STRIP CUTTING IN SHALLOW-SOIL UPLAND BLACK SPRUCE NEAR NIPIGON, ONTARIO

III. WINDFALL AND MORTALITY IN THE LEAVE STRIPS: PRELIMINARY RESULTS

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ABSTRACT

The most important factors affecting windfall and mortality in upland black spruce *(Picea mariana* [Mill.] B.S.P.) strip cuts were leave time, strip edge:area ratio, stand density and site index. To minimize losses, large, wide residual strips should be established in relatively dense stands on sites of poor-to-moderate productivity and harvested as soon as site protection and regeneration considerations permit. Total potential losses resulting from operational strip cutting averaged 6.0%, 7.8% and 10.0% of the merchantable volume in the leave strips for 2-, 3- and 4-year leave periods, respectively. This corresponds to potential losses over the entire forested area of approximately 2.4%, 3.1% and 4.0%, respectively. Losses from strip cutting can easily be overestimated if natural attrition is not accounted for. Damage occurred primarily near the strip edges, particularly at the exposed corners, and black spruce and balsam fir *(Abies balsamea* [L.] Mill.) were the most susceptible species. The relationships of a number of site, stand and strip layout characteristics to windfall and mortality were examined. All together, 74 leave strips in the Nipigon-Beardmore area were sampled.

RÉSUMÉ

Les principaux facteurs de bris par le vent et de mortalité de l'épinette noire *(Picea mariana* [Mill.] B.S.P.) de montagne dans les bandes résiduelles sont: le nombre d'années depuis la coupe; le rapport du périmètre à la surface; la densité du peuplement; et l'indice de terrain. Pour réduire les pertes au minimum, il faudrait laisser de larges bandes résiduelles à peuplement relativement dense dans les stations de productivité faible à moyenne et les récolter aussitôt que les considérations relatives à la protection et à la régénération des stations le permettent. Le total des pertes potentielles résultant de la coupe par bandes s'élève en moyenne à 6,0, 7,8 et 10,0% du volume vendable dans les bandes résiduelles, 2, 3 et 4 ans respectivement après la coupe. Ceci correspond à une perte potentielle pour l'ensemble de la forêt de 2,4, 3,1 et 4,0% respectivement. Les pertes dues à la coupe par bandes peuvent facilement être surestimées si on ne tient pas compte de la mortalité naturelle. Les dommages surviennent surtout le long des côtés, particulièrement dans les coins exposés, et l'épinette noire et le sapin baumier *(Abies balsamea* [L.] Mill.) se sont révélés les essences les plus vulnérables. On a examiné les rapports entre un certain nombre de caractéristiques de la station, du peuplement et de la disposition de la bande et le bris par le vent et la mortalité. En tout, 74 bandes résiduelles ont été échantillonnées dans la région de Nipigon-Beardmore.

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Cover Photo: Windfall at the front of a 4-year-old leave strip, Domtar Camp 75, Nipigon, Ontario (photo by D.S. Mossa).

INTRODUCTION

Over the past 20 years clear-cutting in alternate strips (strip cutting) has gained wide acceptance as a viable harvesting-regeneration system for black spruce *(Picea mariana* [Mill.] B.S.P.). This system is particularly well suited to the shallow-soil upland black spruce ecosystems of northwestern Ontario, as it helps to lessen the impacts of harvesting and maintain the productivity of these fragile sites. It also improves the prospects for successful regeneration (Robinson 1974, Auld 1975, Marek 1975, Fraser et al. 1976, Jeglum 1982). However, windfall in the residual strips[2] has remained a controversial issue. There is concern that a sizeable proportion of trees in the leave strips may blow over or die before the final cut, with volume yields being reduced and harvesting efficiency lowered in consequence (Robinson 1974, Peacock 1975, Ketcheson 1979).

As a result, a two-phase study of windthrow and mortality in upland leave strips near Nipigon, Ontario was begun in 1979 by Dames and Moore, the Canadian Forestry Service, The Ontario Ministry of Natural Resources and Domtar Forest Products. The first phase was a 1-year survey of losses in residual strips that had been established 1 to 5 years previously. This was carried out largely by Dames and Moore, under contract to the federal Department of Supply and Services[3]. Phase II involves a 5-year assessment program conducted annually on plots that were established in selected leave strips immediately after the initial cut[4]. It is scheduled for completion in the fall of 1984. Additional 3- to 5-year-old strips are also being surveyed at this time to improve the data base obtained in Phase I.

This report presents the results of the initial 1979 survey. The amount of windfall and mortality occurring in leave strips over time is estimated, the effects of various site, stand and strip layout characteristics are considered, and general recommendations for reducing blowdown are provided. The results serve as an interim framework to aid in the formulation of management guidelines for strip cutting black spruce on shallow-soil sites.

STUDY AREA

The study was conducted on the Nipigon Working Circle of Domtar Forest Products' Red Rock operation in Site Region 3W (Hills 1959) and the Central Plateau section of the Boreal Forest Region (Rowe 1972). The stands surveyed were 50-100 km north of Lake Superior, between Nipigon and Beardmore, Ontario and encompassed Domtar Camps 56, 75, 81 and 93.

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[2]The terms 'leave strips', 'leaves' and 'residual strips' are used interchangeably in this report, and refer to the strips of mature trees left after the first cut when clearcutting is done in alternate strips.

[3]Parts of this work were later subcontracted to Crossfield Environmental Limited.

[4]As part of this phase pathological studies are being conducted with R.D. Whitney, Great Lakes Forest Research Centre, to determine the importance of root rot as a causal factor of windfall in these strips.

Site conditions and forest types have been described in detail by Jeglum (1980). The growing season generally lasts 150-160 days, with a mean annual frost-free period of 75-90 days. Mean annual precipitation is 740 mm (Chapman and Thomas 1968). The prevailing winds at Geraldton, 50-100 km to the northeast, are from the west and south, although winds from the north are also quite common. Mean annual wind speeds are greatest from a southerly to southwesterly direction, but strong gusts occur from the west and north as well (Anon. 1982).

The topography varies from rolling to slightly undulating, with nearly level to moderately complex slopes broken occasionally by abrupt rock faces and cliffs. A shallow veneer of stony glacial till (silty sand to sandy loam) blankets most of the upland sites, although sizeable areas of moss-covered bedrock are also present. In lowland pockets organic peats cover the till material to varying depths. Characteristically on nearly all sites the underlying bedrock is near the surface (Marek 1975, Canada Soil Survey Committee 1978, Jeglum 1980).

The forest is primarily coniferous, with black spruce dominating on the shallow-soil uplands and the lowland sites. On the deeper, well drained soils, mixedwood types, composed of black spruce, white spruce (*Picea glauca* [Moench] Voss), balsam fir (*Abies balsamea* [L.] Mill.), jack pine (*Pinus banksiana* Lamb.), trembling aspen (*Populus tremuloides* Michx.) and/or white birch (*Betula papyrifera* Marsh.) are common while jack pine stands are found on the scattered sandy outwashes.

Most of the mature forests are relatively high-volume stands of black spruce, with a smaller component of jack pine, trembling aspen, white birch and/or balsam fir. The strips surveyed in this study were located in 85- to 160-year-old stands supporting an average merchantable volume[5] of 195.7 m^3/ha, of which 149.8 m^3/ha was black spruce.

METHODS

Strip Selection

To reduce confounding and allow more detailed examination of interactions between windfall, site, stand and strip layout characteristics, the following guidelines were used for strip selection.

a) The major tree component was to be black spruce.
b) Strips were to be rectangular, at least 90 m long, and at least 20 m wide.
c) The faces of each strip were to be relatively straight with no major indentations.
d) The long axis of each strip had to be protected by another leave strip or by a buffer strip (a forested border left at the edge of a block of strips).
e) There could be no dense clumps of residual trees in either of the adjoining cut strips.

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[5]Merchantable volumes were calculated from local merchantable volume tables supplied by Domtar Forest Products (Table A1). The above estimates include all living and recently killed stems. All volumes reported herein are merchantable volumes.

All together, 74 strips were examined. Of these, 56 were 'survey' strips that had been standing 1 to 5 years after the initial cut, and 18 were 'control' strips[6] that were sampled within 10 days of the initial cut. The control strips provided an estimate of the amount of immediate logging damage. Internal plots located in the centres of these newly established strips were also used to estimate the amount of natural mortality in the uncut forest.

Sampling Methods

For sampling purposes the strips were divided into plotlines 10 m long that ran across the width of the strip (Fig. 1). Locations in the strip that were expected to sustain the most damage were sampled intensively, while the remaining portions were examined by means of a stratified random sampling technique. For closed strips--those which still adjoined uncut forest at the back end, and thus had only three exposed faces--10 m x 20 m plots were laid out adjacent to each side of the strip in the three plotlines closest to the front (Plots 1-6, Fig. 1). A 10-m-wide x 30-m-long area between these plots was also selected (randomly) and examined, if space permitted (Plots 7, 8 and 9 combined, Fig. 1).

The remainder of the strip was then divided into two or three sections, depending on length: if the strip was 120 m or less in length, it was divided into two sections; if it was longer than 120 m, three sections were used. One full plotline per section was selected randomly and established. A full plotline entailed as many 10-m x 20-m and then 10-m x 10-m units across the width of the strip as could be accommodated (Plots 10-13, 14-17, Fig. 1). In addition a partial plotline, consisting of two 10-m x 20-m plots, one located adjacent to the cut face on either side of the strip, was also set out at a randomly determined location in the unsampled portion (Plots 18, 19, Fig. 1).

Open strips (those which had been cut at both ends and consequently had four exposed faces) were sampled in a similar fashion, with the exception that the back as well as the front 30 m were sampled intensively. In the case of strips less than 40 m wide, essentially the same sampling scheme was followed, but only as many subplots (10-m x 5-m units) were set across each plotline as could be accommodated. All plots, regardless of size or location, were broken into 10-m x 5-m subplots for assessment purposes.

A timber inventory and a site description were completed for each strip. All merchantable trees (those greater than 9 cm DBH) in each subplot were classified by species[7], diameter, condition and quality. Four condition classes were used: (1) upright and living, (2) leaning (more than 30° from the vertical) or uprooted, (3) broken off within 5 m of the ground, and (4) standing dead. Trees that had died recently (since the initial cut) were distinguished from those which had been dead for some time. Uprooted, broken or standing dead trees

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[6]The terms 'control strips' and 'newly established strips' are used interchangeably.

[7]Five species were recognized: black spruce, balsam fir, jack pine, trembling aspen (including the occasional balsam poplar *[Populus balsamifera* L.]) and white birch. White spruce, which occurred infrequently and constituted <1.0% of the volume of any strip, were included in the estimates for black spruce.

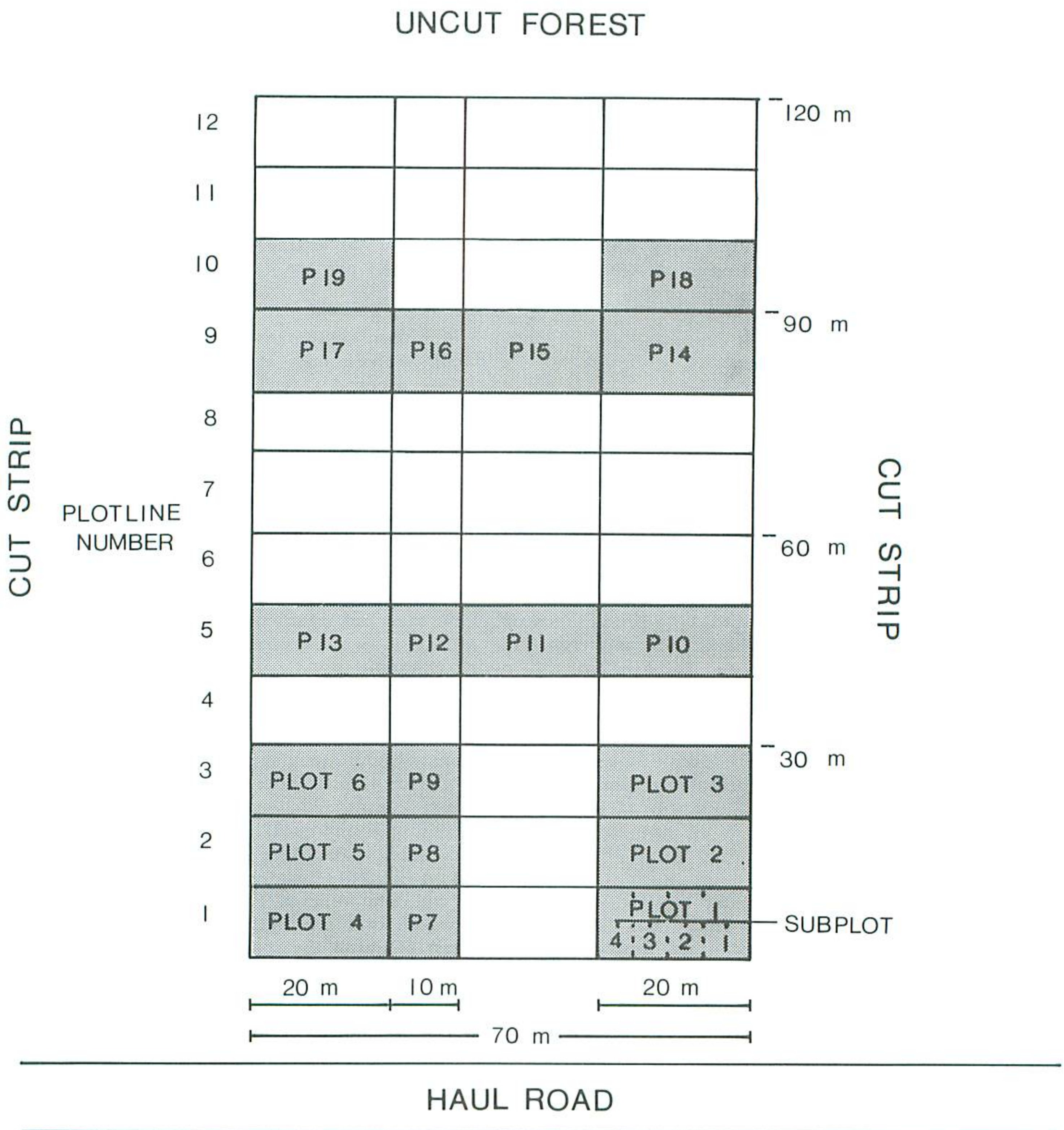

Figure 1. Plot layout in a closed strip.

that still had a combination of green or brown needles, small twigs, fresh throw mounds with little infilling, tight outer bark and white-to-pinkish inner bark were classed as new mortality. Old mortality included trees with no needles or twigs, many branches broken off, loose outer bark, dark inner bark and throw mounds filling in. Felled stems and moss-covered or rotten logs that could be smashed with a kick were not tallied.

Average canopy heights were obtained from measurements of six dominant or codominant black spruce selected at intervals along the side of each strip. Stand ages were determined by ring counts of increment cores taken from these trees at breast height. Ten years were added to account for growth up to breast height. Site indexes[8] were then calculated from this height and age information.

Soil depth, potential rooting depth (soil depth to a major physical impediment to rooting such as boulder pavement, a cemented layer, a gleyed horizon or bedrock), slope orientation, and degree of slope were determined for each plot. Soil and rooting depths were classed as: (1) 0-9.9 cm, (2) 10-19.9 cm, (3) 20-29.9 cm, (4) 30-60 cm or (5) $>$ 60 cm, on the basis of three soundings per plot. Plot ratings were then averaged to get a strip value. Soil texture and drainage (Bélisle 1980) were determined for each full plotline. Drainage was ranked from 1 (very rapidly drained) to 7 (very poorly drained), and values per plotline were averaged to obtain an overall strip rating. The predominant soil texture found in the plotlines was assigned to the strip.

General site and strip layout characteristics were tallied for the strip as a whole. These included the following:

a) Strip width, length and orientation.
b) The amount of buffering the open end(s) of the strip received from adjacent timber. For instance, a stand directly across the road from the survey strip could shelter the strip from wind action and alter wind channeling. Depending on the alignment of surrounding strips and stands, each strip was classed as having more than or less than half of its open end(s) buffered.
c) The length and type (simple or complex, uniform or irregular [Bélisle 1980]) of the major slope affecting the strip (if any).

A number of site, stand and layout characteristics of the strips surveyed are presented in Table 1.

Analysis

All information was summarized on two computer files, a subplot file in which the number and volume of all trees per condition-quality category were tallied for each subplot, and a strip file in which data per species on a strip basis were stored.

Volume data were compared by means of one-way analysis of variance with individual differences established by Tukey's multiple comparison

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[8] Site index at age 100 was used since most of the stands examined were over 100 years old.

Table 1. Some stand, strip layout and site characteristics of the survey strips.

Characteristic	Mean	Coefficient of variation	Largest score	Smallest score
Stand characteristics				
Density (merch. trees/ha)	1 127	.27	1 931	621
Volume (merch. m^3/ha)	191	.20	291	117
Canopy height of black spruce (m)	18.7	.09	22.6	15.7
Site index*, black spruce (m)	17.6	.08	20.5	14.8
Main stand age, black spruce (yr)	117	.10	155	89
Strip layout characteristics				
Leave time (yr)	2.1	.51	5	1
Strip width (m)	58	.30	113	20
Length (m)	158	.33	360	90
Total exposed edge (m)	424	.30	800	240
Area (m^2)	10 527	.50	28 800	2 400
Number of open ends	1.2	.34	2	1
Edge:area ratio (total exposed edge (m)/area [m^2])	24.0	.28	39.1	8.8
Site characteristics				
Soil depth class	4.4	.13	5.0	3.2
Potential rooting depth class	4.2	.16	5.0	2.0
Drainage class	3.7	.24	5.8	1.3

* Age 100.

test. Chi-square tests were used to determine differences in numbers of trees per category. Relationships between stand, site and strip layout variables and volume losses were examined by means of correlation and least-squares multiple regression. Significance in all tests was determined at the $P = 0.05$ level.

Volume losses were expressed as a percentage of total (merchantable) volume (living trees plus windfall and mortality) as well as in (merchantable) volume/ha. The use of percentages eliminated confounding by differences in total volume when comparisons between strips were made. (Total volumes per strip varied from 104 m^3/ha to 303 m^3/ha; strips with greater total volumes/ha suffered larger volume losses for a given percentage loss.) When percentage volume losses were analyzed, the data were first transformed ($y = \text{arc sine} \sqrt{\text{percent}}$) before statistical comparisons were made.

RESULTS

Volume Losses in the Leave Strips

Volumes reported as 'new mortality'[9] include windthrows, windbreaks and dead standing stems, i.e., all losses which could be directly or indirectly attributed to strip cutting, as well as natural mortality. Dead standing stems were included because strip cutting may increase mortality through sudden exposure of trees along the edges of the strip, changes in soil moisture conditions, and mechanical damage during logging, as well as through wind-related events (Watson 1936, LeBarron 1945, Haavisto 1979).

Trees classed as 'old mortality' were assumed to have died before the strips were established and included all older windthrows, windbreaks and dead standing stems. Over all, the classification system used to separate pre-cut from post-cut mortality seemed to work reasonably well. There was no significant correlation between leave time and volume/ha or percentage volume classed as old mortality in individual strips for all species combined, or for jack pine, balsam fir, poplar or white birch individually. However, there was a significant positive relationship (r = .33) between the amount of black spruce classed as old mortality and strip age. Evidently some of the black spruce that had been windthrown soon after establishment of the older strips were erroneously classed as old mortality. Black spruce losses attributable to strip cutting (new mortality) have therefore been underestimated slightly for the 4- and 5-year leaves.

The amount of standing dead and downed material in the strips classed as old mortality is shown in Table 2. All together, 12.1% of the total potentially merchantable volume[10], or 26.9 m^3/ha, was composed of this older dead material. Jack pine, trembling aspen and white birch had sustained greater relative losses through old mortality (natural attrition) than had spruce or fir although over 10% of the total volume of each species fell into this category.

The total volume of old mortality was fairly evenly divided among windthrown, broken off and standing dead stems, but there were marked differences in these categories for individual species. When the percentages of potentially merchantable volume and potentially merchantable stems lost per species through old mortality are compared, it is evident that the smaller jack pine and the larger white birch have suffered considerable attrition. (Of the jack pine stems, 27.8% were old mortality but these constituted only 17.8% of the jack pine volume, while the 14.8% of the birch stems classed as old mortality constituted 24.3% of the total birch volume.)

A comparison of recent volume losses in uncut forest, newly established strips and leave strips is presented in Table 3[11]. In uncut forest

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[9]The term 'mortality' refers only to standing dead stems. The terms 'new mortality' and 'old mortality' refer to windthrows and windbreaks as well as to standing dead trees.

[10]Old mortality is expressed as a percentage of potentially merchantable volume (live + new mortality + old mortality). By comparison, new mortality is expressed as a percentage of merchantable volume (live + new mortality).

[11]Relative losses (%), in terms of numbers of merchantable stems, were similar to those for merchantable volume and consequently are not shown.

Table 2. Percentage of the total number of stems* and the total volume* classed as old mortality, all strips combined.

Species	Sample size (strips)	Old windthrows	Old breakage	Old standing dead	Total old mortality
Portion (%) of stems classed as old mortality⁺					
Black spruce	74	$_{3}5.2_{d}$	$_{2}3.8_{a}$	$_{1}2.4_{a}$	11.4_{a}
Jack pine	51	$_{1}2.8_{c}$	$_{2}8.8_{d}$	$_{3}16.2_{d}$	27.8_{d}
Balsam fir	59	$_{1}2.2_{b}$	$_{2}7.0_{c}$	$_{1}2.8_{a}$	11.9_{a}
Trembling aspen	49	$_{1}3.7_{cd}$	$_{2}8.1_{d}$	$_{2}6.8_{c}$	18.7_{c}
White birch	49	$_{1}1.4_{a}$	$_{2}6.2_{c}$	$_{2}7.2_{c}$	14.8_{b}
All species	74	$_{1}4.7_{cd}$	$_{1}4.6_{b}$	$_{1}4.2_{b}$	13.4_{b}
Portion (%) of volume classed as old mortality⁺⁺					
Black spruce	74	$_{3}5.7_{b}$	$_{2}3.5_{a}$	$_{1}1.6_{a}$	10.8_{a}
Jack pine	51	$_{1}2.5_{a}$	$_{1}4.8_{a}$	$_{2}10.5_{c}$	17.8_{bc}
Balsam fir	59	$_{1}3.0_{a}$	$_{2}6.6_{a}$	$_{1}3.5_{ab}$	13.1_{ab}
Trembling aspen	49	$_{1}1.4_{a}$	$_{2}11.9_{a}$	$_{1,2}6.9_{ab}$	20.2_{c}
White birch	49	$_{1}2.5_{a}$	$_{2}10.7_{a}$	$_{2}11.1_{bc}$	24.3_{c}
All species	74	$_{1}4.7_{b}$	$_{1}3.9_{a}$	$_{1}3.5_{a-c}$	12.1_{ab}

* Number of stems and volume refer to merchantable stems (stems > 9 cm DBH) and merchantable volume only.

⁺Stems classed as old mortality/(number of live stems + stems classed as new mortality + stems classed as old mortality) x 100.

⁺⁺Volume of old mortality/(live volume + volume of new mortality + volume of old mortality) x 100.

There is no significant difference (P = 0.05) between values with the same subscript letter(s) in any given column, or within windthrows, breakage or standing dead categories with the same subscript numeral(s) in any given row.

Table 3. Average percentage distribution of total merchantable volume (live + new mortality) for leave strips, control strips and uncut forest.

Species	Live			New windthrow			New breakage			New standing dead		
	Uncut forest	Control strips	Leave strips	Uncut forest	Control strips	Leave strips	Uncut forest	Control strips	Leave strips	Uncut forest	Control strips	Leave strips
Black spruce	$_{2}97.1_{a}$	$_{2}95.6_{a}$	$_{1}87.2_{a}$	$_{1}1.8_{a}$	$_{1}1.9_{c}$	$_{2}9.0_{b}$	$_{1}0.3_{a}$	$_{1}0.7_{b}$	$_{2}1.4_{b}$	$_{1}0.7_{a}$	$_{1,2}1.8_{a}$	$_{2}2.6_{a}$
Jack pine	$_{1}93.7_{a}$	$_{1}94.0_{a}$	$_{1}87.3_{ab}$	$_{1}0.2_{a}$	$_{1}0.3_{ab}$	$_{1}2.8_{a}$	$_{1}0.0_{a}$	$_{1}0.1_{a}$	$_{1}0.1_{a}$	$_{1}5.9_{b}$	$_{1}5.7_{a}$	$_{1}9.7_{b}$
Balsam fir	$_{2}100.0_{a}$	$_{2}99.7_{a}$	$_{1}89.1_{ab}$	$_{1}0.0_{a}$	$_{1}0.0_{a}$	$_{1}6.3_{ab}$	$_{1}0.0_{a}$	$_{1}0.3_{a}$	$_{1}0.9_{a}$	$_{1}0.0_{a}$	$_{1}0.1_{a}$	$_{1}3.7_{a}$
Trembling aspen	$_{1}100.0_{a}$	$_{1}90.0_{a}$	$_{1}92.0_{b}$	$_{1}0.0_{a}$	$_{1}0.0_{a}$	$_{1}2.1_{a}$	$_{1}0.0_{a}$	$_{1}0.0_{a}$	$_{1}0.1_{a}$	$_{1}0.0_{a}$	$_{1}10.0_{a}$	$_{1}5.8_{ab}$
White birch	$_{1}96.6_{a}$	$_{1}92.9_{a}$	$_{1}84.3_{ab}$	$_{1}0.0_{a}$	$_{1}1.6_{b}$	$_{1}3.7_{a}$	$_{1}0.0_{a}$	$_{1}0.1_{a}$	$_{1}0.8_{a}$	$_{1}3.4_{ab}$	$_{1}5.4_{a}$	$_{1}11.3_{b}$
All species	$_{2}96.9_{a}$	$_{2}95.3_{a}$	$_{1}88.0_{a}$	$_{1}0.9_{a}$	$_{1}1.2_{bc}$	$_{2}7.3_{b}$	$_{1}0.2_{a}$	$_{1}0.5_{ab}$	$_{2}1.1_{b}$	$_{1}2.1_{ab}$	$_{1}3.0_{a}$	$_{1}3.7_{a}$

There is no significant difference (P = 0.05) between values with the same subscript letter(s) in any given column, or between values within each major category (live, new windthrows, new breakage and new standing dead) with the same subscript numeral(s) in any given row.

3.1% of the merchantable volume (live + new mortality) was classed as new mortality, in comparison with 4.7% in the newly established strips and 12.0% in the leave strips. The substantial increase in the leave strips largely reflects accelerated losses to windthrow. Black spruce and balsam fir were the only species to show significant increases in windfall and mortality in the residual strips.

Relationships between the percentage of recently windthrown, broken off and/or standing dead volume and leave time were significant only for all species combined and black spruce alone (Tables 4 and 5, Fig. 2 and 3). There were positive correlations between leave time and total new mortality (r = 0.50 for all species, r = 0.53 for black spruce), leave time and new windthrows (r = 0.46 for all species, r = 0.45 for black spruce), leave time and new breakage (r = 0.33 for all species, r = 0.37 for black spruce) and, for black spruce, leave time and new standing dead volume (r = 0.31). Windthrow was the most important cause of volume losses in the leave strips (Tables 4 and 5). Correlations between new windthrow and total new mortality were r = 0.93 for all species combined and r = 0.97 for black spruce.

Recent volume losses in the leave strips were also expressed in percent per year (Table 6). It was assumed that 3.1% of the total merchantable volume is lost through natural windfall and mortality (uncut forest, Table 3) and this was deducted before calculation of annual losses. Over all there was a trend (r = 0.35) of decreasing yearly losses with longer leave periods.

The damage sustained at various locations within the strips was examined by calculating volume losses at progressive distances from the sides and the open end(s) of all strips. Losses varied inversely with distance from the cut borders and were greater within the first 10 m of a side boundary and the first 20 m of an open end than elsewhere in the strips (Table 7). The first 5 m from the side, the first 10 m from an open end, and, in particular, the exposed corners were the most susceptible (Fig. 4). When volume losses by location were examined for different leave periods similar trends were evident (Tables 8 and 9). Losses were not significantly different between locations (distances from either the sides or open end[s]) within newly established strips, but for all other leave times it was apparent that the first 5 m from the side and the first 10 m from an open end sustained the most damage. With longer leave periods damage tended to extend further into the strips.

Factors Related to Windfall and Mortality

The relationship between site, stand and strip layout characteristics and percentage volume loss (new windfall and mortality, all species combined) was investigated by means of correlation analysis and then multiple regression. An attempt was made to express volume losses in percentage per year to obtain an index that would simplify analysis and allow direct comparisons with studies of windfall in lowland strip cuts (Heinselman 1957, Elling and Verry 1978). However, a distinct trend of decreasing annual losses with increasing leave time confounds this approach despite the use of a correction factor to discount natural mortality and losses incurred during logging.

Table 4. Percentage volume loss (cumulative) to windfall and mortality in uncut forest and in 0- to 5-year-old leave strips, all merchantable species combined.

	Strip leave time (years)						
Loss type	Uncut forest*	0+	1	2	3	4	5
New windthrow	0.9	1.2	4.5	8.9	8.6	7.0	11.2
New breakage	0.2	0.5	0.9	1.0	0.7	2.0	1.6
New standing dead	2.1	3.0	4.5	2.3	4.0	5.5	4.6
Total new mortality	3.1	4.7	9.9	12.2	13.3	14.4	17.3
Sample size (strips)		18	19	20	10	5	2

* Values obtained from internal plots (at least 20 m from a cut face) in the newly established strips.

+ Newly established (control) strips.

Table 5. Percentage volume loss (cumulative) to windfall and mortality in uncut forest and in 0- to 5-year-old leave strips, black spruce only.

	Strip leave time (years)						
Loss type	Uncut forest*	0+	1	2	3	4	5
New windthrow	1.8	1.9	5.4	9.8	12.2	11.2	12.4
New breakage	0.3	0.7	1.0	1.2	0.9	3.1	1.7
New standing dead	0.7	1.8	2.6	1.8	3.6	3.2	4.7
Total new mortality	2.9	4.4	9.0	12.7	16.7	17.5	18.7
Sample size (strips)		18	19	20	10	5	2

* Values obtained from internal plots (at least 20 m from a cut face) in the newly established strips.

+ Newly established (control) strips.

Table 6. Percentage volume loss per year* to windthrow and mortality in 1- to 5-year-old leave strips, all species combined.

Loss type	Leave time (years)				
	1	2	3	4	5
Total new mortality	6.76_b	4.44_{ab}	3.41_a	2.84_a	2.85_a
Sample size (strips)	19	20	10	5	2

* Values have been adjusted to discount natural mortality; the volume loss occurring in uncut forest was subtracted from the values for each leave category above. All volumes are merchantable volumes.

There is no significant difference (P = 0.05) between values with the same subscript letter(s).

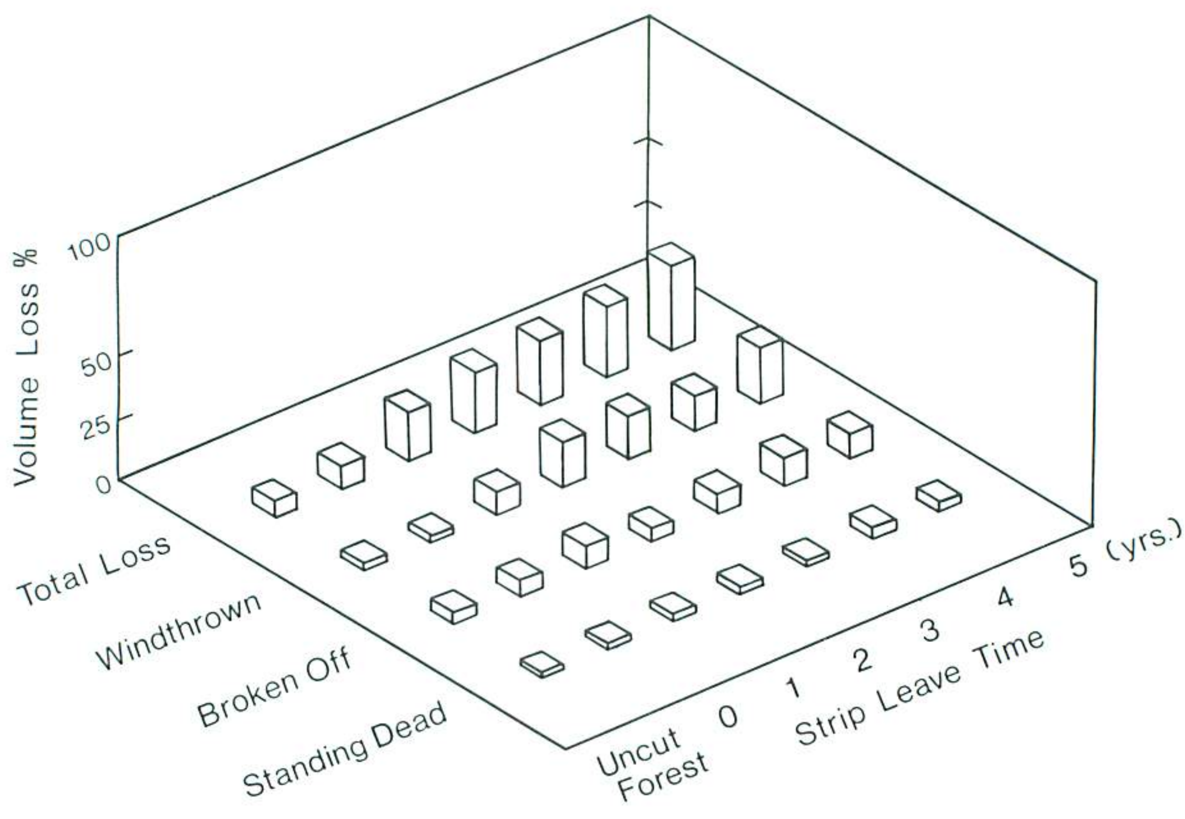

Figure 2. Cumulative merchantable volume loss, all species combined.

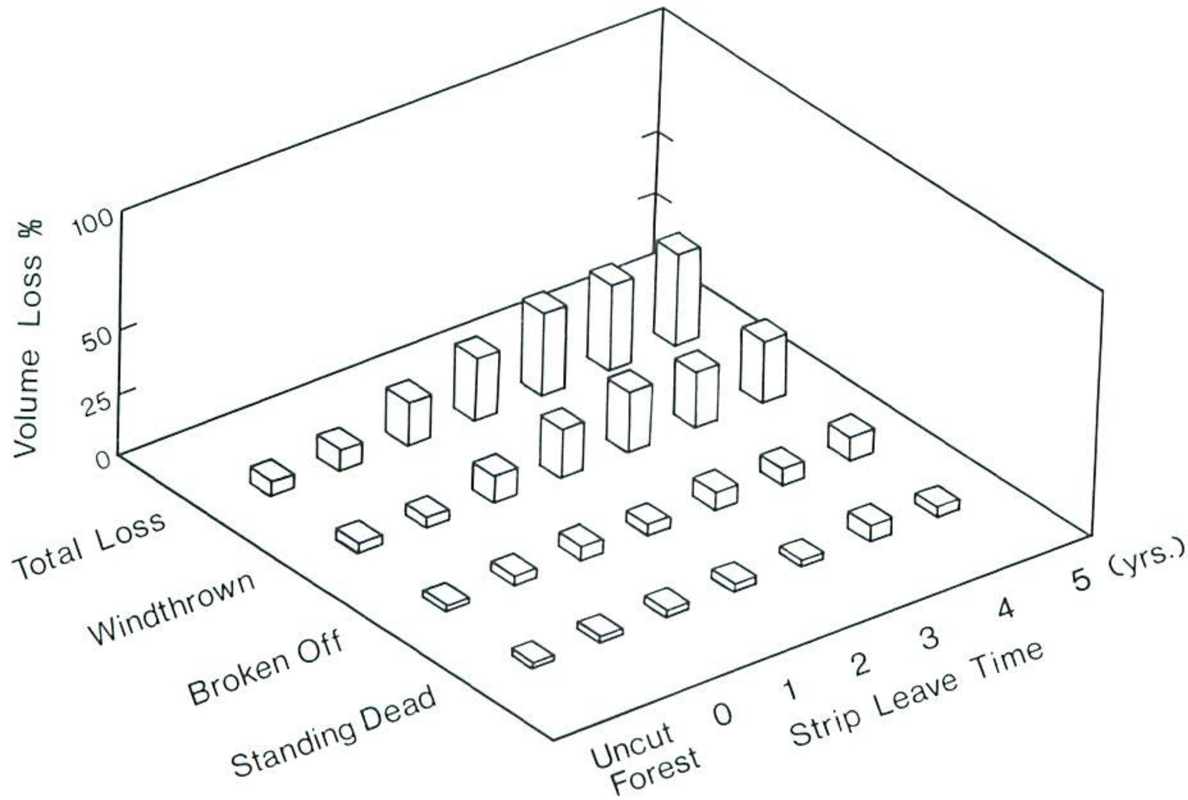

Figure 3. Cumulative merchantable volume loss, black spruce.

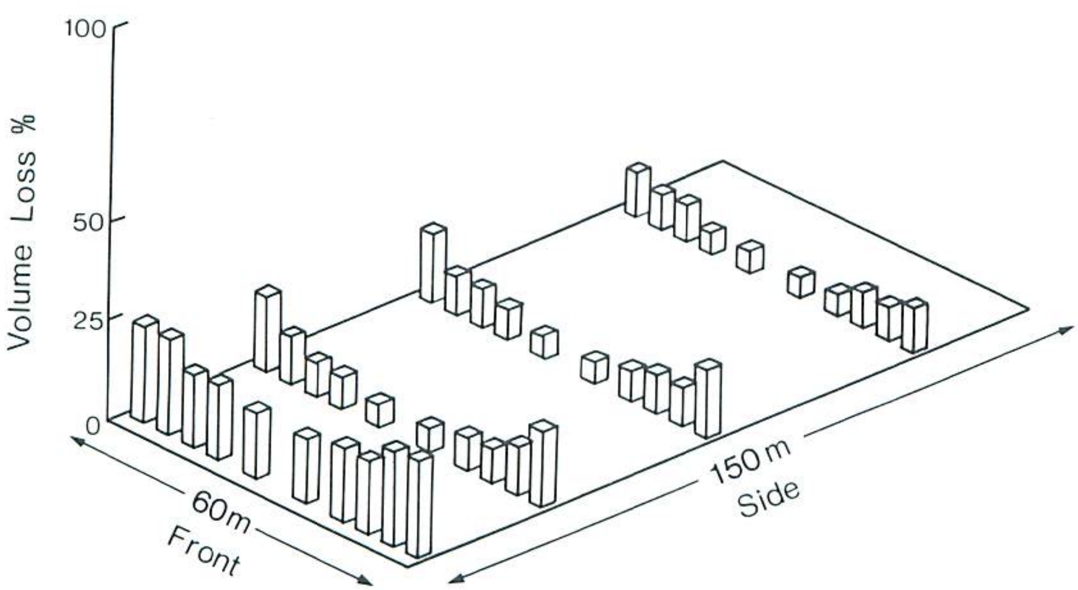

Figure 4. Average merchantable volume loss by position in strip, all strips combined.

Table 7. Occurrence of windfall and mortality within the strip; all survey and control strips combined.

	Distance from the closest side (m)				
	0-5	6-10	11-15	16-20	21+
Volume loss (m^3/ha)*,+	28.0_c	23.0_b	21.0_b	16.0_a	14.7_a
Percentage volume loss*,++	19.3_d	13.4_c	11.5_{bc}	9.7_b	8.4_a
Sample size (5-m x 10-m plots)	1048	1053	980	971	1128
	Distance from the closest open end (m)				
	0-10	11-20	21-50	51-100	101+
Volume loss (m^3/ha)*,1	30.0_c	23.6_b	20.0_{ab}	17.6_{ab}	13.0_a
Percentage volume loss*,++	20.6_d	14.3_c	10.8_b	10.3_{ab}	8.0_a
Sample size (5-m x 10-m plots)	883	883	1440	1032	942

* All volumes are merchantable volumes.

\+ Volume loss (m^3/ha) = new windfall and mortality, all species combined.

++Percentage volume loss = volume of new mortality as a percentage of live volume + new windfall and mortality, all species combined.

Reported losses by location may appear unrealistic. Plots were small (5 m x 10 m) and contained relatively few trees--particularly plots bordering a strip edge and extending into the cutover somewhat. As a result, the loss of two or three trees could increase the percentage volume loss for a plot dramatically.

There is no significant difference (P = 0.05) between values with the same subscript letter(s) in any given row.

Table 8. Occurrence of windfall and mortality* in relation to distance from the side of the strip+ and leave time, all species combined.

Distance from the nearest side (m)	Leave time (years)	Sample size (5-m x 10-m plots)	Volume loss (m^3/ha)*,++	Percentage volume loss*,§
0-5	0	257	10.4_{ab}	6.8_{a-d}
6-10	0	260	11.9_{a-c}	6.4_{a-c}
11-15	0	254	10.9_{a-c}	5.9_{ab}
16-20	0	248	9.0_{a}	5.5_{ab}
21+	0	480	9.3_{a}	4.8_{a}
0-5	1	253	29.3_{e-g}	22.0_{g-h}
6-10	1	253	22.3_{b-f}	13.3_{c-f}
11-15	1	256	22.9_{c-f}	11.0_{a-e}
16-20	1	253	16.9_{a-d}	10.4_{a-e}
21+	1	228	20.6_{a-e}	10.2_{a-e}
0-5	2	316	37.0_{g}	21.9_{gh}
6-10	2	316	28.3_{d-g}	14.8_{e-g}
11-15	2	248	24.9_{d-f}	13.8_{d-f}
16-20	2	248	16.6_{a-d}	8.6_{a-e}
21+	2	168	15.1_{a-d}	10.9_{a-e}
0-5	3-5	222	34.2_{fg}	26.9_{h}
6-10	3-5	224	29.1_{d-g}	19.7_{f-h}
11-15	3-5	222	26.3_{d-g}	15.9_{f-h}
16-20	3-5	222	22.2_{b-f}	14.8_{e-g}
21+	3-5	252	19.5_{a-e}	11.9_{b-e}

* All volumes are merchantable volumes.

+This refers to the distance of individual plots from the closest side border of the strip.

++Volume loss (m^3/ha) = new windfall and mortality, all species combined.

§Percentage volume loss = volume of new windfall and mortality as a percentage of live volume + new windfall and mortality, all species combined.

There is no significant difference (P = 0.05) between values with the same subscript letter(s) in any given column.

Table 9. Occurrence of windfall and mortality* in relation to distance from the end of the strip+ and leave time, all species combined.

Distance from the nearest open end (m)	Leave time (years)	Sample size (5-m x 10-m plots)	Volume loss (m^3/ha)*,++	Percentage volume loss*,§
0-10	0	257	13.9 *a-c*	9.3 *a-d*
11-20	0	259	11.8 *a-c*	5.9 *ab*
21-50	0	440	8.5 *a*	4.6 *a*
51-100	0	304	8.9 *ab*	4.6 *a*
101+	0	239	9.3 *a-c*	5.4 *ab*
0-10	1	219	35.4 *f*	22.3 *g-i*
11-20	1	219	30.0 *ef*	16.5 *d-g*
21-50	1	377	18.4 *b-d*	10.7 *a-e*
51-100	1	219	14.7 *a-d*	8.5 *a-c*
101+	1	209	16.3 *a-d*	11.4 *a-e*
0-10	2	224	38.9 *f*	24.6 *hi*
11-20	2	224	27.1 *d-f*	16.5 *d-g*
21-50	2	345	30.3 *ef*	14.2 *ef*
51-100	2	242	21.0 *c-e*	12.6 *b-e*
101+	2	261	12.0 *a-c*	6.8 *ab*
0-10	3-5	183	35.1 *f*	29.3 *i*
11-20	3-5	181	28.2 *d-f*	20.8 *f-h*
21-50	3-5	278	27.5 *d-f*	16.9 *e-g*
51-100	3-5	267	26.6 *d-f*	16.2 *d-g*
101+	3-5	233	15.1 *a-d*	8.8 *a-c*

*All volumes reported are merchantable volumes.

+This refers to the distance of individual plots from the nearest open (cut) end of the strip.

++Volume loss (m^3/ha) = new windfall and mortality, all species combined.

§Percentage volume loss = volume of new windfall and mortality as a percentage of live volume + new windfall and mortality, all species combined.

There is no significant difference (P = 0.05) between values with the same subscript letter(s) in any given column.

Strip width, length, exposed edge, area and edge:area ratio

Strip widths ranged from 20 to 113 m and were inversely correlated with percentage volume losses ($r = 0.38$). By far the greatest losses occurred in strips < 40 m wide. By comparison there was no relationship between strip length on one hand and windfall and mortality on the other. Both total exposed edge (the cut perimeter of the strip) and strip area were inversely correlated with percentage volume loss ($r = -0.28$ and -0.40, respectively), as the larger strips sustained relatively less damage. The edge:area ratio (E:A = exposed edge [m]/area [m^2]), an index of the proportion of the strip that is near a cut face, was also significantly correlated ($r = 0.46$) with volume losses. The greater the perimeter of the strips relative to their area, the greater the blowdown.

End conditions and buffering

Residual strips were classed as open when they were adjacent to a road or clearcut area at each end, or closed when one end had not been cut or disturbed. Open strips suffered significantly greater volume losses than did closed strips. When the volume losses in open and closed strips with different degrees of buffering were compared, neither the number of ends buffered in open strips nor the degree of buffering in open or closed strips was significantly correlated with windfall and mortality. However, the sample size for the open strips was quite small (11 strips).

Strip orientation

There were no significant relationships between strip orientation and percentage volume loss or volume loss/ha within strips left standing 1, 2 or ≥ 3 years. However, in view of the number of combinations of leave time and orientation (cardinal direction) possible, a larger sampling of strips is needed if the impact of this variable is to be examined properly.

Stand density, volume and composition

Densities in the survey strips varied from 621 to 1931 merchantable trees/ha while merchantable volumes ranged from 117 to 291 m^3/ha. Stand density was significantly correlated with volume loss ($r = -0.37$); strips with a large number of trees/ha sustained relatively small losses. Total merchantable volume per ha, though not directly correlated with windthrow and mortality, was a significant factor in some multiple regressions, losses increasing with stand volume. While black spruce was one of the species most susceptible to blowdown there was no relationship between volume loss and the proportion (by merchantable volume) of the stand composed of black spruce.

Height, age, site index and tree size

The average height and site index (age 100) of dominant and codominant black spruce in individual strips ranged from 15.7 to 22.6 m and 14.8 to

20.5 m, respectively, while average ages varied from 89 to 155 years. Height ($r = 0.30$), site index ($r = 0.28$) and tree size (merchantable volume [m^3]/ha/merchantable trees/ha) ($r = 0.41$) were all significantly correlated with blowdown. The taller the trees, the larger their average volume, and the greater the site index, the larger the proportion of volume lost per strip. Stand age, on the other hand, was not significantly related to windthrow and mortality.

Slope

Within the sample 82% of the strips were rated as generally flat (slopes 0°-3°), 7% were sloping (4° or more) and the remaining 11% had flat and sloping areas. No correlation was found between steepness of slope and blowdown. Likewise, there were no significant relationships between volume loss and slope aspect, the position of the strip on the major slope or the length of the major slope.

Drainage, soil texture, soil depth and potential rooting depth

The leave strips were generally located on upland sites with good drainage. Sixteen percent of the strips were classed as rapidly drained, 76% as well to moderately well drained and 8% as imperfectly drained. Within this range there was no correlation between drainage and blowdown in volume/ha or percentage volume loss. The predominant soil texture of almost all strips was either sandy loam or loamy to silty fine to very fine sand, and these relatively slight differences had no effect on windfall. Similarly, no relationship was found between windfall (volume loss/ha or percentage volume loss) and soil depth or potential rooting depth.

Elling and Verry Index

The Elling and Verry (EV) index

$$\left(\frac{\frac{\text{exposed edge (m)}}{\text{area (m}^2\text{)}} \; [\text{site index (m)}]^2}{2} \right)$$

was derived from a prediction equation that explained a large percentage ($r^2 = 0.93$) of annual wind-caused mortality in lowland black spruce strip cuts in Minnesota (Elling and Verry 1978). Though originally designed to predict annual losses in m^3/ha through non-linear regression, this index demonstrated a strong positive correlation ($r = 0.49$) with percentage volume loss in the present study. The larger the ratio of exposed edge to area and/or the higher the site index, the greater the percentage volume loss to windthrow and mortality.

Relative Importance of Site, Stand and Strip Layout Characteristics

Multiple linear regression was used to determine which of the previously described variables and indices had the greatest impact on windfall and mortality. Transformations were performed on several measures to increase their correlation with the dependent variable, percentage volume loss.

A six-term equation incorporating leave time, stand density, edge:area ratio, stand volume, end condition and strip width explained the greatest amount of variation in relative losses to windfall and mortality among the strips ($r^2 = 0.63$). However, a much simpler three-term equation (Table 10) based on leave time, stand density and the EV index was almost as highly correlated with damage sustained ($r^2 = 0.56$) and gave more reasonable estimates when extended beyond the mean values (± one standard deviation) of the independent variables in the data base. In this equation leave time was the best predictor, followed by the EV index and then stand density. A correlation matrix of these three factors (Table 10) indicates no significant relationships among any of them.

DISCUSSION AND CONCLUSIONS

This 1-year survey was carried out with three primary objectives in mind: to document the amount of windfall and mortality occurring in upland black spruce leave strips left standing up to 5 years after the initial cut; to consider the relationships between a number of site, stand and strip layout variables and volume losses; and to make generalized recommendations to help reduce these losses. All leave strips surveyed were established as alternate strip cuts under operational conditions although most of the narrower strips were part of a regeneration experiment (Jeglum 1980). Hence, the results should be directly applicable to current management practices.

It is evident that windfall and mortality are greater in leave strips than in uncut forest stands. Total merchantable volume losses in the strips increased as the leave period was lengthened although annual losses declined. Of all the site, stand and strip layout variables considered, leave time was the single most important factor affecting volume losses. Volume losses attributable to strip cutting averaged 9.1% (17.8 m^3/ha), 10.2% (20.0 m^3/ha) and 11.3% (22.1 m^3/ha) of the total merchantable volume in 2-, 3- and 4-year-old leave strips, respectively. However, a number of experimental 20- and 40-m-wide strips are included in the above figures; if only operational strips (>55 m wide) are considered, average losses drop to 6.0% (11.7 m^3/ha), 7.8% (15.3 m^3/ha) and 10.0% (19.5 m^3/ha), respectively.

The above percentages apply only to the leave strips, which may constitute about 40% of the original merchantable stand area, 60% having been removed during the construction of road right-of-ways, landings, etc., and by the first cut. Therefore, in terms of the total forested area, operational strip cutting is likely to increase the overall volume loss to windfall and mortality by 2.4%, 3.1% and 4.0% for 2-, 3- and 4-year leave periods, respectively (40% of the percentages given in the paragraph above). As well, no attempt has been made here to determine how much of this volume loss is salvageable during the final cut. Likely a large proportion of material that had blown down within 2 years of the final cut could still be utilized (Gardiner 1975). On the other hand, the location of most blowdowns near the perimeter of the strips will increase logging costs, as this material must be removed to provide access to the standing timber within.

By contrast, an average of 12.1% or 26.9 m^3/ha of the total potentially merchantable volume (live + new mortality + old mortality) in the strips had died from natural causes before the initial harvest and an additional

Table 10. Characteristics of recommended three-term multiple regression for percentage volume loss* per strip.

$$Y = 14.98065 - 0.00724249\, X_1 + 0.783952\, X_2 + 4.83186\, X_3$$

where $Y = 57.3 * \text{arc sine} \sqrt{\frac{\%\ \text{volume loss}}{100}}$

$r^2 = 0.561$

Variable	T-statistics	Contribution+ to r^2
X_1 density (merchantable stems/ha)	-4.37	0.120
X_2 Elling and Verry Index	5.37	0.181
X_3 $\sqrt{\text{leave time}}$	6.51	0.266

Correlation matrix

	Density	EV index
density	1.000	
EV index	0.095	1.000
$\sqrt{\text{leave time}}$	0.084	0.100

* Percentage volume loss = volume of new windfall and mortality as a percentage of live volume + new windfall and mortality. All volumes are merchantable volumes.

\+ The amount by which r^2 would be reduced if the variable were removed from the regression equation.

3.1% (7.0 m^3/ha) of the potentially merchantable volume was recent natural attrition. Evidently volume losses attributed to strip cutting can be substantially overestimated if no allowance is made for natural mortality (cf. Evert 1976).

Blowdown was the major cause of black spruce mortality in the leave strips, accounting for 80% of the recent losses (69% by windthrow and 11% by stem breakage). By contrast, LeBarron (1942) attributed only 54% of the losses in 30-m-wide upland black spruce strip cuts in Minnesota to blowdown while Heinselman (1957) found that 63% of the volume lost in lowland black spruce strip cuts resulted from wind. The small increase in recently killed standing dead stems in the leave strips in comparison with the uncut forest indicates that such factors as post-cut exposure, insect outbreaks, changes in soil moisture conditions and harvesting damage were not major causes of volume losses. Only 1.6% of the merchantable volume in the residual stand was directly destroyed by logging (% loss in newly established strips minus % loss in uncut forest).

Black spruce and balsam fir were more susceptible to wind damage than trembling aspen, jack pine or white birch. This is consistent with previous findings (Ellis 1911, Anon. 1933, Bowman 1944), and could reflect differences in microsite preferences, rooting habits, size, crown shape and foliage characteristics, and/or pathological conditions among species.

On the other hand, black spruce and balsam fir suffered the least natural attrition (as indicated by old mortality). While this is not unexpected in view of the general longevity of spruce and the successional status of fir, it underscores the dynamic nature of these boreal stands. Those who set stocking standards and establish regeneration expectations for extensive management must consider how the present highly productive old-growth forests developed. The data presented here suggest that the mature to overmature upland black spruce stands at Nipigon have evolved from stands with a larger hardwood and jack pine component.

The majority of volume loss to windthrow and stem breakage in both upland and lowland (e.g., Elling and Verry 1978, Haavisto 1979) black spruce leave strips occurs near the edges of the strips, with the exposed corners sustaining the most damage. As a result, volume losses are easily overestimated when strips are viewed from the haul road. Careful planning of the layout of residual strips will help to reduce subsequent windfall and mortality. Of all the site, stand and strip layout characteristics examined, those which reflected the general size and shape of the strips showed the highest correlation with percentage volume loss. Wide strips with only one open end will sustain the least windfall and mortality per unit area, other factors being equal (Table 11, Fig. 5). Strips should be as large as regeneration requirements, topography, and soil and stand conditions permit. Therefore, 80-m-wide as opposed to narrower alternate strip cuts are recommended as long as they provide for sufficient regeneration and adequate site protection on these shallow-soiled uplands (Jeglum 1982). If the size of the first cut strips is to be increased in relation to the leave strips to assure better regeneration (Jeglum 1982), the tradeoffs of additional volume loss through greater windfall and mortality (resulting from narrower leave strips) versus improved natural regeneration must be considered.

Neither buffering of the open end(s) of the strip by adjacent timber nor strip orientation had a consistent effect on volume losses. While more data are required to verify these findings, strip size and shape appear to be much more important. In some locales strip orientation is of great concern (LeBarron 1942, Ruth and Yoder 1953, Alexander 1967) and progressive strip cutting in the direction of prevailing storm winds is recommended. Such precautions do not appear necessary at Nipigon, perhaps because strong winds do not consistently blow from one direction.

Stand characteristics correlated with windfall and mortality included stand density, canopy height and site index, although only stand density and site index were useful regression predictors. The importance of these variables is not surprising; there is widespread consensus that blowdown hazard increases with site quality (Watson 1936, Heinselman 1957, Weetman 1957, Busby 1965, Elling and Verry 1978). Differences in site quality affect stand characteristics in several ways: better-quality sites tend to support larger but fewer trees, greater merchantable volumes, and higher levels of root and stem rot infections which predispose the trees to blowdown (Basham 1973, Whitney 1976). At Nipigon the influence of site quality on blowdown was expressed primarily through stand density. Significant reductions in windfall and mortality should be possible if strip cutting is concentrated on the less productive upland sites in this area, those which support relatively dense stands of low-to-moderate site index. Further work is needed to determine which aspects of site quality are most important in relation to windfall and mortality: physical stand attributes, pathological conditions or soil characteristics.

Stand age was not an important determinant of windfall and mortality in this study, but all of the stands examined were in the mature to overmature age classes. In several studies blowdown has been found to increase with stand age when younger age classes were included in the sample (Ruth and Yoder 1953, Heinselman 1957, Busby 1965).

None of the physical site attributes examined (soil depth, potential rooting depth, soil texture, drainage and slope characteristics) was found to have a significant relationship with volume losses. Slope length, gradient and aspect, and soil texture did not differ greatly among most strips, and along with soil drainage, soil depth and potential rooting depth, were often as variable within as between strips. In view of the undulating topography and associated changes in microrelief over short distances their lack of correlation is not surprising. In most cases differences in slope and physical soil characteristics should not be a major concern when upland strip cuts are being set out in the Nipigon area.

The combined impact of site, stand and strip layout variables on windthrow and mortality was best explained through a three-term regression equation. The low R^2 value of the equation underscores the complex nature of windfall and mortality in these upland stands. Blowdown results from the simultaneous interaction of predetermined variables such as site, stand and strip layout characteristics, and less predictable events such as storm frequency and severity (Moore 1977). The greater the number and range of contributing factors the more difficult it becomes to predict volume losses accurately. For example, Elling and Verry (1978) were able to account for 93% of the annual wind-caused mortality (windthrows and windbreaks) in lowland black spruce stands in Minnesota but the same predictors (EV index and leave time) explained only 44% of the total losses and 55% of the windfall (windthrows and windbreaks) at Nipigon where conditions are much more variable.

When standing dead stems were ignored, leave time, stand density and the EV index accounted for 65% of the variation in volume losses in the Nipigon strips, in comparison with 56% when these trees were included. Differences in rates of natural mortality, which are difficult to forecast

Table 11. Predicted* impact of different strip widths, lengths, end conditions and leave times on percentage volume losses+.

Leave time (years)	Strip width (m) 40: Strip length 120 (m) Open	Closed	40: 200 Open	Closed	60: 120 Open	Closed	60: 200 Open	Closed	80: 120 Open	Closed	80: 200 Open	Closed
2	10.5	9.3	9.6	8.9	7.8	7.1	7.1	6.7	6.6	6.1	6.0	5.7
3	12.4	11.1	11.4	10.7	9.6	8.8	8.8	8.3	8.2	7.7	7.6	7.3
4	14.0	12.7	13.0	12.2	11.1	10.3	10.3	9.8	9.7	9.1	9.0	8.7

* Using the equation presented in Table 10 and assuming a stand density of 1130 merchantable trees/ha and an average black spruce site index (age 100) of 17.5 m.

+ New windfall and mortality resulting from strip cutting (natural attrition [3.1%] deleted).

(Evert 1976, Payandeh 1979), confound attempts to predict volume losses resulting from strip cutting. Nevertheless, dead standing material must be included to obtain an accurate picture of total losses (LeBarron 1942, Heinselman 1957). It should be possible to develop a better regression equation, one which could be used with reasonable confidence for predictive purposes, once the Nipigon data base is augmented. In particular, more information on 3- to 5-year leave times in combination with different strip orientations is needed.

In conclusion:

1) Leave strips suffered proportionally greater potential volume losses through windfall and mortality than did uncut forest stands. Blowdown in the residual strips varied directly with leave time. Total potential losses (windfall and mortality) resulting from operational strip cutting (strips > 55 m wide) averaged 6.0%, 7.8% and 10.0% of the merchantable volume within 2-, 3- and 4-year leave strips, respectively. When compared with clearcutting, strip cutting is likely to result in potential volume losses over the entire forested area of 2.4%, 3.1% and 4.0% for 2-, 3-, and 4-year leaves, respectively.

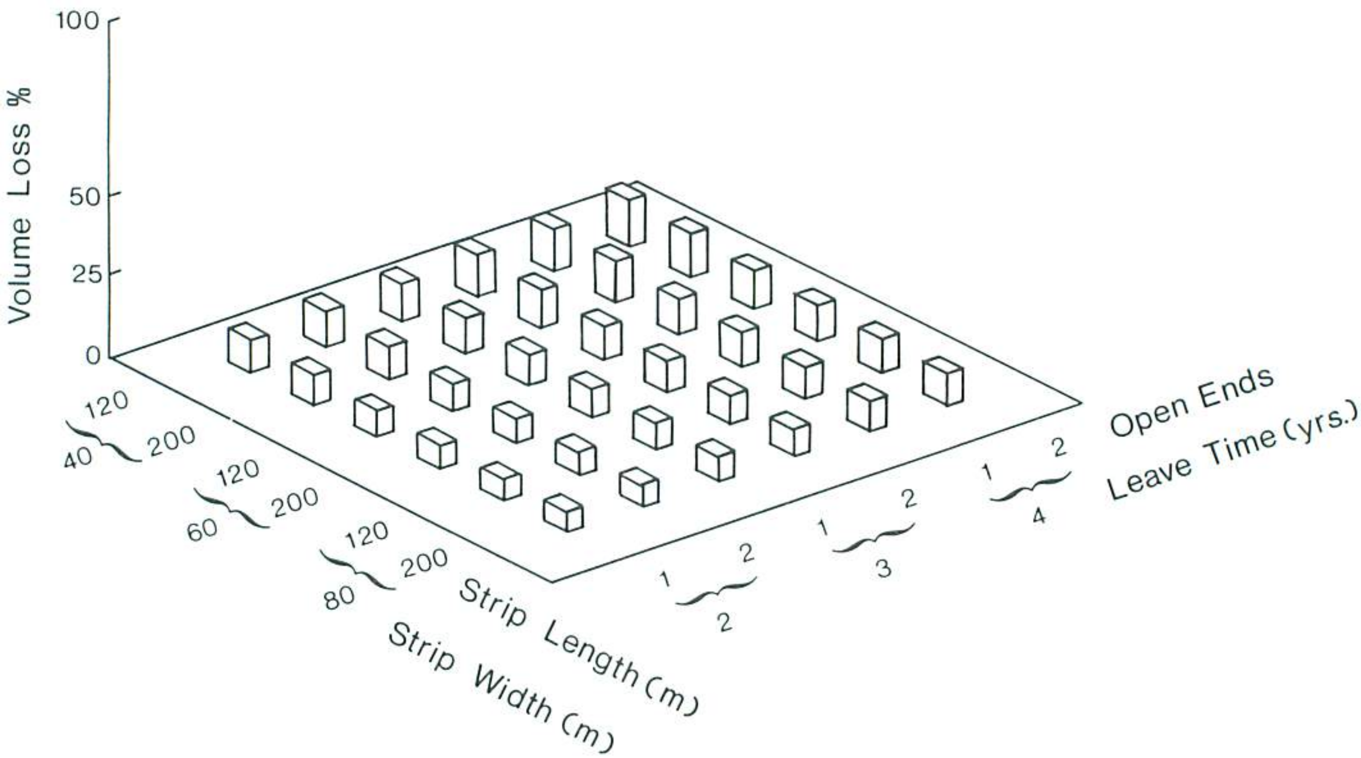

Figure 5. Predicted cumulative merchantable volume loss.

2) Volume losses that result from strip cutting can be overestimated considerably if recent and older natural attrition are not taken into account.

3) Windfall and mortality were greatest within 10 m of the exposed edges (cut faces) of the strips. The highest losses were sustained at exposed corners and losses decreased with increasing distance from the open end(s) of the strip.

4) Leave time, stand density, strip edge:area ratio and site index were the most useful predictors of windfall and mortality. Together they accounted for an r^2 of 56.1% in predicting merchantable volume losses.

5) To reduce blowdown on these sites priority should be given to:

   a) minimizing the leave period for the residual strips,

   b) establishing relatively long, wide leave strips with only one open end,

   c) selecting high-density stands of low-to-moderate site index for strip cutting.

6) Additional sampling, particularly in older leave strips, is needed to verify these results and develop a satisfactory prediction equation for windfall and mortality in upland black spruce strip cuts.

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APPENDIX

Table A1. Domtar local volume table (m^3), Red Rock, Ontario.

Species	Height class (m)	Diameter at breast height (cm)																			
		10	13	15	18	20	23	25	28	30	33	36	38	41	43	46	48	51	53	56	58
Black spruce	12.2–17.9	.02	.05	.10	.15	.22	.30	.39	.48	.60	.72	.85	.99	1.14	1.30	1.50	1.70	1.91	2.13	2.34	2.57
	≥18.0	.03	.05	.11	.17	.25	.33	.43	.53	.65	.77	.91	1.05	1.21	1.37	1.55	1.73	1.92	2.13	2.34	2.57
Balsam fir	All heights	.02	.04	.08	.14	.22	.30	.39	.49	.60	.72	.86	1.00	1.15	1.31	1.48	1.66	1.85	2.05	2.26	2.48
Jack pine	12.2–17.9	.02	.04	.09	.16	.23	.31	.40	.50	.61	.74	.87	1.02	1.18	1.35	1.54	1.74	1.96	2.19	2.41	2.67
	≥18.0	.03	.07	.14	.21	.30	.39	.50	.63	.76	.90	1.06	1.22	1.40	1.59	1.79	2.01	2.23	2.46	2.71	2.97
White birch	All heights	.04	.08	.12	.17	.22	.26	.31	.38	.45	.53	.59	.69	.78	.88	1.00	1.13	1.27	1.42	1.58	1.75
Poplar	12.2–17.9	.03	.06	.08	.16	.24	.33	.44	.47	.67	.78	.90	1.02	1.13	1.25	1.37	1.49	1.61	1.74	1.87	2.03
	≥18.0	.03	.06	.08	.16	.24	.33	.44	.55	.68	.82	.98	1.14	1.31	1.50	1.70	1.90	2.12	2.35	2.59	2.85