9540

Regeneration and Surface Condition Trends Following Forest Harvesting on Peatlands

Arthur Groot

1996

NODA • EDNO
CANADA
ONTARIO
Northern Ontario Development Agreement
Entente de développement du nord de l'Ontario
Forestry • Foresterie

Funding for this report has been provided through the Northern Ontario Development Agreement's Northern Forestry Program.

Canadian Cataloguing in Publication Data

Groot, Arthur

Regeneration and surface condition trends following
forest harvesting on peatlands

(NODA/NFP Technical report; TR-26
Includes an abstract in French.
Includes bibliographical references.
"Funding for this report has been provided through the Northern
Ontario Development Agreement's Northern Forestry Program."
ISBN 0-662-24335-8
DSS cat. no. Fo29-42/26-1996E

1. Black spruce—Growth—Ontatio.
2. Black spruce—Seedlings—Ontario.
3. Peatland forestry—Ontario.
I. Great Lakes Forestry Centre.
II. Title.
III. Series.

SD397.B53G76 1996 634.9'75256 C96-980223-4

Catalogue No. Fo29-42/26-1996E
ISBN 0-662-24335-8
ISSN 1195-2334

Copies of this publication are available at no charge from:
Publications Services
Natural Resources Canada
Canadian Forest Service
Great Lakes Forestry Centre
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

Microfiche copies of this publication may be purchased from:
Micro Media Inc.
Place du Portage
165, Hotel-de-Ville
Hull, Quebec J8X 3X2

The views, conclusions, and recommendations contained herein are those of the authors and should be construed neither as policy nor endorsement by Natural Resources Canada or the Ontario Ministry of Natural Resources. This report was produced in fulfillment of the requirements for NODA/NFP Project No. 4026 "Low-cost regeneration methods for black spruce on peatlands".

Groot, A. 1996. Regeneration and surface condition trends following forest harvesting on peatlands. Nat. Resour. Can., Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON. NODA/NFP Tech. Rep. TR-26. 12 p. + appendix.

ABSTRACT

Advance growth amounts, vegetation cover, and soil surface conditions were measured prior to harvesting in 11 peatland black spruce stands near Kapuskasing, Ontario. Remeasurements were carried out one, three, six, and ten growing seasons after harvesting was conducted using three different methods. Approximately 80 percent of the preharvest stocking persisted after winter harvesting, 70 percent after summer harvesting with wide-tired skidders, and 60 percent after summer harvesting with narrow-tired skidders. Most advance growth mortality took place within the first year after harvesting, and advance growth quantities were stable thereafter. The establishment of substantial numbers of black spruce seedlings following harvest eventually eliminated differences in total black spruce stocking among the various harvest methods.

When equipment traffic is restricted to repeatedly used trails, an alternating pattern of taller and shorter trees can result. Thus, it appears likely that careful mechanized logging will lead to positively skewed diameter structures similar to those created earlier this century by horse logging.

Height growth increased with increasing tree height both for black spruce advance growth and for postharvest origin black spruce seedlings. Postharvest seedlings lagged advance growth in height development by 6 to 8 years.

Summer harvesting with narrow-tired skidders created more deep ruts than did the other harvesting methods. Within areas harvested by this method, survival of advance growth and postharvest seedling establishment decreased with increasing initial deep rut cover. Rapid invasion of *Sphagnum* spp., grasses, and sedges occurred on deeply rutted areas. Rut cover decreased rapidly and did not differ among the various harvest methods after six growing seasons. The better growth of postharvest origin black spruce seedlings on rutted areas was likely related to differences in site types between more and less heavily rutted areas, and to more fertile substrates created by heavy disturbance.

RÉSUMÉ

La régénération pré-établie, le couvert végétal et les conditions du sol superficiel ont été mesurés dans 11peuplements d'épinettes noires de tourbières, près de Kapuskasing (Ontario), avant leur exploitation, puis 1, 3, 6 et 10 saisons de croissance plus tard. Trois méthodes d'exploitation ont été employées. L'exploitation en hiver a préservé environ 80% de la régénération pré-établie, l'exploitation en été avec débusqueuses à pneus larges, environ 70%, et l'exploitation en été avec débusqueuses à pneus étroits, environ 60%. La mortalité de la régénération a surtout eu lieu au cours de la première année suivant l'exploitation, puis la densité de la régénération pré-établie est demeurée stable. L'établissement d'un nombre important de semis d'épinette noire après l'exploitation a éliminé, après un certain temps, les différences dans la densité de l'épinette noire entre les sites exploités selon les divesres méthodes.

Lorsque la circulation de l'équipement est confinée à des sentiers utilisés de façon répétée, il peut se former une alternance d'arbres plus grands et d'arbres plus petits. Il y a donc lieu de croire qu'une exploitation mécanisée bien planifiée entraînera une distribution asymétrique des diamètres avec un biais positif, comme la distribution créée il y a un siècle par l'exploitation avec chevaux.

On a observé que la croissance en hauteur augmentait en fonction de la hauteur des arbres, et ce tant pour les semis pré-établis d'épinette noire que pour ceux qui sont apparus après l'exploitation. Ces derniers accusaient un retard de 6 à 8 ans sur les premiers sur le plan du développement en hauteur.

Par ailleurs, la méthode d'exploitation estivale avec débusqueuses à pneus étroits a créé des ornières plus profondes que les deux autres méthodes. Dans les zones où elle a été utilisée, on a noté que plus le couvert initial des ornières profondes était important, moins la survie de la régénération pré-établie et l'établissement de la régénération post-exploitation étaient élevés. Les zones présentant des ornières profondes ont été rapidement envahies par des sphaignes (*Sphagnum* spp.), des graminées et des carex. Le couvert des ornières a rapidement diminué, et, après 6 saisons de croissance, il n'y avait plus de différence à ce chapitre entre les méthodes d'exploitation. La croissance supérieure de la régénération post-exploitation dans les zones d'ornières est probablement liée aux différences dans le type de site entre les zones orniérées plus profondément et moins profondément ainsi qu'aux substrats plus fertiles créés par les fortes perturbations.

TABLE OF CONTENTS

REGENERATION AND SURFACE CONDITION TRENDS FOLLOWING FOREST HARVESTING ON PEATLANDS

INTRODUCTION

Interest in low-cost forest regeneration methods is growing because of increasing constraints on the proportion of cutover land that can be regenerated by planting (Jeglum 1990). Black spruce (*Picea mariana* [Mill.] B.S.P.) growing on peatland sites is particularly well suited to low-cost regeneration methods. Peatland black spruce forests often contain abundant advance growth (Groot 1984), which can be preserved during harvesting if appropriate equipment and techniques are used.

Little is known about postharvest trends in stocking and density over time, however, or about height growth rates. Few comparisons have been made among different harvesting methods. Forest managers require this information to make decisions about the application of careful logging methods.

This report summarizes the results of a series of measurements carried out over a 10-year period on peatland sites harvested by three different methods. First-year postharvest site disturbance and slash conditions (Groot 1987) and sixth-year effects on advance growth (Groot 1995) have been reported previously.

The objectives of this report are to examine the long-term survival of black spruce advance growth and ingress of black spruce seedlings following harvesting by three methods; to document black spruce height growth rates following harvesting; to examine the initial height structure of regenerated stands; and to examine trends in surface conditions.

METHODS

Measurements

Pre- and postharvest measurements were carried out in peatland black spruce stands harvested by three different methods:

1. Felling with a feller-buncher (John Deere 693B equipped with a shear head) and full-tree skidding with a narrow-tired skidder (John Deere 540) in winter (abbreviated as W).
2. Felling with a feller-buncher (John Deere 693B equipped with a shear head) and full-tree skidding with a wide-tired (tire width of 127 cm) skidder (John Deere 540) in summer (abbreviated as S/w).
3. Felling manually with a chainsaw and tree-length skidding with a narrow-tired skidder (John Deere 540) in summer (abbreviated as S/n).

Three blocks were harvested by the W method, five by the S/w method, and three by the S/n method. The harvest blocks were located in commercial, black spruce-dominated peatland stands (predominantly FEC operational groups OG 11 and OG 12 [Jones et al. 1983]) with abundant black spruce advance growth in the understory. All stands were located within 80 km of Kapuskasing, Ontario.

Stand basal area averaged 22 m^2/ha. Peat depths ranged from 80 to 158 cm, and averaged 104 cm.

Harvesting took place between 1982 and 1984, in forest industry operations designed mainly for the efficient extraction of wood. All merchantable trees (about 10-cm diameter at breast height [DBH] or greater) were removed during harvesting.

All of the W and S/w blocks were treated with aerially applied herbicide (2,4-D at 2.0 to 2.4 a.i. kg/ha) 4 to 7 years after harvest as a part of operational vegetation management programs. This was done mainly to control speckled alder (*Alnus rugosa* [Du Roi] Spreng). S/n blocks were not treated with herbicide.

Sampling in each harvest block was carried out on five parallel line plots, each comprising 20 contiguous 2-m x 2-m quadrats. The long axis of the line plots was oriented perpendicular to the direction of planned machinery traffic. Plots were spaced at intervals of 15 to 25 m between the roadside landing and the back of the harvest block. Skidding distance varied from 75 to 200 m.

Measurements of advance growth and percentage cover of surface conditions and vegetation were carried out on each quadrat prior to harvesting and were repeated 1, 3, 6, and 10 years following harvesting. Ingress of trees was also recorded in the postharvest measurements.

On each quadrat, the number of trees <2.5 cm DBH was recorded for each species. The origin of black spruce trees was additionally classified as advance growth or postharvest seedling. Information from the previous assessment was used as an aid in cases difficult to classify. In assessments conducted three, six, and ten growing seasons after harvest, black spruce stems were classified as being of acceptable quality if they were upright and possessed a single leader with an annual height growth greater than 5 cm. In the tenth-year assessment, the total height and current height growth of all black spruce trees in each quadrat were measured.

The percentage cover of a number of surface conditions was recorded at each assessment: including, living *Sphagnum* spp. mosses; living feathermosses (*Pleurozium schreberi* [BSG.] Mitt., *Hylocomium splendens* [Hedw.] BSG., *Ptilium crista-castrensis* [Hedw.] de Not., *Dicranum* spp.); slash (from the first postharvest assessment onward); deep ruts (machine ruts that were deeply disturbed—often filled with water); and pioneer moss (mainly *Polytrichum* spp.—from the third-year assessment onward). The percent cover of a number of vegetation categories was also recorded, including speckled alder, Labrador-tea (*Ledum groenlandicum* Oeder), grasses (*Poaceae*), sedges (*Carex* spp.), and cattails (*Typha latifolia* L.).

Statistical Analyses

Analysis of variance was used to examine the effect of harvest method on a number of regeneration and surface-cover variables (*see* Appendix 1 and Tables A1 to A11 for details). Treatment effects were deemed significant for $p \leq 0.05$; $p \leq 0.15$ was considered to offer substantial evidence of treatment effects.

Height Growth Patterns

The Richards (1959) function was used to describe height growth–height relationships:

$$[1] \qquad \Delta H = nH^{m} - kH$$

where: ΔH is the current annual height growth (cm), and
H is the total height (cm) at the end of the previous growing season.

Equation [1] was fitted using tenth-year height growth for ΔH and ninth-year height (tenth-year height minus tenth-year height growth) for H. For each harvest method and tree origin (advance growth or postharvest seedling), trees were grouped into 10-cm total height classes (0 to 9.9 cm, etc.). Average ΔH was calculated for each height class–harvest method–tree origin combination that contained more than five trees. Nonlinear regression (Hintze 1991) of these average ΔH values on the height class midpoints was used to determine the coefficients n and m.

The integrated form of the Richards function is:

$$[2] \qquad H(t) = [n/k - (n/k - H_i^{1-m})e^{-(1-m)kt}]^{1/(1-m)}$$

where: $H(t)$ is the tree height (cm) as a function of time,
H_i is the initial tree height (cm) at $t = 0$, and
t is time (yr).

This equation was used to estimate the number of years that postharvest origin black spruce seedlings lagged advance growth in height development. The height of Year 10 postharvest origin black spruce was substituted for H_i, and then the value of t was determined such that $H(t)$ exceeded the Year 10 height of advance growth. This procedure was carried out for all stands, both for the average height of all trees and for the average height of the tallest tree in each quadrat.

RESULTS

Regeneration

Black spruce advance growth stocking and density decreased after harvesting by all three methods, and then remained relatively constant throughout the postharvest period (Fig. 1).

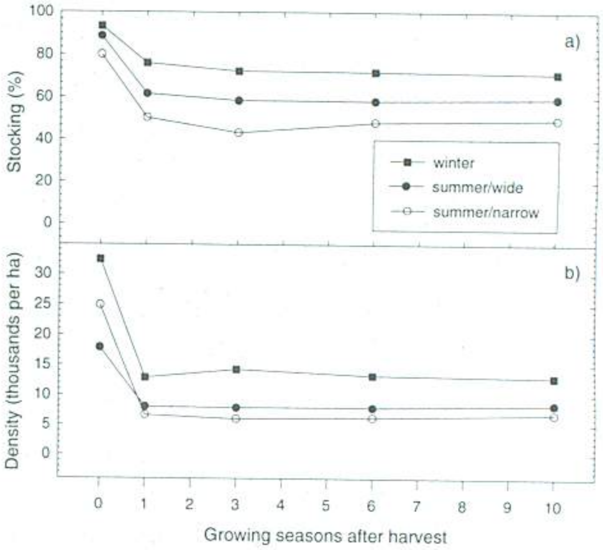

Figure 1. Black spruce advance growth stocking trends (a), and advance growth density trends (b).

Preharvest advance growth density differed significantly ($p=0.02$) among harvest methods (Table 1), with W blocks having the greatest densities and S/w blocks having the lowest densities. W blocks also had the greatest preharvest advance growth stocking, but differences in stocking among harvest methods were less pronounced ($p=0.09$) than were differences in density. Some evidence ($p<0.15$) of differences in advance growth stocking and density existed 1, 3, and 6 years following harvesting, with the greatest stocking and density occurring in the W blocks. Density of black spruce advance growth following S/n harvesting dropped below that following S/w harvesting. This was in reverse of the preharvest situation.

There was evidence ($p<0.15$) of differences among harvest methods in the ratio of postharvest black spruce advance growth stocking to preharvest stocking 1 and 3 years after harvest. Ratios were greatest in the W blocks and least in the S/n blocks (Fig. 2a, Table 1). The ratio of

Table 1. Summary of analyses of variance (*see* Appendix 1 for more details).

Variable	Probability of exceeding F in ANOVA				
	Year 0	Year 1	Year 3	Year 6	Year 10
Black spruce regeneration					
Advance growth stocking	0.090	0.066	0.070	0.114	0.106
Advance growth density	0.020	0.075	0.053	0.129	0.216
Postharvest:preharvest advance growth stocking	-	0.117	0.120	0.216	0.243
Postharvest:preharvest advance growth density	-	0.225	0.250	0.367	0.413
Acceptable advance growth stocking	-	-	0.960	0.105	0.104
Acceptable advance growth density	-	-	0.565	0.369	0.185
Proportion of stocked quadrats with acceptable advance growth	-	-	0.037	0.048	0.426
Proportion of advance growth stems of acceptable quality	-	-	0.001	0.008	0.506
Postharvest origin stocking	-	0.132	0.537	0.907	0.927
Postharvest origin density	-	0.362	0.331	0.663	0.749
Total stocking	0.090	0.084	0.187	0.428	0.786
Total density	0.020	0.078	0.067	0.193	0.388
Other species regeneration					
Balsam fir stocking	0.638	0.426	0.580	0.402	0.336
Balsam fir density	0.870	0.452	0.593	0.366	0.252
Tamarack stocking	0.453	0.430	0.333	0.351	0.331
Tamarack density	0.461	0.470	0.310	0.307	0.300
Trembling aspen stocking	-	-	<0.001	<0.001	<0.001
Trembling aspen density	-	-	<0.001	<0.001	<0.001
Surface conditions and vegetation					
Sphagnum cover	0.010	0.498	0.374	<0.001	<0.001
Feathermoss cover	0.003	0.011	0.064	<0.001	0.010
Pioneer moss cover	-	-	0.138	0.083	0.817
Slash cover	-	0.282	0.012	0.005	0.048
Deep rut cover	-	0.010	0.054	0.729	0.363
Speckled alder cover	0.048	0.780	0.568	0.236	0.756
Labrador-tea cover	0.051	0.736	0.240	<0.001	0.003

postharvest black spruce advance growth density to preharvest density was least in the blocks harvested in the summer with narrow-tired skidders (Fig. 2b), but differences were not significant ($p > 0.20$).

Within the S/n blocks, the ratio of tenth-year black spruce advance growth stocking to preharvest stocking decreased with increasing initial deep rut cover (Fig. 3).

The stocking and density of black spruce advance growth classified as acceptable increased steadily with time (Fig. 4). There was some evidence ($p < 0.15$; Table 1) that the stocking of acceptable advance growth differed among harvest methods in Years 6 and 10, with the greatest stocking in the W blocks and the least in the S/n blocks. No differences in the density of acceptable stems were evident among harvest methods.

The proportion of acceptable black spruce advance growth stems also increased with time (Fig. 5). Seventy-four percent of the stems were acceptable and 95 percent of the stocked quadrats were stocked with acceptable stems by the tenth year. These proportions differed significantly ($p < 0.05$; Table 1) among harvest methods in Years 3 and 6, with the greatest proportions generally occurring in blocks that had been harvested in summer using narrow-tired skidders. However, there was no evidence of differences in acceptable proportions among harvest methods by Year 10.

Stocking and density of black spruce that seeded in after the harvest increased steadily with time (Fig. 6), but no harvest method effects were apparent (Table 1). Year 10 stocking and density averaged 63 percent and 4 250 stems/ha respectively.

Within the S/n harvest blocks, tenth-year density of postharvest seedlings decreased with increasing initial cover of deep ruts (Fig. 7).

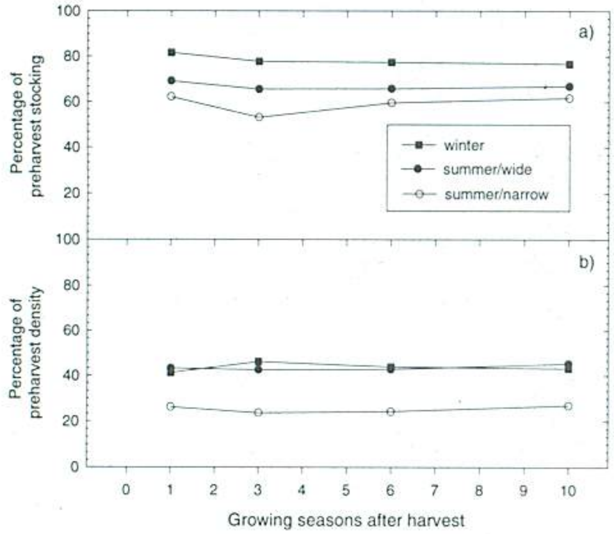

Figure 2. Trends in the ratio of: (a) postharvest black spruce advance growth stocking to preharvest black spruce advance growth stocking, and (b) postharvest black spruce advance growth density to preharvest black spruce advance growth density.

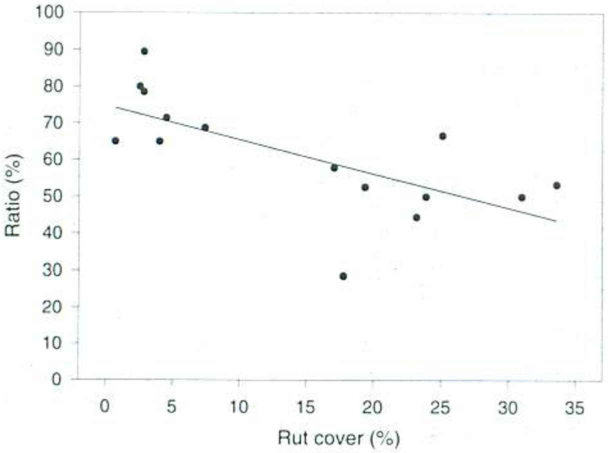

Figure 3. Ratio of Year 10 black spruce advance growth stocking to preharvest stocking versus initial deep rut cover for S/n blocks (the equation for the fitted line is: ratio = 74.8 - 0.929 x initial deep rut cover; R^2 = 0.46).

The stocking and density of all black spruce declined after harvest and increased steadily thereafter (Fig. 8). There was little evidence of any difference among harvest methods in the sixth- and tenth-year assessments (Table 1).

Balsam fir (*Abies balsamea* [L.] Mill.) stocking and density declined sharply after harvest and continued to do so over the 10-year period (Fig. 9). Balsam fir quantities did not differ among harvest methods at any time (Table 1).

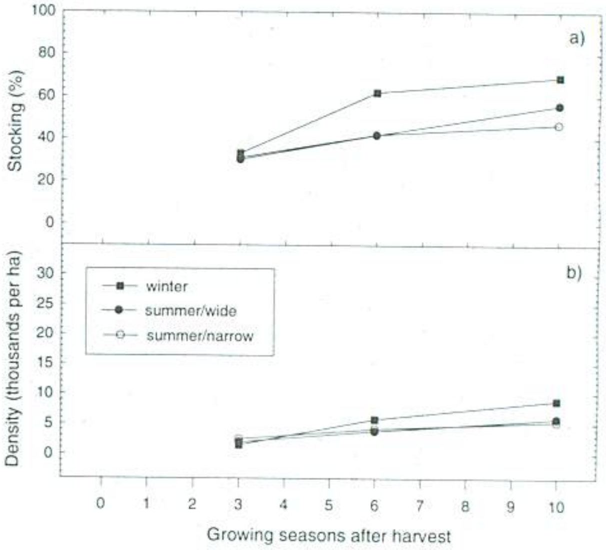

Figure 4. Acceptable black spruce advance growth stocking trends (a), and advance growth density trends (b).

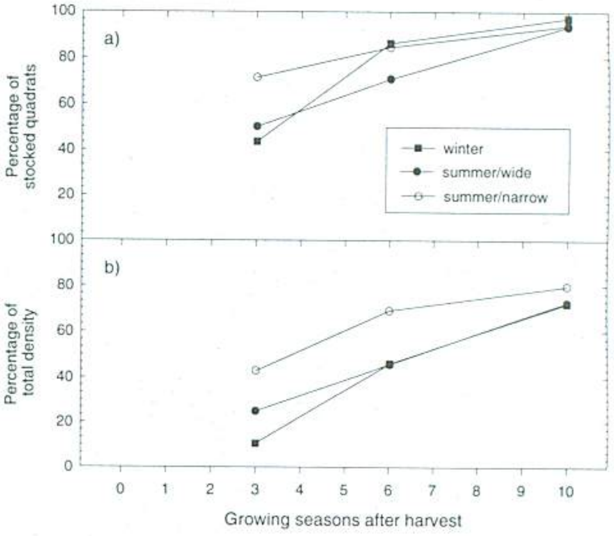

Figure 5. Trends in the ratio of: (a) acceptable black spruce advance stocking to total black spruce advance growth stocking, and (b) acceptable black spruce advance density to total black spruce advance growth density.

Tamarack (*Larix laricina* [Du Roi] K. Koch) regeneration was conspicuous in W blocks starting in the third year (Fig. 10) but, with high variability among blocks, harvest method effects were not significant (Table 1).

Trembling aspen (*Populus tremuloides* Michx.) stocking and density differed significantly among harvest methods from the third year onward (Fig. 11; Table 1). Aspen was virtually absent from W blocks, but relatively abundant in S/n blocks.

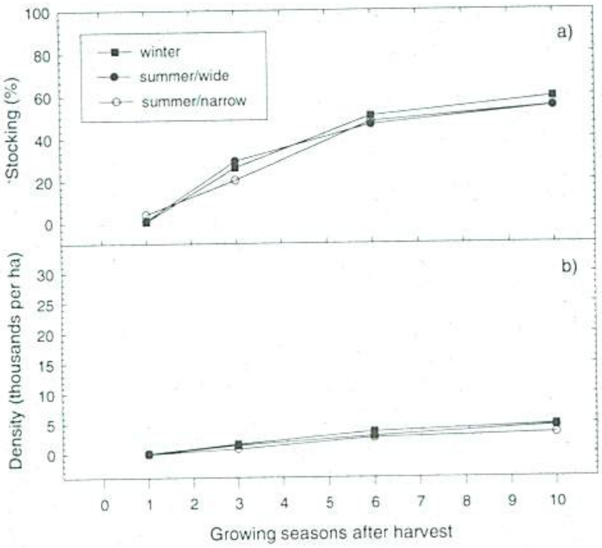

Figure 6. Postharvest origin black spruce seedling stocking trends (a), and density trends (b).

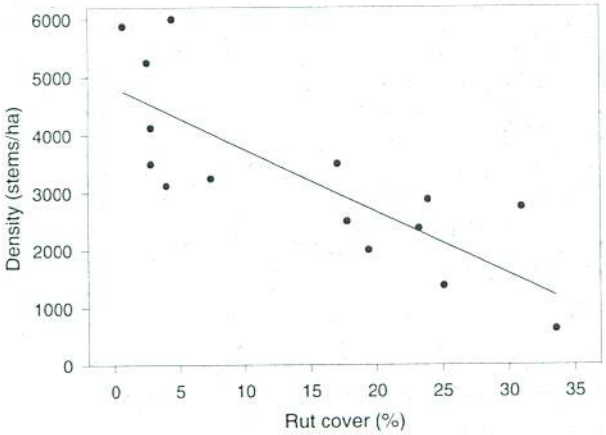

Figure 7. Tenth-year postharvest origin black spruce seedling density versus initial rut cover in S/n blocks (the least squares fit is density = 4828 - 108 x initial deep rut cover; $R^2 = 0.64$).

Height Growth

Harvest method had no effect on the tenth-year height and height growth of black spruce advance growth (Table 2). For all harvesting methods, heights averaged 79.7 cm. The heights of the tallest trees on stocked quadrats averaged 127.9 cm. Corresponding average and quadrat maximum tenth-year height growth values were 10.4 cm and 17.7 cm, respectively.

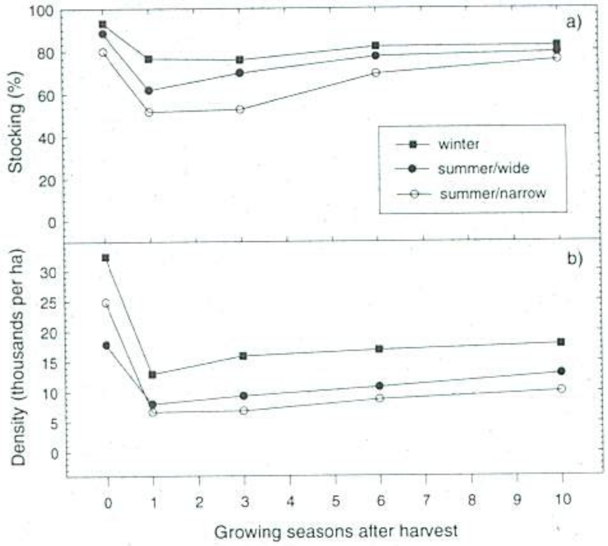

Figure 8. Total (advance growth and postharvest origin seedlings) black spruce stocking trends (a), and density trends (b).

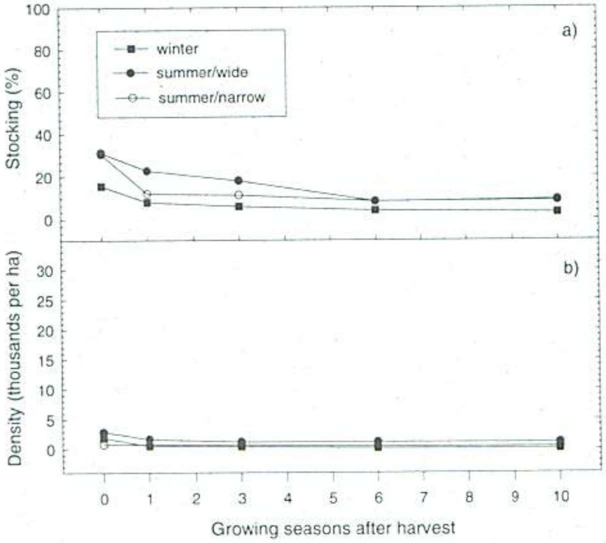

Figure 9. Balsam fir stocking trends (a), and density trends (b).

Tenth-year height and height growth of postharvest origin black spruce seedlings varied significantly among harvest methods, with the greatest values occurring in the S/n method (Table 2). Height and height growth of advance growth were consistently greater than that of postharvest origin stems.

Within the S/n blocks, tenth-year height and height growth of postharvest origin black spruce seedlings increased with initial (Year 1) rut cover (Fig. 12a and b). Similar, but less pronounced, relationships were also evident for black spruce advance growth (Fig. 12c and d). Tenth-year height growth increased with ninth-year total height for all combinations of harvest method and tree origin (Fig. 13).

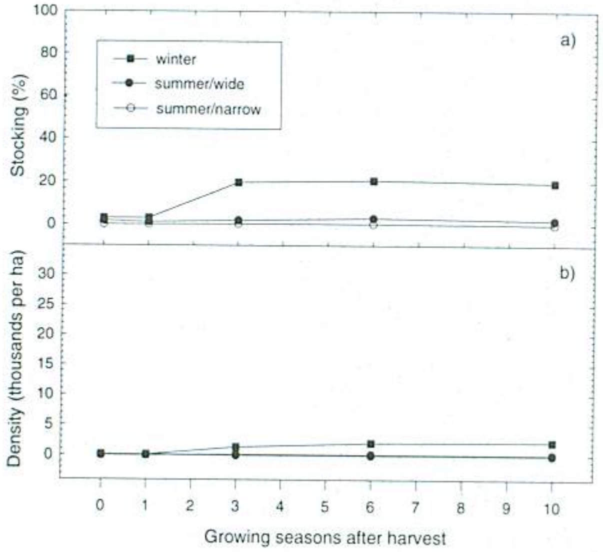

Figure 10. Tamarack stocking trends (a), and density trends (b).

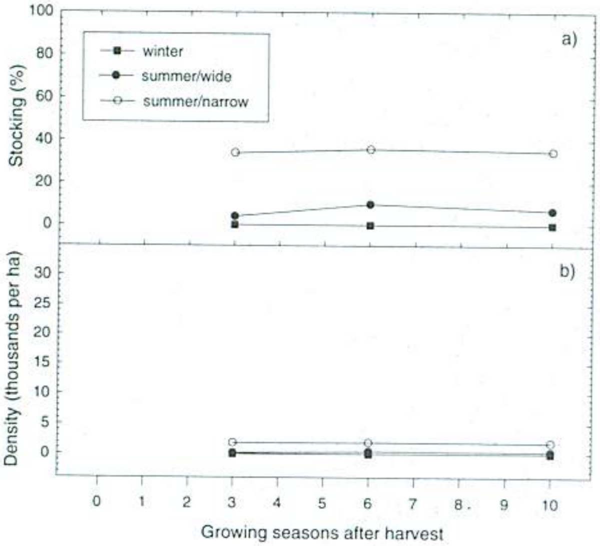

Figure 11. Trembling aspen stocking trends (a), and density trends (b).

The coefficients for Equations [1] and [2] were n = 4.9032, m = 0.98899, and k = 4.5133. The asymptote of Equation [2] was 1 850 cm, a reasonable, although low, value for black spruce on peatland sites. Based on Equation [2], postharvest origin black spruce seedlings lagged advance growth by 6 years for average height, and by 8 years for the height of the tallest tree per stocked quadrat.

In the S/w harvest blocks, an alternating pattern of taller and shorter trees was often evident (Fig. 14). Advance growth was absent or maximum heights of advance growth were low in skid trails, whereas maximum heights were greater between skid trails.

Surface Condition and Vegetation Cover

Preharvest differences existed in the covers of *Sphagnum* moss, feathermosses, speckled alder, and Labrador-tea (Table 1; Fig. 15a and b, Fig. 16a and b). Areas scheduled for S/n harvest showed the greatest *Sphagnum* and speckled alder cover and the least feathermoss and Labrador-tea cover.

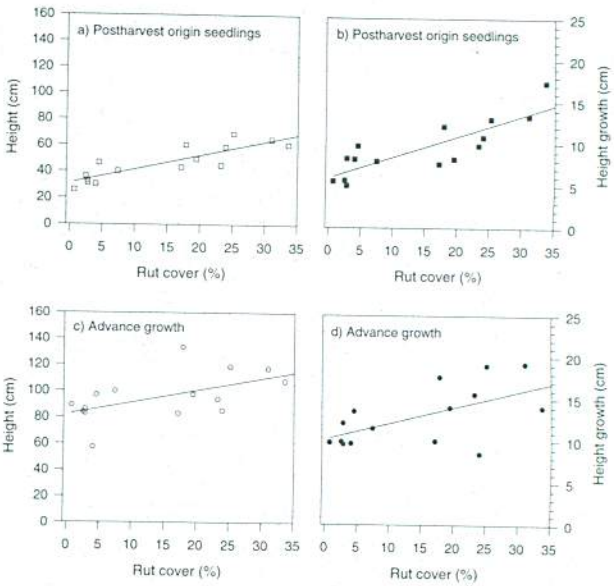

Figure 12. (a) Relation between tenth-year height of postharvest origin black spruce and initial (Year 1) rut cover on S/n harvest blocks (The least squares fit is height = 31.1 + 1.06 rut cover; $R^2 = 0.75$). (b) Relation between tenth-year height growth of postharvest origin black spruce and initial (Year 1) rut cover on S/n harvest blocks (The least squares fit is height growth = 5.9 + 0.25 rut cover; $R^2 = 0.69$). (c) Relation between tenth-year height of black spruce advance growth and initial (Year 1) rut cover on S/n harvest blocks (The least squares fit is height = 82.1 + 0.91 rut cover; $R^2 = 0.27$). (d) Relation between tenth-year height growth of black spruce advance growth and initial (Year 1) rut cover on S/n harvest blocks (The least squares fit is height growth = 10.2 + 0.19 rut cover; $R^2 = 0.33$).

Table 2. Tenth-year height (cm) and height growth (cm) of black spruce advance growth and postharvest origin seedlings for three harvest methods.

Variable	Harvest method			MSE[*]	F[**]	p > F
	Winter	Summer/ wide	Summer/ narrow			
Advance growth						
Mean height	73.3	79.9	85.7	89.8	1.29	0.328
Maximum height (quadrat basis)	125.7	126.4	132.5	252.0	0.18	0.839
Mean height growth	11.0	9.4	11.5	6.2	0.81	0.480
Maximum height growth (quadrat basis)	20.2	15.4	19.2	8.7	2.94	0.111
Postharvest seedlings						
Mean height	21.4	25.7	43.9	29.1	15.34	0.002
Maximum height (quadrat basis)	29.3	33.4	55.8	48.5	13.20	0.003
Mean height growth	5.9	4.7	8.9	3.4	4.88	0.041
Maximum height growth (quadrat basis)	7.7	6.2	11.0	4.5	4.81	0.042

[*] MSE is the mean square error in the analysis of variance.

[**] F is the F-ratio in the analysis of variance.

Sphagnum cover decreased to an average of 13 percent immediately after harvest (Fig. 15a), and no differences were noted among methods. By Year 6, however, harvest effects were significant. By this time cover had risen for all methods, particularly for the S/n harvest, where it nearly attained preharvest levels.

Feathermoss cover also decreased immediately after harvest for all methods, and increases became evident by Years 6 or 10 (Fig. 15b). However, none of the Year 10 cover values approached preharvest levels. Feathermoss cover differed among harvest methods throughout ($p < 0.07$, Table 1), with the lowest cover consistently occurring with the S/n harvest.

A steady decline in slash cover occurred for all harvest methods (Fig. 15c). Harvest effects were significant ($p < 0.05$, Table 1) from Year 3 onward, with the greatest cover consistently occurring in the W harvest.

Grass and sedge cover increased sharply in Year 3 (Fig. 15d), at the same time as the harvest method became a significant influence ($p < 0.05$, Table 1). Cover was consistently least in the W harvest blocks.

Pioneer mosses steadily increased in cover from Year 3 to Year 10 (Fig. 15e), with some evidence ($p < 0.15$, Table 1) of greater cover in the S/w method in Years 3 and 6.

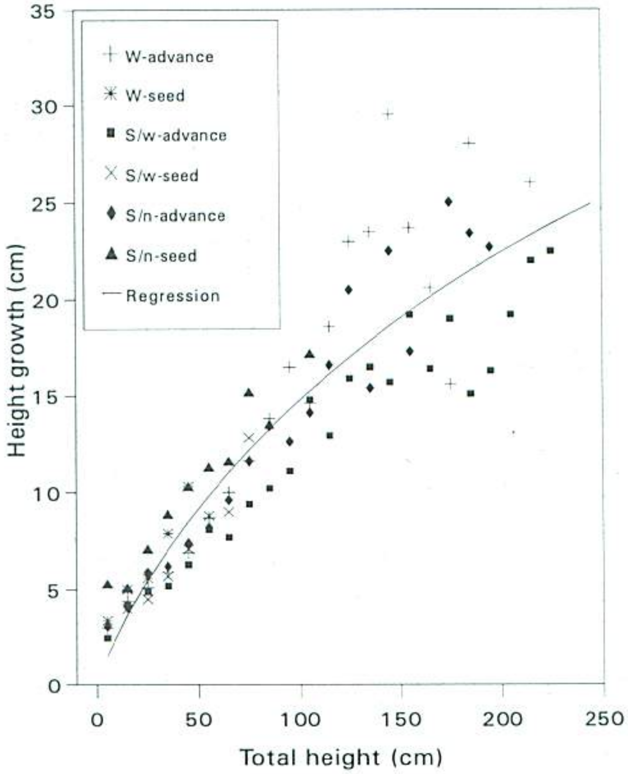

Figure 13. Tenth-year height growth versus tenth-year height for black spruce advance growth and postharvest origin seedlings after harvesting by three different methods.

Deep rut cover differed initially among harvest methods, with the greatest cover occurring in the S/n harvest (Fig. 15f). Deep rut cover decreased rapidly, however, and there were no differences among harvest methods by Year 6 (Table 1). A rapid decrease in deep rut cover was also evident in the S/n plots that had the greatest cover of ruts in Year 1 (Fig. 15f).

Speckled alder cover decreased immediately following harvest (Fig. 16a), and then increased until Year 10. Then, it again decreased. The harvest method did not have an effect on the postharvest cover of speckled alder.

Labrador-tea cover showed a sharp decrease immediately following harvest (Fig. 16b), but then increased steadily to return close to preharvest levels by Year 10. Differences among harvest methods became apparent by Year 6, with the greatest cover occurring in the W harvest.

Cattail cover was generally low (Fig. 16c), but from Year 3 onward there was evidence of an influence by harvest method. No cattails were detected in any of the W harvest blocks, and cover was consistently greatest in the S/n harvest blocks.

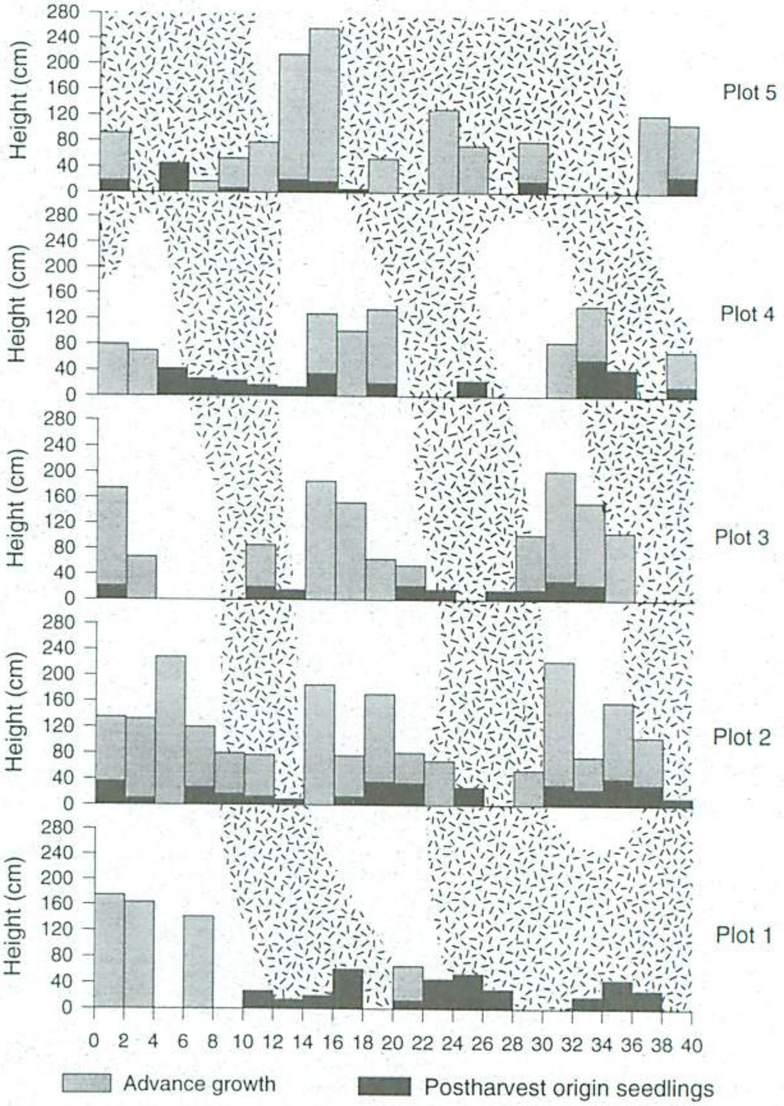

Figure 14. Pattern of tallest stem per quadrat for advance growth and postharvest origin seedlings in a S/w harvest block. Plot 1 was closest to, and Plot 5 was furthest from, the landing. Stippled areas indicate trails used by harvesting equipment. Horizontal scale is in meters.

DISCUSSION

In general, winter harvesting has the least impact on soil and vegetation due to protection by snow and because of the high strength of frozen soil. On peatland sites in summer, high-flotation equipment allows for the repeated use of the same trails. Although the impacts on these trails can be considerable, impacts between the trails may be limited. Equipment with poor flotation has the greatest impact on peatlands, because often the same trails cannot be reused. Not only does a considerable degree of disturbance occur on each trail, but trails also cover a high proportion of the cut block.

Regeneration

As would be expected, the postharvest levels of black spruce advance growth stocking and density decreased as harvest methods of increasing impact were used. However, part of this decrease was related to preharvest differences in stocking and density.

Comparing ratios of postharvest to preharvest stocking and density (essentially survival of regeneration) largely removes the effect of initial differences. These ratios again decrease with an increasing impact of harvest method. The rule-of-thumb proposed by Groot (1995) seems valid: about 80 percent of the original stocking will persist after W harvest; about 70 percent will persist after S/w harvest; and about 60 percent will persist after S/n harvest.

Most of the mortality among black spruce advance growth stems occurred within 1 year after harvest, indicating that assessments of advance growth made at least a year after harvest provide good forecasts of future advance growth stocking and density. Ruel et al. (1995) also found that

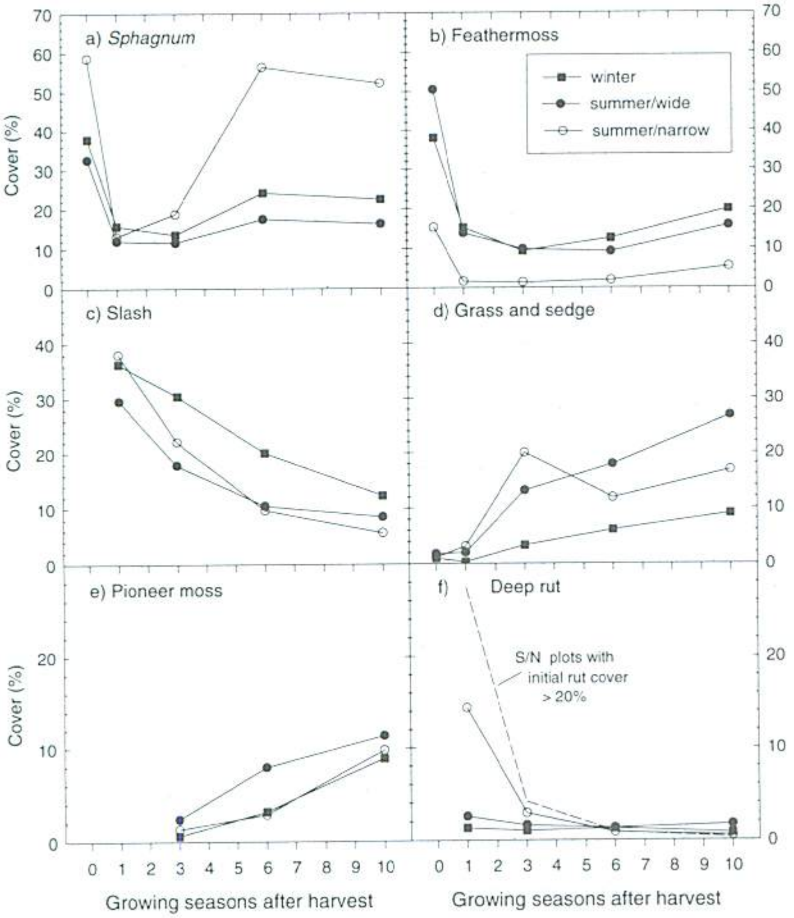

Figure 15. Cover trends for: (a) Sphagnum *spp., (b) feathermoss, (c) slash, (d) grass and sedge, (e) pioneer moss, and (f) deep ruts.*

first-year mortality exceeded that of subsequent years, and that mortality was related to variables such as height, prerelease height growth, live crown ratio, and degree of wounding.

Postharvest black spruce seedlings establish gradually on peatland sites, but eventually make a substantial contribution to the developing stand. The postharvest establishment of black spruce seedlings helped to bring total black spruce stocking to a similar value among the three harvest methods. It should be remembered, however, that in this study the black spruce established from seed were from 6 to 9 years behind advance growth in height development. Most larger advance growth stems were destroyed on these study areas, but continuing improvements in harvesting equipment and methods are preserving larger stems of advance growth. These larger stems will have an even greater height advantage over trees established from seed, and will eventually produce a yield advantage as well (Pothier et al. 1995).

Preservation of larger stems will also accentuate the pattern of alternating taller and shorter trees, or taller trees and no trees observed on the S/w harvest blocks. Size differentials will increase as the growth of smaller trees is reduced by competition from the overstory. Second-growth peatland black spruce stands that developed from horselogging in the first half of the twentieth century are largely of advance growth origin, and invariably possess a positively skewed diameter structure (Groot and Horton 1994). It is likely that contemporary mechanized harvesting methods that are effective in preserving advance growth will result in similar structures.

None of the harvest methods created conditions for tree species other than black spruce to play more than a minor role in future stand development. In contrast to the steadily increasing abundance of black spruce, balsam fir steadily declined in abundance. The establishment of trembling aspen on the S/n blocks may indicate that heavily disturbed peat provides a suitable seedbed for aspen. Brumelis and Carleton (1988, 1989) also observed the establishment of trembling aspen and balsam poplar (*Populus balsamifera* L.) on mesotrophic peatlands after logging with wheeled skidders. How aspen will develop over the long term on these sites is unknown; trembling aspen is an exceedingly rare component of natural stands on peatlands in this region.

Height Development

The height growth of black spruce advance growth generally increases with time since harvest (Paquin and Doucet 1992, Boily and Doucet 1993). Much of this increase is a response to release from the overstory, but the strong relationship between height growth and height observed in this study indicates that part of the growth increase must also result simply from increased height with time since harvest. Increased height growth increments probably allowed more stems to exceed the 5-cm height growth criterion in later assessments, thereby resulting in increases in the stocking and density of acceptable black spruce advance growth with time. Height growth values observed in this study are in the lower part of the range of values observed on peatlands by Brumelis and Carleton (1988).

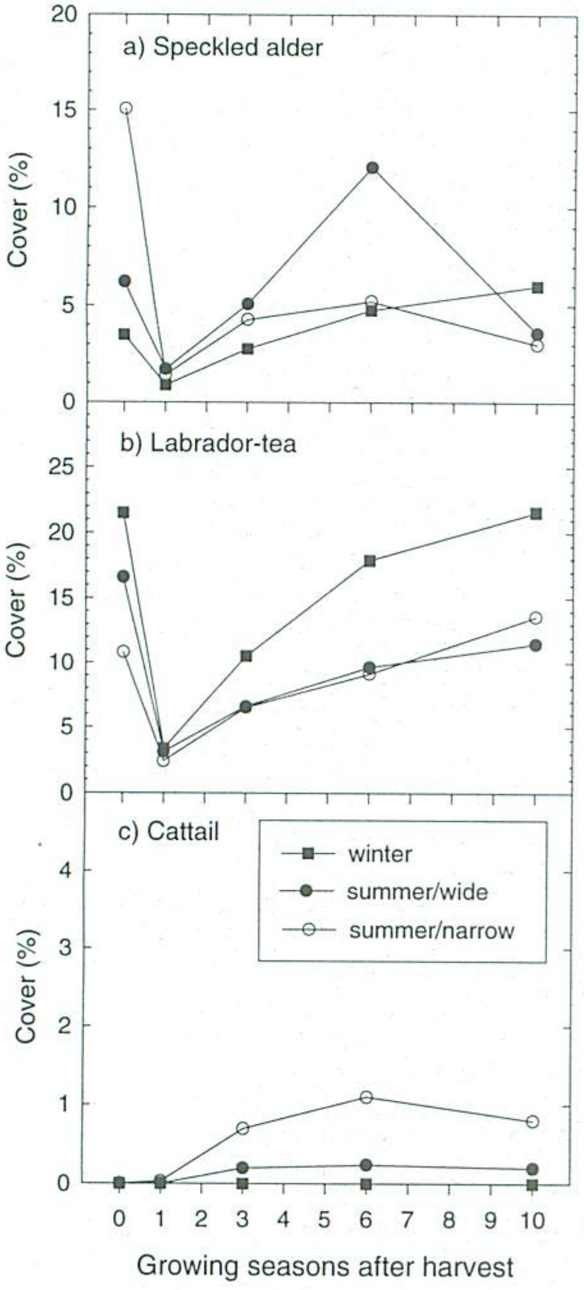

Figure 16. Cover trends for: (a) speckled alder, (B) Labrador-tea, and (c) cattails.

The average height of the tallest tree in each quadrat is a more useful measure of stand development than is the average height of all trees. The tallest trees will become dominant in the stand as it matures.

Site Disturbance

Water-filled ruts are conspicuous evidence of the impact of harvesting equipment on peatlands. In addition to the negative visual impact of rutting, forest managers are concerned about the silvicultural, vegetational, and hydrological impacts of site disturbance. As such, they try to minimize the degree of site disturbance by using high-flotation equipment and by scheduling winter harvesting of sensitive sites.

No studies have been made of the hydrological effects of deep ruts on peatlands, but foresters are concerned that disruption of surface drainage by ruts might cause a rise in the water table, and result in negative effects on tree growth (Gemmell 1981, Jeglum et al. 1983).

This study provides no evidence of deleterious effects of site disturbance on tree growth. To the contrary, greater growth of postharvest origin trees was associated with the S/n method. At least two factors may account for the increase in postharvest origin seedling height and height growth with initial deep rut cover in S/n blocks. First, rut cover was greatest in the portions of these blocks that were dominated by OG 12 (*Alnus* herb-poor) and least in portions dominated by OG 11 (*Ledum*). The superiority of OG 12 over OG 11 in nutrient conditions may have translated into improved seedling growth. Second, it is likely that much of the seedbed in deeply rutted areas was moderately or well decomposed organic matter. Although black spruce does not establish well on this material, seedlings that do establish may grow more rapidly than on living *Sphagnum* or poorly decomposed *Sphagnum* peat seedbeds (Groot and Adams 1994).

Rutting was considerable in the S/n harvest method, but the cover of deep ruts decreased rapidly, even on plots that had a high initial rut cover. The decrease in rut cover was accompanied by increases in *Sphagnum* moss and grass and sedge cover, thereby suggesting a rapid proliferation of these plants in and around the ruts. The rapid regeneration of *Sphagnum* in heavily disturbed peat may be related to its ability to regenerate vegetatively from stems originally at depths of 30 cm or more (Clymo and Duckett 1986). Elling and Knighton (1984) observed a rapid (continuous mat within 7 or 8 years) regeneration of *Sphagnum* on bogs where the upper 45 cm of peat had been removed.

Despite the rapid decrease in rut cover and the lack of evidence of growth reductions in rutted areas, activities that result in site disturbance on peatlands should be avoided. Greater loss of advance growth often accompanies site disturbance. Establishment by planting or seeding is hindered by difficult planting conditions; lack of seedbed; and a rapid proliferation of sedges, grasses, and cattails. Also, casual observations of other rutted areas in this region suggest that disturbed areas do not always recover quickly. More long-term observations of disturbed areas would be valuable.

Surface Condition and Vegetation Cover

Decomposition and *Sphagnum* overgrowth account for the steady decline in slash cover with time. Slash cover decreased most quickly on the S/n sites, where *Sphagnum* growth was most rapid.

The sharp decline and slow recovery of feathermoss cover after harvest is consistent with its adaptation to understory environments (Kershaw et al. 1994). Feathermosses exposed to full sunlight typically show high mortality.

Cattail and grass and sedge cover appear to be good indicators of the degree of disturbance. Areas harvested in winter sustained little disturbance and had the lowest cover of grasses and sedges, and no cattail cover.

Alder cover trends are confounded by the fact that herbicide treatment was not consistent among all the harvested areas. Because of this, interpretation of trends is not warranted.

ACKNOWLEDGMENTS

The author wishes to thank Mike Adams, who contributed skilled technical assistance in the field and in preparing figures. Thanks are also extended to Rod Gemmell, Abitibi-Price Inc., and to René Doucet, ministère des Ressources naturelles du Québec, for their useful comments on an earlier version of this report.

Funding for this project was provided through the Northern Ontario Development Agreement, Northern Forestry Program.

LITERATURE CITED

Boily, J.; Doucet, R. 1993. Croissance juvénile d'épinette noire en régénération après récolte du couvert dominant. Can. J. For. Res. 23:1396–1401.

Brumelis, G.; Carleton, T.J. 1988. The vegetation of post-logged black spruce lowlands in central Canada. I. Trees and tall shrubs. Can. J. For. Res. 18:1470–1478.

Brumelis, G.; Carleton, T.J. 1989. The vegetation of post-logged black spruce lowlands in central Canada. II. Understory vegetation. J. Appl. Ecol. 26:321–329.

Clymo, R.S.; Duckett, J.G. 1986. Regeneration of *Sphagnum*. New Phytol. 102:589–614.

Elling, A.E.; Knighton, M.D. 1984. *Sphagnum* moss recovery after harvest in a Minnesota bog. J. Soil Water Cons. 39(3):209–211.

Gemmell, J.R. 1981. A step toward improved forest management in the Clay Belt. Pulp and Paper Canada 82(9):53–57.

Groot, A. 1984. Site and stand conditions associated with abundance of black spruce advance growth in the Northern Clay Section of Ontario. Dept. Environ., Can. For. Serv., Sault Ste. Marie, ON. Inf. Rep. O-X-358. 15 p.

Groot, A. 1987. Silvicultural consequences of forest harvesting on peatlands: Site damage and slash conditions. Gov't Canada, Can. For. Serv., Sault Ste. Marie, ON. Inf. Rep. O-X-384. 20 p.

Groot, A. 1995. Harvest method affects survival of black spruce advance growth. N. J. Appl. For. 12:8–11.

Groot, A.; Adams, M.J. 1994. Direct seeding black spruce on peatlands: Fifth-year results. For. Chron. 70(5):585–592.

Groot, A.; Horton, B.J. 1994. Age and size structure of natural and second-growth peatland *Picea mariana* stands. Can. J. For. Res. 24:225–233.

Hintze, J.L. 1991. Number Cruncher Statistical System. NCSS, Kaysville, Utah. 442 p.

Jeglum, J.K. 1990. Low-cost regeneration in Ontario: What are the needs? p. 13–28. *in* P.K. Bidwell, ed. Proceedings of the Low-cost Regeneration Workshop. 10–11 October 1990, Hearst, Ontario. Ont. Min. Nat. Resour., Northern Forest Development Group, Timmins, ON. 49 p.

Jeglum, J.K.; Haavisto, V.F.; Groot, A. 1983. Peatland forestry in Ontario: An overview. p. 127–167 *in* J.D. Sheppard, J. Musial and T.E. Tibbetts, eds. A Symposium on Peat and Peatlands '82. 12–15 September 1982, Shippagan, New Brunswick. Energy, Mines and Resources, Halifax, NS. 582 p.

Jones, R.K.; Pierpoint, G.; Wickware, G.M.; Jeglum, J.K.; Arnup, R.W.; Bowles, J.M. 1983. Field guide to forest ecosystem classification for the Clay Belt, site region 3e. Ont. Min. Nat. Resour., Toronto, ON. 161 p.

Kershaw, M.; Wiltshire, R.; Hollstedt, C. 1994. Critical silvics of feathermoss as related to vegetation management. Ont. Min. Nat. Resour., NW Region Sci. Technol., Thunder Bay, ON. Tech. Note. TN-29. 15 p.

Paquin, R.; Doucet, R. 1992. Croissance en hauteur à long terme de la régénération préétablie dans des pessières noires boréales régénérées par marcottage, au Québec. Can. J. For. Res. 22:613–621.

Pothier, D.; Doucet, R.; Boily, J. 1995. The effect of advance regeneration height on future yield of black spruce stands. Can. J. For. Res. 25:536–544.

Richards, F.L. 1959. A flexible growth function for empirical use. J. Exp. Bot. 10:290–300.

Ruel, J.-C.; Doucet, R.; Boily, J. 1995. Mortality of balsam fir and black spruce advance growth 3 years after clear-cutting. Can. J. For. Res. 25:1528–1537.

Appendix 1. Analyses of variance model.

The analysis of variance model used was:

[1] $y_{ij} = \mu + a_i + e_{ij}$

where: y_{ij} = observation j for harvest method i,

μ = the overall experimental mean,

a_i = the fixed effect associated with harvest method (i = 1, 2, 3), and

e_{ij} = the sampling error associated with observation j.

Table A1. Analysis of variance for harvest method effects.

Source of variation	Degrees of Freedom
Total	10
Harvest method	2
Error	8

Table A2. Analysis of variance of harvest method effects on black spruce stocking and density.

Variable	W	S/w	S/n	MSE[*]	F[**]	p > F
Advance growth stocking (percent)						
Year 0	93	89	80	42.0	3.30	0.090
Year 1	76	61	50	127.8	3.89	0.066
Year 3	72	58	43	167.2	3.77	0.070
Year 6	72	59	48	146.9	2.88	0.114
Year 10	71	59	50	117.3	3.01	0.106
Advance growth density (stems/ha)						
Year 0	32 425	17 883	24 867	3.04×10^7	6.60	0.020
Year 1	12 925	7 990	6 592	9.41×10^6	3.65	0.075
Year 3	14 325	7 902	6 008	1.36×10^7	4.33	0.053
Year 6	13 325	7 905	6 117	1.61×10^7	2.67	0.129
Year 10	13 033	8 386	6 791	1.73×10^7	1.87	0.216

[*] MSE is the mean square error in the analysis of variance.

[**] F is the F-ratio in the analysis of variance.

Table A3. Analysis of variance of harvest method effects on postharvest:preharvest ratios (percent) of black spruce advance growth stocking and density.

Variable	W	S/w	S/n	MSE*	F**	p > F
Postharvest:preharvest stocking (percent)						
Year 1	82	69	62	102.6	2.83	0.117
Year 3	78	66	53	161.6	2.80	0.120
Year 6	77	66	60	132.0	1.87	0.216
Year 10	77	67	61	103.4	1.69	0.243
Postharvest:preharvest density (percent)						
Year 1	41	43	26	163.0	1.81	0.225
Year 3	46	43	23	278.8	1.66	0.250
Year 6	44	43	24	346.5	1.14	0.367
Year 10	43	45	27	346.3	0.99	0.413

* MSE is the mean square error in the analysis of variance.

** F is the F-ratio in the analysis of variance.

Table A4. Analysis of variance of harvest method effects on stocking and density of acceptable black spruce advance growth stems. Acceptable stems are upright, possess a single leader, and have annual height growth > 5 cm.

Variable	W	S/w	S/n	MSE*	F**	p > F
Stocking (percent)						
Year 3	33	30	31	190.4	0.04	0.960
Year 6	62	42	42	145.2	3.03	0.105
Year 10	69	55	47	125.0	3.05	0.104
Density (stems/ha)						
Year 3	1 533	2 002	2 533	$1.22\text{x}10^6$	0.61	0.565
Year 6	5 850	3 762	4 225	$3.71\text{x}10^6$	1.13	0.369
Year 10	8 933	5 918	5 375	$5.52\text{x}10^6$	2.10	0.185

* MSE is the mean square error in the analysis of variance.

** F is the F-ratio in the analysis of variance.

Table A5. Analysis of variance of harvest method effects on proportion of black spruce advance growth stems of acceptable quality and on proportion of quadrats stocked with black spruce advance growth that contain stems of acceptable quality.

Variable	W	S/w	S/n	MSE*	F**	p > F
Proportion (percent) of stocked quadrats						
Year 3	44	50	72	129.0	5.12	0.037
Year 6	86	71	85	64.2	4.55	0.048
Year 10	97	94	94	14.6	0.95	0.426
Proportion (percent) of stems						
Year 3	10	25	43	42.4	18.73	0.001
Year 6	46	46	69	61.6	9.41	0.008
Year 10	72	73	80	81.2	0.74	0.506

* MSE is the mean square error in the analysis of variance.

** F is the F-ratio in the analysis of variance.

Table A6. Analysis of variance of harvest method effects on postharvest origin black spruce seedling stocking and density.

Variable	W	S/w	S/n	MSE*	F**	p > F
Stocking (percent)						
Year 1	1	1	4	4.1	2.63	0.132
Year 3	26	29	20	111.5	0.67	0.537
Year 6	50	46	48	156.3	0.10	0.907
Year 10	59	55	55	275.9	0.08	0.927
Density (stems/ha)						
Year 1	42	30	100	4.18×10^3	1.16	0.362
Year 3	1 625	1 440	842	4.07×10^5	1.27	0.331
Year 6	3 558	2 878	2 558	1.84×10^6	0.43	0.663
Year 10	4 741	4 546	3 275	6.71×10^6	0.30	0.749

* MSE is the mean square error in the analysis of variance.

** F is the F-ratio in the analysis of variance.

Table A7. Analysis of variance of harvest method effects on total (advance growth and postharvest origin seedlings) black spruce stocking and density.

Variable	W	S/w	S/n	MSE*	F**	p > F
Stocking (percent)						
Year 0	93	89	80	42.0	3.30	0.090
Year 1	77	62	52	138.3	3.44	0.084
Year 3	76	70	53	215.6	2.08	0.187
Year 6	82	77	69	131.4	0.95	0.428
Year 10	82	79	76	134.8	0.25	0.786
Density (stems/ha)						
Year 0	32 425	17 883	24 867	3.04x10^7	6.60	0.020
Year 1	12 967	8 020	6 692	9.50x10^6	3.58	0.078
Year 3	15 950	9 342	6 850	1.76x10^7	3.86	0.067
Year 6	16 883	10 783	8 725	2.73x10^7	2.04	0.193
Year 10	17 775	12 932	10 067	4.29x10^7	1.07	0.388

* MSE is the mean square error in the analysis of variance.

** F is the F-ratio in the analysis of variance.

Table A8. Analysis of variance of harvest method effects on balsam fir stocking and density.

Variable	W	S/w	S/n	MSE*	F**	p > F
Stocking (percent)						
Year 0	16	31	31	542.4	0.48	0.638
Year 1	8	23	12	247.6	0.95	0.426
Year 3	6	18	11	231.5	0.58	0.580
Year 6	5	18	8	194.0	1.02	0.402
Year 10	3	19	9	201.9	1.25	0.336
Density (stems/ha)						
Year 0	1 925	2 923	2 825	7.20x10^6	0.14	0.870
Year 1	542	1 682	800	1.64x10^6	0.88	0.452
Year 3	450	1 225	742	1.08x10^6	0.56	0.593
Year 6	217	1 257	517	1.00x10^6	1.14	0.366
Year 10	100	1 116	458	0.64x10^6	1.65	0.252

* MSE is the mean square error in the analysis of variance.

** F is the F-ratio in the analysis of variance.

Table A9. Analysis of variance of harvest method effects on tamarack stocking and density.

Variable	W	S/w	S/n	MSE*	F**	p > F
Stocking (percent)						
Year 0	3	2	0	7.9	0.88	0.453
Year 1	3	1	0	9.2	0.94	0.430
Year 3	20	2	0	29.1	1.27	0.333
Year 6	21	3	0	32.2	1.20	0.351
Year 10	20	2	0	29.1	1.27	0.331
Density (stems/ha)						
Year 0	92	50	0	7.40×10^3	0.86	0.461
Year 1	92	40	0	9.65×10^3	0.83	0.470
Year 3	1 325	63	8	1.32×10^6	1.36	0.310
Year 6	2 008	85	8	3.03×10^6	1.38	0.307
Year 10	2 208	63	0	3.66×10^6	1.40	0.300

* MSE is the mean square error in the analysis of variance.

**F is the F-ratio in the analysis of variance.

Table A10. Analysis of variance of harvest method effects on trembling aspen stocking and density.

Variable	W	S/w	S/n	MSE*	F**	p > F
Stocking (percent)						
Year 0	0	0	0	-	-	-
Year 1	0	0	0	-	-	-
Year 3	0	4	34	14.1	78.34	< 0.001
Year 6	0	10	36	18.9	53.78	< 0.001
Year 10	0	7	35	23.4	46.83	< 0.001
Density (stems/ha)						
Year 0	0	0	0	-	-	-
Year 1	0	0	0	-	-	-
Year 3	0	185	1 850	6.38×10^4	51.90	< 0.001
Year 6	8	435	1 958	1.58×10^5	20.68	< 0.001
Year 10	0	345	1 883	7.81×10^4	140.29	< 0.001

* MSE is the mean square error in the analysis of variance.

**F is the F-ratio in the analysis of variance.

Table A11. Analysis of variance of harvest effects on surface cover (percent).

Variable	W	S/w	S/n	MSE[*]	F[**]	p > F
***Sphagnum* cover**						
Preharvest	38	33	59	74.6	8.82	0.010
Year 1	16	12	13	17.2	0.76	0.498
Year 3	14	12	19	44.3	1.11	0.374
Year 6	24	18	56	59.3	25.05	< 0.001
Year 10	23	16	52	57.9	21.89	< 0.001
Feathermoss cover						
Preharvest	38	50	15	87.6	13.29	0.003
Year 1	15	14	2	21.2	8.40	0.011
Year 3	9	10	1	18.8	3.95	0.064
Year 6	12	9	2	4.8	18.82	< 0.001
Year 10	20	16	5	19.6	8.69	0.010
Pioneer moss cover						
Year 3	1	2	1	1.21	2.56	0.138
Year 6	3	8	3	9.63	3.46	0.083
Year 10	9	11	10	29.90	0.21	0.817
Slash cover						
Year 1	36	30	38	53.8	1.49	0.282
Year 3	30	18	22	18.4	8.19	0.012
Year 6	20	10	10	9.9	10.85	0.005
Year 10	12	9	6	7.4	4.53	0.048
Deep rut cover						
Year 1	1	3	14	19.01	8.76	0.010
Year 3	1	2	3	0.66	4.30	0.054
Year 6	1	1	1	0.65	0.33	0.729
Year 10	1	2	0	1.38	1.15	0.363
Speckled alder cover						
Preharvest	4	6	15	24.9	4.55	0.048
Year 1	1	2	1	2.5	0.26	0.780
Year 3	3	5	4	8.3	0.61	0.568
Year 6	5	12	5	39.3	1.74	0.236
Year 10	6	4	3	27.6	0.29	0.756
Labrador-tea cover						
Preharvest	22	17	11	19.4	4.44	0.051
Year 1	3	3	2	2.3	0.32	0.736
Year 3	11	7	7	10.0	1.71	0.240
Year 6	18	10	9	3.8	20.50	< 0.001
Year 10	22	12	14	7.2	13.58	0.003
Cattail cover						
Year 0	0	0	0	0.00	-	-
Year 1	0	0	0	$8.33\text{X}10^{-4}$	1.45	0.289
Year 3	0	0	1	0.03	11.98	0.004
Year 6	0	0	1	0.28	3.56	0.078
Year 10	0	0	1	0.18	3.08	0.102
Grass and sedge cover						
Preharvest	1	2	1	0.92	0.69	0.528
Year 1	0	2	3	2.60	2.32	0.161
Year 3	3	13	20	8.50	25.03	< 0.001
Year 6	6	18	12	23.94	5.54	0.031
Year 10	9	27	17	40.37	7.61	0.014

[*] MSE is the mean square error in the analysis of variance.

[**] F is the F-ratio in the analysis of variance.