SILVICULTURAL CONSEQUENCES OF FOREST HARVESTING ON PEATLANDS: SITE DAMAGE AND SLASH CONDITIONS

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ABSTRACT

The degree of site damage that occurs during forest harvesting on peatlands is influenced by site type and harvesting method. On peatland sites, susceptibility to damage during the frost-free season increases from the *Ledum* (OG 11) to the *Alnus* herb-poor (OG 12) to the *Alnus* herb-rich (OG 13) operational groups. Correspondingly, susceptibility to damage increases with alder cover. On transitional peatlands, the conifer-herb/moss-rich group (OG 9) is more susceptible to damage than the feathermoss *sphagnum* group (OG 8).

In the *Alnus* herb-poor operational group, harvesting in the summer with narrow-tired skidders is more damaging than harvesting with wide-tired skidders. Winter harvesting produces the least amount of damage, but damage can occur during portions of the winter when frost has not penetrated deeply into the ground and snow cover is not deep.

Full-tree harvesting in the summer with wide-tired skidders leaves less deep slash than tree-length harvesting with narrow-tired skidders.

Site damage can likely be reduced by careful planning of harvesting operations, operator training, and modification of equipment and harvesting technique.

RÉSUMÉ

L'intensité des dommages causés aux tourbières par l'exploitation forestière dépend du type de la station et de la méthode d'exploitation. La fragilité des stations pendant la saison sans gel augmente quand on passe de l'association dite opérationnelle à *Ledum* (OG 11) à l'association à *Alnus* pauvre en herbacées (OG 12), jusqu'à l'association à *Alnus* riche en herbacées (OG 13). Elle augmente de même avec la couverture en aulnes. Dans les tourbières de transition, l'association à conifères riche en mousses ou en herbacées (OG 9) est plus fragile que l'association à mousses hypnacées et à *Sphagnum* (OG 8).

Utilisées pour l'exploitation estivale dans les associations à *Alnus* pauvres en herbacées, les débusqueuses à pneus étroits causent plus de dommages que les débusqueuses à pneus larges. L'exploitation hivernale est celle qui provoque le moins de dommages, mais ceux-ci peuvent se produire lorsque le gel n'a pas pénétré en profondeur dans le sol et que la couverture de neige n'est pas épaisse.

En été, l'exploitation par arbres entiers au moyen de débusqueuses à pneus larges laisse moins de rémanents que l'exploitation par troncs entiers au moyen de débusqueuses à pneus étroits.

Il semble que les dommages causés par l'exploitation puissent être réduits par une planification soigneuse des opérations, la formation des opérateurs et la modification de l'équipement et des techniques.

ACKNOWLEDGMENTS

R. McColm generously permitted the use of Ontario Ministry of Natural Resources data, and provided helpful comments on an early draft of this report.

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M. Adams contributed skilled technical assistance in the field and in drafting figures.

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Cover Photo: Ground conditions following summer harvesting on peatlands by (a) chainsaw felling and narrow-tired skidder forwarding (left), and (b) feller-buncher felling and wide-tired skidder forwarding (right).

INTRODUCTION

Timber harvesting is usually the first forestry activity that occurs on forested peatlands in northern Ontario, and it is the activity that can have the farthest-reaching consequences. Forested peatlands are especially susceptible to damage caused by the passage of machinery. Site damage caused by harvesting equipment has often been observed and cited as an important obstacle to reestablishing productive forests on logged peatlands (Anon. 1978, Sleep 1979, Gemmell 1981).

A second consequence of forest harvesting is the deposition of slash over the cutover area. Slash covers potential seedbeds and planting spots, and can suppress advance growth. Excessive slash is not restricted to peatland cutovers, but it has been identified as a significant impediment to regeneration on spruce swamps (Roe 1946, Anon. 1978).

Much of the available information on site damage and slash on peatlands is qualitative and based on casual observation. The purpose of this report is to present quantitative information on site damage and slash amounts on peatlands, and especially to investigate the influence of peatland site type and of harvesting method on site damage.

This study tests two hypotheses: (i) that site type, as defined by the Clay Belt Forest Ecosystem Classification (FEC) system (Jones et al. 1983), influences the degree of site damage that occurs during harvesting, and (ii) that the type of harvesting influences the degree of site damage and the amount of slash that occurs.

Much of the information presented in this report comes from a continuing study designed to investigate the effects of several harvesting methods on survival of advance growth. In this study, information on ground conditions was also recorded. Additional information is derived from a survey conducted by R. McColm, Ontario Ministry of Natural Resources (OMNR)[1].

METHODS

From 1982 to 1984, plots were established in uncut forest stands scheduled for harvesting. These stands met a number of criteria: they were commercial, peatland black spruce (*Picea mariana* [Mill.] B.S.P.)-dominated forests of FEC operational groups 11 and 12 (*Ledum* and *Alnus*/herb-poor), which had an understory well stocked with black spruce advance growth. All stands were located within 80 km of Kapuskasing, Ontario.

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[1] McColm, R.G. 1983. Post cut classification of recent cutover 1978-82. Ont. Min. Nat. Resour., Cochrane District. 11 p. + photographs, survey form and map. (unpubl. rep.)

Each plot comprised five parallel lines of 20 contiguous 2-m x 2-m quadrats. The lines were oriented perpendicular to the direction of planned traffic of harvesting machinery so that the traffic would cross the lines, not run along them. In each plot the lines were a fixed distance apart (15, 20 or 25 m) so that sampling took place across the logging chance. This layout was altered in two places where the fixed inter-line distance would have placed the line in conditions unsuitable for the advance growth portion of the study (e.g., in an alder swale). In these two cases, the distance between the two adjacent lines was simply doubled.

The plots were established in uncut forests scheduled for harvesting by three different methods:

1. felling by feller-buncher and full-tree forwarding by narrow-tired skidder in winter (FB/NT or winter harvesting) (Fig. 1)

2. felling by feller-buncher and full-tree forwarding by wide-tired skidder in summer (FB/WT or summer high flotation) (Fig. 2 and 3)

3. felling manually by chainsaw and tree-length skidding by narrow-tired skidder in summer (CS/NT or summer conventional)

Narrow tires were 60 cm wide and wide tires were 127 cm wide (Fig. 4).

The plots were established in summer and forests were cut according to the prevailing operational method within the subsequent half-year.

All harvesting operations were commercial operations, with equipment and techniques designed mainly for efficient extraction of wood. Machinery operators were unaware that they were working in test plots.

Reassessment took place in June or July of the summer following harvesting. At each assessment, both precut and postcut, the following information was collected on each quadrat: percentage of quadrat covered by *sphagnum* mosses, feathermosses *(Pleurozium schreberi, Hylocomium splendens, Ptilium crista-castrensis, Dicranum* spp.), coniferous litter, deciduous litter, undisturbed bare organic matter, light slash (slash less than 15 cm deep, or through which considerable ground was exposed), deep slash (slash deeper than 15 cm, or through which little ground was exposed), deep ruts (machine ruts that were waterfilled or deeply disturbed), shallow ruts (machine ruts characterized by compaction, scraping, or shallow mixing), other disturbance (disturbance outside of tracks), and mineral soil.

Information collected on vegetation included the percentage of each quadrat occupied by: *Alnus rugosa; Ledum groenlandicum; Chamaedaphne calyculata;* other shrubs; *Typha latifolia;* grasses, sedges and rushes; and herbs.

In addition, the following information was collected during the precut assessment at the center of each quadrat line: FEC vegetation type and operational group, peat depth, and basal area by species.

Figure 1. Feller-buncher harvesting in winter.

Figure 2. Feller-buncher harvesting in summer.

Figure 3. Forwarding with wide-tired skidder in summer.

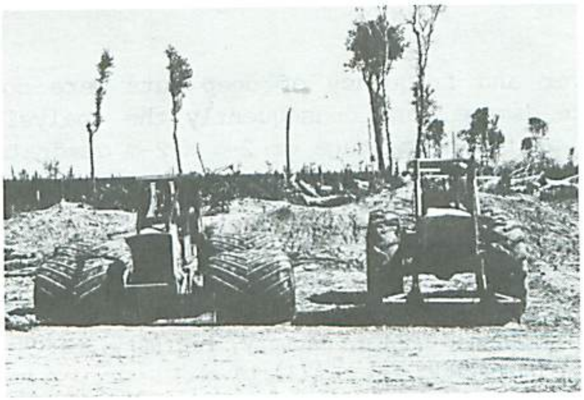

Figure 4. Skidders equipped with wide (127 cm) and narrow (60 cm) tires.

Atmospheric Environment Service snow depth and soil temperature records[2] from the Department of Agriculture station at Kapuskasing were examined to determine conditions prevailing during winter cutting operations. It is recognized that conditions on a short grass cover on an upland site may not give a good representation of conditions on a cutover peatland, but it is assumed that qualitative relationships will hold. For example, deep snow periods at the climate station should correspond with deep snow periods on the peatlands, even though depths may differ to some degree.

In the OMNR postcut survey[1], transects were established in cutover blocks ranging in size from 5 to 15 ha, and slash, residual tree, and site damage conditions were observed. Blocks were classified according to FEC site type as well. An area of 4147 ha was surveyed on the ground in this fashion, and an additional area of 1361 ha that was obviously damaged was examined on aerial photographs. All areas were within 2 km of an all-weather road, and were generally harvested in summer by the conventional method (chainsaw and narrow-tire skidder). The surveyed areas were all within 50 km of Smooth Rock Falls, Ontario.

ANALYSIS

The design of this study demands that some precautions be taken when one is considering the results of the analysis. It was not possible to assign harvesting method randomly to sample plots; instead, it was necessary to place sample plots in areas that were scheduled for harvest by one of the methods. Different harvesting methods were used at widely separated locations, and thus plots harvested by the same method were physically nearer one another and were often harvested more closely together in time than were plots harvested by different methods. This fact makes estimates of variance values for the same harvesting method speculative. They may be lower than the values that would have been obtained if a fully randomized design had been used.

Mitigating this problem somewhat is the homogeneity of the forests in which sample plots were placed. All stands sampled were mature or overmature black spruce forests on swamp sites, with a well developed advance growth understory.

Percentage cover and frequency of deep ruts were considered to be the best indicators of site damage, and consequently the analysis focused on these variables. Frequency was the percentage of 2-m x 2-m quadrats with more than 5% of the surface area in the deep rut condition.

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[2] Anon. 1983. Daily soil temperature data, January, February, March 1983. Dep. Environ., Atmospher. Environ. Serv., Downsview, Ont. 24(1):16.

Anon. 1984. Daily soil temperature data and supplement, October, November, December 1984. Dep. Environ., Atmospher. Environ. Serv., Downsview, Ont. 25(4):31.

The data were analyzed according to a fully randomized design. One-way analysis of variance, with harvest methods as treatments, was performed on precut and postcut variables. A two-way analysis of variance of rut cover and frequency was carried out with operational group and harvest method as factors, and plot means were used for each operational group-harvest method combination in the analysis. Tukey's procedure was used to test the significance of differences among means. Because the number of quadrat lines making up plot means for treatment combinations varied among plots, values of rut cover and frequency were also calculated on the basis of an aggregate of quadrat line means.

For each harvesting method, multiple linear regression was used to identify factors associated with deep rut cover. The independent variables tested were: alder cover, *sphagnum* moss cover, feathermoss cover, peat depth and position in logging chance (relative to distance from the landing). Observations used in the regression analysis were mean quadrat line values.

In the OMNR postcut survey, cutover blocks were summarized by FEC operational group and the silvicultural treatment required. The area that was untreatable was also determined, and on peatland sites an untreatable condition resulted from the deep rutting caused by harvesting machinery.

RESULTS

Precut Stand Characteristics

Characteristics of each stand prior to cutting are presented in Table 1.

No significant differences were detected in proportions of site type among harvesting methods. There were, however, significant differences in *Ledum* and *Alnus* cover among the three harvesting methods. *Ledum* cover was greater in the winter than in the summer conventional harvesting method (p=.05).

Significant differences also occurred in the cover of *sphagnum* and feathermosses (p=.01).

Postcut Stand Characteristics

Postcut conditions are presented in Table 2.

From the one-way analysis of variance, both frequency and cover of deep ruts were significantly influenced by harvest method (p=.01). Deep ruts were more severe in the summer conventional plots, with an average of 14% of the surface area covered by deep ruts, and 48% of 4-m^2 quadrats having at least 5% deep rut coverage (Fig. 5). High flotation in summer and harvesting in winter resulted in about 3 and 1% deep rut cover, respectively.

Table 1. Precut stand characteristics.

Plot	Harvest method	FEC OG proportions	Basal area (m^2/ha)	Peat depth (cm)	Percentage cover						
					Sphagnum	Feather moss	*Alnus*	*Ledum*	*Chamaedaphne*	Grass/Sedge	Herbs
2	winter (FB/NT)	12_8 11_2	17.9	145	48.2	28.6	8.1	22.3	3.0	1.3	5.8
14	winter (FB/NT)	11_8 12_2	29.4	81	33.8	40.2	1.9	18.9	0.0	1.6	9.3
15	winter (FB/NT)	11_{10}	25.3	88	31.7	45.2	0.5	23.3	0.0	0.0	8.4
	mean	11_7 12_3	24.2	105	37.9a	38.0a	3.5	21.5a	1.0	1.07	7.8
3	summer (FB/WT)	12_6 11_2 13_2	21.2	158	38.2	45.9	6.1	8.8	0.3	1.2	8.4
4	summer (FB/WT)	12_8 11_2	20.7	140	27.4	56.0	7.1	16.7	2.4	0.9	11.3
5	summer (FB/WT)	11_7 8_3	14.5	93	17.9	68.1	0.0	20.0	1.6	0.6	8.7
9	summer (FB/WT)	11_6 12_4	20.7	102	40.7	38.9	8.6	19.7	0.1	2.4	5.9
10	summer (FB/WT)	11_4 12_4 8_2	23.0	84	38.9	43.5	9.3	17.7	0.4	3.5	5.6
	mean	12_4 11_4 8_1 13_1	20.0	115	32.6a	50.5a	6.2	16.6ab	1.0	1.7	8.0
6	summer (CS/NT)	12_6 11_4	19.3	94	53.3	15.9	11.9	17.1	0.4	1.5	8.2
7	summer (CS/NT)	12_8 11_2	29.8	80	64.2	12.6	23.6	6.8	1.5	0.9	5.0
8	summer (CS/NT)	12_6 11_4	22.0	82	58.5	17.3	9.7	8.5	2.8	0.9	3.9
	mean	12_7 11_3	23.7	85	58.7b	15.3b	15.1	10.8b	1.6	1.1	5.7
Significance of differences among harvest method means		NS	NS	NS	1%	1%	5%	5%	NS	NS	NS

Mean values in columns followed by the same letter are not significantly different, Tukey's procedure (p=.05)

Table 2. Postcut stand characteristics.

Plot	Harvest method	Freq deep rut	Percentage cover: Deep rut	Shallow rut	Other disturbance	Total disturbance	Light slash	Deep slash	Total slash
2	winter (FB/NT)	0.02	0.3	0.6	1.5	2.4	23.8	21.4	45.2
14	winter (FB/NT)	0.11	1.8	9.0	12.3	23.1	7.2	30.0	37.2
15	winter (FB/NT)	0.06	1.8	17.6	14.4	33.8	4.1	22.6	26.6
	mean	0.06a	1.3a	9.1	9.4	19.8	11.7	24.6ab	36.3
3	summer (FB/WT)	0.12	2.1	11.8	4.9	18.8	14.7	14.3	29.0
4	summer (FB/WT)	0.21	3.8	26.4	4.7	34.9	16.9	17.0	33.9
5	summer (FB/WT)	0.02	0.7	14.7	13.5	28.9	12.9	25.8	38.6
9	summer (FB/WT)	0.18	3.5	4.8	28.5	36.8	12.1	12.5	24.6
10	summer (FB/WT)	0.12	2.6	5.3	37.5	45.4	12.4	9.5	21.9
	mean	0.13a	2.5a	12.6	17.8	33.0	13.8	15.8a	29.6
6	summer (CS/NT)	0.24	6.5	1.1	25.3	33.0	9.3	28.1	37.4
7	summer (CS/NT)	0.71	23.4	1.2	16.2	40.7	8.9	23.5	32.3
8	summer (CS/NT)	0.50	13.3	1.9	19.2	34.3	10.1	34.3	44.3
	mean	0.48b	14.4b	1.4	20.2	36.0	9.4	28.6b	38.0
Significance of differences among harvest method means		1%	1%	NS	NS	NS	NS	5%	NS

Mean values in columns followed by the same letter are not significantly different, Tukey's procedure (p=.05)

Figure 5. Severe deep rutting produced by narrow-tired skidders in summer harvesting.

Deep slash was also significantly influenced by harvesting method ($p=.05$). There was less deep slash cover with the summer high-flotation method (16%) than with the summer conventional method (29%).

Influence of Harvest Method and Site Type on Deep Rut Cover and Frequency

In Tables 3 and 4 the cover and frequency of deep ruts are broken down by FEC operational group and by harvest method.

The two-way analysis of variance showed that both operational group and harvest method had a highly significant effect on rut cover ($p=.01$), with a significant interaction as well ($p=.05$). Deep rut cover was significantly greater on OG 12 sites harvested by the summer conventional method than on any other combination of site-harvesting methods. Operational group had a highly significant effect ($p=.01$) and harvest method a significant effect ($p=.05$) on rut frequency as well. The interaction was not significant. Deep ruts were more frequent on OG 12 sites harvested by the summer conventional method than on OG 11 sites harvested by any method.

The most severe damage occurred with the summer conventional method in the *Alnus*/herb-poor operational group (OG 12), with 20% of the ground surface occupied by deep ruts, and 65% of 4-m^2 quadrats occupied by at least 5% deep ruts.

Regression Analysis

In summer high-flotation harvesting, deep rut cover percentage (RC) was regressed on alder cover percentage (AC):

$$RC = .49 + .33\ AC \qquad [Eq.\ 1]$$
$$r^2 = .56,\ s = 2.23$$
(s is the standard error of the estimate)

Table 3. Percentage of ground covered by deep ruts.

	OG 11*		OG 12**	
Winter harvest	1.0a	(1.1)***	3.9a	(1.6)
Summer harvest wide tires	1.4a	(1.2)	4.5a	(4.1)
Summer harvest narrow tires	2.8a	(2.6)	19.1b	(19.9)

* includes a minor OG 8 component
** includes a minor OG 13 component
*** values in parentheses calculated on aggregate of quadrat line values (as opposed to a mean of plot values)
Mean values followed by the same letter are not significantly different, Tukey's procedure (p=.05)

Table 4. Percentage of $4\text{-}m^2$ quadrats with 5% of surface covered by deep ruts.

	OG 11*		OG 12**	
Winter harvest	6a	(5)***	23ab	(9)
Summer harvest wide tires	8a	(6)	23ab	(21)
Summer harvest narrow tires	16a	(15)	63b	(65)

* includes a minor OG 8 component
** includes a minor OG 13 component
*** values in parentheses calculated on aggregate of quadrat lines (as opposed to a mean of plot values)
Mean values followed by the same letter are not significantly different, Tukey's procedure (p=.05)

In summer conventional harvesting, alder cover was similarly important:

$$RC = 4.67 + .63\ AC \qquad [Eq.\ 2]$$
$$r^2 = .59,\ s = 7.41$$

Sphagnum cover percentage (SC) was also a significant factor in summer conventional harvesting, and with this variable added the equation becomes:

$$RC = -33.7 + .54\ AC + .68\ SC \qquad [Eq.\ 3]$$
$$r^2 = .81,\ s = 5.28$$

In equation [3] RC becomes negative for low values of AC and SC. Negative RC values should be interpreted as 0% rut cover.

Examples of Disturbance Pattern

Figures 6-8 display the patterns of deep rutting and total disturbance found among the various harvesting methods.

Plot 7, harvested in the summer by means of narrow-tired skidders, showed deep ruts distributed throughout most of the four rear sample lines (Fig. 6). The first line, although it was closest to the landing and therefore received the most skidder traffic, had very little deep rutting. This line was in the *Ledum* operational group (OG 11), whereas the other four lines were in the *Alnus*/herb-poor operational group (OG 12).

Plot 4, also harvested in the summer, but with wide-tired skidders, shows clearly the pattern of skidder traffic in the clumping of disturbed quadrats (Fig. 7). Lines 4 and 5, though farthest from the landing, sustained the greatest number of deep ruts. These lines also had much higher amounts of alder in the precut phase than did the other three sample lines.

Plot 2, harvested in winter, shows virtually no disturbance (Fig. 8). It should be noted that this plot, which was cut in February 1983, suffered little deep rutting (0.3% cover), whereas plots cut in December 1984 by the same method showed 1.8% deep rut cover.

Divided Plot

One plot (plot 1) was inadvertently cut half in the summer and half in the winter, because flagging marking the center of the sample lines was mistaken for a cut boundary. This plot was not included in previous analyses, but the side-by-side comparison is interesting and is summarized in Table 5. The pattern of disturbance is displayed in Figure 9.

Before cutting there was slightly more *sphagnum* and considerably more alder in the winter-cut portion than in the summer-cut portion of the plot. After cutting, both light and deep slash covered more of the surface area in the winter-cut portion than in the summer-cut portion. Deep ruts occupied nearly 15% of the ground area in the summer-cut portion, but less than 5% in the winter-cut portion.

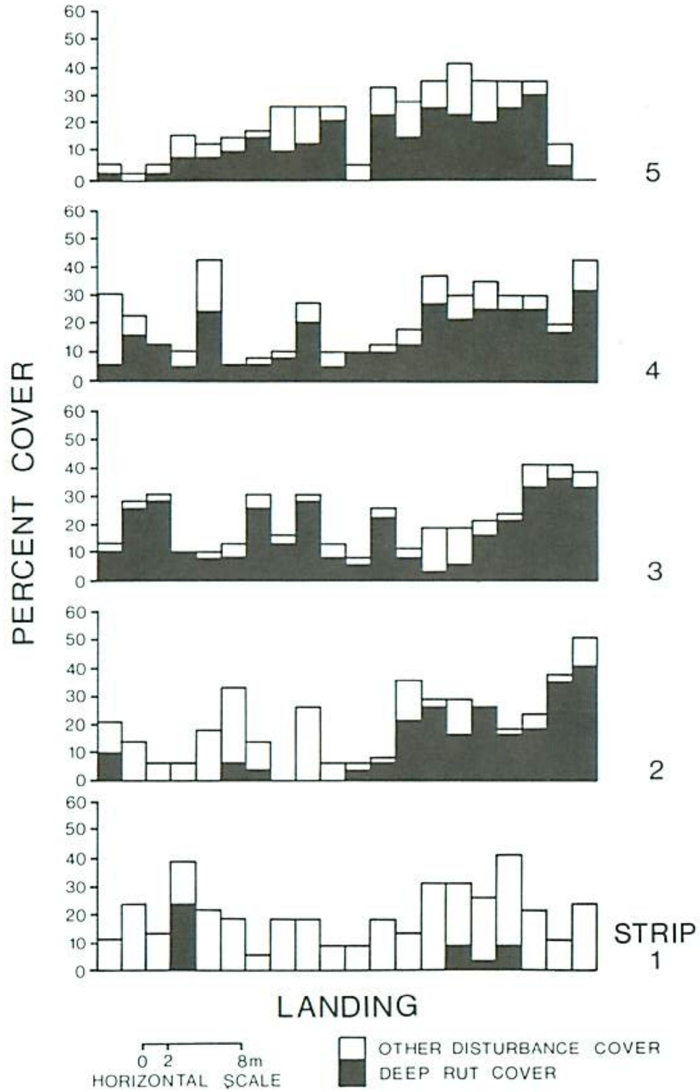

Figure 6. Disturbance pattern caused by summer harvesting with narrow-tired skidders, from 5 strips of 20 contiguous quadrats (plot 7).

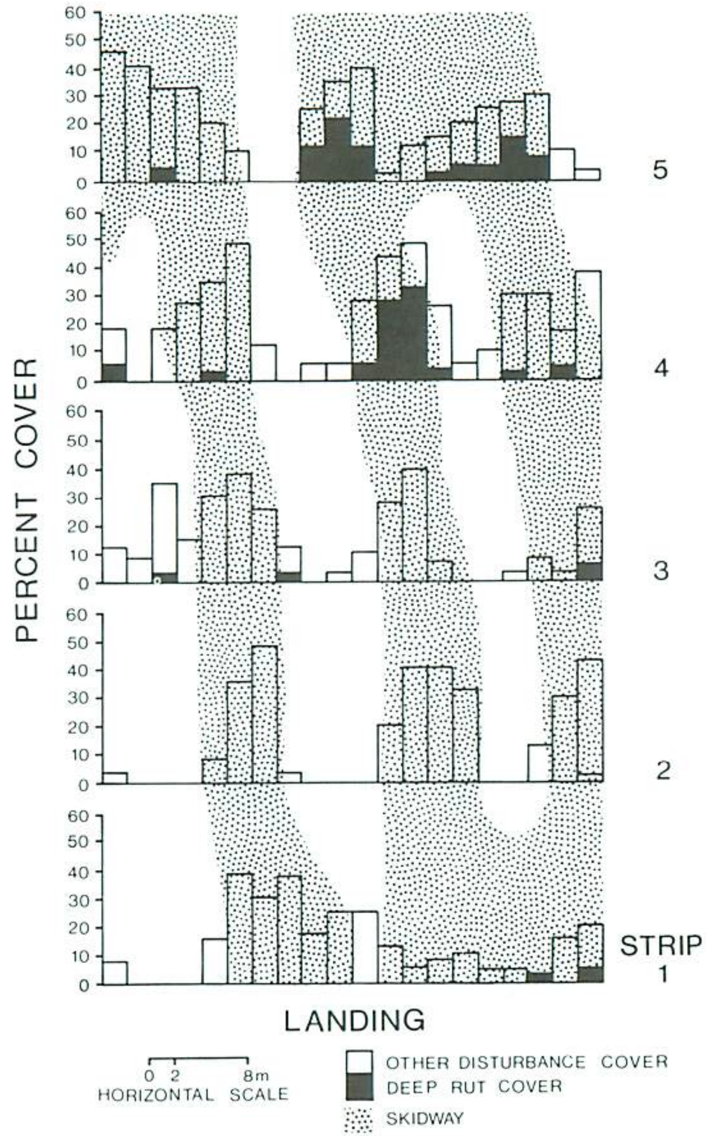

Figure 7. Disturbance pattern caused by harvesting with feller-buncher and wide-tired skidder, from 5 strips of 20 contiguous quadrats (plot 4).

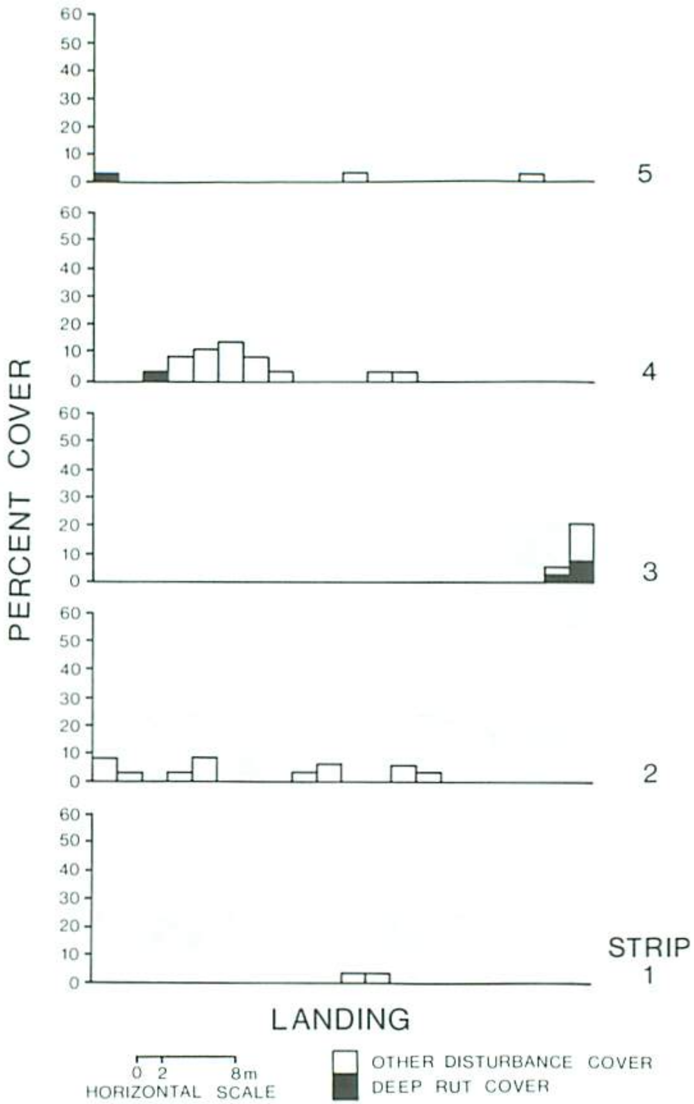

Figure 8. Disturbance pattern caused by winter harvesting from 5 strips of 20 contiguous quadrats (plot 2).

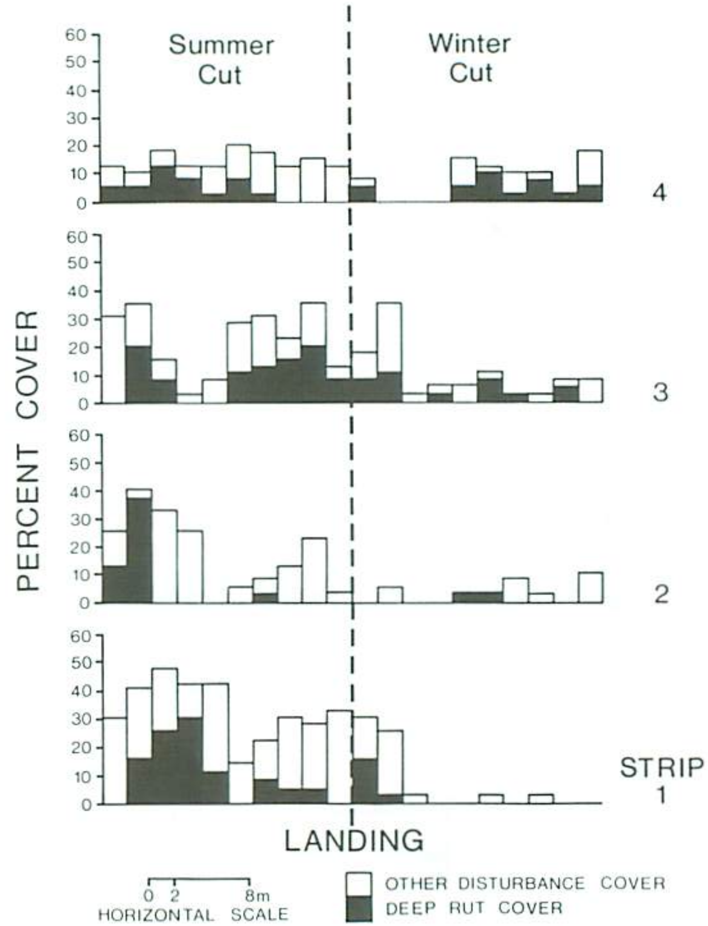

Figure 9. Disturbance pattern caused by summer harvesting with feller-buncher and wide-tired skidder compared with disturbance pattern caused by winter harvesting (plot 1).

Table 5. Conditions on divided plot.

	Winter harvest	Summer high-flotation harvest
Precut		
Sphagnum cover (%)	74.3	66.6
Alder cover	15.4	10.0
Postcut		
Light slash (%)	22.8	17.3
Deep slash (%)	18.8	8.7
Total slash (%)	41.6	25.9
Deep rut (%)	4.8	14.6
Shallow rut (%)	5.0	26.8
Other disturbance (%)	3.7	2.1
Total disturbance (%)	13.5	43.5

Snow Depth and Ground Temperatures

In February 1983, when plot 2 was cut, snow depth at the Department of Agriculture station in Kapuskasing ranged from 44 to 60 cm, and averaged 51 cm. In December 1984, when plots 14 and 15 were cut, snow depth ranged from 0 to 17 cm, and averaged 9 cm. In February 1983, soil temperatures were 0.0°C or lower for the entire month at the 5-, 10- and 20-cm depths. In December 1984, soil temperature was consistently below 0.0°C only at the 5 cm depth, whereas at the 10- and 20-cm depths temperatures during the first half of the month, when harvest operations were most likely carried out, were above freezing.

Ontario Ministry of Natural Resources Postcut Survey[1]

Untreatable areas were least abundant in the feathermoss *sphagnum* operational group, but accounted for nearly a third of the cutover in the conifer-herb/moss-rich and *Ledum* operational groups and two-thirds or more of the cutover area in the *Alnus*/herb-poor and *Alnus*/herb-rich operational groups (Table 6).

Observations indicated that most damaged areas were cut during the frost-free period. Damage was attributed not only to the actual cutting and skidding operations, but also to daily travel to and from distant cutting areas.

Table 6. Ontario Ministry of Natural Resources postcut classifications[a].

FEC OG	Percentage of cutover in untreatable condition
8	6%
9	29
11	30*
12	66*
13	78*

* includes untreatable areas interpreted from aerial photographs

[a] See footnote 1, page 1

DISCUSSION

Site Type

This study provides strong support for the hypothesis that site type influences the degree of site damage during forest harvesting. Areas of the *Alnus* herb-poor operational group suffered much more deep rutting during summer harvesting than areas of the *Ledum* operational group.

Further and consistent support for this hypothesis is given by the results of the OMNR postcut survey. More than twice as much area was rendered untreatable in the *Alnus* herb-poor and *Alnus* herb-rich operational groups as in the *Ledum* operational group.

The importance of site type in harvesting operations on peatlands appears to have been recognized soon after the introduction of the wheeled skidder. Barrett (1966) considered a swamp 'particularly bad' in terms of summer trafficability if it was characterized by 'pools of open water, heavy cedar and alder pockets'. There can be little doubt that the *Alnus* herb-rich site type (OG 13), which this study identifies as the most sensitive type, was being described.

Several explanations are possible to account for the differences in rutting between *Ledum* and *Alnus* herb-poor operational groups.

First, it has been suggested that the rootmat is important in bearing machinery (Barrett 1966), and possibly there are differences between site types in the strength of the rootmat. However, in this study, *Ledum* and *Alnus* herb-poor sites carried similar amounts of forest cover, and each had a well developed understory of shrubs. It seems unlikely that there were important differences in root mats among the different site types.

Second, it is possible that water levels are higher on *Alnus*/herb-poor sites than on *Ledum* sites, and that this renders the former type more susceptible to damage. On several plots in this study, however, the two sites existed in close proximity, with little elevational difference. It seems unlikely that important water-level differences existed. (It is not implied that water level is not an important factor in rutting damage, just that it does not necessarily account for site type differences.)

Third, and most likely, it is possible that the more fibric peat in *Ledum* sites has greater bearing strength than the better decomposed peat in *Alnus*/herb-poor sites. This possibility is supported by the soil descriptions from the FEC (Jones et al. 1983). The surface fibric layer of peat in *Ledum* types is most frequently deeper than 40 cm. In the *Alnus*/herb-poor type the fibric layer is generally less than 20 cm deep, and in the *Alnus*/herb-rich type, the fibric layer is usually less than 10 cm.

Harvesting Method

The results for the *Alnus*/herb-poor operational group support the hypothesis that harvesting method influences the degree of site damage. Summer conventional harvesting was much more damaging than the other methods on this site type. The coefficients of alder cover in the regression equations [1] and [2] suggest that roughly twice as much deep rut cover is produced during summer conventional harvesting as during summer high-flotation harvesting.

Differences among harvesting methods were not clear in the *Ledum* operational group, although a trend toward increased rutting corresponding to the trend on the *Alnus*/herb-poor operational group was suggested. The intercepts in regression equations [1] and [2] indicate that, with alder cover equal to 0, in other words in the *Ledum* operational group, there is more deep rut cover with summer conventional harvesting than with summer high-flotation harvesting.

Disturbance Pattern

Although the cover and frequency of deep ruts is less in summer-harvested areas when wide-tired skidders are used than when narrow-tired skidders are used, differences in skidding patterns should be considered. In narrow-tired skidder forwarding, travel is not concentrated on defined skidways, but is spread throughout the logging chance. In this way, rutting is distributed throughout the area. In wide-tired skidder forwarding, travel is mainly on defined skidways, and other portions are left virtually undisturbed. On an areal basis, perhaps one-half to two-thirds is well travelled (see Fig. 7), and the remainder is relatively undisturbed. The rutting is concentrated on the well travelled portion; consequently, a consideration of average figures for rutting does not indicate what is occurring on the skidways. Average values of cover and frequency should be multiplied by 1.5 to 2 to get an impression of disturbance within the skidways.

Therefore, for *Alnus*/herb-poor sites logged by the summer high-flotation method, within skidways, deep ruts cover 7 to 9% of the surface area and occur in 30 to 40% of 2-m x 2-m quadrats. Summer high-flotation harvesting can reduce the number of deep ruts over all, but in localized portions of the cutover (skidding trails), the number of deep ruts may be comparable to that occurring throughout the cutover with summer conventional harvesting. Evidence from other trials suggests that deep ruts resulting from wide tires are not as deep, on average, as those resulting from narrow tires (Heidersdorf and Ryans 1986).

The alternating pattern of disturbed and undisturbed strips produced by the summer high-flotation harvesting method (Fig. 10) has implications for subsequent silvicultural practice. If the skidways are disturbed without being rutted, it is possible that seeding or planting can be carried out without any further site preparation. The skidways are relatively free of slash and vegetation and surface conditions are improved by light disturbance. Residual trees in the undisturbed portions of the cutover may preclude further planting or seeding without site preparation. If advance growth is present in the undisturbed portions, then planting or seeding will not be necessary in those portions.

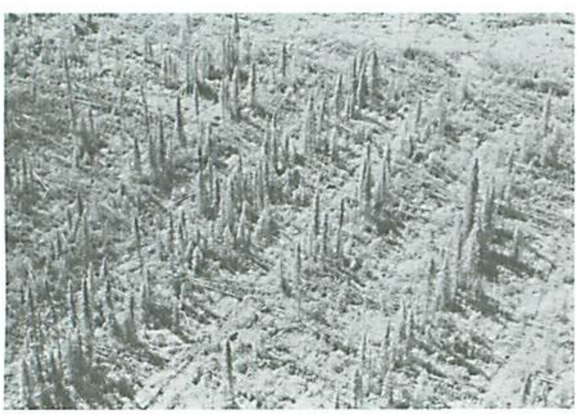

Figure 10. Alternate pattern of disturbed and undisturbed ground imposed by feller-buncher harvesting (Note: photograph taken prior to forwarding).

Terminology: Winter Harvesting

The plots harvested in December 1984 sustained more rutting than the plot harvested in February 1983, and it is possible that the differing soil temperature and snow conditions may be at least partly responsible. Frost penetration and snow depth were greater during the February harvest than during the December harvest.

The term "winter harvesting" is applied to harvesting during the period of the year in which air temperatures are generally below freezing and snow covers the ground. However, the most sensitive sites should be harvested during the deep frost or deep snow season, which probably occurs only during part of the winter harvesting season.

Slash

The results of this study support the hypothesis that slash quantities are influenced by harvesting method.

It is not surprising that the summer conventional operation produced the greatest cover of deep slash, as limbing was done at the stump by this method. The deep slash cover produced by the winter full-tree harvest was not significantly different from this, however. A possible explanation is that in cold weather, branches are more brittle, and more likely to break off during the harvesting operation.

The unanticipated results suggest that further testing of the hypothesis is required.

The total quantity of slash observed in this study (about 30 to 40%) would likely be an impediment to seed-based regeneration methods. Any surface area covered by slash is not available for seedbed.

Deep slash, but not light slash, would be an impediment to planting. In this respect, the summer full-tree harvesting is superior.

Representativeness of Results

Site damage, ground disturbance and quantity of slash can vary widely even within a single harvesting method, and it is not known in which part of the spectrum of variation the conditions observed in this study lie.

The regression equations are useful mainly in identifying factors that are associated with rutting. It is unlikely that they are suitable for prediction purposes, because many unmeasured variables (harvesting equipment, operator, weather) may have an important influence as well.

Effects of Site Damage on Silvicultural Practice

Site damage has many obvious negative effects on silvicultural practice. Advance growth that may have been present in the forest before cutting is largely destroyed by the severe disturbance that is associated with site damage. A large proportion of the surface area of a damaged site is covered by water-filled ruts, slash, and moderately to well decomposed organic matter ('black muck'), none of which is a good seedbed for black spruce establishment. Consequently, seed-tree and direct seeding methods are unlikely to result in successful regeneration of a damaged peatland. The vegetation that has been observed to invade damaged peatlands (sedges, grasses, rushes, alder, and cattails -- see Jeglum 1975, Virgo 1975, Sleep 1979, Gemmell 1981, Jeglum et al. 1983) would also likely hinder the establishment of black spruce from seed.

Planting damaged sites is also problematic from a logistical point of view. Access to such sites, to deliver seedlings or planting personnel, is difficult and may cause additional site damage. The act of planting itself may be even more difficult because of the treacherous footing in a deeply rutted area. Suitable and accessible planting spots may be poorly distributed, a fact that may lead to a poor distribution pattern of planted trees.

If the logistical problems can be overcome, and seedlings are planted, it is likely that frost heaving will be a threat, because much of the plantable area on a damaged peatland will be 'black muck'. Competing vegetation may also become a problem, although large stock may overcome this.

The aforementioned problems all deal with the difficulty of re-establishing trees on a damaged site. A further question, which is not addressed by this study, is whether there is any permanent or transient reduction in the basic productivity of the site as a result of site damage. For instance, foresters believe that machine ruts may block surface drainage of water and cause ponding (Gemmell 1981, Jeglum et al. 1983).

This report does not consider disturbance and slash at the landing and road areas, where it may be substantial. Observations indicate that 10 to 15% of the total cutover area may be in such a condition.

Planning to Reduce Site Damage

Careful planning of the harvesting operation may reduce site damage considerably. A prerequisite for planning is good site type information. For the strategic decision of scheduling areas for winter and summer harvest, relative proportions of site types in an area must be known. Any area with a significant proportion of peatland or transitional sites should be scheduled for winter harvesting. If *Ledum* (OG 11) and feathermoss-*sphagnum* (OG 8) operational groups predominate, however, summer harvesting with high-flotation tires may be possible.

In the tactical phase of planning harvesting layout, when summer harvesting on peatlands cannot be avoided, site type maps are needed. Logging roads should be laid out so that *Alnus* herb-poor (OG 12) and *Alnus* herb-rich (OG 13) areas are at the rear of the logging chance, where they will sustain little or no skidder traffic. In the common situation in which narrow alder drainageways (*Alnus* herb-poor (OG 12) and *Alnus* herb-rich (OG 13) areas) dissect an area that is predominantly of the *Ledum* operational group (OG 11), skidways should not cross the drainageway, but should be oriented in parallel, and the wood winched out of the drainageway. Such a technique is much less likely to cause disruption of surface flow, as would occur if traffic crossed the drainageway.

Some of these recommendations have been made previously, but in the context of trafficability for harvesting. Barrett (1966) suggested that 'road lines should be arranged so that flat draws and alder swails [sic] fall along the dividing line between neighbouring roads'.

Good planning can minimize site damage, but some problem areas will be recognizable only in the course of operations. Proper training of equipment operators to recognize sensitive sites and to avoid damaging practices, such as sharp turns by wheeled skidders (Barrett 1966), can further reduce site damage problems.

Minimizing site damage was not a main objective of any of the harvesting methods studied, and therefore it seems likely that selection of equipment and operating techniques with the objective of reducing site damage would result in further gains.

SUMMARY

In FEC operational group 12, summer harvesting with narrow-tired skidders produces greater cover of deep ruts than summer harvesting with wide-tired skidders or winter harvesting. There are more deep ruts in operational group 12 than in operational group 11 when summer harvesting is undertaken with narrow-tired skidders.

In summer harvesting with wide tires, disturbance is concentrated on skidways. The deep rut cover on these skidways may be similar to the cover that occurs throughtout areas harvested in the summer with narrow-tired skidders.

On susceptible sites, some degree of site damage can occur during winter harvesting, if frost penetration and snow cover are not deep.

The susceptibility of the FEC operational groups to site damage increases in the following order: OG 8, OG 9, OG 11, OG 12, and OG 13.

Full-tree harvesting in summer with wide-tired skidders leaves less slash than does tree-length harvesting with narrow-tired skidders in the same season.

Site damage and slash make it more difficult to regenerate peatlands after harvesting. Careful planning of harvesting operations, operator training, and modification of harvesting equipment and techniques can reduce site damage.

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