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# Ice Storm Impacts On Trees: Prioritized Causes Of Damage

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Major ice storms cause millions of dollars in infrastructure damage and tree loss. Across the Southern United States storm intensity, associated wind speeds, and ice volumes can be great, over-loading trees, and causing canopy and stem failures. In Eastern North America there have been many studies over many years examining how trees were damaged by ice storms. In these studies, a number of observations suggest both damage forms and causes, as well as potential solutions or corrections to make in order to minimize tree risks.

This publication uses information from 45 recent (<35 years old) ice storm studies published in research journals or research reports. From these studies by trained observers, a series of causal agents were identified as leading to or causing tree damage or mortality. A total of 56 individual items / variables were cited as key to tree damage in ice storms. These items identified in ice storm studies could be associated with how ice storms load trees, various structural attributes of trees, or growing site characteristics.

Each item identified by research studies was given an importance value between 0.0 and 1.0, repreenting a decimal percent. Importance values were calculated based upon the number of citations listing each item as a cause of tree damage, and the importance each variable was give within each study. The more individual studies mentioned an item as leading to tree damage, the higher importance value. Relative importance values allow for estimating, from high to low priority, storm / tree / site causes of tree damage in ice storms.

## Importance Values

Figure 1 provides the most important causes of damage to trees during ice storms, sorted by relative importance values in descending numeric order. Importance values range from 1.00 (100%) to .015 (1.5%) for causal agents. There are a number of most cited (i.e. highest importance value) attributes causing tree damage spread among storm loading differences, tree structural components, and site / location observations. There are some causal agents traditionally thought to be critical in tree ice damage which are actually of little importance.

Figure 2 shows the top 15 most important causes of ice storm damage in trees, listed in order of importance. Six of these items have the potential for being managed by aboricultural treatments to reduce or minimize tree damage risks. Note the first three items are all ice storm loading components, two of which far exceed the importance value of all the rest of tree and site attributes. Ice and wind loads placed on a tree are 4-5 times more critical to tree damage than the ability of a tree / site to resist damage.

Damage Catagories

Figure 3 provides the most important causes of damage to trees during ice storms, sorted by categories, with relative importance values listed in descending numeric order in each catagory. This figure contains all 56 items / variables listed before, but seperates and sorts them into general catagories for ease of interpretation. Within each catagory there are observed items much more important in causing tree damage in ice storms than other items. Prioritizing both observations of, and treatments for, tree damage based upon citation importance values avoids dwelling on minor or near insignificant causes, and allows concentration and recognition of major causal agents or structural components.

Catagories of tree damage in ice storms can be defined into three major components and eleven sub-units. Major catagories include storm loads, tree and site attributes, and individual tree components. Within each component and each sub-unit, items are listed in order of importance value priority. Remember, these are 56 indivudual items listed in 45 ice storm studies made in the last few decades by trained observers. Some tree damage causal agents listed early in the last century in older studies as causal agents may or may not have been recognized by these new studies.

Storm Loading

By far the most important of all causal agents for damage in an ice storm is how trees are loaded with ice and associated wind, over some time frame. Figure 4 shows the top three causes of tree damage and demonstrates proportionally how large mechnical loading events can be on trees. Ice thickness or weight is force which a tree / site must resist. The amount of ice varies by loaction across the landscape and within a single storm event. Many complex and chaotic factors lead to great differences in ice accumulation within one storm path. In a general sense, more ice applies more weight, and causes more faults and damage.

Wind plays a major role in ice storm damage to trees. Wind loads, and where these loads are structurally concentrated within a tree, change with ice accumulation. Wind helps propel a more full and complete coverage of ice on tree components. Both average wind speed and peak gust speed all generate dynamic loads over a tree surface. Generally, as ice accumulates and weighs tree component down, load points shifts and are concentrated around previous faults or weak areas. With ice, tree components become stiffer and more incapable of falling back against the wind. More ice generates more drag, leading to more faults and more damage.

Load Time

Having a greater than three times less important value than the first two storm loading attributes, ice load duration is at least as important as the most importance tree or site causal agent. Topography (deep valleys), sunlight (shaded hillsides), warm air / cold air flow, and how quickly surface air temperatures increase after an ice storm all can impact how long ice stays on trees. The longer ice is present, the greater chances of wood creep in branches and stems. The longer ice hangs onto a tree, the more faults which can occur and the more damage.

Although not counted by many observers as an important cause of tree damage, the return rate of ice storms to the same location, can play a role in tree damage and tree adjustments to storm loading. Within a tree's lifespan, how many major ice storms can be expected? In some ways, ice storms generate a natural cleaning / pruning process eliminating potential future faults and damage. Unfortunately, the quicker the return rate, the more loads are applied more often, leading to more faults generated and more total damage. Longer periods between ice storms alternatively lead to more severe damage and mortality.

Arboriculture Solutions

Of the most important items leading to tree damage, some can not be influenced or corrected by tree and site management. People have little control of storm loads in an ice storm. There are some items which can be manipulated to minimize tree damage risks. Figure 5 provides the top 15 causes of tree ice storm damage which can be minimized through appropriate arboricultural practices to potentially reduce risk. Through proper and effective pruning, cleaning and fault removal ahead of major ice storms, tree damage in an ice storm can be minimized. Because the most important features causing tree damage are not under direct managerial control (i.e. storm ice accumulation and wind loads), tree damage will still occur regardless of the most intense tree health care and structural management programs.

Crown Balance -- The most often cited problem or causal agent leading to tree damage in ice storms is asymmetrical crowns. A lopsided crown with a canopy concentrated much more on one side of the stem than the other, generates major bending and torsion (twist) loads on tree parts. Ice accumulation and wind loading accentuates ice storm loads on asymmetrical crowns in trees, and causes faults and failures.

Crown Surface Area -- Another major tree problem in resisting damage from ice storms is a combination of large crown surface areas, and dense branch and twig growth along stems and branches. Increased canopy surface area from large, evergreen, or densely packed crowns increase the total surface area for ice accumulation and associated wind drag. Large trees tend to have the most crown damage, but less mortality. Within tree crowns, dense twig and supporting branch growth forms had more ice accumulation and canopy damage, than less dense tree crowns. Many small branches, close together, allow additional ice to accumulate and form a high drag surface for ice storm winds causing faults and failures. Some tree species and individual trees damaged were cited as being "twiggy."

Figure 6 shows canopy loss associated with tree mortality 5 years after an ice storm. Tree canopy loss of less than 50% usually is survivable, while canopy damage greater than 75% is usually fatal leading to loss within five years. Figure 7 provides short term mortality values of five tree species in different diameter classes having sustained differing crown loss percentages in a major ice storm. Note the short term mortality is generally less in larger diameter classes, but the crown loss is greater.

Figure 8 demonstrates tree mortality four years after a major ice storm for various levels of crown loss. Note less than 25% crown loss yield insignificant mortality after 4 years. Crown loss of 25% to 50% generates roughly 40% mortality after 4 years, and greater than 75% crown loss generates massive mortality in 4 years. Figure 9 demonstrates another view of crown damage and tree health and survival. Three years after a major ice storm, greater than 75% canopy damage led to large tree mortality percents. At 50% canopy damage, 20% of trees showed no decline and appeared healthy after three years.

Another way to look at tree health after crown loss in a major ice storm is shown in Figure 10. Three years after ice storm crown damage, approximately 50% of trees sustaining less than 50% crown loss showed only light / little health declines. Roughly 20% of trees showed moderate health decline after sustaining 75% or less crown damage. About 5-7% of trees with less than 50% crown damage did present heavy health decline.

Branch Structure -- In some cases, general descriptive terms were used for trees badly damaged by ice storms. Two terms frequently used were "poor branch structure" and "poor form." Both of these terms were rarely fully defined and generate an uncertainty regarding precise attributes leading to ice damage.

Under poor branch architecture and poor form, many branch components were listed including large branch angles, forks, many branches / branchlets / twigs on stems and branches (twig density), unspecified weak branch connections (unsound branches), and branches growing in an opposite / whorled formation at each node. In one view, the concept of poor tree form can be paraphrased as "a professional would recognize it when seen."

Figure 11 shows branch losses in a major ice storm combined for two late successional species. A large majority of branches lost averaged 3.1 inches (~7.9cm) at their base. Figure 12 demonstrates unsound branches were more likely to fail at larger branch base diameter than sound branches. As branch base diameters increase, sound / unsound branch structure differences were less important, although ice storms seem to clean out unsound branches early in diameter growth.

Coupled with other canopy and branch issues, more specific branch structural problems were sometimes listed. Large branches with large decay columns, large and open cracks, old wood and periderm injuries, unsound branch connections, and visible and invisible decay pockets generated faults and failed under ice loads. Figure 13 presents an interesting study of unsound branches, by tree species, failing in an ice storm. Note with some tree species, if a branch fails, it is almost always an unsound branch, where other tree species lose more branches without visible signs of structural problems.

On The Edge -- A number of studies cited edge trees, especially in a forest setting, as leading to ice damage. Trees growing at the edge of new openings, right-of-ways, roadways, and cut lands were damaged more than old edge trees (i..e. trees having been in position for many years), or more interior forest trees. In addition, the more ice accumulated, the less edge position mattered at all. Large ice accumulations damages all trees regardless of interior or edge position.

Figure 14 shows the average canopy loss by ice thickness for sugar maple (*Acer saccharum*) in both edge and interior positions. Note as ice accumulates, more interior tree damage occurs. Figure 15 shows, in the same study the avaerge canopy loss by ice thickness for red maple (*Acer rubrum*) in interior and edge positions. Note as ice accumulation increases, more edge trees are damaged. Sugar and red maple are found growing on different sites and have different inherent susceptibilities to ice storm damage. The difference between the two maples species by growing position demonstrates great variability seen in tree damage in ice storms.

In some cases, trees growing both in interior, edge, or gap positions were cited as failing if vines were growing along their stem length or hanging from large branches. Vines were found to increase ice accumulation surface area with little or no increase in structural support. Vines added ice weight and wind drag, leading to failures.

Crown Size -- A more general observation about tree canopy size was not density and surface area, but shear size. Larger crown diameter trees were cited as failing more than small crown diameter trees. Large crowns provided more total load applied and longer mechanical force lever arms, than smaller diameter crowns, leading to generation of more faults and failures.

Additional Faults -- A number of more detailed and specific observations were made in a number of studies. Forks and codominant branches were cited as leading directly to failures. The concentration here is centered upon structural connections which are inherently weak, especially included periderm (bark) within stem-branch confluence areas. In addition, wide branching angles were observed leading to faults and failures. The wider branch angles (and longer a branch), the greater damage, compared to more upright branches. In this case, included periderm was not a cited cause, but branches being end-loaded and pulled down until failure.

Another specific tree attribute which could be placed in earlier branch structure catagories is the number of lateral branches on stems and branches, and opposite branching. The more lateral branches (more density), the more ice damage observed. As alluded to earlier under poor form, opposite branching patterns were specifically found to lead to more damage. Alternate branching patterns generated less damage under ice loads.

Tip-weighted branches and included periderm were specifically cited in a few studies, but usually folded into more general causal agent catagories. Tip-weighted, or lion's tailed branches, especially when long, less tapered or more slender, concentrated branches / twigs / foliage nearer branch ends, generated a longer lever arm and mechanical force on more basal branch tissues and branch / stem confluence areas as ice accumulates. This type of observed fault and failure can be caused by over-pruning, thinning, and/or cleaning the canopy, leading to severe ice damage. Included periderm was specifically cited in some studies as causing branch connection failures under ice and wind loads.

Planting Solutions

There were four primary observations regarding tree ice storm damage which influences tree selection in new plantings. Figure 16. All these observations were of less importance in ice storm damage than most arboricultural treatments, but still were cited as leading to damage. The first is tree species. The species of a tree is moderatly important in ice storm damage. Tree susceptability to ice storms suggests individual species which are damageed the most and the least. Tree species susceptibility lists for regional areas should be consulted and made part of suggested planting plans and ordinance lists. Damage type, damage severity, and tree reactions to damage all have some genetic (by species) basis.

The three other observations of tree damage in ice storms influencing planting involve stem and crown form, and initial gene set location (native / exotic). Multiple stem forms or stems clumped into multiple stem groups are more susceptible to ice damage than single stem forms. Drooping or weeping forms of branches and crowns were cited as more susceptible to ice damage than normal branching or crown forms. Although listed as less important value, exotic species were more susceptible than native species to ice damage. It is suggested that native species have been selected and challenged under the local ice storm regime where exotics have not.

Stand Management

There were some observations in various ice storms which carried intermediate importance for tree and stand attributes suggesting several negative interactions between management of trees and ice storm damage susceptibility. Figure 17 lists five important stand management items associated with ice storm damage. The first two of these causal agents were basal area and thinning of a stand of trees, both sharing equal importance values.

As basal area increases, ice damage tends to increase due to lack of taper in individual tree stems, diameter to height ratio slenderness, lack of wind firmness, and low live crown ratio. On the other hand, low basal area values led to forest stands being susceptible to ice damage due to almost complete exposure to ice storms events, but lack of an established open, wind-firm, well-tapered growth form. Trees unchallenged by ice and wind, or partially protected, may be susceptible to damage under major ice storms. Basal area and tree density can be manipulated by thinning. Observers found both unthinned stands (greater density of stems) and newly, heavily thinned stands, sustained the most ice storm damage as compared with more lightly, medium dense stands.

Stem position or shape were cited as leading to additional ice storm damage. Stem lean away from vertical was found to make trees more susceptible to ice damage. Stem resistence to loading is compromised by changes in
center of mass position over the root plate and crown asymmetry, accentuated by addition of ice and wind loads. Many trees placed into a leaning position by ice storms which do not catastrophically fail can partially to almost fully recover if the lean is less than 20°. Leans over 45° are highly damaging, poorly corrected through subsequent years growth, and at great risks of fault generation and failure. Figure 18. A number of observers noted stem form factor as leading directly to tree failure. A lack of a strong taper, or greater slenderness of main stem form, led to damage especially under strong wind loads.

A Cited Solution - Tree Care !

It was noteworthy a number of authors stated unmanaged trees were at great risk of ice storm damage. Trees and stands of trees which were unmanged, unpruned, and poorly cared for were significantly more susceptible to ice storm damage than well managed and cared-for trees. Trees which were cleaned, dead-wooded, and properly pruned were cited as best surviving with minimal damage any icing event. Wild / feral / neglected trees without care in communities are most prone to ice storm damage.

Conclusion

Ice storm, site and tree attributes interact, and are dynamically consolidated, to generate many types of tree damage with many levels of severity. Many studies have identified a number of causal agents leading to tree damage. Some of these agents are common and important in tree damaging events, while others are less often observed and less important. It is through observational prioritization of ice storm damage that professionals can begin to focus and correct storm, site and tree features leading to the most problems, and suggesting management inputs which could minimize risks.

Citation:

Coder, Kim D. 2022. Ice storm impacts on trees: Prioritized causes of damage. Warnell School of Forestry & Natural Resources, University of Georgia, Outreach Publication WSFNR-22-50C. Pp.29.

Figure 1: The most important causes of damage to trees during ice storms, sorted by relative importance values in descending numeric order.

This figure was derived from 45 ice storm studies which included 56 storm / tree / site variables observed or measured. Damage importance values were based upon the number of citations and estimated relative importance provided within each study.

| RANK | TREE DAMAGE CAUSE | IMPORTANCE VALUE (0.0 – 1.0) |
|---|---|---|
| 1 | ice thickness / weight | 1.000 |
| 2 | elevated wind loads | 0.800 |
| 3 | asymmetrical crowns | 0.250 |
| 4 | ice load duration | 0.250 |
| 5 | tree life-form (evergreen / deciduous) | 0.250 |
| 6 | tree size | 0.225 |
| 7 | branch & twig density | 0.213 |
| 8 | canopy surface area | 0.213 |
| 9 | steep slopes | 0.213 |
| 10 | general topography | 0.181 |
| 11 | stem diameter | 0.175 |
| 12 | poor branch architecture | 0.170 |
| 13 | poor form | 0.163 |
| 14 | tree age | 0.163 |
| 15 | branch structural problems | 0.159 |
| 16 | edge trees | 0.149 |
| 17 | tree species | 0.149 |
| 18 | exposure to wind & ice | 0.138 |
| 19 | crown diameter | 0.125 |
| 20 | decurrent shaped crowns | 0.125 |

Figure 1: The most important causes of damage to trees during ice storms, sorted by relative importance values in descending numeric order. (CONTINUED)

This figure was derived from 45 ice storm studies which included 56 storm / tree / site variables observed or measured. Damage importance values were based upon the number of citations and estimated relative importance provided within each study.

| RANK | TREE DAMAGE CAUSE | IMPORTANCE VALUE (0.0 – 1.0) |
|---|---|---|
| 21 | excurrent shaped crowns | 0.125 |
| 22 | open grown trees | 0.125 |
| 23 | vines | 0.125 |
| 24 | aspect | 0.117 |
| 25 | basal area of stand | 0.105 |
| 26 | thinning stands | 0.105 |
| 27 | emergent / dominant crowns | 0.100 |
| 28 | forks / codominant branching | 0.096 |
| 29 | wood strength | |
| | 1) wood density, MOR, MOE | 0.088 |
| | 2) near neutral / no impact | 0.088 |
| 30 | stem form factor | 0.079 |
| 31 | stem lean | 0.079 |
| 32 | shallow rooting | 0.075 |
| 33 | stiff branches | 0.074 |
| 34 | wide branch angles | 0.074 |
| 35 | lateral branch number | 0.064 |
| 36 | opposite branching pattern | 0.064 |
| 37 | topographic position | 0.064 |
| 38 | unmanaged trees | 0.064 |

Figure 1: The most important causes of damage to trees during ice storms, sorted by relative importance values in descending numeric order. (CONTINUED)

This figure was derived from 45 ice storm studies which included 56 storm / tree / site variables observed or measured. Damage importance values were based upon the number of citations and estimated relative importance provided within each study.

| RANK | TREE DAMAGE CAUSE | IMPORTANCE VALUE (0.0 – 1.0) |
|---|---|---|
| 39 | tree height | 0.063 |
| 40 | brittle wood | 0.053 |
| 41 | juvenile wood | 0.053 |
| 42 | ice storm return rate | 0.050 |
| 43 | intermediate size trees | 0.050 |
| 44 | included periderm (bark) | 0.043 |
| 45 | tip-weighted branches | 0.043 |
| 46 | multiple stems forms | 0.026 |
| 47 | saturated soil | 0.026 |
| 48 | center of mass | 0.025 |
| 49 | codominant crowns | 0.025 |
| 50 | exotics / non-natives | 0.025 |
| 51 | live crown ratio | 0.025 |
| 52 | shade intolerance | 0.025 |
| 53 | drooping branching form | 0.021 |
| 54 | poor compartmentalization | 0.018 |
| 55 | poor health | 0.018 |
| 56 | coarse soils | 0.015 |

| id. | identified damage cause | relative importance value |
|---|---|---|
| I1 | ice thickness / weight | 1.000 |
| I2 | elevated wind loads | 0.800 |
| I3 | ice load duration | 0.250 |
| II1A | tree life-form (leaves) | 0.250 |
| III1A | asymmetrical crowns | 0.250* |
| II1B | tree size | 0.225 |
| II2A | steep slopes | 0.213 |
| III1B | canopy surface area | 0.213* |
| III2A | branch & twig density | 0.213* |
| II2B | general topography | 0.181 |
| III3A | stem diameter | 0.175 |
| III2B | poor branch architecture | 0.170* |
| II1C | poor form | 0.163* |
| II1D | tree age | 0.163 |
| III2C | branch structural problems | 0.159* |

(* = potential managed cause)

Figure 2: Top 15 most important causes of ice storm damage in trees listed in order of importance.

Figure 3: The most important causes of damage to trees during ice storms, sorted by categories with relative importance values listed in descending numeric order.

This figure was derived from 45 ice storm studies which included 56 storm / tree / site variables observed or measured. Damage importance values were based upon number of citations and estimated relative importance provided within each study.

| TREE DAMAGE CAUSE | IMPORTANCE VALUE (0.0 – 1.0) |
|---|---|
| **I. STORM LOAD** | |
| 1. ICE THICKNESS / WEIGHT | 1.000 |
| 2. ELEVATED WIND LOADS | 0.800 |
| 3. ICE LOAD DURATION | 0.250 |
| 4. ICE STORM RETURN RATE | 0.050 |
| **II. TREE & SITE** | |
| **1. TREE FORM** | |
| A) tree life-form (evergreen / deciduous) | 0.250 |
| B) tree size | 0.225 |
| C) poor form | 0.163 |
| D) tree age | 0.163 |
| E) vines | 0.125 |
| F) tree height | 0.063 |
| G) intermediate size trees | 0.050 |
| H) center of mass | 0.025 |
| I) exotics / non-natives | 0.025 |
| **2. POSITION / LOCATION** | |
| A) steep slopes | 0.213 |
| B) general topography | 0.181 |

Figure 3: The most important causes of damage to trees during ice storms, sorted by categories with relative importance values listed in descending numeric order.
This figure was derived from 45 ice storm studies which included 56 storm / tree / site variables observed or measured. Damage importance values were based upon number of citations and estimated relative importance provided within each study. (CONTINUED)

| TREE DAMAGE CAUSE | IMPORTANCE VALUE (0.0 – 1.0) |
|---|---|
| C) edge trees | 0.149 |
| D) exposure to wind & ice | 0.138 |
| E) aspect | 0.117 |
| F) topographic position | 0.064 |

### 3. TREE SPECIES

| | |
|---|---|
| A) species | 0.149 |
| B) wood strength | |
| 1. wood density, MOR, MOE | 0.088 |
| 2. near neutral / no impact | 0.088 |
| C) juvenile wood | 0.053 |
| D) brittle wood | 0.053 |
| E) poor compartmentalization | 0.018 |
| F) poor health | 0.018 |

# III. TREE COMPONENTS

### 1. TREE CROWN / CANOPY

| | |
|---|---|
| A) asymmetrical crowns | 0.250 |
| B) canopy surface area | 0.213 |
| C) crown diameter | 0.125 |
| D) open grown trees | 0.125 |
| E) decurrent shaped crowns | 0.125 |
| F) excurrent shaped crowns | 0.125 |

Figure 3: The most important causes of damage to trees during ice storms, sorted by categories with relative importance values listed in descending numeric order.

This figure was derived from 45 ice storm studies which included 56 storm / tree / site variables observed or measured. Damage importance values were based upon number of citations and estimated relative importance provided within each study. (CONTINUED)

| TREE DAMAGE CAUSE | IMPORTANCE VALUE (0.0 – 1.0) |
|---|---|
| G) emergent / dominant crowns | 0.100 |
| H) codominant crowns | 0.025 |
| I) live crown ratio | 0.025 |
| J) shade intolerance | 0.025 |
| **2. BRANCHES** | |
| A) branch & twig density | 0.213 |
| B) poor branch architecture | 0.170 |
| C) branch structural problems | 0.159 |
| D) forks / codominant branching | 0.096 |
| E) wide branch angles | 0.074 |
| F) stiff branches | 0.074 |
| G) lateral branch number | 0.064 |
| H) unmanaged trees | 0.064 |
| I) opposite branching pattern | 0.064 |
| J) tip-weighted branches | 0.043 |
| K) included periderm (bark) | 0.043 |
| L) drooping branching form | 0.021 |
| **3. STEMS / TRUNK** | |
| A) stem diameter | 0.175 |
| B) basal area of stand | 0.105 |
| C) thinning stands | 0.105 |
| D) stem lean | 0.079 |
| E) stem form factor | 0.079 |
| F) multiple stems forms | 0.026 |

Figure 3: The most important causes of damage to trees during ice storms, sorted by categories with relative importance values listed in descending numeric order.

This figure was derived from 45 ice storm studies which included 56 storm / tree / site variables observed or measured. Damage importance values were based upon number of citations and estimated relative importance provided within each study. (CONTINUED)

| TREE DAMAGE CAUSE | IMPORTANCE VALUE (0.0 – 1.0) |
|---|---|
| **4. ROOTS & SOILS** | |
| A) shallow rooting | 0.075 |
| B) saturated soil | 0.026 |
| C) coarse soils | 0.015 |

# ICE STORM LOADS

| CODE | TREE DAMAGE CAUSE | IMPORTANCE VALUE (0.0 – 1.0) |
|---|---|---|
| I1 | ice thickness / weight | 1.000 |
| I2 | elevated wind loads | 0.800 |
| I3 | ice load duration | 0.250 |

Figure 4: Three most important causes of tree ice storm damage from ice storm loading. Item number three has an importance value in tree damage 3-4 times less than the first two items.

Listed in order of importance value derived from 45 ice storm studies.

# ARBORICULTURE

| | TREE DAMAGE CAUSE | IMPORTANCE VALUE (0.0 – 1.0) |
|---|---|---|
| III1A | asymmetrical crowns | 0.250 |
| III1B | canopy surface area | 0.213 |
| III2A | branch & twig density | 0.213 |
| III2B | poor branch architecture | 0.170 |
| II1C | poor form | 0.163 |
| III2C | branch structural problems | 0.159 |
| II2C | edge trees | 0.149 |
| II1E | vines | 0.125 |
| III1C | crown diameter | 0.125 |
| III2D | forks / codominant branch | 0.096 |
| III2E | wide branch angles | 0.074 |
| III2G | lateral branch number | 0.064 |
| III2I | opposite branch pattern | 0.064 |
| III2J | tip-weighted branches | 0.043 |
| III2K | included periderm (bark) | 0.043 |

Figure 5: Top 15 causes of tree ice storm damage which can be minimized through appropriate arboricultural practices.
Listed in descending numerical order by importance value derived from 45 ice storm studies.

**<50%**

**canopy loss**

**=**

**expected survival**

**>75%**

**canopy loss**

**=**

**expected mortality in 5 years**

Figure 6: Canopy loss and tree mortality in 5 years.
(Prouix & Greene 2001)

| species | crown loss percent (short term mortality percent) | | |
|---|---|---|---|
| Prunus serotina | 26 (14) | 52 ( 3) | 61 ( 4) |
| Acer rubrum | 19 (10) | 37 ( 2) | 44 ( 3) |
| Quercus rubra | 19 (10) | 37 ( 2) | 44 ( 3) |
| Fraxinus americana | 15 ( 8) | 30 ( 2) | 35 ( 2) |
| Betula alleghaniensis | 14 ( 8) | 28 ( 2) | 33 ( 2) |
| tree dbh class | 6-8in | 8-14in | >14in |

Figure 7: Crown loss and associated short term mortality percent for selected species by diameter size class.
(Tremblay et.al. 2005)

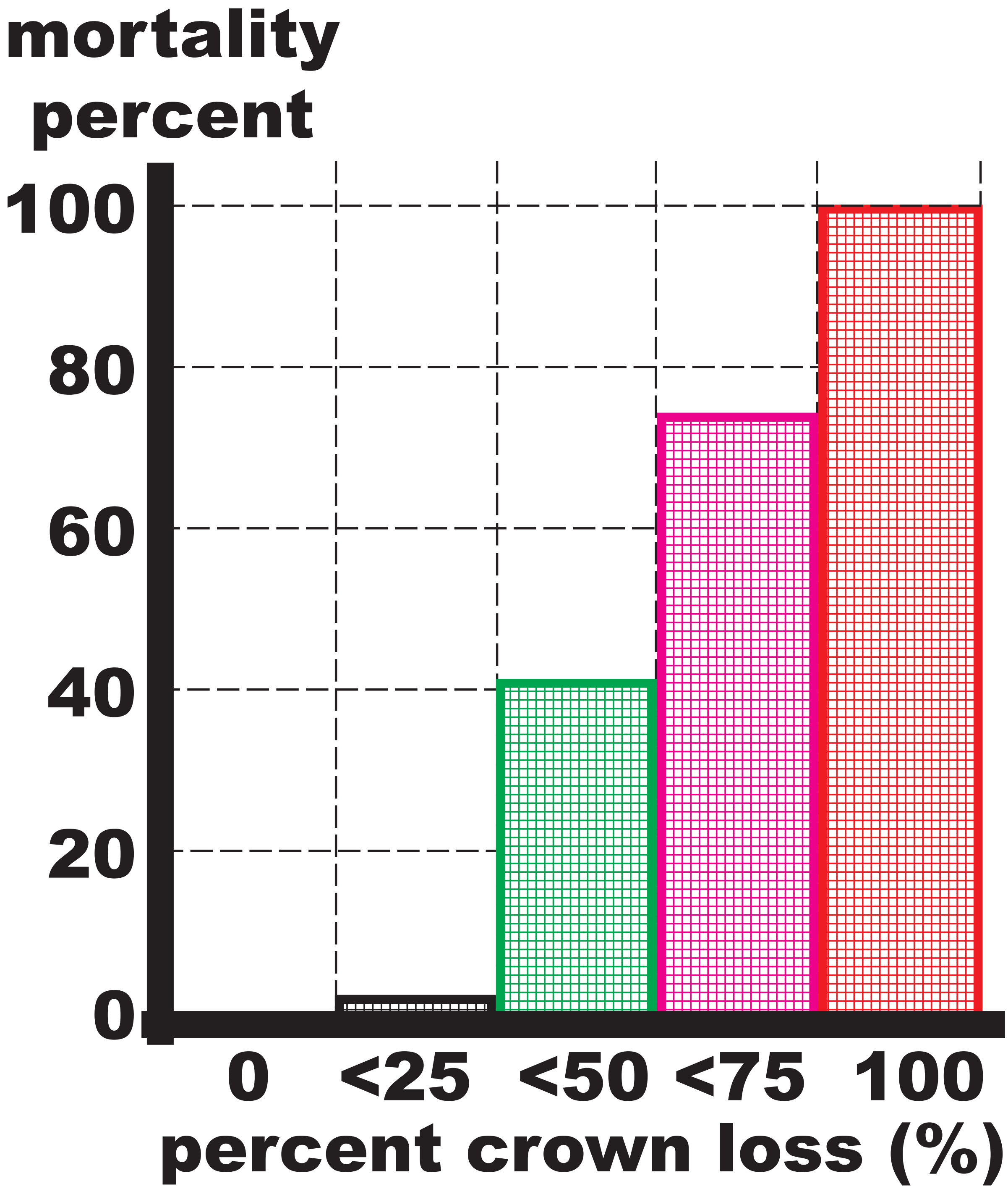


Figure 8: Red pine (*Pinus resinosa*) mortality four years after a major ice storm damaged various portions of tree crowns. (Ryall & Smith 2005)

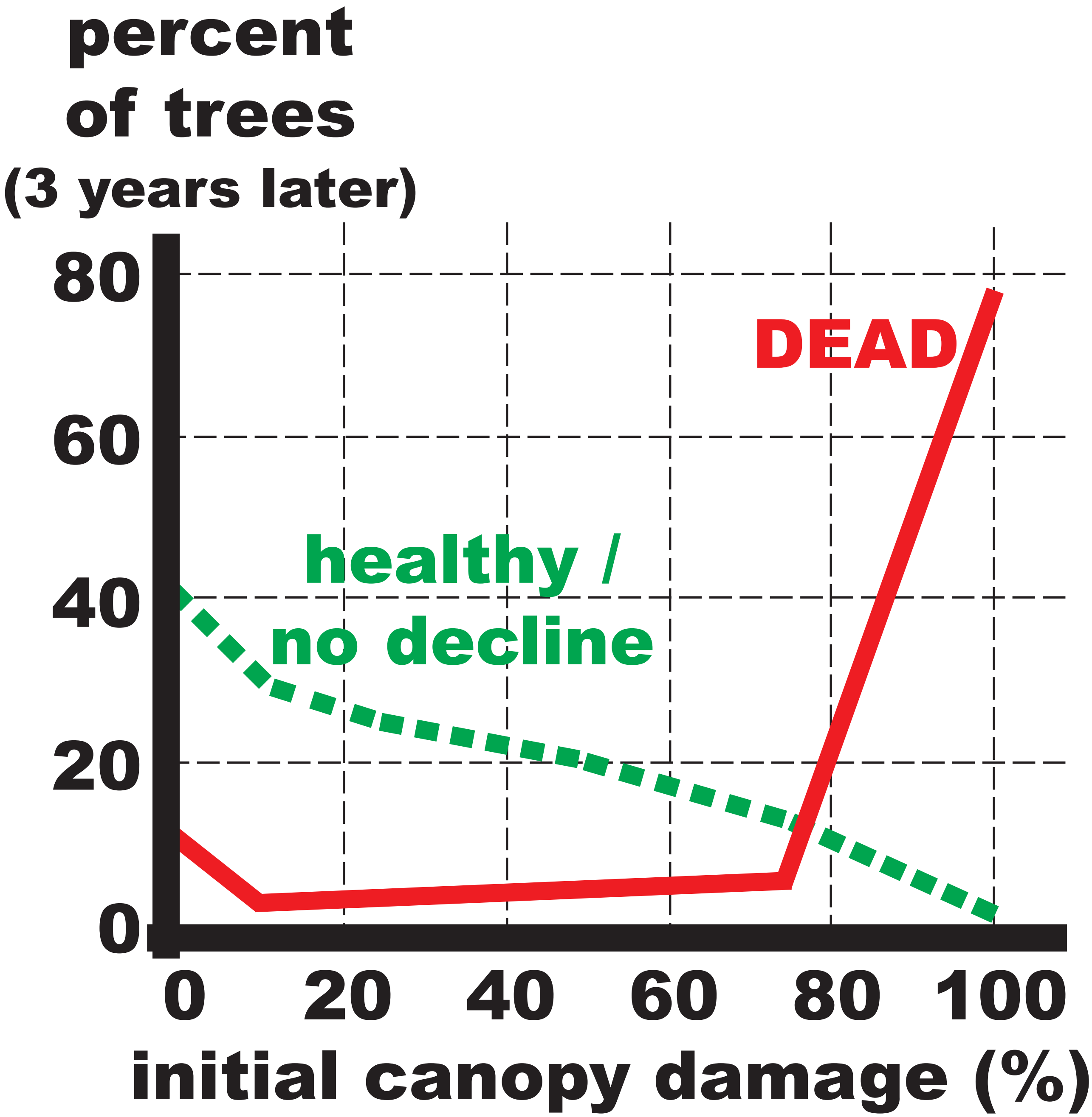


Figure 9: Tree health status after 3 years based upon initial canopy damage from a major ice storm.
(Hopkins et.al. 2003)

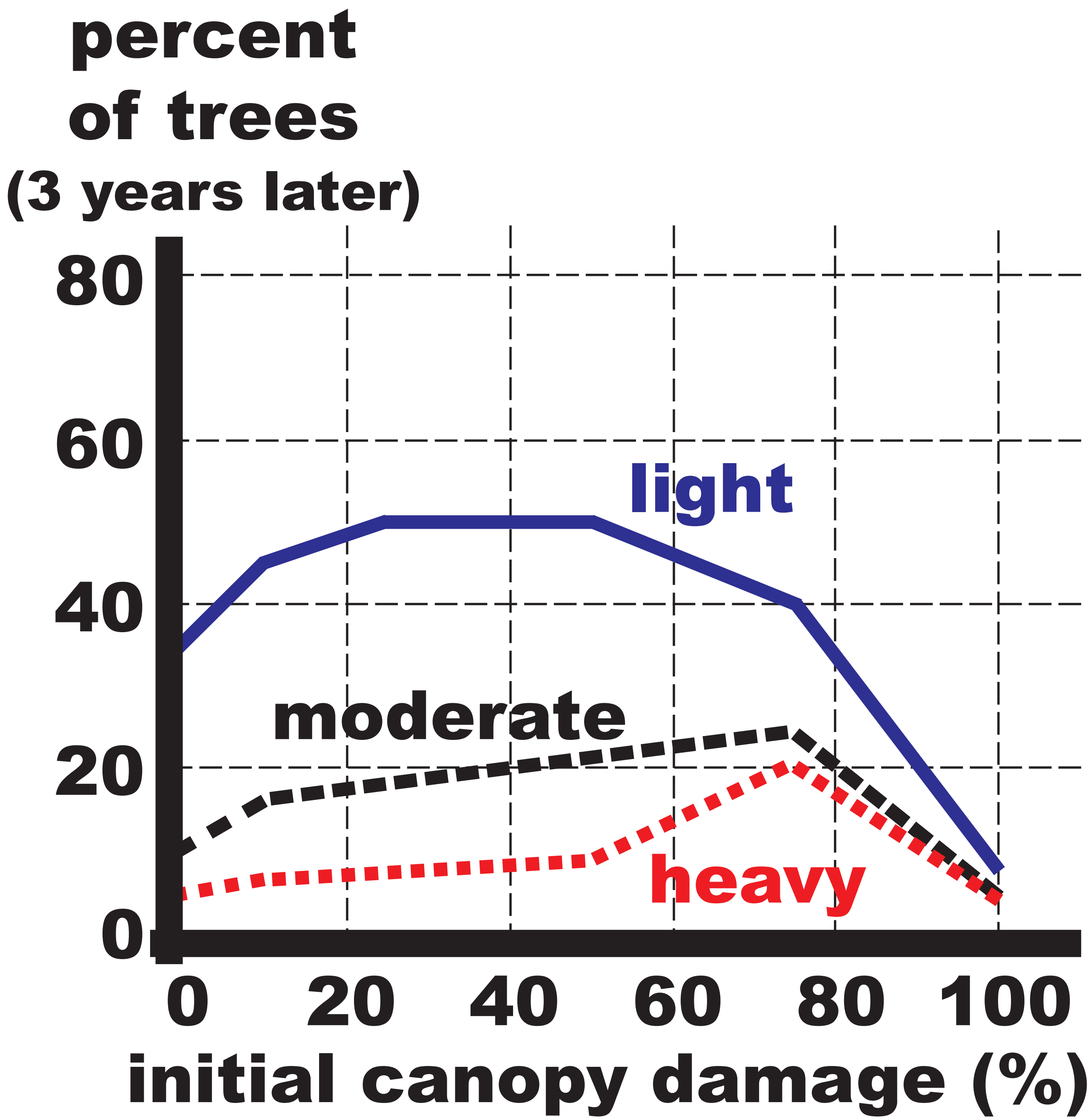


Figure 10: Tree health decline after 3 years based upon initial canopy damage from a major ice storm.
(Hopkins et.al. 2003)

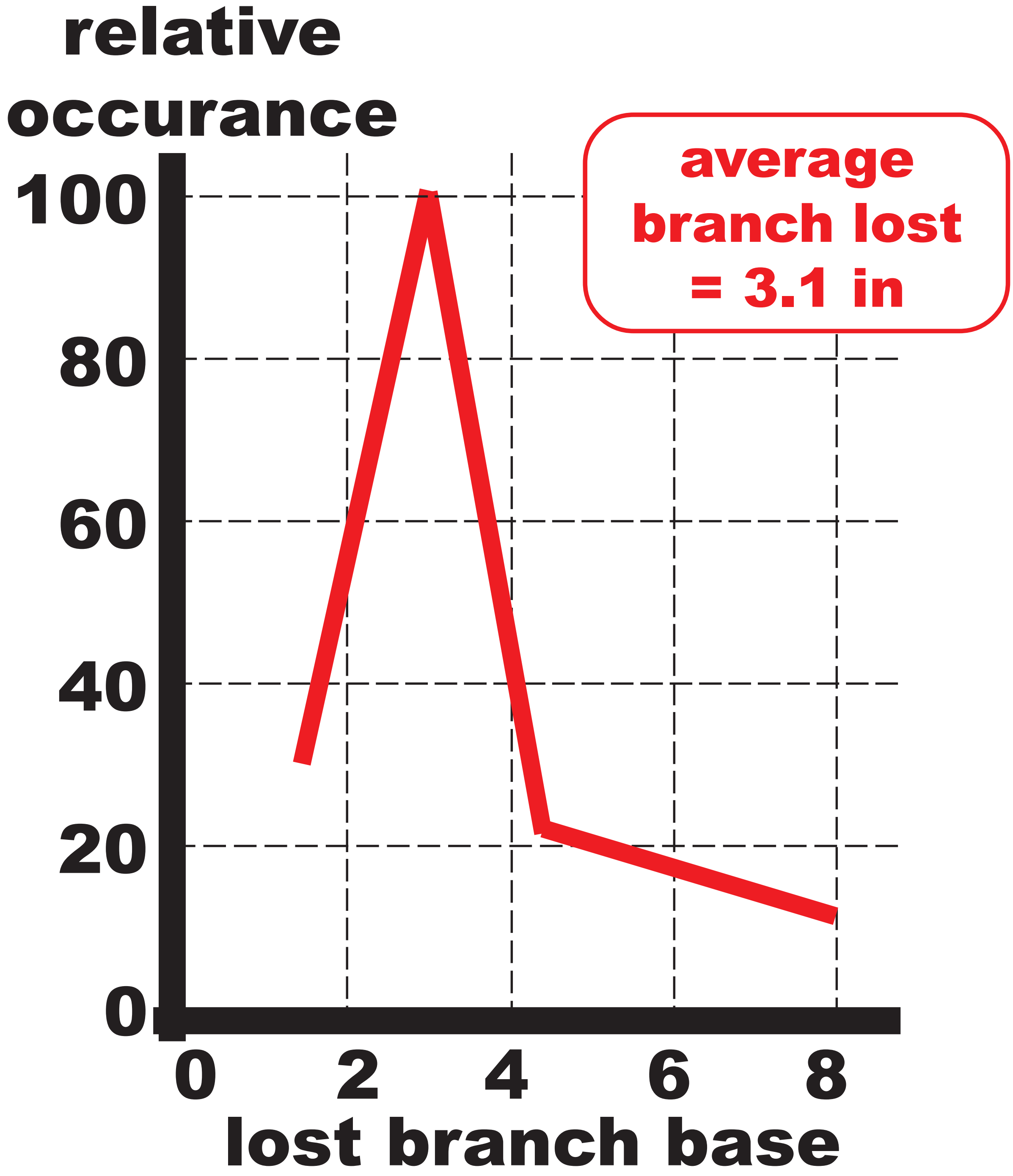


Figure 11: Basal diameter (in) of branches lost in major ice storm for beech (*Fagus grandifolia*) and maple (*Acer saccharum*)). (Melancon & Lechowicz 1987)

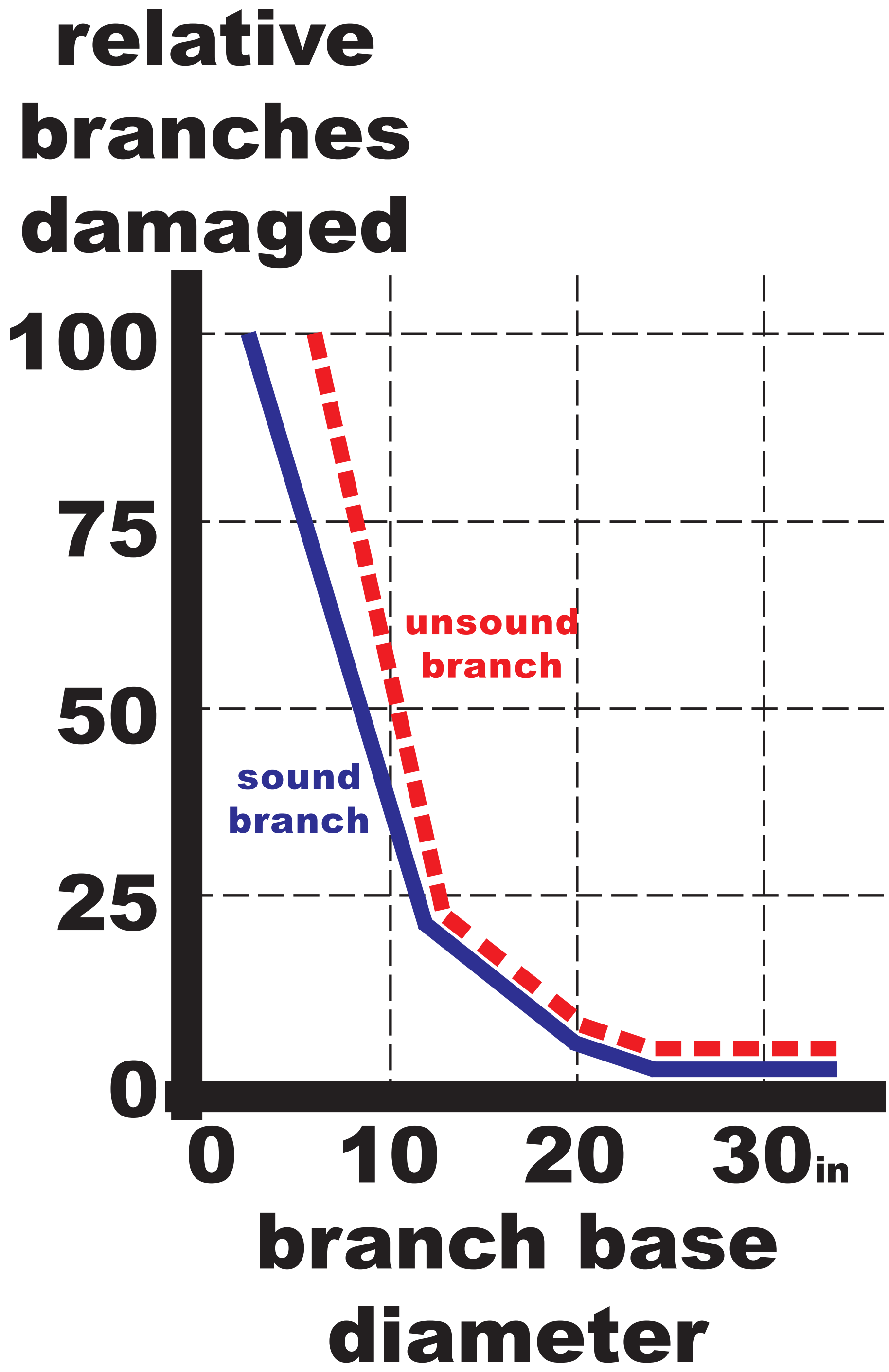


Figure 12: Relative damage to branches by branch base diameter in inches for sound and unsound (i.e. dead / decayed) branch bases. (after Rebertus et.al. 1997)

| species | downed branches unsound percent | |
|---|---|---|
| Carya cordiformis | 100 | above average unsound branches |
| Carpinus caroliniana | 65 | |
| Quercus alba | 58 | |
| Quercus rubra | 50 | |
| Sassafras albidum | 40 | |
| Quercus velutina | 38 | |
| Fraxinus pennsylvanica | 36 | |
| Prunus serotina | 27 | |
| Fagus grandifolia | 25 | |
| Acer saccharum | 23 | |
| Acer saccharinum | 22 | average |
| Fraxinus americana | 20 | below average unsound branches |
| Acer rubrum | 19 | |
| Tilia americana | 12 | |
| Salix nigra | 11 | |
| Populus deltoides | 10 | |
| Tsuga canadensis | 6 | |

Figure 13: Percent of ice storm-downed branches which were unsound. (Seischab et.al. 1993)

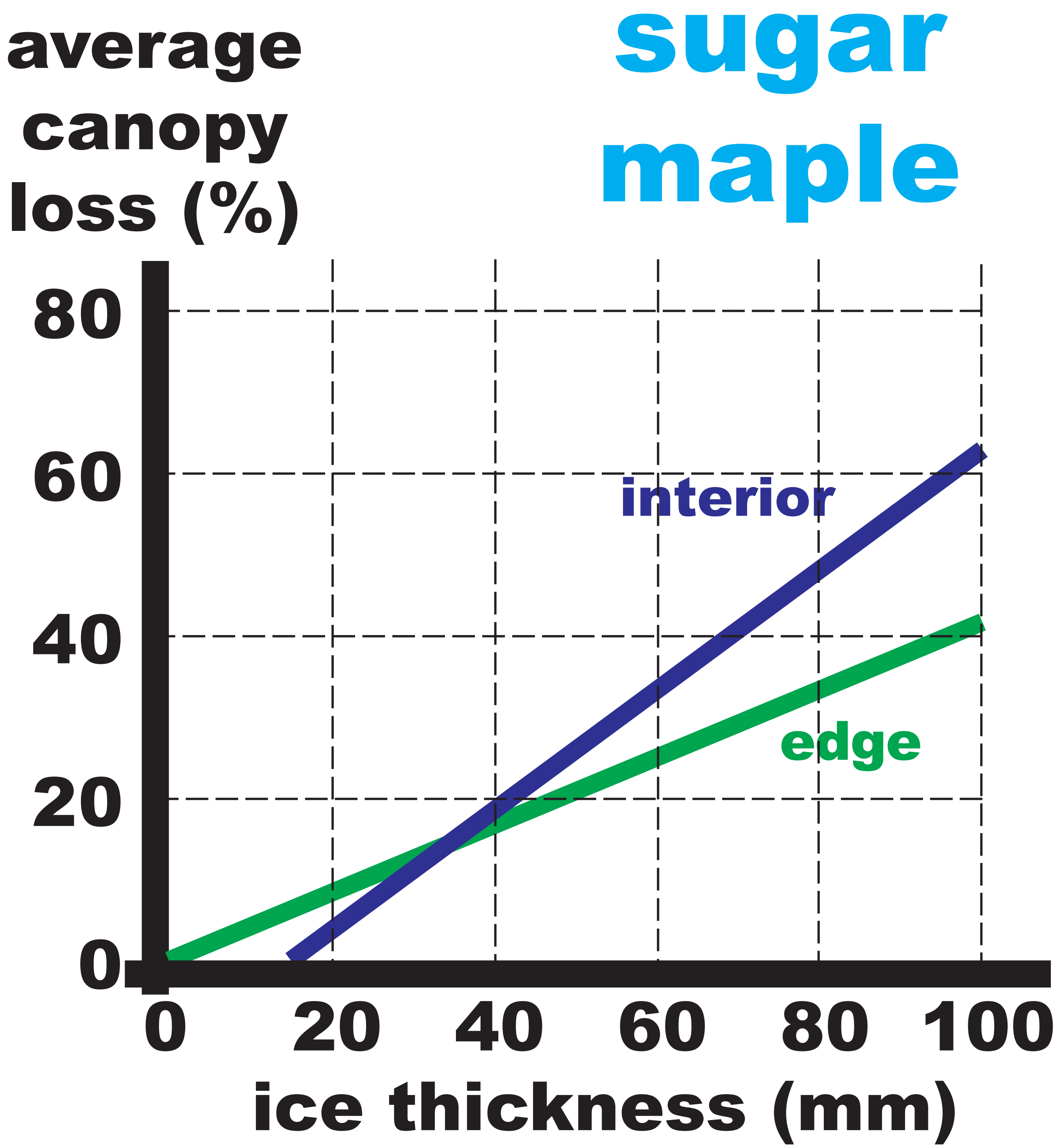


Figure 14: Forest edge and forest interior sugar maple (*Acer saccharum*) tree damage from ice accumulation.
(Prouix & Greene 2001))

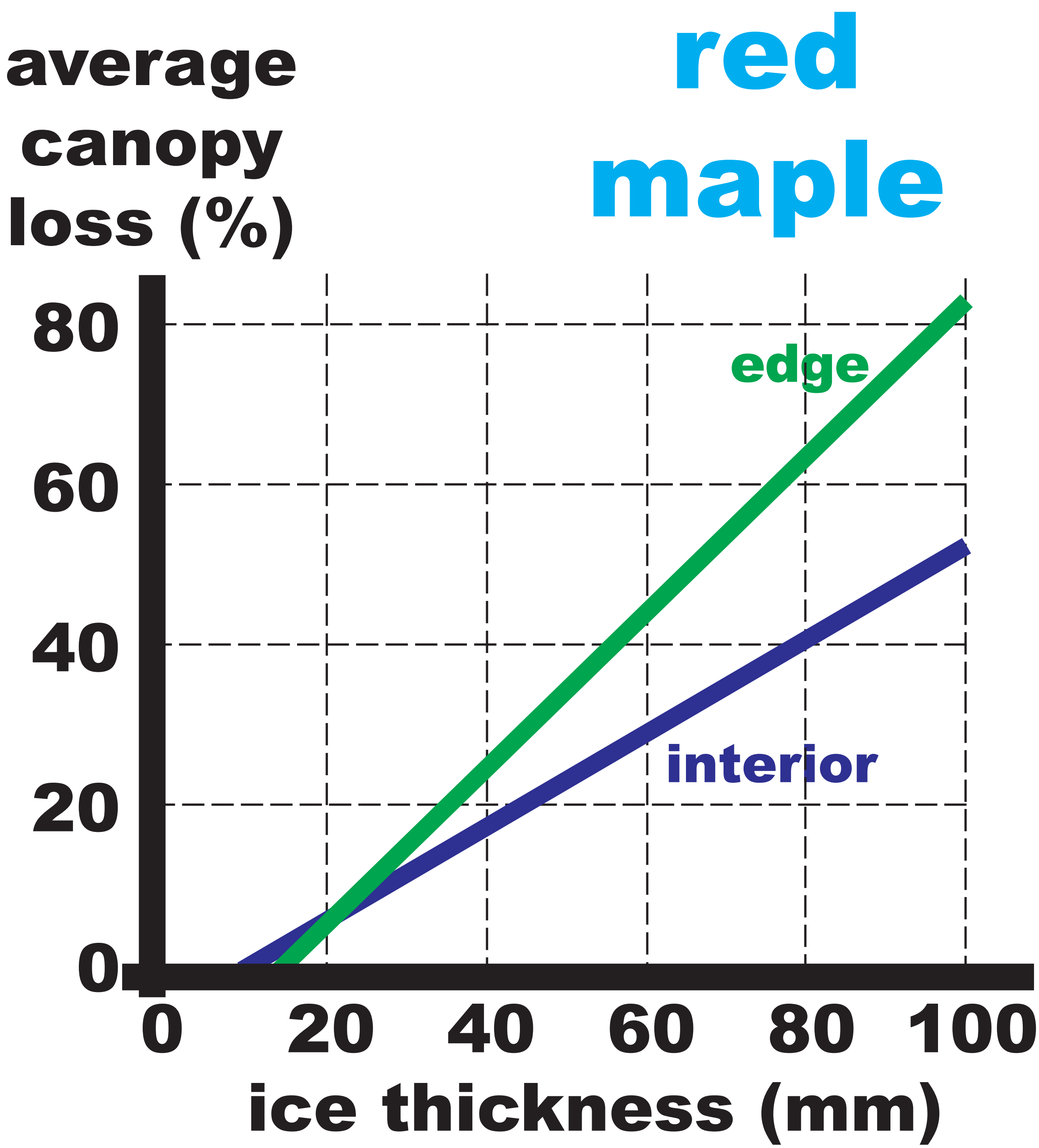


Figure 15: Forest edge and forest interior red maple (*Acer rubrum*) tree damage from ice accumulation.
(Prouix & Greene 2001)

# PLANTINGS

| CODE | TREE DAMAGE CAUSE | IMPORTANCE VALUE (0.0 – 1.0) |
|---|---|---|
| II3A | tree species | 0.149 |
| III3F | multiple stem form | 0.026 |
| II1I | exotics / non-natives | 0.025 |
| III2L | drooping branch form | 0.021 |

Figure 16: Four causes of tree ice storm damage which can be manipulated to minimize risks through appropriate tree species selection and planting practices.
Listed in order of relative importance value from 45 ice storm studies.

# STAND MANAGEMENT

| CODE | TREE DAMAGE CAUSE | IMPORTANCE VALUE (0.0 – 1.0) |
|---|---|---|
| III3B | basal area of stand | 0.105 |
| III3C | thinning stands | 0.105 |
| III3D | stem lean | 0.079 |
| III3E | stem form factor | 0.079 |
| III2H | unmanaged trees | 0.064 |

Figure 17: Five causes of tree ice storm damage in forest stands which can be manipulated to minimize risks through appropriate arboricultural and silvicultural practices.
Listed in descending order of importance value derived from 45 ice storm studies.

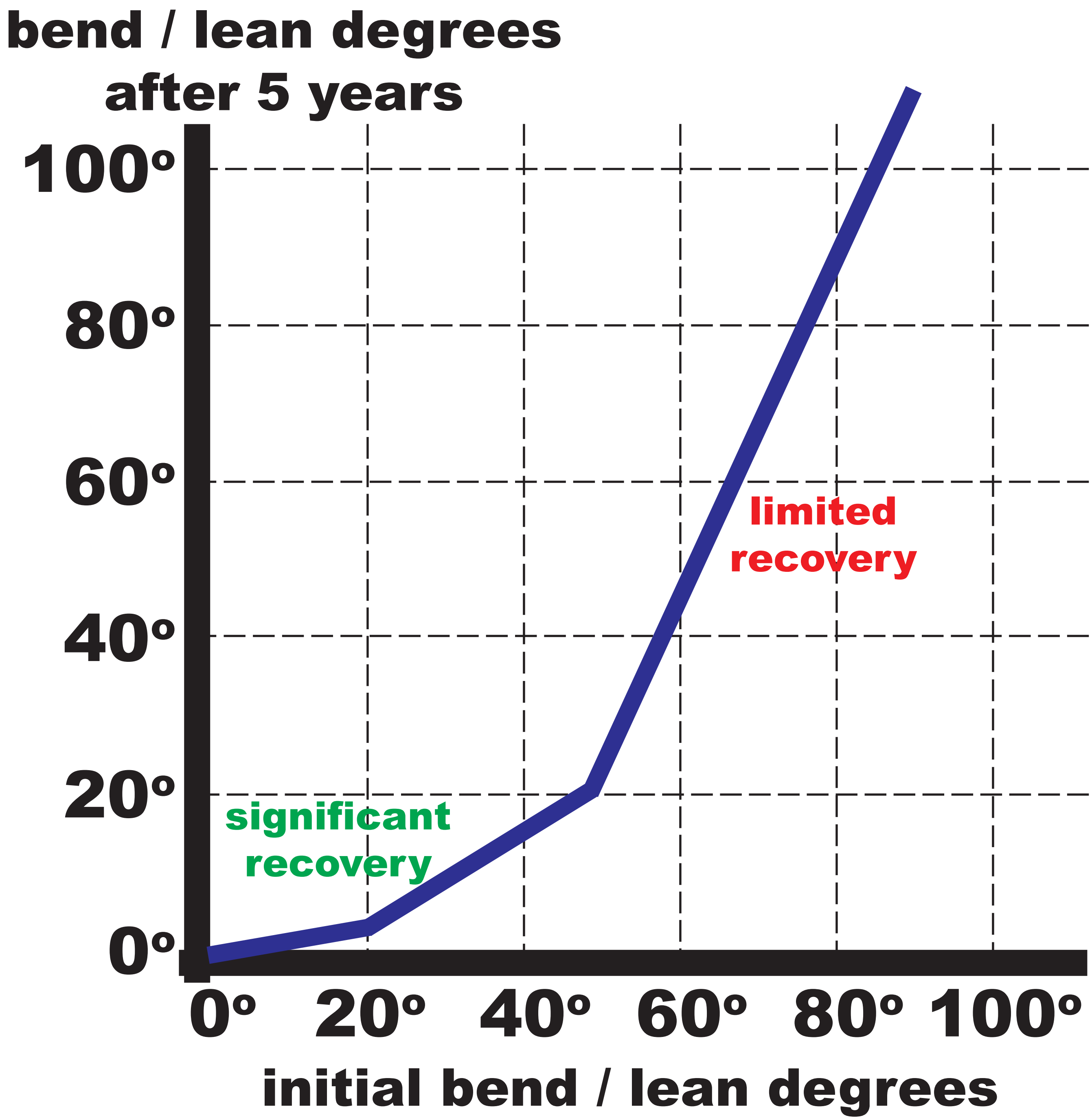


Figure 18: Recovery after five years from a stem bend or lean (not caused by root damage) initiated by a major ice storm. (Bragg & Shelton 2010)