GLAZE DAMAGE IN 13- TO 18-YEAR-OLD, NATURAL, EVEN-AGED STANDS OF LOBLOLLY PINES IN SOUTHEASTERN ARKANSAS

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Abstract—In late December 1998, a severe winter storm deposited 2.1 inches of precipitation on the Crossett Experimental Forest in southeastern Arkansas. Ice, in the form of glaze, accumulated on needles and branches of trees, and resulted in visual damage to sapling and pulpwood-sized pines. Within 60 days after the storm, damage was assessed within naturally regenerated, even-aged stands of loblolly pines (*Pinus taeda* L.) that ranged in age from 13 to 18 years. In all stands, >50 percent of pines were undamaged. When damage occurred in unthinned 13- and 18-year-old stands, pines were mostly affected by bending of the main stem. In thinned 15-year-old stands, damage was mainly in the form of branch loss. Stem breakage most often occurred when pines were 6 to 8 inches d.b.h. The probability of crown loss increased as d.b.h. increased; whereas, the probability of a bent main stem decreased with increasing d.b.h.

INTRODUCTION

Severe ice storms are fairly common in southeastern Arkansas, occurring three times (1974, 1979, and 1994) in 20 years (Guo 1999). During such storms, freezing rain or sleet accumulates as ice on trees. Affected trees can be uprooted, bent, or have their branches and stems broken. When ice storms cause substantial damage to pine stands, future volume production will likely be reduced and hardwoods may gain a competitive advantage over the pines (Halverson and Guldin 1995).

Since the occurrence and severity of ice storms are not predictable, landowners need information on the type and extent of damage that might be expected in their forest stands. The immediate effect of ice damage in loblolly pine (*Pinus taeda* L.) plantations has been extensively reported (McKellar 1942, Brender and Romancier 1960, Shepard 1975 and 1978, Fountain and Burnett 1979), but a literature search revealed no published information derived from natural, even-aged stands of loblolly pine. An ice storm in December 1998 resulted in eye-catching damage and gave the appearance of disaster in 13- to 18-year-old stands of naturally regenerated loblolly pines in southeastern Arkansas. This incident provided an opportunity to quantitatively evaluate the damage caused by ice in young natural pine stands.

METHODS

Study Area

Ice damage assessments were made within six natural, even-aged loblolly pine stands located within a 0.5-mile radius on the Upper Coastal Plain in southeastern Arkansas. Soils are Bude (Glossaquic Fragiudalf) and Providence (Typic Fragiudalf) silt loams with a site index of 85 to 90 feet for loblolly pine at age 50 years (USDA 1979).

Pines in these six stands represented three age classes—13, 15, and 18 years. Although shortleaf pines (*Pinus echinata* Mill.) were present in four of the six stands, their contribution was only 2 percent of total basal area. Each of the six stands contained 5 acres, and they originated on clearcut areas that measured either 660 feet by 330 feet or 1320 feet by 165 feet, with the long axes oriented north to south. Before regenerating naturally, these six areas were occupied by uneven-aged stands of loblolly and shortleaf pines that ranged up to 28 inches d.b.h. with about 100 pines per acre and about 9,000 board feet (Doyle scale) sawlog volume per acre. On four areas, merchantable-sized (>3.5 inches d.b.h.) pines were harvested in spring 1981. On two of these clearcuts, 18-year-old pine stands developed from seeds dispersed before harvest. The other two stands seeded with pines 15 years earlier after mowing a 3-year-old rough of vines, shrubs, and brambles that arose after clearcutting. The two 13-year-old stands developed from seeds dispersed during clearcutting of uneven-aged loblolly and shortleaf pines in autumn 1985.

Stand History

Once regenerated, the two 13-year-old stands and the two 18-year-old stands remained undisturbed until the ice storm of 1998. The two 15-year-old stands were intensively managed by applying herbicides to control competing vegetation for the first 5 years after pine establishment from seed, by precommercial thinning to a residual density of 500 pines per acre at age 5, and by commercial thinning from below at age 14 to leave 200 dominant and codominant pines per acre.

Before the ice storm, pine density and basal area were as follows: 1,222 stems and 124 square feet per acre in the unthinned 13-year-old stands; 200 stems and 79 square feet per acre in the commercially thinned 15-year-old

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stands; 1,192 stems and 173 square feet per acre in the unthinned 18-year-old stands. Mean quadratic d.b.h.'s were 4.3, 8.5, and 5.2 inches for the 13-, 15-, and 18-year-old stands, respectively.

Ice Storm

During 4 days (December 18-21, 1998) before the storm, weather conditions were mild, with high and low temperatures averaging 65° F and 42° F, respectively. During those 4 days, there was an accumulation of 1.2 inches of precipitation. On December 22, the high temperature was 40° F and the low temperature was 27° F. During the next 4 days, high temperatures ranged from 31 to 40° F and the lows ranged from 23 to 27° F. Between December 22 and 27, intermittent precipitation took the form of freezing rain or fine mist with a total accumulation of 2.1 inches. Ice deposits on forest vegetation were not measured, although radial thicknesses of 0.25 to 0.50 inch on pine needles, branches, and stems are not uncommon in this area (Burton 1981). The ice melted on December 27 and 28, when high and low temperatures rose to 49 and 41° F, respectively.

Measurements

Ice damage was assessed in late January through early February 1999. In the 13- and 18-year-old stands, fifty-one 0.01-acre temporary plots were systematically established. In the 15-year-old stand, damage assessments were conducted on 16 permanent 0.1-acre plots. Within these plot boundaries, each pine ≥1.0 inch d.b.h. was evaluated by type and extent of damage. The following damage categories were recognized: branch loss, crown loss, main stem broken, main stem bent, or tree root-sprung (roots loosened and the tree leaned from the base). For this study, branch loss was considered only if branch diameter was > 0.5 inch. The extent of branch and crown loss was estimated to the nearest 10 percent. Crown loss occurred when the central axis or main stem was broken. Branch loss occurred when individual branches were broken, but this category was never > 10 percent. Main stem breakage occurred when crown loss was 100 percent, and the stem broke below the lowest live branch. A root-sprung pine had large lateral roots displaced from the soil. The angle from the stem base to the terminal bud was estimated to the nearest 10 degrees for bent-stem and root-sprung damage categories. Some classes were mutually exclusive by definition: bent stem versus root sprung, and crown loss versus branch loss versus stem breakage. However, root-sprung pines or those with bent stems could also have crown and branch loss, but only two pines were classified as incurring multiple types of damage. Any mitigating circumstances (such as stem defects, forks, or damage caused by a neighboring tree) associated with a pine's damage were also recorded.

Data Analysis

Two plots, one in the 13-year-old stand and one in the 18-year-old stand, contained no pines and were dropped from analyses. To equalize the number of plots assessed for each age, the remaining 50 plots in the 13- and 18-year-old stands were grouped into 16 sets of three and one set of two based on their proximity to each other. Analyses included four severity classes: light (10- or 20-percent loss or degrees), moderate (30 to 50 percent loss or degrees), severe (over 50 percent loss or degrees), and lethal (main stem breakage or root-sprung). Only four trees were root-sprung, and all had tilts of > 60 degrees. Analysis of variance was conducted on the percentage of trees on each plot by damage type and severity class for a completely randomized design with stand age as the treatment variable. Plots were considered as pseudoreplicates (Hurlbert, 1984), which assumes that sampling error would be representative of the experimental error of true replicates. Percentage data were analyzed following arcsine square-root transformation, but only nontransformed percentages are reported. Differences among treatment

Table 1—Type and degree of ice damage in natural, even-aged loblolly pine stands in southeastern Arkansas

Type/degree of ice Damage	----------Stand age in years---------- 13	15	18	Mean Square Error	*P*
	——Percent[a]——				
Type of damage					
None	68.3a[b]	68.1a	53.6b	0.0443	0.04
Branch loss	1.8b	17.8a	0.9b	0.0098	<0.01
Crown loss	9.3a	10.3a	5.8b	0.0145	0.02
Main stem broken	1.1b	1.6ab	5.1a	0.0181	0.04
Main stem bent	19.5b	1.9c	34.2a	0.0517	<0.01
Tree root-sprung	0.0a	0.3a	0.4a	0.0024	0.42
Degree of damage					
None	68.3a	68.1a	53.6b	0.0443	0.04
Light	14.1b	24.4a	14.9b	0.0197	<0.01
Moderate	10.1a	5.0b	16.8a	0.0272	<0.01
Severve	6.4a	0.6b	9.2a	0.0245	<0.01
Lethal	1.1b	1.9ab	5.5a	0.0191	0.04

[a]Percent of all pines that were assessed.
[b]Row means followed by the same letter are not significantly different at the 0.05 level.

means were isolated using the Ryan-Einot-Gabriel-Welsch Multiple Range Test at $\alpha = 0.05$ (SAS Institute, Inc. 1989).

Logistic regression was used to test the effects of tree d.b.h. and plot basal area on the probability of damaged trees having either crown loss, stem breakage, or stem bending (Amateis and Burkhart 1996). This regression equation was based on 303 pines with moderate or severe damage in crown loss, stem breakage, or stem bending, and coefficients were calculated using the SAS procedure LOGISTIC (SAS Institute, Inc. 1989).

RESULTS AND DISCUSSION

The good news for forest landowners was that more than half the pines in these natural stands exhibited no apparent damage from the ice storm (table 1). The 18-year-old stands had a higher ($P = 0.04$) percentage (46.4 percent) of ice-damaged pines than did the 13- or 15-year-old stands. The most common damage category was a bent main stem for the 18-year-old pines (34.2 percent) and for the 13-year-old pines (19.5 percent). For pines in the 15-year-old stands, the greatest damage was branch loss (17.8 percent).

These differences among stands are attributed to the effects of thinning. Pines in the 15-year-old thinned stands were widely spaced with large crowns. Large crowns contributed to limb breakage and branch loss from ice accumulation because of their greater surface area. In contrast, pines in the unthinned 13- and 18-year-old stands were crowded with slender crowns. High pine density plus ice in these latter two stands resulted in a domino effect—as these unthinned pines began to bend from the ice, their neighbors were forced to bend in the same direction because of intertwined crowns. Of all tree and stand characteristics that contributed to ice storm damage (table 2), this neighboring-tree effect was highest ($P < 0.01$) in the 18-year-old stands (32.9 percent) when compared to the other stands. This type of damage was also greater ($P < 0.01$) in the 13- (13.6 percent) versus the 15-year-old stands (0.0 percent). In these natural stands, bole defects (such as cankers from *Cronartium fusiforme* Hedg. & Hunt) and stem forks were minor contributors to subsequent ice damage on trees (table 2).

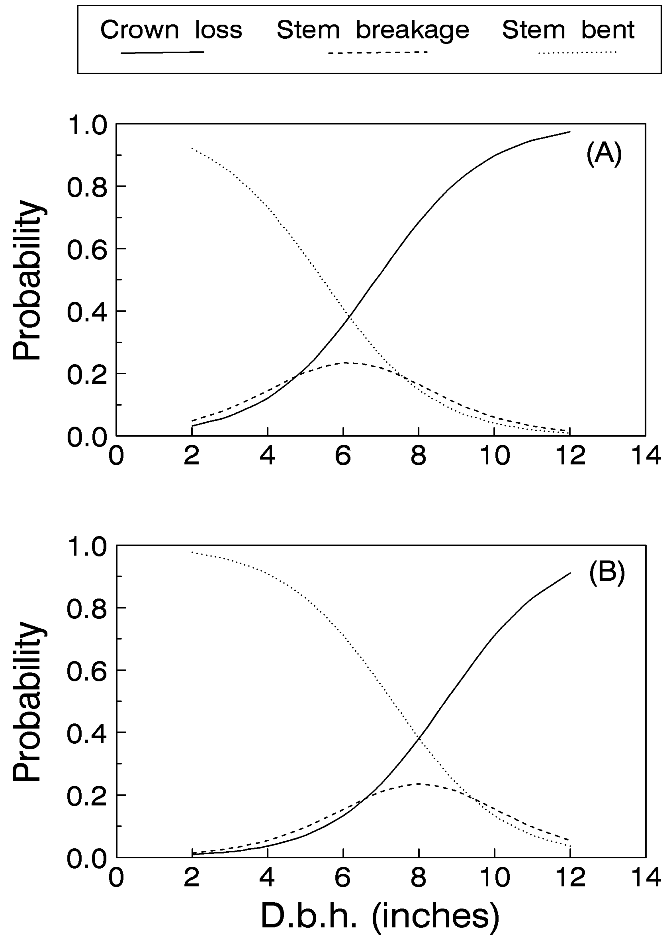

Figure 1—Predicted probabilities for crown loss, stem breakage, and stem bending caused by an ice storm in natural, even-aged loblolly pine stands at two basal-area levels: (A) 80 square feet per acre, (B) 140 square feet per acre. Results are based on 303 pines with moderate or severe damage.

Moderate to severe ice damage was greater ($P < 0.01$) in the 13- (16.5 percent) and 18-year-old (26.0 percent) stands as compared to the 15-year-old (5.6 percent) stands (table 1). Although the degree of damage rated as lethal was < 6 percent of the pines in any stand, Amateis

Table 2—Tree and stand characteristics that contributed to ice damage in natural, even-aged loblolly pine stands in southeastern Arkansas

Tree and stand characteristics	----------Stand age in years-------- 13	15	18	Mean Square Error	*P*
	Percent[a]				
None	85.3b[b]	98.8a	65.6c	0.0620	<0.01
Stem defects	0.6a	0.6a	1.3a	0.0073	0.47
Stem fork	0.5a	0.6a	0.2a	0.0040	0.59
Damage from neighboring pines	13.6b	0.0c	32.9a	0.0597	<0.01

[a]Percent of all pines that were assessed.

[b]Row means followed by the same letter are not significantly different at the 0.05 level.

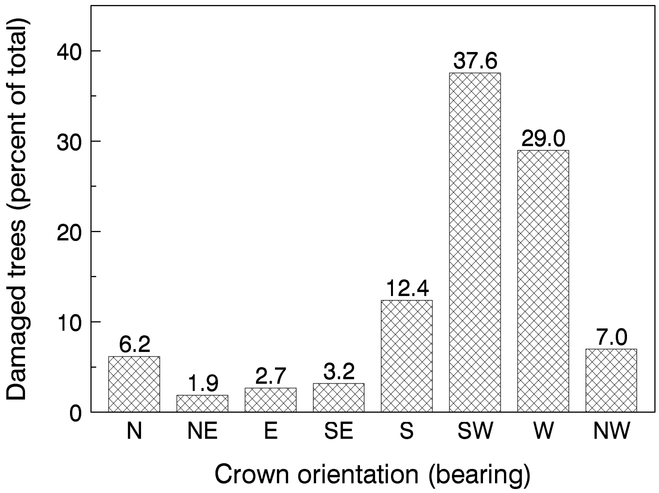

Figure 2—Crown orientation of loblolly pines that were bent, broken, or root-sprung by an ice storm in natural, even-aged stands. Results are based on 372 pines.

and Burkhart (1996) considered glaze damage that was >50 percent on loblolly pines to be so severe that the trees would soon die. Using their criterion in the present study, about 8 percent of ice-damaged pines in the 13-year-old stands and 15 percent in the 18-year-old stands would likely die.

The probability that a damaged tree will have crown loss, stem breakage, or stem bending can be determined from the following series of equations:

$$P_c = \exp(-3.106 + 0.704D - 0.022B) / \{1 + \exp(-3.106 + 0.704D - 0.022B)\} \quad (1)$$

$$P_s = \exp(-2.126 + 0.704D - 0.022B) / \{1 + \exp(-2.126 + 0.704D - 0.022B)\} - P_c \quad (2)$$

$$P_b = 1 - P_c - P_s \quad (3)$$

where P_c, P_s, and P_b are the probability the damaged tree will have crown loss, stem breakage, or stem bending, respectively; D is d.b.h. (inches); B is plot basal area (square feet per acre); and the regression coefficients were determined using logistic regression. All regression coefficients had Wald chi-squares of ≥26 and the probability of a larger value occurring by chance was <0.01 in all cases. The logistic regression had an R-square of 0.38.

These equations were solved for a reasonable range of d.b.h. values and two levels of basal area; the predicted probabilities are illustrated in figure 1. These equations suggest that stem breakage in natural loblolly pine stands under severe ice loading is most likely to occur at a d.b.h. of 6 inches when basal area is 80 square feet per acre or at a d.b.h. of 8 inches when basal area is 140 square feet per acre. Stem breakage is less likely at higher basal areas because the greater number of pines prevents stems from bending to the point of breaking. For both of these moderate to high basal area levels, the probability of crown loss was greater as d.b.h. increased. Conversely, the probability of stem bending declined as d.b.h. increased. These results are similar to those reported by Shepard (1975) in row-thinned loblolly pine plantations that were ice damaged in north Louisiana.

For pines that were bent or leaning as a result of the 1998 ice storm, crown orientation was generally constant. Fully 79 percent of these damaged pines had their crowns oriented in a southerly to westerly direction (figure 2), suggesting that prevailing winds during the storm were from the north and east. Consistency in the direction of lean would facilitate removal of the damaged trees through the use of directional felling.

MANAGEMENT IMPLICATIONS

After an ice storm, forest managers must determine the extent of damaged trees by conducting an inventory. Although merchantability standards vary across the South, about 5 cords of pulpwood or 1,000 board feet (Scribner scale) must be removed per acre to generate a merchantable harvest (Hyman 1985). In the present study, the volume in severely damaged pines >4 inches d.b.h. was estimated to be 0.9, 0.3, and 5.7 cords per acre in the 13-, 15-, and 18-year-old stands, respectively. Consequently, only pines in the 18-year-old stand were marked for a combination salvage and improvement thinning.

Merchantability of damaged trees may be of less importance than preventing an insect infestation. According to Hyman (1985), the greatest hazard to ice-damaged pine stands is the threat of southern pine beetles (*Dendroctonus frontalis* Zimm.). That threat is compounded by the fact that pine stands with basal areas in excess of 100 square feet per acre are highly susceptible to bark beetle infestation (Hicks 1981). In this study, basal area for the unthinned stands averaged 150 square feet per acre, thereby posing an increased risk of infestation to the remaining timber unless salvaged.

Pines in the 15-year-old thinned stands had larger mean diameters and suffered less bending but more branch loss from the ice storm than the higher density pines in the unthinned 13- or 18-year-old stands. These results suggest that early thinning in natural loblolly pine stands is advantageous by not only improving diameter growth but also by reducing the potential of catastrophic loss from periodic ice storms. Natural disturbances such as tornadoes, hurricanes, and ice storms often cause a drop in stumpage prices because of an overabundant supply of salvaged timber. But when forest landowners schedule thinnings outside the parameters of these natural disasters, they are able to take advantage of higher stumpage prices and reduce their probability of loss.

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