

UNDERSTANDING WIND RISK TO FORESTS: TOWARDS MECHANISTIC MODELS OF WIND RISK IN THE SOUTHEASTERN COASTAL PLAIN

Jeffery B. Cannon, Brandon T. Rutledge, R. Kevin McIntyre,
Angela M. Holland, and Steven B. Jack

EXTENDED ABSTRACT

Severe storms such as hurricanes alter the structure and function of forests and add economic and ecological uncertainty to the management of forest ecosystems of the Southeast. In 2018, Hurricane Michael affected over 25 percent of extant longleaf pine systems in a single event and damaged up to 80 percent of trees in some coastal stands (Zampieri and others 2020). Lower severity impacts also reached forests nearly 200 km (125 miles) inland (Rutledge and others 2021). Factors such as tree size, crown architecture, wood strength, stand density, soil type, elevation, and topographic position can influence stability (Cannon and others 2015, Garms and Dean 2019, Peterson and others 2019). Information on how these factors influence wind susceptibility can supply critical information to quantify and mitigate wind risk. Several studies rank longleaf pine (*Pinus palustris* Mill.) among the most wind-resistant species of the southeastern Coastal Plain, yet differences in size structure and association of species with varying soil types confounds a clear understanding of wind susceptibility rankings among southeastern pine species (Johnsen and others 2009). We aimed to rigorously test whether longleaf pine was more wind-resistant than associated pine species and investigate how tree, stand, and landscape factors affect tree stability in a longleaf pine forest.

We collected observations of over 3,000 trees stratified across 268 monitoring plots 0.1 ha (0.25 acre) in size (Holland and others 2018) at the Jones Center at Ichauway (31.21°N -84.45°W) following Hurricane Michael. The Jones Center is the site of 7300 ha (18,000 acres) of second growth longleaf pine woodlands that also contain minor components of other southern pines such as loblolly pine (*P. taeda* L.), slash pine (*P. elliottii* Englem.), shortleaf pine (*P. echinata* Mill.), and diverse hardwood species (Holland and others 2018). For each tree, we recorded whether trees were downed, and used previously collected diameter at breast height (d.b.h.) and stand density data. We derived information on soil type (excessively drained to poorly drained), distance from hurricane track, and wind exposure index (Plattner and others 2003) from publicly available data. Using a binomial generalized linear model, we tested how tree, stand, and landscape factors contributed to tree susceptibility (Zuur and others 2009). We also included two-way interactive effects (d.b.h. x species and species x soil type) to make inferences about wind risk among various size structures and soil types.

Author Information: Jeffery B. Cannon, Landscape Ecologist, The Jones Center at Ichauway, Newton, GA 39870; Brandon T. Rutledge, Conservation Coordinator, The Jones Center at Ichauway, Newton, GA 39870; R. Kevin McIntyre, Education Coordinator, The Jones Center at Ichauway, Newton, GA 39870; Angela M. Holland, Postdoctoral Research Associate, University of Delaware, Newark, DE 19716; and Steven B. Jack, Executive Director, Boggy Slough Conservation Area, T.L.L. Temple Foundation, Lufkin, TX 75901.

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Overall, we found that Hurricane Michael downed 16 percent of all trees sampled, accounting for a total basal area loss of 20 percent. We found that tree- and stand-level factors significantly influenced damage probability, but no landscape-scale factors were significantly correlated with treefall. Among pine species, we found that longleaf pine had the lowest damage (14.8 percent), followed by loblolly pine (24.1 percent), slash pine (28.1 percent), and shortleaf pine, which had the highest damage (39.8 percent). Though comparable to other studies (Johnsen and others 2009, Toulaiatos and Roth 1971), these species rankings should be interpreted with caution because there were significant interactions among species, soil type, and tree size, indicating that susceptibility rankings shift depending on soil type and tree size under consideration (fig. 1). Among pines, susceptibility increased with tree size, and shortleaf pine was most sensitive to changes in size, with probability of treefall increasing to 60-80 percent for large trees (60 cm d.b.h., 24 inches). Pines were more susceptible to windthrow in poorly drained soils, and slash pine and loblolly pine were most sensitive to changes in soil moisture (fig. 1). Longleaf pine did not have the lowest susceptibility in all cases (for example on excessively drained soils, large individuals of loblolly pine may be less vulnerable). However, longleaf pine was more resistant across a greater range of soil types and sizes than other pines. Full results, including those for oaks (*Quercus* spp.), are discussed further by Rutledge and others (2021).

In many southeastern forests, low-intensity fire is a prevailing theme in forest disturbance research. However, coastal pine forests also experience significant disturbance from hurricanes, and much less is known about how wind disturbance potentially shapes overstory structure, function, and competitive dynamics in fire-frequent forests. Wind disturbance is known to interact with and change fire behavior and effects, potentially leading to more complex feedbacks between these common disturbances (Cannon and others 2014, 2019; Gilliam and others 2006) that may shape community organization and function in fire-frequent forests and woodlands.

With several ongoing studies at the Jones Center, we are hoping to further address the role of hurricanes in shaping southeastern forests and conducting studies to develop a hierarchical model of wind risk that mechanistically incorporates tree, stand, and regional risk factors. Tree winching studies provide experimental means to measure tree susceptibility and provide information on the mechanisms and forces needed to topple trees of various species, sizes, and in different soil types. We are currently experimentally testing whether trunk and root strength in longleaf pine is greater than slash pine across a range of sizes and soil conditions using tree winching and experimental wetting (cf. Cannon and others 2015). Tree crowns create drag and convert wind torque on the trunk, and thus are important to understanding mechanisms of wind damage (Peterson and Cannon 2021). Simulation studies of wind damage usually assume that tree crowns have simple elliptical shapes (Gardiner and others 2000), and this assumption overestimates wind susceptibility. We are using terrestrial lidar to improve measurements of crown architecture in wind modeling. We are testing whether tree crowns or trunk strength drive observed post-hurricane patterns. We will incorporate results from tree crown measurements into wind simulation models (e.g., Peterson and others 2019) to refine estimates of wind susceptibility across a range of tree species, sizes, and stand densities. Using hurricane models, past studies have predicted the probability of hurricane-force winds at regional scales (Boose and others 2001, Zeng and others 2009). Borrowing a framework from wildfire-risk modeling (Scott and others 2013), upcoming work seeks to combine regional wind models with stand and tree level models of wind damage. Such hierarchical models can be critical for quantifying wind-risk and guiding management of southeastern landscapes.

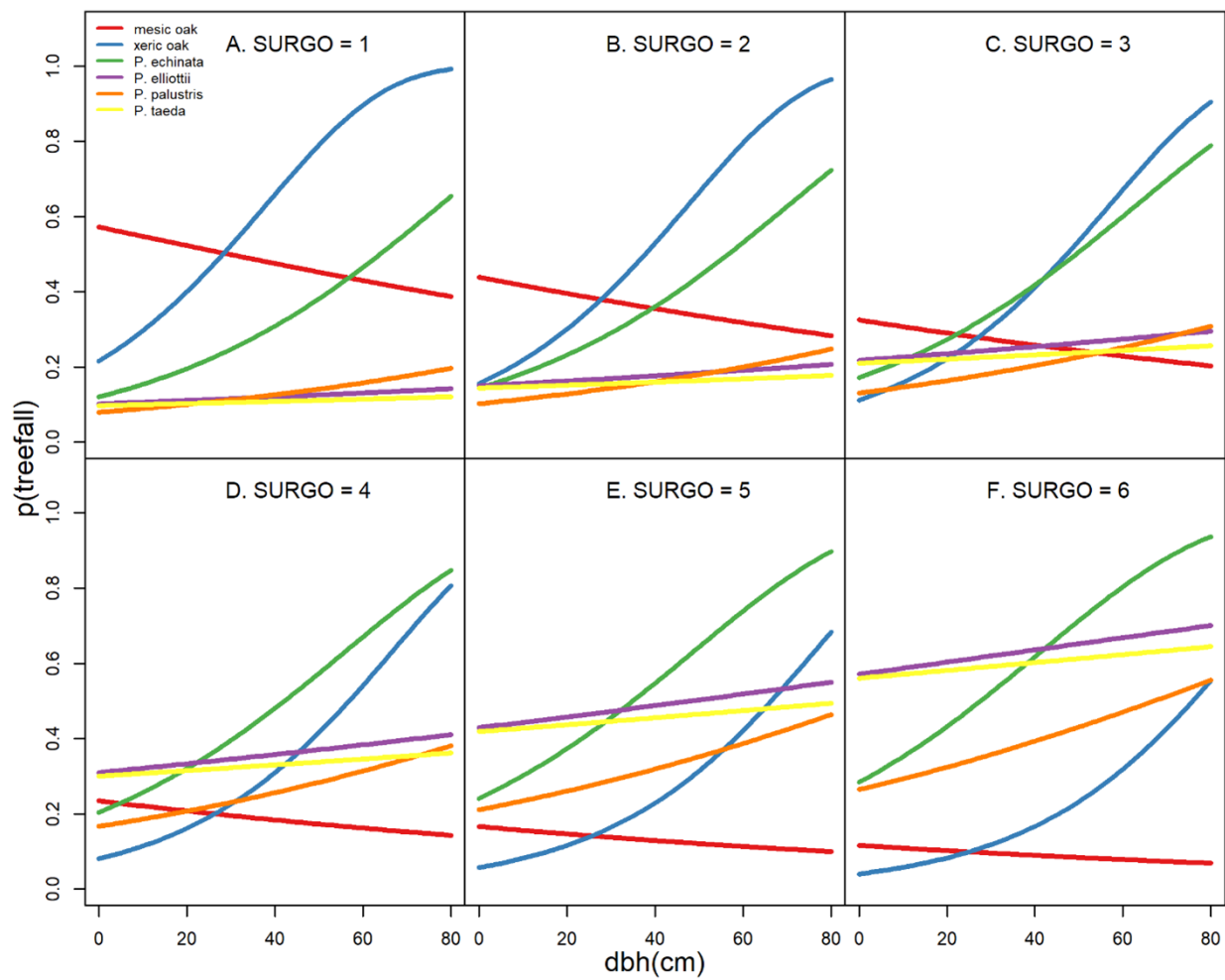


Figure 1—Model prediction indicating the relationship between tree size diameter at breast height (DBH) and estimated probability of treefall across five species and six soil types ranging from excessively drained (SURGO 1) to very poorly drained (SURGO 6). Figure from Rutledge and others (Rutledge and others 2021).

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