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Modeling Hurricane Effects on Mangrove Ecosystems

Mangrove ecosystems are at their most northern limit along the coastline of Florida and in isolated areas of the gulf coast in Louisiana and Texas. Mangroves are marine-based forests that have adapted to colonize and persist in salty intertidal waters. Three species of mangrove trees are common to the United States, black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*), and red mangrove (*Rhizophora mangle*). Mangroves are highly productive ecosystems and provide valuable habitat for fisheries and shorebirds. They are susceptible to lightning and hurricane disturbance, both of which occur frequently in south Florida. Climate change studies predict that, while these storms may not become more frequent, they may become more intense with warming sea temperatures. Sea-level rise alone has the potential for increasing the severity of storm surge, particularly in areas where coastal habitats and barrier shorelines are rapidly deteriorating. Given this possibility, U.S. Geological Survey researchers modeled the impact of hurricanes on south Florida mangrove communities.

Field and experimental studies were conducted to improve our understanding of species tolerance and community zonation and to aid modeling trials of impacts on mangrove ecosystems. Permanent plots and greenhouse experiments were established to determine growth habits and ecology of mangrove species following disturbance from Hurricane Andrew (Fig. 1). Remote videography was taken at low altitude by helicopter over mangrove forests along the southwestern coast of Florida to derive a coast-wide assessment of damage extent and pattern. Coastal and inland transects were flown within the mangrove forest boundary over Ten Thousand Island National Wildlife Refuge and Everglades National Park. Video frame analysis assessed the degree of damage, windfall orientation, and canopy height of the forest below (Fig. 2). Aerial videography proved to be an efficient and timely means to document large-scale hurricane damage and may also help to monitor ecosystem recovery in the coming years.

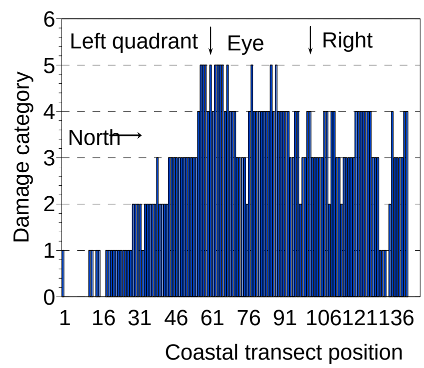

Fig. 2. Mangrove forest damage assessment of coastal transects based on visual interpretation of canopy damage across the hurricane-affected zone.

Measurements of light penetration through mangrove canopies differentially impacted by hurricane winds of estimated force offer a means to calibrate wind damage probabilities on mangrove forests. Mangrove species and forests are susceptible to catastrophic disturbance by hurricanes such as Andrew that cause significant changes in forest structure and function. These functional relationships of hurricane impacts on mangrove species and systems have been incorporated into a landscape simulation model of south Florida mangroves.

Fig. 1. Mangrove forest struck by Hurricane Andrew, 1992.

Hurricane Simulation

A hurricane model, HURASIM, and a mangrove forest model, MANGRO, were combined in a spatially distributed landscape application to review the impact of hurricanes over the last century on forest structure of mangrove communities across south Florida. The model uses historical tracking and meteorological data of dated North Atlantic tropical storms from 1886 to 1990 (Fig. 3). Data input for the model includes tracking information of storm position, latitude and longitude, and maximum sustained wind speed every 6 hours or less. HURASIM model output from Hurricane Andrew was correlated with field data to construct data tables of damage probabilities by site and species and to determine critical windspeeds and vectors of tree mortality and injury.

Mangrove Simulation

MANGRO is a spatially explicit stand simulation model constructed for neotropical mangrove forests of black mangrove, white mangrove, and red mangrove. This individual-based model comprises a species-specific set of biological functions predicting the growth, establishment, and death of individual trees. MANGRO predicts the tree and gap replacement process of natural forest succession as influenced by stand structure and environmental conditions. For our study, tree mortality was modeled as a random process of age, suppression, and hurricane impact derived from damage probability curves developed from observed data of Hurricane Andrew (1992) effects. If in any given year of the simulation a predicted hurricane windforce exceeded 30 square meters per second, a probability was derived based on windspeed from which a percentage of the standing crop or trees were randomly removed from the forest simulation.

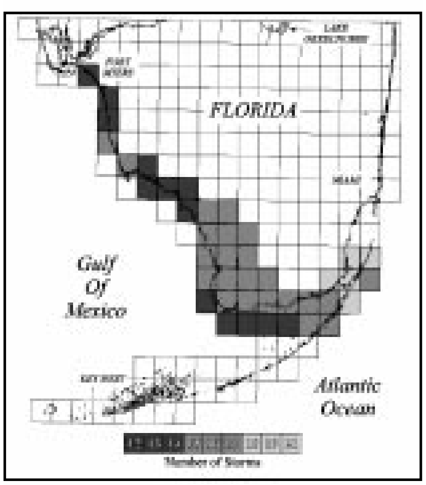

Fig. 3. Frequency of hurricane strikes of category 2 or greater by quadrangle across south Florida for 1886-1989, estimated by the HURASIM model for mangrove habitat.

Model Application

Four treatment effects were implemented including a no-hurricane simulation contrasted with a low, moderate, and high mortality effect that increased with corresponding increases in windspeed. A historical simulation for 1886 through 1989 was achieved by passing hurricane and site-specific information from the HURASIM model to the associated MANGRO simulation for common cells. A cumulative assessment of hurricane impact was achieved by averaging stand attributes and size for the entire simulated landscape and time interval from 1890 to 1989. Simulations of hurricane tracks and history for south Florida showed that storm frequency and intensity varied across the landscape. Hurricane frequencies by quadrangle for the period of record showed that the number of storms with winds exceeding 30 square meters per second were more numerous on the Atlantic side than the gulf side of southern Florida. The southwest coast of Florida has endured stronger storms on record than the gulf and Atlantic coasts to the north. The combined layering of hurricane impact showed that there are portions of the south Florida landscape that have received more frequent and more intense storm activity than other portions.

Conclusions

Historical simulations of actual hurricane tracks and conditions seem to account for the structural composition of modern day mangrove forests across south Florida. The occurrence of major storms every 30 years in this century may be the most important factor controlling mangrove ecosystem dynamics in south Florida. Should storms become more intense over the next century, they may further alter the structure and composition of this mangrove landscape. Model results of global change scenarios (high damage probability) indicate that future mangrove forests may be diminished in both stature and extent.

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