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Uneven-aged Silviculture for Peatland Second-growth Black Spruce: Biological Feasibility

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ABSTRACT

Second-growth peatland black spruce (*Picea mariana* [Mill.] B.S.P.) stands typically possess an uneven-aged structure, suggesting that uneven-aged management may be a possibility. As such, a project was initiated near Cochrane, Ontario, to examine the feasibility of the selection silviculture system in second-growth peatland black spruce stands, last harvested 64 years ago. A cut-to-length harvesting system was used to harvest at light, medium, and heavy intensities during the winter of 1994. A higher density of stems >10 cm DBH, and greater basal area and volume remained after the light and medium treatments than after the heavy treatment. Stocking and density of black spruce advance growth (stems <1.3 m tall) remained high after all treatments. The majority of trees were undamaged after the harvest, and the main type of damage was sheared branches. The postharvest diameter distribution and spatial structure in the light and medium harvests are suitable for continued implementation of selection silviculture. As such, selection silviculture appears to be biologically feasible for second-growth black spruce stands growing on FEC ST 11 and ST 12 site types.

RÉSUMÉ

Comme les peuplements d'épinette noire (*Picea mariana* [Mill.] B.S.P.) de seconde venue des tourbières présentent habituellement une structure inéquienne, il serait sans doute possible de les aménager en futaie jardinée. Pour vérifier la faisabilité de ce régime sylvicole dans de tels peuplements, nous avons entrepris, près de Cochrane (Ontario), un projet portant sur des pessières noires où la dernière coupe remontait à 64 ans. Durant l'hiver 1994, nous avons soumis ces pessières à des récoltes par bois tronçonné d'intensité légère, moyenne ou forte. Par rapport à la récolte de forte intensité, les récoltes d'intensité légère ou moyenne ont laissé sur le terrain une plus grande densité de tiges à dhp de 10 cm, une plus grande surface terrière et un plus grand volume. La densité relative et la densité de peuplement de la régénération préétablie d'épinette noire (tiges de 1,3 m de hauteur) est demeurée élevée après toutes les intensités de récolte. La majorité des arbres n'ont subi aucun dommage au cours des travaux, les branches coupées constituant le principal type de dégât. La répartition des diamètres et la structure spatiale produites par les récoltes d'intensité légère ou moyenne se prêteraient à une continuation de la sylviculture en futaie jardinée. Il semble donc que ce régime sylvicole pourrait convenir, du point de vue biologique, aux pessières noires de seconde venue des types stationnels 11 et 12 de la Classification des écosystèmes forestiers.

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INTRODUCTION

In northeastern Ontario, black spruce (*Picea mariana* [Mill.] B.S.P.) commonly occurs on peatland sites. In the Clay Belt section, one-half of the spruce working group is found on peatlands; in the rest of the region, one-third of the spruce working group occurs on peatlands (Ketcheson and Jeglum 1972). Second-growth black spruce stands on peatlands, typically comprising Forest Ecosystem Classification (FEC) (McCarthy et al. 1994) Site Types 11 and 12 (*Ledum* and *Alnus*/herb poor), have developed an uneven-aged and uneven-sized structure (Groot and Horton 1994). This structure has resulted from past cutting practices (saw and horse logging) that largely removed the overstory of the mature stands, but left black spruce advance growth and residuals.

Since black spruce advance growth is abundant in many natural peatland forests (Groot 1984), preservation of this growth has become the predominant forest regeneration method on such sites. Using this method, most or all of the merchantable trees are removed, and if sufficient advance growth is preserved during harvesting, the site can be considered regenerated immediately after harvest (Groot 1995). This regeneration method is also applicable to second-growth stands, which often contain a high stocking of advance growth. The structure of second-growth stands suggests that uneven-aged silviculture may be an additional option for these areas.

Uneven-aged silviculture has previously not been attempted in northeastern Ontario, and forest industries and natural resource managers have no information on effectiveness or cost. A project was initiated in 1993 to provide information on uneven-aged silviculture in second-growth peatland black spruce. The project investigated the use of a cut-to-length harvesting system (FMG Timberjack 1270 single-grip harvester and 1010 forwarder) and its ability to preserve advance growth and maintain the uneven-aged structure.

The objectives of the project were to ascertain harvesting costs, productivity, and equipment suitability; to determine damage to residuals and advance growth; to forecast stand structure and growth; to perform an analysis of wood supply implications; and to transfer technology relating to harvest equipment and techniques required to implement uneven-aged silviculture. The project team consisted of the Canadian Forest Service (CFS), Great Lakes Forestry Centre; Abitibi-Price Inc. (API) of Iroquois Falls, Ontario; and the Forest Engineering Research Institute of Canada (FERIC). In addition to fulfilling the research objectives of this project, operator training of API employees was to occur simultaneously.

This report describes the structural and mensurational characteristics of the stands before and after harvest, examines damage to residual trees and advance growth, and assesses the biological feasibility of uneven-aged management for peatland second-growth black spruce.

METHODOLOGY

Study Area Description

The study site, located in the Northern Clay Section of the Boreal Forest Region (Rowe 1972), 30 km east of the town of Cochrane, in Stimson Township (49°07'N, 80°36'W), is located just south of the intersection of Highway 652 and the Northwest Industrial Development Road. The study was carried out in peatland second-growth black spruce dominated stands. These stands, which are now nearing maturity, originated mainly from advance growth and residuals left after a harvest in the winter of 1929–30. The current stands are predominantly FEC Site Types 11 and 12 (*Ledum* and *Alnus*/herb poor) (McCarthy et al. 1994). Density of trees >1.3 m in height averaged 5 537 stems/ha, while basal area averaged 25 m^2/ha. Black spruce accounted for 89 percent of the stem density, bal-sam fir (*Abies balsamea* [L.] Mill.) 10 percent, and tam-arack (*Larix laricina* [Du Roi] K. Koch) 1 percent. The total height of the dominant layer was 17 m, and merchantable volume averaged 101.8 m^3/ha. The mean density and stocking of black spruce advance growth (stems <1.3 m in height) was 16 900 stems/ha and 76 percent, respectively. Peat depths ranged from 10 to 100 cm, and averaged 65 cm.

Harvest Treatments

The following harvest treatments were applied in three replications of 3.75 ha units: i) light harvest: planned 35 percent basal area removal (100 percent within equipment trails and 20 percent between trails), ii) medium harvest: planned 50 percent basal area removal (100 percent within equipment trails and 40 percent between trails), and iii) heavy harvest: planned 100 percent removal of all merchantable stems (Fig. 1). Designated trees between the corridors were removed by the harvester. For each treatment, a diameter limit was established using preliminary diameter and basal area data collected from all of the harvest blocks. Using the percentage of basal area to be removed, it was calculated that for the light

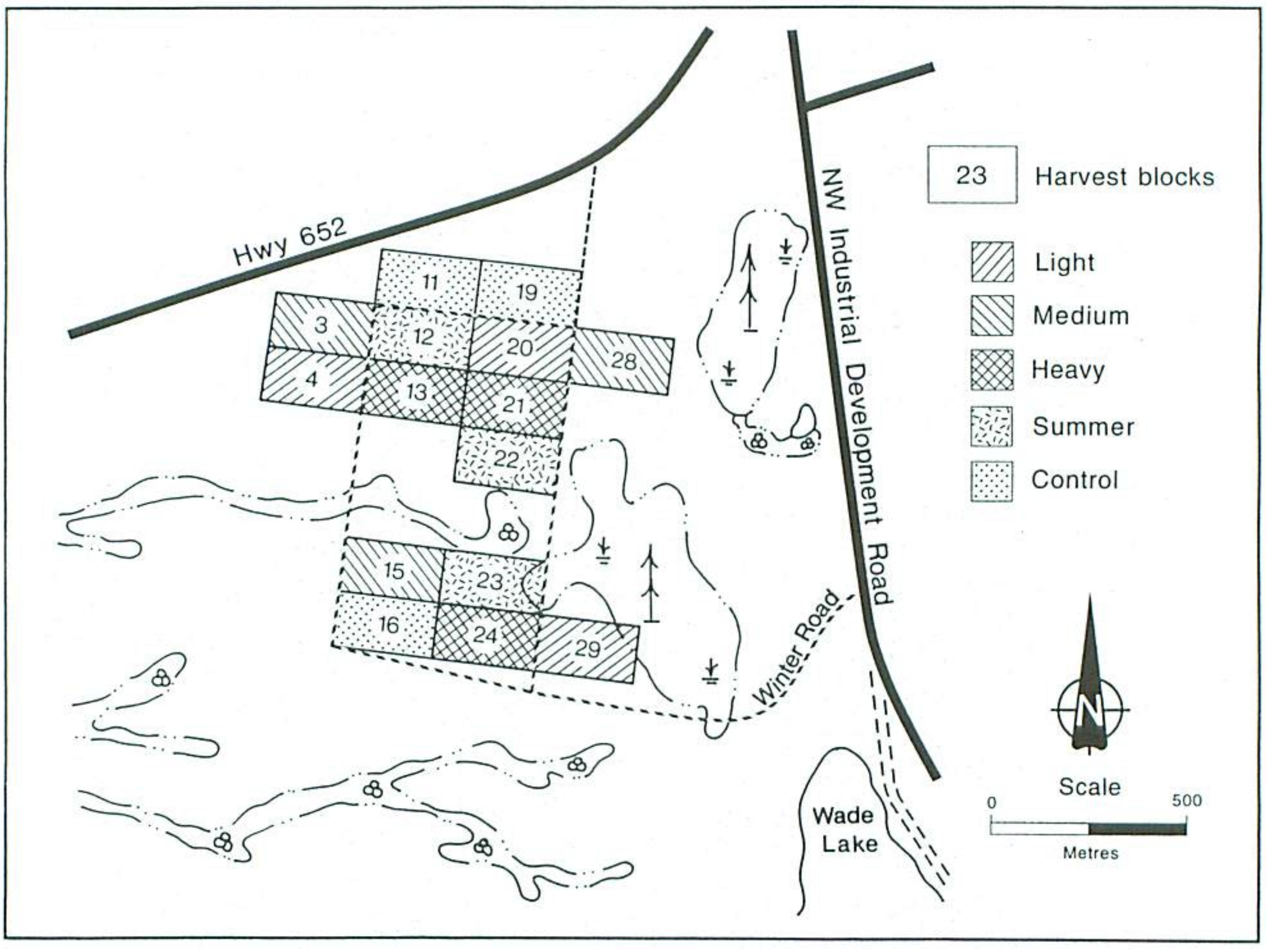

Figure 1. Harvest block layout of the study area.

harvest, all trees greater than 18 cm DBH were to be harvested; for the medium harvest, all trees greater than 15 cm were to be removed; and for the heavy harvest, all merchantable trees (i.e., greater than 10 cm) were to be cut.

Once the diameter limits were established, harvest treatments were randomly assigned to harvest blocks. For treatments i) and ii), the trees to be removed were marked to assist the harvester operator.

The harvest treatments were carried out using a cut-to-length system single-grip harvester (Timberjack FMG 1270) and a forwarder (Timberjack FMG 1010) during the winter of 1994 (January–February) The harvester has an overall width of 2.9 m and its boom has a reach of 8.2 m. The forwarder overall width is 2.8 m. Its' boom has a 7-m reach, and the bunk can handle logs up to 5 m in length.

Black spruce and any large balsam fir were the only species harvested. Tamarack was left standing, as it was an unmerchantable species. Machinery travel was restricted to narrow trails (about 4 m wide). Trail placement was left to the operator's discretion, so as to avoid traveling through thicker concentrations of advance growth. The travel of the machines was parallel to the long axis of the block. Trees were felled and then brought in front of the harvester for delimbing. Slash was deposited on the trail in front of the harvester. The stems were bucked into 5.2-m lengths, to a top diameter of 4–6 cm, and placed perpendicular to the trail in areas with little advance growth. The forwarder retrieved the bucked lengths, and transported them out of the blocks to be piled directly onto trailers, if available, or at roadside. Machine operators were told to avoid damaging the residuals as much as possible. This was done by controlling the swing of the booms, and by planning in advance where to travel, where to drop the felled trees, where to process them, and where to pile the bucked lengths. By choosing, as often as possible, open areas with little advance growth, damage to the residuals was reduced.

Three additional blocks were chosen for a summer cut at the medium harvest intensity. The harvest was never completed because of extensive rutting damage and restrictions in machinery operability, caused by the soft terrain.

Assessments

Prior to harvesting, all the cut blocks were assessed. Each harvest block measured 150 m along the north–south boundaries, and 250 m along the east–west borders. In Replication I, two plots, measuring 50 m (N–S) by 10 m (E–W), were established inside each block. Each plot was located 75 m in from the eastern and western borders and 50 m in from the northern and southern borders. Thus, plots were 80 m apart. In Replications II and III, a single 10-m by 50-m plot was established directly in the middle of the block, 50 m from the northern and southern borders, and 120 m in from the eastern and western boundaries.

Each plot was divided into 125 quadrats, each measuring 2 m by 2 m. Within each quadrat, the species and diameter at breast height (DBH) of all trees >1.3 m in height were recorded. In Replication I, all of the trees taller than 1.3 m were tagged and given a tree number. In Replications II and III, trees were not tagged.

Regeneration data was collected in all of the quadrats along the western side of the plot. All advance growth <1.3 m in height was tallied according to species and height, and the percentage of alder (*Alnus rugosa* [Du Roi] Spreng.) cover was noted. In all, there were 25 regeneration quadrats per measurement plot.

Postharvest assessments were carried out one growing season after harvest in the same plots, from late July to the end of August, 1994. For the remaining trees >1.3 m in height, species and DBH were recorded. Additionally, every tree was given a damage rating of either: undamaged, harvested, dead, broken stem, broken top, sheared branches, scraped (less than one-half of the stem), scraped (more than one-half of the stem), sun scorched, or multiple injuries. The harvested and dead ratings were only used in Replication I, where tree numbers were assigned.

The regeneration quadrats were also reassessed. Species and height of all residuals <1.3 m in height, as well as the current annual height increment, were recorded. A damage rating was also given for all advance growth. The percentage of alder cover was reevaluated, and the percentages of slash, shallow rutting, and deep rutting were also determined.

The heights and diameters of a sample of trees throughout the study site were collected to develop a local height equation. The heights of at least three trees per diameter class were measured.

Analysis of Data

For trees >1.3 m in height, pre- and postharvest density, basal area, total volume, and merchantable volume were calculated for the total conifer species together. The stem density was divided into small trees ($\leq$10 cm DBH), large trees (>10 cm DBH), and all trees totaled. The ratio of postharvest to preharvest was calculated for each variable.

Pre- and postharvest basal areas were determined for each quadrat, which was given an XY coordinate, where (1 m, 1 m) was the northwestern quadrat and (49 m, 9 m) was the southeastern quadrat. Quadrat basal areas were plotted in a scatter plot using the Number Cruncher Statistical System (NCSS) software (Hintze 1991). The location of harvest trails could be identified from the patterns of reduction in basal area.

The total and merchantable volumes were calculated using a modification of Honer's volume equations (Honer et al. 1983). Honer's volume equations are as follows:

$$V_t = 0.0043891\ DBH^2\ (1 - 0.04365\ b_2)^2 / [c_1 + (0.3048\ c_2 / Height)] \quad (1)$$

$$V_m = V_t\ (r_1 + r_2\ X_3 + r_3 X_3^2) \quad (2)$$

where: $X_3 = t^2\ DBH^{-2}\ (1 - 0.04365\ b_2)^{-2}(1 + S / Height)$

where: V_t = total volume (m^3);

V_m = merchantable volume (m^3);

DBH = diameter at breast height (cm);

b_2 = taper coefficient (species specific, found in Honer 1983);

c_1, c_2 = regression coefficients (species specific, found in Honer 1983);

Height = total height (m);

r_1, r_2, r_3 = regression coefficients (species specific, found in Honer 1983);

t = top diameter (cm) (assumed 4 cm); and

S = stump height (m) (assumed 0.15 m).

Honer's merchantable volume equation uses an adjusted squared diameter ratio, making the volume a function of the top diameter and stump height (Honer et al. 1983).

The modification to Honer's equations was the replacement of the height variable (H) with a derived local height equation (Maurer 1993). A height growth model, developed by Schumacher (1939), was used to define local height as a relationship to diameter. The growth model is:

$$Height = 1.3 + (A \cdot [e^{(-B / DBH)}]) \quad (3)$$

where: A and B are regression constants and e is the base of natural logarithms (Maurer 1993). Height is in meters; DBH is in centimeters. Equation (3) was then fitted to the observations of height and DBH using nonlinear regression, with the NCSS statistical package (Hintze 1991). Once A and B were determined, Equation (3) was inserted into Equations (1) and (2) to calculate total and merchantable volume, using the DBH data collected in the pre- and postharvest assessments.

For advance growth (i.e., trees <1.3m in height), pre- and postharvest densities and stockings were calculated for black spruce and balsam fir. Again, postharvest/preharvest ratios were obtained.

The types of damage that occurred with residual trees and advance growth were tallied, and the percentage of the total of each damage rating was calculated. Because of the small percentages of some of the ratings, broken top and broken stem were joined into broken stem/top; scraped (less than one-half of the stem) and scraped (more than one-half of the stem) were combined into scraped stem. Damage percentages were grouped into small trees (≤10 cm DBH), large trees (>10 cm DBH), and all trees totaled.

The means of all the pre- and postharvest variables, and their ratios, were compared by harvest treatment using a one-way analysis of variance (ANOVA) with $\alpha = 0.05$. This was done using the NCSS statistical package (Hintze 1991).

RESULTS

Diameter Distribution

Blocks assigned for harvesting at all three intensities displayed an inverse J-shaped preharvest diameter distribution, with high stem densities in the lower diameter classes gradually dropping to low densities in the higher classes (Fig. 2). Diameters are grouped in 2-cm classes. The value given to each class is the upper diameter in the range (i.e., the 8-cm class includes all diameters from 6.1 cm to 8.0 cm). The number of stems in the lower (2–6 cm) classes showed considerable variation among harvest intensities. From the 8-cm class and up, all three intensities follow the same general pattern with densities dropping to zero around the 22-cm class. Additionally, the light harvest had a few larger trees in the 24–28 cm classes. The stands were dominated by black spruce, with balsam fir and tamarack making up a small proportion within each harvest intensity. Balsam fir accounted for a larger portion of the total in the light and medium harvest blocks than in the heavy harvest. All balsam fir were in the smaller diameter classes, displaying an approximate inverse J-shaped curve distribution. Tamarack density was higher in the heavy harvest blocks. In the light and medium intensity treatments, tamarack was scattered throughout the diameter classes, all in very small numbers.

The inverse J-shaped diameter distribution persisted after harvest at all three intensities (Fig. 3). Black spruce, balsam fir, and tamarack densities decreased overall, although all species roughly maintained the same

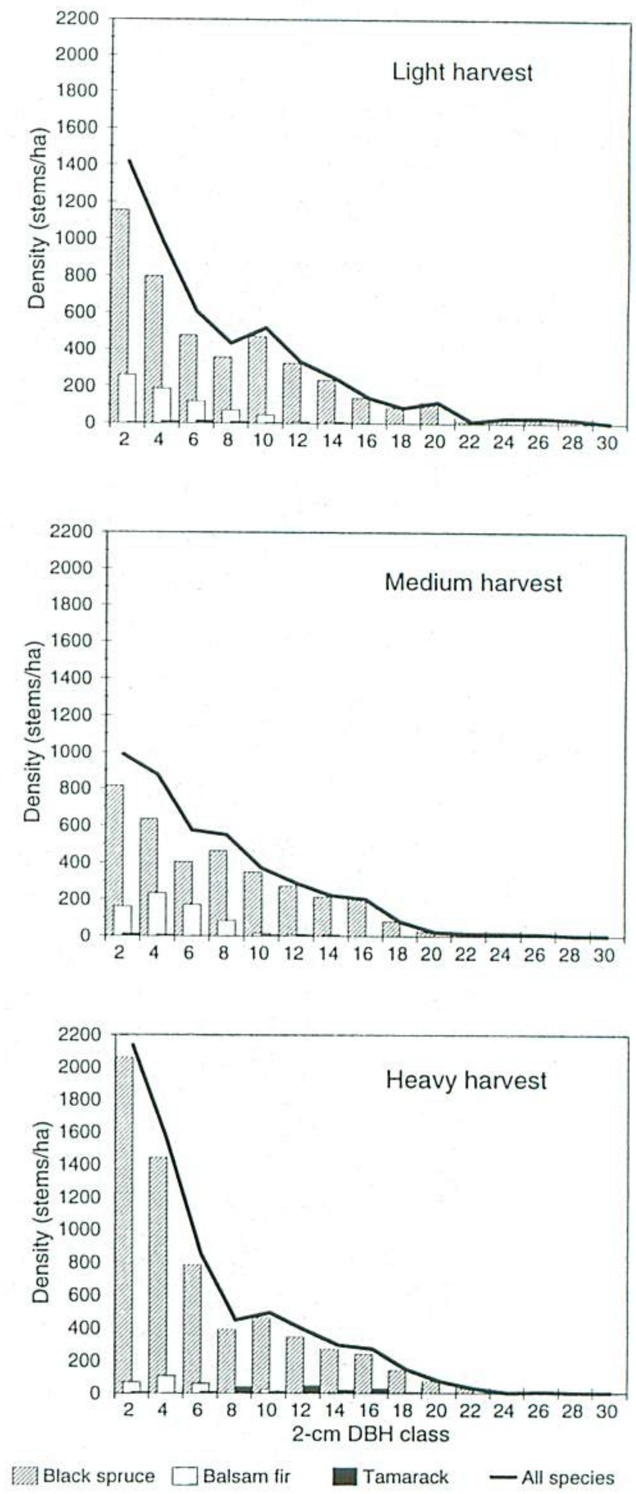

Figure 2. Diameter distribution of conifer species prior to harvesting at three different intensities. (DBH value is the upper diameter of the range.)

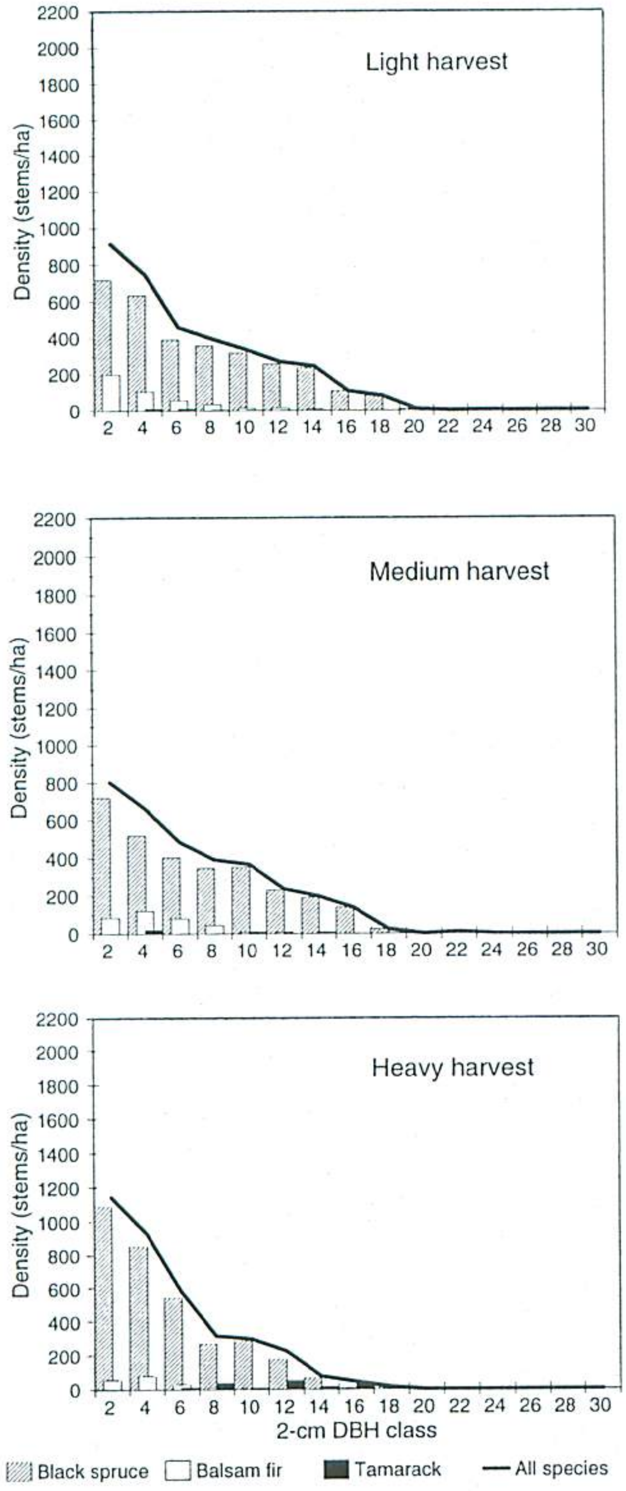

Figure 3. Diameter distribution of conifer species one growing season after harvesting at three different intensities. (DBH value is the upper diameter of the range.)

preharvest distribution. In the light harvest blocks, total species and black spruce densities dropped to a new zero above the 18-cm class. In the medium blocks, densities dropped sharply at the 16-cm class, and to zero above 18 cm. With the heavy intensity treatment, the black spruce density was near zero only after the 14-cm class, above the harvesting limit of 10 cm.

In comparison to the preharvest distribution, the postharvest curves for each harvest treatment showed a smoother drop through the range of diameter classes (Fig. 4). All three intensities displayed approximately the same density structure, with the exception of the upper limits of the diameter classes.

Residual Trees

The total preharvest density of all conifer species varied, although not significantly, among the harvest treatments, with a greater density in the heavy harvest (Table 1). This was due to a greater density of both large (>10 cm DBH) and small (≤10 cm DBH) trees. The total postharvest density of all trees and for small trees did not vary significantly among treatments, but instead showed a high degree of similarity. The postharvest density of large trees, however, did vary significantly among treatments, with the greatest density in the light harvest and the lowest density in the heavy harvest. Similarly, the harvest method did not significantly affect the ratio of postharvest to preharvest density for all trees or for small trees, but it did affect the

Table 1. Density of all conifer species prior to and one growing season after harvesting at three different intensities.

	Density by harvest method (stems/ha)			Probability of exceeding F in ANOVA
	Light	Medium	Heavy	
<10 cm DBH				
Preharvest	3 967	4 010	5 467	0.26
Postharvest	2 843	2 703	3 273	0.84
Ratio	0.67	0.65	0.60	0.79
>10 cm DBH				
Preharvest	993	963	1 210	0.28
Postharvest	707	603	360	0.05*
Ratio	0.70	0.63	0.30	0.005**
Total stems				
Preharvest	4 960	4 973	6 677	0.19
Postharvest	3 550	3 307	3 633	0.95
Ratio	0.68	0.65	0.54	0.40

* Significant at $\alpha = 0.05$
** Significant at $\alpha = 0.01$

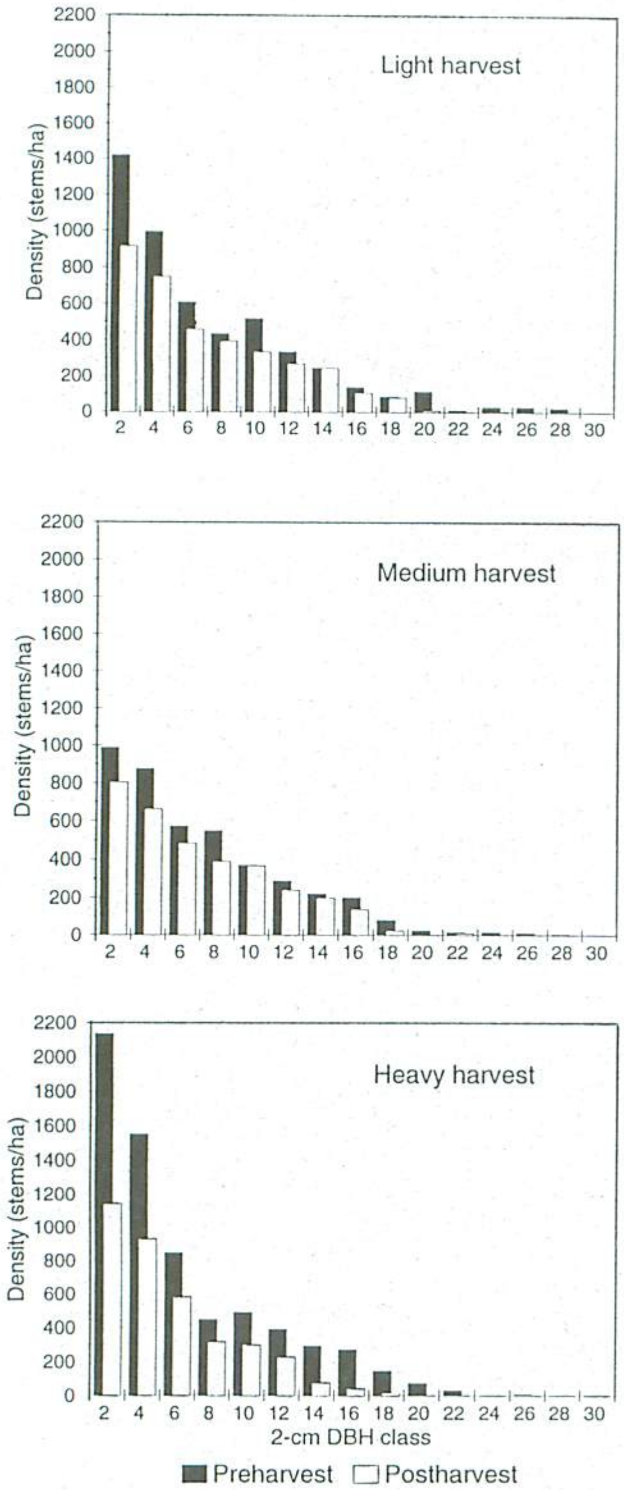

Figure 4. Comparison of diameter distribution of all species before and after harvesting at three different intensities. (DBH value is the upper diameter of the range.)

ratio for large trees. In the heavy harvest, 30 percent of the large trees were present after harvest, whereas in the light harvest, 70 percent of the large trees remained.

Preharvest basal area did not differ among harvest treatments (Table 2). There was evidence of decreasing postharvest basal area with increasing harvest intensity, but differences among treatments were not significant. The ratio of postharvest to preharvest basal area showed some evidence ($p = 0.11$) of difference among treatments, with approximately 60 percent of the basal area remaining after light and medium harvests, and 35 percent remaining after the heavy harvest.

The spatial distribution of basal area throughout the harvest blocks of all three harvest intensities was highly variable (Fig. 5). Comparison of pre- and postharvest distributions revealed the placement of the harvest trails. The harvest trails were 4–6 m wide. An average of four trails, spaced 8–16 m apart, crossed the 50-m length of the plots. Trail placement took advantage of natural open areas with a low density of trees and, as a result, the harvest trails were usually not straight.

Preharvest total volume did not vary significantly among treatments (Table 3). Both postharvest total volume and the ratio of postharvest to preharvest total volume showed evidence of increasing from the heavy intensity to the light intensity harvest ($p = 0.12$ and 0.10, respectively). Merchantable volume followed the same patterns as did total volume (Table 4), but with significant differences among treatments. The heavy harvest removed more than 80 percent of the merchantable volume, whereas the light and medium harvests removed slightly less than 50 percent.

Advance Growth

Preharvest and postharvest black spruce regeneration (stems <1.3 m tall) density was greatest in the heavy harvest blocks. There was an intermediate density in the

Table 2. Basal area of all conifer species prior to and one growing season after harvesting at three different intensities.

Harvest method	Basal area (m^2/ha) Preharvest	Postharvest	Ratio
Light	24.93	14.95	0.59
Medium	23.03	13.64	0.59
Heavy	27.12	9.28	0.35
Probability of exceeding F in ANOVA	0.42	0.23	0.11

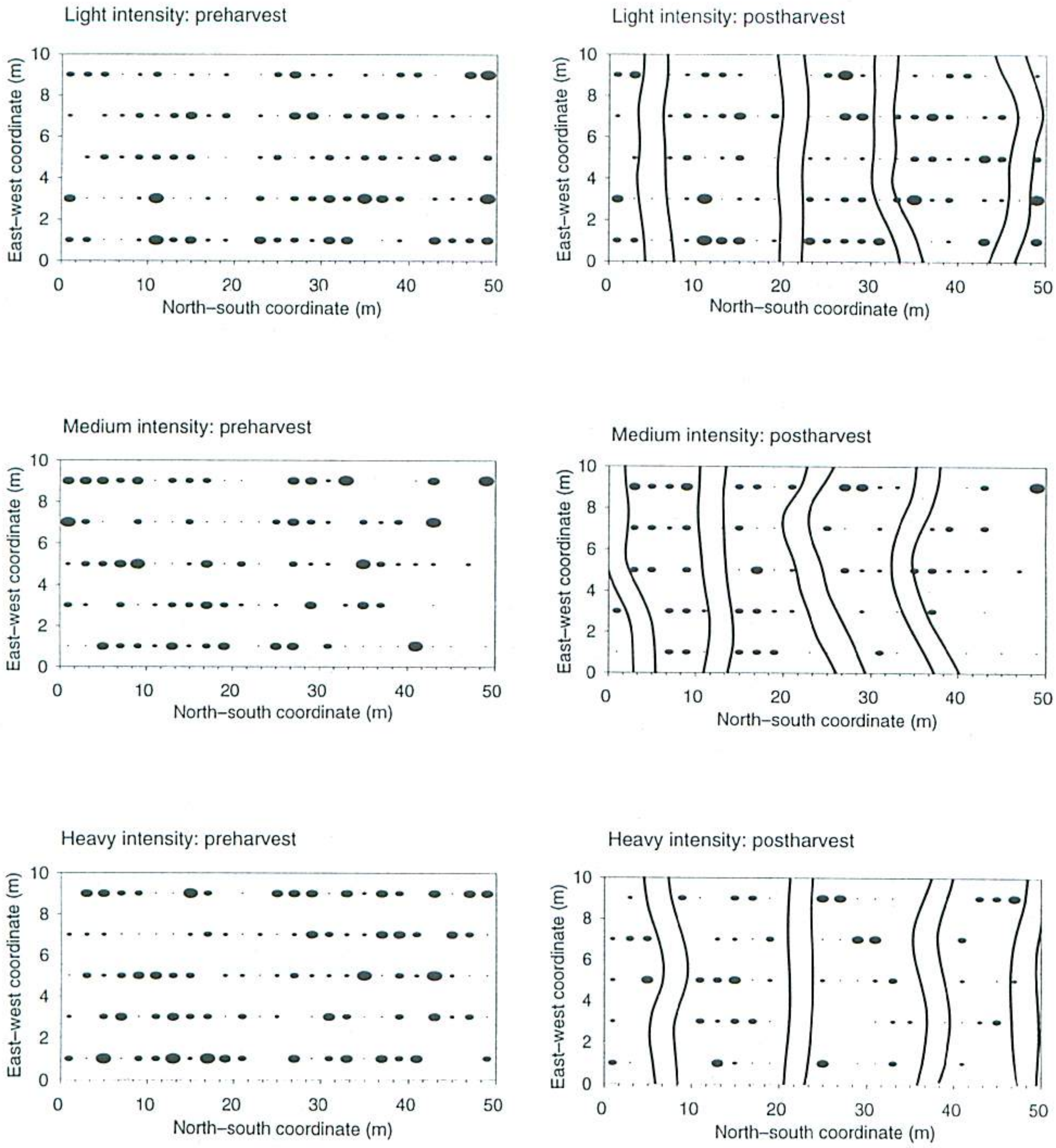

Figure 5. Examples of spatial distribution of preharvest and postharvest basal area per quadrat at three harvest intensities. Equipment trails are indicated on the postharvest plots.

light harvest and a lower density in the medium harvest, although differences were not significant in either case (Table 5). Reduction in black spruce regeneration also did not differ significantly among harvest treatments. Similarly, there was no significant difference in pre- and postharvest stocking or in the ratio of postharvest to preharvest (Table 6). Postharvest stocking averaged more than 60 percent for all treatments, and the proportion of the original stocking that persisted after harvest averaged more than 0.85 for all treatments.

The proportion of balsam fir density that survived harvesting was lower than for black spruce (0.57 vs 0.41, respectively). None of the measures of balsam fir density differed

Table 3. Total volume of all conifer species before and after harvesting at three different intensities.

Harvest method	Total volume (m^3/ha)		
	Preharvest	Postharvest	Ratio
Light	137.02	75.59	0.56
Medium	119.71	66.70	0.56
Heavy	141.77	40.20	0.29
Probability of exceeding F in ANOVA	0.40	0.12	0.10

Table 4. Merchantable volume of all conifer species before and after harvesting at three different intensities.

Harvest method	Merchantable volume (m^3/ha)		
	Preharvest	Postharvest	Ratio
Light	106.85	54.02	0.53
Medium	88.87	45.11	0.51
Heavy	109.65	22.69	0.21
Probability of exceeding F in ANOVA	0.30	0.04*	0.06

* Significant at $\alpha = 0.05$

Table 5. Density of black spruce advance growth prior to and one growing season after harvesting at three different intensities.

Harvest method	Density (stems/ha)		
	Preharvest	Postharvest	Ratio
Light	15 717	9 450	0.62
Medium	12 833	6 883	0.63
Heavy	22 150	10 183	0.47
Probability of exceeding F in ANOVA	0.34	0.29	0.56

Table 6. Stocking of black spruce advance growth prior to and one growing season after harvesting at three different intensities.

Harvest method	Stocking (percent - 4 m^2 basis)		
	Preharvest	Postharvest	Ratio
Light	75	69	0.92
Medium	73	63	0.86
Heavy	81	77	0.95
Probability of exceeding F in ANOVA	0.36	0.26	0.32

significantly among harvest methods (Table 7). Preharvest stocking of balsam fir showed some evidence of differences among harvest treatments (p = 0.07, Table 8), but postharvest differences were not significant.

Damage to Residuals

The majority of black spruce residuals were undamaged after the harvest (Table 9), and there was no significant difference among harvest treatments. The greatest damage category was sheared branches. The percentage of stems in this category differed significantly among harvest intensities for all stems >1.3 m tall, and there was evidence of differences for both the small and large tree subsets. For all stems and large stems, the percentage of sheared branches was least in the medium harvest. In the advance growth, 97 percent or more of the stems were undamaged, with no significant difference among treatments.

Most of the balsam fir advance growth was also undamaged (Table 10), and there was some evidence (p = 0.10) of difference among harvest intensities. The light treatment had the lowest percentage at 90 percent, and the medium and heavy harvest blocks exhibited 99 percent. Damage that did occur to advance growth included broken stems or tops, sun scorching, or multiple injuries. Balsam fir trees, however, sustained more damage than did the advance growth, with an average of 49 percent undamaged. Balsam fir in all three treatments were subjected to all forms of damage, with varying intensity. The major forms of damage were: broken stem or top (light, medium), scraped stem (heavy), sun scorched (all three treatments), and multiple injuries (light). It should be noted that only a few trees >10 cm survived throughout all three blocks, and thus were insufficient for statistical analysis.

DISCUSSION

The selection silvicultural system is defined as the removal of mature timber, usually the oldest or largest trees, by means of which the continuous establishment of reproduction is encouraged and an uneven-aged stand is maintained (Smith 1986). The possibility of selection silviculture

Table 7. Density of balsam fir advance growth prior to and one growing season after harvesting at three different intensities.

Harvest method	Density (stems/ha)		
	Preharvest	Postharvest	Ratio
Light	10 250	4 483	0.46
Medium	8 767	3 983	0.46
Heavy	8 117	3 233	0.30
Probability of exceeding F in ANOVA	0.47	0.75	0.61

Table 8. Stocking of balsam fir advance growth prior to and one growing season after harvesting at three different intensities.

Harvest method	Stocking (percent - 4 m^2 basis)		
	Preharvest	Postharvest	Ratio
Light	61	60	0.98
Medium	59	47	0.71
Heavy	47	36	0.65
Probability of exceeding F in ANOVA	0.07	0.15	0.30

in peatland black spruce was initially recognized in the first half of this century. Early recommendations from Minnesota were for frequent and light partial cutting (e.g., 30 m^3/ha every 20 years) in peatland black spruce (USDA Forest Service 1932, 1942). Heinselman (1959), however, argued against selection systems for black spruce on peatlands because of slow growth of regeneration in the understory. A possible exception was on poor sites, "where stands are open, layering is abundant, and only the largest trees are merchantable in any event".

Selection silviculture can be implemented at varying degrees of refinement. In this project, selection was based mainly on a diameter limit, which is a rather crude level of implementation. It can lead to a considerable variation in the degree of removal if there is variability in size structure within the stand. Heavy removal, and a resulting minimal level of growing stock, will occur in areas that are occupied mainly by larger trees. Little removal will occur in areas that are occupied mainly by smaller trees, even if these trees are dense.

In many forest types, the use of diameter limit cut control is also justifiably criticized because it can increase the proportion of suppressed trees with poor potential for release, trees with poor form, and trees of highly tolerant species. These criticisms have little validity for peatland black spruce stands, however. Black spruce can respond to release after long periods of suppression; trees in the understory do not become deformed; and at least on ST11 and ST12, there is little potential for conversion to more tolerant species.

A modified diameter-limit control is likely the appropriate level of refinement for implementing selection silviculture in peatland black spruce. Modification is required to permit the removal of some trees below the diameter limit from zones of excessive density. Trees above the diameter limit may occasionally be left if doing so will help to protect smaller trees or regeneration. Heavy removal in patches of larger trees may be appropriate for black spruce, because the risk of windthrow increases with tree size. Lack of removal in dense patches of smaller trees is less acceptable, however, since individual tree growth and establishment of regeneration is reduced.

An appropriate diameter limit should be determined based on stand characteristics, but the practical range of such limits is not wide. Trees less than 15 cm DBH have a low volume, but a high potential for future volume growth. Trees above 25 cm DBH have an increased risk of windthrow, and are rather rare on peatlands (*see* Groot and Horton 1994). Thus, diameter limits would normally be 15–25 cm, and most likely in the lower part of this range.

The major prerequisite for the successful implementation of selection silviculture in peatland black spruce is a suitable diameter distribution in the precut stand. Ideally, the whole range of diameters will be represented in an inverse J-shaped distribution. Large deviations from the ideal may defeat the success of the selection system over the long term. Diameter distributions are frequently suitable in second-growth stands, and commonly suitable in overmature natural stands on ST11 and ST12 sites (Groot and Horton 1994). The even-sized structure of younger, fire-origin stands would be unsuitable for the selection method.

Before harvest, the characteristics of black spruce stands in this project largely conformed to this prerequisite. One growing season after an initial harvest, the black spruce stands maintained the uneven-sized structure. For each harvest intensity, the diameters remained distributed over a range of diameter classes. The main difference among harvest intensities resulted from the diameter limits that were established. Few stems larger than 14 cm DBH remained after the heavy harvest, but significant numbers of larger stems remained after the medium and light harvests.

Table 9. Condition of black spruce residuals one growing season after harvesting at three different intensities.

	Condition by harvest method (percent of total)			Probability of exceeding F in ANOVA
	Light	Medium	Heavy	
Advance growth (<1.3 m tall)				
Healthy	97.0	97.6	98.7	0.39
Broken stem / top	1.3	0	0.4	0.30
Sheared branches	0.2	0	0.1	0.44
Scraped stem	0.4	0	0.1	0.59
Sun scorched	0.4	2.0	0.6	0.18
Multiple damage	0.8	0.5	0	0.66
Trees <10 cm DBH				
Healthy	71	74	67	0.26
Broken stem / top	7	6	4	0.40
Sheared branches	11	12	14	0.09
Scraped stem	2	2	2	0.97
Sun scorched	0	2	2	0.13
Multiple damage	9	4	11	0.39
Trees >10 cm DBH				
Healthy	68	78	53	0.31
Broken stem / top	2	0	1	0.38
Sheared branches	21	11	30	0.12
Scraped stem	6	5	7	0.97
Sun scorched	0	6	0	0.44
Multiple damage	3	0	8	0.26
Total of stems >1.3 m tall				
Healthy	68	75	65	0.37
Broken stem / top	6	4	4	0.28
Sheared branches	15	12	16	0.05*
Scraped stem	4	3	3	0.94
Sun scorched	0	4	2	0.34
Multiple damage	7	3	11	0.23

* Significant at $\alpha = 0.05$

The diameter limits for the three harvest intensities were designed to remove 35 percent (light harvest), 50 percent (medium), and 100 percent (heavy) of the basal area. The average removals observed on the measurement plots showed some substantial departures from these targets. For the heavy harvest (planned 100 percent removal), only 65 percent of the basal area was removed. Much of the remaining basal area was in trees of unmerchantable size, but some larger trees were also left when cutting them would have caused additional damage to advance growth or residual stems. The observed removals in both the light and medium harvests averaged 41 percent of the basal area, intermediate between the planned removals of 35 percent and 50 percent. Within-stand variability is likely responsible for this result, operating in two ways. First, as the stand structure varies, a fixed diameter limit will produce varying levels of removal. Second, measurement plots may not be representative of the entire block. A larger number of measurement plots would have been desirable.

The postharvest density of trees ≤10 cm DBH was virtually the same among harvest methods, whereas the density of trees >10 cm DBH was substantially more after medium and light harvests than after the heavy harvest. In all cases, the total number of stems remaining after harvest (ca. 3 500 /ha) seems more than sufficient to perpetuate a well-stocked stand.

Table 10. Condition of balsam fir residuals one growing season after harvesting at three different intensities.

	Condition by harvest method (percent of total)			Probability of exceeding F in ANOVA
	Light	Medium	Heavy	
Advance growth (<1.3 m tall)				
Healthy	90.3	98.4	99.5	0.10
Broken stem / top	3.5	0	0	0.33
Sheared branches	0	0	0	–
Scraped stem	0	0	0	–
Sun scorched	2.2	1.6	0	0.68
Multiple damage	4.0	0	0.5	0.25
Trees <10 cm DBH				
Healthy	50	63	33	0.57
Broken stem / top	15	10	0	0.43
Sheared branches	4	8	7	0.48
Scraped stem	0	2	33	0.47
Sun scorched	14	11	20	0.54
Multiple damage	18	7	7	0.12
Trees >10 cm DBH ***				

*** Insufficient data to perform statistical analysis. Only two balsam fir trees >10 cm DBH remained throughout all of the harvest blocks.

Similarly, the postharvest stocking and density of black spruce advance growth (averaging 71 percent and 8 800 stems/ha, respectively) satisfies the requirement for reproduction in a selection silvicultural system. And the lower basal areas resulting from the harvest will likely create conditions favorable for the establishment of additional regeneration. Heinselman (1959) observed increased stocking of black spruce regeneration with decreasing postharvest basal area on peatland sites in Minnesota. Likewise, stocking and density of black spruce advance growth in natural stands increase with a decreasing basal area (Groot 1984).

It is evident that second-growth black spruce stands on peatlands can be managed using a wide range of harvest intensities. The current practice of careful logging on peatland sites, usually with feller-bunchers and grapple or clam-bunk skidders, approaches the heavy harvest in this study. All merchantable trees are removed, but sufficient advance growth is preserved to regenerate the stand (Archibald and Arnup 1993, Groot 1995). The density of nonmerchantable residual stems present after careful logging varies considerably, depending upon the initial stand structure and the specifics of the harvest operation. The density is typically less, however, than that observed after the heavy harvest in this study.

For careful logging operations that preserve primarily smaller advance growth (i.e., <1.3 m tall), the stand will probably develop a size and age structure similar to that of even-aged stands. According to normal yield tables (Plonski 1974), the culmination of mean annual volume increment occurs at the age of 85 years on Site Class 2 and at the age of 105 years on Site Class 3. These ages are indicative of rotation lengths that could be expected if only the smaller advance growth is preserved.

The heavy harvest, and those careful logging operations that leave a substantial number of residual trees, will likely perpetuate an uneven-aged, uneven-sized stand structure. Because the heavy intensity removes most of the larger trees, only very long cutting cycles will be possible. The heavy harvest is probably similar in intensity to harvests of peatland black spruce stands earlier in the century. The development of second-growth stands after these harvests indicates that cutting cycles of 60 to 80 years may be expected.[1]

[1] Horton, B.J.; Groot, A. 1987. Development of second-growth black spruce stands on peatlands in northeastern Ontario. Govt. Can., Canadian Forestry Service, Sault Ste. Marie, ON. COFRDA Project 33001. Unpublished report.

The stand structure created by the medium and light harvests seems well suited to continued use of the selection silvicultural system. Trees are distributed across a wide range of diameter classes, and the diameter distribution retains an inverse J-shape. These harvests maintain a substantial density of larger stems and a considerable volume of wood on the site. Site occupancy may be sufficient for the annual volume increment to approach the maximum current annual volume increment (MCAVI) for these sites. A rough estimate of cutting cycle length can be obtained by dividing the difference between the postharvest total volume and the average preharvest total volume (133 m^3 ha^{-1}) by the MCAVI. For Site Class 2 (MCAVI = 3.4 m^3 ha^{-1} yr^{-1}), cutting cycles of 17 and 20 years result for light and medium harvests, respectively. For Site Class 3 (MCAVI = 2.4 m^3 ha^{-1} yr^{-1}), the corresponding cutting cycles are 24 and 28 years.

In practice, light and medium harvests would be expected to have more widely separated residual volumes than were observed in this project. Correspondingly, a greater difference in the length of cutting cycles for the two harvest intensities should be expected. These are crude estimates of cutting cycle lengths, and a conclusive evaluation must await long-term measurements of stand growth in this project. More refined early estimates are obtainable, however, using the forest growth and yield projection system ONTWIGS (Payandeh and Huynh 1991). Analyses using ONTWIGS will be described in a separate report.

If the objective is to maintain black spruce dominated stands, the selection method should likely be restricted to stands that are growing on nutrient-poor peatlands (ST11 and ST12). These site types are most likely to support uneven-aged stands of black spruce. On drier and richer sites (e.g., ST8 and ST13), balsam fir becomes a more important component of the stand, and a selection harvest may favor this species. Black spruce regeneration is less abundant on richer sites as well (Groot 1984), making it difficult to maintain a suitable stand structure over the long term.

Harvesting in winter was an advantage in protecting residual trees and advance growth. The frozen peat supported repeated use of the same trails and snow helped to preserve smaller advance growth in the trails. Black spruce and balsam fir advance growth suffered little damage from harvesting, with 90 percent or higher of the total remaining stems undamaged. Very cold weather (-40°C in the daytime) was a factor in the major type of damage observed. Tree branches become very brittle at low temperatures, and even light contact by the equipment booms or by falling trees caused them to shear. There was a significant difference in the amount of shearing damage between harvest levels. Such damage would be lessened in summer. Frozen tree trunks are more resistant to damage from abrasion; however, the incidence and severity of scraped stems would likely increase in summer.

The higher level of shearing in the heavy treatment is understandable, because the increased harvest activity in the heavy blocks leads to greater chances of damage to neighboring trees. In following that line, the medium harvest should have the second highest level of shearing damage, when in fact it had the lowest amount. This is likely a result of the greater density of residuals in the light blocks. More trees are being left, and the higher density of residual trees creates a more confined working environment. Any tree being harvested would have an increased probability of damaging residuals. Improving operators' harvesting skills in partial cutting situations should reduce this type of damage.

No appreciable postharvest windthrow was observed in this study. Black spruce is highly susceptible to windthrow (Burns and Honkala 1990), however, and silvicultural systems for black spruce on any site type must take this fact into account. Experience from Minnesota indicates that light partial cutting (i.e., 25 to 40 percent of the original volume) does not greatly increase windthrow risk, whereas heavier cutting renders the residual trees highly susceptible to windthrow (USDA Forest Service 1932, 1936, 1942; LeBarron 1945; Heinselman 1957). Trees with a DBH in the 8–10 cm range can suffer heavy windthrow if the overstory is removed.

The lack of windthrow to date in this project may be attributable to several factors. Upland stands and those on very shallow peats are more susceptible to windthrow than are those on deeper peats (Heinselman 1957). Windthrow risk also increases with tree height (Smith et al. 1987), but tree heights in the project area were generally modest even before harvest, and the tallest trees were removed by harvesting. And, at least for the light and medium harvests, removals were not heavy enough to increase windthrow risk. The greatest risk for future windthrow is in the heavy harvest blocks. Small patches (usually <0.25 ha) of windthrow were noted prior to harvest. These occurred mainly on slight rises, where organic layers were thinner.

CONCLUSION

In an intensive application of the selection method, the objective is to achieve and maintain a diameter distribution that provides a balance between growth, harvested yield, and reproduction with a stable level of growing stock (Smith 1986). From a biological aspect, the use of selection silviculture in second-growth stands is definitely an additional option for forest managers in northeastern Ontario. The high density of black spruce trees and advance growth after the harvest is sufficient for regeneration purposes. No extra expenditure of time or money would be needed to fully regenerate the study site, according to Ontario guidelines (Arnup et al. 1988). If these results could be achieved in a commercial operation, even a complete removal of merchantable stems would still leave enough advance growth and residuals for regeneration purposes.

The feasibility of the selection silviculture system is dependent on the ability of harvesting equipment and techniques to minimize effects on residual trees. The cut-to-length equipment used in this trial was well suited to this task. Narrow equipment trails, which were widely spaced, limited the proportion of the harvest block occupied by these trails to about 20 or 25 percent. Trails were typically the width of the harvesting equipment, ranging from 4–6 m. A spacing of 8–16 m was observed between trails. The variability in distances corresponds to the operators' efforts to avoid damaging areas of advance growth by moving around thicker patches and by not overextending the reach of the boom, thereby maintaining greater control. Additionally, the compact and maneuverable felling head helped to reduce damage to residual trees.

This system will likely involve greater harvesting costs, but may find application in a variety of circumstances: areas of concern, reserves, situations where the maintenance of wildlife habitat is the primary objective, and areas where visible impacts of forest harvesting must be minimized. Corridor selection logging with this type of equipment could remove a portion of the larger merchantable trees, and yet leave enough trees to maintain stand integrity. Additionally, because of the historical progression of harvest outward from the mill, a high proportion of second-growth sites are within 60 km of the mill. Returning to these closer sites could notably reduce transportation costs of roadside wood to the mill. A variety of factors will play a part in determining the large-scale viability of using the single-grip harvester and forwarder as part of this silvicultural system. Additional reports will address future stand development, as well as the harvesting costs, productivity, and equipment suitability of this system. They will also consider the implications to wood supply.

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