ICE STORM DAMAGE TO URBAN TREES

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Abstract. A damage survey of parkway trees in Urbana, Illinois was made to determine critical removal and repair needs of trees immediately following a severe ice storm. Siberian elm, honeylocust, Bradford pear, common hackberry, pin oak, sycamore, green ash, and tuliptree were among the 25 major parkway tree species that sustained considerable ice damage. Larger diameter trees with broader crowns incurred most of the ice damage. Fine branching pattern, structural weakness, and higher degrees of lateral branching were associated with greater incidence of ice damage. No discernible overall relationship existed between wood specific gravity, modulus of rupture, or modulus of elasticity and susceptibility to ice damage.

Ice storms, also referred to as glaze storms, are regional climatic events that vary considerably in frequency and severity (1,14). During ice storms, supercooled rain falls and freezes on contact with surfaces at or below the freezing point (3). Accumulations have been observed to increase branch weight of trees up to 30 times (1,14,22,26). Ice accretion generally ranges between a trace to 1 inch in additional diameter (3). Accumulations between 1/4 and 1/2 inch can cause small branch and faulty limb breakage, while 1/2 inch to 1 inch thick accumulations can cause conspicuous breakage (18). Branch failure occurs when loading exceeds wood resistance or when constant loading further exacerbates a weakened area in a branch (24). Strong winds increase the potential for damage from ice accumulation (7,14,18,23).

Ice storms occur on a yearly basis in some regions (18). Between 1900 and 1960 in Illinois, 92 ice storms were recorded (8). In Illinois, the central region of the state has the greatest frequency of ice storms and the majority occur between December and March (23).

Previous reports on ice-storm damage to trees have been derived by comparing damaged forests to surrounding, similar undamaged forest stands (27), observation of a set number of damaged or undamaged trees in forested stands and urban areas (9,10,22), sampling damaged areas (2), or measurement of macro-litter accumulation on the forest floor (3). In this study a complete street tree inventory had been taken less than two years prior to an ice storm. Direct comparison of an ice storm damage survey with the pre-storm inventory allowed for determination of urban tree susceptibility to ice storm damage. The purpose of this paper is to describe patterns of ice damage to city trees in Urbana resulting from this intense ice storm. Knowledge of ice storm occurrence and impact on trees can be used to develop plans for emergency situations caused by ice storms and for planning to obtain ice-damage-resistant tree populations in urban areas.

Description of storm. On February 14, 1990 a winter ice storm occurred in Champaign-Urbana. It was one of the most severe ice storms in recent decades. Rainfall was recorded at 1.8 inches during the 10-12 hour period according to the records of the Illinois State Water Survey in Urbana. Ice accumulations between 1/2 and 3/4 inches occurred on exposed surfaces. Winds were 4 mph and from the northeast.

Damage to trees, powerlines, and property was extensive. More than 18,000 homes in Champaign-Urbana lost their power for as long as 8 days due to breakage of ice loaded power structures and damage to these structures resulting from failure of tree stems and branches.

Inventories. A complete street tree inventory for the city of Urbana had been taken in 1988. Tree species; location; diameter at breast height (dbh) at 4.5 feet; condition including root, trunk, and branch injury; disease or insects, crown development and branch structure; physical structures; and tree suitability were measured. Tree value was calculated according to 1988 quidelines of the Council of Tree and Landscape Appraisers (CTLA) (17).

A street tree damage inventory was made by

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the City of Urbana Arbor Division after the 1990 ice storm. Tree location, species, and major damage requiring immediate removal or repair as well as minor damage were recorded at that time. A December 1989 inventory update was used to establish the pre-storm population. Public trees present in the 1989 update sustaining severe damage requiring immediate removal or repair because they were hazardous were used in this analysis. Scientific nomenclature for common names used throughout this paper can be found in Appendix 1.

Results and Discussion

There were 10,713 parkway trees in the city of Urbana according to the 1989 update. There were 24 species of gymnosperms and 123 species of angiosperms. At least 26% (2884 trees) of the street trees were damaged by the storm. Of these trees,about 17% (489 trees) required immediate removal or repair because they were severely damaged and hazardous to life and property (Table 1). These severely damaged trees represented 4.6% of the population. From the damage survey, in addition to the 489 severely damaged trees, 67 trees which were either private trees or public trees such as park trees not accounted for on the 1988 inventory required removal or repair to eliminate public right of way hazards. Only 46 of the 147 parkway tree species in Urbana sustained damage requiring immediate attention.

Eighty five of the severely damaged city trees were in the 12 inch or less dbh class, 187 were in the 13-24 inch dbh class, and 217 trees were greater than 24 inches dbh. Severe damage was sustained by 1.3% of trees 12 inches dbh or less, 6.5% of the 13-24 inch dbh class, and 17.1% of the 24 inch or greater dbh class. A high proportion of angiosperm trees of larger stem diameter, with broader crowns, and often with structural weakness suffered serious damage.

The total value of trees prior to the storm was $13,780,277. Severely damaged city trees were valued at $1,109,413, including $290,796 for trees requiring immediate removal, $796,548 for trees requiring immediate repair, and $22,069 for trees in an intermediate state (Table 2). The value for the removed and repaired trees represents the actual value, as derived by CTLA methods (17), of the damaged trees rather than costs associated with repair or removal. Documentation of damages was used to obtain funding from the Federal Emergency Management Agency to cover losses from the ice storm.

Gymnosperms. Little damage occurred to gymnosperms. Only 3 narrow-leafed conifers, 1 jack pine and 2 bald cypress trees, or 0.6% of 501 total conifers growing on Urbana parkways were injured during the storm. Conifers have been observed to resist ice storm damage (1,10,12,14,18,22). However, conifers are not immune to ice storm damage. Pines including eastern white, Virginia, table-mountain, and pitch pine have been damaged severely by ice storms (18,26,27).

Most narrow-leafed conifers have an excurrent branching habit (13). This form features a dominant central leader and short, horizontal branches which may support their weight against gravitational torque greater than branches which approach the vertical position (15). The typical branch habit and the conical crown of conifers may allow them to resist ice damage.

No parkway arborvitae and few baldcypress trees were damaged by the ice storm. Hundreds of arborvitae trees approximately 25 feet tall in an Urbana windbreak suffered little damage from the storm. There are other reports of the apparent resistance of arborvitae and baldcypress to ice storm damage (9,10,12,22).

Ginkgo was not severely damaged. The majority of ginkgo trees on the parkway were between 2 and 8 inches dbh and the small size may have precluded severe ice storm damage. However, there was little damage to larger ginkgo elsewhere in Urbana. One earlier report indicated that ginkgo resists ice storm damage (26).

Angiosperms. Deciduous angiosperm trees, most of which have a decurrent branching habit (13), seem to be generally more susceptible than conifers to ice storm damage (1,7,12). In Urbana, 486 of the 10,100 angiospermous trees (4.8%) suffered severe damage (Table 1).

Of the 25 major street tree taxa in Urbana, the angiosperms sustaining the most severe damage from the ice storm were Siberian elm (41.7%),

Table 1. Amount of severe damage to trees resulting from a major ice storm by species and dbh class ranked in decreasing order of damage severity.

	Initial number by dbh class (in)				*Percent removed by dbh class*				*Percent repaired by dbh class*			
Tree species*	<13	13-24	>24	total	<13	13-24	>24	total	<13	13-24	>24	total
Siberian elm	48	134	180	362	8.3	33.6	36.1	31.5	10.4	6.7	12.8	10.2
Honeylocust	155	196	10	361	3.2	3.6	0.0	3.3	5.8	12.2	10.0	9.4
Bradford pear	205	1	0	206	7.3	0.0	0.0	7.3	1.5	0.0	0.0	1.5
Hackberry	106	191	90	387	1.9	7.3	5.6	5.4	0.0	0.5	13.3	3.4
Pin oak	39	137	62	238	0.0	0.0	3.2	0.8	0.0	5.1	17.7	7.6
Sycamore	32	258	132	422	0.0	0.4	0.8	0.5	0.0	5.8	9.8	6.6
Green ash	181	80	29	290	1.1	3.8	0.0	1.7	0.6	11.3	17.2	5.2
Tuliptree	58	172	26	256	1.7	1.2	0.0	1.2	0.0	5.8	15.4	5.5
White ash	182	85	73	340	1.1	3.5	0.0	1.5	1.1	3.5	13.7	4.4
Silver maple	224	502	302	1028	0.0	0.6	1.3	0.7	0.0	1.6	8.3	3.2
Bur oak	52	8	4	64	1.9	0.0	0.0	1.6	0.0	0.0	25.0	1.6
Bald cypress	82	8	2	92	0.0	0.0	0.0	0.0	2.4	0.0	0.0	2.2
Norway maple	189	109	10	308	1.6	0.9	0.0	1.3	0.0	0.0	20.0	0.6
Sugar maple	872	352	196	1420	0.3	0.3	1.0	0.4	0.0	2.3	6.6	1.5
Black walnut	25	22	9	56	0.0	0.0	0.0	0.0	0.0	0.0	11.1	1.8
Red maple	672	82	14	768	0.4	1.2	0.0	0.5	0.4	2.4	7.1	0.8
Am. Sweet gum	157	171	5	333	0.6	0.0	0.0	0.3	0.0	1.8	0.0	0.9
L'leaf linden	379	66	0	445	1.1	0.0	0.0	0.9	0.0	0.0	0.0	0.0
White oak	125	5	4	134	0.0	0.0	0.0	0.0	0.0	20.2	0.0	0.7
N. red oak	416	52	8	476	0.0	0.0	0.0	0.0	0.0	0.0	37.5	0.6
Ginkgo	106	6	0	112	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Swamp wt. oak	85	2	0	87	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Arborvitae	67	0	0	67	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Silver linden	61	0	0	61	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Kentucky coffee	52	6	0	58	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other damage (21 taxa)	269	95	70	434	4.8	2.1	1.1	3.2	0.4	4.2	17.1	3.9
Undamaged taxa (101 taxa)				1908								
Totals				10713				2.1				2.5

*Species listed are the 25 most abundant on Urbana city parkways.

honeylocust (12.7%), Bradford pear (8.8%), common hackberry (8.8%), pin oak (8.4%), sycamore (7.1%), green ash (6.9%), and tuliptree (6.6%). Trees sustaining intermediate damage include white ash (5.9%), silver maple (3.9%), and bur oak (3.1%). Angiosperms least damaged include Kentucky coffeetree (0.0%), swamp white oak (0.0%), silver linden (0.0%), northern red oak (0.6%), white oak (0.7%), littleleaf linden (0.9%), American sweetgum (1,2%), red maple (1.3%), black walnut (1.8%), sugar maple (1.9%), and Norway maple (1.9%).

Siberian elm is a brittle, fast-growing species with rough bark and a fine branching pattern which tends to accumulate more ice than trees with less branch surface area. This tree species sustained the greatest damage in Urbana and also in an ice storm in Colorado (4).

Silver maple, noted for weak crotches, weak wood, and susceptibility to wind damage and ice storms (9,22), was damaged only moderately. This might have been due to their tendency to break at the upper or mid branch position when loaded with ice rather than at major branch junc-

Table 2. The pre-storm value of trees that were severely damaged by an ice storm in dollars.

Tree species	Removed	Repaired	Other	Total
Norway maple	4,888	7,254	0	12,142
Red maple	7,465	17,253	0	24,718
Sugar maple	12,686	125,519	300	138,506
Silver maple	9,420	53,899	0	63,319
Hackberry	62,957	111,845	3,146	177,948
White ash	8,204	39,133	4,240	51,578
Green ash	8,713	42,138	1,368	52,219
Honeylocust	15,045	53,695	0	68,714
Am. Sweetgum	684	7,713	0	8,397
Tuliptree	6,217	70,928	0	77,144
Bradford pear	9,180	600	600	10,380
Sycamore	5,371	75,285	0	80,657
White oak	0	7,695	0	7,695
N. red oak	0	19,557	12,215	31,772
Bur oak	7,133	600	0	7,733
Pin oak	8,291	69,538	0	77,829
L'leaf linden	1,700	0	200	1,900
Baldcypress	0	400	0	400
Siberian elm	120,495	37,139	0	157,633
Black walnut	0	4,122	0	4,122
Other (21 taxa)	2,347	52,234	0	54,581
Totals	290,796	796,548	22,069	1,109,413

*Trees in other column were marginal between requiring immediate removal or repair. Small discrepancies in table are due to rounding errors.

Table 3. Common wood physical and mechanical properties related to strength for tree species in Urbana ranked in descending order of ice storm damage severity.

Tree species	Specific[1] gravity (g/cm^3)	Modulus[1] of rupture (psi)	Modulus[1] of elasticity (psi 10^6)	Percent damaged
Siberian elm				41.7
Honeylocust	.60	10,200	1.29	12.7
Bradford pear				8.8
Hackberry	.49	6,500	0.95	8.8
Pin oak	.58	8,300	1.32	8.4
Sycamore	.46	6,500	1.06	.71
Green ash	.53	9,500	1.40	6.9
Tuliptree	.40	6,000	1.22	6.6
White ash	.55	9,600	1.44	5.9
Silver maple	.44	5,800	0.94	3.9
Bur oak	.58	7,200	0.88	3.1
Baldcypress	.42	6,600	1.18	2.2
Norway maple				1.9
Sugar maple	.56	9,400	1.55	1.9
Black walnut	.51	9,500	1.42	1.8
Red maple	.49	7,700	1.39	1.3
Am. sweetgum	.46	7,100	1.20	1.2
L'leaf linden				0.9
White oak	.60	8,300	1.25	0.7
N. red oak	.56	8,300	1.35	0.6
Ginkgo				0.0
Swamp wt. oak	.64	9,900	1.59	0.0
Arborvitae	.29	4,200	0.64	0.0
Silver linden				0.0
Kentucky coffeetree				0.0

[1]USDA (1974)

tures. In addition, silver maples in Urbana had been pruned regularly since 1976, possibly contributing to the low incidence of major damage. Pruning to remove structurally weak branches is probably an effective strategy to minimize ice storm damage.

Tuliptree suffered moderate to severe damage from the Urbana ice storm. Severe damage to tuliptree has occurred in other ice storms (7,20,27). Some reports indicate low susceptibility (2) and moderate susceptibility of tuliptree to ice storm damage (18). Plant age, site, and structural integrity probably account for the differing reports (28).

Norway maple and sugar maple sustained little severe damage. Norway maple seems to resist ice storm damage (9,10). Although we observed little damage to sugar maple, other reports indicate this species is intermediate in susceptibility (9,18,22).

Sycamore trees sustained severe ice storm damage in Urbana. Reports indicate that ice damage can range from little to severe for sycamore (2,12,14). Anthracnose (Apiognomonia veneta) infects sycamore annually in Urbana. This disease sometimes causes death of twigs and loss of terminal bud dominance (16). Lateral buds then assume temporary dominance causing a proliferation of shoots along branches. It is possible that the increased surface area which occurs as a result of anthracnose may increase the susceptibility of sycamore.

The small size of Kentucky coffeetree, silver linden, and littleleaf linden in Urbana probably accounted for their avoidance of ice damage. Nonetheless, 15% of the littleleaf lindens (66 trees) were between 13 and 24 inches dbh and none were damaged. Kentucky coffeetree has previously been reported to be resistant to an ice storm (14).

Most trees that are small at maturity sustained minor damage. Examples include ironwood, serviceberry, Eastern redbud, and amur maple. Ironwood has previously been reported resistant to ice storms (3,22).

Bradford pear were severely damaged by ice accumulation. Bradford pears often have narrow crotches with included bark. Included bark is responsible for weak branch attachment. In contrast, the Aristocrat pear has branches that are more horizontal with a wider crotch angle (11) and exhibited greater ice storm resistance than Bradford pear. Of the 21 Aristocrat pear between 3 and 9 inches dbh, none was damaged.

Pin oak suffered greater damage than northern red oak, white oak, and swamp white oak. The majority of pin oak were greater than 12 inches in dbh and this species has a finer pattern of branching than other local oak species. The majority of northern red oak, white oak, and swamp white oak in Urbana were less than 13 inches in dbh. The lack of damage to these species on Urbana parkways may be attributable to their smaller diameter and coarser branching patterns.

Damage in local native hardwood forests occurred at forest edges where longer and lower branches exist. The narrow, high crowns of forest trees were less susceptible to damage than the crowns of open-grown urban trees. Among the common native upland oak species, only a few northern red oaks, which have a shallower rooting pattern than other native upland oak species, were uprooted by the gravitational pull of accumulated ice. Other authors report northern red oak intermediate in susceptibility to ice damage (1,3,18,22).

Cannell and Morgan (5) studied branch breakage under snow and ice loads and found that branching patterns affect the capability of a branch to resist ice damage. Shoots with laterals are more likely to fail under an ice load than shoots of the same midpoint diameter or length without laterals. Observations from this ice storm are consistent with the idea that branch breakage increases with the degree of lateral branching and density of small branches (4,15,22). For example, heavily-damaged Siberian elm and common hackberry exhibit a high density of small branches.

In addition to crown architecture, pre-storm conditions such as an imbalanced crown, included bark, or dead wood may have predisposed a tree to ice damage. The majority of damaged Siberian elm, common hackberry, and honeylocust inventoried in 1988 had been reported to have structural imperfections, disease symptoms, or insect damage. Butler and Swanson (4) suggested that structurally weak crotches were the principal cause for honeylocust damage in an ice storm.

No apparent relationships exist between ice storm damage susceptibility and specific gravity, modulus of rupture, or modulus of elasticity of a tree species (Table 3). Hence, the strength of wood seems less important in ice-accumulation tolerance than the capacity to accumulate ice until it surpasses the bearing capacity of branches.

Cannel and Morgan (6) believe that measures of branch and trunk strength derived from standardized tests such as modulus of elasticity should include intact bark, as branches and trunks naturally contain bark. The bending of tree branches from ice or snow accumulation more closely fits the structural theory for cantilever beams where one end is fixed and the other is free, rather than modulus of elasticity tests in which a sample is supported on both ends (19). Redden (21) states that a tree is bound together primarily by cantilever joints with inherent characteristics that allow bending and twisting in response to loading by wind, snow, and ice.

An ice storm tolerance rating of commonly planted urban trees was developed from the results of this and other ice storm studies (Table 4). Rankings follow the majority findings of published reports and are not totally consistent with our findings from the Urbana ice storm.

Summary

Trees with an excurrent branching habit (conical form) such as conifers and young American sweetgum, and species with less branch surface area, such as black walnut, American sweetgum, ginkgo, Kentucky coffeetree, white oak, and northern red oak showed the least damage due to ice accumulation. There was no clear relationship between specific gravity of wood, modulus of elasticity, or modulus of rupture and tolerance of

Table 4. Ice storm susceptibility of tree species commonly planted in urban areas.

Susceptible	Intermediate	Resistant
Siberian elm[lm]	White ash[cehijm]	Eastern hemlock[dehk]
American elm[bcefghj]	Red maple[cdegijklm]	Arborvitae[acefgm]
Honeylocust[m]	Northern red oak[cdhjkm]	Baldcypress[am]
Common hackberry[bcjm]	Tuliptree[eghiklm]	Norway maple[fgm]
Bradford pear[m]	Sycamore[bekm]	Catalpa[cfl]
American linden[cehj]	Eastern white pine[dehm]	Ginkgo[am]
Black cherry[ehjk]	Bur oak[cm]	American sweetgum[m]
Black locust[cde]	Sugar maple[cfghjm]	White oak[bcdikm]
Silver maple[abcfghm]		Swamp white oak[cm]
Pin oak[m]		Littleleaf linden[m]
Green ash[m]		Silver linden[m]
		Kentucky coffeetree[bm]
		Black walnut[fm]
		Ironwood[cjm]
		Blue beech[ck]

Sources:
a von Schrenk (1900), **b** Harshberger (1904), **c** Rogers (1923), **d** Abell (1934), **e** Downs (1938), **f** Croxton (1939), **g** Deuber (1940), **h** Lemon (1961), **i** Whitney (1984), **j** Bruederle (1985), **k** Boerner (1988), **l** Pirone (1988), **m** This study (1993)

trees to ice accumulation. Oak trees and honeylocust both possess strong, dense wood. Overall, oaks (except pin oak) generally avoided damage, while honeylocust trees did not. Horizontal branching in some trees seemed to be as good or better in resisting breakage due to ice accumulation than branches approaching near vertical position, such as Bradford pear.

These observations provide information useful in selecting trees with tolerance to ice accumulation. Further study will be necessary to precisely predict the degree to which characteristics of a given tree species interact to afford tolerance of ice accumulation.

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Résumé. Un inventaire des dommages sur les arbres de routes à paysage aménagé à Urbana, Illinois aux États-Unis, a été entrepris immédiatement après une violente tempête de verglas afin d'identifier les cas critiques à abattre et ceux nécessitant des réparations. L'orme de Sibérie, le févier inerme, le poirier Bradford, le micocoulier occidental, le chêne des marais, le sycamore, le frêne rouge et le tulipier comptaient parmi les 25 espèces majeures d'arbres de rues qui ont éprouvé des dommages considérables dus au verglas. Les arbres de plus gros diamètres avec des cimes étendues latéralement ont subi le plus de dommages par le verglas. Une structure en branches effilées et la proportion en branches latérales de la cime ont été des facteurs associés à une incidence plus élevée de dommages par le verglas. Aucune relation d'ensemble discernable s'est dégagée entre la gravité spécifique du bois et son module de rupture ou d'elasticité avec les dommages causés par le verglas.

Zusammenfassung. Direkt nach einem Eissturm wurde eine Schadensbestandaufnahme von Bäumen, die an Parkwegen in Urbana, Illinois/USA, durchgeführt um entscheidende Entfernungs- und Reparaturmaßnahmen für die Bäume zu entwickeln. Sibirische Ulme, Gledetschie, Bradford-Birne, Zürgelbaum, Sumpfeiche, Bergahorn, Grünesche und Tulpenbaum waren unter den 25 Hauptbaumarten, die erheblich unter dem Eisschaden gelitten haben. Bäume mit größerem Stammdurchmesser und breiteren Kronen hatten den größten Schaden zu verzeichnen. Feine Verästelungen und der Anteil seitlicher Äste waren Faktoren, die mit dem Auftreten von Eisschäden in Verbindung gebracht wurden. Es bestand kein eindeutiger Zusammenhang zwischen dem spezifischen Holzgewicht, dem Bruchmodul oder dem Elastizitäts- und Empfindlichkeitsmodul und dem Eisschaden.

Appendix 1. Scientific nomenclature for common names used in this study.

Common name	Scientific name
Amur maple	*Acer ginnala*
Norway maple	*Acer platanoides*
Red maple	*Acer rubrum*
Silver maple	*Acer saccharinum*
Sugar maple	*Acer saccharum*
Serviceberry	*Amelanchier* spp.
Blue beech	*Carpinuscaroliniana*
Catalpa	*Catalpa* spp.
Common hackberry	*Celtis occidentalis*
Eastern redbud	*Cercis canadensis*
White ash	*Fraxinus americana*
Green ash	*Fraxinus pennsylvanica*
Ginkgo	*Ginkgo biloba*
Honeylocust	*Gleditsia triacanthos* var. inermis
Kentucky coffeetree	*Gymnocladus dioicus*
Black walnut	*Juglans nigra*
American sweetgum	*Liquidambar styraciflua*
Tuliptree	*Liriodendron tulipifera*
Ironwood	*Ostrya virginiana*
Jack pine	*Pinus banksiana*
Table-mountain pine	*Pinus pungens*
Pitch pine	*Pinus rigida*
Eastern white pine	*Pinus strobus*
Virginia pine	*Pinus virginiana*
Sycamore	*Platanus occidentalis*
Black cherry	*Prunus serotina*
Aristocrat pear	*Pyrus calleryana* 'Aristocrat'
Bradford pear	*Pyrus calleryana* 'Bradford'
White oak	*Quercus alba*
Swamp white oak	*Quercus bicolor*
Bur oak	*Quercus macrocarpa*
Pin oak	*Quercus palustris*
Northern red oak	*Quercus rubra*
Black locust	*Robinia pseudoacacia*
Baldcypress	*Taxodium distichum*
Arborvitae	*Thuja occidentalis*
American linden	*Tilia americana*
Littleleaf linden	*Tilia cordata*
Silver linden	*Tilia tomentosa*
Eastern hemlock	*Tsuga canadensis*
American elm	*Ulmus americana*
Siberian elm	*Ulmus pumila*