RELATIVE IMPACTS OF ICE STORMS ON LOBLOLLY PINE PLANTATIONS IN CENTRAL ARKANSAS

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Abstract—Catastrophic ice storms can inflict widespread damage to forests in the Southeastern United States. Two severe ice storms struck Arkansas in December 2000, resulting in heavy losses to loblolly pine (*Pinus taeda* L.) plantations. We assessed the type and magnitude of damage in four loblolly pine plantation conditions: unthinned 11- to 12-year-old stands, once-thinned 18- to 19-year-old stands, twice-thinned 24- to 25-year-old stands, and at least twice-thinned > 28-year-old stands. Each condition was replicated three times on similar sites. Patterns in tree damage extent and type were apparent between plantations of different ages and thinning histories. The oldest plantations had the greatest proportion of undamaged survivors, while the youngest stands received the highest injury. Young loblolly pines suffered from bent stems more often than trees in older plantations. Loblolly pines in the oldest plantations were virtually immune to stem damage yet experienced frequent crown and branch loss. Intermediate-aged plantations had somewhat more stem breakage and uprooting than either younger or older pine plantations. Differences in the degree and type of damage were closely related to tree size and stand attributes. Logistic regression models were also developed to predict severe damage probability from stem diameter and tree density.

INTRODUCTION

Ice storms are some of the most catastrophic disturbances in southern forest lands. At least a portion of the region is affected by glazing every year, and some events are truly monumental, covering millions of acres and inflicting many millions of dollars in damage; e.g., Fountain and Burnett 1979, Halverson and Guldin 1995, White 1944.

Pine plantations can be particularly vulnerable to ice damage, especially when storms coincide with thinning operations (Hebb 1973, Nelson 1951). Thinning removes much of the structural support that comes from the close proximity of trees in unthinned stands. Recently exposed pines also tend to be spindly, with relatively thin, weak stems and most ice-accumulating surfaces; e.g., branches, foliage, found in the crown of the tree (Bragg and others, in press).

Two severe ice storms struck Arkansas in December 2000, with especially heavy damage inflicted on recently thinned loblolly pine (*Pinus taeda* L.) plantations. It became apparent in the weeks following these ice storms that not all plantations responded similarly to the glaze events. Since these differences may affect their poststorm management, we quantitatively evaluated the aftermath. This paper reports on a study that compared the type of injury and relative extent of glaze damage for loblolly pine plantations in central Arkansas.

METHODS

December 2000 Arkansas Ice Storms

National Oceanic and Atmospheric Administration records show that the first ice storm began on December 12, 2000, and deposited up to 2 inches of ice before ending on December 13 (National Oceanic and Atmospheric Administration 2001). A second ice storm began on December 25 and continued until December 28, with accumulations approaching 3 inches in western Arkansas. Local observers attributed the majority of the damage in central Arkansas to the first glaze storm. No site-specific measurements of ice accumulation are available, but judging from the damage witnessed in central Arkansas, the region probably received 1 to 2 inches of ice in the first storm and perhaps 0.5 to 1 inch from the second.

Study Sites

Twelve study sites were located on International Paper Company property in Dallas County, AR. Loblolly pine plantations were chosen on the basis of their age and thinning history. Four distinct age and thinning combinations consistent with the management strategies of the cooperating timber company were selected to represent important developmental stages. These combinations consisted of three replicates each of stands that were 11 to 12 years old, unthinned; 18 to 19 years old, once-thinned; 24 to 25 years old, twice-thinned; and > 28 years old, at least twice-thinned.

Field Sampling

Field work began in early March of 2001 and ended approximately 1 month later. Resource constraints prevented sampling any sooner, which may pose some problems in damage assessment because of the potential for recovery of injured trees. For example, pines that are bent by snow or ice can quickly straighten (Kuprionis 1970). However, we did not expect major discrepancies due to recovery between December and April because the winter of 2000-01 was particularly cold, and straightening usually occurs only in small-diameter trees after the growing season has begun.

Each of the 12 stands identified as likely candidates was further subsampled with 3 measurement subplots randomly located from a starting point placed to keep the plots within the stand. These three subplots were averaged to produce a composite value for each replicate, which were then

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tested for their significance. Two subplot sizes were used to reduce the amount of necessary sampling: 0.10-acre circular subplots were used in the 11- to 12- and 18- to 19-year-old stands, while the 24- to 25- and >28-year-old stands were surveyed using 0.25-acre circular subplots. Within each subplot, every merchantable-sized [> 3.5 inches diameter at breast height (d.b.h.)] loblolly pine living at the time of the ice storm was measured to the nearest 0.1-inch d.b.h. and assigned to a damage class (fig. 1). Damage types included apparently undamaged, branch loss (as a percent of total live crown), crown loss (loss of growing tip with some live branches remaining, as a percent of total live crown), stem breakage (bole breakage below the live crown), stem bending (bent stem, root system intact), and uprooting (bent stem, root system broken). Most individuals only had one type of damage reported; however, some had multiple injury types. For example, a tree may experience both branch loss and bole bending. Any mitigating circumstances, such as stem defects, forks, or damage from a neighboring tree, associated with a tree's damage were also recorded.

Statistical Analysis

Differences in stocking and size distribution required that damage comparisons between stand-age classes be performed using relative (percent) information. All percentage (p) data were adjusted using the arcsine transformation ($p' = \arcsin\sqrt{p}$) (Zar 1984). If the adjusted data still experienced major heterogeneity of variance, then an additional log transformation [$p'' = \log(p'+1)$] was performed before significance was determined using Tukey's honestly significant difference test ($\alpha = 0.05$). However, all values are reported in the tables and text as untransformed percentages.

Models to predict the type of damage were also developed for pines with major or critical damage. This approach has been previously used to predict ice damage to individual trees (Amateis and Burkhart 1996, Cain and Shelton 2002). Using a backward elimination procedure ($\alpha = 0.05$), the following were fit with logistic regression (SAS Institute 1990):

$$P_B = \frac{\exp(a_B + bD + cT)}{1 + \exp(a_B + bD + cT)} \quad (1)$$

$$P_C = \frac{\exp(a_C + bD + cT)}{1 + \exp(a_C + bD + cT)} - P_B \quad (2)$$

$$P_R = \frac{\exp(a_R + bD + cT)}{1 + \exp(a_R + bD + cT)} - P_B - P_C \quad (3)$$

$$P_S = 1 - P_B - P_C - P_R \quad (4)$$

where

a_i and P_i = the intercept and probability of the i^{th} damage type (B = stem bending, C = crown damage, R = root sprung, and S = stem breakage)
D = d.b.h. (inches)
T = trees per acre
b and c = fitted coefficients.

If a pine had more than one type of damage, only the most severe injury was used. Stand basal area and plantation age were initially included in the full model but were

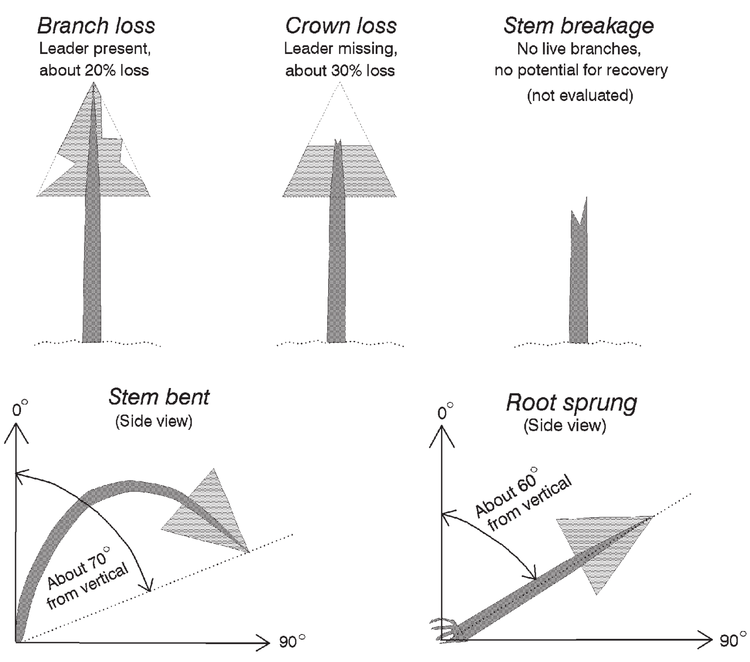

Figure 1—Classes of ice storm damage and measurement technique.

removed from the final equations because their coefficients were not significant.

RESULTS AND DISCUSSION

Stand Conditions

Table 1 contains the summary statistics of the age classes. More than 1,250 loblolly pines ranging from 5 to 13 inches d.b.h. were measured, with 1,125 (90 percent) having some measurable damage. Not surprisingly, the youngest, unthinned plantations had the highest and most variable pine densities, and the oldest (at least twice-thinned) plantations had the lowest and least variable number of stems. Mean pine d.b.h. also increased with stand age, from 5.4 inches in the 11- to 12-year-old plantations to 12.2 inches in the > 28-year-old stands. Basal area declined as the stands matured and were thinned, from an average of almost 105 square feet per acre in the youngest plantation to about 66 square feet per acre in the plantations older than 24 years. These statistics correspond to the loblolly pine plantation management strategy of the corporate landowner in Arkansas, in which plantations are carefully thinned to regulate growth and yield before being clearcut by age 35 years and replanted.

Table 1—Summary statistics of the loblolly pine plantations reported in this study following the December 2000 Arkansas ice storms

	Plantation age class (years)			
Stand attribute[a]	11 – 12	18 – 19	24 – 25	> 28
	trees per acre			
Pine density				
Minimum	330	130	84	68
Maximum	980	370	216	104
Average	640	214	135	81
Standard deviation	185.9	85.3	48.6	11.0
	inches			
Mean pine d.b.h.				
Minimum	5.0	7.5	6.8	11.7
Maximum	5.9	9.6	11.6	13.0
Average	5.4	8.3	9.4	12.2
Standard deviation	0.29	0.63	1.75	0.46
	square feet per acre			
Basal area				
Minimum	52.8	56.7	49.1	60.1
Maximum	142.7	139.8	77.9	82.6
Average	104.8	83.1	64.9	67.3
Standard deviation	29.96	31.75	9.18	6.97

[a] Stand attribute ranges and means are determined from the nine subplots per plantation age class (three subplots per replicate x three replicates). A total of 1,255 loblolly pine trees were measured across all treatments.

Damage Patterns

Loblolly pine plantations of different age and thinning histories experienced significant differences in their response to ice accumulation. The oldest plantations in our study had the trees with lowest levels of damage, while the youngest stands had the highest proportion of injured pines (table 2). Of the pines in the 11- to 12-year-old age classes, < 1 percent escaped the 2000 ice storms with no apparent damage, rising to > 11 percent in the 18- to 19-year-old stands, almost 16 percent by ages 24 to 25 years, and > 40 percent in the > 28-year-old plantations.

The type of damage inflicted on each plantation age class depended on the size of the trees involved. A strong correlation between stand age and diameter was apparent in these managed even-aged stands. Other researchers have noted different types of damage corresponding to tree size; e.g., Burton 1981, Buttrick 1922, Downs 1943, Kuprionis 1970. In natural, even-aged loblolly pine stands, Cain and Shelton (2002) reported more crown damage from an ice storm but less stem breakage than we observed. Assuming no confounding factors like disease, extreme site conditions, or high winds in conjunction with the glazing, variation in damage type was probably a function of bole pliability and crown surface area. Thus, the smallest loblolly pines were much more likely to severely bend when loaded with ice, while those of intermediate sizes experienced both bending and stem breakage, and the largest pines suffered very little bending or breakage (tables 2 and 3). Given the classes in table 2, virtually no statistically significant differences appeared in the extent of damage experienced by pines in the 18- to 19- and 24- to 25-year-old plantations. However, the greater number of smaller diameter pines in the 18- to 19-year-old plantations meant that more pronounced stem bending occurred (tables 2 and 3). These intermediate-sized trees are usually considered the most vulnerable to ice storms because they

Table 2—Comparison of loblolly pine plantation response to glazing from the December 2000 ice storms in central Arkansas

	Plantation age class (years)			
Damage type	11 – 12	18 – 19	24 – 25	> 28
	percent[a]			
Undamaged pines	0.7 a	11.4 b	15.8 b	40.8 c
Pines with branch damage	1.8 a	15.3 b	7.2 ab	37.9 c
Pines with crown damage	11.5 a	11.3 a	11.6 a	17.5 a
Pines with broken boles	1.8 a	14.6 a	8.7 a	3.8 a
Pines with bent boles	87.5 a	60.6 b	62.6 b	0.0 c
Rootsprung pines	2.2 a	1.1 a	4.7 a	0.0 a

[a] Row means with the same letter are not significantly different at $\alpha = 0.05$. Column totals may not sum to 100 percent because multiple damage types were recorded on some trees; e.g., branch loss and bole bending.

Table 3—Distribution of ice damage level by d.b.h. class for branch breakage, bole breakage, and bole bending plus uprooting from the December 2000 Arkansas ice storms

Damage type and level	D.b.h. class (inches)					
	< 7	7 – 10	> 10	< 7	7 – 10	> 10
	- - - - - - *count* - - - - - -			- - - - - *percent* - - - - -		
Branch loss						
Insignificant	7	16	65	70.0	55.2	69.9
Minor	1	12	25	10.0	41.4	26.9
Moderate	2	1	3	20.0	3.4	3.2
Major	0	0	0	0.0	0.0	0.0
Critical	0	0	0	0.0	0.0	0.0
Crown loss						
Insignificant	4	2	15	6.8	4.7	30.6
Minor	14	23	23	23.7	53.5	46.9
Moderate	14	9	4	23.7	20.9	8.2
Major	11	5	5	18.6	11.6	10.2
Critical	16	4	2	27.1	9.3	4.1
Bending/root sprung						
Insignificant	25	36	26	4.4	18.7	32.1
Minor	75	50	38	13.2	25.9	46.9
Moderate	218	48	13	38.4	24.9	16.0
Major	108	21	1	19.0	10.9	1.2
Critical	142	38	3	25.0	19.7	3.7

Insignificant = > 0 to < 10 percent branch or crown loss, > 0 to < 10 degree bend; minor = 10 to 24 percent branch or crown loss, 10 to 19 degree bend; moderate = 25 to 44 percent branch or crown loss, 20 to 39 degree bend; major = 45 to 69 percent branch or crown loss, 40 to 59 degree bend; critical = 70 to 100 percent branch or crown loss, > 60 degree bend, or root sprung.

often do not recover fully from severe bending, and many will experience lethal levels of crown damage and bole breakage (Downs 1943, Kuprionis 1970).

Larger loblolly pines experienced more crown damage and significantly greater branch loss than smaller size classes. Greater resistance to bending or breakage under mechanical loads is observed for larger diameter cantilevered beams (Cannell and Morgan 1989). There appeared to be less uprooting of larger pines in the stands sampled for this study, although at other locations we observed root failure in even bigger trees. Tip-over was uncommon in our study area because of the deep, relatively dry soils and the lack of strong winds associated with this ice storm.

Logistic Damage Models

Fitted coefficients for predicting trees with major or critical damage (see footnote of table 3 for damage class thresholds) can be found in table 4, and the probabilities of a particular type of damage occurring are plotted in figure 2. Even though the models did not explain much of the variance in the data (R^2 = 0.26), model concordance (78.3 percent) and discordance (21.5 percent, with 0.2 percent in ties) were fairly good.

The most prevalent types of major and critical damage were stem bending and breakage. Stem bending was more prevalent in trees with smaller diameters, while stem breakage was more common with the larger trees. An increase in trees per acre caused a slight increase in the probability of stem bending with a concomitant decrease in the probability of stem breakage. The greater number of neighboring trees probably provided support for bending stems, thus preventing individuals from exceeding their failure thresholds.

Pines with major or critical damage had approximately equal probabilities (about 0.15) of having crown damage or being root sprung. These types of damage were most common in trees near the middle of the d.b.h. range, and increases in tree density caused a slight shift in peak probability from smaller to larger trees. In 13- to 18-year-old natural loblolly pine stands, Cain and Shelton (2002)

Table 4—Logistic regression model results to predict glaze injury type in heavily damaged loblolly pine plantations in Arkansas following the December 2000 ice storms

Parameter	Parameter estimate	Standard error of estimate	Wald chi-square	Prob. > chi-square
a_B	2.8197	0.5608	25.3	0.0001
a_C	3.4506	0.5716	36.4	0.0001
a_R	4.0142	0.5843	47.2	0.0001
b	-0.4706	0.0667	49.7	0.0001
c	0.0019	0.0005	13.3	0.0003

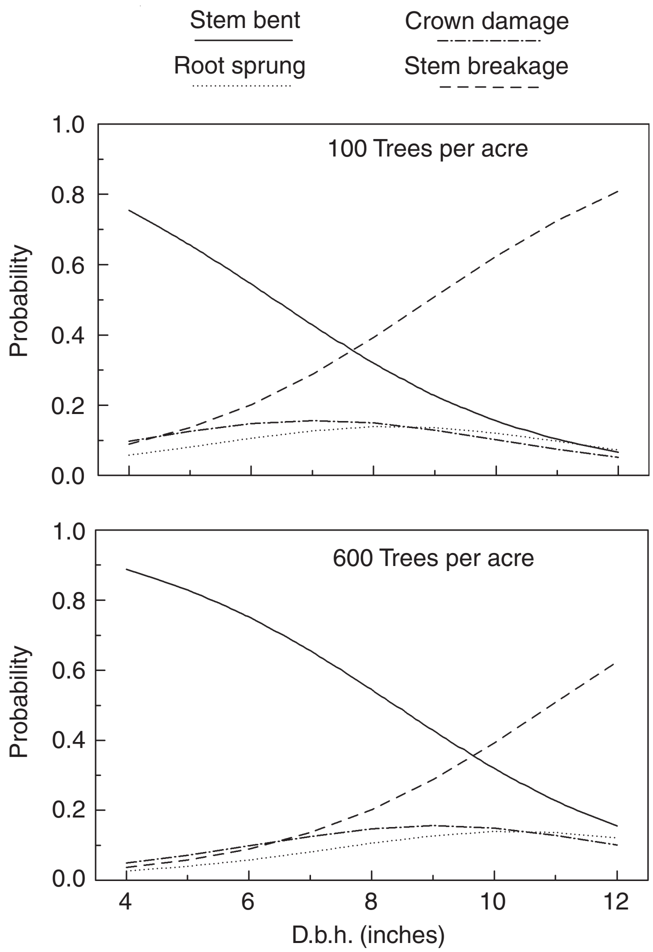

Figure 2—Logistic regression results for ice-damaged loblolly pine plantations in Arkansas, assuming 100 and 600 trees per acre. The curves follow the probability of a tree of a given d.b.h. with major or critical damage classifying into a particular damage type.

similarly found that d.b.h. and stand basal area affected the type of tree damage resulting from an ice storm.

Fourteen percent of the pines with major or critical levels of injury and 10 percent of the root-sprung trees were classified as having damage associated with a neighboring tree. Thirteen percent of the trees with crown damage had forked main stems, compared with 3 percent of the trees with bent stems. Only 1 percent of the trees with major or critical damage was classified as having damage associated with a bole defect, such as cankers from fusiform rust (*Cronartium fusiforme* Hedg. & Hunt).

CONCLUSIONS

As many have reported before, southern pine plantations are susceptible to heavy damage from ice storms. This study provided further confirmation of the relationship between tree size and damage extent and type. Our results support Zeide and Sharer's (2002) assertion that one of the best defenses against glaze damage is to grow trees out of the vulnerable size range as quickly as possible. Determining the appropriate planting density and thinning regime is critical to producing individuals capable of weathering an ice storm.

Combined with other research on glazing, this work also has implications for salvage following severe ice storms. Since a large portion of major or critically injured loblolly pines die within the first growing season (Bragg and others 2002, Kuprionis 1970), salvage efforts should focus on the intermediate-aged stands that suffered the greatest proportion of severe damage. Younger and older plantations probably did not experience sufficient levels of permanent damage to warrant immediate salvage efforts, although some remediation may be needed to minimize fire danger and insect outbreaks.

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