Prepared in cooperation with the National Park Service and U.S. Army Corps of Engineers

The Everglades Vulnerability Analysis: Integrating Ecological Models and Addressing Uncertainty

The Everglades is a large (about 47,000 square kilometers), unique subtropical wetland ecosystem in central and south Florida. This ecosystem provides habitat for many endemic and endangered species, offers protection against flooding, and supplies south Florida with a substantial amount of its water supply. In 2000, the U.S. Congress passed the Water Resources Development Act of 2000 (Public Law 106–541), which authorized the Comprehensive Everglades Restoration Plan (CERP). The CERP seeks to improve the timing, distribution, and quality of water flow through The Everglades to facilitate the recovery of the unique habitats historically present in the system. Restoration of The Everglades is one of the largest and most expensive ecological restoration efforts in the world, and its implementation requires extensive cooperation among stakeholders to ensure that restoration efforts are successful (LoSchiavo and others, 2013).

The Role of Ecological Models in Everglades Decision Making

Decision makers are tasked with balancing the needs of various stakeholders and must select among competing restoration plans. Ecological models facilitate evaluation and assessment of each plan's potential impacts on The Everglades system. However, there are many distinct models which may or may not account for the variability present within the system. These different model outputs must be synthesized by considering the assumptions of each model and how uncertainty might factor into the predicted outcomes. More efficient and accessible decision making could be achieved through the integration of The Everglades ecological models into a common modeling framework that would provide standardized outputs and measures of uncertainty.

What Is the Everglades Vulnerability Analysis?

The Everglades vulnerability analysis (EVA) is a project led by the U.S. Geological Survey in cooperation with the National Park Service and U.S. Army Corps of Engineers to accomplish one of the science goals of Restoration Coordination & Verification (RECOVER), a multiagency group responsible for providing scientific and technical evaluations and assessments for improving CERP's ability to restore, preserve, and protect the south Florida ecosystem while providing for the region's other water-related needs. In 2016, RECOVER acknowledged the need for a tool that could synthesize the decades of ecosystem science in The Everglades and identify areas vulnerable to changing conditions on the landscape. The EVA tool answers this need through a landscape-scale modeling framework that provides annual responses and relative vulnerability for a suite of indicators of ecosystem health in The Everglades (fig. 1). (Herein, "vulnerability" is defined as the degree to which an indicator of ecosystem health moves away from an ideal state defined by the tool's end users.) The tool helps scientists and decision makers visualize the variability in predictions across the landscape to inform decision making. The EVA tool integrates multiple systemwide indicators of ecosystem vulnerability, explicitly accounts for system variability, and can consider alternative restoration plans and how climate-related long-term changes such as sea-level rise may affect the projected outcomes of those plans.

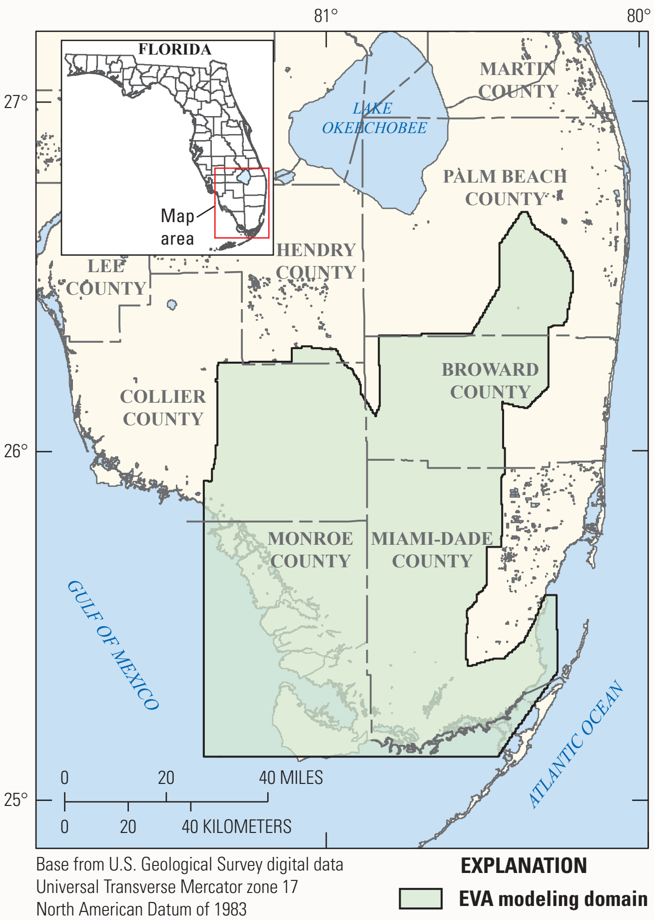

Figure 1. The extent of the modeling domain of the Everglades vulnerability analysis (EVA) in 2021 in south Florida.

Modeling Framework

Currently, the EVA tool assesses four indicators of ecosystem health: (1) dynamics of sawgrass (*Cladium jamaicense*) peat subsidence and accretion; (2) patterns of vegetation across the landscape; (3) suitability of the landscape for nesting American alligators (*Alligator mississippiensis*); and (4) size and location of nesting wading bird colonies. The EVA tool employs a flexible modeling approach through a series of connected spatially explicit Bayesian networks (fig. 2). This modeling framework allows for the integration of information from experiments and observations and knowledge from experts into its analysis. For each indicator of ecosystem health, influence diagrams were developed to describe how a system works. Those influence diagrams were then translated into a Bayesian network.

Each Bayesian network requires hydrologic and landscape information, which is then rendered into categorical outcomes through probability tables that describe the relation among variables in the network. These probability tables show how the Bayesian network incorporates uncertainty within the system. The EVA tool has the flexibility to use outputs from various hydrological models as inputs, including the Everglades Depth Estimation Network (Haider and others, 2020), the Biscayne and Southern Everglades Coastal Transport model (Swain and others, 2019), or the Regional Simulation Model (South Florida Water Management District, 2005). The outcomes for each indicator are then compared to an ideal state defined by the user. Through an ordination process, the distance from the ideal state is calculated for each indicator, and areas further from the ideal state are classified as relatively more vulnerable.

Managers and decision makers can use the resulting vulnerability surface (fig. 3) to compare restoration projects to consider the landscape-scale impacts and the probability of these outcomes. Similarly, sea-level rise impacts on the system's vulnerability can be investigated through adjusting the Bayesian network inputs to reflect potential climatic futures and comparing restoration alternatives in the context of a changing climate.

Data Flexibility

Using the Bayesian network modeling framework, data from multiple sources and formats are combined to generate the relations that drive model outcomes. For example, the Bayesian networks of vegetation type dynamics, alligator nesting, and wading bird colony size are developed from long-term monitoring data. The Bayesian network of peat subsidence and accretion dynamics uses results from mesocosm experiments in the coastal areas of The Everglades (Wilson and others, 2018) (fig. 4). Bayesian networks of future indicators may use expert opinion to describe the relations between variables. The EVA tool allows for integration across these disparate data sources to leverage the vast amounts of scientific research generated on The Everglades ecosystem into a comprehensive landscape-scale analytic tool for decision making.

Future Directions

Currently, the EVA focuses on vegetation, soil elevation, and wildlife species within The Everglades system. Climate impacts beyond sea-level rise, such as changes in precipitation or severe weather patterns, could be easily incorporated into this framework. Additionally, because of the tool's built-in flexibility, further Bayesian networks for indicators of economic and social impacts can be integrated into the current framework.

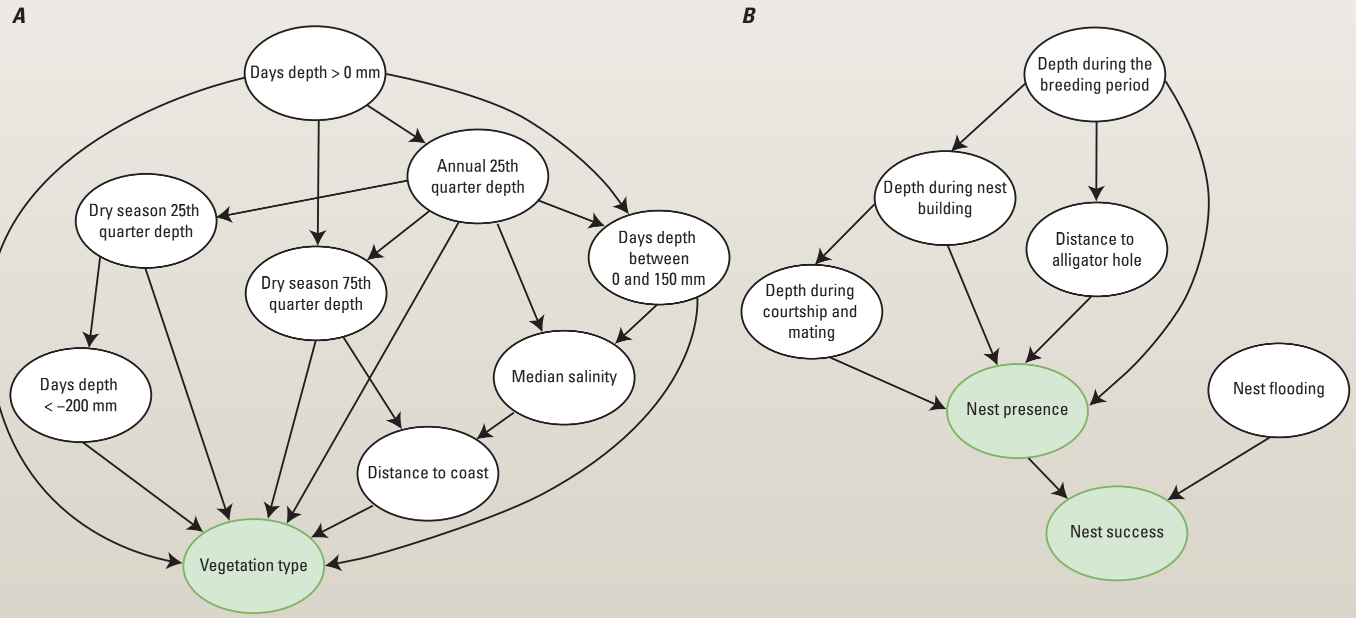

Figure 2. Influence diagrams of two indicators within the Everglades vulnerability analysis (EVA) tool. *A* predicts vegetation type across the landscape, and *B* predicts American alligator nest presence across the landscape. White circles are hydrologic or landscape inputs to the model, whereas green circles are outcomes from the model. mm, millimeter.

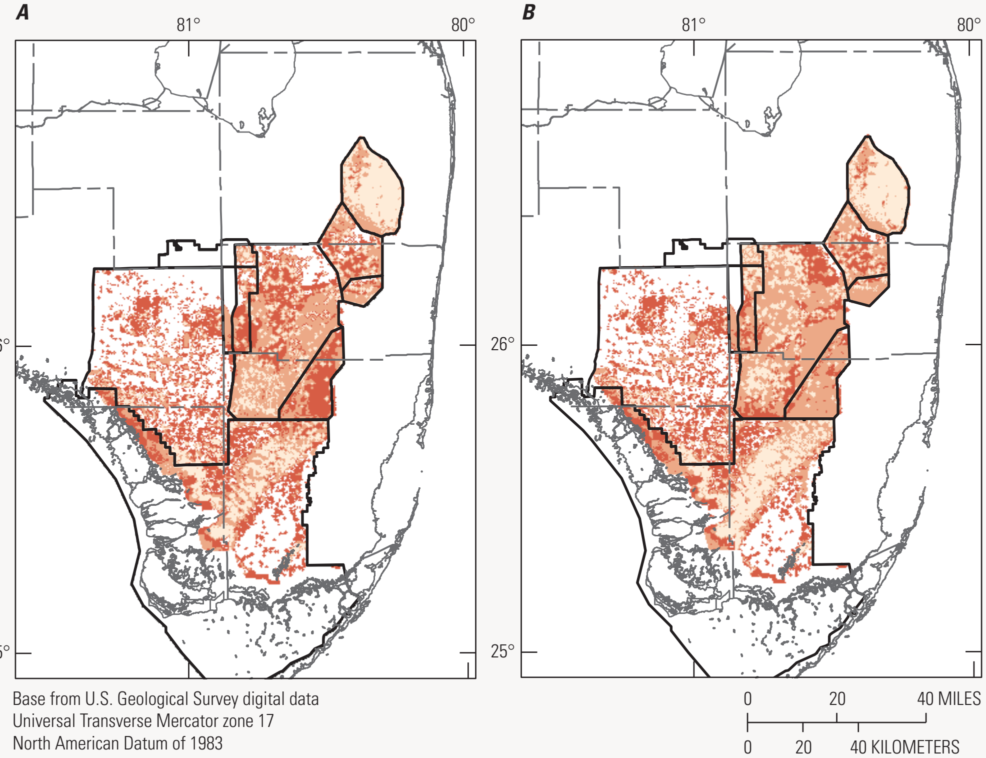

Figure 3. Vulnerability surfaces for the American alligator resulting from two restoration alternatives. *A* is a baseline alternative that assumes no future changes to hydrologic conditions, whereas *B* is an alternative that assumes some changes to hydrologic conditions.

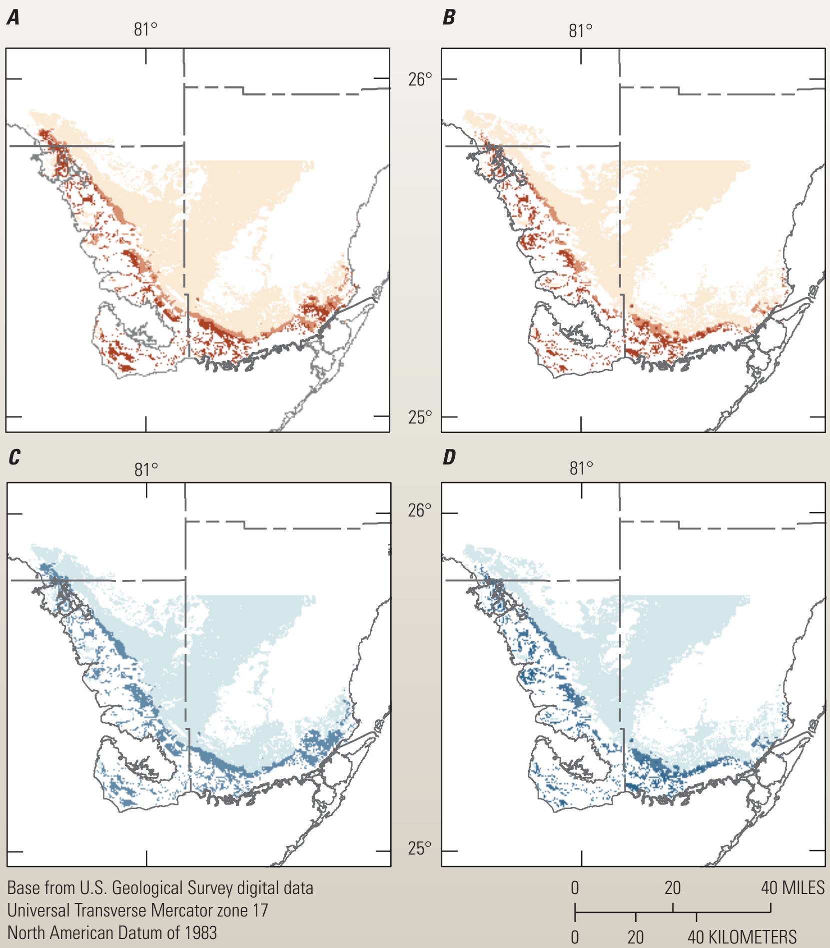

Figure 4. Coastal sawgrass peat vulnerability (*A*, *B*) for two separate years and relative certainty of the predictions (*C*, *D*) for those respective years. Darker reds indicate areas where sawgrass peat is most likely to collapse into open water because of an interaction between drought and saltwater intrusion. Darker blues indicate areas with higher certainty.

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