A literature review of ice storm impacts on forests in Eastern North America

Ontario Ministry of Natural Resources
Southcentral Sciences Section
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Landmark Consulting

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SUMMARY

Ice storms are a recurring natural disturbance that effects our forests. Although their frequency in any particular region is extremely low, ice storms occur in all parts of Canada except the North, but are especially common from Ontario to Newfoundland. Heavy glaze storms are common across the U.S. Mid-west to the eastern seaboard. Because of its uncharacteristic severity and extent, Ice Storm '98 caused extensive damage to the forests over a large geographic area.

This project was designed to search out and summarise all the relevant research information regarding the effects of ice storms on natural forests and plantations, the recovery and mortality of trees from ice storm damage, as well as management recommendation to minimise negative impacts.

An ice storms' effect on a particular forest will depend on the total amount of ice load, the duration of the storm, as well as stand and individual tree characteristics. Damage is usually patchy, worse in the northern, eastern and windward exposures. Damage caused by an ice storm can be intensified by strong winds. Trees of different sizes generally suffer different damage. Saplings and small polewood become badly bent. Polewood in many instances breaks below the crown. As diameter increases the proportion of bent trees decreases until in large polewood the majority of damage is breakage. Larger trees suffer mainly from loss of branches and breakage of the main stem.

The differences in susceptibility between species is related to the inherent characteristics of the species including growth characteristics such as crown form, fineness of branching, branch angle, crown size and wood strength. A table comparing species susceptibilities as recorded after numerous storm events is presented.

The expectations of recovery for an individual tree can be related to the amount of crown loss due to breakage. Hardwood trees are seldom killed by breakage. Many species will sprout prolifically to recover from damage. Hardwood trees with greater than 75% crown loss are expected to die. Conifers that have broken below the live crown, or that have had a majority of crown removed are not expected to survive.

Managing forests according to prescribed silvicultural methods will, in most cases, produce healthy trees that are less susceptible to damage from ice storms. In severely damaged stands where salvage is necessary, operations should be carried out when the soil conditions are relatively dry to prevent tree root and site damage. Residual stand damage should be avoided. If a stand is known to be infected with *Armillaria* root disease salvage should be delayed until desirable crop trees have recovered from storm damage.

Pine plantations should be planted at a wide spacing to encourage the growth of trees with sturdy boles and strong crowns. Thinnings should start early, and be frequent. Severely damaged pine will be susceptible to infestations by bark beetles and wood borers, and hence the introduction of stain. These trees should be salvaged immediately.

From an insect and disease standpoint there is no immediate need to salvage standing hardwoods. Stain and decay develop slowly in living trees. Any downed hardwoods should be harvested as soon as possible; they will degrade within one or two seasons. With the exception of stands infected with *Armillaria* root disease, trees with broken tops or branches larger than 7.6 cm in diameter should be harvested during the next cutting cycle. When harvesting damaged trees the basal area should be maintained above 15 m^2 /ha to maintain optimum volume growth and to minimise the formation of epicormic branching.

Although the information provided by past studies of ice storm damage is extensive, there is very little information about the long-term effects of ice storms on forests. Damage as severe and widespread as that suffered as a result of Ice Storm '98 is unprecedented. Ice Storm '98 provides new opportunities to continue past research and to initiate new research to fill information gaps.

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TABLE OF CONTENTS

LIST OF TABLES

INTRODUCTION

This literature review is the synthesis of the published literature on the following topics:

1. The ecological and possible economic effects of ice storms on natural forests and plantations; including where possible, the influences of past management.
2. The recovery and mortality of individual trees and forests after ice storm damage. A superficial search of literature on wind and snow damage was also completed, as well as a search into some of the biological functions of tree reaction to wounds, crown damage, defoliation, and increased exposure.
3. Management recommendations of ice damaged woodlots and plantations to minimise negative impacts.

Disease and insect implications have only been covered very superficially. A separate literature search is being completed and will be available through the Ontario Forest Research Institute, Sault Ste. Marie, Ontario, Canada. Literature specific to ice storm damage effects on sugar bushes and maple syrup production can be found in "Sugar Bush Ice Storm Literature Synthesis" available from the Ontario Ministry of Agriculture Food and Rural Affairs, Kemptville, Ontario, Canada.

An annotated bibliography of the complete literature search is available as a searchable electronic database (Microsoft Access) from the Ontario Ministry of Natural Resources, South Central Science and Technology Unit, Kemptville, Ontario.

ICE STORM DEFINITION

Glaze is a smooth coating of ice on objects. A deposit of glaze on an extensive scale constitutes a glaze or ice storm. Typically, glaze or ice formation occurs when a winter warm front follows ground level temperatures that are below 0°C (Lemon, 1961). For freezing precipitation to occur the atmosphere must by properly layered: a layer of warm air, with temperatures above freezing, must be sandwiched between layers of colder, below freezing air. Often in winter, the warm moist air overrides the heavier, denser cold air found near the surface (Environment Canada, 1998). When rain falls, or snow melts through the warm layer, it reaches the cold layer as rain. The rain droplets fall through the cold layer and reach the ground as supercooled liquid (water droplets at a temperature below 0°C), or, as a mixture of liquid and ice. As they land on cold objects such as tree branches, hydro lines etc the supercooled rain droplets spread out and freeze almost immediately, forming a smooth thin layer of ice (Environment Canada, 1998).

ICE STORM '98

Although their frequency in any particular region is extremely low, ice storms are a major hazard in all parts of Canada except the North, but are especially common from Ontario to Newfoundland (Environment Canada, 1988). Heavy glaze storms are common across the U.S. Mid-west to the eastern seaboard (Lemon, 1961). The severity of an ice storm depends largely on the accumulation of ice, the duration of the storm and the size of the affected area. Based on these criteria, the ice storm in January 1998 was the worst ever to hit Canada in recent memory (Environment Canada, 1998). From January 5-10, 1998 the total water equivalent of precipitation, comprised mostly of freezing rain and ice pellets exceeded 85 mm in Ottawa, 73 mm in Kingston, 108 mm in Cornwall and 100 mm in Montreal (Environment Canada, 1998). Winds during this period were generally from the northeast, and ranged between 7 and 24 km/hr with gust up to 35 km/hr. A thaw on January 10 reaching across the southern portion of the affected area began melting some of the accumulated ice from trees and hydro lines.

The Ice Storm of '98 was unprecedented not only in the amount of ice deposited, but also in its duration and expanse. On average, Ottawa and Montreal receive freezing precipitation on 12 to 17 days a year. Each individual incident lasts for a few hours at a time, for an annual average of between

45 to 65 hours. During Ice Storm '98 the accumulated hours of freezing rain and drizzle was over 80 hours (Environment Canada, 1998). In most cases freezing precipitation is described in terms such as "a line of', or "scattered incidences of'. At the peak of the Ice Storm '98 the area of freezing precipitation extended from Muskoka and Kitchener in Ontario through eastern Ontario, western Quebec and the Eastern Townships to the east coasts of New Brunswick and Nova Scotia (Environment Canada, 1998). In the United States, the ice storm spread across the states of New York, Vermont, New Hampshire, and Maine.

PAST STORMS

In comparison, the Ice storm that affected Monroe County in the vicinity of Rochester, New York in 1991 was "the most severe on record". It recorded the most freezing rain 1.5 inches (38 mm); ranked second in the recorded accumulation of glaze (0.75-1 inch (19-25 mm)) and had the fifth longest icing event (22.6 hours). During the height of the storm the Rochester weather office reported northeast winds gusting to 24 miles per hour (38 km/hr) (Sisinni *et al*, 1995).

The most recent ice storm events that occurred in the area affected by Ice Storm '98 occurred in December 1986 depositing 30 mm of ice on Ottawa, and in February 1961 depositing 40 mm of ice on Montreal (Environment Canada, 1998).

The reporting of the weather conditions, ice accumulations as well as the assessment of damage to trees has been inconsistent in methodology making it difficult to directly compare the severity of the storms and their corresponding damage.

The effects of severe ice storms have been studied in Manitoba (Cayford and Haig , 1961 a & b), Ontario (Borzon *et al* 1978; Dance and Lynn, 1963), Quebec (Melancon and Lechowicz, 1987), P.E.I (Glen, 1997), in the mid-western United States (Bruederle and Stearns, 1985; De Steven *et al*, 1991) in the Appalachian region (Downs, 1938; Spaulding and Bratton, 1946; Carvell *et al*, 1957; Lemon, 1961; Siccama *et al*, 1976; Whitney and Johnson, 1984; Boemer *et al*, 1988; Seishab *et al*, 1993; Rebertus *et al*, 1997) and in the Southern States (McKellar, 1942; Van Lear and Saucier, 1973; Williston, 1974; Shepard, 1978; Shepard, 1981, Belanger *et al* 1993). Table 1 is a summary of ice storm events that have been reported or studied. Only those storms about which some meteorological detail is given were included.

ICE STORMS AND FORESTS

Ice storms must be recognised as important and recurring natural disturbances within our forests (Lemon, 1961; Smith and Musser, 1998). Although their occurrence in any one location is spotty and unpredictable, the records suggest that glaze events are among the most frequent forest disturbances (Lemon, 1961). Ice storms of various magnitudes occur in northern New England states twice per decade (Smith and Musser, 1998). Major ice storms, with a return time of 20-100 years (Lemon, 1961; Melancon and Lechowicz, 1987), are considerably more frequent than similar natural disturbances such as windstorms or fire which have a return time of 100 to 1,000 years (Melancon and Lechowicz, 1987; Smith and Musser, 1998)

Damage from an ice storm is usually patchy because numerous geographic and climatic factors affect them: 1) elevation differences; 2) proximity to bodies of water; 3) inclination and aspect of slope; 4) composition of the ground surface; 5) direction and velocity of the wind (Bruederle and Stearns, 1985).

Table 1: A comparison of ice storm events studied in literature[1]

Location	Year	Extent	Severity/ice accum (as described in literature)[2]	Reference
North Carolina	1934	severe damage in an approximately 42 square miles	"severe"	Abell, 1934
New York Pennsylvania	1936	6,000,000 acres (2,428,200 ha)	" damage most severe where there was 3 inches (7.6 cm) or more of precipitation", no wind	Downs, 1937; Downs, 1938
Quebec	1942	Montreal region	"comparable to 1983 storm"	Melancon and Lechowicz, 1987
New York	1942-43	St. Lawrence, Mohawk and Hudson River Valleys	"ice accumulation between 0 and 1 inch"	Lemon, 1961
New York	1949	eastern New York	"gradients of zero to 2 inches (0-5 cm) in ice thickness"	Lemon, 1961
Connecticut	1940	"belt 5-10 miles (8-16 km) wide parallel to and inland 1 to 10 miles (1.6-16 km) from the coast"	"heavy sleet storm"	Kienholtz, 1941
West Virginia	1956	Cheat Mountain range	"spectacular, very severe", severe injury to trees above 2,100 feet (640 m) elevation	Carvell *et al*, 1957
Manitoba	1958	Sandilands Forest Reserve (approx 40,000 acres (16,188 ha)),areas above 1,200 feet (366 m) elevation	"layer of ice up to I inch thick" ",winds up to 38 m.p.h. (61 km/hr)"	Cayford and Haig, 1961 a; Cayford and Haig, 1961b
Quebec	1961	Montreal region	"comparable to 1983 storm"	Melancon and Lechowicz, 1987
Iowa	1961	large section of central Iowa	"heavy ice storm, accompanied by wind, inflicted severe damage to trees"	Goebel and Deitschman, 1967
New Jersey, Pennsylvania, New York, southern new England	1973	"extensive " New Jersey, Pennsylvania, New York, southern new England	"worst ice storm in history ...2.23 cm (0.8 ") of precip, 1.78 cm (0.7 ") glaze, winds 47 km/hr (29 m.p.h.))	Siccama *et al*, 1976
Wisconsin	1976	"extensive", wide arc from the Mississippi River to Lake Michigan	"as much as 5 inches (12.8 cm) of glaze formed" 80.6 km/hr (50 m.p.h.) winds	Bruederle and Stearns, 1985; DeSteven *et al*, 1991
Ontario	1977	160 ha (400 acres) Northumberland County	11 cm (4.3 ") pecip	Borzon *et al*, 1978
Arkansas	1978-79	3.6 million acres (1.5 million ha)	"destructive"	Fountain and Burnett, 1979
Georgia	1983	all of central Georgia	"average ice storm total precip 1.38-1.9 inches (3.5-4.8 cm) avg wind speed 10 m.p.h. (16 km/hr)"	Belanger *et al*, 1996
Quebec	1983	Montreal region	"severe ice storm glaze accumulation of 15mm (0.6"), accompanied by winds up to 18 km/hr (11 m.p.h.)"	Melancon and Lechowicz, 1987
Ohio	1986	Neotoma Valley (72 ha)	"3 cm (1.2 ") of glaze deposited"	Boemer *et al*, 1988
Illinois	1990	Champaign-Urbana	1.8" (4.6 cm) rainfall, ice accumulations of /Z to'/<" (1.3-1.9 cm)	Hauer *et al* 1993
New York	1991	19740 km`	"described as a 50-100 year storm ...deposited ice ...of at least 2 cm (0.8 ")"	Seischab *et al*, 1993; Sisinni etal, 1995
Virginia	1994		severe "heavy loading followed by high winds"	Amateis and Burkhart, 1996
Missouri, Kansas and Iowa	1994	area covering approximately 400 x 150 km	"major ice storm... 4.62 cm (1.8") of precipitation, coating trees with 2.5 cm (1") of ice"	Rebertus *et al*, 1997

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[1] Only events about which details were given regarding extent and severity of the storm were included.
[2] Storm descriptions are directly quoted from literature.

Damage is usually found to be worse in north and eastern slope exposure where there is a colder microclimate (Abell, 1934; Downs, 1938; Seischab *et al*, 1993). Trees that grow on steep slopes are more likely to develop asymmetrical crowns which accumulate ice and snow unevenly, resulting in greater breakage (Sanzen-Baker and Nimmo, 1941; Bruederle and Stearns, 1985; Boemer, 1988; Seischab *et al* 1993; Nykanen *et al*, 1997). Generally, trees that are open grown, found in fencerows, or along forest edges suffer more severe damage (Sanzen-Baker and Nimmo, 1941; Seischab *et al*, 1993; Williston, 1974).

The damage caused by an ice storm can be intensified by the presence of strong winds (Downs, 1937; Dueber, 1941; Carvell *et al*, 1957; Lemon, 1961; Hough, 1965; Shepard, 1975; Bruederle *et al*, 1985; De Steven *et al*, 1991; Hauer *et al*, 1994; Amateis and Burkhart, 1996). A moderate accumulation of ice combined with strong winds has the same effect as a heavier deposit with gentle winds (Lemon, 1961). Damage on the windward exposure of a storm has been documented as more severe (De Steven *et al*, 1991; Sanzen-Baker and Nimmo, 1941; Carvell *et al*, 1957; Borzon *et al*, 1978; Bruederle and Stearns, 1985). Sanzen-Baker and Nimmo (1941) found that where the ground was frozen it held the roots of trees, in most cases preventing windthrow.

TYPES OF DAMAGE

Ice accumulation usually ranges in thickness from trace to approximately 1 inch (2.5 cm). Severe storms may deposit greater accumulations than this (Lemon, 1961). Ice accumulation between ¼ to Y2 inch (0.6 -1.3 cm) will cause small branches and week limbs to break. Accumulations of greater than ½ inch (1.3 cm) cause larger branches to break, resulting in extensive damage (Lemon, 1961). Branches break when the weight of the ice exceeds wood resistance, or, when constant loading further stresses a weakened area in a branch (Hauer *et al*, 1994).

Trees of different sizes generally suffer different damage. Saplings and small polewood become badly bent. Polewood in many instances breaks below the crown. As diameter increases, the proportion of bent trees decreases until the majority of damage in large polewood is breakage. Larger trees suffer mainly from loss of branches and breakage of the main stem within the crown (Abell, 1934; Downs, 1938; Sanzen-Baker and Nimmo, 1941; Cayford and Haig, 1961b; Kienholz, 1941). In severe cases all side branches can be stripped leaving only the main trunk (Spaulding and Bratton, 1946). Breakage is the most common type of storm damage (Barry *et al*, 1993; Nykanen *et al*, 1997).

FACTORS AFFECTING SUSCEPTIBILITY

Similar glaze conditions affect trees of different species to different degrees. The differences in susceptibility between species is related to the inherent characteristic of the species including growth characteristics such as crown form, fineness of branching, branch angle, crown size, and to some extent the mechanical strength of wood (Bruederle and Stearns, 1985; Boerner *et al* 1988).

Crown exposure to glaze affects a trees' susceptibility to damage. Compact, cone shaped crowns expose a small proportion of their lateral branches to ice accumulation (Dueber, 1981; Bruederle and Stearns, 1985). For this reason conifers generally suffer less damage than hardwoods (Dueber, 1941; Carvell *et al*, 1957). Broad, flat crowns such as in American elm expose a large surface area of branches and usually suffer severe damage. Large crowns, or those that protrude from the canopy also have an increased exposure to glaze and suffer more damage (Bruederle and Stearns, 1985; Hauer *et al*, 1993).

Early successional species exhibit excurrent growth (trees with a main axis or trunk extending to the top of the crown e.g. spruce) in early years and slowly change to decurrent form as they respond to competition. These species are consistently susceptible to glaze damage (Lemon, 1961; Bruederle and Stearns, 1985). Trembling aspen, black cherry, and white birch exhibit this trait and were all severely damaged during the Ice Storm '98 (Ontario Ministry of Natural Resources, 1998f).

Decurrent form tends to have upward branching with acute angles, resulting in lower overall exposure to glaze (Bruederle and Stearns, 1985). Horizontal branching increases susceptibility to glaze damage. Species with opposite branching (e.g. ash) tends to have wide branch and twig angles (approaching 90 degrees) and suffer greater damage (Lemon, 1961; Bruederle and Stearns, 1985). Wide branch angle combined with large coarse twigs and brittle wood appear to explain the heavy damage sustained by species of ash.

The amount of ice a tree species can accumulate is proportional to its crown surface area in winter (Lemon, 1961). Trees with numerous small branches and twigs have a large crown surface area and, therefore, can accumulate larger amounts of ice than trees with fewer twigs (Bruederle and Stearns, 1985; Hauer *et al*, 1993). The type of damage is dependent on the size of twigs. Small twigs are relatively flexible and tend to bend with ice accumulation. Glaze remains on the twigs and the weight is concentrated onto the larger branches that may break under the stress (e.g. sugar maple, elm species, and American beech). Large twigs (e.g. hickory, ash) accumulate less glaze per unit diameter, but are less flexible, and tend to snap at the ends more readily than fine branches (Dueber, 1941; Bruederle and Stearns 1985).

On an individual tree basis the age and presence of decay also determine susceptibility to glaze damage. Decay and insect damage are positively correlated with glaze injury, with age compounding the effects (Bruederle and Stearns, 1985). Older trees are more susceptible to injury due to an increase in crown size, internal decay, and a decrease in the flexibility of branches (Bruederle and Stearns, 1985). Van Lear and Saucier (1973) and Shepard (1981) found stem breakage in Southern pine was often associated with fusiform rust cankers.

Position within the canopy also plays a role in a trees susceptibility. Dominant and co-dominant trees suffer most; there is almost no breakage in intermediate and suppressed trees (Carvell *et al*, 1957; Rebertus *et al*, 1997). The most common damage suffered by understory trees is bending of the main stem (Siccamma *et al*, 1976; Whitney and Johnson, 1984; Boerner *et al*, 1988). The resistance of ironwood to glaze is attributed to its location in the understory (Bruederle and Stearns, 1985). Based on mechanical wood strength, branch pattern and twig size, the species should be susceptible to damage.

Numerous authors have noted a difference between damage that is a direct result of ice accumulation on branches (primary damage) and damage that is a result of impact from other trees, or parts of trees falling on them (secondary damage) (Campbell, 1937; Boerner *et al*, 1988). Among all species the degree of direct damage was positively correlated with tree height, tree diameter and canopy crown diameter (Boerner *et al*, 1988). No correlation could be found between secondary damage and any biological or physical parameter measured (Boerner *et al*, 1988). The probability of a tree suffering secondary damage is related to its position in relation to trees susceptible to primary damage (Boerner *et al*, 1988).

There has been no direct correlation found between mechanical wood strength and susceptibility to ice damage (Dueber, 1941; Carvell *et al*, 1957; Lemon, 1961; Bruederle and Stearns, 1985; Hauer *et al*, 1993). Wood strength is of obvious significance, but a species susceptibility cannot be correlated with this property alone (Bruederle and Stearns, 1985).

Table 2 provides a summary of susceptibility ratings for different species as they are presented in literature.

Table 2: Species susceptibility as presented in literature

Location	**Reference**	**low susceptibility**	**Intermediate**	**Highly susceptible**
North Carolina	Abell, 1934	hemlock, white pine	black oak, white oak	black locust red maple scarlet oak
New York Pennsylvania	Downs, 1938	hemlock white pine white cedar ash, hickory, Norway pine, spruce, sugar maple, sycamore, white oak	American elm, American beech, birch spp black locust, red maple, yellow poplar, black gum, cucumber, magnolia	aspen, basswood, black cherry, willow
England	Sanzen-Baker and Nimmo, 1941	American elm, cedar, fir spp, Norway spruce,	oak spp	alder, American beech, ash, birch, Douglas fir, European larch, poplar, Japanese larch, Scot pine, Sitka spruce, sycamore
Connecticut	Kienholtz, 1941	red pine, Scots pine, white pine		jack pine
West Virginia	Carvell *et al*, 1957	American beech, hemlock, hickory spp, red pine, red spruce, Scotch pine, white pine	black oak, red maple, sassafras, scarlet oak, white oak	black cherry, chestnut oak, red oak, yellow poplar
New York	Lemon, 1961	red spruce, shagbark hickory, white ash, yellow birch	American beech, gray birch, hemlock, red oak, sugar maple, tuliptree, white pine	American elm, basswood, black cherry, butternut, eastern cottonwood, silver maple
Manitoba	Cayford and Haig, 1961b	balsam fir, balsam poplar, green ash, larch, trembling aspen, white birch, white spruce,	black spruce, cedar	jack pine
Iowa	Goebel and Deitschman, 1967	eastern red cedar, Norway spruce, other spruce spp.	Austrian pine, American elm, basswood, cedar, oak	Scots pine, white pine
Wisconsin	Bruederle and Stearns, 1985	basswood, bitternut hickory, shagbark hickory	American beech, red maple, red oak, sugar maple	American elm, black ash, black cherry, hackberry, largetooth aspen, slippery elm, tamarack, trembling aspen, white ash, white birch, yellow birch
Virginia	Whitney and Johnson, 1984	hickory	chestnut oak, red maple, scarlet oak , white oak	black oak, pitch pine, Virginia pine, yellow poplar
Ontario	Borzon *et al*, 1978	larch	white pine	jack pine, red pine, Scots pine
Ohio	Boemer *et al*, 1988	elm spp, tuliptree, yellow birch	American beech, black cherry, white ash, chestnut oak, red maple, white oak	hemlock, pitch pine red oak, red pine sycamore
New York	Seischab *et al*, 1993	American elm, green ash, hemlock, hickory, white ash, white oak	American beech, basswood, largetooth aspen, red maple, sugar maple	black cherry ,red oak, sassafras, willow
Missouri	Rebertus *et al*, 1997	black walnut , ironwood, shagbark hickory	black oak, red elm, serviceberry, white ash	American elm, basswood, bitternut hickory, red oak, sugar maple,
Quebec	Gouv du Quebec, 1998	balsam fir, black spruce, hemlock, ironwood, red pine, red spruce, shagbark hickory, tamarack, white pine, white spruce,	white cedar	American beech ,American elm, basswood, , black cherry, butternut, gray birch, hard maple, Manitoba maple, pitch pine poplars, red maple, red oak, silver maple, slippery elm, white oak, willows

DAMAGE SPECIFIC TO PINE PLANTATIONS

Similar to other forest types, the damage in pine plantations is dependent on the size of the tree. Seedlings and small polewood bend, polewood and larger trees tend to break, either mid crown or below the crown. Some trees become uprooted (Williston, 1974; Downs, 1943). Bending in young plantations may be severe, but most trees recover (Downs, 1943; Cayford and Haig, 1961b; Borzon *et al*, 1978). Downs (1943) found that in dense stands 2-6 inches d.b.h. (5-15 cm), bending was prevalent with some uprooting. In stands with stocky individuals with vigorous crowns, damage was light and limited to slight bending and a little top breakage. Bole and top breakage, as well as uprooting were the most common damage in stands 6-10 inches d. b. h (15-25 cm). Generally, stocky trees (with a low height/diameter ratio) resist damage from ice, snow and wind better than tall spindly trees (Keinholtz, 1941; Downs, 1943; Shepard, 1978; Cremer *et al*, 1982).

Recently thinned plantations are particularly susceptible to damage by ice and wind storms (Downs, 1943; Sanzen-Baker and Nimmo, 1941; Shepard, 1975; Shepard, 1978; Shepard, 1981; Williston, 1974; Borzon *et al* 1978; Cremer *et al*, 1978; Fountain, 1979; Burton, 1981; Belanger *et al*,1996). Shepard (1978) found that row thinned plantations were more susceptible to damage (57.6% of trees damaged) than selectively thinned plantations (8.9% of trees damaged). He also hypothesised that ice storm damage in a stand that had undergone a recent heavy selective thinning would be similar to that found in a row thinned plantation.

Overstocked or dense plantations suffer more severe damage than more widely spaced plantations with trees with sturdier boles and well developed canopies (Sanzen-Baker and Nimmo, 1941; Downs, 1943; Cayford and Haig, 1961a; Borzon *et al*, 1978; Burton, 1981; Cremer, 1982). In dense stands the majority of the damage is to trees that are larger than average, which suffer severe crown breakage (Shepard, 1975). Amateis and Burkhart (1996), however, found no relationship between stand density and severity of damage. They noted, however, that the damage they were studying was the result of a severe storm with heavy ice loading, followed by high winds.

In dense, spindly stands where the crowns support each other, ice matts the trees together and can bend over and collapse entire sections of the stand (the domino effect) (Borzon *et al*, 1978; Kienholtz, 1941). Harrington and DeBell (1996) described similar findings in young, dense hybrid poplar plantations.

ASSESSMENT METHODS

Individual tree assessment forms the basis for most forest health research. The comparability of data between studies depends on the consistency and accuracy of the data collected. The methods used for assessing forest health are usually based on the crown transparency and crown discoloration in individual trees. Problems with standardisation of assessment procedures and collection of objective data have been noted in past research (Innes and Boswell, 1989; Innes, 1993). They note that rates of "defoliation" in different studies are not comparable. Innes and Boswell (1989) noted that observers (assessors) must be trained to high standards to ensure consistency of results.

Lachance *et al* (1993) describe the normal assessment procedures followed in the North American Sugar Maple Program (NAMP), a long term forest health study. They have addressed concerns of data comparability and consistency with the use of a rigorous system of quality assurance in data collection. Assessors attend a training and certification course prior to any field work. To further ensure quality two certified crown raters simultaneously rated dieback and transparency from opposite sides of the trees. A minimum of 5% of the trees are remeasured within 2-3 weeks of the first assessment. Less than 10% error (one class above or below original measurement) are accepted. If data are rejected the plot is remeasured. Crown condition assessments are based on dieback and crown transparency. Dieback is estimated as a proportion of the crown that shows this condition, and is recorded in 10% classes, with 0% and 1-5% classes included. Trees with 0-15% dieback are considered to be in good condition. An estimate for transparency is averaged for the living crown as a whole and recorded in the same percent classes as dieback. Crown transparency of 25% is considered normal for sugar maple.

Numerous assessment methods have been used to record damage from past ice storms. Assessment procedures were established based on the types of damage witnessed and the objectives of the individual study. In most cases, assessments were based on assessing the damage sustained by individual trees (Downs, 1938; Cayford and Haig, 1961b; Boerner *et al*, McKellar, 1942; Shepard, 1976; Siccama *et al*, 1976; Burton, 1981; Whitney and Johnson, 1984; Seischab *et al*, 1993; Rebertus *et al*, 1997). The exception to this is Bruederle and Stearns (1985) who determined the extent of damage by measuring the wood volume (macro-litter) along transects. By recording the species and diameter of macro-litter and comparing it to pre-storm conditions, and making allowances for pre-storm species dominance (using basal area), they were able to determine relative susceptibility of different species.

A majority of damage classifications were based on qualitative criteria. Typically, criteria were based on the type of damage incurred: degrees of bending or type and location of breakage, the amount of crown loss suffered and uprooting, if present. Whitney and Johnson (1984), Boerner *et al* (1988) and Rebertus *et al* (1997) based their classifications on a mixture of qualitative and quantitative criteria. The qualitative criteria were based on the proportion of live crown damage. There was little consistency in the classifications used to judge the severity of damage. Boerner *et al* (1988) separated crown loss classes with less than or more than 50% of branch and stem loss. Rebertus *et al* (1977) separated crown damage on the basis of snapping off of the central bole or major limbs > 15 cm (6 inches) in diameter, and the loss of more than 1/3 of the crown. Damage classification in Sissini *et al* (1995) were based on ranges of live crown loss, classifications being: less than 50% live crown loss, between 50 and 74% loss, and greater than 75% loss. Seischab *et al* (1993) measured the actual % crown loss on each individual tree.

There is more consistency in the methodology used to classify conifer damage. Studies dealing with only conifer species measured damage by the degree of bending, the location of breakage within or below the crown, and uprooting (Kienholtz, 1941; Shepard, 1976; Cayford and Haig, 1961a; Burton, 1981). Only Cayford and Haig (1961a) measured the degree of bending in quantitative terms (degrees from vertical).

Table 3 provides a comparison of assessment methods that have been developed for assessing damage from Ice Storm '98. Each assessment procedure was developed with different objectives in mind, and as a result the scope in information collected varies considerably. It should be noted that the damage of individual trees in all cases is based on qualitative measurements of crown damage to the tree.

RECOVERY & MORTALITY

The survival and response of an individual tree to injury involves many factors including the pre-storm condition of the tree as well as the tree vigour, site quality and additional stresses that trees are subjected to in the years immediately following the storm (Allen *et al*, 1998). The expectations of recovery for an individual tree can be related to the amount of crown loss due to breakage (Shortle and Smith, 1998).

Table 3: Assessment procedures developed to assess damage from Ice Storm '98

Reference	**Purpose of Assessment**	**Intensity**	**Crown damage descriptor**	**Branch or stem breakage descriptor**	**Bending**	**Tree Size and Quality**	**Other information collected**
Ontario Ministry of Natural Resources, 1998e	• Developed by Ontario Government • for extension services to landowners • quick damage assessment	• one prism plot per stand (2 BAF) • all trees >10 cm d.b.h. within prism plot assessed	Conifer **crown damage** categories: 1- no damage up to 2 yrs. growth broken 2- broken mid crown 3- < 3 live branches Hardwoods **crown damage** categories 1- 0-25% 2- 26-50% 3- 51-75 % 4- >75 %	• none	<20° 20-60° >60°	• size categories • pre-storm AGS* or • UGS **	• regeneration- **species, *size*** and % ground cover and distribution • other vegetation-species, % ground cover and distribution • downed debris -size, quantity ground cover) and distribution • wildlife-nesting cavities, sightings, • stick nest, loss of habitat
Ministers de Ressources naturelles du Quebec, 1988	• Developed by Quebec Government • self assessment system for landowners • results of assessment are the basis for stand *level* management recommendations	• # of plots dependant on total area: 0-5 ha - 6 plots; 5-10 ha -12 plots; 10-20 ha-18 plots; 20-40 ha -24 plots. • plots randomly distributed plots of 5 trees - Ist tree chosen at random, then four closest trees	• estimate crown loss according to categories: • 0%, or no damage; 25%; 33 %, or one third; 50 % or *one* half; 66 % or two-thirds; 75%; 100% (lost all branches). • average **crown damage** for stand is calculated and classified according to categories: 1- 0-20% 2- 21-40% 3- 41-60% 4- 61+	• none			
Ontario Ministry of Agriculture, Food and Rural Affairs,		• circular 0.1 ha plots [illegible] • all maple trees and 3 most	**crown loss** categories: [illegible] 2- 11-25 %	• stem breakage	none or >30°	• size categories; description of pre-storm condition	

Breakage

Hardwood trees are seldom killed by breakage. When a tree suffers crown damage it reallocates carbon reserves to increase efficiency in the remaining leaves and to produce leaves from dormant buds. Even when tops are completely broken, some species will sprout new branches prolifically and allow the tree to recover (Barry *et al*, 1993). Two and a half years following a severe ice storm Spaulding and Bratton (1946) found abundant sprouting in the tops of damaged white ash and basswood, even in trees that had been completely stripped of branches. The regrowth of the crown combined with the rough bark, prevented the infection by saprot fungi and the dying of the bark on the main stem. American beech sprouted less prolifically, but in most cases still adequately to prevent dying of the bark of the main stem. Sugar maple sprouted even less. Severely injured trees could not sprout enough leaves to survive. The study concluded that sugar maple with greater than 50% crown loss will die progressively. Hough (1965) found that black cherry had great crown regenerative potential.

The reallocation of carbon to compensate for top loss may reduce carbon allocation to root development, diameter growth, and to internal defences (Smith and Musser, 1998). This can increase an individual trees' susceptibility to insect and disease attack (Dance and Lynn, 1963; Smith and Musser, 1998). The degree of growth reduction and possible mortality is dependent on the degree of damage. Dance and Lynn (1963) found that there was a 50% reduction in growth increment and a 42% mortality rate in red oak following severe breakage from an ice storm. Based on expert opinion Smith and Shortle (1998) present the following relationships:

1. < 50 % crown loss - most trees will survive; any reduction in growth will be small and short-term.; there will be little degradation in the wood
2. 50-75% crown loss - many trees will survive; reduction in growth will be variable and in some cases may be long term
3. 75% crown loss - few trees will survive; there will be severe growth loss in surviving trees; wood degradation will be severe and long-term

Whitney and Johnson (1984) found that approximately 38% of storm damaged trees died by the end of the second growing season after damage. Mortality varied among species. Pines exhibited the highest mortality; yellow poplar, red maple, and hickory exhibited the lowest rates. Oaks died at intermediate rates. There was a significant interaction between tree size and damage class in the degree of mortality sustained. There was a strong trend of increasing mortality with increase in damage class. Small trees that had lost more than 50% of their crown through removal of branches or trunk breakage died at higher rate than larger trees suffering the same amount of damage. The mortality of trees with less than 50% crown damage, bent trees and fallen trees was not affected by tree size. With the exception of species that have a strong sprouting ability (pitch pine, yellow poplar, and red maple) there was a strong correlation between species that are highly susceptible to ice damage and high mortality rates. Hickory is highly resistant to ice damage and had a low mortality rate. Pines suffered severe damage, and had a high mortality rate.

Lachance *et al* (1995), in their long-term study of sugar maple dieback, concluded that if trees had a greater than 55% dieback, they would likely die within 5 years. Because these conclusions were reached from studies of crown loss as a result of dieback, not of crown loss due to breakage, these results are not directly applicable for predicting tree mortality as a result of ice storm damage.

Although not a direct study of the effect of total crown loss from ice damage, Godman and Mattson (1970) found that all decapitated and branch-pruned trees and half of the twig pruned trees died by the beginning of the third growing season following treatment. They found that although the sugar maple did sprout epicormic branches prolifically, there was a decline in the number of epicormic shoots within the live crown surviving at the end of the second growing season. This appeared to be related to a loss in overall vigour and impending mortality of the tree. Although new, vigorous epicormic shoots were abundant on the upper stem at the beginning of the second season, this foliage alone was not capable of supporting tree functions

In hardwoods, the major effect of breaks in the trunk and branches is to provide possible points of entry for stain and decay fungi. Decay hazard created by ice damage is no different than decay hazard caused by other types of injury that exposes large areas of heartwood and sapwood. A trees' susceptibility to decay is influenced by the relative proportions of heartwood and sapwood present at the time of injury (Campbell, 1937). In live trees heartwood is more subject to decay that sapwood. Sapwood decay is usually confined to dry injured areas and stops spreading when the wound is callused over. In young trees, where there is little heartwood, wounds present less danger of decay compared to wounds on trees where considerable area of heartwood has been exposed. Small, young trees will have smaller areas of heartwood exposed than will larger or older trees with the same type of injury, and wounds will take shorter time to close (Campbell, 1937).

Top injuries that do not involve the main stem and large branches present a low decay hazard in all species (Campbell, 1937). Generally, wounds resulting from broken branches less than 3 inches in diameter callus over quickly and present a low decay hazard (Hough, 1965; Rextrode and Auchmoody, 1982; Barry *et al*, 1993). Top injuries where large main branches are broken, especially if shattered, offer high decay hazard for red maple and American beech (Campbell 1937). Black cherry and sugar maple seem to be somewhat resistant to decay following top breakage (Hough, 1965; Rextrode and Auchmoody, 1982). This may be in part do to the slow formation of heartwood in these species (Campbell, 1937).

Breaks that are over 3 inches (7.6 cm) in diameter will allow the entry of stain and decay fungi (Campbell and Davidson, 1940; Rextrode and Auchmoody, 1982; Barry *et al*, 1993). Large trunk injuries caused by splitting of forked stems and by breaking of large lower branches offer a high decay hazard for all species. Splitting of forked stems is particularly hazardous because of the large surface area left exposed.

Wounds in the trunk have much more serious implications than damage to branches in the crown (Shortie and Smith, 1998b). In management recommendations pertaining to storm damaged trees in the southern US, Barry *et al* (1993) suggest that, generally trunk wounds that do not penetrate more than 2 inches (5 cm) into the sapwood or that are greater than 144 square inches (929 cm^2) in surface area will have only localized stain, but little decay. However, Campbell (1937) states that any trunk wounds in species such as red maple, American beech, and yellow birch 20 years or older, constitute a high decay hazard. In more decay resistant species such as black cherry and sugar maple only large trunk wounds (regardless of trees age) constitute a high decay hazard. Wounds that are in contact with the soil generally result in greater amounts of decay because the wound surface remains moist and provides a favourable environment for infection (Anderson and Rice, 1993).

Barry *et al* (1993) reported that stain progressed vertically from injuries at a rate of 6 to 18 inches (15-46 cm) per year and that decay followed within 8 to 10 months. The spread of stain and decay depends on the wound size, its location, the individual tree vigour, and local pathogens and insects (Shigo, 1984). Campbell and Davidson (1940) found that two years after an ice storm, decay from breakages 3 inches (7.6 cm) in diameter or less in black cherry was limited to 24 to 36 inches (61-91 cm) below the break, and only to 6 inches (15 cm) below the break in sugar maple. Following up Campbell and Davidson's (1940) work Rextrode and Auchmoody (1982) found that major top rot had not developed during the 46 years following severe ice damage in black cherry. They found that the progress of decay slowed from 6 inches (15 cm) per year in the first 4 years, to only 2 inches (5 cm) per year in the remaining 42 years. They found no upward progression of the decay from the point of injury into the new wood produced after the storm.

The following table (Table 4), although not specific to ice storm damage, shows the relative rates of spread of decay as a result of various sizes of defect in yellow birch.

Table 4: Spread of decay in yellow birch[3]

DEFECT TYPE	SCAR SIZE	SCAR AGE	
		<10 years	>10 years
		vertical spread of decay (cmlyr.)	
Broken Branch (diam)	>10.4 cm	21.6	51.0
	6.6 -10.1 cm	19.8	33.3
	<6.3 cm	14.0	6.6
Mechanical Scar (surface area)	>587 cm	26.9	37.8
	329 - 581 cm	20.8	10.7
	<323 cm	16.0	12.4

From Anderson and Rice, 1993

Hardwood trees that have suffered crown loss are in a stressed condition and suffer a decrease in vigour due to a reduction in photosynthetic rate and food production. Dance and Lynn (1963) found that this loss in vigour, following severe damage during an ice storm, predisposed red oak to *Armillaria* root disease. Dessureault (1985) states that the growth of *Armillaria* is greatly stimulated by glucose and asparagine, the production of which is triggered by defoliation. In their study of Maple decline in Quebec, Roy *et al* (1985) found that the incidence of *Armillaria* root disease increased with crown loss due to decline. Over 3/ of the trees with over 51 % decline were afflicted (Roy *et al*, 1985). Other stresses such as drought predispose trees to attack by *Armillaria* (Dessureault, 1985).

In northern Ontario Boreal mixedwood stands that suffered several years of defoliation by spruce budworm it was observed that although many large spruce survived the budworm attack they died in the next few years from *Armillaria* root disease (McLaughlin, 1999, pers. comm.). McLaughlin speculates that *Armillaria* was present on these sites for many years, probably increasing in distribution and virulence through spread on the highly susceptible balsam fir understory. Infection in these forests would be widespread although many of the infections would have been quiescent or at least kept in check by the deciduous and conifer hosts in the overstory while they were in a vigorous state. In the Black Sturgeon Boreal mixedwood partial cutting study area the stumps and root systems of harvested trees provided a very good food base for the *Armillaria*, increasing root disease pressure on residual spruces and aspen. Of 100 trees selected for study in 1993, 42 were dead two years later (McLaughlin and Dumas, 1996). By 1998, 70 of the trees had died, most with at least one major root infected with *Armillaria*. McLaughlin (1999, pers. comm.) recommends that after a period of severe defoliation, actions that may give *Armillaria* a further advantage, (such as increasing *Armillaria*'s food base by salvage cutting) should be avoided until trees have a chance to restore their crowns and vigour to a more normal level.

Although there is very little knowledge about *Armillaria* in Southern Ontario (species present, hosts, and virulence have not been surveyed) McLaughlin (1999, pers. comm.) speculates that *Armillaria* may react similarly in these forests. Therefore, in stands that have been defoliated through crown loss as a result of ice storm damage, and where *Armillaria* is already present, conditions may favour the spread of infection and disease. The immediate removal of severely damaged trees may compound the conditions that are already favourable for the disease. Allowing future crop trees to recover their crowns before salvaging damaged trees may reduce some of the possible impact of *Armillaria* in these stands.

Allen (1998), although stating that secondary problems cause minimum injury, lists the following as possible problems following ice storm injury:

1. *Armillaria* root infection in sugar maple as well as yellow birch and American beech.
2. Glycobius borer in sugar maple
3. Agrilus and ambrosia beetles in yellow birch
4. Agrilus and Goes borer in American beech

In conifers, it is generally agreed that trees broken below the live crown, or with a majority of crown removed or uprooted will not survive (Williston, 1974; Whitney and Johnson, 1984; Boemer *et al*, 1988). Loblolly and slash pines have a greater than 75% chance of survival with as few as 3 remaining live limbs (Barry *et al*, 1993). In cases of severe top breakage a lateral branch will develop into a terminal, developing a crook where the break occurred (Barry *et al*, 1993). In Douglas fir, hemlock, noble fir, western white pine, and silver fir, lateral branches on trees whose main stems were broken turned upward and were competing for tree dominance by the end of the growing season following breakage (Williams, 1966). Basham (1971) found no decay or decay fungi in jack pine 7.5 years after their tops were severely damaged by glaze.

In their study of loblolly pine plantations following ice damage Belanger *et al* (1996) found a 42% reduction in radial growth in damaged trees in the year following the storm. The growth rate of these trees remained slow for the 5-year period following the storm. The height growth in damaged trees in this 5-year period was 15.6 feet (4.7 m), compared to11.5 feet (3.5 m) in undamaged trees. The need to restore damaged crowns through development of new foliage and branches took precedence over stem radial growth.

Severely damaged conifers will be susceptible to bark beetles and wood borers (Barry *et al*, 1993; Allen, 1998). These insects can kill the trees or reduce their value by reducing the value of the lumber cut from affected trees. They can also introduce blue stain fungus that will further reduce the value of the lumber (Barry *et al*, 1993; Allen *et al*, 1998; Allen, 1998). Barry *et al* (1993) provides an excellent summary of utilisation guidelines for beetle-killed pines. The bark beetles found in the areas affected by Ice Storm '98 are not aggressive, it is unlikely that any of the insects that invade dead and dying material will be able to harm surrounding healthy trees (Allen, 1998).

Bending

If bending is not severe, studies show that generally trees will recover; particularly if the trees affected are young (Cayford and Haig, 1961b; Williams, 1966; Williston, 1974; Borzon, 1978) Most of the recovery takes place by the spring, soon after the weight of the ice or snow has been removed. Carvell *et al* (1957), Cayford and Haig (1961b), Williams (1966), and Williston (1974) similarly conclude that trees that have not recovered by late summer or early fall following an ice storm will not improve. Cayford and Haig (1961b) found that trees that remained moderately bent, badly bent, or arched the fall after the ice storm, either deteriorated, or were classified in the same condition the following spring. They conclude that surviving bent or arched trees will eventually break or uproot. Lemon (1961) found that birch, cherry, red cedar and willow do not recover from severe bending. Hough (1959) found that not only did young cherry sapling and small polewood not recover from bending, they grew sprouts along the bent bole, limiting their future worth.

In conifers, Sanzen-Baker and Nimmo (1941), Mckellar (1942), and Burton (1981) agree that trees bent greater than 45 degrees will not recover. Williston (1974) states that pine with a 50-60% bend will recover with a sweep, and that trees with a 60% bend, will not recover. Roberts and Clapp (1956) found that they could straighten severely bent slash pine by pruning them up to the leader. Pruning had to take place within four weeks of the storm in order to be successful. As a result of severe pruning the growth rate of the trees was retarded until the crown had regrown.

Although bent trees may appear to have recovered, the amount of permanent damage is probably underestimated because trees that appear completely recovered may contain compression failures (Anon, 1941; Cayford and Haig, 1961b; Barry *et al*, 1993). Trees that have sustained compression failure are normally undesirable for sawtimber. Boards from the affected part of a log often break during sawing (Anon, 1941; Rendle *et al*, 1941; Mergen and Winer, 1952; Cayford and Haig, 1961b; Barry *et al*, 1993).

Compression failures are most common in young trees with tall, slightly tapered stems, which are easily whipped by the wind. Dense pole timber stands are particularly subject to this injury if they have recently been thinned. Trees that have compression failure can be identified by callus swellings that may develop on stems at points where the tissues have been ruptured (Rendle *et al*, 1941). Often, the only external evidence of damage in pine is pitch flow where the bark has been broken (Barry *et al*, 1993).

Bending of trees can also result in scars 2 - 4 cm long (.8-1.6 inches) on the north, the northwest, or west sides of stems of young hardwoods. Lutz (1936) concluded that these horizontal scars were caused by a frozen layer of ice formed along the trunk that damaged bark tissue as it cracked under the tension or compression of the bending of the stem. The scars can persist for many years in species that do not slough bark rapidly. The scars do not appear below 45 cm (18 inches) above the ground (there is usually no bending below this point). There is no evidence of any serious consequences from this damage. Red maple, blue beech, flowering dogwood, largetooth aspen, chestnut oak, red oak, black cherry, white ash, pignut hickory, bitternut hickory, American beech have been known to be affected in this way.

Epicormic branching and sunscald

Many tree species will respond to crown damage and the increased exposure following ice storm damage by activating latent buds to produce epicormic branches. The following are conclusions from controlled research studies regarding epicormic branching. Although not directly applicable, they may be helpful in understanding the implications of epicormic branching in the management of ice damaged stands.

1. The amount of epicormic branching is dependent on the species. Blum (1963) found sugar maple, American beech and yellow birch all respond to excessive exposure by sprouting epicormic branches from dormant or adventitious buds. Yellow birch was the most prolific producer of epicormic branching followed by sugar maple and then American beech, at a ration of 13:6:1. Smith's (1966) study in Appalachian hardwoods produced the following list of species listed from most, to least likely to produce epicormic sprouts : A - white oak; B- black cherry, red oak, chestnut oak; C- hickory, yellow poplar, red maple, sugar maple; D- white ash (grouping indicate similar rates of epicormic sprouting).
2. The crown of the tree exerts a major influence on the formation of epicormic shoots (Godman and Mattson, 1970). Books and Tubbs (1970) found that the degree of crown loss, not the intensity of thinning, had significant effect on the degree of epicormic branching in sugar maple. Similarly Erdmann and Peterson (1972) found that the intensity of thinning, although having noticeable effects on diameter growth, had little effect on the degree of epicormic sprouting in yellow birch.
3. The degree to which a tree produces epicormic branches is dependant on the amount of crown damage (Brooks and Tubbs, 1970) and the crown position of the tree. More epicormic sprouts are formed in trees with severe crown damage (Lamson and Leak, 1998). More sprouts develop on intermediate and overtopped trees than on dominant and codominant trees (Skilling, 1957; Smith, 1966; Stubbs, 1986).
4. On average, more sprouts develop on second logs than on first logs (Smith, 1966; Erdmann and Peterson, 1972; Stubbs, 1986). Bole sprouting is somewhat greater on poor sites (Smith, 1966).
5. Godman and Mattson (1970) found that there was an increase in epicormic branching in sugar maple from the first to the second season after four specific crown-removal treatments. They also found that within the severe crown treatments there was a decline in the number of epicormic shoots within the live crown surviving at the end of the second growing season. All trees having undergone severe crown treatment were dead by the beginning of the third growing season.
6. If epicormic branches persist knots develop and log and lumber quality are reduced (Blum, 1963; Erdmann and Peterson, 1972; Stubbs, 1986). Epicormic branches and their associated defects are leading causes of degrade and value loss in lumber sawed from hardwood logs. The defect may be in the form of small knots, ingrown bark, wood blemishes, and/or rot (Smith, 1966).

7. Erdmann and Peterson (1972) found that sapsuckers attacked crown-released trees more often and more severely than unreleased trees. The most severe damage was to dominant and codominant trees that were moderately (trees within 10 feet of released tree were cut) or heavily released (trees within 15 feet of released tree were removed). Control and lightly crown-released trees were only casually damaged. The sapsucker damage caused more serious reduction in stem quality than damage resulting from epicormic branching.

Sunscald is the death of cambial tissue on one side of a tree caused by rapid freezing of sun-thawed tissue. Generally sunscald is common when smooth, thin-barked trees are exposed to direct sunlight (Spaulding and Bratton, 1946). After a severe ice storm Spaulding and Bratton (1946) found that there was visible sunscald injury in young maple and to a lesser extent American beech less than 18 inches (46 cm) d.b.h. that had suffered severe crown damage. Blum (1963) recorded similar findings. There was no evidence of sunscald in white ash, basswood (Spaulding and Bratton, 1946), or yellow birch (Books and Tubbs, 1970; Erdmann and Peterson, 1972). The scald resulted in the death of bark, followed by the discolouration of the underlying wood (Spaulding and Bratton, 1946; Blum, 1961).

Spaulding and Bratton (1946) found saprot fungi (Caerrena unicolor, Peniophora spp. Bjerkandera adustus, Trametes. hirsuta, Trametes versicolor, Irpex tulipiferae, and Schizohpyllum commune) on the lower trunks of surviving sugar maple and American beech. Caerrena unicolorfirst attacked the dead patches (a result of sunscald) and spread quickly upward and sideways to a lesser extent. Its parasitic ability enabled it to be the first fungus present and enabled it to out-compete most other fungi that attacked later.

Vegetative reproduction

Vegetative reproduction may be an important means for some species to retain their presence in stands following ice storm damage. The following information is from research literature, not specifically ice storm related, but may be useful in management efforts in ice damaged areas.

In general, in order to encourage sprouting, trees should be cut in the dormant season. Solomon and Blum (1967) found that small diameter stumps produce more sprouts than larger stumps (red maple, sugar maple, white birch). Sprout numbers declined rapidly in sugar maple as the stump diameter increased above 6 inches (15 cm) (Solomon and Blum, 1967; MacDonald and Powell, 1983). Smaller (sugar maple) or younger (red maple) stumps produced taller sprouts (Solomon and Blum, 1967). In white birch, sprout height tended to decline with increase residual basal area (Solomon and Blum, 1967). No similar relationship was found for red maple, sugar maple or oak. It is expected that moderate or high residual basal areas would gradually suppress height growth of sprouts. Yellow birch was found to be a non-sprouting species (Solomon and Blum, 1967). In a study of white oak McGee (1978) found that trees over 60 years of age, and larger than 8 inches (20 cm) d.b.h., produced few sprouts. Sprouting was not significantly affected by the removal of the overstory.

In addition to the species discussed above the following native hardwoods have varying abilities to sprout from the stump: balsam poplar, basswood, American beech, bur oak, cottonwood, green ash, silver maple, white ash (USDA, 1990).

In many cases healthy good quality trees can originate from stumps. However, coppice sprouts are vulnerable to rot transfer from the parent stump unless they originate below the stump root collar. This is especially evident in red oak (Anderson and Rice, 1993).

Melancol and Lechowicz (1987) maintain that although American beech was more severely affected by the ice storm than sugar maple, it will be able to maintain its co-dominance in stands due to its ability to root sprout. Root sprouts from the American beech will out-compete sugar maple seedlings.

The vegetative reproductive capabilities of conifers native to eastern North America area are very limited. With the exception of pitch pine, which has the ability to produce stump sprouts, pines do not vegetatively reproduce. Cedar and black spruce will layer (send out roots from parts of branches or stem where moisture is favourable); tamarack and balsam fir may layer under favourable site conditions but it is uncommon (USDA, 1990).

SUCCESSION

Three different views concerning the effects of ice storms and forest succession were found. The first is based on the observation,that early successional species are generally more susceptible to ice damage than climax species (Table 2). The damage sustained by any intolerant overstory would allow the more tolerant late successional species a competitive edge in filling canopy gaps, shifting the stand into a more advanced successional stage (Carvell *et al*, 1957; Lemon, 1961).

The opposite view is that extensive damage to the canopy creates large gaps allowing more light to reach the forest floor, therefore allowing reproduction of early successional species. The rapid reproduction and growth of the early successional species would effectively retard successional changes (Downs, 1938; Siccama *et al*, 1976).

The final view is that ice storms could advance succession in some stands and retard it in others. The effects on forest succession depend upon individual stand structure, species composition, landscape features, as well as upon storm intensity. Boemer *et al* (1988) conclude that in areas of heavy overstory pine damage, where few pine seedlings are present and considerable advanced regeneration of tolerant hardwoods is present, succession will probably be accelerated. In areas of heavy damage to oak and American beech overstory succession is expected to be retarded. Large canopy gaps created by heavy damage will favour establishment of early successional species such as tuliptree (not found in eastern Ontario), black cherry and American elm. DeSteven *et al* (1991), studying the changes in composition in beech-sugar maple forests in Wisconsin after an ice storm, found that stands with a leeward aspect during an ice storm exhibited advanced succession towards an increase in dominance of sugar maple. In forests with a windward aspect, where damage was much more severe, succession was retarded due to increased recruitment of intolerant species. Earlier studies by Sicamma *et al* (1976), Whitney and Johnson (1984) support these conclusions.

COARSE WOODY DEBRIS (MACRO-LITTER)

The effect of ice storms or other damage on the input of coarse woody debris has not been addressed in most studies (Rebertus *et al*, 1997). Bruederle and Stearns (1985) used a modified forest fuel sampling technique to measure the volume of macro-litter resulting from a "severe" ice storm striking southern Wisconsin in 1976 (up to 5 inches (13 cm) of glaze, followed by 80.6 km/hr). The average macro-litter volume resulting from the ice storm was determined to be 19.35 m^3 /ha. Following "a major" ice storm (4.62 cm of precipitation) affecting Missouri, Kansas and Iowa, Rebertus *et al* (1997) found that coarse woody debris (CWD) from the storm averaged 5.1 m^3 /ha, 27°/0 of the prestorm total downed wood volume. In their discussion of CWD dynamics in old-growth stands Rebertus *et al* (1997) stated: 1) In a young stand the volume of CWD may be high reflecting mortality of residual trees as well as the residual CWD from the previous stand; 2) The volume of CWD decreases as the stand develops and decomposition increases, outpacing addition of new CWD; 3) The volume of CWD increases again as the stand approaches old growth; 4) Conifer forests commonly have 4 to 12 times more accumulated CWD than hardwood forests, reflecting higher input levels, and lower rates of decay; 5) They believe that in old-growth forests in Missouri rapid decay, combined with episodic mortality results in a variable pattern of CWD over time.

FIRE

Few references were found discussing the effect of increased CWD and changes in fire hazard. Watt (1951) noted that more open stand conditions and added fuel following severe damage from snow/ice storms could make fire protection more difficult. Cayford and Haig (1961b) stated that where ice storms cause breakage and severe bending the above normal accumulation of flammable material would increase the fire hazard over that of undisturbed stands.

Ontario Ministry of Natural Resources fire specialists visited ice storm affected sites to assess the changes to fuels as a result of ice damage following Ice Storm '98. They found that although forest fuels have been altered by the storm, they have not created unmanageable situations (OMNR, 1998d). Table 5 presents a summary of their findings.

Table 5: Summary of fire behavioural changes in different forest types in Eastern Ontario[4]

Forest type	Fuel and Fire Behaviour Change	Fuel type	Change in Fire Suppression
white pine	• very little fuel change	• scattered branch material	• none
red pine (minimal damage stands)	• very little fuel change	• scattered top and branch material	• none
red pine (with pockets of severe damage)	• crown fire unlikely • if develops will drop back to ground as it moves from pocket	• broken crowns laying down or hung up in adjacent trees	• concentrate fire suppression away from damaged pockets
red pine severe damage	• very quick burning and intense • increase fire hazard from large amounts of slash after salvage	• many crowns hung up in remaining trees	• treat as heavy slash fuel
spruce	• little fuel change	• scattered tops	• none
jack pine (young severely damaged stands)	• would result in fast spreading crown fire (ladder fuel arrangement)	• abundance of downed and hanging fuel	• best opportunity located where there are good fire breaks
Scots pine (severely damaged)	• dramatic increase in fire behaviour due to available fuel	• many crowns downed and hanging in remaining stems	• treat as heavy fuel slash with open arrangement • suppression most successful from firebreak location
cedar	• most sites are dense and in moist to wet location - extended drought required to create significant hazard fire hazard increased on upland dry sites	• broken tops, with dry foliage	• intense fire
hardwood stands	• fire hazard will increase do to additional fuel available; hazard will increase as downed material seasons • greatest fire hazard will be in spring and fall (leaf fires) • increase in understory vegetation will reduce hazard after green-up	• variety of downed material, it will take a minimum of one season to cure	• material not consider "fine fuel"; additional mopping up may be required to stop smouldering of large material

[4] (Ontario Ministry of Natural Resources, 1998d)

EFFECTS ON WILDLIFE

Ice Storm `98 raised many concerns about the impacts of the ice and its damage on wildlife species. Some species suffered short term food reduction and mobility problems; but lasting impacts are expected to be minimal (McLellan, 1998). In the long term the changes that result in forest cover may actually help some species and populations. In both the short and longer term, the damage will lead to a greater diversity of habitat conditions, including increases in CWD, potential cavity trees, tree regeneration and other ground level vegetation. (McLellan, 1998).

A storms' effect on wildlife is dependant on the duration of the storm, the length of time that the ice cover remains, air temperatures before, during, and after the storm, and the physical condition of the wildlife population when the storm hits (McLellan, 1998). For this reason the impact on wildlife may differ across the affected area.

An internal Ontario Ministry of Natural Resources (1998c) report speculates that:

1. There is no reason to suspect that the ice storm resulted in high direct mortality to wildlife as a result of broken trees and branches, or due to wildlife being covered by ice.
2. Herbivores and carnivores may have suffered a lack of food as a result of the storm. Wild turkeys, Hungarian partridge, and songbirds such as finches, larks, buntings and tree sparrows found most of their regular food sources knocked down and covered by ice. Hungarian partridge numbers may have been reduced because of the birds size and their relatively small (less than 20 ha) home range. Because of their larger size and mobility, wild turkey numbers were likely not reduced. The abundance of CWD resulted in plenty of food for small mammals. It is possible that some species may have experienced a higher than normal rate of predation.
3. White-tailed deer and moose numbers were not reduced by the ice storm, although movement may have been restricted in some areas. There will be an increase in food availability for these species over the next decade due to an increase in ground vegetation growth.
4. Detailed mapping of forest damage suggest that squirrel nests withstood the storm well. Although squirrels may have had less food available after the storm it is not expected to result in a major decline in the population.
5. Hawks and owls are highly mobile and likely left the storm affected area in search of food.
6. The greatest impact for wildlife likely occurred in forest habitats in general, and mature closed canopy forest in particular. In many stands the ice storm has opened up the forest canopy; forest interior nesting birds are very sensitive to the amount of canopy opening. Red-shouldered hawk is very sensitive to crown closure, requiring a closed canopy.

The assessment of species that may have been impacted by the storm is ongoing (Ministry of Natural Resources, 1988c). One study has found that the ice storm has affected Cerulean Warbler nesting success during the first breeding season after the storm (Robertson, 1998). Although the core population in Eastern Ontario appears to be stable, only four (8.9%) nests successfully fledged one or more young (Robertson, 1998). This is a significant decrease from the previous four-year average of 76%. Most losses are presumed to be due to predation of eggs and nestlings. Nest site characteristics such as the height of the nest and distance from the trunk were the same as in pre-storm years. There has been no change in populations of known nest predators. It is hypothesised that the decreased nesting success is a result of the increased exposure of parental movement to and from the nest as a result of canopy loss (Robertson, 1998).

MANAGEMENT RECOMMENDATIONS

Most ice storm damage research ends with some conclusions that have direct management implications. Some recommendations deal with changes in management to reduce forest susceptibility to damage; while others deal with managing the damaged forests. The following recommendations are taken from the literature.

GENERAL

1. Measures to lessen damage from future ice storms are synonymous with good silviculture (Downs, 1938).
2. Determine feasibility of salvage

- Barry *et al* (1993) do not recommend salvage if damaged volume is less than 3-5 cords per acre because damage to residual trees would be greater than benefits.
- 5-7 cords (45-63 m^3/ha) of pulpwood or 2,000 bd.ft./acre (28 m^3 /ha) of sawtimber are needed for a commercial harvest (Lamson and Leak, 1998).
- Pine stands should be salvaged first because they are more susceptible to insect outbreaks (Barry *et al*, 1993). Salvage most severely damaged timber first (Barry *et al*, 1993, Sleeth, 1938).
- Trees of all species with >75% damage are at risk of being infected by insects and disease and should be considered for harvest within one year of damage (Lamson and Leak, 1998).

3. Trees with 50-75% damage should be retained but may develop stain and should be re-evaluated in three to five years (Lamson and Leak, 1998).
4. Severely damaged (badly broken tops, or large broken branches) hardwood and coniferous trees that are greater than 18 inches (46 cm) d.b.h. have a good chance of developing into wildlife cavity trees (Lamson and Leak, 1998). Some of these trees could be retained for this purpose if they do not pose a safety hazard.
5. If a stand is known to be inflicted with *Armillaria* root disease salvage should be delayed (even if above criteria are met) until desirable crop trees have recovered from storm damage. Harvesting before recovery will add to the *Armillaria* pressure. (McLaughlin, 1999 pers. comm.)
6. To prevent site and tree root damage by equipment in severely damaged stands salvage operations should be carried out when the soil conditions are relatively dry (Allen *et al*, 1998).
7. Avoid residual stand damage. A wound on the butt log is more serious in terms of economic loss than broken branches (Lamson and Leak, 1998, Shortle and Smith, 1998b).
8. If a woodlot was marked for thinning prior to the ice storm the following guideline should be followed: if > 20% of the overall forest canopy has been destroyed OR > 20% of dominant and co-dominant trees have been destroyed, the cut should be delayed and the woodlot should be re-marked. If the damage is less than indicated above, marking should be reviewed on an individual tree basis prior to cutting (Ministere de Ressources naturelles du Quebec, 1998).

PINE PLANTATIONS

1. Initial planting should be at a wide spacing to encourage trees with sturdy boles and strong crowns that are resistant to damage (Borzon *et al*, 1978; Shepard, 1975; Stoempl, 1971).
2. Thinning should be light, frequent and occur early in the life of the stand (Downs, 1943; Stoempl, 1971; Williston, 1974; Shepard, 1978; Fountain, 1979; Burton, 1981; Sheehan *et al*, 1982; Seidel, 1986; Jonas and Brand, 1988; Belanger *et al*, 1996; Amateis and Berkart, 1996). Thinnings should remove intermediate and overtopped trees (Downs, 1943; Williston, 1974; Cremer *et al*, 1982; Seidel, 1986). Thinning will encourage the development of sturdier stems with stronger branches (Downs, 1943; Williston, 1976; Borzon *et al*, 1978; Shepard, 1978; Burton, 1981; Sheehan, 1982; Seidel, 1986). Downs (1943), Williston (1974), and Fountain (1979) agree that thinnings should start when the d.b.h. reaches 6 inches (15 cm). Borzon *et al* (1978) recommend starting thinning at age 25, removing no more than 1/3 of the basal area.
3. Selective thinning would be the best management alternative. Because it is not practical to thin entire stands selectively Shepard (1975) recommends row thinning at wide intervals such as every 8t" or 10'" row.
4. Trees with compression failures should be recognised and removed from the stand in salvage cuttings or during the next thinning (Mergen and Winer, 1952, Barry *et al*, 1993).
5. It is not likely that even a severe storm will cause sufficient damage to reduce the future merchantable volume beyond the point where the landowner is left with no option other than to clearcut and plant. Most stands will probably contain a sufficient stocking for sawlog production, although tree distribution will be irregular and some trees will have to be left for the duration of the rotation that might not otherwise have been left (Shepard, 1978). Plantations that are >1.5 m (5 ft) tall and are less than 15 years are still viable for sawlog production if there are at least 1,000 healthy, well distributed tress/ha; areas where density is insufficient may have to re-established. Plantations >15 years old are still viable if > 800 trees /ha (324 trees/acre) are undamaged, if 40% of these are dominant or codominant trees. If the plantations has already undergone a thinning only 500 undamaged tree/ha (200 trees/acre) are required to remain viable, if 40% are dominant or codominant. Replanting of poorly stocked areas is in these older plantations is not feasible because of the height of stands (Ministere de Ressources naturelles du Quebec, 1998).
6. Salvage should be completed promptly. To reduce possibility of bark beetle infestation build-up the slash should be encouraged to dry quickly by: a) removing all merchantable material; b) scattering slash in open areas where possible; c) keeping large accumulations of slash away from bases of residual trees; d) severing severely leaning trees from their roots.
7. Trees broken below the crown or uprooted should be salvaged immediately (Barry *et al*, 1998; Lamson and Leak, 1998).

HARDWOODS

1. From an insect and disease standpoint there is no need to salvage standing hardwoods immediately (Barry *et al*, 1993; Allen *et al*, 1998; Lamson and Leak, 1998).
2. Salvage of any downed hardwood should take place as soon as possible; they will degrade within one or two growing seasons (Lamson and Leak, 1998).
3. Hardwood trees with broken tops or branches over 3 inches (7.6 cm) in diameter should be harvested during the next scheduled harvest (Barry *et al*, 1993).
4. If stocking is below 80 ft^2/acre (18 m^2 /ha) epicormic branching could persist; retain some damaged trees to reduce formation of epicormic branches in high value trees (Lamson and Leak, 1998).
5. To minimise development and persistence of epicormic branching and to maintain optimum volume growth residual basal area should be maintained at or above the optimal stocking (B-line). For hardwoods this is 65 ft^2/acre (15 m^2 /ha), for conifers 100 ft^2/acre (23 m^2 /ha). If removing all severely damaged trees reduces the stocking below these levels, some damaged trees should be retained (Lamson and Leak, 1998).
6. In areas of patchy severe damage group selection should be considered. Remove patches of severely damaged trees. Marking guidelines for group selection should be followed (Lamson and Leak, 1998).
7. Bent sapling and young polewood stands should be re-evaluated 3 - 5 years after damage. Groups selection can be considered if areas have not recovered from bending (Lamson and Leak, 1998).
8. Sugar maple does not sprout efficiently to replace lost crowns. Trees with more than 50% crown loss are not likely to resume vigorous growth, they will die progressively. Individual trees with this extent of damage should be harvested as soon as possible. Rot is likely to run downward from broken branch stubs in about 10 years (Spaulding and Bratton, 1946).
9. American beech should be treated like sugar maple. However, in American beech rot is likely to progress faster from large wounds than it is in sugar maple (Spaulding and Bratton, 1946).
10. Basswood sprouts profusely, and can maintain itself even if severely damaged. It can be held over for up to 10 years to gain diameter increment (Spaulding and Bratton, 1946).
11. Ash reacts similarly to basswood, but has a greater resistance to rot so it can be held over longer than 10 years (Spaulding and Bratton, 1946).
12. Black cherry trees with breakage wounds 3 inches (7.6 cm) or less in diameter confined to the branches and the upper part of the main stem, accompanied by vigorous crown regeneration, are considered a good risk for sawtimber production and should be retained (Rextrode and Auchmoody, 1982).

SUMMARY

Ice storms have been studied extensively in the past and these studies provide a large amount of information. Management recommendations in the literature are synonymous with "good forestry practices" and follow already established silvicultural practices.

The author found however, that although some information is available, there are very few studies that examine the long-term effects of ice storms on forests. Damage as severe and widespread as that suffered as a result of Ice Storm '98 is unprecedented. In its wake the storm leaves many unanswered questions, for instance, how many trees will die as a result of damage, will there be outbreaks of insect and disease, how will damage effect long-term stand quality? Ice Storm '98 provides a new opportunity to continue past research and to initiate new research that will fill information gaps in past research.

LITERATURE CITED

1. Abell, C.A. 1934. Influence of glaze storms upon the hardwood forests in the southern Appalachians. Journal of Forestry 32: 35-37.
2. Allen, D.C., 1998. Forest Insect Concerns in Irland, L.C., co-ordinator, Ice Storm 1998 and the forests of the northeast. Journal of Forestry 96(9): 32-40.
3. Allen, D.C., P.J. Smallidge, and L. Staats, 1998. Preliminary guidelines for forest owners following the January Ice storm New York Forest Owner 36: 2,4-5.
4. Amateis, R.L. and H.E. Burkhart. 1996. Impact of heavy glaze in a loblolly pine spacing trial. Southern Journal of Applied Forestry, 20(3): 151-155.
5. Anderson, H.W. and J.A. Rice, 1993. A tree-marking guide for the tolerant hardwoods working group in Ontario. Ontario Ministry of Natural Resources. Queen's Printer for Ontario. Toronto. 227 pp.
6. Anonymous, 1941. Utilization of timber damaged by the ice-storm of January 1940. Quarterly Journal of Forestry 35: 120-123.
7. 7Barry, P.J., C. Doggett, R.L. Anderson and K.M. Swain, 1993. How to evaluate and manage storm-damaged forest areas. Management Bulletin R8-MB 63. Atlanta, GA.: Southern Region. Forest Health, USDA Forest Service. 12 pp
8. Basham, 1971. Canadian Journal of Forest Research 11: 206-214.
9. Belanger, R.P., J.F. Godbee, R.L. Anderson, and J.T. Paul, 1996. Ice damage in thinned and non-thinned loblolly pine plantations infected with fusiform rust. Southern Journal of Applied Forestry 20(3): 136-142.
10. Blum, B.M., 1963. Excessive exposure stimulates epicormic branching in young northern hardwoods. Research Note NE-9. Upper Darby, PA.: Northeastern Forest Exp. Sta., USDA. Forest Service. 6 pp.
11. Blum, B.M. 1971. Some correlations between sugar maple tree characteristics and sap and sugar yields. Research Note NE-143. Upper Darby, PA.:, Northeastern Forest Experiment Station, USDA Forest Service. 4 pp.
12. Blum, B.M., 1966. Snow damage in young northern hardwoods and rapid recovery. Journal of Forestry 64(1): 16-18.
13. Boemer, R.E.J., S.D Runge, D.S. Cho, and J.G. Kooser, 1988. Localized ice storm damage in an Appalachian plateau watershed. American Midland Naturalist 119(1): 199-208.
14. Books, D.J. and C.H. Tubbs, 1970. Relation of light to epicormic sprouting in sugar maple. Research Note NC-93. St. Paul, MN.: North Central Forest Experiment Station, USDA Forest Service. 2 pp.
15. Borzon, E.L., A.F. Beckwith, and W.G. Irwin, 1978. Ice and snow damage to coniferous plantations in Northumberland forest. Ontario Ministry of Natural Resources. 22 pp.
16. Bruederle, L.P., and F.W. Stearns, 1985. Ice storm damage to a southern Wisconsin mesic forest. Bulletin of the Torrey Botanical Club 112(2): 167-175.
17. Burton, J.D., 1981. Thinning and pruning influence glaze damage in a loblolly pine plantation. Research Note No. SO-264. New Orleans, LA.: Southern Forest Experiment Station, USDA Forest Service. 4 pp.
18. Campbell, W.A., 1937. Decay hazard resulting from ice damage to northern hardwoods. Journal of Forestry 35(11): 1156-1158.
19. Campbell, W.A. and R.W. Davidson, 1940. Top rot in glaze-damaged black cherry and sugar maple on the Allegheny Plateau. Journal of Forestry 38: 963-965.
20. Carvell, K.L., E.H.Tryon, and R.P. True, 1957. Effects of glaze on the development of Appalachian hardwoods. Journal of Forestry 55(2): 130-132.
21. Cayford, J.H. and R.A. Haig, 1961a. Glaze damage in Red and Scots pine plantations in southeastern Manitoba. Forestry Chronicle 37(1): 16-21.
22. Cayford, J. H. and R.A. Haig, 1961b. Glaze damage in forest stands in southeastern Manitoba. Technical Note No. 102. Forestry Canada. Forest Research Branch 16pp.
23. Cremer, K.W., C.J. Borough, F.H. McKinnell, and P.R. Carter, 1982. Effects of stocking and thinning on wind damage in plantations. New Zealand Forest Science 12(2): 244-268.

24. Dance B.W., and D.F. Lynn 1963. Excessive Red Oak mortality following ice-storm damage. Bimonthly program report. 19(6): 3. Forest Entomology and Pathology Branch, Department of Forestry Canada.
25. Dessureault, M., 1985. Tree Decline: Nature, causes, and mechanisms. Phytoprotection 66: 71-81.
26. De Steven D., J. Kline, and P.E. Matthiae, 1991. Long-term changes in a Wisconsin Fagus-Acer forest in relation to glaze storm disturbance. Journal of Vegetation Science 2: 201-208.
27. Deuber, C.G., 1941. The Glaze storm of 1940. American Forest 46: 210-211.
28. Downs, A.A. 1937 Glaze Storm of March 17-19, 1936, in Pennsylvania and New York. Monthly Weather Review 65: 100-101 USDA, Weather Bureau.
29. Downs, A.A., 1938. Glaze damage in the birch-beech-hemlock type of Pennsylvania and New York. Journal of Forestry 36(2): 63-70.
30. Downs, A.A., 1943. Minimising glaze damage in pine. Technical Note No. 55. Asheville, NC.: Appalachian Forest Experimental Station. USDA Forest Service. 5 pp.
31. Environment Canada, 1998. wwwl.tor.ec.gc.ca/events/icestorm98
32. Erdmann, G.G. and R.M. Peterson, 1972. Crown release increases diameter growth and bole sprouting of pole-size yellow birch. Research Note No. NC-130. St. Paul, MN.: North Central Forest Experiment Station. USDA Forest Service. 4pp
33. Forestry Canada, 1998. North American Maple Project ice Storm 1998 Assessment training presentation. Forestry Canada, Ontario Region, Sault Ste. Marie. 17 pp.
34. Fountain, M.S., and F.E. Burnett, 1979. Ice-damage to plantation grown loblolly pine in south Arkansas. Arkansas Farm Research 28(3): 3.
35. Glen, W.M., 1997. Freezing rain and tree damage in Prince Edward Island. Management Notes Number 12. P.E.I. Department of Agriculture and Forestry, Forestry Division. 9pp.
36. Godman, R.M. and G.A. Mattson, 1970. The sprouting potential of dormant buds on the bole of pole-sized sugar maple. Research Note NC-88. St. Paul, MN,: North Central Forest Experiment Station, USDA. Forest Service. 4 pp.
37. Goebel, C.J. and G.H. Deitschman, 1967. Ice storm damage to planted conifers in Iowa. Journal of Forestry 65(7): 496-497.
38. Gouvernement du Qu6bec, 1998. Quoi de neuf - cartograhie d'territoire affecte par le verglas. (Information on previous ice storms). Gouvernement du Quebec, Ministere des ressources naturelles, Direction de la conservation des forets. 15 pp.
39. Harrington, C.A. and D.S. DeBell, 1996. Above- and below-ground characteristics associated with wind toppling in a young Populus plantation. Trees 11(2): 109-118.
40. Hauer, R.J., W.Wang, and J.O. Dawson, 1993. Ice storm damage to urban trees. Journal of Arboriculture 19(4): 187-193.
41. Hiratsuka, Y, and H. Zalasky, 1993. Frost and other climate-related damage of forest trees in the prairie provinces. Inf. Rep. NOR-X-331. Forestry Canada, Northwest Region, Northwest Region, Northern Forestry Centre. 25 pp.
42. Hough, A.F., 1959.Zoning for the management of black cherry on the Allegheny Plateau. Journal of Forestry 57: 353-357.
43. Hough, A.F., 1965. What a glaze storm brings. Pennsylvania Forest 33(1): 4-5.
44. Innes, J.L., 1993 Methods to estimate forest health. Silva Fennica 27(2): 145-157.
45. Janas, P.S. and D.G. Brand, 1988. Comparative growth and development of planted and natural stands of jack pine. Forestry Chronicle 64(4): 320-328.
46. Kienholz, R., 1941. Jack pine in Connecticut damaged by sleet storm. Journal of Forestry 39: 874-875.
47. Lachance, D., A. Hopkin, B.Pendrel, and J.P. Hall, 1995. Health of sugar maple in Canada. Results from the North American Maple Project, 1988-1993. 2
48. Lamson, N. and W. Leak, 1998. Silvicultural Approaches for managing ice-damaged stands. Ice Storm 1998, Information Sheet #4., Durham, NH.: Northeastern Research station, USDA Forest Service. 2pp.
49. Lemon, P.C., 1961. Forest ecology of ice storms. Bulletin of the Torrey Botanical Club 88(1): 21-29.
50. Lutz, H.J., 1936. Scars resulting from glaze on woody stems. Journal of Forestry 34: 1039-1041.

51. MacDonald, J.E., and G.R. Powell, 1983. Relationships between stump sprouting and parent-tree diameter in sugar maple in the 1st year following clear-cutting. Canadian Journal of Forest Research 13: 390-394.
52. Manion, P., 1998. Forest Health Monitoring in relation to the North Country ice storm damage of January 1988. Unpublished presentation at the 1998 Research Forum, Ottawa, Canada. 1998.
53. McCulloch, W.F., 1943. Ice breakage in partially cut and uncut second growth Douglas-Fir stands. Journal of Forestry 41: 275-278.
54. McEvoy, T.J. and N. Lamson, 1998. Harvesting ice-damaged timber. Ice Storm 1998, Information Sheet #9. Durham, NH.: Northeastern Research Station. USDA Forest Service. 2pp.
55. McGee, C.E., 1978. Size and age of tree affect white oak sprouting. Research Note SO-239. New Orleans, LA.: Southern Forest Experiment Station, USDA Forest Service. 2pp.
56. McKellar, A.D., 1942. Ice damage to slash pine, longleaf pine, and loblolly pine plantations in the Piedmont Section of Georgia. Journal of Forestry 40(10): 794-797.
57. McLellan, T., 1998. Lucky break for wildlife. Ice Storm 1998, Information Sheet #5.Durham, NH.: Northeastern Research Station, USDA Forest Service. 2pp.
58. McLaughlin, J.A. and M. Dumas. 1996. Pathological implications of partial cutting in boreal mixedwood stands. Pp. 167-169, in C.R. Smith and G.W. Crook, compilers, "Advancing Boreal Mixedwood Management in Ontario: Proceedings of a Workshop held at Sault Ste. Marie, Ontario, on October 17-19, 1995". Natural Resources Canada and Ontario Ministry of Natural Resources. ISBN 0-662-24190-8. 239 pp
59. McLaughlin, J.A., 1999. Personal communication, A/Provincial Forest Pathologist, Ontario Forest Research Institute, Sault Ste. Marie, Ontario, Canada.
60. Melancon, S., and M.J. Lechowicz, 1987. Differences in the damage caused by glaze ice on codominant Acer saccharum and Fagus grandifolia. Canadian Journal of Botany. 65(6): 1157-1159.
61. Mergen, F. and H.I. Winer, 1952. Compression Failures in the boles of Living Conifers. Journal of Forestry 50(9): 677-679.
62. Ministere de Ressources naturelles du Quebec, 1998. La Foret sous le verglas: prudence et patience. In response to ice storm damage. Direction de la recherche forestiere, Ministere des Rossources naturelles du Quebec. Sainte-Foy, Quebec. 16 pp.
63. Nykanen, M.L., H.Peltola, C.Quine, S. Kellomaki, and M. Broadgate, 1997. Factors affecting snow damage of trees in particular reference to European conditions. Silva Fennica 31(2): 193-213.
64. Ontario Ministry of Agriculture, Food and Rural Affairs, 1998. Instructions for the completion of ice damage assessments in sugar bushes in eastern Ontario. Government of Ontario, Ministry of Agriculture, Food and Rural Affairs, unpublished internal document, Kemptville, Ontario. 9 pp.
65. Ontario Ministry of Natural Resources, 1998a. A Silvicultural guide for the tolerant hardwood forest in Ontario version 1.1. Ont. Min. Nat. Resources. Queen's Printer for Ontario. Toronto. 500 pp.
66. Ontario Ministry of Natural Resources, 1998b. Ice Damage manual for permanent sample plots. Ontario Government, Ministry of Natural Resources, Growth and Yield Program, unpublished internal document. 3 pp.
67. Ontario Ministry of Natural Resources, 1998c. Assessing the impacts on wildlife of ice Storm '98. Unpublished internal report, OMNR South Central Science and Technology Development Unit. Kemptville, Ontario, Canada. 11 pp.
68. Ontario Ministry of Natural Resources, 1998d. Ice Storm fire behaviour assessment. Unpublished internal report. OMNR, Aviation, Flood and Fire management, Fire Management Section, East Fire Region. Sault Ste. Marie, Ontario, Canada. 3 pp.
69. Ontario Ministry of Natural Resources, 1998e. Ice Damage Assessment. Unpublished internal document. OMNR, South Central Science and Technology Development Unit. Kemptville, Ontario, Canada.
70. Ontario Ministry of Natural Resources, 1998f. Ontario in Irland, L.C., coordinator, Ice Storm 1998 and the forests of the northeast. Journal of Forestry 96(9): 32-40.
71. Rebertus, A.J., S.R. Shifley, R.H. Richards, and L.M. Roovers, 1997. Ice storm damage to an old-growth oak-hickory forest in Missouri. American-Midland-Naturalist 137(1): 48-61.

72. Rendle, B.J., F.H. Armstrong, and E.H. Nevard, 1941. The utilisation of softwood timber damaged in the glazed frost, 1940. Forestry 15: 55-65.
73. Rextrode, C.O., and L.R. Auchmoody, 1982. 46 years after storm… Glaze-damaged black cherry. Pennsylvania Forests 2(3): 8-9.
74. Roberts, E.G. and R.T. Clapp, 1956. Effects of pruning on the recovery of ice-bent Slash Pines. Journal of Forestry 54(9): 596-597.
75. Robertson, R., 998. Managing Landscapes for avian diversity. Wildlife habitat Canada unpublished Progress Report, fall, 1998.7 pp.
76. Roth E.R., 1941. Top rot in snow-damaged yellow poplar and basswood. Journal of Forestry 39: 60-62.
77. Roy, G, Robitaille, L. and G. Gagnon, 1985. A study of major factors in maple stand decline in Quebec. Phytoprotection. 66: 91-99.
78. Sanzen-Baker, R.G. and M. Nimmo, 1941. Glazed frost 1940 - Damage to Forest trees in England and Wales. Forestry 15: 37-54.
79. Seischab, F.K., J.M. Bernard, and M.D. Eberle, 1993. Glaze storm damage to western New York forest communities. Bulletin of the Torrey Botanical Club 120(1): 64-72.
80. Sheehan, P.G., P.B Lavery, and B.M. Walsh, 1982. Thinning and salvage strategies in plantations prone to storm damage - case study of radiata pine plantations in the Ovens Valley, Victoria. New Zealand Journal of Forest Science. 12(2): 269-280.
81. Shepard, R.K. Jr., 1975. Ice storm damage to Loblolly Pine in northern Louisiana. Journal of Forestry 73(7): 420-423.
82. Shepard, R.K. Jr., 1978. Ice storm damage to thinned loblolly pine plantations in northern Louisiana. Southern Journal of Applied Forestry 2(3): 83-85.
83. Shepard, R.K. Jr., 1981. Ice damage to slash and loblolly pine in northern Louisiana. Tree Planters' Notes 32(1): 6-8.
84. Shigo, A. L., 1984. Compartmentalisation: A conceptual framework for understanding how trees grow and defend themselves. Annotated Review of Phytopathology 22: 189-214.
85. Shortle, W. and K. Smith, 1998. How to determine percent live crown loss in hardwoods before leaf-out. Ice Storm 1998, Information Sheet #1. Durham, NH.: Northeastern Research Station, USDA Forest Service 2pp.
86. Shortle, W. C. and K.T. Smith, 1998b. Prospects for Recovery in Irland, L.C., coordinator, Ice Storm 1998 and the forests of the northeast. Journal of Forestry 96(9): 32-40.
87. Siccama, T.G., G. Weir, and K. Wallace, 1976. Ice damage in a mixed hardwood forest in Connecticut in relation to Vitis infestation. Bulletin of the Torrey Botanical Club 103(4): 180-183.
88. Sisinni, S.M., W.C Zipperer, and A.G. Pleninger, 1995. Impacts from a major ice storm: street-tree damage in Rochester, New York. Journal of Arboriculture 21(3): 156-167.
89. Skilling, D.L., 1957. Is the epicormic branching associated with hardwood pruning wounds influenced by tree crown class? Technical Note LS-510. Lake States Forest Experiment Station, USDA Forest Service. 2pp.
90. Sleeth, B., 1938. Decay in black cherry damaged by glaze. Tech Note 20. Philadelphia, PA.: Allegheny Forest Experimental Station, USDA Forest Service. 2 pp.
91. Smith, H.C., 1966. Epicormic branching on eight species of Appalachian hardwoods. Research Note NE-53. Upper Darby, PA.: Northeastern Forest Experiment Station. USDA Forest Service. 4pp.
92. Smith, W.H., and C.R. Musser, 1988. Relation to Disease and Decay in Irland, L.C., coordinator, Ice Storm 1998 and the forests of the northeast. Journal of Forestry 96(9): 32-40.
93. Smith, K.T. and W.C. Shortle, 1998. Will winter storm injury affect hardwood quality and maple sap production? Ice Storm 1998, Information Sheet #2. Durham, NH.:, Northeastern Research Station, USDA Forest Service. 2pp.
94. Solomon, D.S. and B.M. Blum, 1967. Stump sprouting of four northern hardwoods. Research Report NE-59.Upper Darby, PA.: NE Forest Experiment Station, USDA Forest Service. 13pp.
95. Spaulding, P. and Q.W. Bratton, 1946. Decay following glaze storm damage in woodlands of Central New York. Journal of Forestry 44(7): 515-519.
96. Stroempl, G., 1971. Gale damage in coniferous plantations in southeastern Ontario. Forestry Chronicle 47(5): 273-278.

97. Stubbs, J., 1986. Hardwood epicormic branching - small knots but large losses. Southern Journal of Applied Forestry 10: 217-220.
98. Travis, D.J., H.D. Grissino-Mayer, and P.W. Suckling, 1989. The impact of ice storms on tree-ring widths of loblolly pine in northern Georgia. 19th Conference on Agricultural and Forest Meteorology and ninth Conference on Biometeorology and Aerobiology, March 7-10, 1989, Charleston, South Carolina. 1989, J38-J40; American Meteorological Society; Boston, Massachusetts, USA.
99. USDA, 1990. Agricultural handbook 654: Silvics of North America. Volumes 1 &2.
100. Van Lear, D.H. and J.R. Saucier, 1973. Comparative Glaze Damage in Adjacent Stands of Slash and Longleaf Pine. Forest Research Series No. 27. Clemson, SC.: Clemson University, Department of Forestry. 7 pp.
101. Watt, R.F., 1951. Snow damage in a pole stand of western white pine. Research Note No. 92. Missoula, Montana.: Northern Rocky Mountains Forest Range Station, USDA Forest Service. 4 pp.
102. Whitney, H.E., and W.C. Johnson, 1984. Ice storms and forest succession in southwestern Virginia. Bulletin of the Torrey Botanical Club 111(4): 492-437.
103. Williams, C.B. Jr., 1966. Snow damage to coniferous seedlings and saplings. Research Note PNW-40. Portland, OR.: Pacific Northwest Forest Range Experiment Station, USDA Forest Service. 10 pp.
104. Williston, H.L., 1974. Managing Pines in the Ice-Storm Belt. Journal of Forestry 72(9): 580-582.