

# GEOSPATIAL RELATIONSHIPS OF TREE SPECIES DAMAGE CAUSED BY HURRICANE KATRINA IN SOUTH MISSISSIPPI

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## ABSTRACT

Hurricane Katrina generated substantial impacts on the forests and biological resources of the affected area in Mississippi. This study seeks to use classification tree analysis (CTA) to determine which variables are significant in predicting hurricane damage (shear or windthrow) in the Southeast Mississippi Institute for Forest Inventory District. Logistic regressions were run based on the terminal nodes of the CTA analysis to provide a greater detailed examination of the variables significant to damage. By studying tree species and areas that may be more prone to wind/hurricane damage, foresters and private land owners will have greater knowledge of how to effectively manage their timberlands. Two predominant species groups across the Southeast MIFI Forest District were examined in this analysis, including pine (*Pinus sp.*) and oak (*Quercus sp.*).

## INTRODUCTION

Hurricane Katrina made landfall in Plaquemines Parish, Louisiana on August 29, 2005. With sustained winds recorded at 204.4 kmh, Hurricane Katrina was a Category 3 storm on the Saffir-Simpson scale at landfall (Knabb et al. 2006). Once over land, the storm quickly lost power and six hours after making landfall was reduced to a tropical storm just northwest of Meridian, Mississippi. In addition to hurricane-strength winds, the storm brought substantial amounts of rainfall over a very short period of time and a storm surge of up to 8.5 m across southern Louisiana and Mississippi (Graumann et al. 2005). This storm surge penetrated 10 km inland in many areas of southern Mississippi, and up to 20 km inland along bays and rivers (Knabb et al. 2006). Hurricane Katrina generated substantial impacts on the forests and biological resources of the affected area in Mississippi. According to Mississippi Institute for Forest Inventory (MIFI) and United States Forest Service Forest Inventory and Analysis (USFS FIA) assessments, over one half million hectares of forest land and approximately 39 million m<sup>3</sup> of timber were damaged across the Southeast Forest District of Mississippi due to Hurricane Katrina. Total damages/costs for the entire storm

event were estimated to be \$125 billion (Graumann et al. 2005). With so much data potentially available after severe weather phenomena it is important to understand which variables have the most importance in developing models to predict damage. This study uses CTA to examine the importance of variables addressing storm meteorology, stand conditions, and site characteristics for predicting damage to pine and oak tree species.

Previous research has focused on identifying biotic and abiotic factors that can predict the severity of wind-related damage. For example, following Hurricane Katrina, Kupfer et al. (2008) set out to map the hurricane-induced damage within the DeSoto Ranger District of the DeSoto National Forest located in southern Mississippi. Four damage classes were used (none, low, moderate, and heavy) to classify 450 plots within 153,000 hectares using a combination of air photo interpretation and field sampling. Predictive damage models were then developed using single tree classification tree analysis (CTA) and stochastic gradient boosting (SGB) which examined variables such as storm meteorology, stand conditions, and site characteristics for predicting forest damage. Damage was shown to be more strongly related to stand conditions and site characteristics and less related to measures of storm meteorology.

Wang and Xu (2008) conducted a similar study evaluating the effects of Hurricane Katrina in the Lower Pearl River Valley and the surrounding area in St. Tammany and Washington Parishes in Louisiana, and Hancock and Pearl River Counties in Mississippi. Fifty-three percent of the study area was forested lands including wetland forests, upland forests, and urban forests. A series of full and reduced logit models were developed to analyze the effects of forest characteristics and site conditions on the hurricane disturbance and to model probabilities that forests would be disturbed by hurricanes. Wang and Xu (2008) indicated that Hurricane Katrina damaged 60 percent of the forested land,

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with 18 percent highly, 35 percent moderately, and 7 percent lightly disturbed in the Lower Pearl River Valley. A large fraction of highly damaged forest and a small portion of moderately damaged forest were clustered in the Lower Pearl River Valley and south Hancock County. Lightly disturbed forests were randomly scattered as small patches in this region, whereas undisturbed forests clustered in the Lower Pearl River Valley, the lower portion of St. Tammany Parish, and the northwestern portion of Hancock County (Wang and Xu 2008). This is the same area that received the highest levels of storm surge inundation (Knabb et al. 2006).

Forests adjacent to streams and rivers in the study area showed a higher level of disturbance from the hurricane, indicating a high susceptibility of bottomland forests to the hurricane damage (Wang and Xu 2008). With increased distance away from river channels, the percentage of highly damaged forest declined (Wang and Xu 2008). These findings correspond with those from Kupfer et al. (2008) as well. An increase in distance from perennial streams resulted in less notable damage. It was shown that the most susceptible to damage were hardwoods located in bottomlands and along river channels (Kupfer et al. 2008).

These studies examine hurricane force damage to forests at the individual tree level, plot level, and at the landscape scale. Most previous research utilizes logistic and linear regression to correlate damage type and severity to biotic or abiotic factors. However, very few use CTA to determine significant predictor variables. Using the MIFI database and CTA in R (a free statistical software package), this study seeks to determine and test significant predictor variables for determining shear and blowdown damage in pine and oak species caused by Hurricane Katrina. Coupled with logistic regressions based on the terminal nodes of the pruned classification trees this will provide a detailed view at the variables significant in hurricane damage. Using these methods, this study seeks to test the following hypothesis: Hurricane damage will be more strongly correlated with stand characteristics than measures of storm meteorology.

## MATERIALS AND METHODS

The study area for this research is the Southeast MIFI Forest District which contains 15 counties that suffered the most Hurricane Katrina damage within Mississippi. Forest plot locations were derived from the MIFI data and span the 15 counties included in the district. Following Hurricane Katrina, about 1,700 0.2-ha circular plots were randomly installed in forest strata within the Southeast MIFI Forest District to measure forest damage (shear and blowdown). The MIFI data included plot location (x,y coordinates of plot centers), tree species, individual tree diameter at breast height (cm), total height (m), damage type (shear or

blowdown), and trees per hectare (tph). Other calculated variables include Lorey's mean height (m) and Quadratic Mean Diameter (cm). The species of interest were pine and oak; these species were chosen for their abundance throughout the study area and for their widespread spatial distribution throughout the southern and Atlantic coastal regions. Pine species included loblolly pine (*Pinus taeda*), slash pine (*Pinus elliottii*), longleaf pine (*Pinus palustris*), and shortleaf pine (*Pinus echinata*) which are found on a multitude of sites in the Coastal Plains and Lower Piedmont Plateau (Hodges et al. 2008) throughout Mississippi. The range of these pines is from southern New Jersey south to central Florida, west to southeastern Texas and southern Oklahoma. Loblolly pine is also almost exclusively planted for timber production in plantation settings, adding to the amount found within Mississippi. In comparison, oak species are slightly more limited in their natural range. Oak species included white oak (*Quercus alba*), Durand oak (*Quercus durandii*), southern red oak (*Quercus falcata*), cherrybark oak (*Quercus pagoda*), turkey oak (*Quercus laevis*), laurel oak (*Quercus laurifolia*), overcup oak (*Quercus lyrata*), blackjack oak (*Quercus marilandica*), swamp chestnut oak (*Quercus michauxii*), chinkapin oak (*Quercus muehlenbergii*), water oak (*Quercus nigra*), Nuttall's oak (*Quercus texana*), willow oak (*Quercus phellos*), Shumard oak (*Quercus shumardii*), post oak (*Quercus stellata*), black oak (*Quercus velutina*), and live oak (*Quercus virginiana*). Oak species are generally characterized by their tendency to grow in wet lowland to moist upland soils and on deep sand deposits in bottom lands. All of the previously mentioned oak species are found naturally throughout Mississippi (Hodges et al. 2008).

CTA was conducted for the two species groups using a binary classification (0 no damage, 1 damage) for each damage type and combined damage. First, all CTA were performed using the same predictor variables to create the over-fit classification and regression trees. CTA is a non-parametric statistical process and can be interpreted as those plots/stands with the highest proportion of damage would occur on the terminal nodes on the right side of the tree. Pruning of these trees was then done using the highest cross-validation error less than one standard error above the minimum cross-validation error (Steinberg et al. 1997). This was determined by analyzing the cross-complexity parameter (CP) table provided by R. This was also visually inspected by plotting the cross-validation relative error against the Cost-complexity Parameter (CP) value. The CP value is a measure of how much additional accuracy a split will add to the entire tree. As the CP value increases, a greater number of nodes are pruned away, resulting in a simpler classification/regression tree. Forward stepwise logistic regressions were run based on the terminal nodes of the pruned classification trees. This was done to provide a more detailed examination of the potentially significant variables when predicting tree damage.

## RESULTS

The fully-grown Classification Tree for all oak species total damage included fourteen terminal nodes. The cross-validation plot indicated that a tree with four terminal nodes provided the greatest accuracy and results in a much simpler classification tree (Figure 1). The first split for the pruned classification tree for total damage in oak species indicated that a Lorey's mean height (LMH) of 15.54 m was the first splitting criteria with plots having a LMH less than 15.54 m splitting to the right, being more likely to be damaged, and plots with a LMH greater than or equal to 15.54 m splitting to the left, being less likely to be damaged. At the next split, plots/stands with a Quadratic Mean Diameter (QMD) less than 6.45 cm have a smaller proportion of damage than those plots with a QMD greater than or equal to 6.45 cm. The final splitting criteria was based on TPH, with those plots/stands having a TPH less than 3.14 have a lower proportion of damage than those with TPH greater than or equal to 3.14. When examining shear damage in oak species the cross-validation plot indicates a tree with only one node would provide the best fit. This shows a poor fit to the data and may be a result of an overall lack of shear damage in oak trees. The pruned blowdown classification tree uses slightly different split parameters when compared to the total damage classification tree (Figure 2). Following the right split, those plots with the highest proportion of blowdown damage had a LMH less than 12.90 m and QMD greater than or equal to 7.87 cm. The subsequent logistic regressions were run on each terminal node of the pruned classification trees, for this paper the logistic regressions for only the nodes with the highest proportion of damage will be reported. For oak total damage the only significant variable for node 4 (69 percent damage) was distance from Hurricane Katrina's track (km). This was also the case when examining the logistic regression for node 3 (67 percent damage) for oak blowdown damage. Both were negatively correlated, meaning as the distance from Hurricane Katrina's track increases, damage is likely to decrease (Table 1).

A slightly different pattern emerged when examining pine species damage. The pruned classification tree for all pine species total damage included three terminal nodes (Figure 3), with plots/stands with the highest proportion of damage (59 percent damage) being less than 93.35 km from the coast and less than 66.54 km from Hurricane Katrina's track. For these plots/stands near the track and near the coast the logistic regression showed the significant variables are QMD, LMH, Height Variation, TPH, and hard sustained wind speed (Table 2). The pruned classification tree for all pine shear damaged resulted in a classification tree with four nodes (Figure 4). Plots/stand with the highest proportion of shear damage had a QMD greater than or equal to 4.07 cm, a distance from the coast less than 70 km, and a distance from Hurricane Katrina's track less than 52.22 km. The logistic regression for terminal node four (61 percent damage) resulted in significant variables QMD, Height

Variation, and TPH (Table 2). The pruned classification tree for pine blowdown damage was slightly more complex having five terminal nodes (Figure 5). This resulted in two terminal nodes having the highest proportion of damage, nodes four and five. Terminal node four (56 percent damage) included plots/stands with a TPH greater than or equal to 69.81, a LMH greater than or equal to 11.23 m, a QMD greater than or equal to 5.71 cm, and a LMH less than 14.37 m. Terminal node five (60 percent damage) included plots/stands with a LMH less than 11.23 m, a QMD greater than or equal to 5.71 cm, and a LMH less than 14.37 m. The logistic regressions for both of these terminal nodes showed LMH and Height Variation to be the most significant (Table 2).

## DISCUSSION

This study set out to test if damage was more strongly related to stand characteristics than measures of storm meteorology. The resulting pruned classification trees were almost entirely limited to stand/plot characteristics; this confirms previous research and the hypothesis for this study. The classification trees for the oak species were entirely limited to TPA, LMH, and QMD. This shows a strong relationship between these variables and damage type. This was slightly unexpected, oak trees are known to be a more site specific species so local factors were expected to be more prevalent in their classification trees. While oaks are overall a more site specific species, all oak trees tend to grow in wet lowland to moist upland soils and on deep sand deposits in bottomlands. They are most commonly found along streams and in bottomlands. For both oak damage types, the logistic regressions resulted in distance from Hurricane Katrina's track being the only significant variable.

This was not the case when examining pine species damage. The classification trees for all pine species were limited to LMH, QMD, TPH, distance to the coast, and distance from Hurricane Katrina's track. This could be explained by the different pine species having more specific growing site characteristics. When examining the distribution of MIFI plots with loblolly pine trees present and the distribution of MIFI plots with damaged loblolly pine trees present there is a very widespread distribution within the study area. Every county had loblolly pine trees present, and every county had loblolly pine trees that received either shear or blowdown damage. The other pine species are much more limited in their range. Slash pine is a coastal species found in swamps and along streams growing in sandy soils, this is evident when mapping the distribution of this species throughout the study area. Slash pine is almost exclusively found in the southernmost counties of the study area. Longleaf pine has similar site characteristics as loblolly pine but is not as abundant throughout the study area. With a more limited spatial distribution among the pine species this may have added a greater complexity to the relationships between damage type and species group. The logistic

regressions for pine damage resulted in LMH, QMD, TPH, Height Variation, and Sustained Wind Speed as significant variables. This shows more complexity in the relationship between damage type and pine trees.

This classification tree analysis was important because it begins to identify variables important in the prediction of Hurricane Katrina tree species damage. To develop a better fitting model, other modeling methods will be tested and examined, including logistic regression and neural networks. With a better understanding of how site characteristics influence damage severity and type we will be able to better predict potential damage. This will aide in recovery and salvage operations as well as allow managers to make better species selections based on the type of site available for planting. Previous research has found that recently thinned stands or stands with large open spaces are more susceptible to wind damage than those with a smooth forest landscape (Roberts et al., 2007; Zeng et al., 2009). While recent thinning or harvest activities were not taken into account for this study, silvicultural methods should be accounted for in future research.

Future research in this area should utilize other geostatistical processes to better model and predict forest damage. Specifically, linear regression modeling and regression tree analysis should be used to predict damage based on multiple co-variates as well as multiple logistic regressions. This will utilize biotic and abiotic factors that may influence damage type and severities for the species utilized in this study, as well as expand the research to other predominant species within the Southeast MIFI Forest District.

**Table 1—Oak species damage logistic regressions results**

Oak Species		
Total Damage, Node 4		
Variable	Estimate	Pr>ChiSq
Intercept	1.648	<0.000
Track Dist.	-0.019	0.000
Blowdown Damage, Node 3		
Intercept	1.569	<0.000
Track Dist.	-0.025	0.003

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**Table 2—Pine species damage logistic regressions results**

Pine Species		
Total Damage, Node 3		
Variable	Estimate	Pr>ChiSq
Intercept	-3.321	0.022
QMD	0.202	<0.000
LMH	-0.073	0.003
Height Variation	-0.252	<0.000
TPH	0.011	<0.000
Sustained Wind Speed	0.018	0.022
Blowdown Damage, Node		
Intercept	0.256	0.727
LMH	0.223	0.027
Height Variation	-1.099	0.009
Shear Damage, Nodes 4 & 5		
Intercept	-0.511	0.415
QMD	0.096	0.039
Height Variation	-0.209	0.004
TPH	0.008	0.002

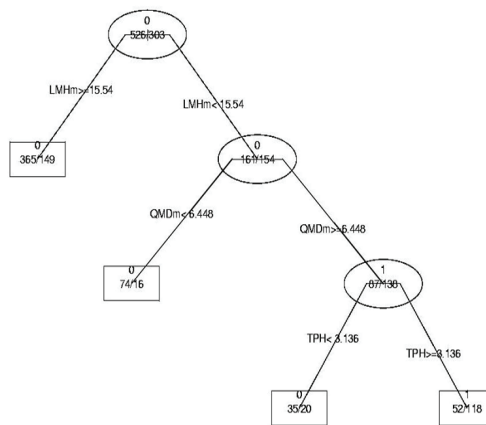


Figure 1—Pruned classification tree for all oak species damage.

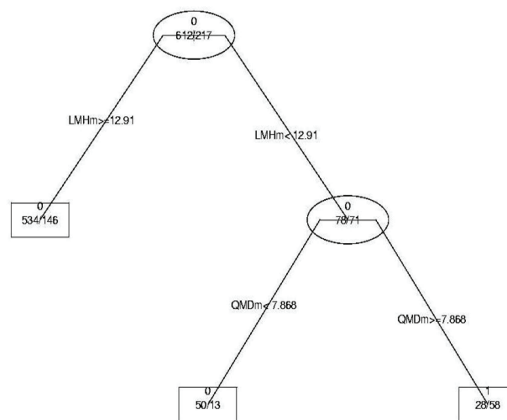


Figure 2—Pruned classification tree for all oak species blowdown damage.

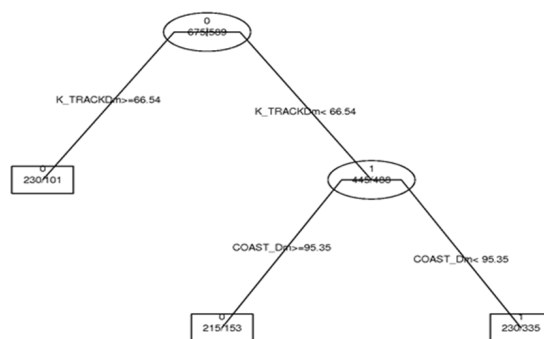


Figure 3—Pruned classification tree for all pine species damage.



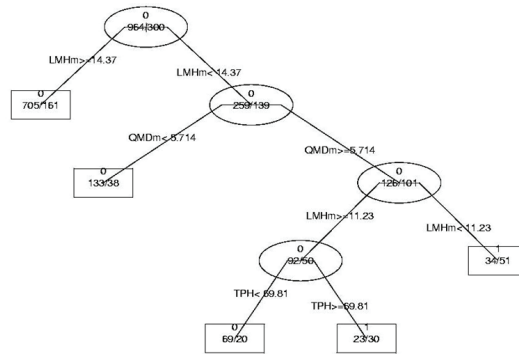


Figure 4—Pruned classification tree for all pine species shear damage.

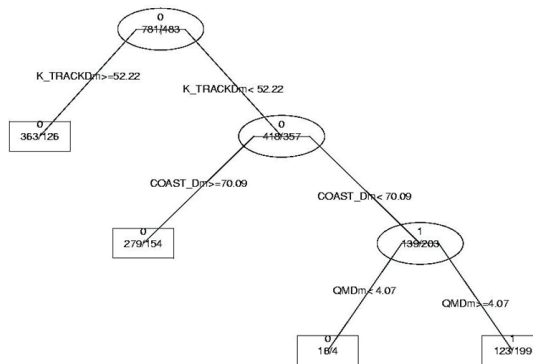


Figure 5—Pruned classification tree for all pine species blowdown damage.