Application of a Multi-Modeling Framework to Linking Ecosystem Pattern and Process Across Scales: Implementation of a Decision Support Tool for Adaptive Ecosystem Management in the Everglades Mangrove Zone

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Overview

Objectives: ATLSS ALFISHES Landscape Model

Everglades Ecosystem Restoration

- Everglades ecology
- The Models: SICS/ALFISHES

Modeling Challenges

- Multimodeling
- Modeling and Simulation
- Model Implementation

Summary

Objectives

ALFISHES Landscape Fish Model

- The ATLSS (Across Trophic Level System Simulation) models are designed to predict the impact of hydrology scenarios on biota in the greater Everglades in support of the Comprehensive Everglades Restoration Plan (CERP).
- The objective of the ATLSS landscape fish model ALFISHES, combined with the hydrologic model SICS, is to predict the impact of hydrology on the availability of prey base fishes of the Everglades mangrove zone of Florida Bay to wading birds (and crocodiles).

Everglades Ecology: Fish and Birds

Resident fish (food) of the mangrove zone north of Florida Bay – Sailfin Molly (Poecillia latipinna)

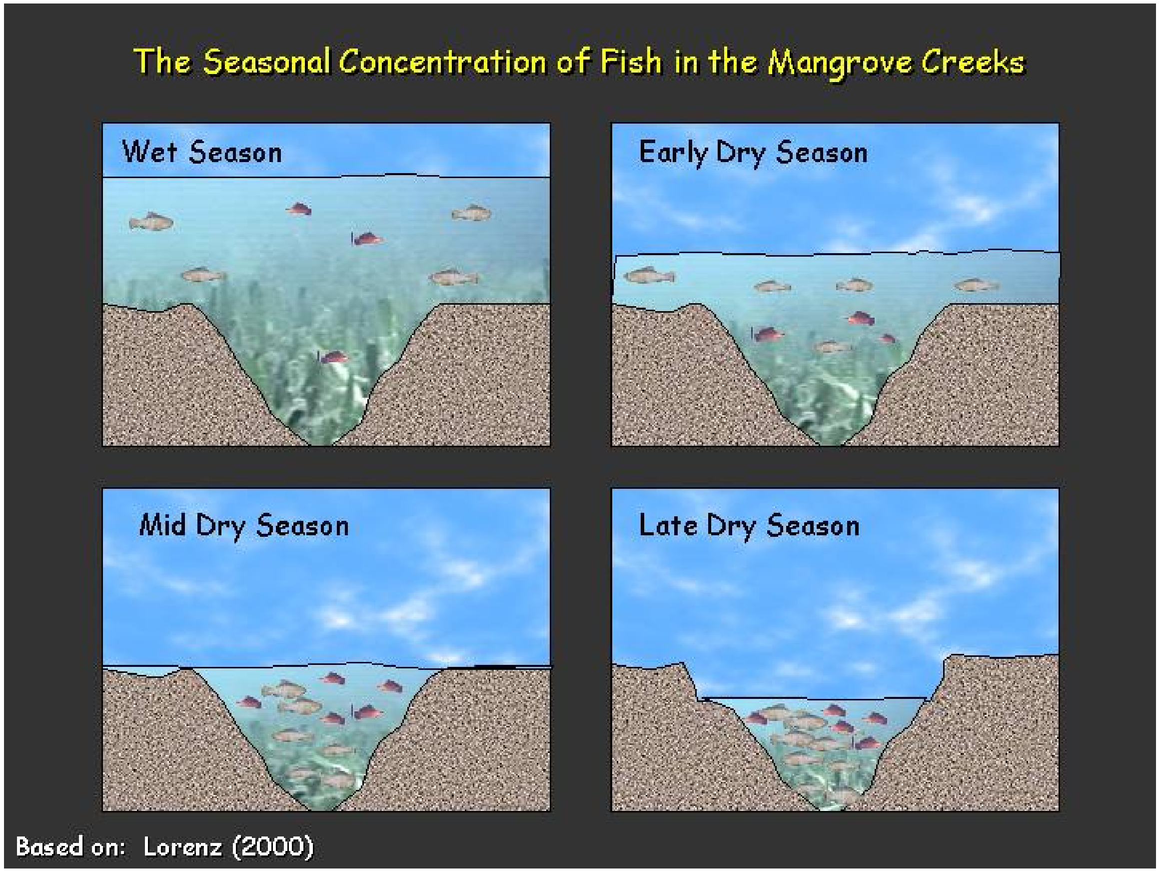
Charismatic megafauna – Roseate Spoonbill (Ajaja ajaja)

Everglades Ecology: The Habitat

The creeks and flats of the mangrove zone

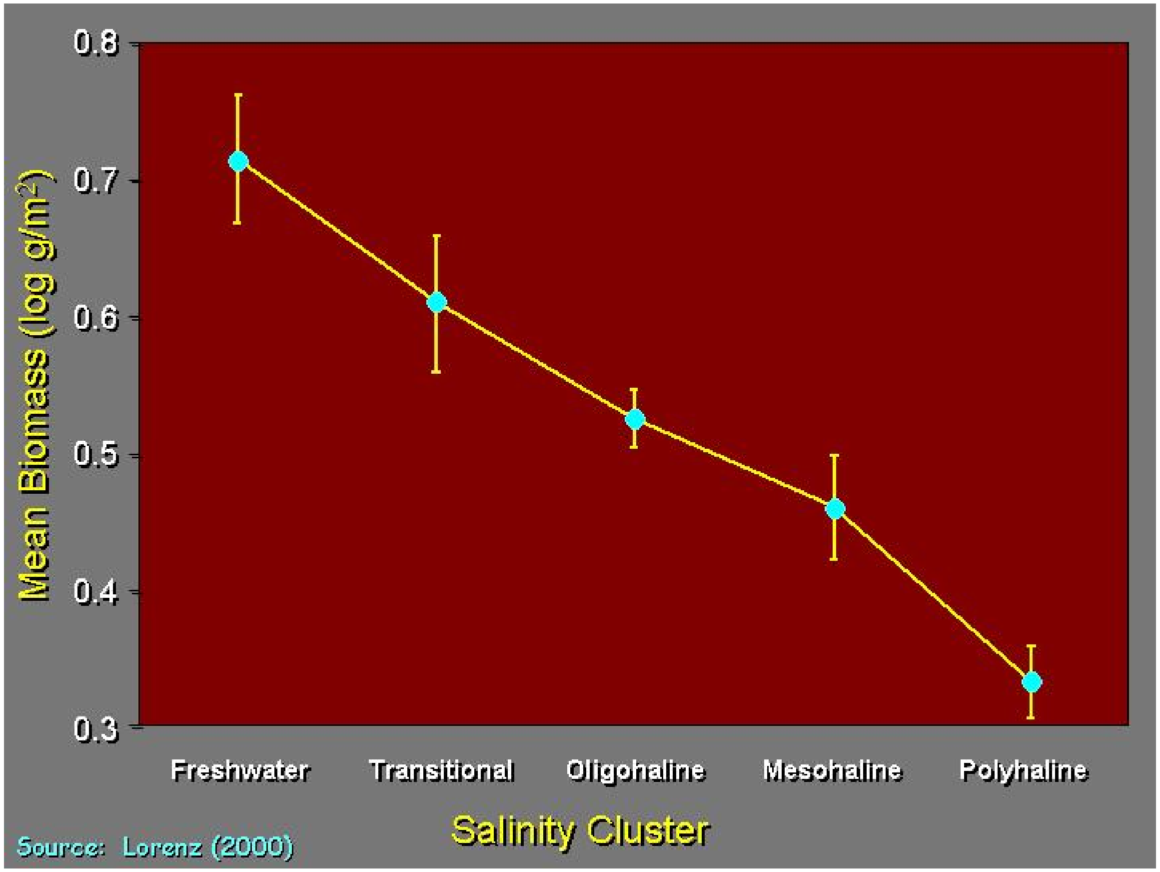
Seasonal flooding

Changes in bay level



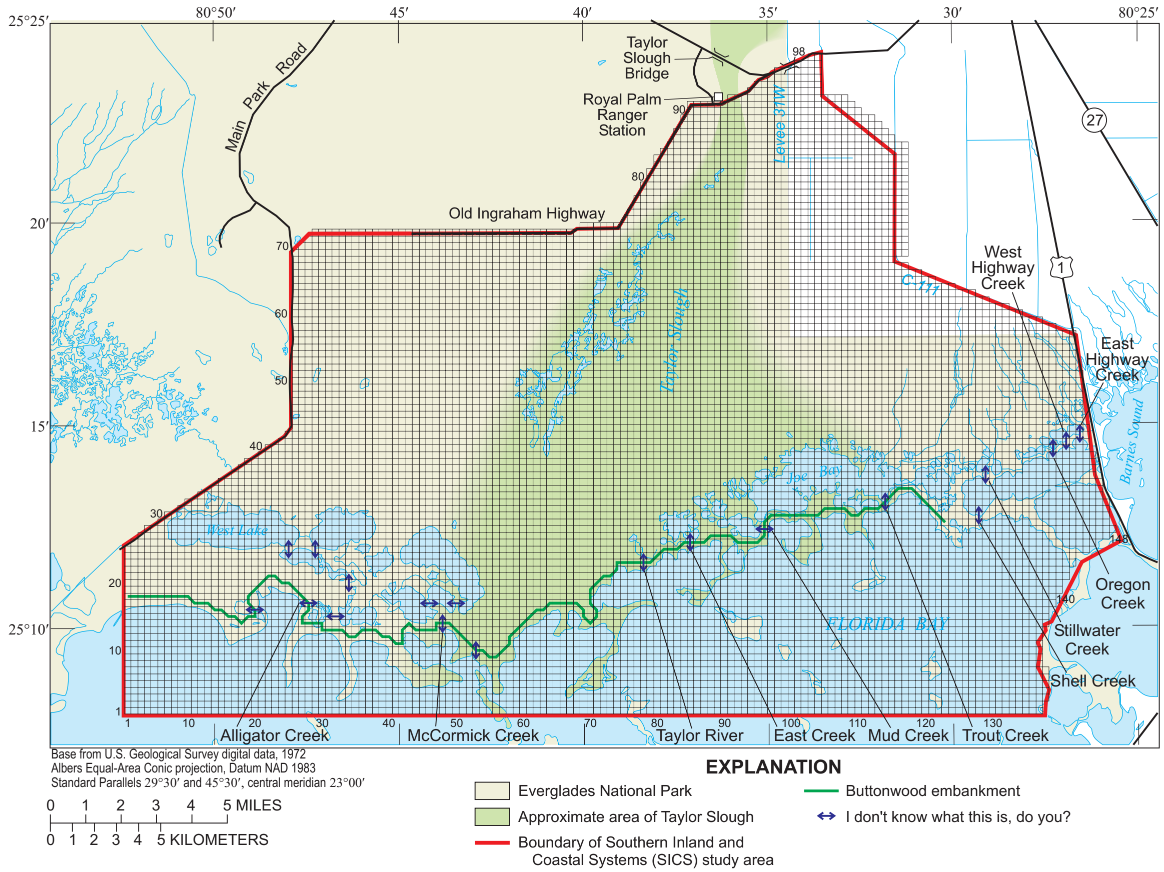
The resident fish biomass is negatively impacted by saline period due to reduced food availability

The resulting fish community is less robust than the historic one



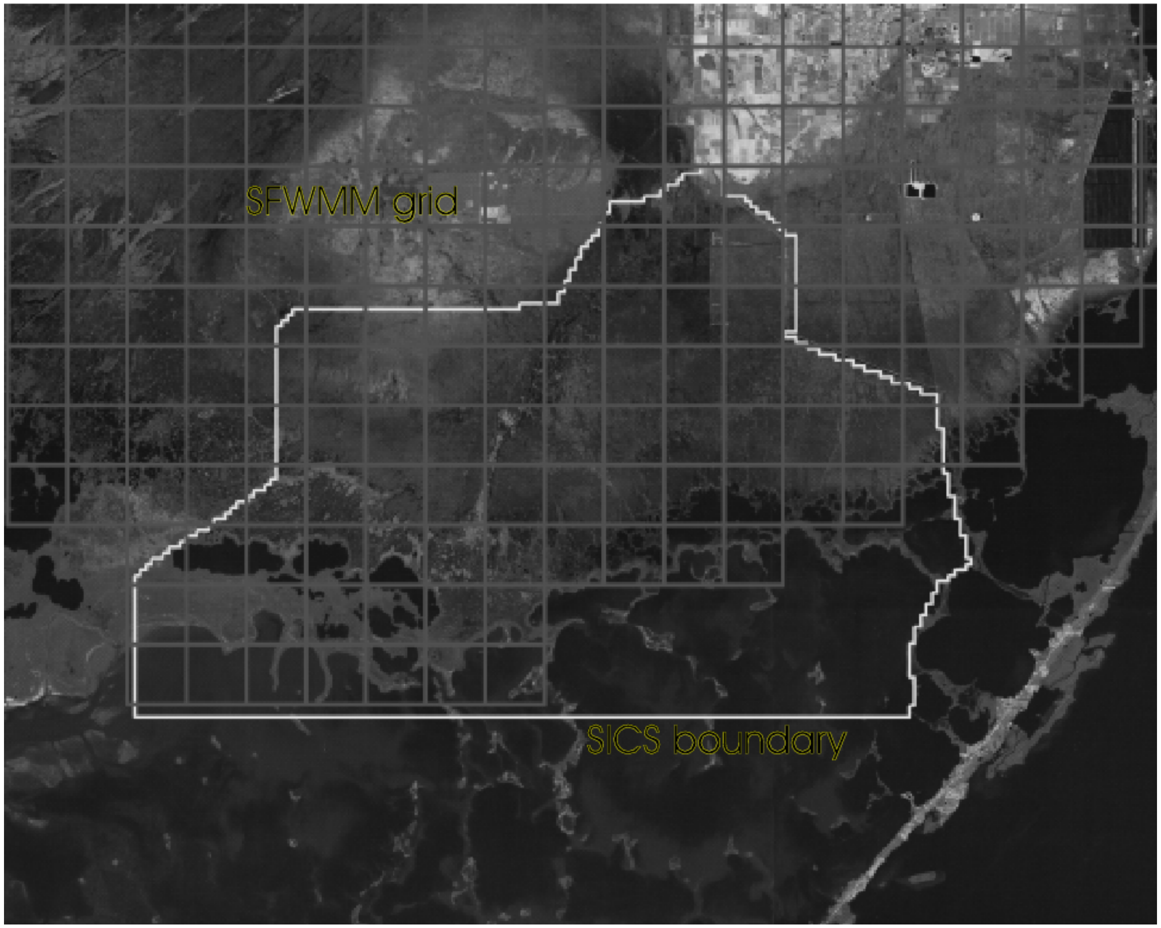
Everglades Hydrology: SICS

SICS utilizes a two-dimensional, dynamic surface-water model, called SWIFT2D, coupled to a three-dimensional ground-water model, called SEAWAT.



Linking Everglades Ecosystem Restoration and SICS

In order to model ecosystem restoration scenarios, the SICS model field-data-produced boundaries are replaced with interpolated water-level values from the SFWMM model.



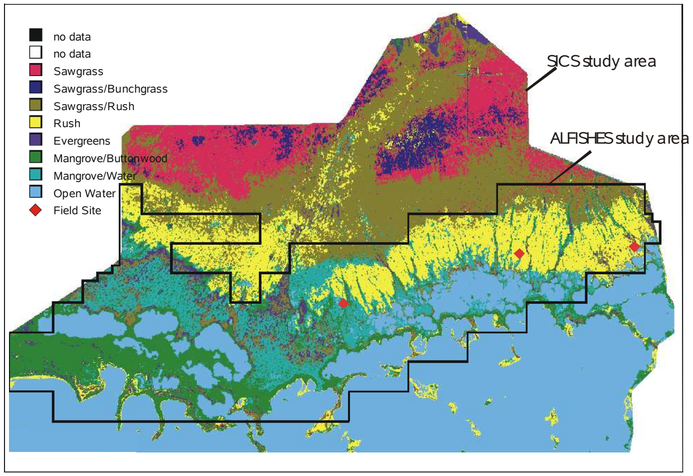
The Ecology: ALFISHES

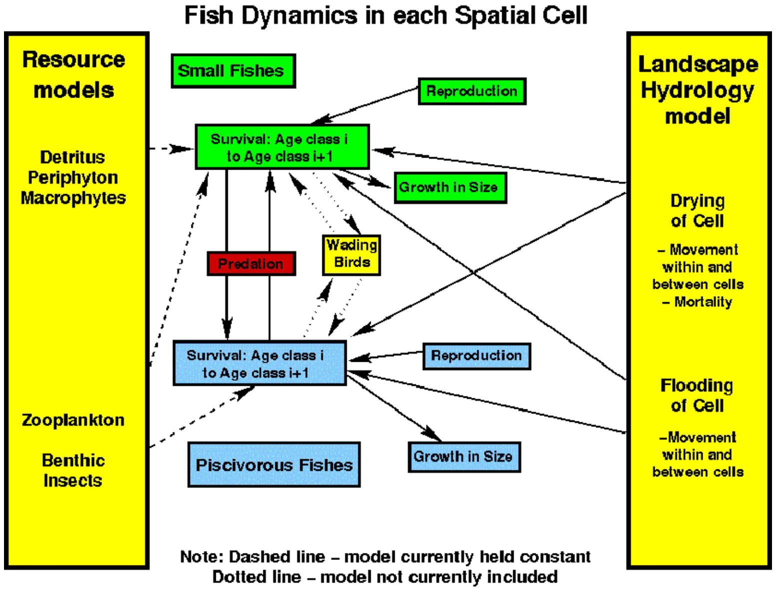
hydrology: SFWMM and SICS (water levels, salinity)

landscape cell: 500 × 500 m cells with permanent vs. flooded habitat (percent creek, percent flats)

lower trophic level: process model incorporating negative response of periphyton to salinity

fish population: age and size-structure model with movement within and between cells





The Ecology: ALFISHES – Landscape

Inputs:

1. SICS vegetation map at the 30 meter scale
2. hypsographs by habitat type based on surveys of study sites

Output:

distribution of habitat type within each 500 × 500 m cell and a corresponding hypsograph

SICS veg type	creek	high creek	flats	high flats
sawgrass	na	na	na	na
sawgrass/bunchgrass	na	na	na	na
sawgrass/rush				√
rush (dwarf mangrove)			√	
evergreens (tree islands)				
mangrove/buttonwood		√		
mangrove/water	√			
open water				

The Ecology: ALFISHES – Lower Trophic Level Dynamics

$$\frac{dB_1}{dt} = \gamma_1 B_1(t) - \delta_1 B_2(t)^2 - \alpha \left[\gamma_4 B_4(5) + \gamma_5 B_5(t)\right] B_1(t)$$
$$\frac{dB_2}{dt} = \gamma_2 B_2 - \delta_2 B_2(t)^2$$
$$\frac{dB_3}{dt} = \gamma_3 \left[\delta_1 B_1(t)^2 + \delta_2 B_2(t)^2 + \delta_4 B_4(t)^2 + \delta_5 B_5(t)^2\right] - \delta_3 B_3(t)$$
$$\frac{dB_4}{dt} = \gamma_4 B_1(t) B_4(t) - \delta_4 B_4(t)^2$$
$$\frac{dB_5}{dt} = \gamma_5 B(t) B_5(t) - \delta_5 B_5(t)^2$$

where

i	component
1	periphyton
2	macrophytes
3	detritus
4	mesoinvertebrates (those $<$1 mg body weight)
5	macroinvertebrates (those $>$1 mg body weight)

B_i =biomass of component i

α is the inverse of assimilation rate of macroinvertebrates and macroinvertebrates

$\gamma_i$and $\delta_i$are seasonally varying growth and death (percentage production and decay rates for detritus) parameters

Revisiting a hypothesis: the resident fish biomass is negatively impacted by saline period due to reduced food availability

Approach: as salinity increases, the lower trophic level system switches from a periphyton-driven system to a detritus-drive system

$\delta_1 = \delta(t, x)$ =death rate of periphyton in cell x at time t= $\delta_{min} \exp^{\kappa s(x,t)}$

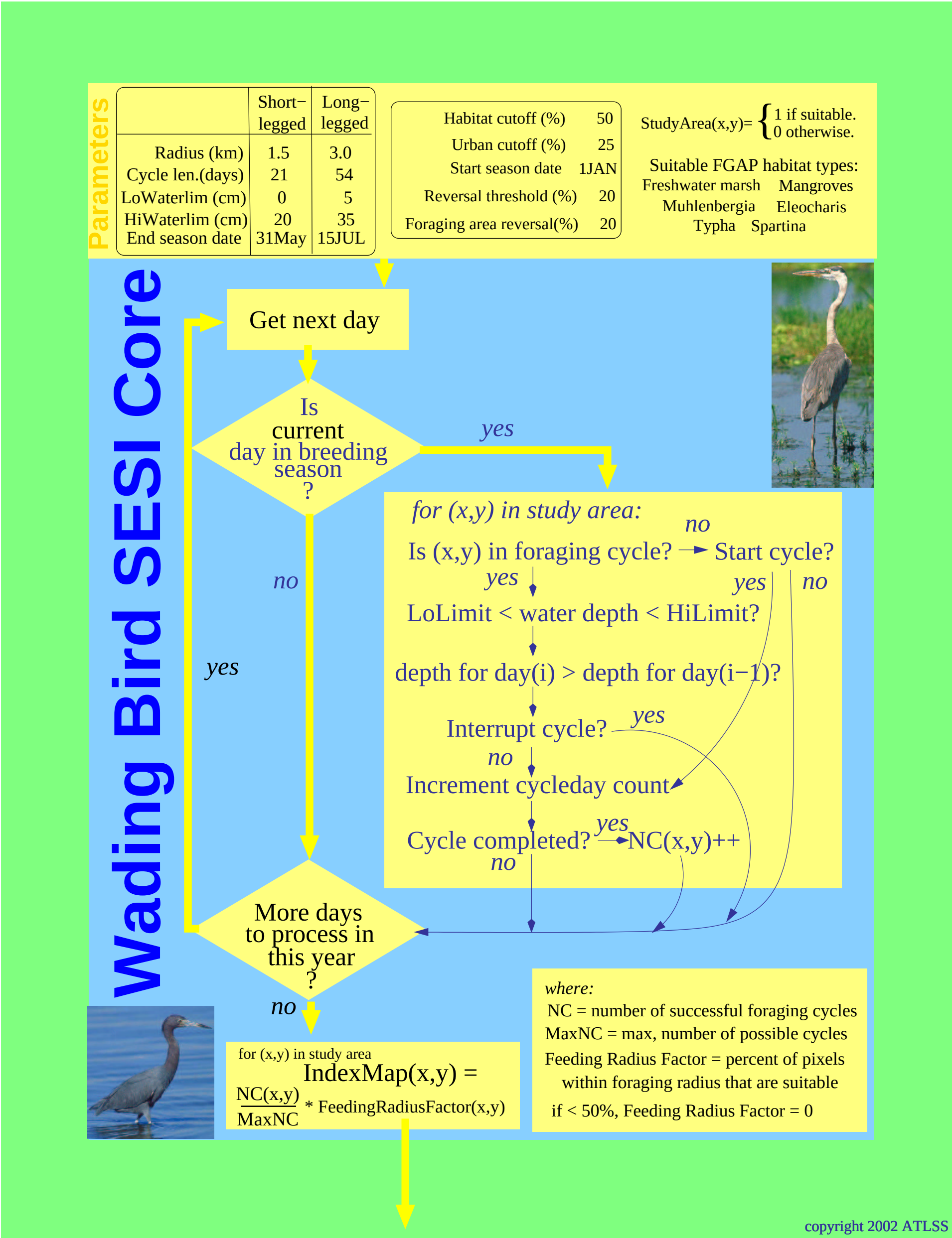
where

δ_{min} =death rate of periphyton in freshwater

κ =constant

$s(x, t)$ =salinity in cell x at time t

The Ecology: A Wading Bird SESI Model



Provide a method to assess the impact of management scenarios on species' habitat

Allow for the input of static and dynamic landscape features importable from a geographic information system (GIS) or spatial models of physical

Provide a method to rapidly assess alternative local indices, in conjunction with individuals highly familiar with the species being modeled, to speed model development

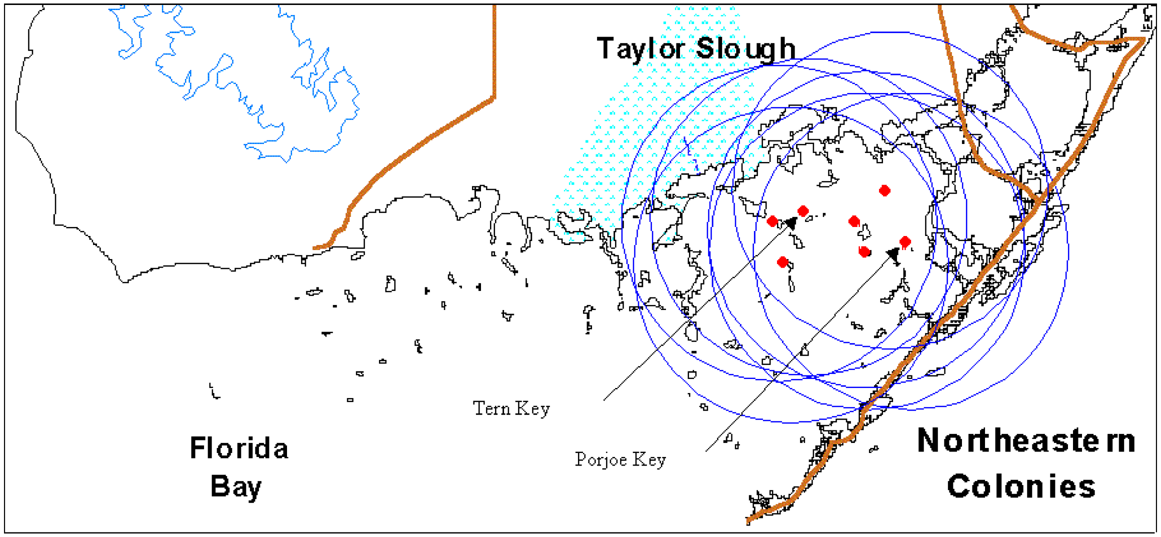
Provide a method to compare simple assessments with those derived from more complex models as part of a multimodeling approach to regional management

Everglades Ecology: A SESI Model for Spoonbills

The critical period for spoonbills in Florida Bay: from December 1 to March 31.

- Nesting in Florida Bay between November 1 and December 15.
- Incubation period is approximately 21 days.
- Chicks require constant care and an unbroken supply of food for about 42 days.
- For another 42 days the chicks are still unable to leave the colony.

Foraging spoonbills require water levels at or below the concentration threshold of 12.5 cm somewhere within the coastal mangrove wetlands for the duration of this period.



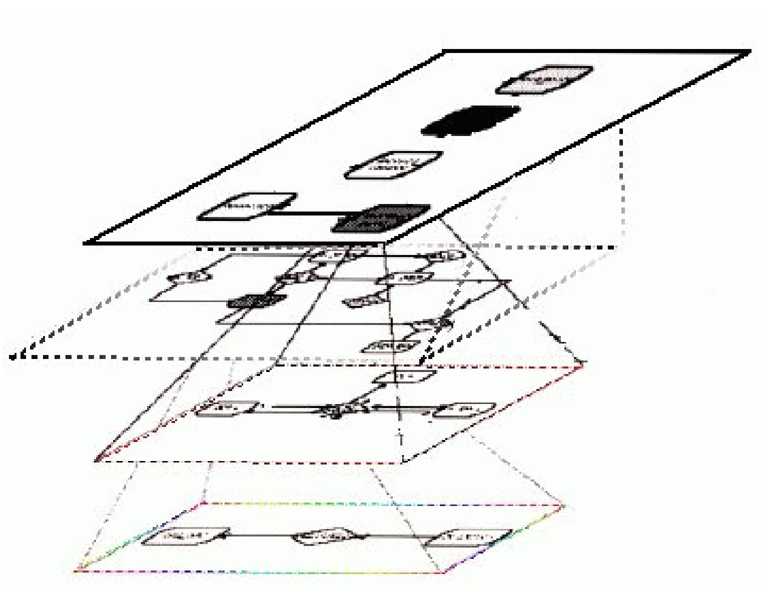
The Model Implementation: ATLSS

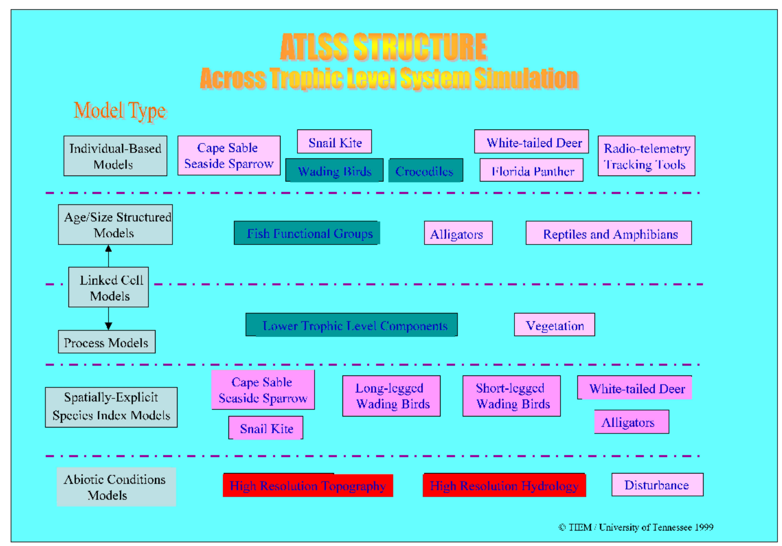
ATLSS consists of a suite of component models that may be linked together as a multimodel

Integrates spatial data with agent-based models

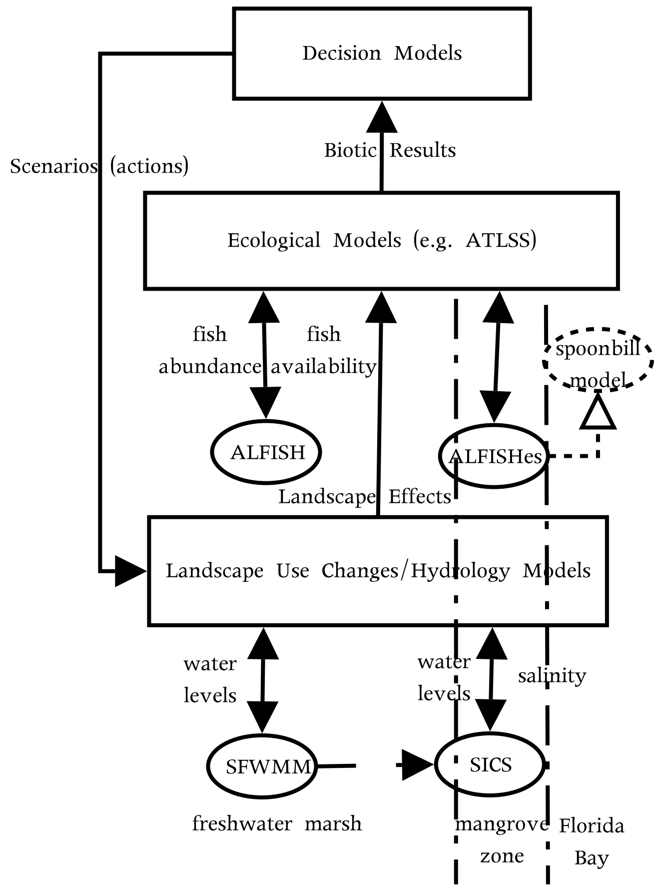
The models and data are linked via the Landscape classes, a collection of C++ classes designed to manage spatial data

Incorporates preprocessed landscape and hydrology components





The Models: The Big Picture



The Modeling Challenge

Why? To simplify (we all do it)

- Refining the question
- How much simplification is appropriate?

From individuals to populations to ecosystems

- Addressing issues of scale
- "...searching for the intermediate scale of non-trivial determinism..." (Pascual and Levin 1999)

Atomic models: irreducible model components

- Inputs
- Model state
- State transitions
- Outputs

Atomic Models

Approach: simplification of a complex hierarchy

Problem: complex systems may be described by multiple hierarchies with multiple tops

Challenge: linking models with different world views

Modeling Approach: Multimodeling

Suite of atomic models that may be linked as component models (I.e. ecosystem components)

- Hierarchical assembly
- Coupling physical and biological models

Different model representations: multiple modeling paradigms

- Process-based models
- Stage-structured models
- Individual-based models

Incorporate different spatial and temporal scales

- Intermediate scale models to explicitly model linkages across scales (aggregation and distribution)

Separate Models From Simulators

Separate Models From Experimental Frames

Use the DEVS (Discrete Event System Specification) Formalism (Zeigler et al 2000)

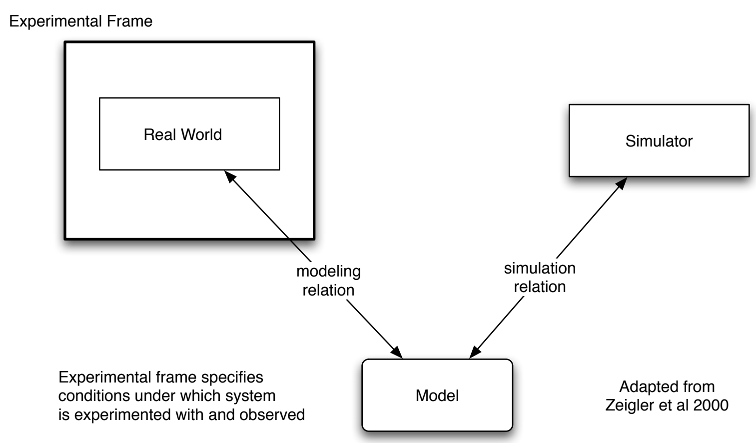


Figure 1: Entities and relations in modeling and simulation

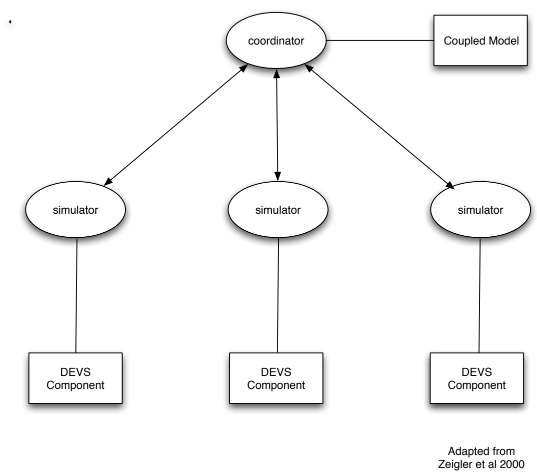
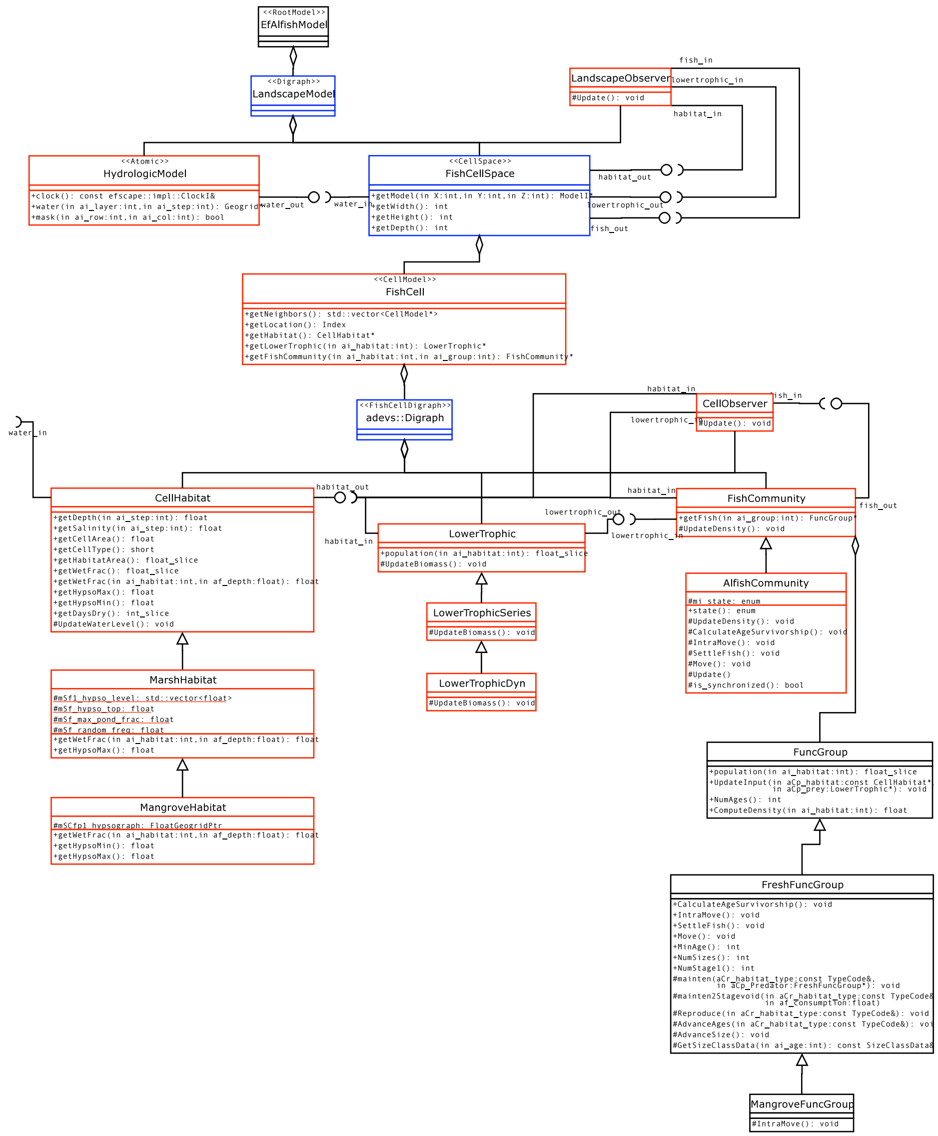


Figure 2: DEVS coordinator with a coupled model

ALFISHES Model Hierarchy



ALFISHES Model: Landscape Cell Habitat

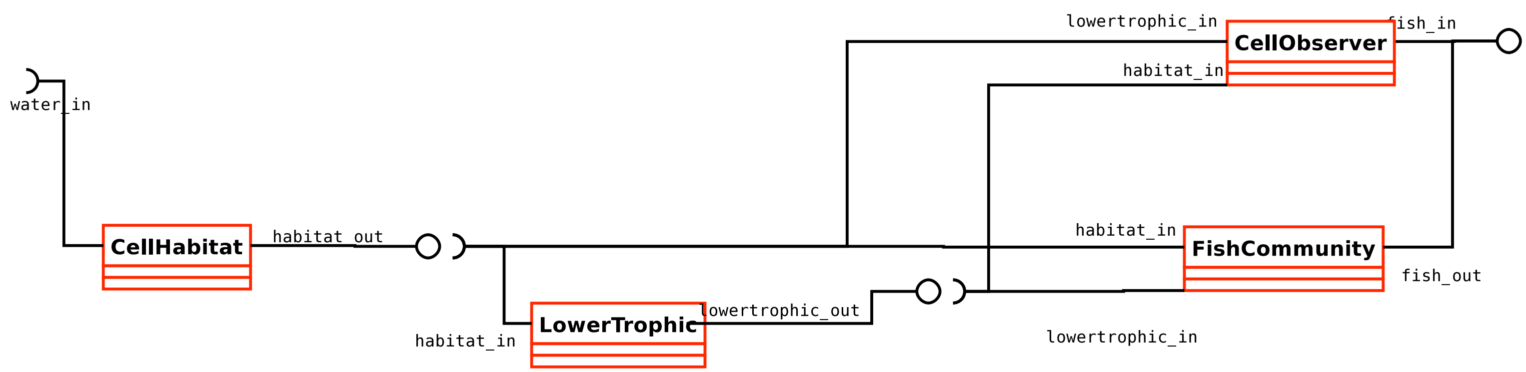
Cell habitat: within cell environment

- pond/creek habitat
- marsh/creeks habitat

Lower trophic model: resource base

Fish community: fish functional groups

Cell observer: collections simulation model data



The Model Implementation

Open source software components and libraries

- Internet Connection Engine (ICE) - object-oriented middleware with bindings for C++, Java, Python
- adevs (A Discrete EVent system Simulator) library - a C++ implementation of the Parallel DEVS formalism
- netCDF - Network Common Data Format

Uses open standards for geospatial data

Platform neutral

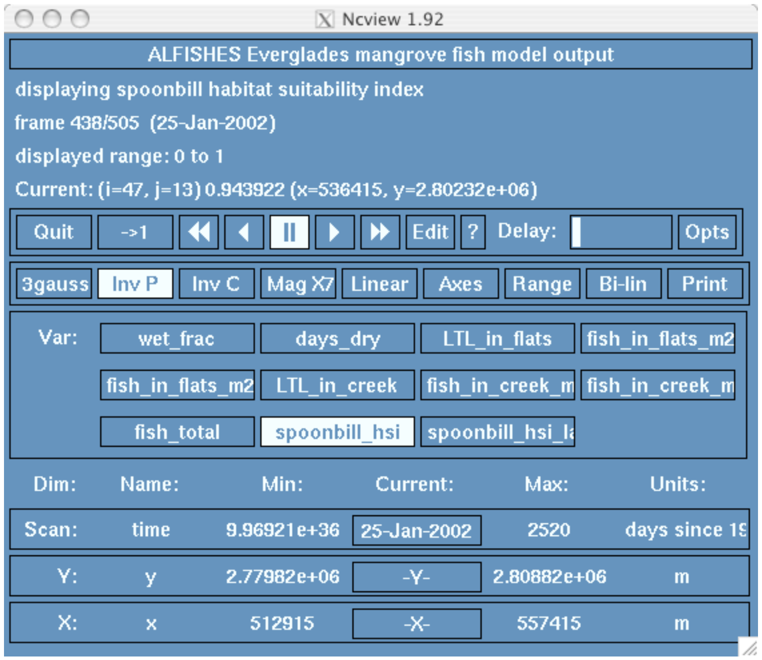
Model builder application

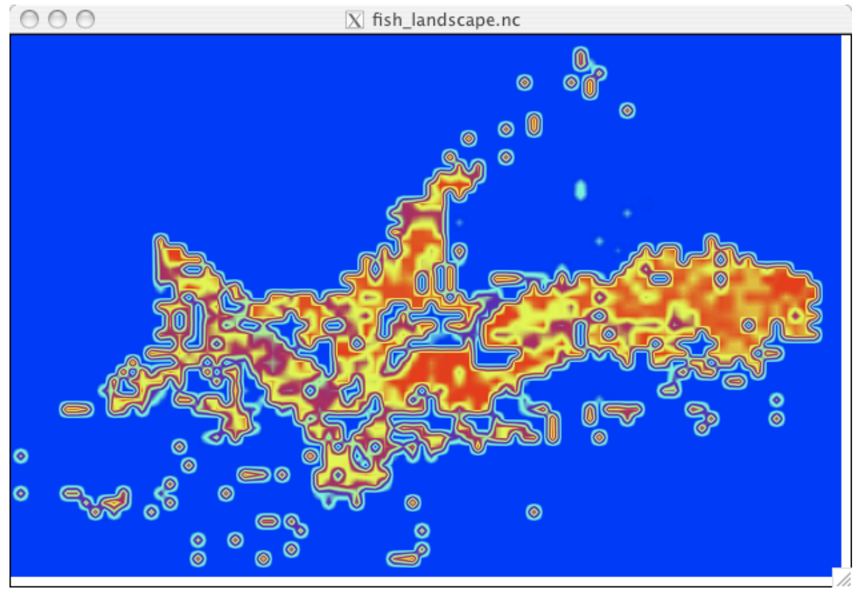
Client-server architecture implemented with ICE

- Java Application/Applet client
- C++ server runs the simulation engine
- XML used to specify simulation parameters
- Visualization of simulation output
- Component models specified by XML and loaded on demand from a model repository

Viewing Model Output

Using a standard netCDF dataviewer (ncview) to view alfishes output





What's Next?

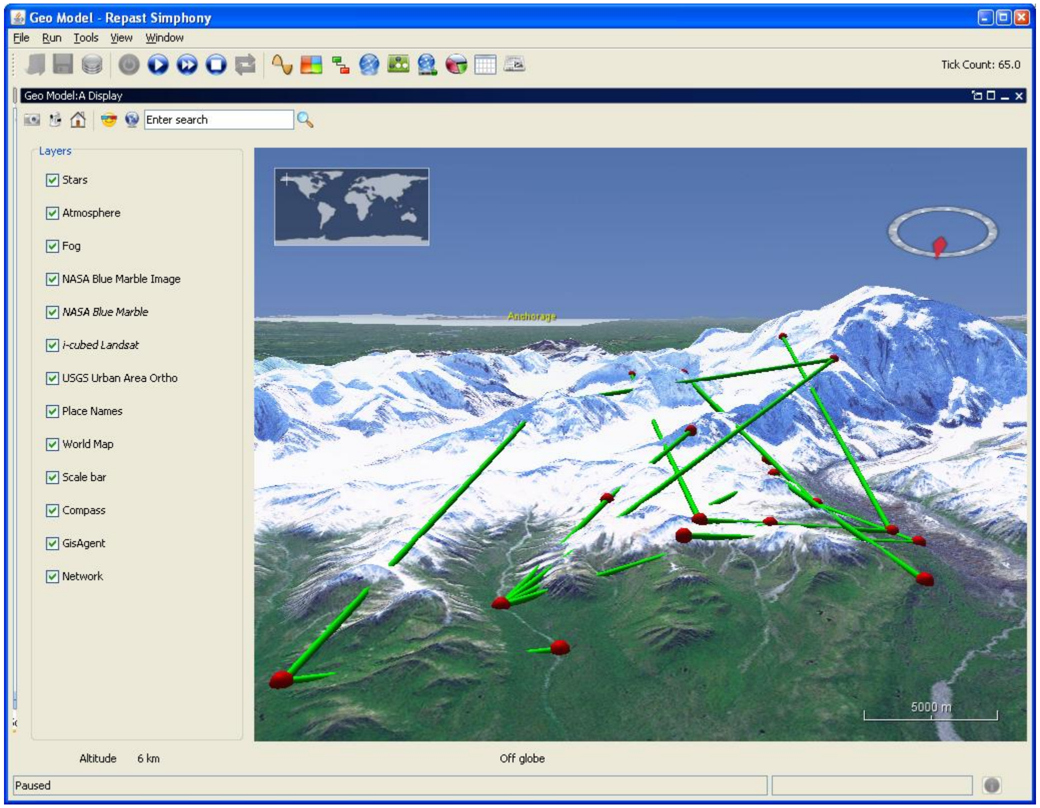
Further development of ALFISHES

- Extend and expand model components (e.g. Lower Trophic Model)
- Add model components (e.g. individual-based spoonbird model?)
- Implement model contests
- Expand modeling area to incorporate TIME (Tides and Inflows in the Mangrove Ecotone) hydrologic scenarios

Implement an interactive modeling environment for decision support based on on REcursivePorous Agent Simulation Toolkit (Repast), a free, open source ABMS toolkit (http://repast.sourceforge.net/)

- Integrated Development Environment (IDE) for models
- Visual model development
- Supports 2D, 3D, and GIS views of data
- Supports active links to GIS and relational databases
- Supports active links to external programs for data analysis and visualization such as R

A screenshot of a 3D GIS display Repast Simphony (from the Repast home page)



Summary

Developing linkages between models is important

- Big picture
- Tool for managing complexity
- Framework for model contests

Frameworks make implementation of linkages easier

- Model assembly
- High performance computing

Models don't have to be right to be useful (used only as directed)

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