A comparison of mortality risk factors associated with large, infrequent wind disturbances of Carolina piedmont forests

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INTRODUCTION

Hurricanes and catastrophic tornados are major disturbance agents in the forests of the eastern United States and many regions of the world. A major objective of disturbance ecology is to explore the factors controlling tree mortality in order to predict the damage risk for future events. Past studies have shown that prediction of tree mortality can be very complex due to the interactions of major abiotic & biotic factors, and have left open the extent to which these limited previous findings are representative and can be used to predict forest damage. We here present a multi-scale comparative analysis and evaluate the consistency in mortality risk factors associated with three major wind events that occurred in Carolina piedmont forests.

STUDY SITES AND METHODS

Hurricane Hugo (1989)

South Carolina
2352 plots (400 m²)
Response variables:
Tree damage (heavy vs light or no)
-Predictable variables:
Winds
Wind speed
Precipitation
Tree architecture
height
diameter
Canopy position
Species
Site factors
Forest edge
Soil moisture
Aspect
Slope
Community attributes
Density
Basal area

Hurricane Hugo damage in SC forests (by SC forestry commission)

tornado

Umstead State Park, NC
11 plots (ca. 1000 m²)
Response variables:
Tree damage (heavy vs light or no)
- Predictable variables
Tree diameter
Species
Site factors
Soil moisture
Aspect
Slope
Topographical position
Community attributes
Density
Basal area

The 1988 tornado was rated F4 in the Fujita scale, but only rated F2 when passed though Umstead State Park, indicating wind speed 50-70 m/s. The width of the tornado track ranging between 81-218 m.

Hurricane Fran damage in Duke Forest (by Duke Forest Office)

Hurricane Fran (1996)

The Duke Forest, NC
45 plots (1000 m² up to 6.5 ha)
Response variables:
Tree damage (heavy vs light/no)
- Predicable variables
Tree architecture
diameter
Species
Site factors
Aspect
Slope
Community attributes
Density
Basal area

•The maximum sustained wind speed at Duke Forest was about 26.8 m/s, and the total rainfall was 224 mm. Overall, this forest region had experienced about 423 mm rainfall total for September 1996.

Hurricane Fran damage in Duke Forest plot (by W. Xi)

Data Analysis

1. Logistic regression was used to identify factors that might have influenced tree damage and mortality. Damage was classified as heavy damage versus light or no damage.

2. Multiple regression was used to identify the factors that most strongly influenced uprooting and breakage. Statistical analyses were performed using SAS 8.0.

Abstract

Past studies of large, infrequent wind disturbances have shown how meteorological, topographical, and biological factors interact to generate damage patterns, but have left open the extent to which these limited previous findings are representative and can be used to predict damage. We present a multiple-scale comparative analysis and evaluate the consistency in mortality risk factors associated with three major wind events: the Umstead tornado (1988), Hurricane Hugo (1989), and Hurricane Fran (1996). Our results reveal distinct differences in the damage caused by hurricanes relative to the tornado, and to some extent consistency between hurricanes. As compared to hurricanes, the tornado caused significantly greater and less species-specific mortality. Within-stand hurricane damage was more patchy, indicating tree morality risk must be conditioned on occurrence of unpredictable individual gusts. Differences in associated rainfall have strong influences on damage patterns with high rain increasing the risk of blow down relative to breakage. Landscape-scale analyses show relatively predicable patterns controlled by a combination of wind speed, topography, and pre-disturbance species composition, in contrast to local patterns, which can be understood only in the context of site conditions and small-scale wind patterns.

Key words: mortality risk factors, wind disturbances, multi-scale analysis, piedmont forests.

RESULTS & DISCUSSIONS

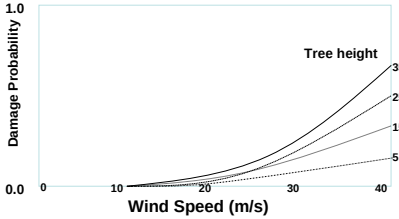

Figure 1. The probability of tree damage during Hurricane Hugo increased with tree height, indicating tree height (size) is a significant factor. There was an interaction between height and wind such that the probability of damaged increased exponentially with wind speed, and exponent increased with increasing tree height.

Relative importance of variables during 1998 Hurricane Hugo

Variables	% Variation Explained
Wind speed	**58.39**
Tree size/height	6.37
Other tree characters	12.13
Species	9.30
Site variables	0.56
Community attributes	0.98
Interactions	11.81

Table 1. Wind speed variation largely explain the variation in tree damage during 1989 Hurricane Hugo. Note that species characters play an important role in damage risk.

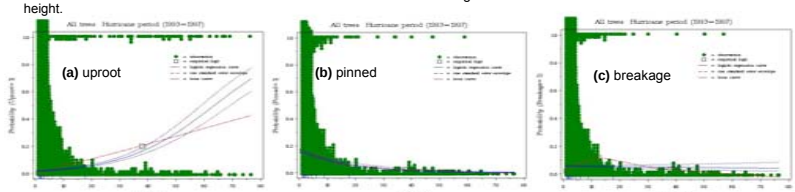

Figure 2. Relationship between tree size and damage probability (a) The possibility of a uprooting tree during 1996 Hurricane Fran increased with increases in tree size (dbh). (b) The probability of being pushed over by a falling tree (pinned) is higher among small size trees. (c) There is no clear trend for breakage. Interactions between diameter and species showed that rate of increase in damage with diameter varies among species.

Empirical log odds and the probability plot for (a) uproot, (b) pinned and (c) breakage as a function of pre-hurricane tree size (dbh). The observed response are plotted as stacked points at the top (i.e. uprooted, pinned or snapped) and bottom of the figure (i.e. no such type damage). The squares show the empirical sample logits and the analogous adjusted sample probability. The curves on these plots show predicted probabilities and 95% confidence bands.

MAJOR LITERATURE CITED

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RESULTS & DISCUSSIONS

Damage risk factors

	Hurricanes			Tornado	
	Regional	Landscape	Stand scale		
Abiotic					
Wind speed	***	n/a	n/a	n/a	*** p≤0.001
Rainfall	**	n/a	n/a	*	** p≤0.01
Slope	*	**	*	*	* p≤0.05
Aspect	*	**	**	*	
Soil moisture	**	**	*	*	
Biotic					
Tree size	**	**	***	*	
Species	**	**	**	**	
Stand density	*	**	**	*	

Table 2. Factors that were significantly related to wind damage and tree mortality

The consistency in mortality factors between hurricanes

Region Wind speeds and rainfall associated with storms are the ultimate factors to control regional damage patterns. Trees that experience with greater wind speed and high rainfall also experience higher mortality risk through uprooting.

Landscape The interactions of site conditions and community attributes, especially relative exposure and soil moisture mediate tree mortality risk. Greater uprooting was found on exposure sites with high soil moisture.

Stand Within-stand variation may be explained by tree size and species susceptibilities. Tree size is consistently found to be a factor that predicts damage severity and type, with large trees being associated with high damage risk.

Hurricane Vs Tornado The most distinct difference in the effects of the two hurricanes versus the 1988 tornado is the extent of the damage; (the tornado had only local impacts), though the tornado was also different in that maximum wind speed was greater such that virtually all trees were damaged or a large portion of the damaged area. The tornado and hurricanes were consistent in the importance of tree species and tree size as risk factors.

CONCLUSIONS

1. Wind speeds consistently are the primary determinant of damage severity. Rainfall has strong influences on damage patterns with high rain increasing the risk of blow down.

2. Landscape-scale patterns are relatively predicable and are controlled by a combination of wind speed, site exposure and pre-disturbance tree species, tree size and soil moisture.

3. Stand-level variation may be explained by tree size and species susceptibilities. Local patterns can be understood only in the context of site conditions, stand attributes and tree species.

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