IMPACTS FROM A MAJOR ICE STORM: STREET-TREE DAMAGE IN ROCHESTER, NEW YORK

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Abstract. In March 1991, a major ice storm occurred in Rochester, New York. Data from a comprehensive public tree survey, designed to include information on storm damage, were used to identify responses of urban trees to severe glaze accumulation. Storm-damaged trees were classified as follows: Removal 1 (R1s), those that sustained 75% or greater live crown loss; and Removal 2 (R2s), those that sustained 50%-74% live crown loss. The inventory identified 58,536 trees and 129 species distributed throughout the city. Of the total population, 3,391 trees (5.8%) were listed as R1s and 8,606 (14.7%) were listed as R2s. Seventy species (54.2%) had at least one reported R1, and 87 species (67.4%) had at least one reported R2. Because Rochester's street-tree population is comprised of so many species, each with varying degrees of storm damage, this study focused on those that represented greater than 1% of the total population. Seventeen species met this criterion. Damage to these species is reviewed, and management implications are discussed.

In March 1991, a major ice storm hit 19 counties in western New York State, resulting in extensive physical damage, severe fiscal repercussions, and a declared federal emergency. Most of the destruction, including downed power lines and structural damage, was traced to tree failure. Clearly, identifying and understanding responses of urban trees to severe storms are critical to their proper management and to minimizing damage from future events. Results from a detailed analysis of street-tree conditions in the City of Rochester following the 1991 storm were used to suggest appropriate street-tree management strategies for similar northeastern cities.

Ice, or glaze, storms are the result of super-cooled rain freezing on contact with surfaces that are at or below freezing (12). Much of the damage associated with these storms is caused by several interacting factors, including ice thickness, elevation, slope exposure, and wind velocity (2,15,22,23). Each storm has a different combination of these; consequently, tree damage patterns are difficult to predict. This is especially true in urban areas where the landscape has been severely altered, artificial surfaces and buildings have created varied microclimates, and many of the trees are non-indigenous and growing in unnatural settings. Studying the differences in species susceptibility, past maintenance practices, geography, and demographic data may identify trends that will allow managers to prevent severe losses in the future. The first two trends are discussed here, and the latter two will be addressed in future papers.

Ice storms in New York state. Disastrous glaze storms strike parts of North America every winter. The National Bureau of Standards (20) mapped the extent of icing in the United States based on the experience of utility wire maintenance firms. New York is in the heavy glaze area, indicating that ice thickness often exceeds 0.5 inch, with winds up to 40 miles/hour. However, ice storm occurrence is variable within the state, with the western and southern portions being more susceptible than northern areas. According to Lemon (15), serious glaze damage was recorded for various regions of the state in 1884, 1909, 1914, 1922-23, 1925, 1929-30, 1936, 1942-43, 1948-49, 1956-57, and 1959. Two more severe storms were recorded in 1987 and 1991. In the Rochester area, freezing precipitation was recorded in 1913, 1922, 1929, 1936, 1941, 1951, 1956, 1958, 1976, 1985, and 1991 (19).

Little published data exist for most of the storms listed. The 1936 storm, studied by Downs (9), impacted 6,178 mi^2 of western New York and 3,124 mi^2 of northern Pennsylvania, depositing an ice load 2.75 to 3.0 inches thick. During the 1942-43 storm that occurred in the St. Lawrence, Mohawk, and Hudson River valleys, ice accumulation ranged from 0 to 1.0 inch. A similar storm, spanning the first few days of 1949, covered eastern New York with up to 2.0 inches of ice (15).

Study Site

Rochester is located in Monroe County in western New York, approximately 70 miles east-northeast of Buffalo and 6 miles south of Lake Ontario (Figure 1). It is the third largest city in the state occupying 37 mi^2 with a population density of approximately 7,000/mi^2 (14). Rochester rests on the Erie-Ontario Lake Plain, which has a nearly level to gently sloping topography and an elevation of about 400 feet above sea level. The Genesee River bisects the city with a series of waterfalls flowing through a narrow gorge (13).

Rochester's climate is humid-continental with warm summers and long, cold winters. The city is in or near the path of most major weather systems moving across the continent or up the Atlantic Coast. This results in varied seasonable weather from year to year. Lakes Erie and Ontario influence local climate by moderating temperatures throughout the year and producing frequent, heavy snowfall in winter (13). Average temperatures are 90°F for a high, 2°F for a low, and 57°F for an annual average (14). Annual precipitation is approximately 32 inches of rain and 80 inches of snow (13).

1991 storm. According to the U.S. Weather Bureau, the frontal system responsible for this 50-100 year icing event deposited at least 0.8 inch of glaze on tree limbs, power lines, and telephone transmission towers in an area spanning 7,622 mi^2 (10). Several transmission towers were toppled by the weight of the ice, resulting in a loss of power to 300,000 customers (22). Mroz (20) examined

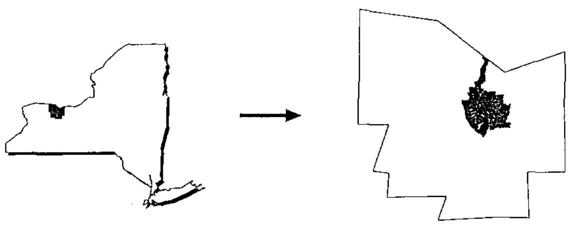

Figure 1. Locator map of Rochester, New York (with Street Maintenance Zones), as it relates to New York State, and Monroe County, respectively.

meteorological data for Monroe County for the 1905-91 period and determined that the 1991 storm was the most severe on record for several reasons. The 1991 storm had the most freezing rain (1.5 inches), ranked second in recorded glaze accumulation (0.75-1.0 inch), and had the fifth longest icing event (22.6 hours). During the height of the storm (which occurred at 3:51am, March 4, 1991), the Rochester weather office reported northeast winds gusting to 24 miles/hour.

Weather conditions after an ice storm, such as persistent sub-freezing temperatures and high winds, can significantly contribute to tree and infrastructure damage, and prolong repair periods. On March 7, three days after the icing event, winds gusted to 51 miles/hour, producing additional damage to trees, poles, and lines. Winds of this magnitude have never been recorded in this region so shortly after an ice storm. Mroz (20) concludes, based on his review of the record and the frequency and intensity of other ice storms, that this storm should be classified as a rare and extreme event.

Methods

Data from a comprehensive public tree survey completed in the summer of 1991 by ACRT, Inc. were analyzed to determine the relationship between ice damage and the following factors: tree species, diameter class, and, to the extent possible, previous maintenance practices. (ACRT is an urban forestry consultant firm hired by the City of Rochester. The use of this firm's name and data is not intended as an endorsement.) Because the inventory was conducted shortly after the icing event, it was designed to include information on storm damage, as well as more standard street-tree data such as tree location, species and size, available planting sites, condition and size of growing spaces, proximity of utility lines, tree health, and maintenance recommendations like pruning and training (Table 1).

Data variables most relevant to this study were species code, diameter, and maintenance. The latter was used to determine degree of storm damage. Specifically, storm-damaged trees were listed in the following maintenance categories: Removal 1, Removal 2, and Corrective Pruning. Removal 1 trees (R1s) were those scheduled for

Table 1. Data variables and definitions used for the 1991 street-tree inventory in Rochester, New York. Variables in bold print are those used to analyze ice-storm damage to trees.

Variable	Definition
Address	Lot number or tree site. If address was not available, an assigned number was used to help locate tree or site later.
Street	The name of the street where the tree or site is located.
Section	Section of the city where the tree or site is located. Sections were based on the city's Street Maintenance Zones (Figure 1).
Subsection	Subsection within a section where the tree or site is located. Sections were arbitrarily subdivided into 3 subsections (A,B,C) such that each contained approximately 2,000 trees.
Tree number	Each tree or site on the property is assigned a number from 1-N, where N is the total number of public trees on that property.
Side of lot	The position on the lot (front, median, rear, side), relative to the street, where the tree or site is located.
Assign address	Indicates through a 'yes' or 'no' whether the given address has been assigned.
Species code	Species code for trees generally consisted of the first two letters from both the genus and species names. For example, red maples's (*Acer rubrum*) code is ACRU.
Diameter	Diameter of the tree at breast height (4.5'). Planting site diameters equal zero.
Maintenance	Work to be performed on the tree or site. For example, monitor, prune, remove, stake, or train.
Condition	A condition rating is assigned to the tree or site based on the Council of Tree and Landscape Appraisers method of appraising trees.
Location	A location rating is assigned to the tree or site based on the Council of Tree and Landscape Appraisers' method of appraising trees.
Utilities	The location of utility wires or pipes present, e.g., none, overhead, underground, or both.
Site type	Tree lawn, cutout, mall, or planter.
Tree lawn	Width in feet of the tree lawn (when present).
Damage codes	Single letter code describing damage caused by the tree to adjacent infrastructure (e.g., sidewalk, driveway). Up to three codes may be entered per tree/site.
Inventory date	Date that this tree or site was inventoried.
Inventoried by	Initials of person who inventoried the site.

immediate removal because they sustained at least 75% live crown loss (either as a direct result of the storm or from remedial pruning to correct storm damage), or had major limb breakage into the trunk heartwood and were considered hazardous. Removal 2 trees (R2s) were those that sustained between 50% and 74% live crown loss as a result of the storm or remedial pruning. Their removal was scheduled following completion of R1 removals and more detailed evaluations of individual trees than those conducted during the initial inventory. Trees requiring Corrective Pruning were those that had at least one severely damaged limb, and up to 49% live crown loss. Percentage of crown loss for all trees was determined subjectively by visual assessment. Relative storm damage was determined by dividing individual species' percentage of total R1s and R2s by the percentage of the total population.

Our analyses focused on the R1 and R2 trees because they were severely damaged and considered terminal or too costly and labor-intensive to maintain. Trees classified as Corrective Pruning were not included because they could survive long enough, with minimal added maintenance, to provide adequate benefits to city residents. In addition, Corrective Pruning trees had such a wide range of damage (1 to 49%) that few conclusions could be drawn about the direct impacts of the ice on species or individual trees. If these trees were included in the analyses, storm damage would equal nearly 54% of the total population.

Results

The inventory identified 58,536 trees and 129 species distributed throughout the city (Appendix A). Of the total population, 3,391 trees (5.8%) were listed as R1s and 8,606 (14.7%) were listed as R2s. Seventy species (54.2%) had at least one reported R1 and 87 species (67.4%) had at least one reported R2. All but five of the R1 damaged species also had R2 damaged trees.

The entire street-tree population, including the R1 and R2 trees, were divided into 9-inch-diameter classes: 1-9 inches, 10-18 inches, and so on (Table 2). More than 38% of the citywide population was 9 inches dbh or less; 79.6% was 18 inches or less. All size classes had some R1 and R2 trees: Of the R1 trees (2,444 of 3,391 trees) 72.0% were 18 inches or less, 54.8% were between 10 and 18 inches, and 27.9% were 19 inches or greater. Of the R2 trees, 61.0% were 18 inches or less, 47.5% were between 10 and 18 inches, and 39.0% were 19 inches or more.

Because Rochester's street-tree population is comprised of so many species, each with varying degrees of storm damage, this study focused on those that represented greater than 1% of the total population. (Species that comprised less than 1% of the total population were excluded because their numbers were often insufficient to draw conclusions about storm damage.) Seventeen species met this criterion: Japanese pagoda (*Sophora japonica*), green ash (*Fraxinus pennsylvanica*), silver maple (*Acer saccharinum*), London planetree (*Platanus x acerifolia*), callery pear (*Pyrus calleryana*), Norway maple (*A. platanoides*), honeylocust (*Gleditsia triacanthos*), red maple (*A. rubrum*), littleleaf linden (*Tilia cordata*), sugar maple (*A. saccharum*), northern red oak (*Quercus rubra*), crabapple (*Malus spp.*), sweetgum (*Liquidambar styraciflua*), Schwedler Norway maple (*A. platanoides 'Schwedleri'*), columnar Norway maple (*A. platanoides* 'Columnare'), Crimson King Norway maple (*A. platanoides 'Crimson King'*), and ginkgo (*Ginkgo biloba*). Together, these 17 species represented 88.1% of the R1 and R2 trees, and 87.0% of the total street-tree population (Table 3). However, only 10,582 trees from these 17 species were listed as R1s and R2s, this was only 18.1% of the city's street-tree population. (In Tables 3 and 4, R1 and R2 trees have been totaled and listed as one category, hereafter reported variously as: R1s and R2s, storm-damaged trees, storm-damaged population, and storm losses.)

Damage to all of these species, except Norway maple, was disproportionate as indicated by Relative Storm Damage (RSD) values (percentage of total R1s and R2s divided by percentage of total population—Table 3). Values greater than one indicate that the species had a greater proportion of storm loss (R1s and R2s) than its proportion of the total population, suggesting a susceptibility to glaze damage. Similarly, values less than one indicate that the species had a smaller proportion of storm loss than its proportion of the total population, suggesting a greater tolerance to glaze accumulation. The following discussion focuses on those species with RSD values greater than or equal to 0.7; species with RSD values between 0.7 and 1.0 are included because they suffered between 15% and 20% loss of their individual populations.

Five of the study species—Japanese pagoda, green ash, silver maple, London planetree, and callery pear—had a RSD value greater than one. Norway maple had a RSD value of one indicating that percentage of storm damage to this species was proportionate to its percentage of the total

Table 2. Diameter distribution (%) for Total, Removal 1 and Removal 2 trees.

Diameter class (in.)	City total	Removal 1	Removal 2
1-9	22,633 (38.7)	583 (17.2)	1,166 (13.5)
10-18	23,981 (40.9)	1,861 (54.8)	4,083 (47.5)
19-27	8,316 (14.2)	705 (20.8)	2,355 (27.4)
28-36	2,795 (4.8)	207 (6.1)	796 (9.2)
37+	812 (1.4)	35(1.0)	206 (2.4)
Total	58,537 (100)	3,391 (100)*	8,606 (100)

*Total does not equal 100 percent because diameter class percentages were rounded to the nearest tenth.

Table 3. Seventeen dominant species (i.e., those that individually comprise 1% or greater of the Rochester, New York, street-tree population) listed by total individuals, percentage of total population, number of storm-damaged trees (R1s and R2s), percentage of total storm-damaged trees, and Relative Storm Damage (RSD—%Storm-Damaged Trees/ % Total Population). Species are listed in order of most to least storm damage as indicated by RSD values.

Species	Total (% of total[1])	Storm-damaged (% of total[2])	RSD[3]
Japanese pagoda	1068 (1.8)	674 (5.6)	3.1
Green ash	5262 (9.0)	2676 (22.3)	2.5
Silver maple	3013 (5.1)	1083 (9.0)	1.8
London planetree	1802 (3.1)	449 (3.7)	1.2
Callery pear	837 (1.4)	197 (1.6)	1.1
Norway maple	16,226 (27.7)	3259 (27.2)	1.0
Honeylocust	6118 (10.5)	1118 (9.3)	0.9
Red maple	1384 (2.4)	232 (1.9)	0.8
Littleleaf linden	4117 (7.0)	550 (4.6)	0.7
Sugar maple	2322 (4.0)	182 (1.5)	0.4
Northern red oak	714 (1.2)	38 (0.3)	0.3
Crabapple	1084 (1.9)	42 (0.4)	0.2
Sweetgum	772 (1.3)	25 (0.2)	0.2
Schwedler Norway maple	1619 (2.8)	34 (0.3)	0.1
Columnar Norway maple	1391 (2.4)	9 (0.1)	<0.1
Crimson King maple	2596 (4.4)	13 (0.1)	<0.1
Ginkgo	614 (1.0)	1 (<0.1)	<0.1
Total	50,939 (87.0)	10,582 (88.1)	NA

1. Total population = 58,537 trees
2. Total R1s and R2s = 11,997 trees
3. % storm-damaged /% total

population. Honeylocust, red maple, and littleleaf linden had RSD values between 0.7 and 0.9; the remaining eight species (sugar maple, northern red oak, crabapple, sweetgum, Schwedler, columnar, and crimson king Norway maples, and ginkgo) had RSD values less than 0.7 and percentage of population loss less than 8%, indicating that they fared relatively well in this storm.

Ninety-four percent of all Japanese pagoda was 18 inches dbh or less. Similarly, 92.2% of the R1 and R2 Japanese pagoda trees were 18 inches or less. Most storm losses (81.1%) were between 10 and 18 inches dbh. All size classes above 9 inches had RSD values greater than one indicating a greater proportion of storm loss than the species' total population (Table 4).

Of the green ash in the city, 87.5% was 18 inches dbh or less. Storm losses were greatest (59.1%) between 10 and 18 inches. Trees 1 to 9 inches had less damage (20.9%), and those between 19 and 36 inches had the fewest losses (20.1%). The 10 to 18 and 19 to 27-inch size classes had RSD values greater than one (Table 4).

Seventy-four percent of the silver maple population was greater than 18 inches; 44.1% was greater than 28 inches. Of the storm damaged silver maples, 82.3% were more than 18 inches dbh; 46.7% were 28 inches or more. Storm losses were most significant in the larger size classes (19 inches or more) as indicated by RSD values greater than one (Table 4).

More than 69% of the total London planetree population was between 1 and 18 inches; 30.1% was greater than 18 inches. Of the R1 and R2 population, 72.2% was 18 inches or less and 27.6% was greater than 18 inches. The 10 to 18 and 19 to 27-inch classes had a greater proportion of storm loss than the total population, as indicated by their RSD values (Table 4).

Callery pear had no trees greater than 18 inches in diameter; 85.0% of the total population was between 1 and 9 inches, and 15.0% was 10-18 inches. Of the storm-damaged trees, 67.5% were 1-9 inches and 32.5% were 10-18 inches. RSD values were greater than one for the 10 to 18-inch class (Table 4).

More than 73% of the Norway maple population was between 10 and 27 inches; 20.4% was 9 inches or less and 5.8% was 28 inches or larger. Of the R1 and R2 population, 85.1% was between 10 and 27 inches, 2.8% was 9 inches or less, and 12.0% was 28 inches or larger. RSD values were greater than one for trees 19 inches or larger (Table 4).

Of the remaining three species, the following trends were observed. Honeylocust and littleleaf linden had more than 90%, and red maple had more than 65%, of their total populations between 1 and 18 inches in diameter. Honeylocust and littleleaf linden had more than 60% of their R1 and R2 populations between 10 and 18 inches. Red maple storm loss was fairly evenly distributed, with the smallest (1-9 inches) and largest (37+ inches) size classes having the least amount of

Table 4. Diameter distribution of nine primary storm-damaged street tree species in Rochester, New York listed as percent of that species' total and storm-damaged (R1s and R2s) populations, and including RSD values.

	Diameter class (inches)				
	1-9	10-18	19-27	28-36	37+
Japanese pagoda					
% Total	20.4	73.6	5.6	0.3	—
% R1 and R2	11.1	81.1	7.3	0.4	—
RSD	0.5	1.1	1.3	1.3	—
Green ash					
% Total	45.9	41.6	11.6	1.0	0.1
% R1 and R2	20.9	59.1	19.1	1.0	—
RSD	0.5	1.4	1.6	1.0	—
Silver maple					
% Total	12.4	14.3	29.6	31.6	12.5
% R1 and R2	3.3	14.3	35.6	33.8	12.9
RSD	0.3	1.0	1.2	1.1	1.0
London planetree					
% Total	23.7	46.1	12.6	10.8	6.7
% R1 and R2	17.4	54.8	16.2	8.8	2.6
RSD	0.7	1.2	1.3	0.8	0.4
Callery pear					
% Total	85.0	15.0	—	—	—
% R1 and R2	67.5	32.5	—	—	—
RSD	0.8	2.2	—	—	—
Norway maple					
% Total	20.4	47.4	26.3	5.3	0.5
% R1 and R2	2.8	41.7	43.4	10.9	1.1
RSD	0.1	0.9	1.7	2.1	2.2
Honeylocust					
% Total	48.2	43.2	8.4	0.1	<0.1
% R1 and R2	20.4	61.1	18.2	0.4	—
RSD	0.4	1.4	2.2	4.0	—
Red maple					
% Total	44.8	21.0	14.9	13.1	6.2
% R1 and R2	10.3	27.1	25.4	26.7	10.3
RSD	0.2	1.3	1.7	2.0	1.7
Littleleaf linden					
% Total	50.1	45.3	4.3	0.3	<0.1
% R1 and R2	27.5	63.7	7.8	0.6	0.2
RSD	0.5	1.4	1.8	2.0	-2.0

damage (10.3% each). All of these species had RSD values greater than one for all size classes except 1-9 inches (Table 4).

With the exception of callery pear, trees less than 9 inches fared well in this glaze event. In general, the storm-damaged species reviewed here had few large trees in their populations due to a relatively recent surge in planting popularity following the loss of elms to Dutch elm disease. It is unclear from the current data how well these species would survive a similar storm if their populations had a greater percentage of large trees.

Discussion

Observations of tree characteristics as they relate to ice damage and species' susceptibility to glaze helps to understand the impacts of the 1991 storm on Rochester's street trees. The following review provides a necessary perspective for evaluating tree damage and identifying associated management implications.

Glaze damage to trees. Most detailed studies on the mechanics of tree damage from ice storms have focused on natural stands, not urban trees. However, many general observations from these works can be applied to street and lawn trees. First, it is important to recognize that there are different sources of potential damage to a given tree. Failure can be the direct result of glaze, indicating susceptibility due to habit or age, or it may occur indirectly from falling trees or their parts (2). In the latter case, damage is most often to smaller trees but no correlation can be drawn between ice accumulation and tree failure; the resulting damage is coincidental. The extent of direct glaze damage to trees has been attributed to the following characteristics: crown size, shape, position and symmetry; trunk diameter; branching pattern and weak branch crotches; and age and degree of decay (3,12,22). Each of these is discussed below.

In general, trees with cylindrical or long, symmetrical crowns suffer less damage from glaze accumulation than those with conical, short, or one-sided crowns (6). In forested stands, needle-leaved trees suffer damage directly from ice rather than secondarily from falling trees. They also experience more severe damage (i.e., uprooted or >50% stem and branch loss) than slight damage (i.e., bent over or 50% stem and branch loss) (2). Contrary to these reports, only 22 (5.3%) of the 413 conifers growing on Rochester streets at the time of the storm were severely damaged.

Broad-leaved trees, however, typically have more secondary than direct damage; large trees are severely damaged and small trees are slightly damaged (2). Although it cannot be determined with the available data, some of the tree damage in Rochester may have been caused by indirect effects, perhaps creating the impression that certain species are more susceptible to ice-loading than, in fact, they are.

Downs (9) noted that damage during the 1936 storm in Pennsylvania and New York was more serious in old- and second-growth forests. Presumably, increased damage with age is a function of increased crown size and internal decay, and decreased flexibility of limbs and bole (24). Similar observations were made regarding the 1991 storm in New York (22). Forests with larger diameter trees suffered more damage (30%) due to large, unsound limbs, while those with smaller diameter trees had approximately 15% damage. Pioneer trees, particularly those with an excurrent growth form, suffer more damage than equilibrium species (26).

Most of the storm damage to Rochester's street trees occurred in intermediate (10-18 inches) and large (19 inches or more) size classes, suggesting that they may have had unsound limbs, or a combination of decreased flexibility and poor growth form (e.g., the acute branch angles typical of callery pear and green ash). Thirty-nine percent of the total Rochester street-tree population was 9 inches or less; only 14.6% of the R1s and R2s, or approximately 3.0% of the total population, was 9 inches or less.

Larger trees suffer mainly from loss of branches and breakage of main stems within the crown. Pole-size trees have more juvenile wood and are often broken below the crown, and small poles and saplings are often badly bent over (1). These different responses to glaze accumulation are most apparent when comparing different aged populations of the same species. Populations dominated by larger, older individuals suffer mostly severe crown and bole damage, whereas those dominated by small stems and/or subcanopy individuals tend to bend over rather than snap off or become uprooted (2).

Initial glaze damage to trees seems to be confined to faulty limbs and functions as a natural pruning process (15). Such branch and limb breakage is not necessarily fatal to trees in a managed setting. According to Croxton (6), if wounds are properly cared for, the effect of glaze damage, in some situations, is similar to that of heavy pruning during a routine maintenance cycle. However, when accumulations exceed 0.5 inch, healthy young branches and well-formed trees may also break. This is evidenced by the breadth of species and number of trees damaged by the 0.8 inch of glaze in Rochester. Ice accumulations have been noted to increase branch weight by as much as 15-30 times (1,12); the total ice load a tree might bear depends on its size and branching, and on ice thickness. A 50-foot evergreen, for instance, may bear as much as 50 tons of glaze (23).

Attempts to correlate wood strength via comparisons of different species' modulus of rupture, modulus of elasticity, and specific gravity to glaze susceptibility have met with little success (12,15,18). Wood strength significance is intuitively obvious, but glaze susceptibility is not the result of any single factor and cannot, therefore, be associated with this property alone (6,15). A given species' wood characteristics and strength vary, depending on the individual tree's age, degree of decay present, and local growing conditions, such as available moisture and space, and soil type (3,15). For example, a large diameter, open-grown oak more than a century old may suffer extensive ice-storm damage, whereas the same species, 50 years old, may suffer little to no damage. Hauer et al. (12) maintain that the strength of wood is less important in ice-accumulation tolerance than the tree's ability, based on its growth form, to accumulate ice until the bearing capacity of its branches has been surpassed.

Branching pattern, specifically branch angle and the amount of fine branches, affects resistance to ice damage (5). Trees with horizontal branching have a higher susceptibility to damage because this orientation favors glaze accumulation through greater exposed surface area. In Rochester, this was evidenced by damage to honeylocust, London planetree, Japanese pagoda, and Norway maple (Pleninger, A.G., Rochester City Forester, personal observation, 1992). Conversely, branches growing upward at an acute angle are oriented perpendicular to the exposed surface of the crown, resulting in lower overall glaze exposure. Species with opposite branching patterns tend to have wide branch and twig angles, and therefore suffer more storm damage (3). Contradictory to these data, the maples in Rochester fared relatively well, except for larger size classes. Structurally weak crotches, especially those with included bark, also increase damage in an ice storm (4). Storm damage to green ash, callery pear, and red maple in Rochester has been attributed, in part, to weak crotches and included bark (Pleninger, A.G., Rochester City Forester, personal observation, 1992).

Numerous small twigs and branches increase total surface area, resulting in greater ice accumulation and damage (15). In addition to causing differences in the amount of accumulated glaze, branching pattern and twig size also influence the type of damage. Small twigs are relatively flexible and tend to bend under added weight. Glaze will remain on these twigs, concentrating weight onto larger, less flexible branches that may break under stress. This pattern of damage was observed in green ash, honeylocust, and Norway maple in Rochester (Pleninger, A.G., Rochester City Forester, personal observation, 1992). By contrast, relatively large twigs accumulate less glaze per unit diameter. However, these are less flexible and snap off distally to a greater extent than those of finely branching species (3).

Species susceptibility and glaze damage in Rochester. Ice-storm tolerance ratings for tree species vary for different geographic locations and from natural stands to urban settings (2,3,12). This is due to differences in local topography and climate, as well as site conditions, plant age and structural integrity, and past maintenance practices (2). Richards (21) notes that "within New York, there are major differences in species adaptation among climate and soil regions."

Examples of variable tolerance exist for many of the Rochester storm-damaged species. Seischab et al. (22) rated species susceptibility to ice damage in western New York based on observations in natural stands following the 1991 storm. They found that ash as a group had minimal damage; green ash had 10% and white ash (*F. americana*) had 17% crown damage. By contrast, Bruederle and Stearns (3) rated white ash as highly susceptible in southern Wisconsin. In the urban settings of Urbana, Illinois (12), and Rochester, New York, green ash sustained severe damage. Fifty-one percent of the green ash population in Rochester was lost to the 1991 ice storm. These differences between urban and natural trees may be due to the less-protected, open grown nature of shade trees (1,26).

Species variety might contribute to ice tolerance as well. For example, Marshall's seedless ash, a variety of green ash commonly planted in public settings, including Rochester, has a more upright form with more acute branch angles, a dense branching pattern, and weaker crotches than forest trees of the same species. This difference in habit results in different responses to glaze accumulation. Marshall's seedless ash is tolerant of harsh growing conditions in urban areas, but does not fare as well in ice storms as native forest trees.

Conflicting reports also exist for some of the maple species found in Rochester. Extensive ice damage to silver (central Illinois (6); PA to Boston (7); Syracuse, NY (16)), red (North Carolina (1,7)), and Norway (Syracuse, NY (16)) maples grown as public trees has been observed. However, data supporting the glaze tolerance of these trees are available as well; some are presented below.

Silver maple sustained only moderate damage in Urbana, Illinois (12). The authors observed that this species typically breaks at upper- or mid-branch positions when loaded with ice, and suggest that damage was low because these trees had been regularly pruned since 1976. Although 35.9% of the silver maple population in Rochester suffered severe storm damage, most (82.3%) affected trees were 19 inches dbh or more. The damaged trees in Urbana were mostly greater than 24 inches dbh. Differences in the amount of damage to silver maples in Urbana and Rochester might be attributable to past pruning practices.

Similarly, red maple sustained little damage in Urbana, those that were impacted were greater than 24 inches dbh (12). In Rochester, 16.8% of the red maple population was severely damaged by glaze. More than 62.0% of the storm-damaged red maples were 19 inches or more.

A clear demonstration of variable tolerance and interpretation of results is that Norway maple's success (7) and susceptibility (16) have been attributed to its crown compactness and branching pattern. Norway maple in central Illinois had no damage (6) and those in Urbana sustained little damage (12). Likewise, Norway was the most resistant maple following the 1940 storm which stretched from Pennsylvania to Boston (7). In Rochester, 20.1% of the Norway maple population was lost to glaze damage; however, most of these were generally in poor condition before the storm (Pleninger, A.G., Rochester City Forester, personal observation, 1992).

Sycamore *(Platanus occidentalus)* is used here to review ice susceptibility of London planetree because these species are closely related and structurally similar (both have horizontal branching resulting in high surface area (8)), and response to ice loading is assumed to be comparable. In Urbana, sycamores sustained severe damage (12). The authors suggest that this was the result of anthracnose increasing surface area and elevating susceptibility to ice damage, and is not a direct reflection of this species' ice tolerance (12). Twenty-five percent of the Rochester London planetree population was lost to glaze damage, and the city forester reports similar increases in surface area due to past episodes of anthracnose (Pleninger, A.G., Rochester City Forester, personal observation, 1992).

Hauer et al. (12) maintain that Bradford pear, a variety of callery pear, had extensive damage in Urbana because its narrow branch crotches, often with included bark, form weak attachments. They suggest that the Aristocrat pear performed better (none was damaged) because its branches are more horizontal with a wider crotch angle. Only one representative of this cultivar was present in Rochester at the time of the storm, it suffered minimal glaze damage. Approximately 24% of the Bradford pear in Rochester was storm damaged.

Littleleaf linden suffered minimal damage in Urbana (12); only 13.4% of the population was lost in Rochester. Storm damage to honeylocust in Urbana was attributed to structural imperfections, disease, or insects (12); 18.3% of the species' population was lost in Rochester. No glaze storm data from other cities could be found for Japanese pagoda, however, 63.1% were lost in Rochester.

Management Implications

Specific recommendations regarding the primary storm-damaged trees in Rochester are outlined below, with some observations on their past performance provided by the city's forester.

Four species—silver maple, green ash, callery (Bradford) pear, and honeylocust—that were severely damaged in Rochester were also severely damaged in Urbana, Illinois (12). Possible reasons for the failure of silver maple have already been discussed; some of its advantages will be outlined below. The remaining three trees seem to consistently fare poorly in ice storms and may be inappropriate in areas that experience frequent or severe glaze events. Other species that were extensively damaged in Rochester include Japanese pagoda, London planetree, Norway and red maples, and littleleaf linden. These had less damage (RSD values less than or equal to one) but still lost 15% to 20% of their populations.

The disadvantages of green ash (e.g., acute branch angles, dense secondary branching, included bark, weak crotches) suggest that its use should be reduced. However, it is very urban tolerant and newer cultivars have better branching patterns than the Marshall's seedless variety (11).

Strong evidence for success or failure does not exist for callery pear and honeylocust indicating that their continued use in Rochester should be more closely evaluated. Bradford callery pear has a late leaf drop (making it susceptible to damage during early, wet snowfalls), and a poor branching pattern, weak crotches, and included bark. Other cultivars may perform better.

The city forester in Rochester favors continued use of honeylocust despite its susceptibility to glaze damage. It is very tolerant of urban conditions, and performs well on heavily salted arterials, in a variety of soils, and in limited space. Its overall success in non-glaze situations warrants risking damage from rare icing events like the 1991 storm.

Silver and red maples should continue to be planted in Rochester. Much of their individual populations are 19 inches or more (73.7% and 34.2%, respectively), demonstrating their potential longevity. Most damage to these species was sustained by larger trees, suggesting some glaze tolerance when they are younger. Based on storm-damage data alone, silver maple, in particular, is a strong candidate for street-tree planting in Rochester. It is tolerant of urban conditions, very long lived, can weather ice storms if pruned regularly, and was found to be healthier than sugar and Norway maples in Poughkeepsie, Syracuse, and Rochester, New York (25). However, 2- to 3-inch limbs often break off of larger trees, creating wounds that are prone to decay. Maintaining this species at a level that minimizes limb breakage requires a 2- to 3-year pruning cycle, which is difficult to establish in a city like Rochester with a large street-tree population. Red maple requires acid soils and good training when young, but is a good residential street tree in Rochester where site and space requirements are met.

Japanese pagoda should not be planted because 63.1% of its population was lost to glaze. Despite this species' tolerance of urban conditions, it has a variety of shortcomings in addition to its susceptibility to ice damage. It produces a lot of litter, especially petals during its extensive flowering period, and fruits persist year-round. In addition, its flowers attract bees, leading to many complaints from residents.

Norway maple should be used less (it currently comprises 27.7% of the total population) since it represented more than 27.2% of the storm-damaged trees. Its use should not be eliminated completely, however, because it can endure urban conditions, as evidenced by the many older trees in the Rochester population (32.1% are 19 inches or more). It performs well in a variety of soils and in Rochester's climate, but requires good rooting space and will decline rapidly after sustaining severe injuries. Several varieties, Schwedler, Crimson King, and columnar, fared well in the 1991 storm, suggesting that their use as street trees may be more appropriate.

Littleleaf linden has been a good residential street tree in Rochester and will continue to be planted. London planetree has good urban tolerance and longevity, compartmentalizes well, and can survive significant crown loss. Both of these species had a smaller proportion of storm loss than their individual populations.

Conclusion

Major ice storms have a return time on the order of 20 to 100 years (17). In Rochester, storms of comparable magnitude to the 1991 event have a probable return time exceeding 120 years (19). Consequently, it is difficult and impractical to develop a public tree management plan specifically designed to accommodate infrequent potential glaze damage. In addition, the degree of damage in Rochester was elevated due to poor maintenance practices in the past (Pleninger, A.G., Rochester City Forester, personal observation, 1992). Before 1985, street maintenance in Rochester was crisis-oriented, that is, pruning and removals were prioritized based on hazardous conditions or citizen requests. Regular treatments were not scheduled. Since that time, the forestry department has been restructured and has established a regular schedule of routine maintenance and pruning, which may lessen damage from future storms.

The best approach is to plant trees that are biologically adapted to the region and that have proven successful as urban trees in that area (21). Those trees that repeatedly perform poorly in glaze events, regardless of region, should not be used in areas that are highly susceptible to severe storms. However, species that suffer some ice damage should only be excluded from street-tree use after weighing this possible disadvantage with known long-term advantages.

A sustainable 5- to 10-year pruning rotation of mature street trees and 3-year pruning rotation of young trees is equally important to minimizing the impact of storms. Evaluations of injuries resulting from the 1991 storm to particular species indicate proper maintenance would have greatly reduced damage. Annual inspections to identify tree defects, and a remedial pruning and removal program will reduce potential damage from periodic natural disasters.

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Résumé. En mars 1991, une tempête majeure de verglas s'est produite à Rochester dans l'état de New York. Un inventaire exhautif des arbres du domaine public, composé de données pensées à cette fin, a été réalisé dans le but de déterminer la nature de la réponse des arbres en milieu urbain lors d'accumulations sévères de glace. Les arbres endommagés par la tempête ont été classés comme suit: abattage niveau 1 (R1), soit ceux ayant subi 75% ou plus de perte de cime; abattage niveau 2 (R2), soit ceux ayant subi entre 50 et 75% de perte de cime. L'inventaire comportait 58,536 arbres regroupés en 129 espèces distribuées dans l'ensemble de la ville. De la population totale,391 (5.8%) ont été classés abattage niveau 1 et 8,606 (14.7%) ont été classés abattage niveau 2.

Zusammenfassung. Im März 1991 gab es in Rochester, New York, einen starken Eissturm. Die Daten aus einer großen Studie über Stadtbäume, die auch Informationen über Sturmschäden enthält. wurden dazu herangezogen, die Reaktionen der Stadtbäume auf schwere Eiseinbrüche zu untersuchen. Die sturmgeschädigten Bäume wurden wie folgt klassifiziert; Entnahme 1 (R1), diejenigen, die 75% und mehr von der Krone verloren haben und Entnahme 2 (R2), diejenigen, die 50 - 75% der Krone verloren haben. Die Bestandsaufnahme ergab 58.536 Bäume und 126 Arten, die über die ganze Stadt verteilt sind. Von der gesamten Population waren 3.391 Bäume (5.8%) als R1 und 8.606 Bäume (14.7%) als R2 gezählt.

Appendix A. 1991 street-tree inventory data for Rochester, New York. Species[1] are listed alphabetically by common name, and reported values include total trees, Removal 1s, Removal 2s, and percentage of storm loss (Removal 1 + Removal 2/Total). Species in bold print are those evaluated for ice-storm damage.

Species	Total	R1s	R2s	% Loss
Ailanthus	38	4	2	16
Arborvitae	32	1	7	25
Ash, European	207	20	83	50
Ash, flowering	50	1	13	28
Ash, green	5262	1094	1582	51
Ash, Hesse European	16	0	2	13
Ash species	318	25	64	28
Ash, white	418	36	98	32
Baldcypress, common	16	0	0	0
Beech, European	11	0	0	0
Birch, European	11	0	0	0
Birch, paper	27	5	3	30
Birch species	19	0	7	37
Boxelder	77	10	18	36
Buckeye, Ohio	49	0	0	0
Catalpa, northern	119	8	16	20
Cherry, black	22	0	4	18
Cherry, flowering	249	12	5	7
Cherry, Kwanzan	228	0	2	1
Corktree, amur	283	2	12	5
Cottonwood, eastern	15	0	10	67
Crabapple	1084	17	25	4
Dogwood, flowering	16	0	1	6
Douglas-fir	12	0	1	8
Elm, American	83	5	38	52
Elm, Siberian	37	4	8	32
Elm species	248	58	74	53
Filbert, Turkish	13	0	0	0
Ginkgo	614	0	1	<1
Goldenraintree	137	14	32	34
Hackberry	134	12	22	25
Hawthorn species	83	11	17	34
Honeylocust	6118	351	767	18
Hophornbeam	14	0	2	14
Hornbeam, American	53	0	3	6
Hornbeam, European	113	5	6	10
Horsechestnut	216	5	4	4
Katsura	82	3	23	32
Lilac, Japanese tree	175	13	36	28
Linden, American	580	33	86	21
Linden, littleleaf	4117	84	466	13
Linden, silver	42	0	14	33
Linden species	341	7	55	18
Locust, black	98	14	24	39
Magnolia, saucer	89	2	4	7
Magnolia species	68	0	4	6
Maple, amur	36	9	3	33
Maple, columnar sugar	192	1	5	3
Maple, columnar Norway	1391	1	8	<1
Maple, Crimson King	2596	4	9	<1
Maple, hedge	101	2	3	5
Maple, Norway	16226	653	2606	20
Maple, red	1384	66	166	17
Maple, Schwedler	1619	6	28	2
Maple, silver	3013	205	878	36
Maple species	170	4	6	6
Maple, sugar	2322	45	137	8
Maple, sycamore	323	1	23	7
Mountain ash, American	74	1	2	4
Mountain ash, European	74	1	0	1
Mulberry, white	13	2	2	31
Oak, bur	14	0	1	7
Oak, English	15	1	1	13
Oak, northern red	714	9	29	5
Oak, pin	153	2	12	9
Oak species	138	1	9	7
Oak, white	37	1	1	5
Other species	230	18	19	16
Pagoda, Japanese	1068	271	403	63
Pear, callery	837	94	103	24
Pine, Austrian	73	0	0	0
Pine, red	56	0	0	0
Planetree, London	1802	97	352	25
Plum, purpleleaf	47	0	0	0
Poplar, Lombardy	14	0	1	7
Redbud, eastern	16	1	2	19
Serviceberry species	13	1	2	23
Spruce, blue	118	0	1	<1
Spruce, Norway	44	0	0	0
Spruce, white	18	0	0	0
Sweetgum	772	6	19	3
Sycamore, American	233	10	47	25
Tuliptree	314	5	55	19
Walnut, black	28	2	1	11
Walnut, English	22	0	1	5
Yellowwood	28	4	11	54
Zelkova	165	11	19	18
Total	58,536	3,391	8,606	20

1. Trees that could not be identified beyond genus were grouped in a single category (for example, maple species); these categories may have included more than one unknown species. The category "Other Species" includes trees not identified and species comprising less than 0.02% of the total population.