ICE STORM DAMAGE AND EARLY RECOVERY IN AN OLD-GROWTH FOREST

STÉPHANIE M. DUGUAY, KEN ARII, MICHAEL HOOPER
and MARTIN J. LECHOWICZ*
Department of Biology, McGill University, 1205 Dr. Penfield, Montréal, Québec, Canada H3A 1B1
(author for correspondence, e-mail: martin@bio1.lan.mcgill.ca)*

Abstract. We quantified the damage caused by a major ice storm to individual trees in two 1-ha permanent plots located at Mont St. Hilaire in southwestern Québec, Canada. The storm, which occurred in January 1998, is the worst on record in eastern North America; glaze ice on the order of 80–100 mm accumulated at our study site. All but 3% of the trees (DBH ≥ 10 cm) lost at least some crown branches, and 35% lost more than half their crown. Damage to trees increased in the order: *Tsuga canadensis*, *Betula alleghaniensis*, *Ostrya virginiana*, *Acer saccharum*, *Fagus grandifolia*, *Quercus rubra*, *Betula papyrifera*, *Acer rubrum*, *Tilia americana*, and *Fraxinus americana*. Only 22% of the saplings and small trees (4 cm < DBH < 10 cm) escaped being broken or pinned to the ground by falling material. Levels of damage generally were greater in an exposed ridge top forest than in a cove protected from wind. By August 1999 only 53% of the trees had new shoots developing from the trunk or broken branches; among the more dominant canopy trees, *Fagus grandifolia* had the least sprouting and *Acer saccharum* and *Quercus rubra* the most. We anticipate and will monitor both significant turnover in the tree community and some shift in composition of the canopy dominants.

Keywords: forest disturbance, ice storm, monitoring, northern hardwood forest, old-growth forest, tree damage, tree recovery

1. Introduction

Glaze ice is a common but relatively little studied form of forest disturbance in the temperate regions of eastern North America (Lemon, 1961). Glaze ice forms when a relatively warm air-mass passes over colder air near ground level; precipitation falling through the colder air-mass becomes super-cooled and freezes on contact with surfaces at ground level. It is not unusual for tree limbs to accumulate sheaths of ice many tens of mm in thickness during an ice storm, and the resultant ice-loading will often lead to branch breakage and disruption of crown form. Although there are a good number of descriptions of tree damage in eastern North America due to ice storms (Harshberger, 1904; Illick, 1916; Rogers, 1922, 1923, 1924; Abell, 1934; Downs, 1938; Croxton, 1939; Deuber, 1940; Carvell *et al*., 1957; Lemon, 1961; Siccama *et al*., 1976; Whitney and Johnson, 1984; Bruederle and Stearns, 1985; Melancon and Lechowicz, 1987; Boerner *et al*., 1988; Nicholas and Zedaker, 1989; De Steven *et al*., 1991; Rebertus *et al*., 1997), few studies monitor

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and report the nature of forest recovery over the years following the storm event (Campbell, 1937; Campbell and Davidson, 1940; Spaulding and Bratton, 1946; De Steven *et al*., 1991). There can be little doubt that many trees die or never fully recover crown form and full growth potential in the aftermath of an ice storm, but we know almost nothing about differences in recovery from species to species and site to site. This is especially true in old-growth forests, which have scarcely been studied from the point of view of ice damage (Rebertus *et al*., 1997). Permanent plots in place for monitoring forest health and dynamics in old-growth forests therefore can provide a valuable opportunity to quantify both the initial damage caused by an ice storm and the degree of tree recovery and death in the aftermath of a storm event.

In this article we report the impact of a major ice storm on two permanent plots established within a tract of old-growth forest on Mont St. Hilaire (45°32′N, 73°09′W) near Montreal, Quebec, Canada. Mont St. Hilaire is a hill complex of plutonic origin (Feininger and Goodacre, 1995) with peaks that rise between 200–300 m above the level floor of the surrounding St. Lawrence River Valley. The tract of forest at Mont. St. Hilaire is the largest remaining remnant of the primeval forests of the St. Lawrence River Valley. The site is protected as an International Biosphere Reserve under the Man and Biosphere program (MAB) of the United Nations. The diverse forest types on the mountain are species-rich and essentially undisturbed by human activities (Maycock, 1961; Enright and Lewis, 1985; Leckie *et al*., 2000). A number of long-term monitoring plots are located at the site because of its ecological significance and protected status. These include two 1-ha plots established in 1996–1997 under the auspices of the Canadian Ecological Assessment and Monitoring Network. These SI/MAB plots follow the general protocols dictated by the Smithsonian Institution's worldwide network of plots for monitoring forest health and biodiversity (Dallmeier, 1992). Individual stems of all trees and saplings greater than 4 cm diameter at breast height are identified, scored for size and health, and mapped to dm spatial resolution within a 100×100 m plot. The plots provide an opportunity to record the forest composition, ice damage and tree recovery or mortality in this representative tract of old-growth forest in eastern North America.

In early January 1998, not long after these permanent plots were established, the forest at Mont St Hilaire was hit by the worst ice storm on record in eastern North America (Hooper, 1999). Between January 5th and 9th somewhere between 80–100 mm of glaze ice accumulated in the vicinity of Mont St. Hilaire (Kerry *et al*., 1999), more than double the amounts of glaze ice recorded in any previous storm this century. Forests throughout a large part of northeastern North America were damaged by this extensive storm system (Irland, 1998), but no other region had this much ice loading. The forest canopy at Mont St. Hilaire lost at least 19.9 metric tons or 33.6 m^3 of woody biomass per hectare in this ice storm (Hooper, 1999). Severe ice storms in Wisconsin (Bruederle and Stearns, 1985) and Missouri (Rebertus *et al*., 1997) brought down only 19.4 and 5.1 m^3 ha^{-1}, respectively. The average canopy cover in the forest at Mont St. Hilaire went from 13% open sky before the ice storm to 24% open sky after the storm (Arii *et al*., unpublished). We estimate that it will take a minimum of 20–25 yr for the forest canopy cover to return to pre-storm values, which were already somewhat lower than usual because of an earlier ice storm in the winter of 1983–1984 (Melancon and Lechowicz, 1987). By continued monitoring in our permanent plots at Mont St. Hilaire, we will be able to follow recovery from the ice storm of January 1998 on both a species and site basis. Our primary objective in this article is to document the damage and early stages of recovery in the two years immediately following the January 1998 storm.

2. Methods

We had established two SI/MAB plots within the Preservation Sector of the Mont St. Hilaire Biosphere Reserve, an area to which access is restricted and where there is little or no evidence of human disturbance since the arrival of European settlers in this region during the 17th century. We refer to the two sites as the Botany Bay (BB) plot and the Lake Hill (LH) plot. The BB plot (center at 45°32.664′N, 73°08.563′W), which was set out in summer 1997, is on the lower part of a steep southwest-facing slope on the shore of Lac Hertel. Lac Hertel is a 34 ha lake surrounded by the low peaks that ring the perimeter of Mont St. Hilaire. There is a 58 m elevational range within the plot and the canopy height is about 28 m (90th percentile of tree heights). Parts of the forested slopes of this interior bowl of Mont St. Hilaire, including the BB plot, are somewhat more sheltered from disturbance by wind than are the ridges and outer slopes of the mountain. The BB plot is within such a steep-walled and sheltered embayment at the northeast corner of the lake; there are many large, old trees in this embayment including at least one sugar maple in excess of 400 yr old (Cook, 1971). The LH plot (center at 45°32.479′N, 73°08.838′W), which was set out in summer 1996, is on an exposed ridge that forms part of the rim of peaks around Lac Hertel. A semi-permanent pond occupies about 10% of the site. The elevational range of the LH plot is only 11 m; the canopy height is about 28 m. Limited coring of a few large sugar maple trees in the LH plot yielded an average age of 161 yr with growth rates of 1.8 mm yr^{-1} (Sager *et al*., 1999).

At each plot both trees (DBH $\geq$ 10cm) and saplings (4 cm < DBH < 10 cm) were identified, mapped and tagged at breast height (1.3 m from the base) with pre-numbered aluminum tags. The diameter at breast height (DBH) of every sampled stem was measured and the heights of the trees were also determined. These data provide the baseline against which storm damage is assessed. In late summer 1998 and again in August 1999 we resampled each plot to evaluate the damage attributable to the ice storm of January 1998. This recensus followed protocols developed in Québec (Jacques Brisson, personal communication) for scoring ice damage in two size classes: 1) assessment of the trees and 2) assessment of large saplings and small trees. We used the same two size classes as when the plots were established. We scored trees on a five point scale: 1) *essentially undamaged:* less than 5% of branches damaged, 2) *little affected:* 5–25% of branches damaged, 3) *moderately affected:* 25–50% of branches damaged, 4) *badly affected:* more than 50% of branches damaged and 5) *severely affected:* total loss of canopy, breakage of trunk. We scored the smaller stems as: 1) undamaged, 2) upright, but with some broken branches and 3) bent over as well as damaged. In August 1999, we scored which the trees had sprouted new shoots 1) from the trunk base and 2) from the bole or broken branches.

3. Results

3.1. Site comparison – forest composition

The two permanent plots represent different types of old-growth forest at Mont St. Hilaire, although sugar maple (*Acer saccharum*) is the dominant species in both size classes and in both plots (Table I). Beech (*Fagus grandifolia*), hemlock (*Tsuga canadensis*), and red oak (*Quercus rubra*) are codominants in the Botany Bay (BB) plot; red oak is the codominant in the Lake Hill (LH) plot. The BB plot has a higher diversity of tree species, 19 species compared to only 14 species in the LH plot. Neither the species present nor the forest composition in the two plots is unusual for this region near the northern limits of deciduous forest in eastern North America. The size and height distributions of the trees are consistent with old-growth status. The two plots have comparable levels of standing volume, but there are more trees and fewer saplings and small trees in the BB plot. The sugar maple trees are somewhat larger in the LH plot, but there are also over three times as many small sugar maples.

3.2. Damage to trees

The pattern of damage to trees in the two plots differs: species in the LH plot generally were more damaged. No trees in the LH plot escape damage entirely, but 5% of the trees in the BB plot were essentially undamaged (Table II). Crown loss in excess of 50% occurred in 46% of the trees in the LH plot but only in 26% of the trees in the BB plot. In the two plots combined all but 3% of the individual trees lost at least some crown branches, and 35% lost more than half their crown. Sugar maple at LH were much more damaged than at BB; 41% of the sugar maples at LH lost over half their crown compared to only 17% at BB. Similarly, 46% of red oaks at LH lost over half their crown compared to only 17% at BB. Beech at BB were slightly more damaged than at LH. Hemlock (*Tsuga canadensis*), yellow birch (*Betula alleghaniensis*) and ironwood (*Ostrya virginiana*) stand out as relatively little damaged overall.

TABLE I

Forest composition in two permanent plots located at the Mont St. Hilaire Biosphere Reserve (45°32′N, 73°09′W). BA is the basal area in cm^2 and DBH is the diameter at breast height (1.4 m) in cm

Species	Botany Bay							Lake Hill						
	4 < DBH < 10 cm			DBH > = 10 cm				4 < DBH < 10 cm			DBH > = 10 cm			
	# stems	BA (cm^2)	Mean DBH (cm)	# stems	BA (cm^2)	Mean DBH (cm)	Mean height (m)	# stems	BA (cm^2)	Mean DBH	# stems	BA (cm^2)	Mean DBH (cm)	Mean height (m)
Abies balsamea	5	117	5.3	1	90	10.7	10.0	–	–	–	–	–	–	–
Acer pensylvanicum	9	169	4.8	1	78	10.0	6.0	118	3328	5.8	3	389	12.8	11.0
Acer rubrum	–	–	–	1	908	34.0	20.0	–	–	–	15	23392	41.6	22.8
Alnus rugosa	5	146	5.8	–	–	–	–	–	–	–	–	–	–	–
Acer saccharum	138	5253	6.7	201	115902	23.9	19.6	427	11645	5.7	232	172794	28.4	19.8
Acer spicatum	91	2010	5.1	1	80	10.1	9.0	9	129	4.3	–	–	–	–
Betula alleghaniensis	16	616	6.8	31	13486	21.9	16.4	3	133	7.3	5	1588	19.1	13.2
Betula papyrifera	–	–	–	20	12771	27.4	16.9	–	–	–	–	–	–	–
Cornus alternifolia	–	–	–	–	–	–	–	1	18	4.8	–	–	–	–
Fraxinus americana	1	71	9.5	2	594	19.5	18.5	16	461	5.9	15	16493	34.3	19.5
Fagus grandifolia	83	2693	6.2	68	52648	28.1	21.4	63	1838	5.9	42	20321	22.0	15.1
Fraxinus nigra	–	–	–	1	83	10.3	11.0	–	–	–	–	–	–	–
Juglans cinerea	–	–	–	1	1626	45.5	31.0	–	–	–	–	–	–	–
Ostrya virginiana	51	1858	6.6	45	6471	13.2	11.8	15	546	6.6	6	933	13.9	11.3
Prunus pensylvanica	–	–	–	–	–	–	–	1	24	5.5	–	–	–	–
Pinus resinosa	–	–	–	1	1263	40.1	24.0	–	–	–	–	–	–	–
Prunus serotina	–	–	–	6	8853	36.9	24.2	–	–	–	–	–	–	–
Quercus rubra	–	–	–	29	35193	37.9	19.0	–	–	–	35	56040	44.3	23.2
Tilia americana	11	256	5.4	15	13736	32.0	20.7	11	211	4.9	2	1106	24.1	21.5
Tsuga canadensis	28	891	6.2	78	43974	24.5	14.3	–	–	–	1	531	26.0	10.0
Ulmus americana	1	30	6.2	1	394	22.4	14.0	2	28	4.3	–	–	–	–
Total	439	14108	6.2	503	308151	24.8	18.0	666	18361	5.7	356	293586	29.4	19.4

TABLE II

Damage to trees with DBH >10 cm. Damage increases from class 1 to 5; see text for details. The table is arranged from most to least damaged species based on the average of the weighted mean damage score in the two plots. Results for species with very low stem numbers in the two plots are not tabulated

Species	Botany Bay							Lake Hill						
	Damage class					#	Mean damage	Damage class					#	Mean damage
	1	2	3	4	5	stems	score	1	2	3	4	5	stems	score
Fraxinus americana								0.0	14.3	35.7	35.7	14.3	14	3.50
Tilia americana	0.0	6.7	46.7	40.0	6.7	15	3.47							
Acer rubrum								0.0	20.0	26.7	46.7	6.7	15	3.40
Betula papyrifera	0.0	30.0	20.0	40.0	10.0	20	3.30							
Quercus rubra	0.0	20.7	62.1	17.2	0.0	29	2.97	0.0	0.0	51.4	45.7	2.9	35	3.51
Fagus grandifolia	2.9	20.6	27.9	42.6	5.9	68	3.28	0.0	30.9	35.7	33.3	0.0	42	3.02
Acer saccharum	2.5	43.2	32.2	16.6	5.5	199	2.79	0.0	15.3	37.3	41.2	6.1	228	3.38
Ostrya virginiana	4.6	54.6	20.4	15.9	4.5	44	2.61	0.0	16.7	50.0	16.7	16.7	6	3.33
Betula alleghaniensis	6.4	41.9	19.4	22.6	9.7	31	2.87	0.0	60.0	0.0	40.0	0.0	5	2.80
Tsuga canadensis	18.4	52.6	19.7	6.6	2.6	76	2.22							

TABLE III

Damage to saplings and small trees (4 < DBH < 10 cm). The table is arranged from the species with the greatest to the least proportion of very badly damaged stems; results for species with low stem numbers in the plots are not tabulated

Species	Botany Bay				Lake Hill			
	% no damage	% upright broken	% very damaged	# stems	% no damage	% upright broken	% very damaged	# stems
Ostrya virginiana	16.0	12.0	72.0	50	0.0	6.7	93.3	15
Tsuga canadensis	11.5	19.2	69.2	26				
Acer saccharum	20.0	19.3	60.7	135	24.4	19.9	55.7	422
Fagus grandifolia	14.8	25.9	59.3	81	23.8	28.6	47.6	63
Acer pensylvanicum	11.1	33.3	55.6	9	21.9	40.0	38.1	105
Acer spicatum	27.6	26.4	46.0	87	11.1	55.6	33.3	9
Tilia americana	18.2	36.4	45.5	11	27.3	54.6	18.2	11
Betula alleghaniensis	12.5	25.0	62.5	16	0.0	100.0	0.0	1
Fraxinus americana	0.0	100.0	0.0	1	31.3	37.5	31.3	16

TABLE IV

Percentage sprouting of new shoots. Values do not add to 100% because new shoots at crown and trunk base can occur on the same individual. Table is arranged from species with the least to the greatest degree of sprouting overall; results for species with low stem numbers in the plots are not tabulated

Species	Botany Bay			Lake Hill		
	None	Trunk	Crown	None	Trunk	Crown
Tsuga canadensis	100	0	0			
Fagus grandifolia	86.8	4.4	8.8	66.7	7.1	26.2
Betula papyrifera	75	5	20			
Acer saccharum	57.7	5	38.8	17.4	24.8	79.1
Ostrya virginiana	57.8	6.7	35.6	16.7	33.3	66.7
Quercus rubra	37.9	0	62	8.6	14.3	91.4
Betula alleghaniensis	45.1	3.2	54.8	0	0	100
Fraxinus americana				21.4	28.6	78.6
Acer rubrum				0	33.3	86.7
Tilia americana	0	53.3	80			

3.3. Damage to saplings and small trees

The saplings and small trees in the forest suffer two threats: ice-loading and falling debris. Only 22% of the saplings and small trees (4 cm < DBH < 10 cm) escaped being broken or pinned to the ground by falling material in the two plots. Ironwood was the most badly damaged, although a few stems at BB escaped damage entirely (Table III). Although hemlocks are the least damaged of trees, hemlocks are among the most damaged saplings. Substantial numbers of sugar maple, striped maple (*Acer pennsylvanicum*), mountain maple (*Acer spicatum*), basswood and beech saplings escaped serious damage.

3.4. Resprouting of damaged trees

In summer 1999, there was a marked contrast in the degree to which damaged trees in the two plots showed signs of recovery. Only 35% of the trees at the BB plot had sprouted new shoots on their trunk base or on damaged branches in the crown, compared to 78% in the LH plot. Overall, only 53% of the damaged trees had some sprouting of new shoots. Sugar maple, red maple, ironwood, white ash, and red oak in the LH plot and basswood in the BB plot all had substantial sprouting from the trunk base, but most trees had greater sprouting from broken crown branches (Table IV). Only hemlock had no resprouting at all. Beech had very little in either the crown or at the trunk base. Basswood and red maple had the greatest incidence of sprouting overall, but canopy co-dominants such as sugar maple and red oak also had good sprouting.

4. Discussions

It is not unusual for two sites close together in the same tract of forest to differ considerably in the degree of damage inflicted by an ice storm. Variation in exposure to ice accumulation caused by topography and wind direction as well as differences in stand age and composition can account for site to site differences in damage (Bruederle and Stearns, 1985; De Steven *et al*., 1991; Seischab *et al*., 1993; Rebertus *et al*., 1997). The less damaged BB plot at Mont St. Hilaire is richer in hemlock, which generally is resistant to ice damage (Seischab *et al*., 1993), and the plot is more sheltered from winds that would break ice-laden limbs than is the LH plot. However, even tree species occurring in both plots often had greater damage in the LH plot. It is not unusual for individual tree species to show divergent degrees of damage from site to site and storm to storm (see tabulation in Seischab *et al*., 1993). Since the trees at both sites are of comparable size, size-dependent susceptibility (Rebertus *et al*., 1997) is unlikely to account for these differences in damage at the two plots. The LH and BB plots might have differed in the incidence of rot that leaves larger branches prone to breakage (Seischab *et al*., 1993), but a pre-storm census of tree health (unpublished) does not support this possibility. The greater exposure of the ridge-top LH plot may account for greater damage there than at the BB plot. Ice-laden trees at the LH plot would not only be more exposed to wind, but also were more heavily glazed in the storm itself (MJ Lechowicz, personal observation). Whatever may have caused the differing levels of ice damage from species to species between the two plots, the overall impact of the ice storm of January 1998 on the forests at Mont St. Hilaire was unquestionably very substantial.

Over a third of the trees lost more than half their crown, a level of damage classed as severe. This level of damage was inflicted on only 7% of the trees and saplings in an old-growth oak-hickory forest in Missouri struck by a severe ice storm (Rebertus *et al*., 1997). In culled, old-growth stands of forests in Pennsylvania comparable to those at Mont St. Hilaire, 29% of the trees were severely damaged by an ice storm in 1936; in 20–40 yr old, second-growth stands severe damage ranged from 1.3 to 25.2%, increasing with altitude (Downs, 1938). Yellow birch, sugar maple, and beech in these Pennsylvania forests averaged 15% severe damage and hemlock only 5%. The levels of severe damage on these species at Mont St. Hilaire are substantially greater (cf. Table II). Combining data from both plots, 43% of beech, 36% of sugar maple, 33% of yellow birch and 9% of hemlock were severely damaged at Mont St. Hilaire. These high levels of damage to canopy trees raise two questions with regard to the dynamics of forest recovery: 1) to what degree will individual trees rebuild their damaged crown structure and persist in the canopy and 2) to what degree will saplings and small trees be able to take advantage of the canopy openings created by the ice storm?

What little literature there is on the recovery of damaged canopy trees suggests that the most severely damaged stems gradually will succumb to fungal and insect attack (Campbell, 1937; Campbell and Davidson, 1940; Spaulding and Bratton, 1946). The reduction in numbers of canopy beech and sugar maple in the 16 yr following a severe ice storm in Wisconsin is consistent with these older reports (DeSteven *et al.*, 1991). Those canopy trees that do survive must rebuild their crown, a capacity not equally shared by all the canopy species. Contrary to an earlier report from second-growth stands in central New York (Spaulding and Bratton, 1946), beech at Mont St. Hilaire shows little capacity for sprouting from damaged trunk or branches. Well-established, older beech may depend on its shade tolerance and its capacity to root sprout to persist at a site after ice damage to canopy trees (Melancon and Lechowicz, 1987). Sugar maple on the other hand sprouts very well from damaged branches, again contrary to results in younger, second-growth stands (Spaulding and Bratton, 1946). Red oak, yellow birch and white ash also all sprout vigorously at Mont St. Hilaire. Basswood, which was badly damaged in this ice storm, sprouts well from broken branches in the crown and also from the trunk base. Only hemlock shows no capacity for sprouting, but this species also is the least susceptible of the canopy trees to ice damage. In general, all the canopy species that are damaged by ice show some capacity to rebuild their crowns and persist at the site. The fate of individual stems and the dynamics of recovery in the forest canopy as a whole can only be known by monitoring these permanent plots over time.

There also is significant potential for saplings of canopy trees to capture canopy gaps created by the ice storm. Sapling sugar maple, beech, basswood, and white ash all increased in numbers in the 16 yr following a severe ice storm in Wisconsin (DeSteven *et al.*, 1991). Although most saplings and small trees at Mont St. Hilaire were badly damaged by falling debris, a surprisingly high number of stems in the sapling stratum were unscathed. There are good numbers of small and intact sugar maple and beech that can take advantage of damage to canopy trees to grow into the canopy themselves. The same is true of other shade-tolerant species such as basswood, yellow birch, and white ash that are well represented by small, but undamaged stems. Red oak lacks this advance regenerenation and is likely to diminish in importance as the forest recovers from the ice storm. Striped maple, mountain maple and ironwood all have good numbers of intact individuals that should grow well in the aftermath of the storm, but these are species that never grow to canopy height. These subcanopy species may increase in importance in the forest. We can expect saplings of canopy trees in the subcanopy stratum to increase their growth rates in response to the opening of the canopy by the ice storm, and some individuals little damaged by the ice storm may well attain canopy heights if situated under a suitable opening. Monitoring the fate of mapped individuals and their immediate neighbors in these permanent plots should reveal the balance of stochastic and deterministic influences on recovery of the forest. We will follow the dynamics of recovery from the January 1998 ice storm at both these permanent plots in old-growth forests at the Mont St. Hilaire Biosphere Reserve.

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