Second Edition

Trees and Ice Storms

The Development of Ice Storm–Resistant Urban Tree Populations

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Summary

Severe ice storms occur every year in the United States and Canada, particularly in the midwestern and eastern regions of the United States. Along with fires and wind, ice storms are a frequent and major natural disturbance factor in eastern deciduous forests. Likewise ice storms are responsible for deaths and injuries of people and cause dramatic damage and tree loss to urban forests. Ice storms annually result in millions of dollars in loss, and potentially billions of dollars in losses for extreme and widespread ice storms. Damage to electric distribution systems, blocked roadways, and property damage from fallen trees and limbs pose safety concerns and disrupt normal community functions.

Tree species vary in their resistance to ice accumulation. Certain characteristics, such as weak branch junctures indicated by included bark, dead and decaying branches, a broad crown, and fine branching, increase a tree's susceptibility to ice storm damage.

Planting a diverse urban forest that includes trees resistant to ice storms and performing regular tree maintenance to avoid or remove structural weaknesses will reduce damage caused by severe ice storms. Management plans for urban trees should incorporate information on the ice storm susceptibility of trees in order to: limit potential ice damage; to reduce hazards resulting from ice damage; and to restore urban tree populations following ice storms. Susceptibility ratings of species commonly planted in urban areas are presented in this publication for use in developing and maintaining healthy urban tree populations.

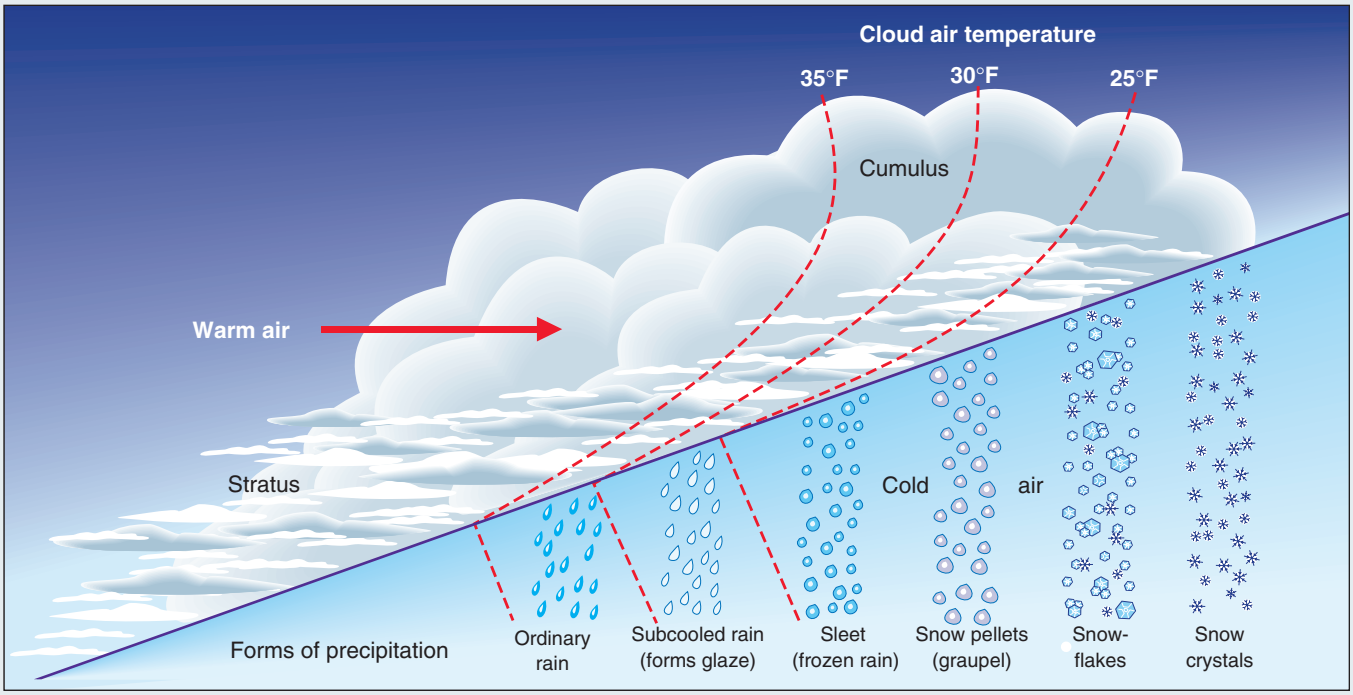

Figure 1. Forms of precipitation that result when a winter warm front slowly advances into ground layer air at or below 0°C and the relationship to cloud air temperature (from Lemon, 1961).

Introduction

Ice storms, also referred to as glaze storms, cause considerable damage every year to trees in urban and natural areas within the United States. They vary considerably in their severity and frequency and are one of the most devastating winter weather events (Figures 1 and 2). Every year at least one major ice storm is expected. Glazed roads and pathways, fallen power lines, power outages, and falling trees and branches result in deaths and injuries to people. Monetary losses typically are tens to hundreds of millions of dollars. In extreme cases that occur once every 10 to 20 years, ice storms have the potential to cause losses in the billions of dollars.

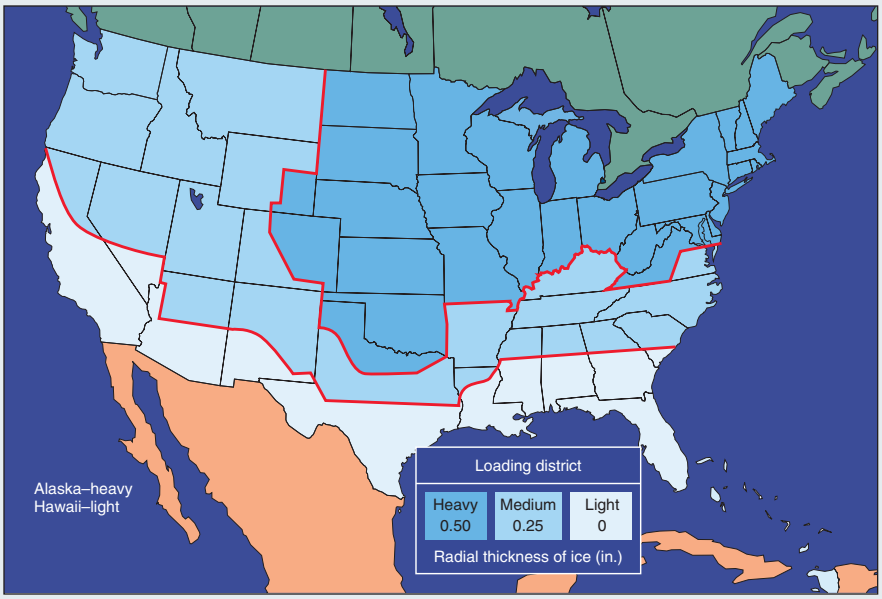

Figure 2. Ice-loading districts in the United States for ice accumulation on surfaces (from National Bureau of Standards, 1948 and National Electric Safety Codes Rule 250B, 2002).

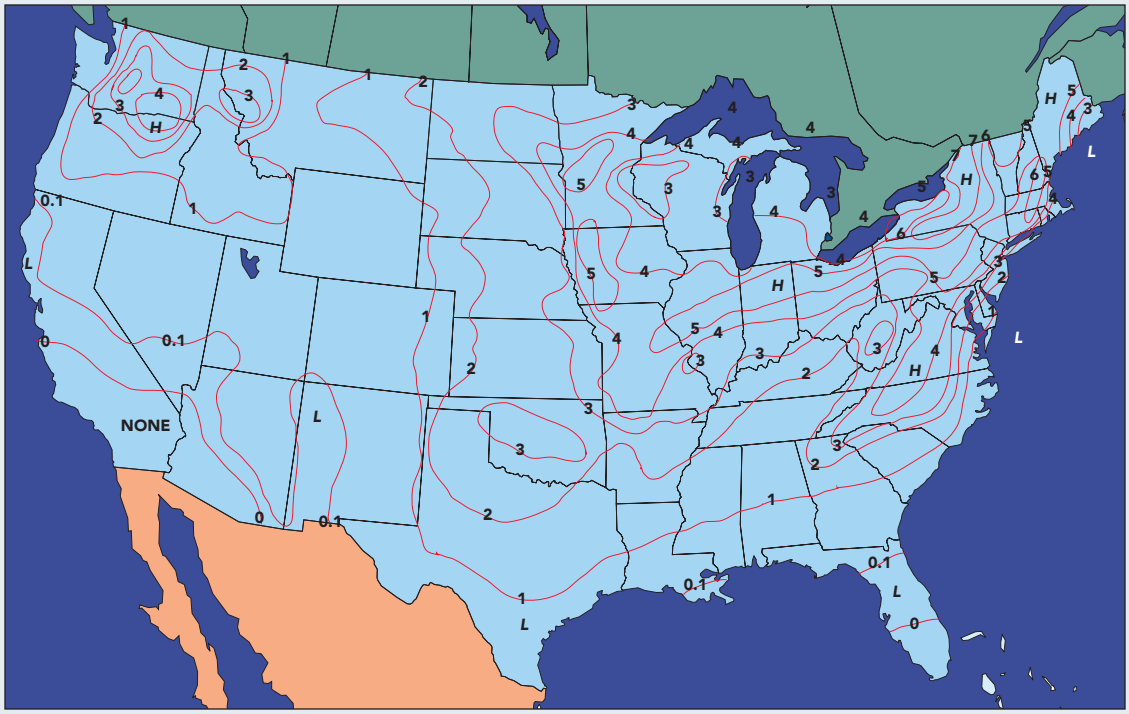

Figure 3. Annual mean number of days with freezing rain within the United States recorded between 1948 and 2000 H = High and L = Low (from Changnon 2003).

Within the eastern deciduous forests of North America these storms are among the most frequent forest disturbances.

Ice storms result in the accumulation of freezing rain on surfaces such as tree branches and electrical wires. The U.S. National Weather Service defines ice storms as the accumulation of at least 1/4 inch (0.625 cm) of ice on exposed surfaces. The ice formation process is influenced by general weather patterns. Typically ice storms can develop when a moist winter warm front passes over a colder surface-air layer (Figure 1). Rain falls from a warmer layer (above 32°F/0°C) through layers of cooler air (below 32°F/0°C) without freezing, becoming supercooled. Less commonly, ice storms occur when the temperature at the top of clouds is greater than 15°F (-10°C), ice particles are in low concentration or do not form, and supercooled water arises. In either case, ice accumulates when supercooled rain freezes on contact with surfaces that are at or below the freezing point (32°F/0°C). Most ice storms last only a few hours, but they may occur over several days depending on weather patterns.

Ice storms occur from October through April. Ninety percent occur between December and March with most occurring in January. Conditions that result in ice storms are most prevalent in the central, northeastern, and southeastern parts of the United States, as illustrated through maps of ice accumulation and ice storm frequency (Figures 2 and 3).

Accumulations of ice can increase the branch weight of trees by a factor of 10 to 100 times. Ice accumulation on stems generally ranges from a trace to 1 inch (2.5 cm) in diameter and in extreme cases reports up to 8 inches (20 cm) of ice encasing the stem. The severity of damage increases with greater accumulations of ice (Table 1). Accumulations between 1/4 and 1/2 inch can cause small branches and weak limbs to break, whereas 1/2-inch to 1-inch or greater accumulations can cause larger branches to break, resulting in extensive tree damage (Figure 4). Branch failure

Figure 4. Included bark and wood decay enhance branch breakage and tree damage when ice accumulates on trees.

occurs when loading from the weight of ice exceeds wood resistance to failure or when constant loading further stresses a weakened area in a branch (Figure 4). Strong winds substantially increase the potential for damage from ice accumulation. Residual damage from ice storms can occur several months to years later when wood of branches and trunks weakened by ice loading fails.

Monetary losses to forests, individual trees, utility lines, agriculture, commerce, and property can be extensive after an ice storm. Between the years of 1949 and 2000, insured property losses from freezing rain were $16.3 billion U.S. dollars (adjusted to the value of year 2000 dollars). Actual losses are even greater as this total excludes non-insured losses. As an example, losses from a 1998 ice storm covering the northeastern United States and southeastern Canada were estimated at $6.2 billion with less than one-half of this amount insured. Other effects include more than four million people without power and more than 40 deaths attributed to the ice storm. Tree damage to electrical systems are the primary cause of outages. In 1990, more than a million dollars in damage to parkway trees alone occurred as a result of a severe ice storm in Urbana, Illinois documented by a $12 million federal disaster declaration. According to records from the U.S. Federal Emergency Management Agency, a severe ice storm in 1991 in Rochester, Minnesota, caused $16.5 million worth of property damage. In the same year, a widespread ice storm in Indiana caused $26.8 million in property damage. On average, ice storms account for more than 60 percent of winter storm losses within the United States at a mean total annual cost of $226 million.

Table 1. Ice loading index and damage to trees and structures. (Modified from Jones and Mulherin 1998)

Freezing Rain Induced Event and Structural Damage Occurrence	Increased Ice Accumulation
Slippery roads	
Minor ice accumulation on trees	
Tree induced outages (communications and power distribution systems)	
Bending birch trees	
Broken branches on susceptible trees *Characteristics:* fine branching, included bark, unsound wood, broad or unbalanced crowns, old or injured trees (Examples: poplars, soft maples, beeches, willows, trees at edges of a clearing or pruned on one side)	
Outages to transmission lines caused by galloping (wind-induced)	
Broken branches on resistant trees *Characteristics:* coarse branching, excurrent branching pattern, narrow crowns, young, sound trees (Examples: white oaks, black walnut, interior forest trees)	
Outages, not caused by trees, in the distribution system	
Broken branches on resistant coniferous trees	
Outages, not caused by trees, in the transmission system	
Communication tower failures	

Note: Damage to trees and structures, in order of increasing ice load. High winds concurrent with the ice load increases the level of damage.

Historical Accounts

". . . great tree branches ripped from their moorings with startling suddenness came hurtling downward through the air to strike the ground with such force that the sounds at times resembled those of a thunderstorm."

The damage inflicted by ice storms and their mystique have been captured in both popular and scientific literature. "In America the ice-storm is an event. And it is not an event which one is careless about. When it comes, the news flies from room to room in the house, there are bangings on the doors, and shoutings, 'the ice-storm! the ice-storm!' and even the laziest sleepers throw off the covers and join the rush for the windows" (From *Following the Equator* by Mark Twain 1897). In this way the spectacle of ice storms has been immortalized in Mark Twain's description of "Connecticut's Weather." W.E. Rogers bore eloquent witness to the impact of ice storms on trees. Reporting on a severe storm in southern Wisconsin, Rogers (1924) wrote that ". . . great tree branches ripped from their moorings with startling suddenness came hurtling downward through the air to strike the ground with such force that the sounds at times resembled those of a thunderstorm. Pedestrians kept to the middle of the thoroughfares and many people remained indoors rather than risk the uncertainties of the public streets." He also reported that where trees had stood close together, streets became completely blocked and passageways had to be chopped out with axes.

Technical reports on the extent and severity of ice storms date to over 100 years ago. In one of the earliest documented accounts of an ice storm in the United States, von Schrenk (1900) describes the potential severity of ice storms and tree damage–the enormous loading of the trees over the 5,000 square mile region of Missouri, Illinois, Indiana, and Ohio was exacerbated by ice accumulation and strong winds. Harshberger (1904) later reported that there were two exceptionally destructive ice storms around Philadelphia in 1902. One storm was accompanied by high winds and did irreparable damage to numerous fruit, forest, and shade trees. The other storm deposited more ice, but because of the lack of wind there was less damage. Twelve years later in eastern Pennsylvania and western New Jersey, an area of approximately 600 square miles was damaged by an ice storm (Illick, 1916). Actual counts of damaged trees indicated that 90 percent of the forest trees either had their crowns broken off entirely or were damaged so badly that only stubs

of branches remained. Viewed from a distance, the forests resembled broken masts. Buttrick (1922) noted that disarray and closure of schools and business in Michigan cities and towns occurred from the ". . . unparalleled severity, a storm which broke down and completely wrecked trees, pole lines, and transmission systems."

Abell (1934) reported that forests of the southern Appalachian area had been repeatedly damaged by ice storms. Referring to a storm in western North Carolina in 1932, he quoted a mountaineer to have said, "By two o'clock Sunday morning there was no sleeping at all for the noise of breaking timber." According to Croxton (1939), press reports of a substantial ice storm in Missouri and Illinois suggested "Trees are ruined" and, "There was scarcely a tree escaped the ravages of the ice." In Central Iowa, "a heavy ice storm, accompanied by wind, inflicted severe damage to trees, telephone lines, and power lines" in February 1961 (Goebel and Deitschman 1967).

More recently, on Valentine's Day 1990, a severe ice storm in Urbana, Illinois, damaged at least 26 percent of the city's parkway trees (Hauer et al. 1993). About 5 percent of the entire public tree population was severely damaged and required immediate removal or repair. The air was filled for hours with the rifle report of snapping branches followed by the crash of ice-laden branches smashing to the ground. Most of the city was without power, for as long as eight days. A severe 1994 southeastern ice storm within Alabama, Mississippi, and Tennessee caused over $3 billion in losses (Lott and Sittel 1996). The January 1998 ice storm that struck the northeastern United States and southeastern Canada impacted millions of people through lost power and billions of dollars in damages to trees and property (Kerry et al., 1999). The recorded history of ice storms and their impacts also explain how damage occurs and provides suggestions to minimize the impact of these storms on society.

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Tree Features and Ice Storm Susceptibility

Damage to trees occurs for a number of reasons. For example, branch breakage from ice loading can occur at indiscriminant or random points because of a variety of factors (decay, dead branches, severed roots) or at points of attachments (included bark, long and heavy branches). The damage to trees from ice storms depends on several factors: amount and duration of accumulated ice, exposure to wind, and duration of the storm. An increased susceptibility of tree species to ice storms also involves tree characteristics: weak branch junctures indicated by included bark, decaying or dead branches, tree height and diameter, increased surface area of lateral branches, broad crowns, unbalanced crowns, restricted and unbalanced root systems, and shallow rooting habit (Figure 5). Included bark results from in-grown bark in branch junctures. This weak connection enhances a tree's susceptibility to breakage under ice-loading. For example, 'Bradford' pear branches often break during ice storms where there is included bark in branch junctures. In contrast, the 'Aristocrat' cultivar of the same pear species has few branches with included bark and sustains less damage during ice storms.

Decaying or dead branches already are weakened and have a greater probability of breaking when loaded with ice. Decay, in combination with included bark, further increases tree susceptibility. The surface area of lateral branches increases as the number of branches and the spread of the crown increase. With

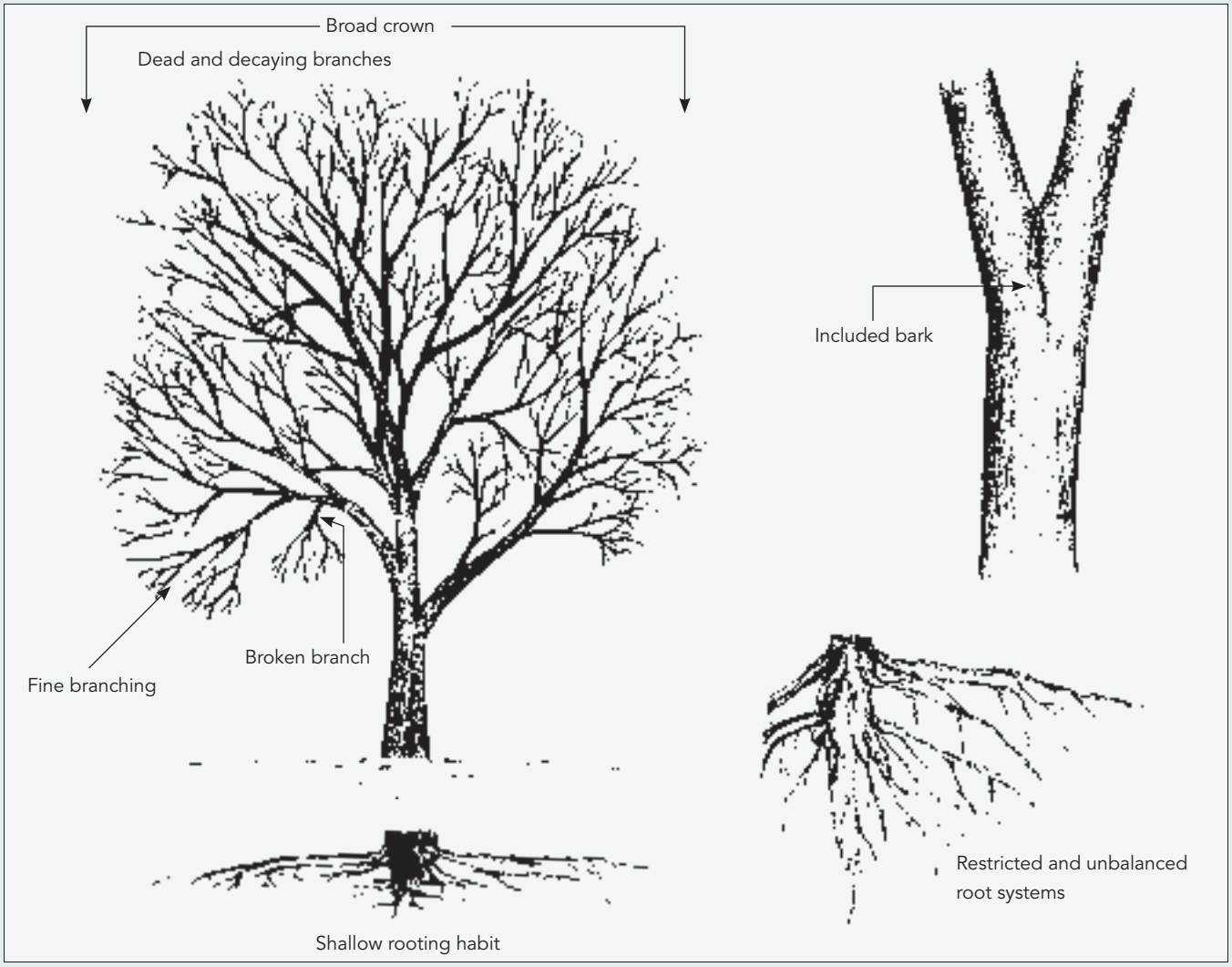
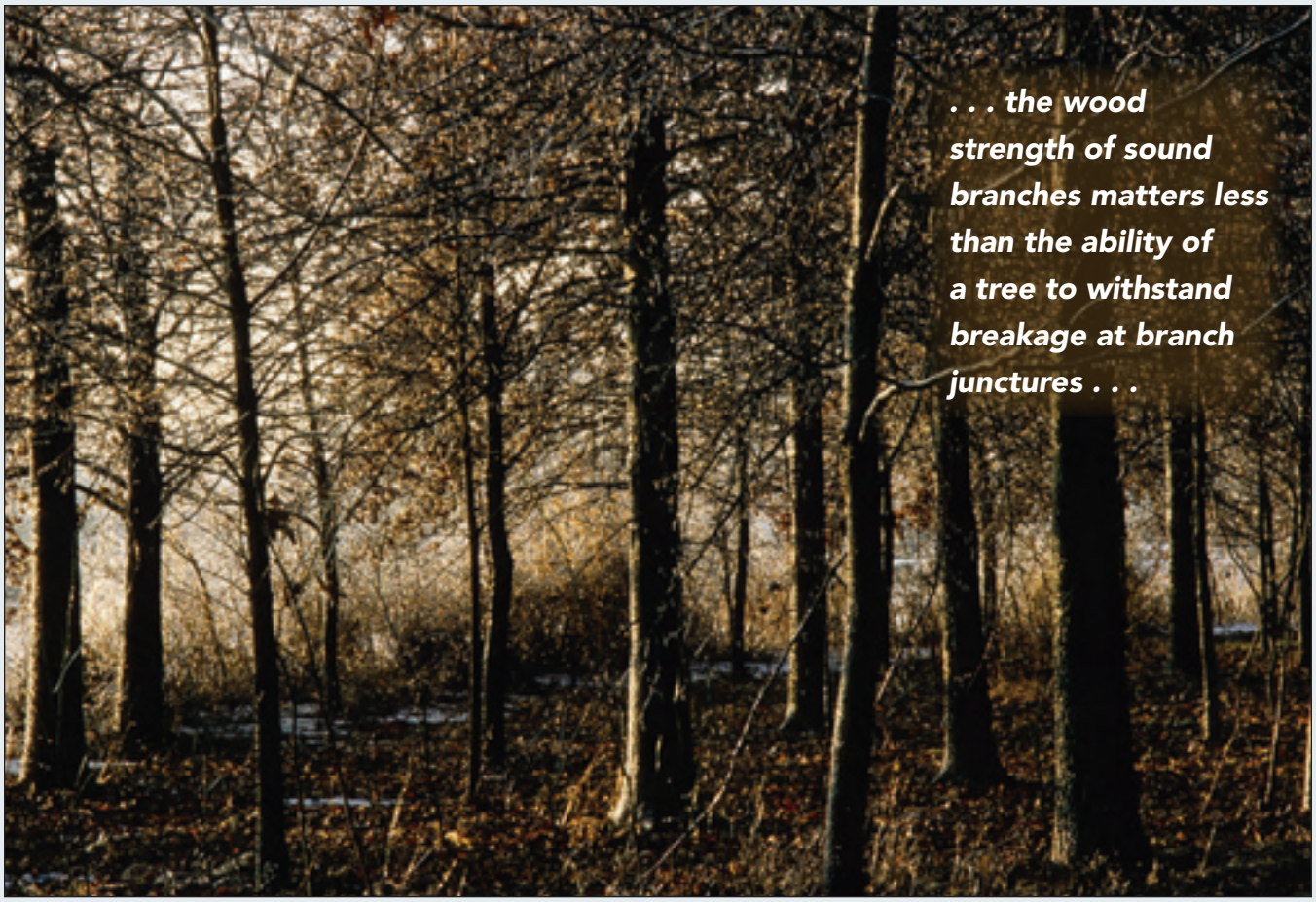


Figure 5. Characteristics that increase a tree's susceptibility to damage from ice storms.



increased surface area, more ice can accumulate on lateral branches, the greater ice load results in greater branch failure. Contrary to popular belief, the wood strength of sound branches matters less than the ability of a tree to withstand breakage at branch junctures and the presence of fine branching or a broad crown that enhances ice accumulation. Tree branch length, horizontal branching, and inflexibility of the stem, in general, lead to greater susceptibility. Many broad-leafed tree species, when grown in the open, form broad crowns (decurrent branching), that increase their susceptibility to ice storms. Examples include Siberian elm, American elm, hackberry, green ash, and honey locust. Trees with unbalanced crowns (such as at forest edges) are more susceptible to ice damage and increased bending through greater ice accumulation on the side with more branches.

Tree root systems influence susceptibility to ice storm damage. Trees with diseased (i.e., *Armillaria*) and damaged (i.e., construction injury) root systems are generally more susceptible to ice storms. Root system configuration also may play a role with shallower roots making a tree more prone to tipping, especially if the soil is unfrozen, moist, and winds are present.

Tree susceptibility can change as a result of tree pathogens. An increase in ice storm susceptibility in American beech is reported as a result of beech bark disease. Historic reports prior to beech bark disease consistently rated this tree with moderate to little susceptibility. More recent reports document American beech with high susceptibility resulting from decay that follows beech bark disease infections. Likewise, loblolly pine susceptibility to ice storm damage has increased as a result of fusiform rust. In these cases, ice storms are considered secondary damaging agents and interact with primary causes of tree damage (i.e., insects, diseases, and injury).

Tree susceptibility to ice storms is influenced by position in a forest with upper canopy (dominant and co-dominant) trees incurring greater damage than lower canopy (intermediate or suppressed) trees. For example, American elm expresses greater resistance as a member of the lower canopy, yet becomes more susceptible to damage as an upper canopy or open grown tree. The lower canopy trees are damaged more so from falling branches and whole tree failure of the upper canopy members. This relates to the positive correlation between direct tree damage from ice storms and tree diameter, tree height, and canopy spread. No correlation exists between understory trees and ice storm damage in which case secondary damage is a factor of proximity to failing trees.

Tree Features and Ice Storm Resistance

Juvenile and mature trees that have excurrent (conical) branching patterns, strong branch attachments, flexible branches, and low surface area of lateral branches are generally resistant to ice storms

Trees also have characteristics that impart resistance to the damage resulting from ice storms. Juvenile and mature trees that have excurrent (conical) branching patterns, strong branch attachments, flexible branches, and low surface area of lateral branches are generally resistant to ice storms (Figure 6). Many conifers have an excurrent branching pattern and resist ice storm damage. Some tree species, such as sweet gum and tulip poplar, have an excurrent growth habit when young but develop a decurrent growth habit later in life. These species are more resistant to breakage when young than broadleaf trees that do not exhibit a juvenile excurrent branching pattern. The resistance of tulip poplar to ice storms decreases as they become older and exhibit a decurrent (or broad) crown form. Some tree species that typically exhibit a decurrent branching pattern have forms and cultivated varieties (cultivar) that possess an excurrent form. These would likely have greater resistance to ice storm damage. An example is a clone of European black alder with a columnar crown form in the collections of the Morton Arboretum near Chicago.

Tree species with strong branch attachments have greater resistance to breakage than those with weak branch junctures indicated by included bark. Trees with coarse branching patterns and, as a consequence, lateral branches with reduced surface area, such as Kentucky coffee tree, black walnut, and ginkgo, accumulate less ice and typically have little breakage from ice storms. Forest understory tree species, such as hophornbeam and blue beech, and trees that mature at small heights, such as amur maple and serviceberry, also are relatively resistant to ice storm damage. Younger trees and those with greater flexibility or elasticity of branches have greater resistance. Trees that develop a greater taper of the main trunk or with buttresses can support more mass and tend to have greater resistance to failure of the main stem than spindly trees with less taper. Decreased taper allows greater bending and breakage of the stem at its basal pivotal point.

Seed source of trees also influences ice storm resistance. Seed source variation in ice tolerance is due to natural selection, according to climatic influences, of trees comprising populations and species. Local variants of a tree species and tree species themselves indigenous to areas subject to severe ice storms seem to have greater resistance than those not from such areas. For example, loblolly pine trees from more northern latitudes experience less ice storm damage than those from more southerly locations when grown in the same location. Also, shortleaf pine, native to more-northerly locations that have more frequent and severe ice storms, are more resistant to ice storm damage than loblolly pine trees.

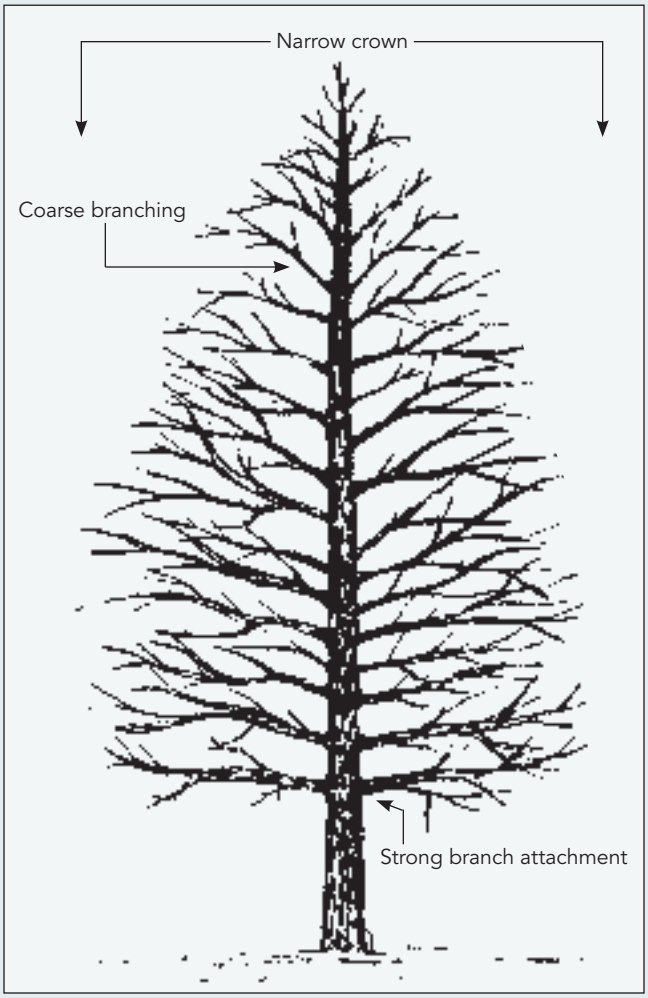


Figure 6. Characteristics that reduce a tree's susceptibility to damage from ice storms.

Ice Storm Damage in Forests

Stands of trees in forests, greenbelts, and other natural areas are damaged by ice storms. The location of a tree within a stand often influences its susceptibility. Edge trees tend to have large, unbalanced crowns with longer, lower, and more branches on the open side. Interior trees, the crowns of which must compete for light, have small crowns with shorter main branches and fewer lower limbs and typically show less damage than edge trees. Edge trees accumulate more ice on the open side, which can result in major branch failure, crown breakage, and uprooting of entire trees. Trees on slopes, and especially those facing north and east, tend to have greater ice storm damage because of imbalances in the crowns and roots. Vine growth on forest trees can increase susceptibility to ice storm damage by increasing the surface area that accumulates ice.

Species with shallow root systems, such as red oak, are more prone to tipping during ice storms than deep-rooted species, such as white oak and bur oak, especially if the ground is unfrozen and the soil is saturated. Likewise, frozen ground greatly reduces the chance for tree tipping. Streams or rivers that dissect forests are often lined with edge trees having unbalanced crowns and root systems. These trees are more susceptible to ice storm damage. During the 1990 Valentine's Day ice storm in central Illinois, there was extensive edge tree damage on the Middle Fork of the Vermilion River in Vermilion County. Whole trees uprooted by the weight of accumulated ice were stacked up to four deep at every bend of the river.

Forests are dynamic systems and respond to ice storms through changes in species composition. Depending upon the level of damage, tree species such as jack pine and sugar maple will likely die within a few years if canopy damage exceeds 50 percent. In contrast, tree species such as pitch pine and American beech have an excellent sprouting ability and the potential to develop new branches and survive. Ice storms play a role in natural forest succession with many pioneer tree species (i.e., pin cherry, quaking aspen, and jack pine) that are highly susceptible and easily damaged. Late successional species, especially if present as seedlings and saplings in the understory, are able to respond to ice storm-induced disturbance and become dominant in the affected forest stand. Finally, tree stocking level, or the relative crowding of trees in a stand, influences forest and plantation susceptibility with overstocked, crowded stands having spindly trees with less taper. This condition lends itself to greater bending and snapping of individual trees at the base of the trunk, potentially leading to a domino effect of trees falling upon adjacent trees, increasing the area of damage in the forest.

Forests are dynamic systems and respond to ice storms through changes in species composition.

Ice Storm Damage Management and Prevention

Steps can and should be taken to manage and minimize ice storm damage, particularly to urban forests, through tree selection, maintenance, and recovery plans. Integrating ice storm and tree damage information into management plans and preparing in advance to mitigate and respond to storm damage is recommended. Specific ice storm prevention, response, and recovery actions can be incorporated into existing management plans. As a first step, selection and planting tree species resistant to ice damage can reduce tree and property damage from ice storms. Ice storm susceptibility should not be the sole criterion for selecting trees for urban planting, but the numbers of susceptible trees should be limited, particularly in regions with high frequencies of damaging ice storms (Figures 2 and 3). Ice storm resistance ratings based on the authors' research and a review of published reports on commonly planted urban trees are presented in Table 2. In addition, even though small stature trees are more resistant to ice storm damage, focusing solely on smaller trees in the urban forest greatly reduces potential functional benefits including air pollution amelioration, interception of precipitation, and energy conservation from shading.

For species not included in Table 2, resistance to ice accumulation can be estimated based on general tree characteristics. Tree species and cultivars genetically prone to forming included bark and those having decurrent branching patterns and large branch surface area will be more susceptible to damage. In contrast, species and cultivars with coarse branching patterns and excurrent branching and those that lack included bark and other structural weaknesses will generally be more tolerant to ice storms. However, ratings based directly on measurements and observations of ice-storm-related tree damage are more reliable when available.

Trees with a greater risk for failure, such as those with extensive decay and cavities in the trunk and major branches, especially those near sidewalks, streets, driveways, and buildings, should be removed promptly. Proper tree placement and pruning on a regular cycle will reduce the potential for property damage and decrease a tree's susceptibility to ice storm damage. Property damage from trees broken by ice accumulation can be reduced by locating trees where they can do the least damage. Trees located near homes and other structures should be evaluated regularly for tree risk failure potential, and corrective actions taken when needed. Trees pruned regularly from a young age

Table 2. Ice Storm Susceptibility of Tree Species Found Growing in Urban Areas.

Susceptible	Intermediate	Resistant
American basswood	American beech	Amur maple
American elm	Boxelder	Baldcypress
Bigtooth aspen	Chestnut oak	Balsam fir
Black ash	Choke cherry	Bitternut hickory
Black cherry	Douglas-fir	Black walnut
Black locust	Eastern white pine	Blackgum
Black oak	Gray birch	Blue beech
Bradford pear	Green ash	Bur oak
Butternut	Japanese larch	Catalpa
Common hackberry	Loblolly pine	Colorado blue spruce
Eastern cottonwood	Northern red oak	Crabapple
Honey locust	Paper birch	Eastern hemlock
Jack pine	Pin oak	Eastern redcedar
Pin cherry	Red maple	European larch
Pitch pine	Red pine	Ginkgo
Quaking aspen	Scarlet oak	Hophornbeam
Red elm	Scotch pine	Horsechestnut
River birch	Slash pine	Kentucky coffeetree
Siberian elm	Sourwood	Littleleaf linden
Silver maple	Sugar maple	Mountain ash
Virginia pine	Sycamore	Northern white cedar
Willow	Tamarack	Norway maple
	Tulip poplar	Norway spruce
	White ash	Ohio buckeye
	Yellow birch	Pignut hickory
		Shagbark hickory
		Swamp white oak
		Sweetgum
		White oak
		White spruce
		Witch-hazel
		Yellow buckeye

Adapted from Hauer et al. (1993) and published reports from 42 primary publications. Species ratings are consistent with the first edition of this publication except for green ash, pin oak (both previously rated as susceptibe) and bur oak (previously rated as intermediate).

Tree branches that break and limbs that sag from ice accumulation cause the majority of electric power outages and utility damage.

should be more resistant to ice storms as a result of removal of structurally weak branches, decreased surface area of lateral branches, and decreased wind resistance. Professional arborists can install structural support, such as cabling to hold major branches together, to increase a tree's tolerance to ice accumulation in situations where individual trees are not weakened beyond reasonable limits for saving.

Trees should not be planted in locations where their growth will interfere with above-ground utilities—branches that grow into power lines and fail during ice storms create power outages and safety concerns. Tree branches that break and limbs that sag from ice accumulation cause the majority of electric power outages and utility damage. Regular utility right-of-way inspection and tree trimming is important to minimize outages. Public education about the need to manage trees near utility lines should be encouraged, because it is in the best interests of utility companies, communities, and electricity consumers. Ways to educate the public include annual messages inserted with bill mailings; public service announcements through printed, radio, and television media; door-to-door contacts prior to tree trimming; tree replacement programs; and community presentations.

After storm damage has occurred, trees and branches deemed hazardous require immediate removal to ensure safety and prevent additional property damage. Trees that can be saved should have broken branches properly pruned to the branch collar. Stubs and flush-cut pruning result in weakly attached sprouts and future insect and disease problems. Loose bark should be cut back only to where it is solidly attached to the tree. A split fork of the main trunk normally necessitates tree removal. Repair through cabling and bracing is not recommended in this case. Avoid deliberate removal of ice from trees as this can result in more damage than by doing nothing. Trees such as river birch, bald cypress, and arborvitae will naturally bend with the weight of ice and often return to natural habit after melting of ice.

Where severe ice storms occur, disaster plans should be developed to assist in recovery. Guidelines available from the Forest Service (Burban and Andresen, 1994) can assist with planning for and mitigating the impact of natural disasters in urban forests. The impact of ice storms can be minimized through planning, tree selection, and tree maintenance as outlined in this publication. Assistance in planning and carrying out programs to lessen the impact of future ice storms is available from governmental and private agencies concerned with urban and community forestry. Concerted action over many years is needed to minimize ice storm damage. Sustained efforts will undoubtedly reduce fatalities, injuries, monetary losses, tree damage, and cleanup costs to individuals and communities in regions where ice storms occur.

Recovery

Storm damage can be placed into five categories: broken branches, trunk bending, splitting of main or "co-dominant" stems, complete trunk failure, and tipping or up-rooting.

The remarkable resiliency of trees poses a problem for municipal foresters and property owners as they struggle with the decision to repair or remove trees damaged by ice storms in urban areas. Removing a tree when it can be repaired with an equal investment of time and resources represents a net loss in benefits to the community and property owners. Conversely, failure to remove a tree that cannot be restored to a safe and sound condition increases both the likelihood of future failure with consequent property damage and personal injury.

Storm damage can be placed into five categories: broken branches, trunk bending, splitting of main or co-dominant stems, complete trunk failure, and tipping or up-rooting. Trees that have been uprooted, sustained trunk failure or have broken branches account for more than 50 percent of the crown should be removed immediately (Table 3). In such instances the severity of damage precludes adequate recovery and, if trees are left in their debilitated state, constitutes a liability through an increased risk of further failure.

A thorough assessment of the entire tree (e.g. branches, trunk, roots) with respect to the location and severity of the wounds is essential in deciding whether to remove or repair a tree. Projections of survivability and the initiation of corrective treatments must be tempered by limitations owing to tree species, development stage, and the extent of internal defects. Tree species differ in their capacity to compartmentalize, or block with fungal-resistant barriers, decay in the tissues behind a wound. In weak compartmentalizing trees, extensive pockets of discolored wood and decay can form due to fungal infection of even the smallest of wounds. The coalescing of many small wounds over the entire tree can compound the decline in structural integrity and increase the probability of future failures. Older trees support more non-productive living tissue in the stems and roots than younger trees. As a result

Table 3. Common tree damage categories and decision criteria.

Uprooted Trees	Complete Trunk Failure	Broken Branches >50%	Broken Branches 30—50%*	Broken Branches <30%	Trunk Bend*	Split Co-dominant Stems*
Remove because structural integrity is compromised and future growth/form adversely affected.			**Repair following pruning guidelines and natural targets.**			

* Location and severity of the recent damage must be evaluated with respect to exposed defects, tree species, and tree age.

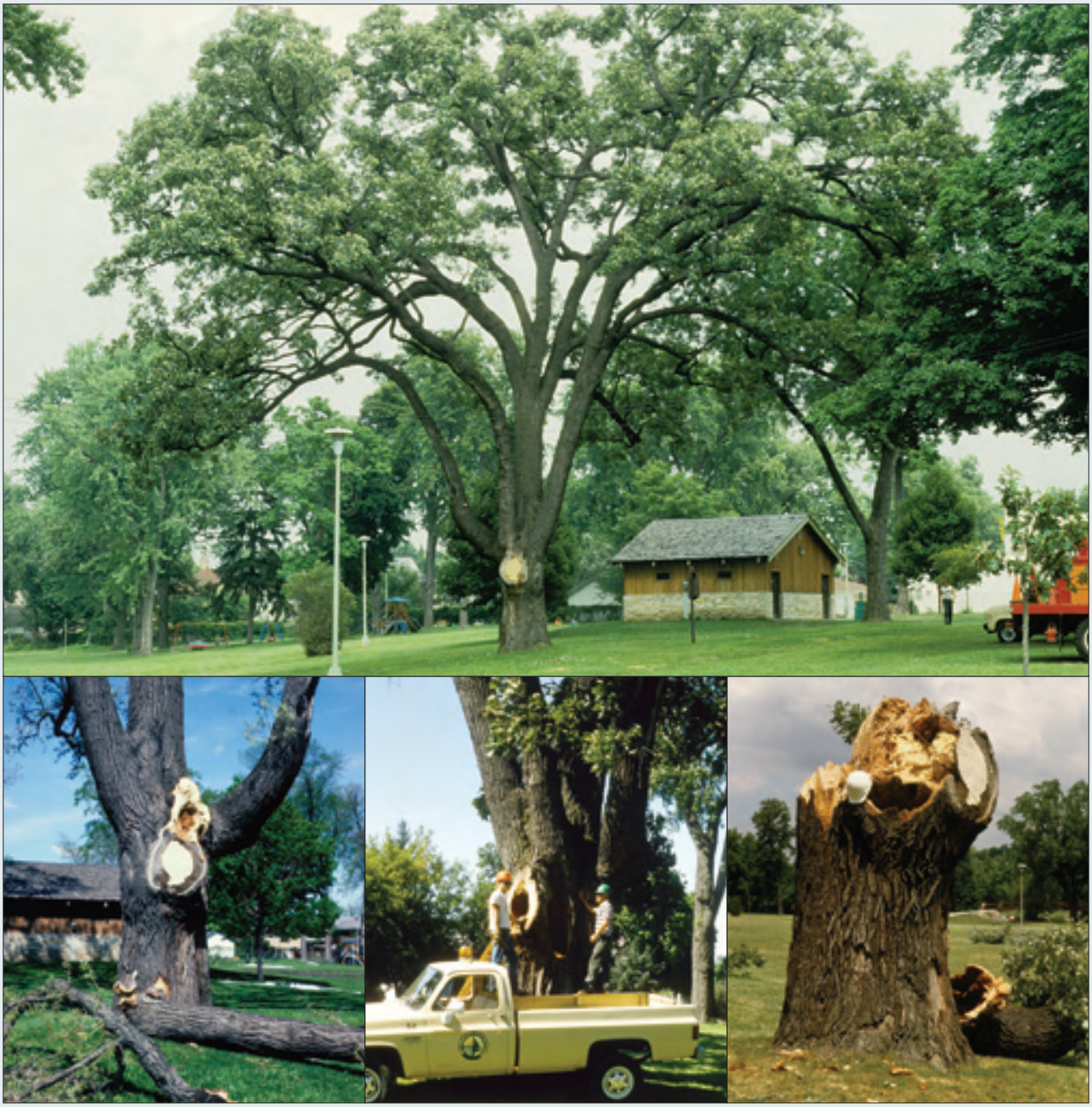


Figure 7. Extensive pockets of decay were exposed when this historic bur oak lost a lower scaffold limb. Cavity treatments and the cabling of the remaining lower scaffold limbs prolonged the life of the tree. The defect persisted, despite treatment efforts, and complete trunk failure occurred seven years after treatment at the point of decay.

older trees have a decreased capacity for recovery from storm damage. By way of example, an older, weakly compartmentalizing tree that loses 35 percent of the crown would be less likely to recover to a pre-storm condition compared to a young, strongly compartmentalizing tree, having the same extent of damage.

The presence and extent of decayed or discolored wood exposed by the damage should influence decisions as to whether a limb or tree is retained or removed. These decisions must take into account the position and load balance of the remaining crown relative to the point of damage. Crowns weighted to the side opposite the lost limb, where there is advanced decay, have a higher likelihood of future failure (Figure 7). Additional consideration should be given to the magnitude of stress loading at the point of damage that emanates

The long term impact on tree survivability and structural integrity is related to the total number of branches lost relative to the entire canopy and the size of the branches lost.

from the remaining crown. Under the simplest models there is a linear amplification in stress loads with increasing length. For additional information on the biomechanics of trees and tree failure see Mattheck (1991) and Lonsdale (1999).

Branch breaking is the most common form of ice-induced damage and generally is the most easily repaired. Branch breaking typically occurs at weak points associated with changes in tissue orientation (e.g. junctures between lateral and scaffold branches or scaffold branches and the main trunk) or at a point of defect. The long term impact on tree survivability and structural integrity is related to the total number of branches lost relative to the entire canopy and the size of the branches lost. Generally, damaged trees can be sustainably managed if less than 50 percent of the branches are affected and the loss is predominantly to lateral branches or the tips of scaffold branches. Corrective pruning cuts should follow natural pruning targets with the intent to promote balanced crown development (Gilman 2002). Major wounds resulting from the loss of a co-dominant stem can result in the discoloration and decay of remaining trunk tissues at the point of attachment (Figure 4). Preserving trees that have lost one or more co-dominant stems requires monitoring on a regular basis to assess the extent of the spread

of decay. The frequency of monitoring depends on public use and occupancy patterns. Pokorny (2003) provides more details to establish tree risk management guidelines.

The accumulation of ice can often produce damage to a branch that is not immediately evident. This hidden damage manifests itself in the formation of cracks that run parallel to the branch and originate near or at the point of attachment. These branches must be removed as soon as they are identified as they possess a high potential to fail.

Excessive ice loads can also induce branch splitting at the point of attachment (i.e. splitting of co-dominant stems). Repair typically involves pruning the ends of one or more of the affected branches to reduce load and the installation of cables and braces to provide additional mechanical support. Branches that have structural support systems installed in them must be monitored on an annual basis. In some cases, particularly on large, older trees, the extent of the split is too severe and the affected branch must be removed.

Trees that bend under the load of accumulated ice will, in most cases, return to their pre-storm form, once the load is dissipated by melting. The mere fact that the tree did not break under the tremendous load suggests good structural integrity. Concerns surrounding trees that have bent under ice loads, center on the position of the bend along the trunk and length of time the trees remained in the bent condition. Attention should be given to those instances in which the bend occurred in the lower 1/3 of the trunk. The position of the bend relative to the overall canopy (Figure 8), under such conditions may create internal cracks which can become a weak point in the future. Small, bent trees can be staked into an upright position to provide support while the stem grows and strengthens.

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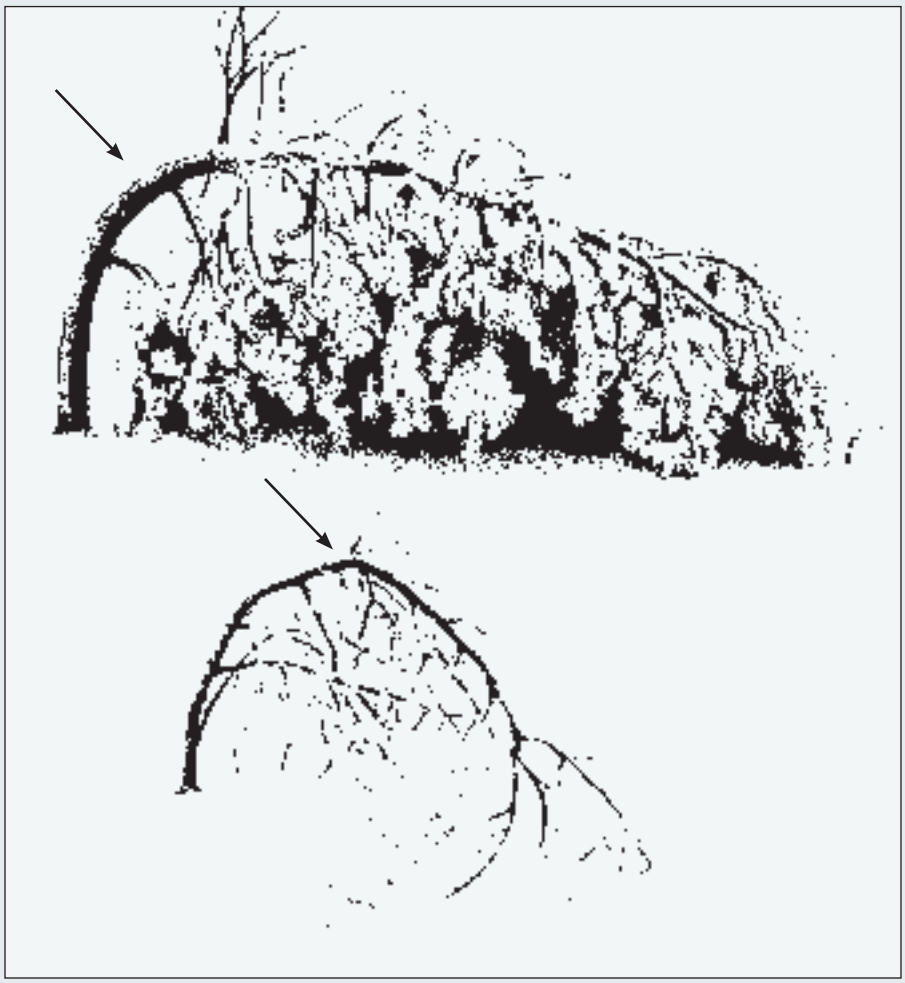

Figure 8. In most instances young, healthy trees can recover from bending due to excessive loading in the crown. If the bend occurs in the lower 1/3 of the trunk, then frequent monitoring of the tree is warranted.

Conclusion

Ice storm frequency and severity within the eastern United States necessitates the incorporation of ice storm information into the urban forestry planning process. While we cannot stop ice storms from occurring, we can take steps to reduce the impact of this major forest disturbance on urban forests and the interface between forests, buildings, and infrastructure.

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Additional Resources

General Arboriculture and Urban Forestry

International Society of Arboriculture—www.isa-arbor.com/
National Arbor Day Foundation—www.arborday.org/
Tree Inventory Management Tools—www.itreetools.org/
TreeLink—www.treelink.org/
Urban & Community Forestry—http://na.fs.fed.us/urban/index.shtm

Ice Storms

General Fact Sheets—http://extension.unh.edu/forestry/icestorm.htm
Ice Storm Mitigation Research—www.crrel.usace.army.mil/icestorms/
Historical Summary of Storms—www.americanlifelinesalliance.org/pdf/icestormsummaries.pdf
Trees and Ice Storms: . . . (pdf of this publication)—www.ag.uiuc.edu/~vista/abstracts/aicestorm.html
Urban Trees Research Paper—www.na.fs.fed.us/spfo/pubs/uf/sotuf/chapter_4/appendix_b/appendixb.htm

Storm Preparedness and Response

Disaster Resources—http://web.extension.uiuc.edu/disaster/
How to Evaluate and Manage Storm-damaged Forest Areas—www.fs.fed.us/r8/foresthealth/pubs/storm_damage/contents.html
Storm Damaged Trees: Prevention and Treatments—http://pubs.caes.uga.edu/caespubs/pubs/pdf/c806.pdf
Storm Damage to Landscape Trees: Prediction, . . . —www.extension.umn.edu/distribution/naturalresources/dd7415.html
Storm Recovery Tools—www.arborday.org/media/stormrecovery/
Storms over the Urban Forest—www.na.fs.fed.us/spfo/pubs/uf/sotuf/sotuf.htm
Tree Emergency Manual for Public Officials—www.umass.edu/urbantree/TEM.pdf
Urban Tree Risk Management—www.na.fs.fed.us/spfo/pubs/uf/utrmm/index.htm
When a Storm Strikes—www.arborday.org/programs/treecitybulletinsdownload.cfm

Tree Planting and Care

Best Management Practices for Community Trees—www.athensclarkecounty.com/documents/pdf/landscape_management/best_management_practices.pdf
How to Prune Trees—www.na.fs.fed.us/spfo/pubs/howtos/ht_prune/prun001.htm
Planting Trees in Landscapes—http://hort.ifas.ufl.edu/woody/planting/index.htm
Pruning Shade Trees in Landscapes—http://hort.ufl.edu/woody/pruning/
Shade Tree Maintenance—http://hort.ifas.ufl.edu/woody/maturetreecare/