Michael M. Fuller, Louis J. Gross, Scott M. Duke-Sylvester, and Mark Palmer. 2008. Testing the robustness of management decisions to uncertainty: Everglades restoration scenarios. *Ecological Applications* 18:711–723.

Appendix A: Management background and description of model parameters.

***Ecological Archives* A018-023-A1.**

Methods

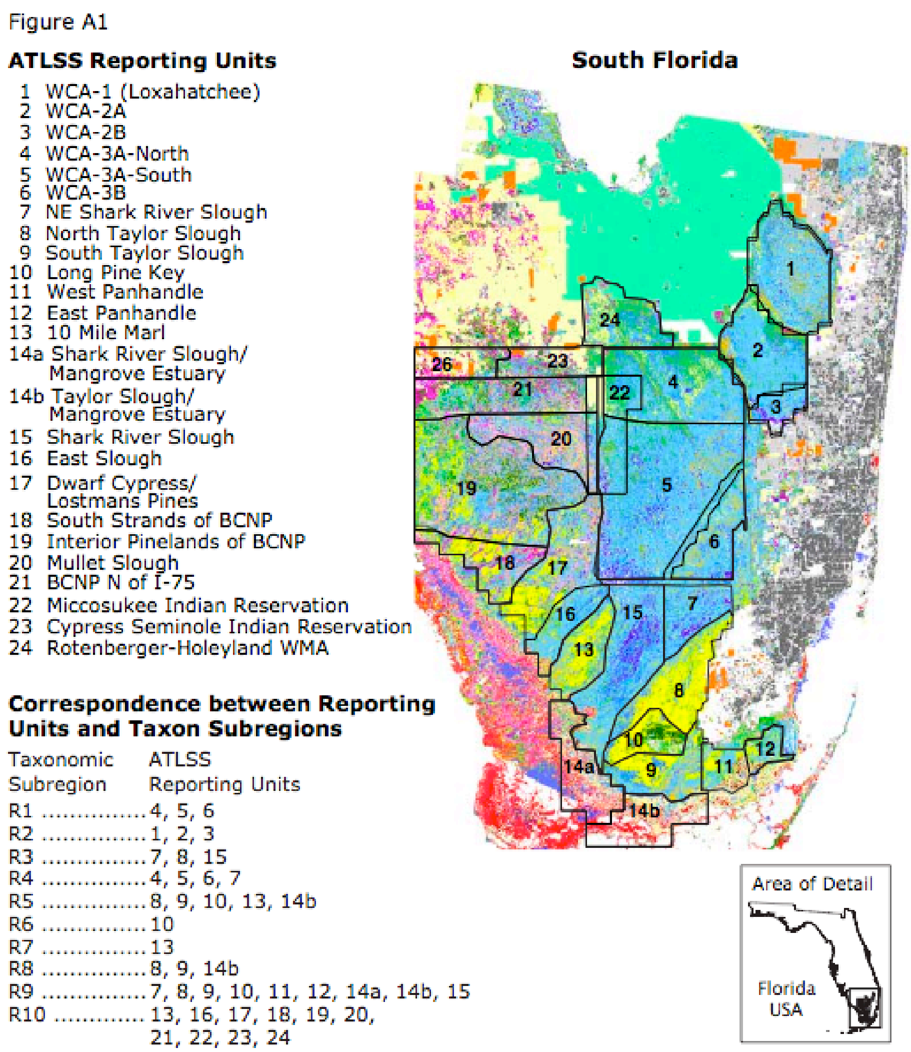
Environmental Setting and Management Background

In south Florida, the physical character of the hydrologic system of freshwater wetlands interacts with variation in the timing and amount of rainfall and controlled water release schedules to determine the quantity and quality of habitats. For example, variation in water levels determines access to spawning areas for fish and availability of tree islands that provide browse and shelter for deer. Water depth affects the availability of food for piscivorous species (e.g. wading birds) and species that feed on aquatic plants and invertebrates (e.g. the apple snails eaten by the Florida snail kite *Rostrhamus sociabilis*). Multi-species management in such systems is complicated by the fact that water levels that are optimal for some wildlife are suboptimal or even detrimental for others (DeAngelis et al. 1998).

Water levels in south Florida are a function of the location of pumping stations, canals, and levees and the timing of water release schedules. The difficulty in choosing a particular water management plan is compounded by seasonal forcing and multi-annual stochasticity in rainfall and seasonal temperature. Regulation of water levels via pumps, canals, and reservoirs can offset or exacerbate unpredictable variation in precipitation. In addition, the management of south Florida's freshwater resources is influenced by a variety of local stakeholders with conflicting interests. Stakeholders include local farms and nearby residential communities as well as the resource managers tasked with maintaining functioning ecosystems while meeting the requirements of various federal and state regulations. Choosing a hydrologic regime that meets the needs of these diverse groups is not trivial, even without the environmental variability inherent in this managed system.

There are two time scales associated with hydrologic management in south Florida: tactical decisions about water regulations are made on a minute to weekly scale by South Florida Water Management District (SFWMD), while strategic decisions that incorporate changes to the major structures (canals, pumps, levees) which directly impact options for hydrology are made on a decadal scale. The focus of Everglades restoration planning has been on strategic scales with a 30-35 year planning horizon typically applied and that time scale is the focus of our analysis.

Figure A1 depicts the taxon-specific, geographic subregions of the Florida Everglades that we included in our analysis. We evaluated six wildlife taxa independently within the entire Restudy area and within 10 subregions, R1-R10. The taxonomic categories and their associated subregions are defined in Table 1 of the main text. The subregions represent different combinations of reporting units and roughly correspond to different habitat types. Figure A1 contains two tables. The upper table is a key to the ATLSS reporting units. The lower table defines the correspondence between the ATLSS reporting units and the subregions we used in our analysis.



(Figure legends appear at end of document)

Description of Model Settings

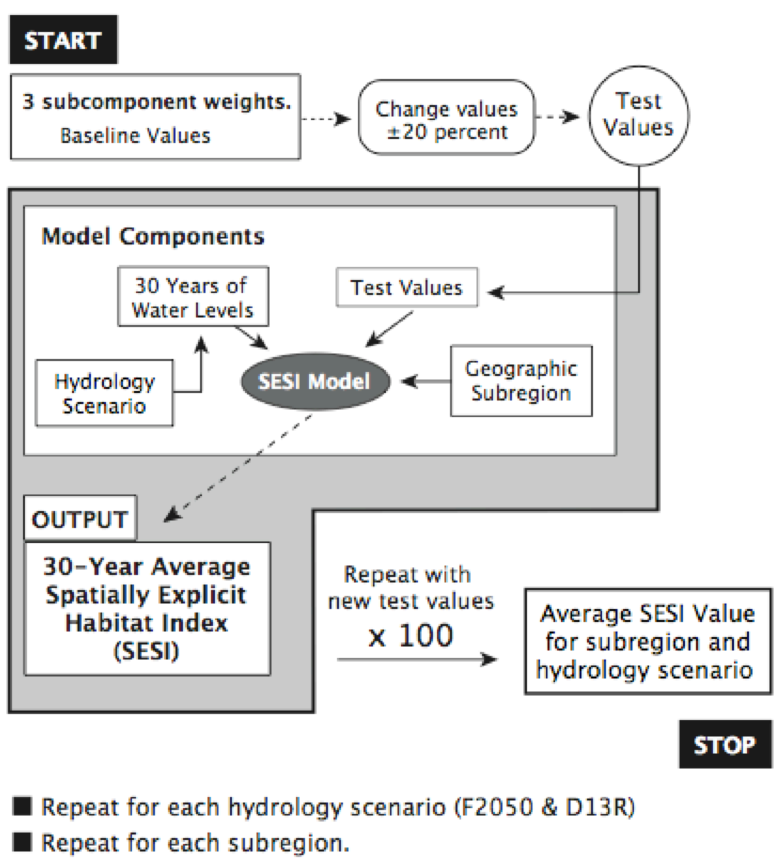
Our example utilizes multiple, species-specific models designed to project the effect of water levels on the value of habitat for foraging and breeding over a 30-year time horizon. The models M_i produce yearly spatial maps of breeding or foraging conditions for each of these species. In our analysis, we compared two management scenarios (k=2), although a large number were developed for Everglades restoration planning. The evaluation criteria used in the ranking R was based upon average breeding/foraging condition measured across the 30 years, in some cases across the entire Restudy region and in some cases in separate subregions. The robustness of the rank order of the alternatives was determined relative to model parameter variation (at ±20% and ±30%), and to two variations in hydrologic inputs (the E_i) designed to investigate large climatic changes. The model output (M) are the SESI averages calculated using detailed hydrologic maps of the study area. The model inputs (E) included vegetation maps compiled from satellite images provided by the Florida Gap Analysis project (Pearlstine et al. 2002).

Scenario Group 1: Uncertainty in Reproduction Parameters of the American Alligator

To test the robustness of the relative ranking of the two hydrologic plans to changing parameters we randomly varied the weights of the three subcomponents of the American alligator SESI model. The weights determine the relative contribution of habitat quality, flooding probability, and nest site suitability to the index. We formed 100 independent parameter sets by changing the weights on each parameter by a random amount. Values were chosen from the range of up to ± 20% of the respective baseline value. In other words, we chose uniformly 100 parameter weight sets from the three-dimensional cube centered at the baseline values.

Then, for each of the two hydrologic plans, we performed a 30-year simulation using each of the 100 parameter weight sets and the water levels projected by the plan. During each simulation we calculated a separate SESI for each year (spatially averaged over the subregion) and used these values to calculate a 30-year temporal average for each of the 100 parameter sets. We then calculated a spatio-temporal global average SESI (average of the 100 30-year simulations) for each subregion. The general procedure is depicted in Fig. A2.

FIGURE A2



We used the global average SESI to calculate the difference *D* between the two alternative plans for each subregion, where $D = \overline{I}_{D13R} - \overline{I}_{F2050}$ and $\overline{I}$ is the global average of the alligator SESI for a particular hydrologic plan, as indicated by the subscripts. To determine the statistical significance of the variation in SESI, we generated frequency distributions of *D* for each subregion and compared them to the base difference $D_{Base} = I_{D13R}^{Base} - I_{F2050}^{Base}$ determined using baseline parameter weights (e.g. the weight values at the center of the cube, which were those used in the Restudy process).

As a further test of the robustness of the model rankings to parameter variation, we repeated the above analysis but allowed the parameter weights to vary randomly by up to 30 percent.

Uncertainty in Future Climate Conditions

We used two climate themes to test the effect of variation in input data on the rank order of the two hydrologic plans. Here, our intention was to generate strong differences in the pattern of water level variation to illustrate the general approach. In scenario group 2, we assembled test data representing different climate themes of wet, dry, and average conditions. In scenario group 3, test data represented a shift in rainfall of ±25 percent relative to historical levels. These simulations are detailed below.

Scenario Group 2: Selective Sampling and Permutation of Historical Data

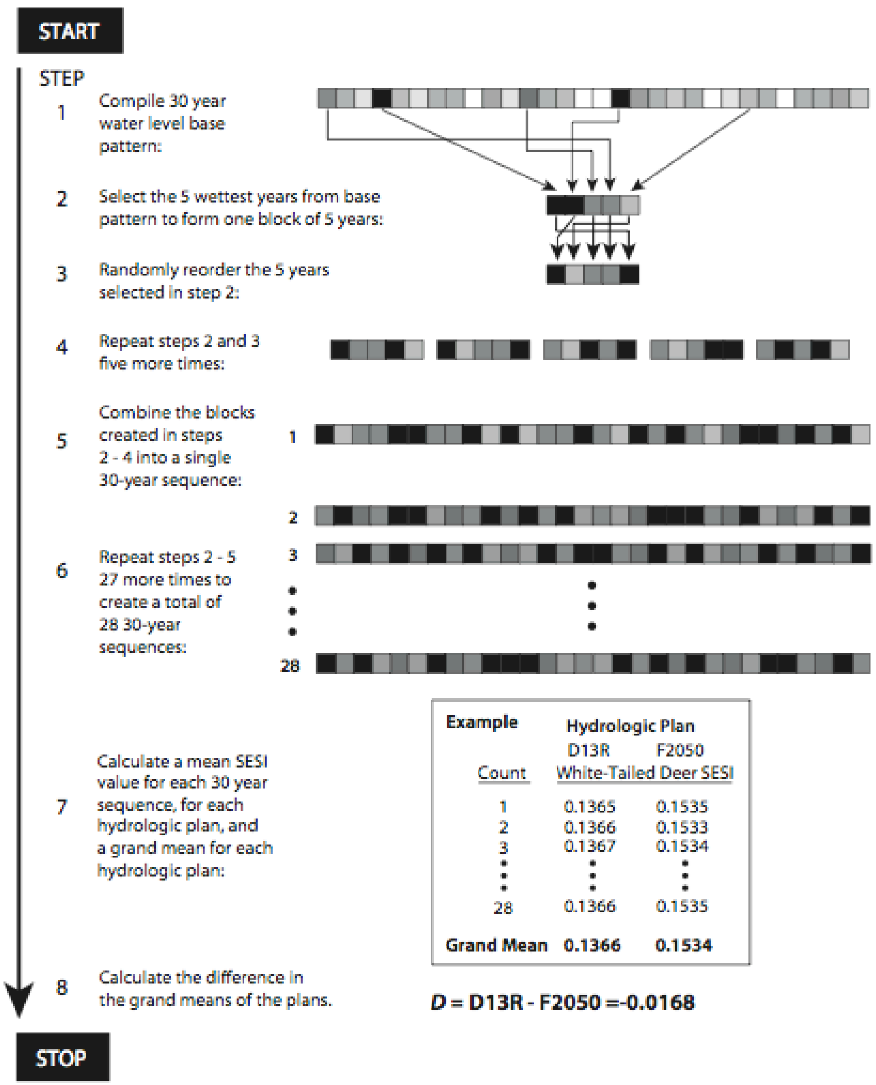
In scenario group 2, we compared the SESI for each taxon calculated for the 30-year historical climate data to data representing three hypothetical climate patterns corresponding to wet, dry, and average hydrologic conditions, relative to the baseline conditions. Our permutations were based upon stage height data, the height of the water surface above the bottom of the channel, provided by SFWMD. To generate the test input data for wet conditions we chose the five wettest years from the baseline pattern, reordered them randomly, and repeated this six times to produce a 30 year test data set. We repeated this procedure 28 times for each alternative hydrologic plan for a total of 58 different 30-year data sets (one base data set plus 28 resampled data sets for each alternative plan). We applied the same resampled data sets to each of the hydrologic plans. Fig. A3 depicts the procedure.

We evaluated the effect of each 30-year climate scenario on projections of habitat potential by calculating the average SESI across each 30-year simulation. We applied the same method for the dry climate pattern using the five driest years. For the average climate pattern, we chose the five years closest to the average of the baseline 30-year data and reordered them as above.

In all three cases, the input data fell within the range of baseline values observed in the study area over a 30 year period. Nevertheless, the test values signify a considerable change from the baseline pattern, and correspond to extended periods of drought, flooding, or reduced variation in hydrologic conditions. As such, each climate theme is analogous to a "press" experiment in which a particular scenario is maintained over a long period of time (30 years). However, the resulting reordering of yearly hydrology does induce sudden shifts at the transitions from one year to the next, as well as a sharp reduction in the year-to-year variation in water levels. As such, the wet, dry, and average climate themes we generated do not represent realistic climate patterns.

To determine the robustness of the rank order of the alternatives to variation in input data, we compared the difference in the base SESI $D_{Base} = I_{D13R}^{Base} - I_{F2050}^{Base}$ (utilizing the baseline management scenarios D13R and F2050) to the difference in the average SESI $D = \overline{I}_{D13R} - \overline{I}_{F2050}$ using each simulated climate regime for each subregion. We repeated this

FIGURE A3



procedure for each taxon. Positive values of D indicate that D13R is preferred to F2050, negative values indicate F2050 is preferred over D13R. A change in the ranking of the alternative

scenarios is indicated by a reversal in the sign of D relative to D_{Base}. To determine the effect of the wet, dry, and average climate themes on the ranks of the two management plans we compared the sign and magnitude of the difference in D to the base difference D_{Base}. The relative magnitude of D indicates the sensitivity of the models to a change in climate in a given subregion.

Scenario Group 3: Uncertainty in Rainfall Levels

As a further test of the effect of climate uncertainty on the ranking of the two alternative hydrologic plans, we used two climate scenarios applied to the hydrologic models by SFWMD. One climate scenario projected the hydrologic effects of a 25% increase in rainfall, while the other projected the effects of a 25% decrease in rainfall. We used these hydrologic data to generate 30 annual SESI values for each taxon and subregion (Table 3 of the main text). As above, we compare D_{Base} to D for each taxon. A change in the ranking of the alternative plans is indicated by a reversal in the sign of the difference in average SESI, D, relative to the base value, D_{Base}. The magnitude of change indicates the sensitivity of the models to the changes in climate conditions.

Model Implementation

All of the above simulations were carried out using the ATLSS SESI models developed in C++, using a Sun Microsystems Enterprise 4500 symmetric multi-processor (SMP), with 14 processors. This required 1,458 simulations (Table 3) in total, and approximately two months of computer time to complete. The ATLSS model interface, a grid-computing interface (Wang et al. 2005) between the SMP and client workstations was used to implement the required simulations.

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FIGURE CAPTIONS (APPENDIX)

Figure A1. Aggregated ATLSS reporting units and taxonomic subregions analyzed. For our analysis, we grouped the original ATLSS reporting units into taxonomic subregions which roughly correspond to habitat type. The tables in the figure show the identity of the ATLSS reporting units and the correspondence between the reporting units and the subregions used by each taxon. See also Table 1.

Figure A2. Relationship between the different subcomponents of the scenarios used to analyze the effect of parameter weight variation on the alligator SESI (scenario group 1). See text for description.

Figure A3. Steps involved in constructing artificial climate data used in scenario group 2 (wet climate theme depicted). The steps advance from the top of the figure to the bottom. See text for description.