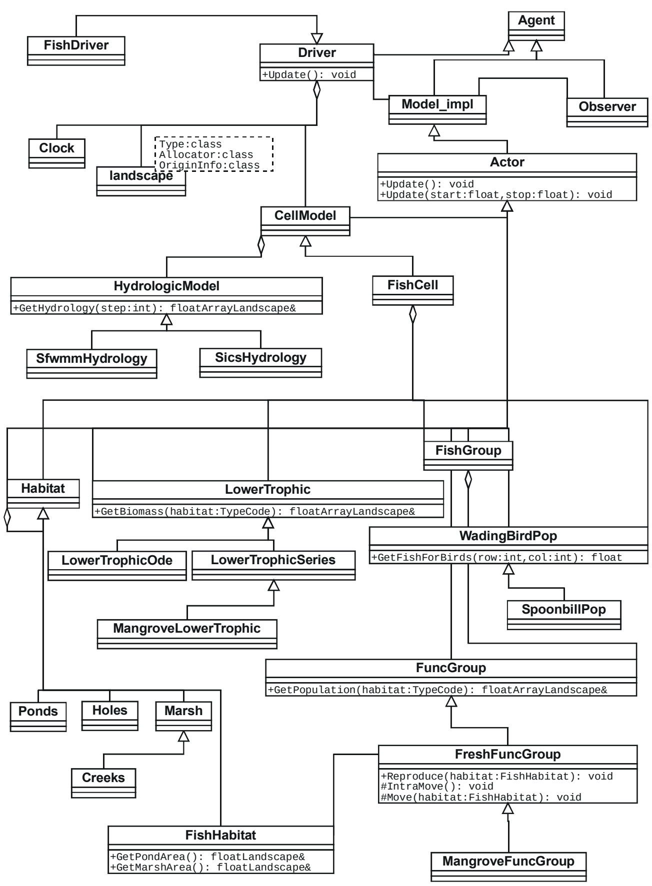

Figure 4: Classes of the ALFISHES Model

Table 1: Agent classes used by ALFISHES (classes shown in italics are derived from ALFISH version 5.0.0)

Base Class	Subclasses	Description
Driver	FishDriver	Manages a simulation scenario; contains the landscape, simulation clock, and simulation model
FishCell	MarshFishCell MangroveFishCell	The simulation model; updates the state each cell; subclasses for marsh and mangrove estuarine zones respectively
HydrologicModel	SfwmmHydrology SicsHydrology	Manages the interface between the hydrologic data and the FishCell subclasses for different hydrologic models
Habitat	FishHabitat, Ponds *Holes*, Marsh, Creeks	Manages the physical environment; may contain subhabitats; FishHabitat provides a single interface for fish habitat; other subclasses manage lower subhabitats
LowerTrophic	LowerTrophicOde LowerTrophicSeries MangroveLowerTrophic	Models lower trophic level biomass within each grid; subclasses implement ordinary differential equation (ODE) models, seasonal forcing, and productivity as a function of salinity
FishGroup		Manages multiple functional groups
FuncGroup	*FreshFuncGroup* EstuarineFuncGroup	Models a functional fish group; subclasses model freshwater and estuarine functional groups
WadingBirdPop	SpoonbillPop	Models the impact of hydrology on wading birds
FishObserver	MarshFishObserver MangroveFishObserver	Generates simulation statistics and reports

At the root of the ALFISHES agent hierarchy is the simulation driver, which contains the three primary simulation subcomponents: model landscape, simulation clock, and model that serves as the engine of the simulation. The model landscape utilizes the ATLSS landscape classes and consists of static and dynamic layers. Static layers represent static features of the landscape, such as the distribution of creek and flats habitat within each grid cell with an associated hypsograph. Dynamic layers, which use 500-m resolution and are updated at each time step, represent the hydrology, lower trophic levels biomass, and number of fish for each size class habitat type and cell.

The simulation model, an object of class “FishCell,” is responsible for updating the state of each cell in the landscape for each time step. The time step of the model is 5 days, although a daily snapshot of hydrologic data is used to assess foraging conditions for wading birds. Different subagents are responsible for updating different aspects of the model. The “HydrologicModel” object interfaces the hydrologic and ecological model and simplifies the utilization of different hydrologic datasets. The “Habitat” agent updates the distribution of water within the different habitat types in each grid cell. The “Habitat” agent contains subagents, including “Ponds,” “Holes,” and “Marsh” which manage different subhabitats associated with the freshwater marsh. The “Creeks” habitat agent generates the mangrove habitat and manages the distribution of water in the creeks and flats habitats. The “LowerTrophic,” “FishGroup,” and “FuncGroup” agents update lower trophic level biomass and the number of fish. Two new derived subclasses of “LowerTrophic” and “FreshFuncGroup”, namely, “MangroveLowerTrophic” and “EstuarineFuncGroup,” were constructed to simulate the dynamics of the lower trophic level food base and small fish in the mangrove zone. At the end of each time step, the “WadingBirdPop” agent computes the habitat viability from the perspective of wading birds, and the “FishObserver” generates simulation statistics.

IMPLEMENTATION

To evaluate the effectiveness of the model coupling, a SICS dataset was generated for input into ALFISHES. The dataset includes a single daily snapshot of water depth and salinity for each cell in a region that is 98 rows x 148 columns at a spatial resolution of 304.8 meters for a 694 day period from July 16, 1996 to June 9, 1998. The 304.8 m spaced SICS data was resampled for the 500 m ALFISHES grid. Calibrating SICS/ALFISHES requires hydrologic and ecological data sampled from the landscape. Comparison of simulation data with hydrologic data and drop net data collected at three field sites in the Florida Bay mangrove zone (Lorenz, 1999) is the primary means of evaluating SICS/ALFISHES. Because SICS and ALFISHES continue to evolve as model output is generated and evaluated, developing a linkage between the two models has been an iterative process.

The ability to run ALFISHES on a remote server through a web-browser-based Java SimApp client that supports a GIS display and other data visualization facilities has simplified the process of evaluating model output and facilitated communication among project collaborators. After two iterations of SICS output, the salinity regimes in the ALFISHES model are reasonably consistent with field data. The SICS water depths, however, remain greater than expected at the field sites (Figure 5), a discrepancy that would result in an underestimate of prey fish biomass available to wading birds.

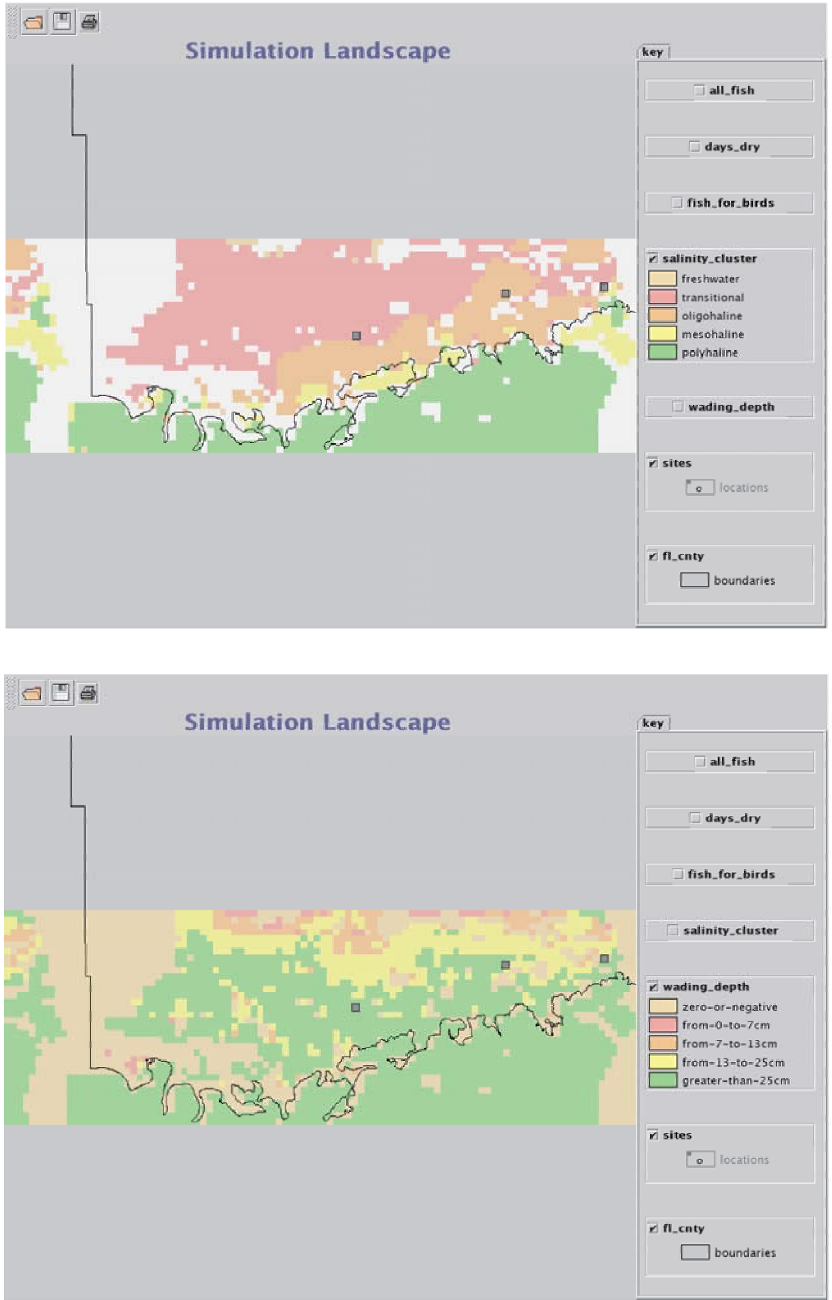

Figure 5: Snapshots from the Java "SimApp" client of SICS-generated salinities and water depths in the ALFISHES study area on day 175 (field sites from left to right: Taylor River, Joe Bay, Highway Creek)

CONCLUSIONS AND FUTURE WORK

The linkage between SICS and ALFISHES continues to evolve as model data and field data, particularly water depths, are reconciled. Incorporation of additional typographical information, such as location of river channels, from SICS into ALFISHES may address some of the discrepancies between model and field data. Expansion of the sampling effort to include additional field sites is planned. The lower trophic level, fish, and wading bird components of the ALFISHES model are being refined as more field data become available. With the incorporation of different water-management scenarios from the SFWMM into the boundary conditions for SICS hydrology scenarios, the SICS/ALFISHES coupling should provide an effective tool for evaluating the potential impact of hydrologic scenarios on wading bird populations in the Everglades mangrove zone.

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