Red-Cockaded Woodpecker Cavity-tree Damage by Hurricane Rita: An Evaluation of Contributing Factors

Ben Bainbridge[1,2], Kristen A. Baum[1,*], Daniel Saenz[3], and Cory K. Adams[3]

Abstract - *Picoides borealis* (Red-cockaded Woodpecker) is an endangered species inhabiting pine savannas of the southeastern United States. Because the intensity of hurricanes striking the southeastern United States is likely to increase as global temperatures rise, it is important to identify factors contributing to hurricane damage to Red-cockaded Woodpecker cavity-trees. Our objectives were to examine the effects of landscape-level factors on wind damage to cavity-trees and assess the relative risk of wind damage for different tree species and trees with different types of cavities. We evaluated wind damage to cavity-trees from Hurricane Rita on the Angelina, Sabine, and Davy Crockett national forests in eastern Texas. Basal area and number of cavity-trees in a cluster were identified as factors influencing the likelihood of damage to a cavity-tree. The likelihood of damage increased with decreasing basal area and an increasing number of cavity trees in a cluster. The increase in damage associated with an increase in the number of cavity-trees in a cluster likely reflects an increase in cluster area with more cavity-trees and the maintenance of lower basal areas in clusters to meet the habitat requirements of Red-cockaded Woodpeckers. Therefore, increasing basal area is not a reasonable management option because clusters will become unsuitable for Red-cockaded Woodpeckers. A higher proportion of trees with natural cavities were damaged than trees with artificial cavities in all three forests. A higher proportion of *Pinus echinata* (Shortleaf Pine) cavity-trees were damaged than *Pinus palustris* (Longleaf Pine) or *Pinus taeda* (Loblolly Pine) cavity-trees. Longleaf Pine cavity-trees were more likely to snap at the cavity, compared to a higher likelihood of wind throw for Shortleaf and Loblolly Pine cavity-trees. Restoring Longleaf Pine habitat and allowing stands to develop under lower tree densities could decrease the likelihood of damage to cavity-trees and the impact of hurricanes on Red-cockaded Woodpeckers.

Introduction

Picoides borealis Vieillot (Red-cockaded Woodpecker) is a federally endangered species that inhabits pine savannas of the southeastern United States (Jackson 1986, Ligon 1970). It is a cooperative breeder that generally lives in family groups consisting of a breeding pair and two to four helper birds (Lennartz et al. 1987, Ligon 1970). The woodpeckers excavate cavities for roosting and nesting in old living pines, preferably *Pinus palustris* P. Mill. (Longleaf Pine), but will also excavate roost and nest cavities in several other pine species (Hooper 1988, Hooper et al. 1991). A group of cavity-trees maintained by a

[1]501 Life Sciences West, Department of Zoology, Oklahoma State University, Stillwater, OK 74078. [2]Current address - PO Box 186, Bellevue, ID 83313. [3]506 Hayter Street, Wildlife Habitat and Silviculture Laboratory, Southern Research Station, United States Forest Service, Nacogdoches, TX 75965. [*]Corresponding author - kristen.baum@okstate.edu.

family group is referred to as a cluster. Each group consists of 2 to 6 individual birds occupying a cluster of 5 to 10 cavity-trees, but the cluster can contain more than 20 cavity-trees (Ligon 1970, Walters et al. 1988). Red-cockaded Woodpeckers are susceptible to population losses from hurricanes because of their reliance on cavities, their selection of trees with heart rot for cavity excavation (Hooper et al. 1991), and their preference for open stands (Loope et al. 1994, Torres and Leberg 1996), all of which can weaken a tree in the event of strong winds (Conner and Rudolph 1995b).

From 1875 to 1989, 20 major hurricanes occurred within the range of the Red-cockaded Woodpecker. The largest of these was Hurricane Hugo in 1989, which was a Category 4 hurricane when it made landfall just north of Charleston, SC (Hooper 1995). As Hurricane Hugo passed over the Francis Marion National Forest, at the time home to 1908 Red-cockaded Woodpeckers, it was a Category 3 storm which weakened to a Category 2 storm (Hooper 1995, Watson et al. 1995). Hurricane Hugo destroyed approximately 87% of the 1765 active cavity-trees in the Francis Marion National Forest (Watson et al. 1995).

Numerous studies have demonstrated the destructive power of wind in a forest, which is magnified when the canopy is broken by a clearing (Alexander 1964, Conner and Rudolph 1995b, Gordon 1973, Tang et al. 1997, Zeng et al. 2004). Forest edges are at greater risk of wind damage, especially if they are located on a ridge line, or shaped into a U or V to funnel the wind (Alexander 1964, Tang et al. 1997). Zeng et al. (2004) showed that forests were most vulnerable to wind damage after a clear-cut occurred when older trees (100 years or more) were suddenly exposed to wind entering the forest from a newly created edge.

Neuman (1987) developed the HURISK model to determine the return interval of hurricane force winds to specific areas. When applied to the 15 largest stable populations of Red-cockaded Woodpeckers, 11 were found to be vulnerable to hurricanes (Hooper 1995). The five most vulnerable populations, based on hurricane return intervals for their locations, had return intervals of approximately 130 years for Category 3 force winds and less than 55 years for Category 2 force winds. The predicted return interval for Category 1 force winds on the Francis Marion National Forest, the most vulnerable of all major Red-cockaded Woodpecker populations, was only 14 years. The Sam Houston National Forest, which is close to our study area in eastern Texas, was ranked as the ninth most vulnerable population, with return intervals for storms of Category 1, 2, and 3 force winds of 48, 290, and >500 years, respectively (Hooper 1995).

With such short hurricane return intervals in some Red-cockaded Woodpecker populations, it is important to identify factors contributing to hurricane damage to Red-cockaded Woodpecker cavity-trees. We evaluated the impact of Hurricane Rita on Red-cockaded Woodpecker cavity-trees on the Angelina, Sabine, and Davy Crockett national forests in eastern Texas. Hurricane Rita made landfall 24 September 2005, between Johnson's Bayou, LA and Sabine Pass, TX, as a Category 3 hurricane with maximum sustained winds of 209 km/h. As it moved up the Texas/Louisiana border it weakened rapidly to a Category 1 storm and then to a tropical storm. As it moved inland, the storm passed over the Angelina, Sabine, and Davy Crockett national forests, each home to populations of Red-cockaded Woodpeckers (Conner and Rudolph 1989, 1995b). Numerous Red-cockaded Woodpecker cavity-trees were damaged or downed due to the intense winds. We examine the effects of distance to clearing, midstory density, basal area, elevation, and diameter at breast height on wind damage to cavity-trees. Also, we assess the relative risk of wind damage for different tree species and trees with different types of cavities.

Field-Site Description

Our study area included the Angelina, Sabine, and Davy Crockett national forests in eastern Texas. The Angelina National Forest is a 61,990-ha pine forest located in San Augustine, Angelina, Nacogdoches, and Jasper counties. It is bisected east to west into two approximately equal-sized parcels by the Sam Rayburn Reservoir. The northern half is composed predominantly of *Pinus echinata* P. Mill. (Shortleaf Pine) and *Pinus taeda* L. (Loblolly Pine), and the southern half is predominantly Longleaf Pine. There has been some development of lakeshore property near the towns of Broadus and Zavalla, which are adjacent to the national forest. The Angelina National Forest is located approximately 12 km west of the path of the eye of Hurricane Rita (Fig. 1).

The Sabine National Forest is a 65,015-ha pine forest located on the Texas side of the Louisiana/Texas border in San Augustine, Shelby, and Sabine counties. It is bordered on the eastern edge by Toledo Bend Reservoir and divided into northern and southern portions by private lands. The northern portion is composed predominantly of Shortleaf and Loblolly Pine, while the southern portion is predominantly Longleaf Pine. The lake shore of Toledo Bend Reservoir has not been developed to the extent of Sam Rayburn Reservoir. The eye of Hurricane Rita passed approximately 19 km to the west of Sabine National Forest (Fig. 1).

The Davy Crockett National Forest is a 65,564-ha pine forest located in Houston and Trinity counties. Unlike the Angelina and Sabine national forests, Davy Crockett National Forest is not bordered by a reservoir. Shortleaf Pine is the dominant species. The Davy Crockett National Forest is the most developed of the three national forests, with the towns of Kennard and Groveton located adjacent to the national forest. The Davy Crockett National Forest is located approximately 95 km west of the path of the eye of Hurricane Rita (Fig. 1).

Methods

A large-scale damage assessment on the Angelina, Sabine, and Davy Crockett national forests was undertaken by the United States Forest Service following

Hurricane Rita. For each damaged Red-cockaded Woodpecker cavity-tree, the compartment, cluster, tree number, tree species (Longleaf, Shortleaf, or Loblolly Pine), damage type (wind thrown or snapped), cavity type (artificial [Allen 1991], natural, or start [an incomplete cavity]), azimuth of fall, and diameter at breast height (DBH) were recorded.

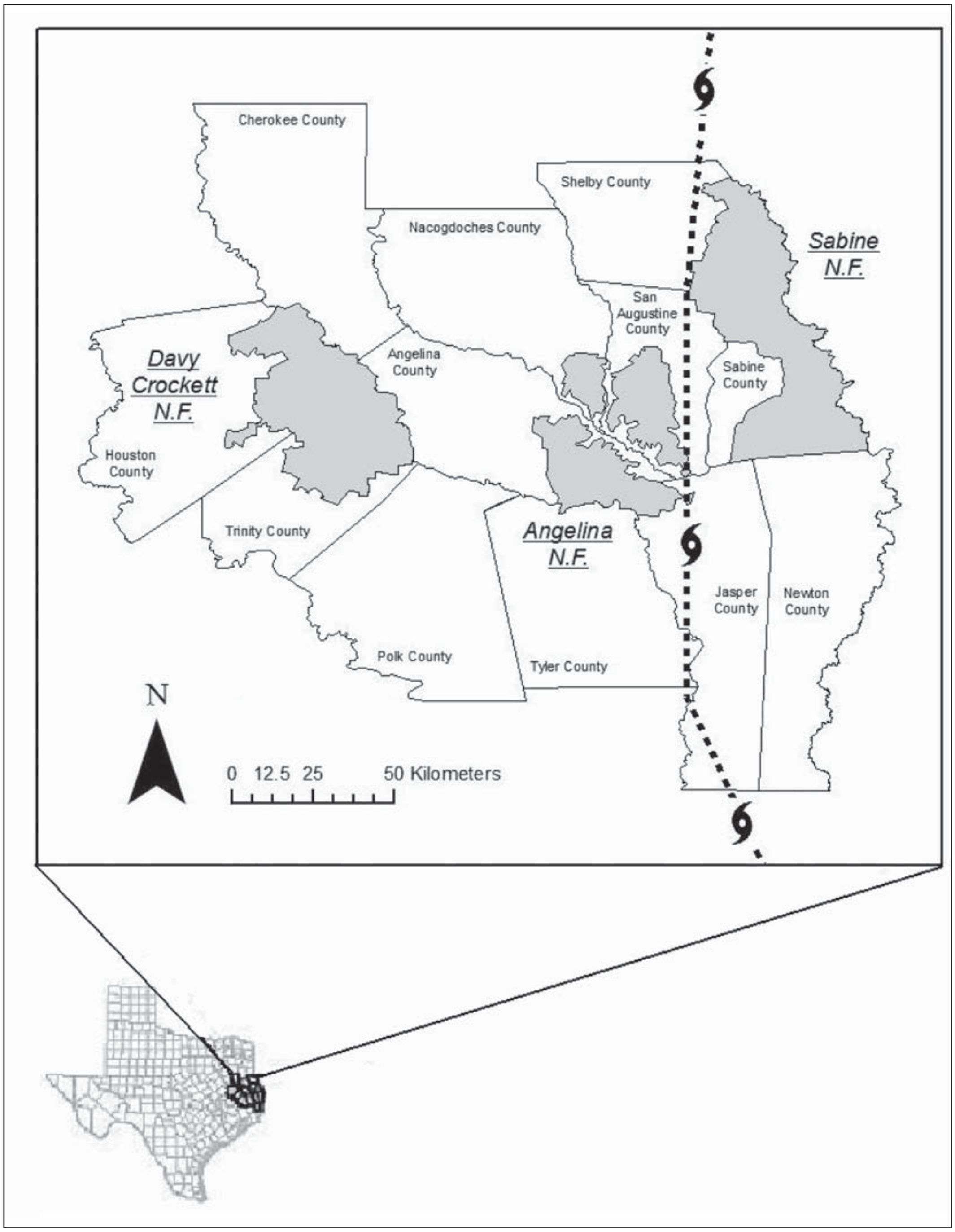

Figure 1. The locations of the Angelina, Sabine, and Davy Crockett national forests in Texas in relation to the path of Hurricane Rita. The path of the eye of Hurricane Rita from 24 September 2005 is represented by the bold, dashed line.

The distance to the nearest windward clearing was measured in ArcView 9.1 (Environmental Systems Research Institute, Redlands, CA) using 2004 National Agricultural Imagery Program (NAIP) images with a 1- x 1-m resolution, a GIS layer of all damaged clusters, and the direction of the wind based on azimuth of tree fall (average of 202º [SSW] and 220º [SW] for cavity-trees on the Angelina and Sabine national forests, respectively). Azimuth of fall and geographic coordinates for downed cavity-trees on the Davy Crockett National Forest were not available, so the average azimuth of fall for trees on the Angelina National Forest was used for these clusters because the Angelina National Forest is the closest national forest for which data were available. An equal number of clusters not damaged by Hurricane Rita were randomly chosen as control clusters. The average azimuth of fall of all damaged cavity-trees for each national forest was used to determine the wind direction for the undamaged clusters because variation in individual tree azimuths due to roads or other clearings may have funneled the wind in slightly different directions making the azimuth of fall for the nearest damaged cavity-tree inaccurate for undamaged clusters.

We also obtained a GIS shape file (NOAA 2006) which denoted where the storm changed index ratings on the Saffir-Simpson Scale, which is used to classify hurricanes and tropical storms. Hurricane Rita became a category 1 storm approximately 91 km after making landfall and remained a category 1 storm for 123 km. Taking into account that category 1 winds range from 119–153 km/h, we developed a graded scale for the category 1 and tropical storm sections of the storm based on the assumption that wind speed dropped at a constant rate of approximately 7 km/h with every 25 km the storm traveled north. The HURRECON model, which was developed to model the winds of a hurricane given a specific set of meteorological data (Boose et al. 1994), was used to estimate wind speed at each damaged and undamaged cluster.

Basal area was estimated using a one-factor metric basal-area prism. All measurements were made to the northeast of each damaged or undamaged control cluster to account for the direction of the wind. One measurement was taken at the northeastern-most cavity-tree in a cluster, and a second measurement was taken 50 m to the northeast of that cavity-tree. The average of these two locations was used to represent the basal area of the forest directly to the northeast of each cluster.

Midstory density was visually estimated based on the northeastern-most cavity-tree of each damaged and undamaged control cluster by categorizing the midstory into 1 of 5 categories (Saenz et al. 2002). A cluster with a midstory value of 5 had a thick, wall-like midstory to the northeast, and a cluster with a midstory value of 1 had an open, savanna-like midstory. Categories 2, 3, and 4 ranged in between, with category 3 being a half-full midstory. Estimates were made for a 60° wide section of midstory extending out 100 m from the northeastern-most cavity-tree to account for small fluctuations in wind direction during Hurricane Rita.

Elevation for each damaged and undamaged control cluster was obtained from 3-m (10-ft) interval digital topographic maps available from the Texas National Resource Information System (2006). The DBH of each damaged cavity-tree was measured in centimeters using a logger's tape. The DBH of the closest undamaged tree of the same species and cavity type also was recorded.

A multiple logistic regression analysis was performed to evaluate the effect of landscape-level factors on wind damage to cavity-trees, including distance to nearest windward clearing, wind speed, basal area, midstory density, number of trees in a cluster, and elevation. A paired *t*-test was used to compare DBH between damaged and undamaged cavity-trees on the Angelina National Forest. A Wilcoxon signed rank test was used to compare DBH between damaged and undamaged cavity-trees on the Davy Crockett National Forest and on the Angelina and Davy Crockett national forests combined because the data were not normally distributed. Diameter at breast height of downed cavity-trees on the Sabine National Forest was not available for analysis. We used a chi-square test to compare expected and observed values for presence/absence of damage and cavity type (natural or artificial; starts were excluded because of the small number of damaged starts; trees with both a cavity and start were included based on cavity type), and presence/absence of damage and tree species (Longleaf, Shortleaf, or Loblolly Pine). We also used a chi-square test to compare expected and observed values for damage type (wind throw or snap) and cavity type, and damage type and tree species. Analyses were performed using SAS 9.1 (The SAS Institute, Carey, NC), and the significance level was set at $\alpha = 0.05$.

Results

A total of 122 of 1805 cavity-trees were damaged on the Angelina, Davy Crockett, and Sabine national forests. On the Angelina National Forest, 59 cavity-trees were downed by Hurricane Rita and 34 of 84 surveyed clusters had at

Table 1. Results of a multiple logistic regression model for the effect of landscape-level factors on wind damage to Red-cockaded Woodpecker cavity-trees. Variables in bold were significant factors.

Variable	Estimate[A]	SE[B]	χ^2 [C]	$P > \chi^2$ [D]	Odds ratio
Intercept	1.335	2.428			
Midstory density	-0.362	0.211	2.932	0.087	0.70
Basal area	**-0.108**	**0.043**	**6.347**	**0.012**	**0.90**
Distance to clearing	0.001	0.001	0.023	0.880	1.00
Wind speed	-0.006	0.010	0.383	0.536	1.03
Number of trees	**0.215**	**0.051**	**17.464**	**<0.001**	**1.24**
Elevation	-0.004	0.015	0.055	0.815	0.99

[A]Estimate of explanatory slope (β_x).
[B]Standard error of slope estimate.
[C]χ^2 statistic testing H_o: slope estimate = 0.
[D]Probability to reject H_o.

least one downed cavity-tree. Ten cavity-trees in 8 of 46 surveyed clusters were damaged by Hurricane Rita on the Sabine National Forest. On the Davy Crockett National Forest, 53 cavity-trees were damaged in 26 of 83 surveyed clusters. Basal area and number of trees in a cluster were the only variables to significantly influence the probability of wind damage (Table 1, Fig. 2). The probability of damage in a cluster decreased 10% with each unit increase of basal area (m^2/ha)

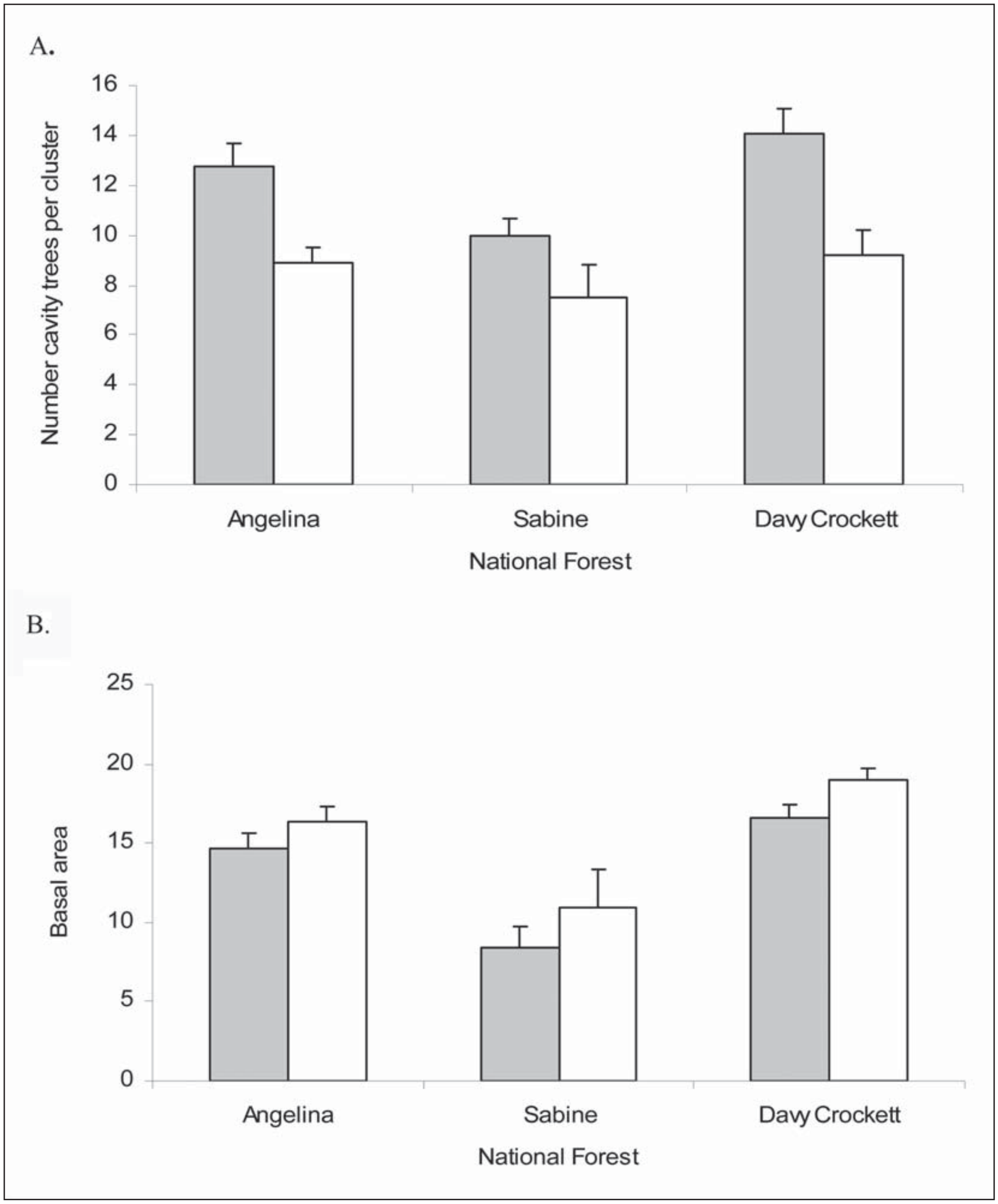

Figure 2. The number of damaged and undamaged cavity-trees per cluster (mean ± se) in the Angelina, Sabine, and Davy Crockett national forests (part A). Basal area (m^2/ha; mean ± se) of damaged and undamaged clusters in the Angelina, Sabine, and Davy Crockett national forests (part B). Data for damaged clusters are represented by shaded bars and undamaged clusters by white bars.

and increased 24% with each additional tree in a cluster (see the odds ratio column in Table 1). There was no difference in DBH between damaged and undamaged cavity-trees on either the Angelina or Davy Crockett national forests (df = 40, t = -1.860, P = 0.070; Z = 0.210, P = 0.839, respectively), or for both forests combined (Z = 1.354, P = 0.177).

A higher proportion of trees with natural cavities were damaged on the Angelina (12.7% compared to 6.4% of trees with artificial cavities; df = 1, χ^2 = 6.35, P = 0.012), Sabine (7.7% compared to 2.3% of trees with artificial cavities; df = 1, χ^2 = 4.164, P = 0.041), and Davy Crockett national forests (12.4% compared to 6.3% of trees with artificial cavities; df = 1, χ^2 = 6.586, P = 0.010), and for all three forests combined (11.9% compared to 5.4% of trees with artificial cavities; df = 1, χ^2 = 20.506, P < 0.001).

A higher proportion of Shortleaf Pine cavity-trees (17.3%) were damaged, on the Angelina National Forest, than Longleaf (4.7%) or Loblolly (8.1%) cavity-trees (df = 2, χ^2 = 19.988, P < 0.001). A higher proportion of Shortleaf Pine cavity-trees (9.8%) were damaged than Loblolly cavity-trees (1.3%) on the Davy Crockett National Forest (df = 1, χ^2 = 11.905, P < 0.001; no cavities were located in Longleaf Pine). There was no difference in damage among tree species on the Sabine National Forest (df = 2, χ^2 = 0.996, P = 0.318). When all three forests were combined, a higher proportion of Shortleaf Pine cavity-trees (10.8%) were damaged than Longleaf (4.2%) or Loblolly (4.9%) cavity-trees (df = 2, χ^2 = 24.785, P < 0.001).

There was no association between damage type (snap or wind throw) and cavity type on the Angelina (df = 1, χ^2 = 3.03, P = 0.082), Sabine (df = 1, χ^2 = 0.104, P = 0.747), or Davy Crockett national forests (df = 1, χ^2 = 0.288, P = 0.592), or for all three forests combined (df = 1, χ^2 = 2.677, P = 0.102).

On the Angelina National Forest, Longleaf Pine cavity-trees predominantly suffered a snap (69.6%), whereas Shortleaf Pine and Loblolly Pine cavity-trees predominantly suffered wind throw events (85.7% and 60%, respectively; df = 2, χ^2 = 13.784, P = 0.001). Tree species did not differ with regards to damage type on the Sabine or Davy Crockett national forests (df = 1, χ^2 = 0.476, P = 0.490; df = 1, χ^2 = 1.26, P = 0.262, respectively), or for all three forests combined (df = 2, χ^2 = 3.512, P = 0.173).

Discussion

Distance to the closest windward clearing was not an important factor influencing which clusters were more likely to lose cavity-trees during a hurricane (Table 1). However, numerous studies on wind damage to forests have shown that trees on the windward edges of stands—where the wind enters the canopy—are at greater risk of wind damage than trees located on the leeward edge of the stand (Gordon 1973, Tang et al. 1997, Zeng et al. 2004). One possible explanation is that the cluster itself may be open enough for wind to enter the canopy and damage a cavity-tree. Wind may be funneled into clusters if the surrounding forest possesses higher tree densities, and thinning may make trees not previously exposed to high winds more vulnerable to damage (Conner and Rudolph 1995b, Zeng et al. 2004). This explanation also may account for why the number of trees in a cluster significantly influenced the probability of damage in a cluster (Fig. 2A). Cluster area tends to increase with the number of cavity-trees, and larger clusters may be more susceptible to wind damage because of the larger cluster area (Table 1).

Basal area also significantly influenced the probability of damage in a cluster, with the probability of damage decreasing with increasing basal area (Table 1, Fig. 2B). Alexander (1964) showed that thinning of spruce-fir forests increased the vulnerability of the entire stand to wind damage. Furthermore, stands of mature trees which are thinned may be more susceptible to damaging winds (Zeng et al. 2004) because of a decrease in lateral support provided by contact among the crowns (Cucchi and Bert 2003). However, higher basal areas (i.e., higher stand densities) are less suitable for Red-cockaded Woodpeckers and the 19 m^2/ha basal area observed on the Davy Crockett National Forest is approaching the upper limit of suitable basal area for Red-cockaded Woodpeckers (James et al. 2001, Walters et al. 2002).

Wind speed, elevation, and midstory density did not affect the probability of damage (Table 1). Midstory density may not protect against catastrophic wind events because most of the stress incurred on mature pine trees occurs from wind passing over the canopy, not moving through the boles of the trees (Putz et al. 1983). Furthermore, increased hardwood midstory is detrimental to Red-cockaded Woodpeckers (Ligon 1970) because of decreased arthropod biomass (Collins et al. 2002), interference with foraging locations on pines (Rudolph et al. 2002), and increased competition for cavities from other species (Borgo et al. 2006, Conner and Rudolph 1989). Diameter at breast height did not differ between damaged and undamaged cavity-trees, although one might expect to find larger pine trees damaged by severe wind events (Oswalt and Oswalt 2008) as well as larger cavity-trees, given the higher probability of red heart disease in older trees (Hooper 1988, Hooper et al. 1991).

Trees with natural cavities were more likely to be damaged than trees with artificial cavities on the Angelina, Sabine, and Davy Crockett national forests. Red-cockaded Woodpeckers typically select pines with fungal heart rot for cavity excavation (Conner and Locke 1982, Hooper 1988, Hooper et al. 1991, Jackson 1977), which may weaken the bole of a tree more than the addition of an artificial cavity. Artificial cavities are generally placed in trees with sound heartwood, since decayed heartwood makes it more difficult to secure the artificial cavity into the tree (Allen 1991).

There was no difference in presence/absence of damage among tree species on the Sabine National Forest. Shortleaf Pine cavity-trees were more likely to receive damage on the Angelina and Davy Crockett national forests. Given the small sample size on the Sabine National Forest, and the dominance of Shortleaf Pine on the Davy Crockett National Forest, the variation found on the Angelina National Forest provides the best information about the relative susceptibility of different tree species to hurricane damage. On the Angelina National Forest, Shortleaf Pine cavity-trees had the highest incidence of damage. Gresham et al. (1991) and Johnsen et al. (2009) evaluated the frequency of damage to Longleaf and Loblolly Pines without cavities following Hurricanes Hugo and Katrina, respectively, and found that Longleaf Pines were less likely to suffer damage than Loblolly Pines. Longleaf Pines typically have a tap root extending 2.4–3.7 m deep, which may make them more stable during storms (Wahlenburg 1946). Loblolly and Shortleaf Pines grow on clay based soils and do not have a large or deep root structure (Little and Somes 1964, Wahlenburg 1960).

Longleaf Pine cavity-trees were more vulnerable to trunk snap as opposed to wind throw than Loblolly and Shortleaf Pine cavity-trees on the Angelina National Forest. The southern portion of the Angelina National Forest is dominated by Longleaf Pines growing on deep, loamy sands (Conner and Rudolph 1995a). The deep root structure of Longleaf Pines likely causes them to appear to be more prone to snapping at the cavity because wind stress incurred on the trunk will snap the trunk before the root structure gives way. Seventy-four percent of snapped cavity-trees were snapped at the cavity, not at other heights on the trunk, indicating the cavity creates a point of weakness in the tree trunk and increases its vulnerability to snapping.

Loblolly and Shortleaf Pine cavity-trees were more likely to be wind thrown than expected by chance on the Angelina National Forest. The northern half of the Angelina National Forest is dominated by Shortleaf and Loblolly Pines growing on shallow, mesic, shrink-swell clay soil types (Conner and Rudolph 1995a). These types of soil causes them to have a shallow root system and may make them more prone to wind throw. However, this may not always be the case, such as with Loblolly Pines on the Congaree Swamp National Monument in South Carolina which were equally likely to be snapped or wind thrown following Hurricane Hugo (Putz and Sharitz 1991).

There was no association between cavity type and damage type. Artificial-cavity installation involves using a chainsaw to cut a rectangular portion out of the bole of a mature, healthy tree and securing an artificial-cavity box (10.16 x 25.4 x 15.24 cm) into the space created (Allen 1991). Thus, despite the invasive nature of artificial-cavity installation, the trees still can withstand catastrophic wind events, as demonstrated by the roots yielding before the trunk snaps at the cavity in Loblolly and Shortleaf Pines. The substantial root system of the Longleaf Pine likely supports the tree past the breaking point, causing the tree to snap at the cavity, regardless of the type of cavity present.

The HURISK model identified return intervals for hurricanes to specific areas of the southeastern United States (Neuman 1987). However, these return intervals may change as global temperatures continue to rise, and the intensity of hurricanes striking the southeastern United States is likely to increase (Bengtsson et al. 1996, Trenberth 2005, Webster et al. 2005). In 2005, two major hurricanes, Katrina and Rita, struck the southeastern United States in one month, causing damage to forest resources estimated between $2 and $3 billion (Stanturf et al.

2007). Thus, it is important to identify factors contributing to hurricane damage in the southern pine savannah and to Red-cockaded Woodpecker cavity-trees. However, predicting damage at the level of stands or individual trees can be difficult with heterogeneous environmental conditions, especially when attempting to apply results at the landscape scale (Oswalt and Oswalt 2008).

Longleaf Pines were more resistant to strong winds than Loblolly and Shortleaf Pines, with Longleaf Pines primarily being snapped at the cavity, whereas Loblolly and Shortleaf Pines were wind thrown prior to the point of snapping. Restoration of Longleaf Pine habitat and the establishment of Red-cockaded Woodpecker populations in restored areas could reduce cavity-tree damage during hurricanes. Furthermore, allowing stands to develop under lower tree densities would decrease the likelihood of damage to cavity-trees compared to stands that are thinned once mature (Zeng et al. 2004). When cavity losses do occur, artificial cavities can be installed to mitigate these losses, as cavity-trees with artificial cavities are less susceptible to wind damage than cavity-trees with natural cavities.

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