Radial growth of hardwoods following the 1998 ice storm in New Hampshire and Maine

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Abstract: Ice storms and resulting injury to tree crowns occur frequently in North America. Reaction of land managers to injury caused by the regional ice storm of January 1998 had the potential to accelerate the harvesting of northern hardwoods due to concern about the future loss of wood production by injured trees. To assess the effect of this storm on radial stem growth, increment cores were collected from northern hardwood trees categorized by crown injury classes. For a total of 347 surviving canopy dominant and subdominant trees, a radial growth index was calculated (mean annual increment for 1998–2000 divided by the mean annual increment for 1995–1997). Sugar maple (*Acer saccharum* Marsh.), yellow birch (*Betula alleghaniensis* Britt.), white ash (*Fraxinus americana* L.), and red maple (*Acer rubrum* L.) categorized in injury class A (crown loss of less than one-half) had mean growth index values of approximately 1.0, indicating no loss of mean radial growth after 3 years. For injury class B (crown loss of one-half to three-quarters) and class C (crown loss greater than three-quarters), growth index values significantly decreased for sugar maple, yellow birch, and red maple. For white ash, growth index values of classes B and C were not significantly different from those of class A trees. Growth index values of *A. saccharum* and *A. rubrum* in injury class C were the lowest of those measured. These results indicated that the severity of growth loss due to crown injury depends on tree species and crown replacement as well as the extent of crown loss.

Résumé : Les tempêtes de verglas et les blessures qui en résultent dans la cime des arbres surviennent fréquemment en Amérique du Nord. La réaction des aménagistes aux dommages causés par la tempête de verglas survenue dans la région en janvier 1998 risquait d'accélérer la récolte des feuillus nordiques à cause des pertes futures appréhendées de matière ligneuse chez les arbres endommagés. Pour évaluer l'effet de cette tempête sur la croissance radiale de la tige, des carottes ont été prélevées sur des feuillus nordiques regroupés par classes de dommages dans la cime. Un indice de croissance radiale (accroissement annuel moyen de 1998 à 2000 divisé par l'accroissement annuel moyen de 1995 à 1997) a été calculé pour un total de 347 arbres dominants et codominants qui avaient survécu. Les tiges d'érable à sucre (*Acer saccharum* Marsh.), de bouleau jaune (*Betula alleghaniensis* Britt.), de frêne blanc (*Fraxinus americana* L.) et d'érable rouge (*Acer rubrum* L.) regroupées dans la classe de dommages A (perte de cime inférieure à la moitié) avaient des valeurs moyennes d'indice de croissance d'approximativement 1,0, une indication qu'il n'y avait pas de diminution de la croissance radiale moyenne après trois ans. Dans les classes de dommages B (perte de cime de la moitié à trois quarts) et C (perte de cime supérieure à trois quarts), la diminution des valeurs d'indice de croissance était significative chez l'érable à sucre, le bouleau jaune et l'érable rouge. Dans le cas du frêne blanc, les valeurs d'indice de croissance des classes B et C n'étaient pas significativement différentes de celles des arbres de la classe A. Les valeurs d'indice de croissance de l'érable à sucre et de l'érable rouge dans la classe de dommages C étaient les plus faibles parmi celles qui ont été mesurées. Ces résultats indiquent que la sévérité de la perte de croissance due aux dommages à la cime dépend de l'espèce d'arbre et du remplacement de la cime aussi bien que de l'envergure de la perte de cime.

[Traduit par la Rédaction]

Introduction

Ice storms are a frequent disturbance agent throughout North America (Irland 2000). Under suitable meteorological and topographic conditions, tree stems and branches become coated with ice. Tree crowns are injured when the added weight of ice exceeds the threshold for breaking stress of stems and branches (Cannell and Morgan 1989). Ice storms and resulting injury occur annually but are usually limited in geographic extent and strongly localized with respect to elevation and directional exposure.

In January 1998, parts of eastern Canada and the northeastern United States were struck by a series of ice storms of unusual scope and magnitude (Irland 1998; Lautenschlager and Nielsen 1999). Severe injury to trees occurred in discontinuous patches across the impacted region, with hardwood species being the most affected (Miller-Weeks and Eagar 1999). After the 1998 ice storm, foresters and wood utilization professionals became concerned about the effects of crown injury on wood production. Accelerated timber harvesting based on this concern threatened to oversupply processing capacity and markets for hardwood products.

Previous research in southwestern Virginia found that the greatest severity of injury occurred on steep, east-facing slopes

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Table 1. Numbers of dominant and codominant trees analyzed for each species and crown injury class.

	Crown injury class		
Species	A	B	C
Sugar maple	60	41	26
Yellow birch	42	37	29
White ash	18	18	24
Red maple	24	16	12

and that Virginia pine (*Pinus virginiana* Mill.) and pitch pine (*Pinus rigida* Mill.) were most susceptible to injury (Mou and Warrillow 2000). Research on urban trees in Rochester, New York, found that the severity of injury increased with increased tree size and with particular forms of crown architecture such as a horizontal branching pattern (Sissini et al. 1995). The effect of species and crown architecture indicates that constitutive features contribute to reduced tree injury from ice storms. These features are analogous to constitutive features that confer other types of protection such as wood extractives that contribute to decay resistance (Loehle 1988), foliar chemicals that defend against herbivory (Herms and Mattson 1992), and thick bark that reduces injury from fire exposure (Jackson et al. 1999).

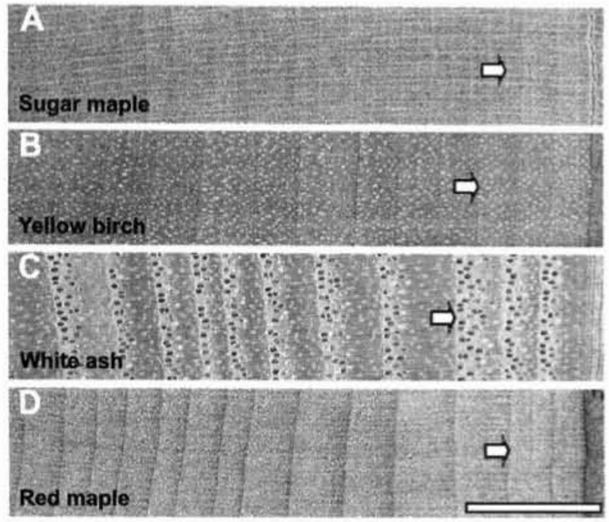
Radial ring width at breast height is a commonly used measure for tree growth. Ring widths vary within and among individual trees in response to changes in physical condition, maturation, soil fertility, climate, and stand dynamics. Changes in ring width due to ice injury of southern pines has been described (Belanger et al. 1996; Travis and Meentemeyer 1991). Ring width patterns or signatures have been proposed to aid development of ice storm chronologies from tree ring series, in the absence of other records of storm events (Lafon and Speer 2002). Although recent ice storms have been extensively surveyed (Miller-Weeks and Eagar 1999; Lafon et al. 1999), the relationship of tree growth to the intensity of crown injury has not been previously described.

In this article, we assess the relationship of annual radial increment of sugar maple (*Acer saccharum* Marsh.), yellow birch (*Betula alleghaniensis* Britt.), white ash (*Fraxinus americana* L.), and red maple (*Acer rubrum* L.) to crown injury attributable to the 1998 regional ice storm in New Hampshire and Maine.

Materials and methods

Northern hardwood trees were selected in New Hampshire and Maine during September and October of 1998 to assess the effects of crown injury on radial growth. A total of 347 surviving dominant or codominant trees (23–46 cm diameter at breast height) within the area of storm injury (Irland 1998; Miller-Weeks and Eagar 1999) were selected on the basis of accessibility, tree species, and visual crown loss due to branch or stem breakage (Table 1). Selected trees included 127 sugar maple, 108 yellow birch, 60 white ash, and 52 red maple. Trees were categorized by crown injury classes: class A (crown loss of less than one-half), class B (crown loss of one-half to three-quarters), and class C (crown loss of more than three-quarters). Because of adventitious sprouting in later years, the accurate categorization of trees would not have been possible after more than one growing season after crown injury. The sampled trees were commingled with respect to species, size, and degree of crown injury.

Fig. 1. Examples of radial growth increments following ice storm injury. Arrows indicate the ring boundary between the 1997 and 1998 growth increments. (A) Sugar maple (injury class A); (B) yellow birch (injury class B); (C) white ash (injury class C); (D) red maple (injury class B). Scale bar = 5 mm.



In late September and October of 2000, single cores (12 mm in diameter) were extracted along the radial plane of each selected tree and parallel to the ground contour at 1.3 m above ground (Tre-Cor drill bits, J. Blackwood & Son Ltd., Smithfield, Australia) powered by a reversible gasoline-powered drill (Tanaka model TED262R). Cores were glued into grooved wooden mounts and sanded with a graded series of papers to 400 or 600 grit. Ring widths were measured with a precision of 0.001 mm with a binocular microscope and measuring stage. No staining was required to see the ring boundaries. In both the diffuse-porous maple and birch and the ring-porous white ash, the ring boundaries were usually identified by the thick-walled, darker cells formed late in the growing season and the comparatively thin-walled cells in the succeeding ring (Fig. 1). A radial growth index was calculated to compare the effects of crown injury on the width of annual rings before and after the 1998 ice storm. The radial growth index for each ring series was calculated as mean annual increment for the 1998–2000 period divided by the mean annual increment for the 1995–1997 period. An index value <1 indicated decreased growth and an index value >1 indicated increased growth following the 1998 storm. Preliminary trials comparing poststorm growth with 5- and 10-year periods prior to the 1998 storm produced similar results. Only results from the 3-year radial growth index are reported here.

To improve normality of distribution and homogeneity of variance, the $\log_e$ of index values was used in statistical comparisons. Two-way analysis of variance (ANOVA) was used to test the relationship of growth index to crown injury

Fig. 2. Total yearly precipitation (line plot) and normalized departures from mean total June and July precipitation for the average of Maine State climate division 1 and New Hampshire State division 1 (bar plot).

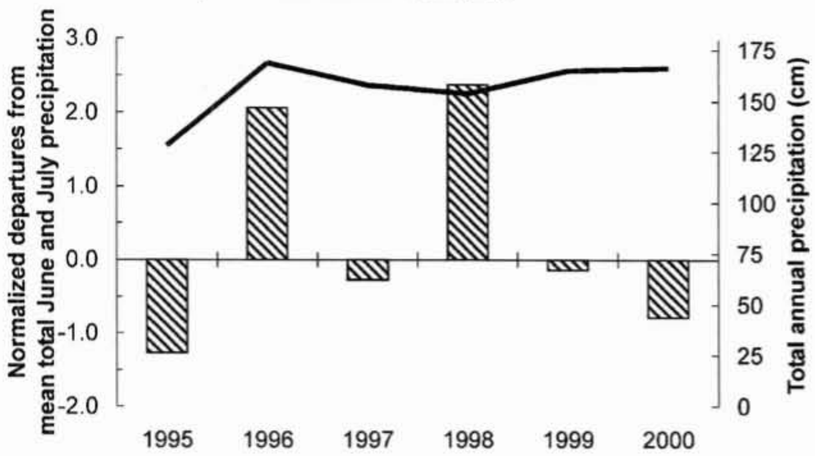


Table 2. ANOVA of the effects of tree species and crown injury class on the 3-year growth index (log-transformed, $N = 347$) after injury from the 1998 ice storm injury.

Source	Sum of squares	df	Mean square	F ratio	P
Species*	12.9	3	4.3	10.4	<0.001
Crown injury class†	37.4	2	18.7	45.3	<0.001
Species × injury class	7.3	6	1.2	3.0	0.008
Error	138.3	335	0.4		

Note: The 3-year growth index was calculated as the annualized mean radial increment for the 3 years after storm injury (1998–2000) divided by the annualized mean radial increment for the 3 years before the storm injury (1995–1997). The $\log_e$ of the growth index was used in the ANOVA.

*Tree species tested included sugar maple, yellow birch, white ash, and red maple.

†Crown injury classes were A (loss of less than one-half of the crown), B (loss of one-half to three-quarters of the crown), and C (loss of more than three-quarters of the crown).

class and tree species. To minimize the effect of inflation due to multiple comparisons, ANOVA significance was tested at a nominal $P < 0.01$. When significant differences were indicated by ANOVA, treatment means were separated using the Bonferroni technique (Neter et al. 1985) ($P < 0.05$, adjusted for multiple comparisons). For clarity of presentation, nontransformed values are shown in the tables and figures.

Variation in ring width in northern hardwoods has a weak yet significant relationship to climate, especially to precipitation during the growing season (Graumlich 1993; K.T. Smith, unpublished data). Total June and July precipitation values were derived from data obtained from the U.S. National Climatic Data Center of the National Oceanic and Atmospheric Administration. Total precipitation for a 16-month period was calculated for each year as the average between New Hampshire State climate division 1 and Maine State climate division 1 of the summed monthly total precipitation for June of the previous year through September of the current year.

Normalized departures from mean total June and July precipitation were calculated for each year by summing the June and July monthly total precipitation separately for New Hampshire State climate division 1 and Maine State climate division 1 and then averaging the sums for each year. The normalized departure (z score) for the averaged total June and July precipitation for each year was calculated for 1895–2000.

Results

Visual comparisons of ring width patterns across species and crown injury classes indicated several patterns of growth changes for the 1998–2000 annual growth increments. These patterns included increased radial increment (Fig. 1A) and decreased radial increment that was slight (Figs. 1B and 1C) or severe (Fig. 1D).

For the 1995–2000 time period, the 16-month total precipitation was relatively low in 1995 and relatively high in 1996, 1999, and 2000 with intermediate levels in 1997 and 1998 (Fig. 2). Mean total precipitation for the 1995–1997 and 1998–2000 periods was 151 and 161 cm, respectively. Total June and July precipitation was least in 1995, high in 1996, and peaked in 1998 (Fig. 2). Total June and July precipitation differed little from the long-term mean in 1997, 1999, and 2000.

Two-way ANOVA indicated that the log-transformed growth index was related to the main effects of tree species and crown injury class and the interaction of species with injury (Table 2). The growth index was significantly greater

Fig. 3. Mean of the radial growth index (untransformed ± SE) by tree species and crown injury class. Markers followed by similar letters are not statistically different ($P < 0.05$, adjusted for multiple comparisons of log-transformed values).

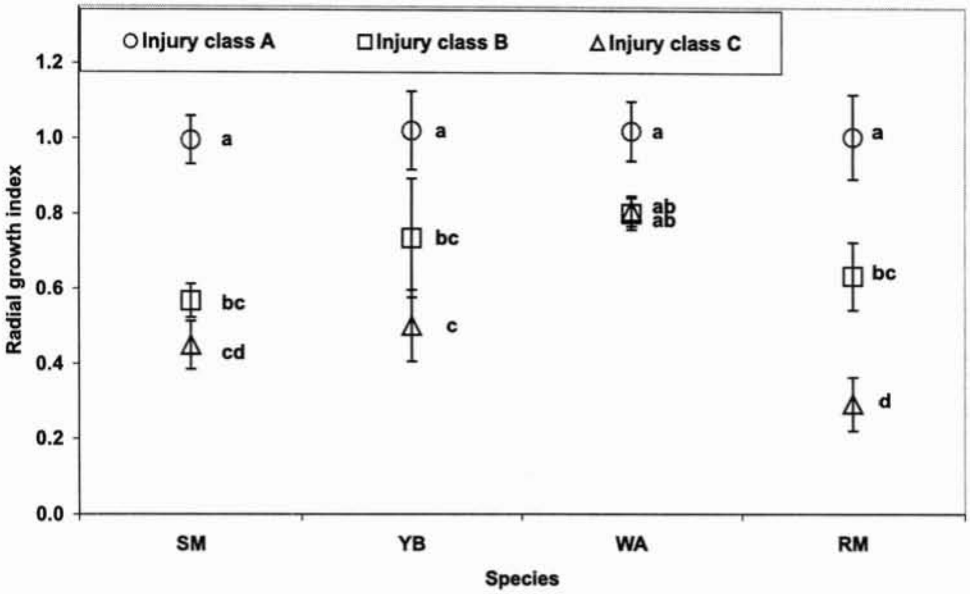


Table 3. Means of main effects of tree species and crown injury class on the 3-year growth index following injury from the 1998 ice storm.

Treatment effect	Mean index (SE)*
Tree species	
Sugar maple	0.75 (0.04)b
Yellow birch	0.78 (0.07)b
White ash	0.87 (0.03)a
Red maple	0.73 (0.07)b
Crown injury class[†]	
A	1.01 (0.04)a
B	0.67 (0.06)b
C	0.54 (0.04)c

*Within each treatment effect, values followed by similar letters are not significantly different ($P \leq 0.05$).

[†]Crown injury classes were A (loss of less than one-half of the crown), B (loss of one-half to three-quarters of the crown), and C (loss of more than three-quarters of the crown).

for white ash followed by the species group of sugar maple, yellow birch, and red maple (Table 3).

As crown injury increased in severity, the radial growth index decreased (Table 3). The growth index was significantly dependent on the interaction of tree species and injury class (Fig. 3). All four species in injury class A had mean growth index values of approximately 1, with some individual trees having growth index values >3. Sugar maple, yellow birch, and red maple in injury class B had significantly lower growth index values than class A trees. White ash in injury classes B and C had growth index values statistically similar to those of class A trees. Growth index values were statistically similar between injury classes B and C for sugar maple and yellow birch. Red maple in class C were the most severely affected and had the lowest growth index values (Fig. 3).

Discussion

Ring width at breast height integrates many factors including genetic and environmental circumstances of the individual tree, stand dynamics, and climate (Fritts 1976). Indexing growth on an individual tree basis before and after injury accommodated differences in growth attributable to individual tree genetics and circumstance. Variation in ring width due to tree age and size trends was not likely to be significant due to the short 6-year period of growth being investigated. Ring width was not likely to have been differentially affected during the prestorm 1995–1997 and the poststorm 1998–2000 periods due to the similarity in weather conditions in the 1998–2000 period compared with the 1995–1997 period.

Crown loss of greater than one-half (injury classes B and C) due to the 1998 ice storm resulted in reduced radial growth by one-third to three-quarters. White ash experienced the most severe crown loss, with many class C trees losing their entire crowns to ice breakage. Through vigorous stem sprouting, crowns of white ash were substantially replaced during the 1998 growing season and radial growth was not significantly affected over the 3-year period following the ice storm for all three crown injury classes. Birch and maple were less effective in replacing portions of lost crowns, and radial growth showed a highly variable narrowing of the annual growth increments that was generally more severe in class C than in class B trees.

The capacity to rapidly replace portions of broken crowns is an inducible survival strategy. Previous research on the effects of ice injury on hardwood growth in Slovenia indicated a similar pattern of decreased radial growth for the first annual increment after injury followed by a species-dependent recovery (Azarov 1988). In the Slovenian research, European beech (*Fagus sylvatica* L.) replaced injured crowns and restored radial growth rates 3–4 years after storm injury, while oaks (*Quercus* species) were slow to replace injured portions of the crown and continued to have reduced growth 5 years after injury (Azarov 1988).

The 3-year growth index was a sensitive and unbiased measure of changes in radial increment likely to be due to the 1998 ice storm. Comparison of mean ring widths from pre- and post-storm portions of individual tree ring series standardized variation that was due to differences in growth rates among species and individual trees. The annualized mean for the 3-year period before and after the 1998 storm reduced the impact of single-year effects on growth such as those caused by weather anomalies. The two successive 3-year periods were also short enough to likely not contain long-term changes in growth due to tree age or to stand competition not related to the ice storm. The 3-year period is also long enough to record the rapid recovery of growth rates following a brief, yet dramatic suppression of growth in the year following injury.

Decisions to accelerate harvest schedules in response to concerns about decreased radial increment following storm injury need to take into account the species-dependent ability of trees to recover growth rates to prestorm levels. In this study, white ash recovered very quickly. Sugar maple and yellow birch have recovered more slowly, but many trees are likely to continue to recover prestorm radial growth rates in the next few years.

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