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Tree Species Susceptibility To Ice Storm Damage

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Ice storms have three components which interact to cause tree damage: ice accumulation, duration of ice on trees, and associated wind loads. Major ice storms are events causing millions of dollars in property and infrastructure damage, and occur periodically. These major ice storm events generate huge amounts of downed tree crown material, as well as complete tree loss, as direct impacts. In years following major storms, residual tree damage and mortality directly associated with these events continue to affect landscapes, forests, and right-of-ways.

Across Eastern North America, there have been many studies of localized and regional ice storm events causing significant tree damage and loss. In this publication, 16 studies (some of which report multiple studies) suggest different tree species have various susceptibility or resistance to ice storm damage. This publication is an attempt to establish composite (multiple study) susceptibility to ice storm damage lists for various tree species. This is not a comprehensive review of the literature, but a selected examination of more recent studies from catastrophic ice storms in Eastern North America.

Problems?

Attempting to consolidate results from multiple studies into a tree species susceptibility list has many problems. One issue is tree species susceptibility or resistance to ice storm damage citations are camparisions to neighboring species noticed by observers, not individual camparisions to all other tree species in the area. As such, some lists have only a few species. Also, tree species damage is highly variable with many compounding factors including species, site, topography, and ice storm attribute differences. Damage variation within a tree species is dependent upon complex features of individual tree position in a landscape, as well as impact by specific ice storm forces. Even with these concerns, there is value in looking at composite tree species ice load susceptibility values.

Before The ‘90s

An early 1961 study assigned tree species susceptibility classes. Figure 1 provides a relative list of 18 tree species divided into three susceptibility classes. White ash (*Fraxinus americana*), shagbark hickory (*Carya ovata*), red spruce (*Picea rubens*), and yellow birch (*Betula alleghaniensis*) were listed as most resistant to ice damage. (Lemon 1961)

A 1985 study in Wisconsin examined tree susceptibility to ice storm damage stemming from impacts of approximately 5 inches of ice accumulation and 50 mph wind gusts. Thirty-five percent (35%) of the total canopy was lost in measured areas. Figure 2 shows three classes of tree species susceptibility to ice storm

damage. Hickory (*Carya* spp.), Eastern hophornbeam (*Ostrya viginiana*), and basswood (*Tilia americana*) were found to be least susceptible or most resistant to ice damage. (Bruederle & Stearns 1985)

One study in the Appalachian Plateau region in 1988 occurred after an ice storm with 1.2 inches of ice accumulated. Approximately 16% of all trees were severely damaged. One means of estimating relative ice storm damage was in developing a Damage Importance Percent (DIP) which accounts for a species' basal area and percent of that species damaged in a stand. Figure 3 provides a list of 14 tree species and their Damage Importance Percent. Northern red oak (*Quercus rubra*) and pitch pine (*Pinus rigida*) were cited with the most damage for their importance in a stand, and hornbeam (*Carpinus caroliniana*) and yellow-poplar (*Liriodendron tulipifera*) were the least damaged. (Boerner et.al. 1988)

Figure 4 shows three damage susceptibility classes for tree species ranging from highly susceptible to low susceptibility to ice loads. In this figure, red pine (Pinus resinosa), pitch pine (*Pinus rigida*), Eastern hemlock (*Tsuga canadensis*), and Northern red oak (*Quercus rubra*) were cited as highly susceptible to ice damage. Note this study also surveyed four other studies. (Boerner et.al. 1988)

1990 To 1995

A 1993 New York study examined tree species susceptibility to ice damage across nine major ice storms from 1923-1991. Figure 5 demonstrates three classes of composite susceptibility. Five genera are listed along with nine species. Willow species (*Salix* spp.), black cherry (*Prunus serotina*), and cottonwood / aspen species (*Populus* spp.) were most susceptible to ice damage, and white oak (*Quercus alba*) and hickory species (*Carya* spp.) were least susceptible or most resistant to damage. (Seischab et.al. 1993)

In the same study, tree species were scored for the amount of canopy damage sustained under ice loads. Figure 6 provides tree canopy percent damaged in an ice storm, dividing species with above average and below average crown damage. Sugar maple (*Acer saccharum*) had an average amount of damage. Sassafras (*Sassafras albidum*), black willow (*Salix nigra*), and black cherry (*Prunus serotina*) sustained the most damage, and yellow birch (*Betula alleghaniensis*), American elm (*Ulmus americana*), and green ash (*Fraxinus pennsylvanica*) sustained the least damage. In this study, species suscepitibility for Eastern hemlock (*Tsuga canadensis*) was opposite the 1988 study mentioned earlier. Note many tree species vary greatly in susceptibility by ice storm, location, and observer. (Seischab et.al. 1993)

A 1993 paper examined tree species susceptibility for the 1990 Illinois ice storm where 0.5 to 0.75 inches of ice accumulated. Figure 7 provides tree susceptibility to ice damage in three classes. A relative large number of tree species were considered resistant to ice damage. Figure 8 shows the percent of community trees damaged most severely. Siberian elm (*Ulmus pumila*) was by far the largest casualty of ice damage. (Hauer et.al. 1993)

A 1995 study in New York examined results from a 1991 ice storm with 0.8 inches of ice accumulated. A Relative Storm Damage (RSD) value was determined for select tree species. The RSD value helps determine the importance of a tree species within the whole population of trees, and how many trees sustained more than 50% crown loss. Figure 9 shows 13 tree species divided into three ice load susceptibility classes and provides a RSD value for each. If the RSD value is >1.0, then a tree species would be considered susceptible to ice storm damage. Sugar maple *(Acer saccharum*), green ash (*Fraxinus pennsylvanica*), London planetree (*Platanus X hispanica*), and callery pear (*Pyrus calleryana*) were found susceptible to ice damage. Some of these species observations for tree susceptibility to ice damage were much different than found in earlier studies. (Sisinni et.al. 1995)

1996 To 1999

A 1997 study in Missouri old growth under 1 inch ice accumulation lasting >5 days resulted in 27% of all trees damaged with 7% severely damaged. Figure 10 provides a susceptibility index value for select tree species greater than four inches in diameter. The larger the value, the more susceptible a tree species to ice damage. Basswood (*Tilia americana*) and American elm (*Ulmus americana*) were most susceptible to ice damage, and black walnut (*Juglans nigra*) and shagbark hickory (*Carya ovata*) were least susceptible or most resistant to ice damage. (Rebertus et.al. 1997)

In the Southern Appalachians (Virginia) with a recurrence rate for major ice storms every 20 years, one 1999 study listed relative overstory tree damage. Figure 11 compares four overstory tree species and severity of ice damage. Note evergreen species top the list. This study observed 22% of overstory trees were damaged, with a majority of damaged trees up-rooted. (Rhoades 1999)

Another 1999 study in Virginia pulled together ice storm damage from seven (7) different studies ranging from 1959-1993. Figure 12 provides a composite value of species susceptibility to ice storm damage for Angiosperm trees. Hickory species (*Carya* spp.), sycamore (*Platanus occidentalis*), and black walnut (*Juglans nigra*) were strongly resistant to ice damage. Boxelder (*Acer negundo*) and basswood (*Tilia americana*) were most susceptible or least resistant to ice damage. Again, some tree species susceptibility values observed in this study differed greatly from other studies. (Warrillow & Mou 1999)

Figure 13 provides a relative susceptibility to ice damage among six Gymnosperm trees. Virginia pine (*Pinus virginiana*) was most susceptible or least resistant to ice damage, and longleaf pine (*Pinus palustris*), loblolly pine (*Pinus taeda*), and hemlock (*Tsuga canadensis*) were most resistant to ice damage. Comparing tree species in this study using ice damage susceptibility values, most Angiosperms are more susceptible to ice damage than Gymnosperms. (Warrillow & Mou 1999)

Figure 14 sorts tree species susceptibility to ice damage into a gradient of 16 species listed from most resistant to damage (least susceptible) to least resistant to damage (most susceptible). Pines (*Pinus* ssp) were listed as least resistant to ice storm damage among species listed, and yellow-poplar (*Liriodendron tulipifera*) and yellow buckeye (*Aesculus flava*) were most resistant to damage across seven studies. (Warrillow & Mou 1999)

2000 To 2004

A 2000 study looked at the 1998 Northeastern North American ice storm, especially how it impacted trees in Maine (USA) and Quebec (CAN). The categories of moderate, heavy, severe, or very severe ice storm damage accounted for ~31% to ~36% of trees measured. Figure 15 divides tree species susceptibility / resistance to ice storm damage into three classes. A large number of tree species were considered low resistance or susceptible to ice damage. Note seven entries are genera only. (Irland 2000)

In a 2001 study of old growth trees which had sustained a >3 inch ice accumulation, 97% of all trees lost some crown and branch volume. Greater than 50% of crown loss (severe class) was sustained by 35% of trees examined. Figure 16 provides a relative ice damage score for ten (10) tree species, with the lower number representing tree species more resistant or less susceptible to ice storm damage. White ash (*Fraxinus americana*) and basswood (*Tilia americana*) showed the most damage, with hemlock (*Tsuga canadensis*) showing the least damage. (Duguay et.al. 2001)

In a 2002 study in a Southern Appalachian area where ice storms have a return rate of once every 2-4 years, a tree species damage list was prepared. Figure 17 shows a tree species list by percent of total basal area damaged and dominant damage type. This list shows the most and least damaged tree species

(percent column). The dominant form of damage and its severity did not seem to match up with the damage percent. For example, white ash (*Fraxinus americana*) has a low damage percentage, but is listed as having bending and stem breakage problems, while beech (*Fagus grandifolia*) has a relative high percentage of damage, but its dominant damage is bending only. (Rhoads et.al. 2002)

A 2004 study also examined the massive 1998 ice storm which hit Northeast North America with areas of 2.4 to 3.5 inches of ice accumulation. Of the trees examined, 60% had some crown loss, with crown loss per tree averaging 23%. Figure 18 shows tree species susceptibility to ice damage in three classes. Here, oaks (*Quercus* spp.), ironwood (*Ostrya virginiana*), and pine species (*Pinus* spp) were least susceptible to ice storm damage. American elm (*Ulmus americana*), basswood (*Tilia americana*), black cherry (*Prunus serotina*), and cottonwood / aspen species (*Populus* spp) were most susceptible to ice storm damage. (Brommit et.al. 2004)

2005 And Beyond

A collection of tree species susceptibility to ice damage studies were reviewed in Tremblay et.al. 2005. This paper reviewed 11 Eastern North American ice storm damage rating lists. Figure 19 is a composite average ice damage value from the studies reviewed divided into three classes. Note six of the tree groups listed are genera only. An ice storm damage value of two (2) acts as the center point of this distribution. Willow species (*Salix* spp.) were cited as highly susceptible to ice damage, while white oak (*Quercus alba*) was listed as low susceptibility. It was interesting to note within five (5) years of ice storm damage, some species listed as either low or high susceptibility to ice damage sustained significant mortality. (Tremblay et.al. 2005)

A 2007 study in Virginia examined tree species susceptibility to ice storm damage. This storm caused >17% of trees larger than 24 inches DBH to sustain severe damage. Figure 20 provides select tree species susceptibility to ice damage in three classes. Pin oak (*Quercus palustris*) and Northern red oak (*Quercus rubra*) were cited as resistant to ice damage. Note the exotic Alaskan white-cedar (*Chamaecyparis nootkatensis*) was cited as susceptible to ice damage. (Rhoades & Stipes 2007)

A 2012 study in Kentucky with trees under one (1) inch of ice accumulation developed tree species susceptibility index values. Figure 21 shows four classes of damage susceptibility and numeric index values for select tree species. White oak (*Quercus alba*) and sassafras (*Sassafras albidum*) showed no significant damage, while Eastern hophornbeam (*Ostrya virginiana*) and red maple (*Acer rubrum*) were listed as sustaining severe damage. (Vowels 2012)

A Composite List

Ice storm, site, and tree attributes are highly variable across a landscape, and all interact in complex and chaotic ways. Observations of tree species susceptibility to ice damage is also highly variable and appears contradictory across many studies. If all previous studies cited have their tree species susceptibility list combined, an Eastern North America composite list is generated. Remember, some citations actually reviewed multiple other studies, and so generated multiple counts. Figure 22 is a list of tree species susceptibility to ice storm damage averaged across all citations. All susceptibility values were combined into a one (1) to three (3) scale, with 1 being resistant to damage and low susceptibility, and 3 being susceptible and subject to heavy damage from ice storms. There is a large number of tree species categorized as to ice storm damage susceptibility.

In addition to individual species and genera susceptibility lists, a list of tree family group susceptibility to ice damage was developed from composite data from earlier discussed studies.. Figure 23

catalogs, by tree family, susceptibility to ice storm damage. This list is divided into three parts – resistant (1.0-1.5), intermediate (1.6-2.4), and susceptible (2.5-3.0) to ice storm damage. There is great variation among tree species even within the same family. Cypress, sycamore, maple, willow, locust, and elm family groups are most susceptible. Family group does not help determine ice storm damage susceptibility well.

Most Evaluated

Of all tree species ranked or rated with an ice storm damage susceptibility value, only a few species were mentioned in enough studies to allow strong comparisons. Figure 24 shows trees species cited greater than 6 (six) times in reviewed studies, and their average ice storm damage susceptibility rating. Also included is the variation among authors in rating a species. Note almost all species have been cited as having a susceptibility ranging from 1 (resistant) to 3 (susceptible). For example, red maple (*Acer rubrum*) was rated by different studies as either highly suscepitible or highly resistant to ice damage. Across many studies, the average rating for red maple was 2.1 (intermediate). Clearly other tree, site and storm differences impact ice storm damage in addition to species alone.

Summing Up

In summary, Figure 25 provides a list of tree species cited as susceptible to, or at high risk of, ice storm damage. Species cited only once were not included. Figure 26 provides a list of tree species cited as intermediate or moderately susceptible to, or at moderate risk of, ice storm damage. Again, species cited only once were not included. Figure 27 provides a list of tree species cited as resistant to, or at low risk of, ice storm damage. Species cited only once were not included.

Figure 28 provides a list of the most and least susceptible tree species to ice storm damage across Eastern North America. The list of most susceptible tree species to ice damage is filled with some of the usual suspects in catastrophic tree failures during ice storms. The most resistant list of tree species to ice storm damage does not contain a number of tree species with strong, dense wood, or considered long-lived. Clearly there are many factors involved with tree species susceptibility to ice storm damage.

Conclusion

It is evident from these studies and composite figures, tree species alone is not a sole determinator of ice damage. Additional attributes of tree, site, and storm are needed to estimate damage level in addition to species. A tree's susceptibility to ice storm damage is also tied to severity of ice storm, structural components of tree and site, vulgarities of past tree and site damage, and individual tree growth form. Tree species inventory counts alone would not generate a reliable damage assessment index for a community forest or stand of trees.

Citation:

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species	susceptability
Betula alleghaniensis	R
Carya ovata	R
Fraxinus americana	R
Picea rubens	R
Acer saccharum	I
Betula populifolia	I
Fagus grandifolia	I
Liriodendron tulipifera	I
Pinus strobus	I
Populus tremuloides	I
Quercus rubra	I
Tsuga canadensis	I
Acer saccharinum	S
Juglans cinerea	S
Populus deltoides	S
Prunus serotina	S
Tilia americana	S
Ulmus americana	S

S = susceptible; I = intermediate; R = resistant.

Figure 1: Susceptability of tree species to ice damage.
(Lemon 1961)

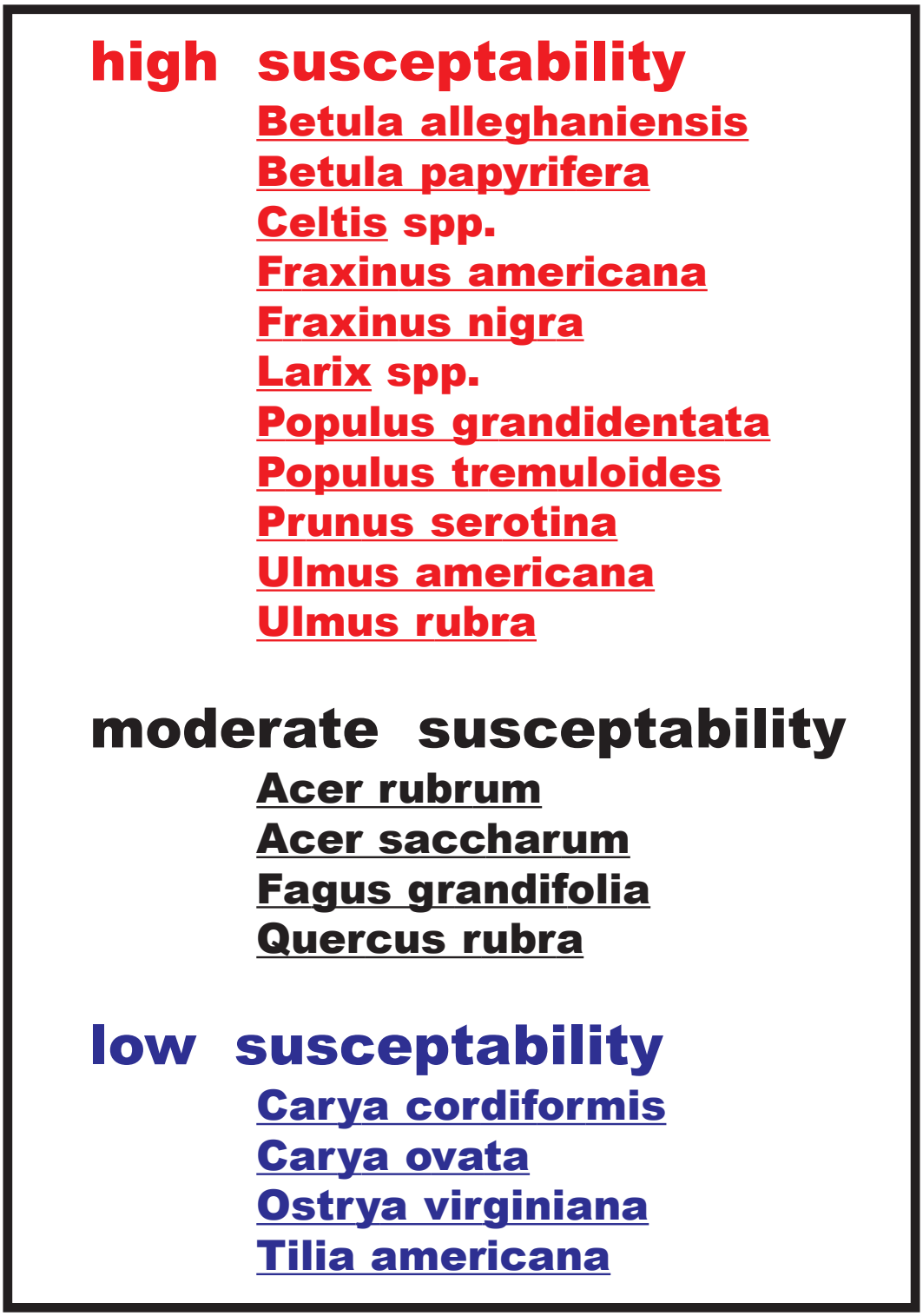

Figure 2: Tree species susceptability to ice damage after a major ice storm with 50 mph gusts and ~5 inches ice accumulation. (Bruederle & Stearns 1985)

species	DIP
Quercus rubra	**30**
Pinus rigida	**29**
Tsuga canadensis	**24**
Fagus grandifolia	**19**
Acer rubrum	**19**
Pinus resinosa	**18**
Cornus florida	**18**
Oxydendrum arboreum	**18**
Prunus serotina	**17**
Quercus alba	**13**
Quercus montana	**12**
Fraxinus americana	**10**
Carpinus caroliniana	**8**
Liriodendron tulipifera	**5**

DIP = (species basal area + percent trees damaged of species) / 2.

Figure 3: Damage Importance Percent (DIP) for severe ice impacts (larger number = more severe damage from ice).
(modified from Boerner et.al. 1988)

species	damage susceptibility
Pinus resinosa	H
Pinus rigida	H
Quercus rubra	H
Tsuga canadensis	H
Acer rubrum	I
Cornus florida	I
Fagus grandifolia	I
Oxydendrum arboreum	I
Prunus serotina	I
Quercus alba	I
Quercus montana	I
Betula lenta	L
Carpinus caroliniana	L
Fraxinus americana	L
Liriodendron tulipifera	L
Ulmus spp.	L

H = highly susceptible to ice damage; I = intermediate; L = low susceptability to ice damage.

Figure 4: Tree species damage susceptibility to ice storms.
(derived from Boerner et.al. 1988)

species	ice damage susceptibility value	class
Salix spp.	**3.0**	**H**
Prunus serotina	**2.8**	**H**
Populus spp.	**2.8**	**H**
Tilia americana	**2.7**	**H**
Ulmus spp.	**2.3**	**H**
Acer rubrum	**2.0**	**M**
Quercus rubra	**2.0**	**M**
Quercus velutina	**2.0**	**M**
Fagus grandifolia	**1.8**	**M**
Acer saccharum	**1.8**	**M**
Tsuga canadensis	**1.7**	**L**
Fraxinus spp.	**1.5**	**L**
Quercus alba	**1.2**	**L**
Carya spp.	**1.1**	**L**

value 3 = highly susceptible to ice damage = H class
value 2 = moderately susceptable to ice damage = M class
value 1 = low susceptability to ice damage = L class

Figure 5: Tree species susceptibility to ice damage across 9 major ice storms (1923-1991). (Seischab 1993)

species	canopy damage (%)	
Sassafras albidum	60	above average damage
Salix nigra	47	
Prunus serotina	45	
Quercus velutina	33	
Quercus rubra	30	
Acer rubrum	25	
Tilia americana	24	
Acer saccharinum	21	
Acer saccharum	20	average
Populus deltoides	18	below average damage
Fagus grandifolia	18	
Fraxinus americana	17	
Carya cordiformis	17	
Ostrya virginiana	16	
Quercus alba	15	
Tsuga canadensis	14	
Carpinus caroliniana	13	
Betula alleghaniensis	11	
Ulmus americana	10	
Fraxinus pennsylvanica	9	

Figure 6: Tree species canopy damage percent in ice storm.
(Seischab 1993)

species	class	species	class
Celtis occidentalis	S	Acer platanoides	R
Fraxinus pennsylvanica	S	Acer rubrum	R
Gleditsia triacanthois	S	Acer saccharum	R
Liriodendron tulipifera	S	Carpinus caroliniana	R
Platanus occidentalis	S	Catalpa speciosa	R
Prunus serotina	S	Ginkgo biloba	R
Pyrus calleryana	S	Gymnocladus dioicus	R
Quercus palustris	S	Juglans nigra	R
Robinia pseudoacacia	S	Liquidambar styriciflua	R
Tilia americana	S	Ostrya virginiana	R
Ulmus americana	S	Quercus bicolor	R
Ulmus pumila	S	Quercus rubra	R
		Quercus alba	R
Acer rubrum	I	Taxodium distichum	R
Acer saccharinum	I	Thuja occidentalis	R
Fraxinus americana	I	Tilia cordata	R
Pinus strobus	I	Tsuga canadensis	R
Quercus macrocarpa	I		
Quercus rubra	I		

S = susceptible; I = intermediate; R = resistant.

Figure 7: Tree species susceptibility to ice damage (0.5 - 0.75 inch ice). (Hauer et.al. 1993)

species	percent severely damaged
Ulmus pumila	**42%**
Gleditsia triacanthois	**13%**
Celtis occidentalis	**9%**
Pyrus calleryana	**9%**
Quercus palustris	**8%**
Fraxinus pennsylvanica	**7%**
Liriodendron tulipifera	**7%**
Platanus occidentalis	**7%**

Figure 8: Percent of community trees damaged most severely under 0.5 - 0.75 inches of ice by species.
(Hauer et.al. 1993)

species	RSD	class
Fraxinus pennsylvanica	2.5	S
Acer saccharum	1.8	S
Platinus X hispanica	1.2	S
Pyrus calleryana	1.1	S
Acer platanoides	1.0	I
Gleditsia triacanthos	0.9	I
Acer rubrum	0.8	I
Tilia cordata	0.7	I
Acer saccharinum	0.4	R
Quercus rubra	0.3	R
Liquidambar styraciflua	0.2	R
Malus coronaria	0.2	R
Ginkgo biloba	<0.1	R

S = susceptible; I = intermediate; R = resistant.

Figure 9: Relative Storm Damage (RSD) of select trees under 0.8 inches of ice. RSD = % of a tree species with >50% crown loss / % of tree species among all trees in the total population. (Sisinni et.al. 1995)

species	susceptibility index X 100
Tilia americana	92
Ulmus americana	70
Acer saccharum	58
Quercus rubra	58
Carya cordiformis	51
Fraxinus american	47
Amelanchier arborea	42
Ulmus rubra	42
Quercus velutina	39
Quercus alba	25
Ostrya virginiana	24
Juglans nigra	17
Carya ovata	13

Figure 10: Tree species susceptibility to a long duration, 1 inch ice accumulation, ice storm. Larger value = more susceptible to ice damage. (derived from Rebertus et.al. 1997)

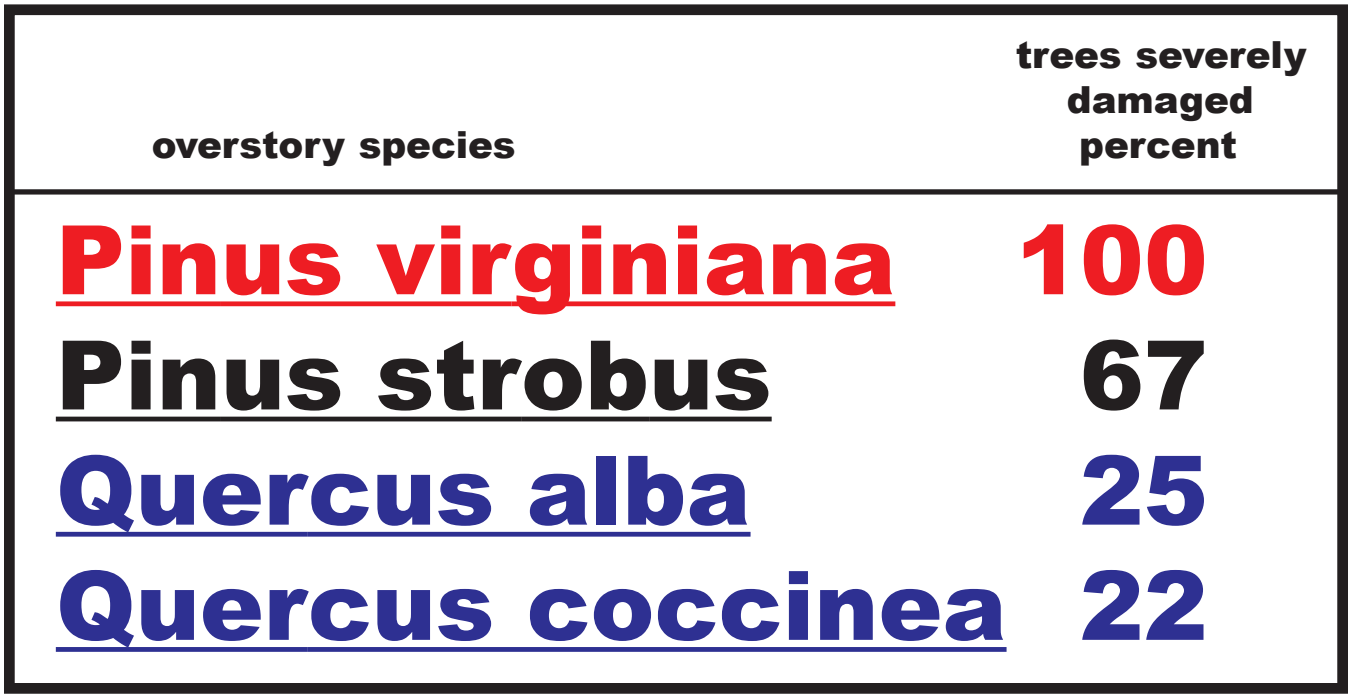

Figure 11: Overstory tree species damaged in Southern Appalachian ice storm. (derived from Rhoades 1999)

species	ice damage susceptibility value	ice damage resistance class
Acer negundo	3.0	weak
Tilia americana	2.9	weak
Prunus serotina	2.7	weak
Ulmus spp.	2.6	weak
Quercus coccinea	2.7	weak
Populus spp.	2.5	weak
Betula alleghaniensis	2.3	moderate
Betula lenta	2.3	moderate
Acer rubrum	2.3	moderate
Robinia pseudoacacia	2.2	moderate
Acer saccharum	2.2	moderate
Quercus alba	2.1	moderate
Liriodendron tulipifera	2.0	moderate
Quercus rubra	2.0	moderate
Magnolia acuminata	2.0	moderate
Nyssa sylvatica	2.0	moderate
Quercus velutina	2.0	moderate
Fagus grandifolia	2.0	moderate
Fraxinus spp.	2.0	moderate
Carya spp.	1.3	strong
Platanus occidentalis	1.0	strong
Juglans nigra	1.0	strong

ice damage susceptibility values:
1 = strong resistance; 2 = moderate resistance; 3 = weak resistance

Figure 12: Angiosperm tree species susceptibility to ice damage across 7 studies (1959-1993). (Warrillow & Mou 1999)

species	ice damage susceptibility value	ice damage resistance class
Pinus virginiana	3.0	weak
Pinus elliottii	2.0	moderate
Pinus strobus	1.9	moderate
Pinus palustris	1.5	strong
Pinus taeda	1.5	strong
Tsuga canadensis	1.5	strong

ice damage susceptibility valus:
1 = strong resistance; 2 = moderate resistance; 3 = weak resistance

Figure 13: Gymnosperm tree species susceptibility to ice damage across 7 studies (1959-1993).
(Warrillow & Mou 1999)

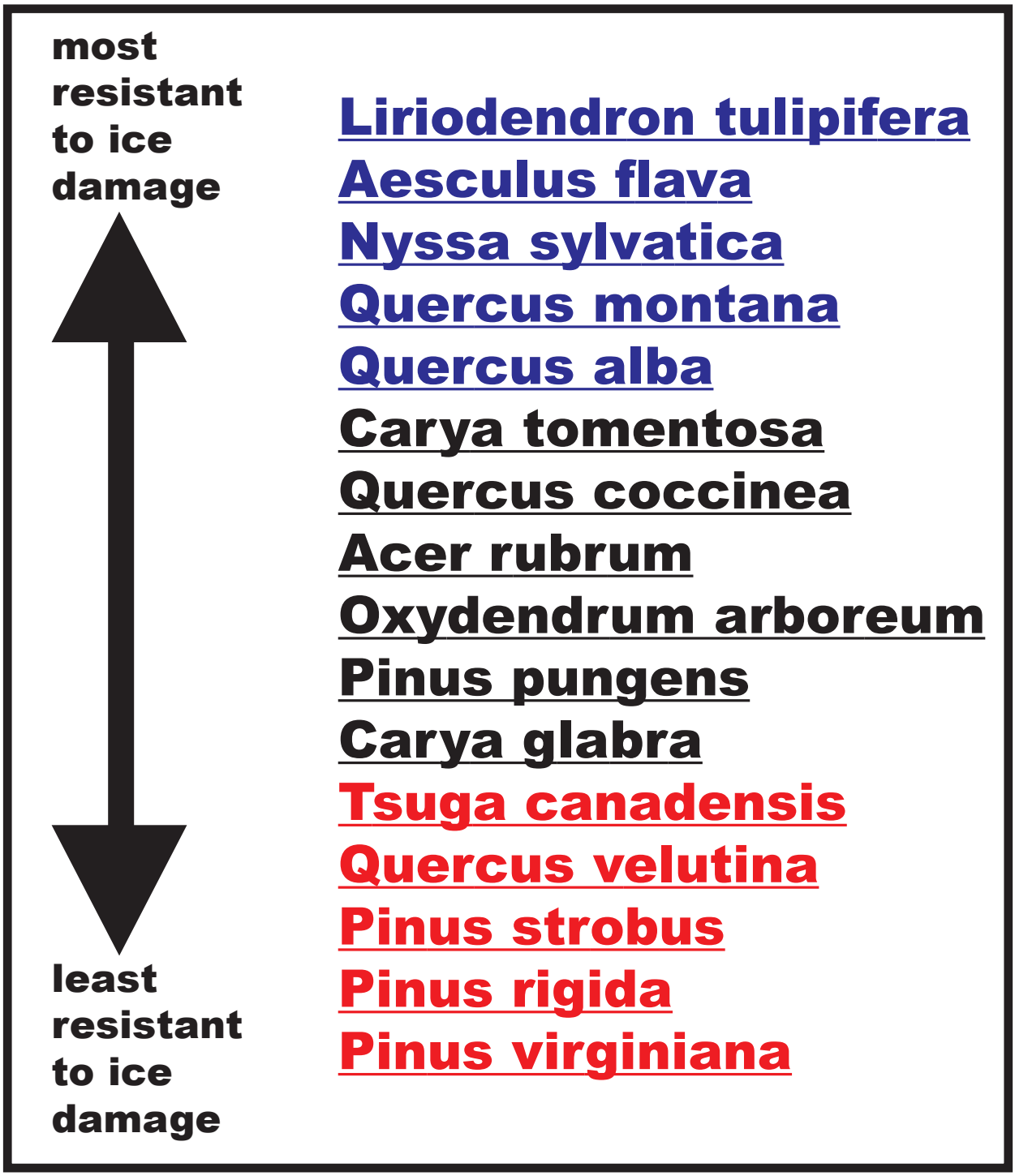

Figure 14: Tree species resistance to ice damage across 7 studies (1959-1993). (Warrillow & Mou 1999)

LOW RESISTANCE:	INTERMEDIATE RESISTANCE:
Acer negundo	Abies balsamea
Acer pensylvanicum	Acer saccharum
Acer platanoides	Betula alleghaniensis
Acer rubrum	Crataegus spp.
Acer saccharinum	Fagus grandifolia
Alnus spp.	Fraxinus americana
Betula papyrifera	Malus spp.
Betula populifolia	Pinus strobus
Celtis occidentalis	Prunus avium
Fraxinus pennsylvanica	Tilia cordata
Gleditsia triacanthos	Ulmus spp.
Larix laricina	**HIGH RESISTANCE:**
Pinus banksiana	Carpinus caroliniana
Pinus resinosa	Juglans nigra
Populus spp.	Ostrya virginiana
Prunus pensylvanica	Picea spp.
Prunus serotina	Quercus alba
Prunus virginiana	Quercus bicolor
Robinia pseudoacacia	Quercus macrocarpa
Salix spp.	Tsuga canadensis
Sorbus americana	
Thuja occidentalis	
Tilia americana	

Figure 15: Select tree species resistance to crown damage from ice storms. (low = weak; high = strong)
(Irland 2000)

species	ice damage score
Fraxinus americana	3.5
Tilia americana	3.5
Acer rubrum	3.4
Betula papyrifera	3.3
Quercus rubra	3.3
Fagus grandifolia	3.2
Acer saccharum	3.1
Ostrya virginiana	3.0
Betula alleghaniensis	2.9
Tsuga canadensis	2.2

Figure 16: Ice damage susceptability of tree species, with larger scores showing more severe damage.
(Duguay et.al. 2001)

species	total basal area damaged percent	dominant damage
Fagus grandifolia (beech)	**34%**	**b**
Betula papyrifera (birch)	**33%**	**b**
Betula alleghaniensis (birch)	**43%**	**b s**
Acer rubrum (maple)	**22%**	**b s**
Acer saccharum (maple)	**33%**	**b s**
Acer pensylvanicum (maple)	**39%**	**b s**
Fraxinus americana (ash)	**12%**	**b s**
Prunus pensylvanica (cherry)	**58%**	**b s t**

bend = b stem break = s root tipped = t

Figure 17: Example of tree species and dominant ice damage forms. (Rhoads et.al. 2002)

species	susceptibility class
Populus tremuloides	H
Populus grandidentata	H
Prunus serotina	H
Tilia americana	H
Ulmus americana	H
Acer rubrum	I
Acer succharum	I
Ostrya virginiana	L
Pinus spp.	L
Quercus alba	L
Quercus rubra	L

H = highly susceptible to ice damage; I = moderately susceptible to ice damage;
L = low susceptibility to ice damage

Figure 18: Susceptibility of tree species to damage from ice accumulation of 2.4 - 3.5 inches. (Brommit et.al. 2004)

species	average ice damage value	damage class
Salix spp.	3.0	H
Populus spp.	2.8	H
Prunus serotina	2.8	H
Tilia americana	2.8	H
Ulmus spp.	2.4	H
Acer rubrum	2.0	M
Quercus rubra	2.0	M
Quercus velutina	2.0	M
Fagus grandifolia	1.9	M
Acer saccharum	1.7	M
Fraxinus spp.	1.6	M
Betula spp.	1.5	L
Tsuga canadensis	1.5	L
Carya spp.	1.2	L
Quercus alba	1.0	L

1 = low susceptability to ice damage (L)
2 = moderate susceptability to ice damage (M)
3 = highly susceptabile to ice damage (H)

Figure 19: Average tree species susceptability to ice damage across 11 Eastern North America studies.
(derived from Tremblay et.al. 2005)

species	susceptibility
Quercus palustris	R
Quercus rubra	R
Cornus florida	I
Platanus occidentalis	I
Quercus alba	I
Acer nigrum	S
Acer saccharum	S
Chamaecyparis nootkatensis	S
Ulmus americana	S

S = susceptible; I = intermediate; R = resistant.

Figure 20: Susceptibility of tree species to ice storm damage. (Rhoades & Stipes 2007)

species	ice damage susceptibility index value	class
Ostrya virginiana	1.63	S
Acer rubrum	0.86	S
Quercus rubra	0.61	M
Nyssa sylvatica	0.43	M
Fraxinus americana	0.33	M
Quercus prinus	0.33	M
Fagus grandifolia	0.26	L
Carya glabra	0.24	L
Cornus florida	0.23	L
Quercus velutina	0.20	L
Quercus alba	0.09	N
Sassafras albidum	0.06	N

ice damage susceptibily index:
0 = none (N); 1 = light (L); 2 = moderate (M); 3 = severe (S).

Figure 21: Ice damage susceptibility index values for tree species under 1 inch of ice. (Vowels 2012)

Scientific Name	Common Name	Suscepibility	Citations
Abies balsamea	balsam fir	2.0	1
Acer negundo	boxelder	3.0	1
Acer nigrum	black maple	3.0	1
Acer pensylvanicum	striped maple	3.0	2
Acer platanoides	Norway maple	2.0	3
Acer rubrum	red maple	2,1	18
Acer saccharinum	silver maple	2.2	6
Acer saccharum	sugar maple	2.1	16
Aesculus flava	yellow buckeye	1.0	1
Alnus spp.	Alder species	3.0	1
Amelanchier arborea	serviceberry	1.9	8
Betula alleghaniensis	yellow birch	1.9	8
Betula lenta	sweet birch	1.5	2
Betula papyrifera	paper birch	2.5	4
Betula populifolia	gray birch	2.5	2
Betula spp.	birch species	1.0	1
Carpinus caroliniana	American hornbeam	1.3	6
Carya cordiformis	bitternut hickory	1.8	4
Carya glabra	pignut hickory	1.5	2
Carya ovata	shagbark hickory	1.0	3
Carya spp.	hickory species	1.0	3
Carya tomentosa	mockernut hickory	2.0	1
Catalpa speciosa	Northern catalpa	1.0	1
Celtis occidentalis	hackberry	2.7	3
Celtis spp.	hackberry species	3.0	1
Chamaecyparis nootkatensis	Alaska yellow-cedar	3.0	1
Cornus florida	dogwood	1.8	4
Crataegus spp.	hawthorn species	2.0	1

Figure 22: List of all tree species cited, average susceptibility to ice storm damage rating, and number of citations.

1.0 = resistant; 2.0 = intermediate; 3.0 = susceptible to ice damage.

Scientific Name	Common Name	Suscepibility	Citations
Fagus grandifolia	American beech	1.9	14
Fraxinus americana	white ash	1.8	13
Fraxinus pennsylvanica	green ash	2.3	6
Fraxinus nigra	black ash	3.0	1
Fraxinus spp.	ash species	1.5	2
Ginkgo biloba	ginkgo	1.0	2
Gleditsia triacanthos	honeylocust	2.5	4
Gymnocladus dioicus	Kentucky coffee-tree	1.0	1
Juglans nigra	black walnut	1.0	4
Larix laricina	Eastern larch	3.0	1
Larix spp.	larch species	3.0	1
Liquidambar styraciflua	sweetgum	1.0	2
Liriodendron tulipifera	yellow-poplar	1.6	7
Magnolia acuminata	mt. cucumbertree	2.0	1
Malus coronaria	sweet crabapple	1.0	1
Malus spp.	crabapple species	2.0	1
Nyssa sylvatica	blackgum	1.7	3
Ostrya virginiana	Eastern hophornbeam	1.1	8
Oxydendrum arboreum	sourwood	2.0	3
Picea spp.	spruce species	1.0	1
Picea rubens	red spruce	1.0	1
Pinus banksiana	jack pine	3.0	1
Pinus elliottii	slash pine	2.0	1
Pinus palustris	longleaf pine	1.0	1

Figure 22: List of all tree species cited, average susceptibility to ice storm damage rating, and number of citations. (continued)

1.0 = resistant; 2.0 = intermediate; 3.0 = susceptible to ice damage.

Scientific Name	Common Name	Suscepibility	Citations
Pinus pungens	table mountain pine	2.0	1
Pinus resinosa	red pine	2.7	3
Pinus rigida	pitch pine	3.0	3
Pinus strobus	Eastern white pine	2.0	7
Pinus spp.	pine species	1.0	1
Pinus taeda	loblolly pine	1.0	1
Pinus virginiana	Virginia pine	3.0	1
Platanus occidentalis	American sycamore	1.8	4
Platanus X hispanica	London planetree	3.0	1
Populus deltoides	Eastern cottonwood	2.0	3
Populus grandidentata	bigtooth aspen	3.0	2
Populus spp.	aspen / cottonwood	3.0	4
Populus tremuloides	quaking aspen	2.7	3
Prunus avium	sweet cherry	2.0	1
Prunus pensylvanica	fire cherry	3.0	2
Prunus serotina	black cherry	2.8	13
Prunus virginiana	choke cherry	3.0	1
Pyrus calleryana	callery pear	2.7	3
Quercus alba	white oak	1.3	15
Quercus bicolor	swamp white oak	1.0	2
Quercus coccinea	scarlet oak	2.2	2
Quercus macrocarpa	bur oak	1.5	2
Quercus montana	chestnut oak	1.5	4
Quercus palustris	pin oak	2.0	3
Quercus rubra	Northern red oak	2.1	17
Quercus velutina	black oak	2.3	8
Robinia pseudoacacia	black locust	2.7	3
Salix nigra	black willow	2.0	2
Salix ssp.	willow species	3.0	3

Figure 22: List of all tree species cited, average susceptibility to ice storm damage rating, and number of citations. (continued)

1.0 = resistant; 2.0 = intermediate; 3.0 = susceptible to ice damage.

Scientific Name	Common Name	Suscepibility	Citations
Sassafras albidum	sassafras	2.3	3
Sorbus americana	American mt.-ash	3.0	1
Taxodium distichum	bald-cypress	1.0	1
Thuja occidentalis	Northern white-cedar	2.0	2
Tilia americana	American basswood	2.6	12
Tilia cordata	little-leafed linden	1.7	3
Tsuga canadensis	Eastern hemlock	1.5	13
Ulmus americana	American elm	2.7	7
Ulmus pumila	Siberian elm	3.0	2
Ulmus rubra	slippery elm	2.5	2
Ulmus spp.	elm species	2.2	5

Figure 22: List of all tree species cited, average susceptibility to ice storm damage rating, and number of citations. (continued)

1.0 = resistant; 2.0 = intermediate; 3.0 = susceptible to ice damage.

Scientific Family Name (Common Family Name)	Number of Species	Damage Susceptibility Rating
Bignoniaceae (Catalpa)	**1**	**1.0**
Ginkgoaceae (Ginkgo)	**1**	**1.0**
Hamamelidaceae (Witch-hazel)	**1**	**1.0**
Hippocastanaceae (Buckeye)	**1**	**1.0**
Taxodiaceae (Redwood)	**1**	**1.0**
Juglandaceae (Walnut)	**6**	**1.4**
Nyssaceae (Tupelo)	**1**	**1.7**
Caesalpinaceae (Honeylocust)	**2**	**1.8**
Cornaceae (Dogwood)	**1**	**1.8**
Fagaceae (Beech)	**9**	**1.8**
Magnoliaceae (Magnolia)	**2**	**1.8**
Betulaceae (Birch)	**8**	**1.9**
Ericaceae (Heath)	**1**	**2.0**
Pinaceae (Pine)	**16**	**2.0**
Oleaceae (Ash)	**4**	**2.2**
Tiliaceae (Basswood)	**2**	**2.2**
Rosaceae (Cherry)	**10**	**2.3**
Lauraceae (Laurel)	**1**	**2.3**
Cupressaceae (Cypress)	**2**	**2.5**
Platanaceae (Sycamore)	**2**	**2.4**
Aceraceae (Maple)	**7**	**2.5**
Salicaceae (Willow)	**6**	**2.6**
Fabaceae (Locust)	**1**	**2.7**
Ulmaceae (Elm)	**6**	**2.7**

Figure 23: Tree family susceptibility to ice damage.
1.0 = resistant; 2.0 = intermediate; 3.0 = susceptible to ice damage.

tree species	susceptibility average value	susceptibility variation range	citations
Ostrya virginiana Eastern hophornbeam	1.1	1-3	8
Quercus alba white oak	1.3	1-3	15
Tsuga canadensis Eastern hemlock	1.5	1-3	13
Liriodendron tulipifera yellow-poplar	1.6	1-3	7
Fraxinus americana white ash	1.8	1-3	13
Betula alleghaniensis yellow birch	1.9	1-3	8
Fagus grandifolia beech	1.9	1-2	14
Pinus strobus Eastern white pine	2.0	1-3	7
Acer rubrum red maple	2.1	1-3	18
Acer saccharum sugar maple	2.1	1-3	16
Quercus rubra Northern red oak	2.1	1-3	17
Quercus velutina black oak	2.3	1-3	8
Tilia americana basswood	2.6	1-3	12
Ulmus americana American elm	2.7	1-3	7
Prunus serotina black cherry	2.8	2-3	13

Figure 24: Tree species cited more than six times in selected literature, average susceptibility value, variation across different studies, and number of literature citations.

HIGH RISK

scientific name	common name	susceptibility	citations
Acer negundo	boxelder	3.0	2
Acer pensylvanicum	striped maple	3.0	2
Betula papyrifera	paper birch	2.5	4
Betula populifolia	gray birch	2.5	2
Celtis occidentalis	hackberry	2.7	3
Fraxinus pennsylvanica	green ash	2.3	6
Gleditsia triacanthos	honeylocust	2.5	4
Pinus resinosa	red pine	2.7	3
Pinus rigida	pitch pine	3.0	3
Pinus virginiana	Virginia pine	3.0	3
Populus grandidentata	bigtooth aspen	3.0	2
Populus spp.	aspen/cottonwood	3.0	4
Populus tremuloides	quaking aspen	2.7	3
Prunus pensylvanica	fire cherry	3.0	2
Prunus serotina	black cherry	2.8	13
Pyrus calleryana	callery pear	2.7	3
Quercus velutina	black oak	2.3	8
Robinia pseudoacacia	black locust	2.7	3
Salix ssp.	willow species	3.0	3
Sassafras albidum	sassafras	2.3	3
Tilia americana	basswood	2.6	12
Ulmus americana	American elm	2.7	7
Ulmus pumila	Siberian elm	3.0	2
Ulmus rubra	slippery elm	2.5	2

Figure 25: List of tree species cited as susceptible to heavy ice storm damage. Species cited only once were not included.

MODERATE RISK

scientific name	common name	susceptibility	citations
Acer platanoides	Norway maple	2.0	3
Acer rubrum	red maple	2.1	18
Acer saccharinum	silver maple	2.2	6
Acer saccharum	sugar maple	2.1	16
Betula alleghaniensis	yellow birch	1.9	8
Carya cordiformis	bitternut hickory	1.8	4
Cornus florida	dogwood	1.8	4
Fagus grandifolia	American beech	1.9	14
Fraxinus americana	white ash	1.8	13
Malus spp.	crabapple species	2.0	2
Nyssa sylvatica	blackgum	1.7	3
Oxydendrum arboreum	sourwood	2.0	3
Pinus strobus	Eastern white pine	2.0	7
Platanus occidentalis	sycamore	1.8	4
Populus deltoides	Eastern cottonwood	2.0	3
Quercus coccinea	scarlet oak	2.0	2
Quercus palustris	pin oak	2.0	3
Quercus rubra	Northern red oak	2.1	17
Salix nigra	black willow	2.0	2
Thuja occidentalis	Northern white-cedar	2.0	2
Tilia cordata	little-leafed linden	1.7	3
Ulmus spp.	elm species	2.2	5

Figure 26: List of tree species cited with intermediate susceptiblility to ice storm damage. Species cited only once were not included.

LOW RISK

scientific name	common name	susceptibility	citations
Betula lenta	sweet birch	1.5	2
Carpinus caroliniana	American hornbeam	1.3	6
Carya glabra	pignut hickory	1.5	2
Carya ovata	shagbark hickory	1.0	3
Carya spp.	hickory species	1.0	3
Fraxinus spp.	ash species	1.5	2
Ginkgo biloba	ginkgo	1.0	2
Juglans nigra	black walnut	1.0	4
Liquidambar styraciflua	sweetgum	1.0	2
Liriodendron tulipifera	yellow-poplar	1.6	7
Ostrya virginiana	Eastern hophornbeam	1.1	8
Quercus alba	white oak	1.3	15
Quercus bicolor	swamp white oak	1.0	2
Quercus macrocarpa	bur oak	1.5	2
Quercus montana	chestnut oak	1.5	4
Tsuga canadensis	Eastern hemlock	1.5	13

Figure 27: List of tree species cited as resistant to ice storm damage. Species cited only once were not included.

MOST RESISTANT:

Carya spp.
Ginkgo biloba
Juglans nigra
Liquidambar styraciflua
Ostrya virginiana
Quercus bicolor

MOST SUSCEPTIBLE:

Acer negundo
Acer pensylvanicum
Pinus rigida
Pinus virginiana
Populus spp.
Prunus pensylvanica
Prunus serotina
Salix ssp.
Ulmus pumila

Figure 28: The most resistant and most susceptible tree species cited in ice storms across Eastern North America.