Ice Damage in Thinned and Nonthinned Loblolly Pine Plantations Infected with Fusiform Rust

R.P. Belanger *(retired), USDA Forest Service, Southeastern Forest Experiment Station, Athens, GA 30602;* **J.F. Godbee,** *Union Camp Corporation, Savannah, GA 31402;* **R.L. Anderson,** *USDA Forest Service, Region 8, Asheville, NC 28804; and* **J.T. Paul,** *SCITRAN, Inc., Gray, GA 31032.*

ABSTRACT. *Portions of two loblolly pine (*Pinus taeda *L.) plantations in central Georgia were thinned in 1982 to remove trees with severe fusiform rust infections on the main stem. In January 1983, a widespread ice storm damaged both plantations. Stem breakage and storm-related mortality were greater in thinned than in nonthinned portions of the plantations. There was a weak association between the occurrence of stem breakage and location of rust infections. Tree-ring chronologies show that trees with the greatest potential for stem growth are also most susceptible to ice damage. Significant losses in the diameter and basal area growth of damaged trees occurred during the first year after the storm. The stem growth of trees with severe crown damage did not totally recover during the 5-yr period following the storm. The demands for restoring crown components in damaged trees appear to take precedence over lower stem growth. Findings are related to storm conditions, tree and stand characteristics, and management practices. South. J. Appl. For. 20(3):136–140.*

Ice storms occur frequently across portions of the Southern United States. The accumulation of ice on trees can cause stem and branch breakage and tree bending and uprooting. Mortality and injury can range from slight to severe, depending on stand structure, tree species, local topography, and weather conditions. The risk of mortality resulting from stem breakage below the crown is greatest in thinned stands (Brender and Romancier 1965, Belanger and Brender 1968, Shepard 1978). Trees with little stem taper are most susceptible to breakage (Petty and Worrell 1981). Stem breakage within the crown is the most common type of damage in densely grown stands. It is relatively easy to assess the immediate impact of tree mortality on stand structure and volume loss. For damaged trees, however, the relationships between the extent of damage and subsequent growth, recovery, or mortality are unknown.

Van Lear and Saucier (1973) reported that stem breakage often occurs at stem galls caused by fusiform rust (*Cronartium quercuum* [Beck.] Miyabe ex Shirai F. Sp. *fusiforme*). In a study of comparative glaze damage in adjacent stands of slash pine (*Pinus elliottii* Engelm. var. *elliottii*) and longleaf pine (*Pinus palustris* Mill.), fusiform rust was associated with about 52% of main stem breakage in the longleaf stand. About 32% of the broken slash pines had an infection where main stem breakage occurred. Relationships between fusiform rust and stem breakage during ice storms have not been reported for loblolly pine.

In January 1983, a severe ice storm swept across central Georgia (Figure 1). Two pulpwood-size loblolly pine plantations that were part of a regional thinning study on fusiform rust sustained different levels of ice damage. Measurements taken before and after the storm provided the information needed to (1) determine the extent and types of tree breakage and storm-related mortality that occurred in the thinned and nonthinned portions of the two plantations, (2) examine relationships between stem breakage and fusiform rust galls, and (3) measure the growth, recovery, or mortality of trees with varying degrees of crown breakage. Findings are discussed in reference to historical weather conditions associated with ice storms in the Piedmont region of the southeastern United States.

Materials and Methods

The two study plantations are located in Glascock County (Plantation G) and Washington County (Plantation W), Georgia. They were selected as part of a southwide project to evaluate the selective thinning of merchantable loblolly and

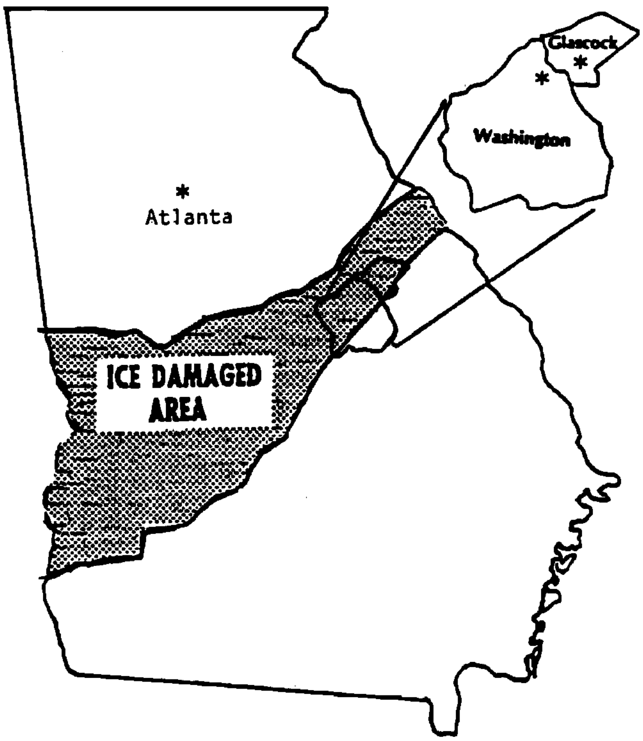

Figure 1. A widespread ice storm occurred in Central Georgia in January 1983. Asterisks indicate location of Plantation G in Glascock County and Plantation W in Washington County.

slash pine plantations severely infected with fusiform rust (Belanger et al. 1985). Plantation G, 170 ac in size, was planted in 1964; plantation W, 130 ac in size, was planted in 1961. A portion of each plantation was selected for thinning; the remaining portion was not thinned. Four 1/4 ac permanent plots were established in the thinned and nonthinned portions of each plantation. In the summer of 1982, all trees in the study plots were numbered, examined for rust, and stem diameters measured at breast height. Twenty percent of the study trees were subsampled to determine total height and length of the live crown. Plantation G and Plantation W were 19 and 22 yr old, respectively, when selectively thinned during the fall and early winter of 1982.

The ice storm occurred in January 1983. A heavy accumulation of ice remained on the trees for approximately 2 days. Trees on the study plots were remeasured and assessed for mortality and injury within a month after the storm. Each tree was examined to determine if the accumulation of ice had caused stem breakage below the crown (main stem), stem breakage within the crown (top breakage), branch breakage, severe tree bending, or uprooting. Trees were also examined to determine if stem breakage was associated with fusiform rust galls.

Storm-related mortality was surveyed annually for 5 yr after the storm. The study plots were remeasured in January 1988 to determine the impact of storm damage on diameter growth, crown response, and stand structure. A subsample of 108 damaged and nondamaged trees was selected from the nonthinned plots to examine relationships among injury, tree growth, and recovery. Damaged and nondamaged trees were paired based on comparable 1983 stem diameters (± 0.1 in.), crown class (dominant or codominant), and stem gall characteristics. The selection of sample trees to establish tree-ring chronologies was restricted to nonthinned study plots since growth in the treated plots would likely be confounded by response to thinning. Each pair of sample trees was restricted to the same 1/4 ac study plot to minimize variation in stand and site conditions.

Diameter at breast height, total tree height, length of the live crown, and crown class were measured for all paired trees; height of stem breakage was an additional measurement taken for damaged trees. Two increment cores were extracted from each tree at dbh, labeled, and refrigerated until measured with a dendrochronometer. Each core was crossdated to ensure a similar time sequence in ring patterns for each tree. Comparison of damaged and nondamaged trees was based on annual and periodic basal area growth 5 yr before and 5 yr after the ice storm. Paired t-tests (SAS 1986) were used to analyze differences in growth between damaged and nondamaged trees.

Archival weather data and estimates of temperature, relative humidity, wind speed, and wind direction relevant to the storm were made using hourly observations taken at National Oceanic and Atmospheric Administration climatological stations in Augusta, Athens, and Macon, Georgia. Estimates of total precipitation were made from daily measures of frozen, freezing, and liquid rainfall taken at stations in Warrenton and Sandersville, Georgia.

Stand Conditions Prior to the Storm

Average tree, stand, and fusiform rust conditions of thinned and nonthinned portions of the plantations are summarized in Table 1. Prior to thinning, there were no statistical differences in tree and stand characteristics between the two plantations. Major differences between the plantations were in incidence and severity of fusiform rust infections. Average number of infected stems, rust incidence, and the degree of stem girdling were higher in Plantation G than in Plantation W. Thinning was based on the severity and location of stem galls (Belanger et al. 1991). Consequently, levels of thinning were different in the two plantations.

Moderate thinning removed an average of 203 trees/ac from the study plots in Plantation G, leaving a residual basal area of 81 ft^2/ac. By comparison, in Plantation W, lighter thinning removed an average of 121 trees/ac, leaving a residual basal area of 117 ft^2/ac. Average spacing after thinning was approximately 12 × 12 ft in Plantation G compared to 10 × 10 ft in Plantation W. Stand density in the nonthinned portions of the two plantations was similar, with an average of 518 trees/ac in Plantation G and 508 trees/ac in Plantation W. Average spacing in the nonthinned study plots was approximately 9 × 9 ft.

Ninety-four percent of the trees removed from the two plantations had fusiform rust galls on the main stem. Thinning lowered both the incidence and severity of rust galls. However, incidence and percentage of stem girdling by rust were still greater in Plantation G than Plantation W. In the nonthinned study plots, number of infected stems per acre, rust incidence, and amounts of stem girdling

Table 1 Average tree, stand, and fusiform rust characteristics of thinned and nonthinned portions of two loblolly pine plantations before and after treatment.

Variable	Unit	Plantation G			Plantation W		
		Thinned			Thinned		
		Before	After	Nonthinned	Before	After	Nonthinned
Tree							
Dbh	in.	6.7	6.9	6.6	6.7	6.9	7.0
Height	ft	46	46	48	50	50	54
Stand							
Density	trees/ac	497	294	518	552	431	508
Basal area	ft^2/ac	128	81	129	144	117	143
Fusiform rust							
Stems infected	trees/ac	341	154	358	306	189	293
Rust incidence[1]	percent	69	52	69	55	44	57
Stem girdled[2]	percent	67	56	63	59	48	56

1 Rust incidence = number of trees/acre with stem infections/number of trees/acre
2 Stem girdled = proportion of stem circumference affected by the most severe rust gall.

caused by rust were also greater in Plantation G than Plantation W.

Characteristcs of the Ice Storm

Localized weather conditions relevant to the storm at the two study locations are summarized in Table 2. Archival weather data show that severe ice storms have a probable recurrence interval of 20 yr in central Georgia. The storm on January 20–21, 1983, was an "average event"—mean temperature, relative humidity, windspeeds, and wind direction are all near the long-term average (Table 3) for ice storms.

Average temperatures throughout the duration of the storm were 32°F at Plantation G and 33°F at Plantation W. These small differences in temperature may be related to the geographic location of the two plantations. Plantation G was located about 19 miles north of Plantation W. Historically, freezing precipitation in middle Georgia has occurred within a narrow temperature band centered near 31°F with a few occurrences up to 35°F and more frequent occurrences below 32°F with a minimum observed temperature of 22°F.

There was little difference in relative humidity at the two sites during the ice storm: 88% at Plantation G and 89% at Plantation W. Relative humidity during freezing precipitation is lower than commonly observed for nonfreezing precipitation with an average close to 90%. This is reasonable since freezing precipitation occurs when a cold dry surface air mass is overrun by warmer moist air aloft. The precipitation forms at upper levels and falls through the dry cold air Rain or drizzle freezes on impact to form a coating of glaze upon the ground and on exposed objects (Geiger 1965).

Windspeeds averaged 10 mph at both sites with occasional gusts of over 20 mph occurring over 10 and 12 hr time periods. Historically, windspeeds during ice storms averaged 9.6 mph with frequent gusts being the norm and extended periods of calm being the exception. Relative degrees of stand disturbance are obvious since the higher the windspeed, the greater the potential for damage of ice covered trees.

The predominant wind direction during the January 1983 ice storm was from the northeast. Records of previous ice storms show wind direction is usually from the northeastern quadrant, occasionally from the southeast and northwest quadrants, and rarely from the southwest quadrant. This fits a commonly observed wind pattern where cold air is advected into the state

Table 2. Summary of localized weather conditions for two loblolly pine plantations damaged by an ice storm occurring January 20–21, 1983.[1]

Variable	Plantation G[2]	Plantation W[2]
Average temperature	32°F	33°F
Average relative humidity	88%	89%
Time of first freezing precip.	Jan. 20, 11:00PM	Jan. 20, 11:00PM
Time of last freezing precip-ended	Jan. 21, 9:00AM	Jan. 21, 8:00AM
Duration of freezing precip.	10 hr	9 hr
Total precip. (frozen, freezing, liquid)[3]	1.90 in.	1.38 in.
Average windspeed	10 mph	10 mph
Hours of gust over 20 mph	12 hr	10 hr
Predominant wind direction	NE	NE

1 The data in this table (except for total precipitation) were estimated using hourly observations at Augusta, Athens, and Macon, Georgia, and North America surface maps.
2 Plantation G is located about 19 miles north of Plantation W.
3 From National Oceanic and Atmospheric Administration daily precipitation observations at Warrenton and Sandersville, Georgia.

Table 3 Historical weather conditions during ice storms occurring in middle Georgia:1948–1986.

Variable	Average	Min.	Max
Temperature (°F)	30.6	22.0	35.0
Relative humidity (%)	89.6	53.0	100.0
Duration freezing precip. (hr)	7.0	1.0	20.0
Windspeed (mph)	9.6	0.0	22.0

Frequency of wind direction			
NE	SE	SW	NW
Percent			
85	6	1	8

[1] Data based on hourly data from Augusta, GA (1949–1986), Athens, GA (1956–1986), and Macon, GA (1948–1986).

behind a cold front. Frontal systems that pass through the piedmont frequently becomes stationary in an east-west orientation somewhere on the Florida peninsula. The cold air behind (north of) the front is organized as a system of high pressure with clockwise circulation. If the center of the high is located to the north of the piedmont, this will usually produce a surface wind in the northeast quadrant.

Freezing precipitation in Georgia typically occurs in an approximate 100 mile band oriented west to east or southwest to northeast, bounded on the south by a broad area of liquid precipitation, and on the north by a broad area of solid precipitation or no precipitation. Local conditions can influence the occurrence of freezing precipitation, and it is not unusual to find significant changes within a quarter of a mile on the southern boundary. Going north to south, these changes may first be seen as freezing rains fairly uniformly distributed on the entire tree and surface objects, than changing to an occurrence of glaze only on the tree tops, and finally into a zone of no freezing precipitation. Again, the differences in geographic location may explain the longer duration and greater amount of freezing precipitation at Plantation G and Plantation W. The differences in ice load may partially explain the different amounts of tree damage that occurred in the two plantations.

Results

Storm Damage

Total ice damage and storm-related mortality from 1983 through 1987 were more severe in Plantation G than Plantation W (Table 4). Stem breakage within the crown accounted for more than half of the damage in the two plantations. Top breakage was greatest in the nonthinned portion of Plantation G, accounting for 71% of the damaged trees.

Stem breakage below the crown was greater in thinned portions of the plantations than in the nonthinned areas. The most severe damage occurred in Plantation G. Open stands are obviously more susceptible to damage as ice forms on the crown, followed by tree bending and eventual stem breakage. The treated portion of Plantation G was thinned heavily in 1982 and had a low number of residual stems when the storm occurred. The average spacing between trees in thinned plots was 12.1 feet compared to 9.2 feet in nonthinned plots.

Analyses of the initial 1982 inventory data showed no statistical differences in the average dbh, stem taper, or rust incidence of trees damaged or not damaged by the storm (Table 5). In Plantation G, the average height of damaged trees prior to the storm (48.2 ft) was significantly greater ($P = 0.05$) than for undamaged trees (46.9 ft). The crowns of taller trees may have a larger surface area, therefore, subject to greater ice load and more bending than shorter trees.

The cumulative frequency distributions of rust galls and points of stem breakage are illustrated in Figure 2. The majority of all stem galls (93%) was on the lower 30 ft of the stem but only 18% of total stem breakage occurred in this lower stem area. There was a weak association between points of stem breakage and locations of rust galls. On the lower bole, 26% of the breakage occurred at the point of rust infections. Less than 1% of top breakage was directly associated with rust galls. Top breakage occurred mostly in the mid-crown area. The profiles show the average height of top breakage in thinned portions of the plantations was lower on the stem than in unthinned plots.

Table 4. Ice damage and mortality in thinned and nonthinned portions of two loblolly pine plantations following an ice storm in January 1983.

	Plantation G		Plantation W	
Impact	Thinned	Nonthinned	Thinned	Nonthinned
	No. trees/ac			
Damage				
Stem breakage				
Below crown	46	18	16	5
Within crown	87	119	33	26
Broken branches	20	26	18	9
Bending	12	5	4	3
Total	165	168	71	43
Storm-related mortality				
1983	48	18	16	5
1984–1987[1]	—	11	1	4
Total	48	29	23	9

[1] Because of severe stem breakage and mortality, the thinned portion of Plantation G was harvested and replanted in spring 1984.

Table 5. Characteristics of trees damaged or not damaged by an ice storm in two loblolly pine plantations.

Tree characteristics	Unit	Plantation G		Plantation W	
		Damaged	Nondamaged	Damaged	Nondamaged
Dbh	in.	6.8	6.6	6.8	6.9
Height	ft	48.2	46.9*	51.5	51.4
Stem taper	dbh/ht	1.85	1.85	1.91	1.89
Rust incidence	percent	64	72	54	57

[1] Average values based on inventories taken in 1982 prior to ice storm in January 1983.
[2] Significant at 0.05 probability level. All other comparisons among plantations were nonsignificant.

Impact on Tree Growth in Nonthinned Plots

Comparisons between paired damaged and nondamaged trees showed that trees with the greatest potential for diameter and related basal area growth are also most susceptible to ice damage (Figure 3). During the 5-yr period prior to the ice storm (1978–1982) annual and periodic radial growth at breast height were significantly greater (P = 0.01) for trees damaged by ice in 1983 than for nondamaged trees. Periodic basal area growth during this 5-yr prestorm period was 8.61 square in. for trees eventually damaged by ice compared to 6.94 square in. for nondamaged trees.

Marked reductions in the radial growth of damaged trees occurred the first year after the storm. The proportional reduction in radial growth between 1982 and 1983 was significantly (P = 0.01) greater for damaged trees than for nondamaged trees—47% and 16%, respectively. The radial and basal area growth of damaged trees remained slow through 1987. Annual and periodic radial and basal area growth were consistently and significantly (P = 0.05) less for trees damaged by ice than for nondamaged trees. Ice damage caused a total reduction in basal area growth of approximately 37% during the poststorm study period.

All paired trees classified as codominant in 1982 were examined to determine relationships between degree of damage and changes in radial growth (Figure 4). Damaged trees classified as suppressed in the 1988 inventory had the fastest rates of annual growth prior to the storm and the most severe growth reductions after the storm. Stem breakage for these trees occurred at an average height of 39 ft, an initial loss of effective top crown totaling 11 ft. Radial growth continued to decline after stem breakage. Reductions in annual radial growth were less severe for damaged trees that maintained a codominant position in the canopy after the storm. Average stem breakage occurred at 43 feet for these trees. Average loss of effective top crown was only 7 ft with annual radial growth remaining fairly constant following damage. Before the storm, the relative radial growth of codominant trees subsequently damaged by ice was significantly more (P = 0.01) than nondamaged trees. Conversely, after the storm trees that sustained severe damage trees grew significantly less (P = 0.01) than nondamaged trees.

Slow stem growth of damaged trees is attributed to an immediate response in crown development. Following the ice storm, the average 5 yr height growth of damaged trees from 1983 through 1987 was 15.6 ft compared to 11.4 ft for nondamaged trees. Results indicate that the demands of foliage and branch development take precedence over stem

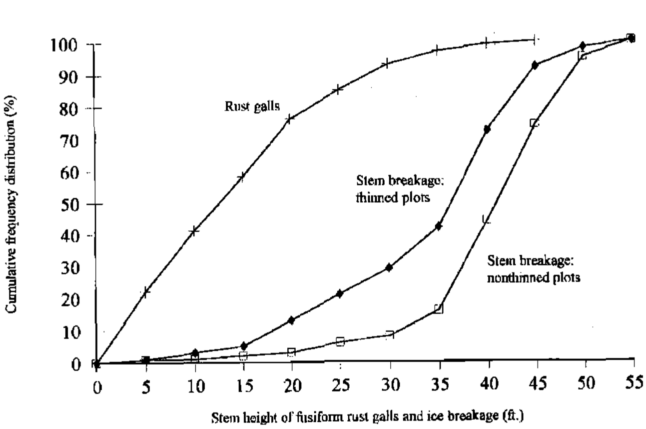

Figure 2. The cumulative frequency distribution of the height of stem breakage and location of fusiform rust galls in thinned and nonthinned portions of two loblolly pine plantations damaged by an ice storm.

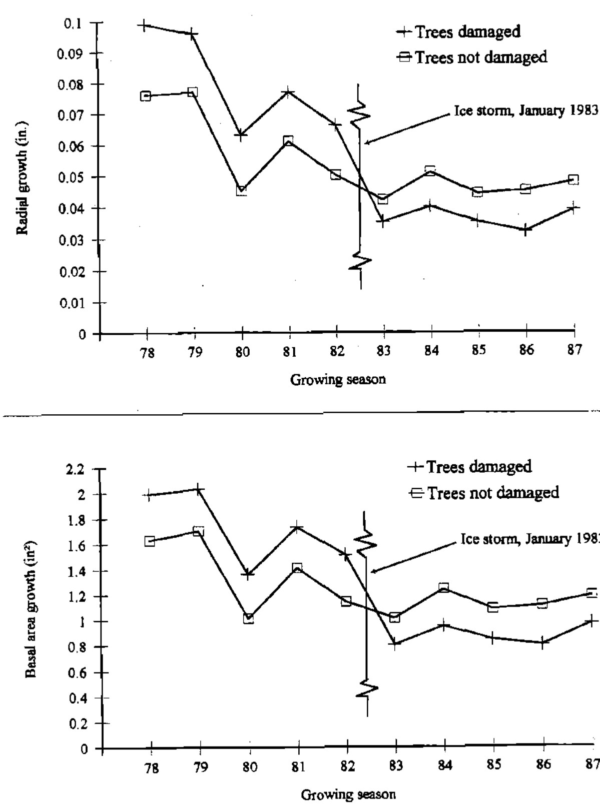

Figure 3. Average radial growth (top) and basal area increment (bottom) of damaged and nondamaged loblolly pine trees before and following a severe ice storm.

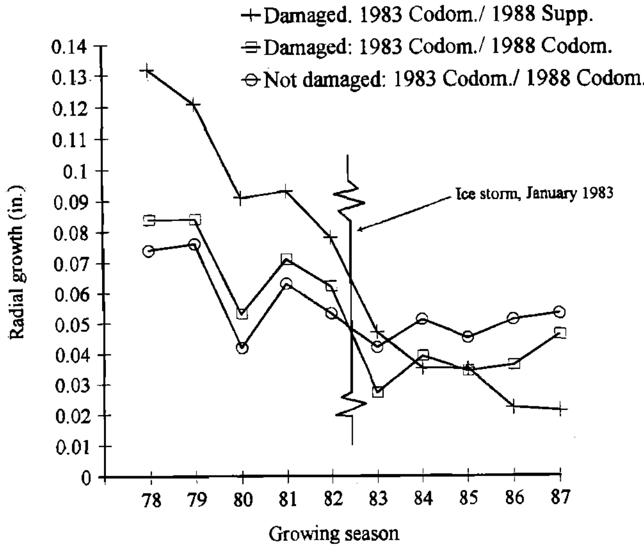

Figure 4. Crown position influenced the average radial growth of damaged and nondamaged loblolly pine trees following an ice storm.

growth. Findings are in accordance with the proposal by Waring and Pitman (1985) that the first-order hierarchy for normal carbon allocation in a tree is photosynthetic tissue represented by buds and new foliage. The accelerated crown development of damaged trees appears strongly related to tree survival. Only 12% of the trees that sustained top breakage died during the 5-yr study period.

Discussion

Thinning is a silvicultural practice widely used to benefit several forest management objectives in the South. Damage caused by ice storms can offset these gains. The impact of ice damage in merchantable loblolly pine plantations is closely related to the choice and intensity of management practices. In this study, total mortality and top breakage were greatest in thinned plots, whereas the least mortality and top damage control occurred in nonthinned areas. Portions of the stands severely damaged by ice will never fully recover.

Results showed little association between ice breakage and the occurrence of fusiform rust galls on loblolly pine. The majority of rust infections was located in the lower portion of the main stem, whereas most of the ice breakage occurred in the upper portions of the tree. Low windspeeds may partially account for the little association between breakage and rust galls. In this study, the average percentage of severe girdling in diseased trees was 54%. Wenger (1950) reported that a maximum wind speed of 25 mph is required before breakage is likely to occur in trees with 55% of the stem girdled. Average wind speed during the 11 hr storm period was 10 mph, and only occasionally did wind gusts exceed 20 mph. The dense and uniform crown canopies of the two plantations may have dissipated windspeeds within the stands even more (Fons 1940). It appears most of the breakage resulted from vertical forces on the stem caused by ice load on the crown and not from wind forces exerted against the crown surface.

The growth of individual trees following the ice storm was strongly dependent on the loss of effective crown and subsequent crown position in the canopy. Radial growth was significantly reduced in dominant and codominant trees that sustained severe crown damage and reclassified as intermediate or suppressed after the storm. The crowns of adjacent trees not damaged by ice expanded quickly to fill gaps in the upper canopy caused by breakage. These undamaged trees should continue to grow rapidly and can be retained as future crop trees for a sawlog rotation. Competition and suppression of damaged trees contributed to a constant decline in stem growth and an increase in the potential for mortality. Trees with little crown damage experienced small growth reductions that nonetheless, remained below the level of nondamaged trees. It is not known if these trees will ever fully recover. Equating growth loss to foliage loss is an oversimplification. Impact is more closely related to the total complex of tree characteristics, stand structure, and crown architecture.

Historical records show that hours of freezing precipitation required for a substantial accumulation of ice occur about every 20 yr in middle Georgia. This indicates that during normal rotations—approximately 25 yr for pulpwood; 35+ yr for sawtimber—any stand has a high possibility of a damaging ice storm. Stand growth, yield, and structure are influenced by the timing, frequency, and severity of storms. In this study, findings and conclusions are based on a single ice storm that occurred soon after thinning. Lower stem breakage and tree mortality would likely be less severe had the storm occurred several years after thinning and the crown canopy had partially or completely closed. Conversely, individual tree crowns would be larger, subject to heavy ice loads, and more susceptible to top and limb breakage. Multiple storms would obviously compound losses. A point of importance is that tree-ring chronologies have shown that damaged trees are more sensitive to environmental stresses than nondamaged trees (Travis et al.. 1990). For that reason, visual evidence of ice damage is being assessed as part of classification systems being used to monitor the health of southern pines.

Within the ice belt, land managers should consider the risks associated with winter storms when developing thinning prescriptions. Should an ice storm occur shortly after treatment, stands that have been thinned heavily are highly susceptible to mortality from stem breakage and growth losses from top breakage. Findings confirm the general conclusion that thinnings increase the potential for storm damage unless they are light, frequent, and occur early in the life of the stand (Hawley and Smith 1954, Williston 1974). Results in this study are based on an "average" ice storm that occurred in two plantations soon after moderate to light thinnings. The recent 1994 ice storms that occurred in Arkansas and Mississippi with devastating ice loads may well be impossible to manage for. However, climatological records indicate that such devastating storms are most unusual. Consequently, in areas subject to winter storms, silvicultural practices should be prescribed that minimize, as much as possible and practical, tree and stand disturbances caused by ice damage.

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