EFFECTS OF CUTTING METHOD AND SEEDBED TREATMENT ON BLACK SPRUCE REGENERATION IN MANITOBA

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INFORMATION REPORT NOR-X-316

FORESTRY CANADA
NORTHWEST REGION
NORTHERN FORESTRY CENTRE
1991

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Catalogue No. Fo46-12/316E
ISBN 0-662-18123-9
ISSN 0704-7673

This publication is available at no charge from:
Forestry Canada
Northwest Region
Northern Forestry Centre
5320 – 122 Street
Edmonton, Alberta
T6H 3S5

A microfiche edition of this publication may be purchased from:
Micromedia Ltd.
Place du Portage
165, Hôtel-de-Ville
Hull, Quebec
J8X 3X2

Printed in Canada

Kolabinski, V.S. 1991. *Effects of cutting method and seedbed treatment on black spruce regeneration in Manitoba.* For. Can., North. For. Cent., Northwest Reg., Edmonton, Alberta. Inf. Rep. NOR-X-316.

ABSTRACT

An experiment begun in 1955 to test various cutting methods to induce regeneration in mature upland black spruce (*Picea mariana* [Mill.] B.S.P.) stands in western Manitoba indicated regeneration failure for five cutting methods. To improve seedbeds, bulldozer blade scarification (scalping) was carried out 5 years later. This report deals with regeneration stocking and density (in terms of 4-, 5-, and 10-m^2 quadrats) 29 years after logging and 24 years after scarifying. The results showed that using cutting techniques without seedbed treatment was ineffective in promoting adequate regeneration, but scarified seedbeds were well stocked. Severe damage to the residual stand indicates a need to scarify early followed by harvesting of the residual stand. Alternate strip or small-sized block clear-cutting (1–5 ha in size) followed by immediate scarification is recommended.

RÉSUMÉ

Une expérience entreprise en 1955 dans l'ouest du Manitoba afin de vérifier si diverses méthodes de coupe favorisaient la régénération dans des peuplements d'épinettes noires (*Picea mariana* [Mill.] B.S.P.) arrivés à maturité de bas-plateaux a révélé que 5 méthodes de coupe étaient négatives à cet égard. Les lits de germination ont été scarifiés à l'aide d'une lame de bouteur (dégazonnement) 5 ans plus tard afin de les améliorer. Le présent rapport porte sur la proportion de surface occupée par la régénération et sa densité (par quadrats de 4, 5 et 10 m^2) 29 ans après la coupe et 24 ans après la scarification. Les résultats montrent que l'utilisation des méthodes de coupe sans traitement des lits de germination n'a pas permis de favoriser une régénération adéquate, mais que les lits de germination scarifiés étaient bien pourvus. Les graves dommages qu'a subi le peuplement résiduel laissent voir qu'il est nécessaire de scarifier rapidement et de récolter ensuite les arbres qui restent sur pied. Il est recommandé d'exécuter des coupes par bandes alternées ou des coupes rases par trouées (petits blocs de 1 à 5 ha) suivies immédiatement d'une scarification.

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The exclusion of certain manufactured products does not necessarily imply disapproval nor does the mention of other products necessarily imply endorsement by Forestry Canada.

INTRODUCTION

A study was initiated in 1955 by Forestry Canada to investigate various methods of laying out cut blocks in upland black spruce (*Picea mariana* [Mill.] B.S.P.) stands for inducing regeneration and to assess the effects of logging on residual stands. Establishment of this experimental cutting project was undertaken in the Duck Mountain Park in western Manitoba.

An examination of the post-logging conditions after the first 5-year period indicated that stand manipulation was ineffective in inducing black spruce regeneration and that failure was due largely to lack of seedbeds favorable for reproduction of spruce (Jarvis and Cayford 1961). Consequently, a seedbed treatment trial was carried out by bulldozer, blading portions of these cutovers in an endeavor to induce better stocking. Five years following treatment, post-scarification successes were reported by Jarvis and Cayford (1967). They also found considerable tree mortality by the 10th year in the uncut residual stands.

In the summer of 1985, 29 years after logging and 24 years after the seedbed treatment, these cutovers were resurveyed to assess stocking and growth of the reproduction as well as the condition of the unharvested residual stands. This report presents the remeasurement results.

LOCATION AND DESCRIPTION

The study area is located in the Duck Mountain Provincial Park in western Manitoba at latitude 51°30′N, longitude 100°45′W (Fig. 1). Duck Mountain falls within the Mixedwood Section (B.18a) of the Boreal Forest Region (Rowe 1972).

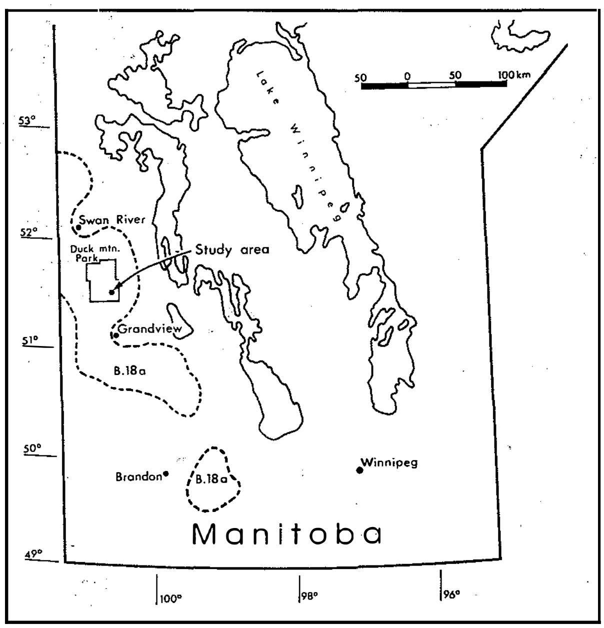

Figure 1. Location of the study area in western Manitoba.

The climate is characterized by cold winters and cool summers. Mean January and July temperatures are approximately –18.9 and 17.9°C, respectively. The frost-free period averages 80 days (Weir 1983), and average annual precipitation at Grandview[1] is 460 mm, of which 297 mm falls during the period from May to September (Atmospheric Environment Service 1981).

In 1955, the mature to overmature upland black spruce stands selected for this study were 105–135 years old. Approximately 95% of the trees were black spruce; the remainder were jack pine (*Pinus banksiana* Lamb.), trembling aspen (*Populus tremuloides* Michx.), and white birch (*Betula papyrifera* Marsh.). Dominant black spruce averaged 19.8 m in height, 23.6 cm in diameter[2], and 120 years of age. Site index at age 50 years was 40 (Gevorkiantz 1957), and merchantable volume averaged about 98.8 m^3/ha.

The topography of the area is rolling; parent materials are glacial till, and soils are clay loams. The upper soil (Ae horizons) consists of sandy

1 Grandview is approximately 35 km south of the study area.

2 Diameter at breast height was taken at 1.37 m.

loams and is overlaid by an organic layer varying from 2.5 cm to 30+ cm in depth. According to Hills' (1952) method of site classifcation, moisture regimes range from moderately fresh (2) to very moist (6), with some wet (7+) micro sites occurring in low lying areas.

Before cutting, minor vegetation on the experimental area consisted primarily of a complete moss cover with scattered shrubs and herbs. On moderately fresh to moderately moist sites feather mosses (*Pleurozium schreberi* [Brid.] Mitt, *Hylocomium splendens* [Hedw.] B.S.G., and *Ptilium crista-castrensis* [Hedw.] DeNot.) were dominant. Scattered shrubs such as wild rose (*Rosa acicularis* Lindl.), wild currant (*Ribes* spp.), and some Labrador tea (*Ledum groenlandicum* Oeder) were also present. On moist and very moist sites, small patches of sphagnum (*Sphagnum nemoreum* Scop.) occurred among the feather mosses. The principal shrub species on these latter sites was usually Labrador tea and some speckled alder (*Alnus rugosa* [Du Roi] Spreng. var. *americana* [Regel] Fern.).

METHODS

Cutting

Beginning in 1955, fourteen representative upland black spruce stands varying from 0.6 to 2.6 ha in size were selected and marked for testing the following six cutting treatments (Fig. 2):

1) Clear-cutting—cutting all trees on two square blocks, each 1.0 ha in size.

2) Alternate strips 20-m wide, running east and west, varying from 40 to 200 m in length.

3) Alternate strips 20-m wide, running north and south, varying from 40 to 100 m in length.

4) Patch cutting—clear-cutting circular patches 0.12 ha in size.

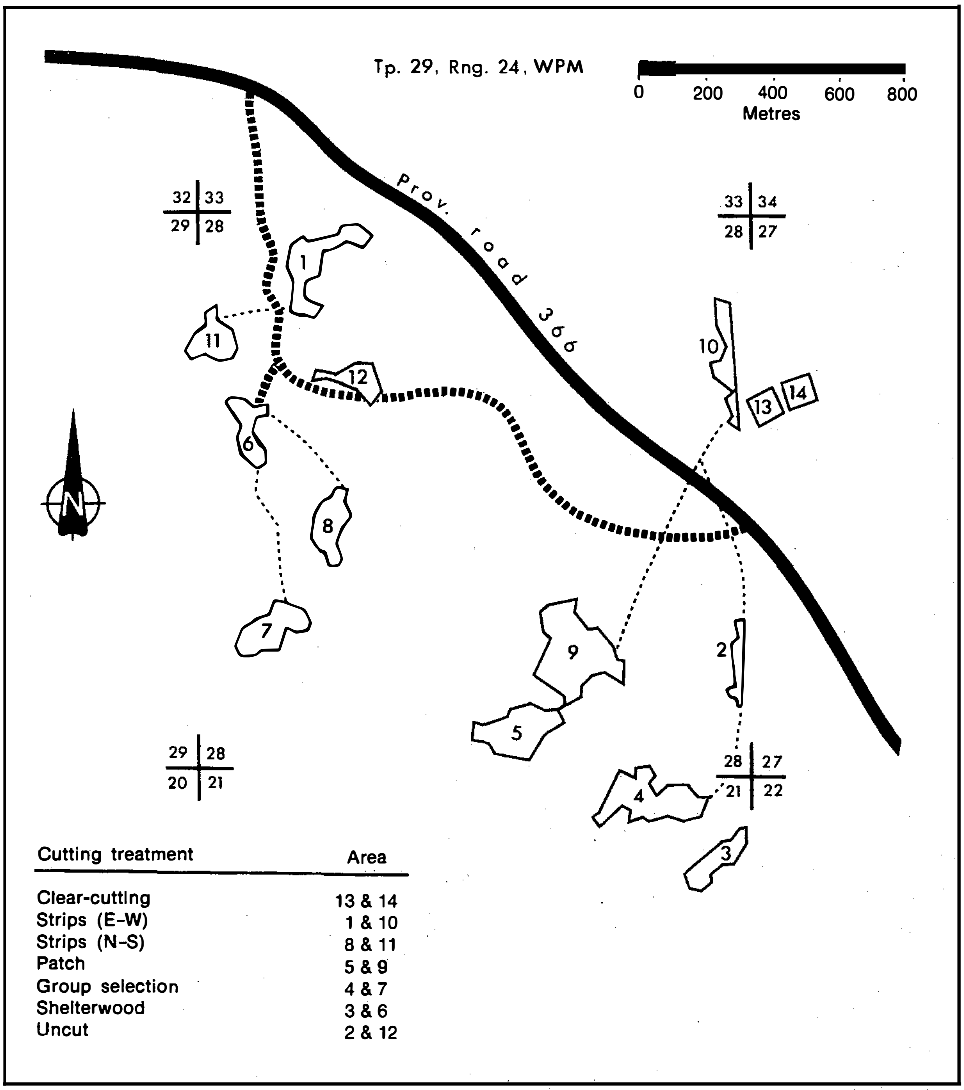

Figure 2. Layout of the various cutting treatments at Duck Mountain.

5) Group selection—clear-cutting circular patches 0.04 ha in size.

6) Shelterwood cutting—uniform partial cutting, which removed approximately one-half of the merchantable volume.

Uncut portions of each treated stand, except for the clear-cut, were sampled as controls. In addition, two uncut (separate) blocks were also established to serve as controls, and were averaged with the uncut control data for all treated stands for purposes of analysis. The areas were logged during the winter of 1955–56, under the supervision of the Manitoba Department of Natural Resources. The operations entailed manual cut and pile, with the use of horses and sleighs for removal of the wood.

Sample Plots

On each area in 1956, permanent contiguous 4-m^2 transect plots were established at 40-m intervals. On the strip areas, transect lines were located at right angles to the strips; while on the other areas, these transects were laid out in a north-south or east-west direction. This provided a 5% sample.

Scarification

In 1960, 5 years after the logging, randomly selected portions of the alternate strip, patch, and clear-cut areas were bladed with a D–6 Caterpillar tractor equipped with a hydraulically controlled straight blade. In addition, approximately half of each bladed area was plowed with an Athens plow to loosen compacted soil.

1985 Survey

The 1985 survey work entailed some procedural changes and modifications to conform to regeneration survey standards formerly and currently in use in the three prairie provinces. Larger 5-m^2 and 10-m^2 plots were superimposed over the preexisting mechanically run 4-m^2 quadrat transect lines. Plot dimensions for each area were 1) 2 × 2 m, 2) 2 × 2.5 m, and 3) 2 × 5 m for the respective 4-m^2, 5-m^2, and 10-m^2 quadrats.

Each quadrat was examined for the presence or absence of regeneration and advance growth[3]. A quadrat was considered stocked if it contained any of the following:

1) one coniferous seedling at least 3 years old,
2) two or more healthy 2-year-old seedlings, or
3) hardwood reproduction ≥50 cm in height.

Other information collected included density counts of regeneration on every tenth 4-m^2 quadrat, the height of the tallest seedling by species on each stocked quadrat, and moisture regime classification (Hills 1952) of each quadrat for both treated and control areas.

Unharvested portions of stands that were not clearcut were measured for diameter and mortality. This was done by recording living trees and classifying mortality by type of damage by 1-inch dbh classes from 5.0 m-wide tally strips established on the center line of the permanent regeneration transects.

Analysis

Regeneration data for each area was summarized and tabulated by quadrat size, cutting method, and scarification treatment used. Minimum stocking standards of 60, 65, and 75% were thus used as the measure of satisfactory stocking for the respective 4-m^2, 5-m^2 and 10-m^2 quadrats. This was largely based on Candy's (1951) criterion of 60% for 4-m^2 quadrats; today, Saskatchewan uses 65% based on 5-m^2 quadrats (Saskatchewan Parks and Renewable Resources 1985), and Manitoba uses 75% on 10-m^2 quadrats (Manitoba Department of Natural Resources 1980)[4].

3 Advance growth remaining at the time of the last remeasurement was nearly all from seed origin, although earlier tallies indicated some seedlings had originated from layers.

4 The restocking success level of conifers by basis of 10-m^2 quadrats is 80% for Alberta (Alberta Forest Service 1979).

Stocking

After 29 years, black spruce regeneration on untreated seedbeds in both cut and uncut stand conditions did not attain the minimum stocking requirements of 60, 65, and 75% for the 4-m^2, 5-m^2, and 10-m^2 quadrats (Fig. 3). Cut and scarified areas, by contrast, were well regenerated and exceeded 75% stocking (based on 4-m^2 quadrats) after 24 years. The slightly larger 5-m^2 quadrat provided only marginal increases in stocking percentages, while the 10-m^2 quadrat indicated substantially higher levels. For example, overall stocking of scarified areas was 79, 81, and 90%, respectively, for the three sizes of quadrats.

The high stocking levels on scarified areas were evidently not dependent on cutting treatment. The same stand manipulations and time lapse did not significantly improve seedbed receptivity on cut nonscarified and unccut areas. These lower stocking levels on cut nonscarified seedbeds averaged 31% (based on 4-m^2 quadrats). But some variation and stocking improvement was shown in the case of patch, shelterwood, and group selection cutting (44, 35, and 34%, respectively). Overall stocking for seedbeds in uncut stands averaged only 21% after 29 years.

Some contributions to conifer reproduction were made by tamarack (*Larix laricina* [Du Roi] K. Koch) and jack pine stocking. These two species combined amounted to 9% on scarified, 2% on nonscarified, and 1% on uncut areas (Table 1). Hardwood reproduction (trembling aspen, balsam poplar (*Populus balsamifera* L.), and white birch) varied among areas and treatments. Hardwood stocking based on 4-m^2 quadrats ranged from 12 to 51% and was correspondingly higher on 5-m^2 and 10-m^2 quadrats.

Density

Stem densities for black spruce were much higher on scarified than on nonscarified areas (Fig. 4). On scarified areas, the greatest numbers of seedlings occurred on north-south strips (Table 2). This was probably due to better seed dispersal

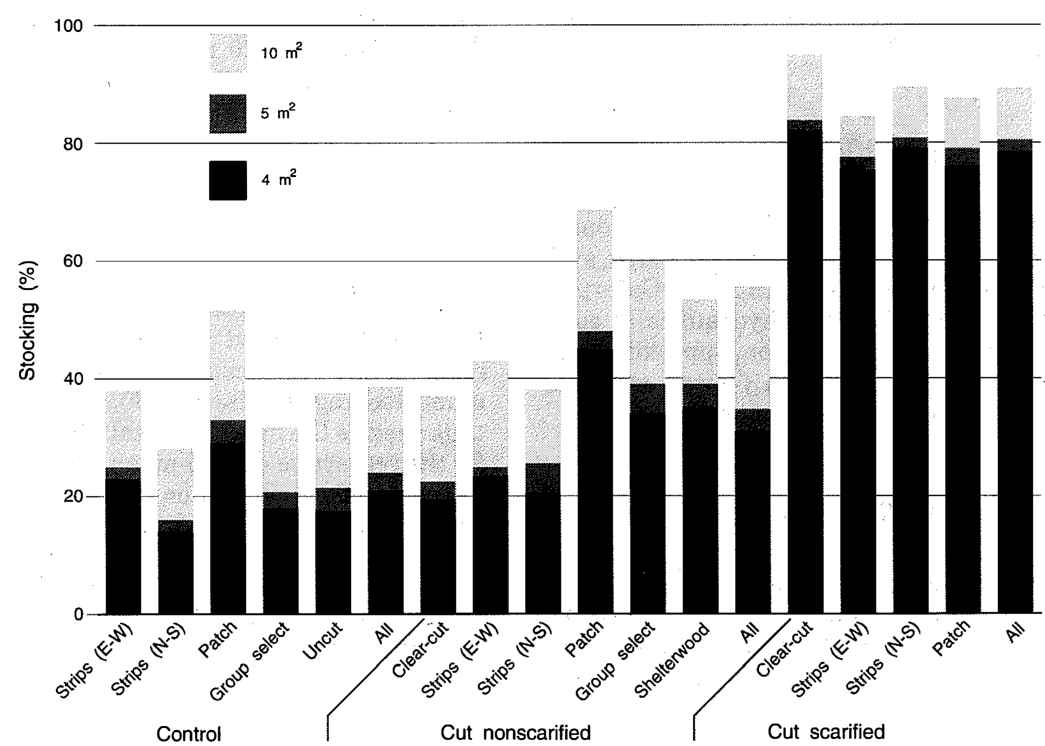

Figure 3. **Black spruce stocking by cutting method and seedbed treatment.**

Table 1. Summary of percentage stocking for black spruce, other softwoods, and hardwoods by areas and treatment

Method of cutting and area	Quadrat size (m^2)	Cut and scarified[a]				Cut nonscarified[b]						Controls[b]					
			Black spruce				Black spruce						Black spruce				
		No. quadrats	R[c]	OS[d]	H[e]	No. quadrats	R	A[f]	R&A	OS	H	No. quadrats	R	A	R&A	OS	H
Clear-cut, Areas 13 & 14	4	207	81.6	17.4	50.7	193	19.7	2.6	22.3	1.0	37.8	–[g]	–	–	–	–	–
	5	167	83.2	21.6	55.1	153	22.1	3.3	26.2	1.3	49.0	–	–	–	–	–	–
	10	83	94.0	36.1	74.7	77	37.7	6.5	44.2	2.6	59.7	–	–	–	–	–	–
Strips (E-W), Areas 1 & 10	4	141	75.2	7.1	20.6	106	27.4	–	27.4	2.8	20.8	170	22.4	5.9	27.0	–	15.3
	5	113	77.9	8.8	26.5	88	28.4	–	28.4	3.4	22.7	134	23.9	6.7	29.1	–	17.1
	10	58	84.5	15.5	37.9	43	46.5	–	46.5	7.0	25.6	65	36.9	15.4	47.6	–	27.7
Strips (N-S), Areas 8 & 11	4	73	79.4	4.1	20.5	59	20.3	20.3	39.0	–	11.9	120	13.3	13.3	25.8	–	17.5
	5	58	81.0	5.3	24.6	48	25.0	20.8	41.7	–	12.5	98	15.3	16.3	28.6	–	20.4
	10	30	90.0	10.0	36.7	24	37.5	29.2	54.2	–	20.8	48	27.1	25.0	47.9	–	27.1
Patch, Areas 5 & 9	4	127	76.4	1.6	30.7	137	44.5	5.1	48.9	2.9	28.5	343	28.3	7.3	34.4	1.2	41.7
	5	101	79.2	2.0	34.6	118	47.5	6.8	52.5	3.4	32.2	268	32.5	8.6	39.6	1.5	45.5
	10	50	88.0	4.0	46.0	60	68.3	11.7	75.0	5.0	45.0	133	51.1	14.3	61.6	2.3	63.9
Group selection, Areas 4 & 7	4	–	–	–	–	221	33.5	6.3	38.5	1.4	42.5	226	18.1	7.1	24.8	1.3	23.9
	5	–	–	–	–	181	38.7	7.2	44.8	1.7	44.8	179	20.7	8.4	27.4	1.7	26.8
	10	–	–	–	–	92	59.8	12.0	65.2	3.3	57.6	86	31.4	14.0	41.9	2.3	37.2
Shelterwood, Areas 3 & 6	4	–	–	–	–	176	34.7	4.0	38.6	1.7	40.3	–	–	–	–	–	–
	5	–	–	–	–	143	38.5	4.2	42.6	2.1	44.1	–	–	–	–	–	–
	10	–	–	–	–	70	52.9	7.1	60.0	4.3	57.1	–	–	–	–	–	–
Uncut (control), Areas 2 & 12[h]	4	–	–	–	–	–	–	–	–	–	–	191[h]	17.3[h]	3.7[h]	20.4[h]	–	16.2[h]
	5	–	–	–	–	–	–	–	–	–	–	153[h]	20.9[h]	4.6[h]	24.2[h]	–	17.6[h]
	10	–	–	–	–	–	–	–	–	–	–	75[h]	37.3[h]	6.7[h]	42.7[h]	–	28.0[h]
All areas[i]	4	548	78.5	9.3	34.3	892	30.8	5.0	35.2	1.7	34.3	1050	21.4	7.0	27.6	0.7	26.2
	5	439	80.6	11.6	40.0	731	34.6	5.7	39.5	2.0	38.7	832	24.4	8.4	31.1	0.8	28.7
	10	221	89.6	19.9	53.4	366	52.2	9.6	58.5	3.8	49.7	407	39.9	14.4	50.1	1.2	41.5

[a] Regeneration 24 years after scarification.
[b] Regeneration 29 years after logging.
[c] R = black spruce regeneration.
[d] OS = other softwood regeneration; includes jack pine, white spruce, balsam fir, and tamarack.
[e] H = hardwood reproduction; includes trembling aspen, balsam poplar, and white birch.
[f] A = seedlings > 29 years of age.
[g] No data by definition.
[h] External to treated stands.
[i] Controls within cut stands except for areas 13 and 14 are averaged with areas 2 and 12.

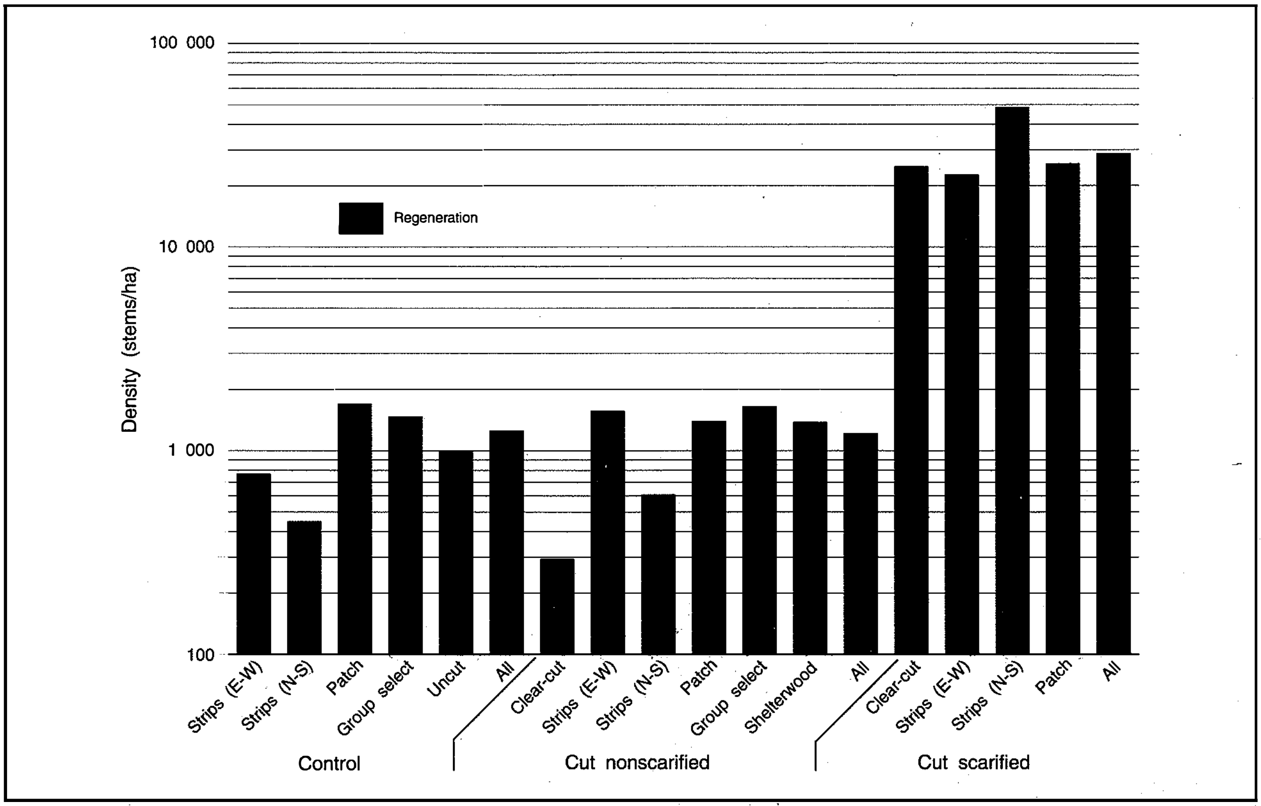

Figure 4. Black spruce density by cutting method and seedbed treatment (basis: 4-m^2 quadrats).

from prevailing north-west winds. Differing soil moisture and aspect conditions were also recognized between strip-cut areas. The highest seedling count (75 367 stems/ha) occurred on relatively moist sites on the north-south strip cut in Block 8. In comparison, the lowest count (8 402/ha) occurred on the east-west strips on Block 10, which had a south facing aspect with drier sites.

A considerable amount of seedling ingress occurred during the 20 years from the last seedling count in 1965, notably on scarified seedbeds. On the scarified areas, seedling density increased from 20 947/ha (Jarvis and Cayford 1967) to 29 339/ha, an increase of 31%. On the cut nonscarified and uncut areas combined seedling density increased from 1 144/ha to 1 287/ha, an increase of 11%. On the scarified areas, stem numbers of other softwood regeneration (jack pine, tamarack, balsam fir, and white spruce) were considerably less than black spruce. Other softwoods averaged 358/ha, while black spruce averaged 29 339/ha. This reflects the original stand composition, which was 95% black spruce and 5% hardwoods and other softwoods combined. On the nonscarified areas other softwoods approximated zero on the cut areas and 30/ha on the uncut.

Hardwood reproduction ranged from 166/ha to 4 823/ha over all areas and treatments. Average hardwood density was 3 138/ha on cut nonscarified, 1 898/ha on uncut, and 1 163/ha on scarified areas.

Advance Growth

Small amounts of advanced growth black spruce from seed and layer origin were present on nonscarified areas but were generally not in sufficient quantity to provide significant increases to stocking (Fig. 5 and 6). Those on scarified areas were all destroyed by the blading operation. Figure 6 shows that the highest densities of this seedling component occurred on cut nonscarified seedbeds in the patch cuts (1 236 stems/ha) and that in uncut stand conditions it was highest in the group selection cuts (726/ha). In 1961, 5 years after logging, advance growth seedlings (Jarvis and Cayford 1961) comprised about 10% stocking (4-m^2 quadrats) with 580

Table 2. Number of black spruce, other softwoods, and hardwood stems per hectare by area and treatment

Method of cutting and area	Cut and scarified[a]				Cut nonscarified[b]					Controls[b]				
	No. quadrats ($4\text{-}m^2$)	Black spruce R[c]	OS[d]	H[e]	No. quadrats ($4\text{-}m^2$)	Black spruce R	Black spruce A[f]	OS	H	No. quadrats ($4\text{-}m^2$)	Black spruce R	Black spruce A	OS	H
Clear-cut, Areas 13 & 14	23	25 247	430	2 365	17	292	–[g]	–	4 070	–	–	–	–	–
Strips (E & W), Areas 8 & 11	12	23 062	205	1 030	12	1 648	–	–	2 058	13	761	571	–	1 329
Strips (N & S), Areas 8 & 11	7	58 245	1 060	707	4	618	618	–	1 236	11	450	450	–	1 572
Patch, Areas 5 & 9	13	26 801	–	1 520	16	1 544	1 236	–	1 853	26	1 806	94	–	3 613
Group selection, Areas 4 & 7	–	–	–	–	21	1 764	–	–	4 823	17	1 599	726	146	1 453
Shelterwood, Areas 3 & 6	–	–	–	–	15	1 483	166	–	2 471	–	–	–	–	–
Uncut (control), Areas 2 & 12[h]	–	–	–	–	–	–	–	–	–	15[h]	988[h]	166[h]	–	166[h]
All areas[i]	55	29 339	358	1 663	85	1 307	292	–	3 118	82	1 265	361	30	1 898

[a] Regeneration 24 years after scarification.
[b] Regeneration 29 years after logging.
[c] R = black spruce regeneration.
[d] OS = other softwood regeneration; includes jack pine, white spruce, balsam fir, and tamarack.
[e] H = hardwood reproduction; includes trembling aspen, balsam poplar, and white birch.
[f] A = seedlings 29 years after logging.
[g] No data by definition.
[h] External to treated stands.
[i] Controls within cut stands except for areas 13 and 14 are averaged with areas 2 and 12.

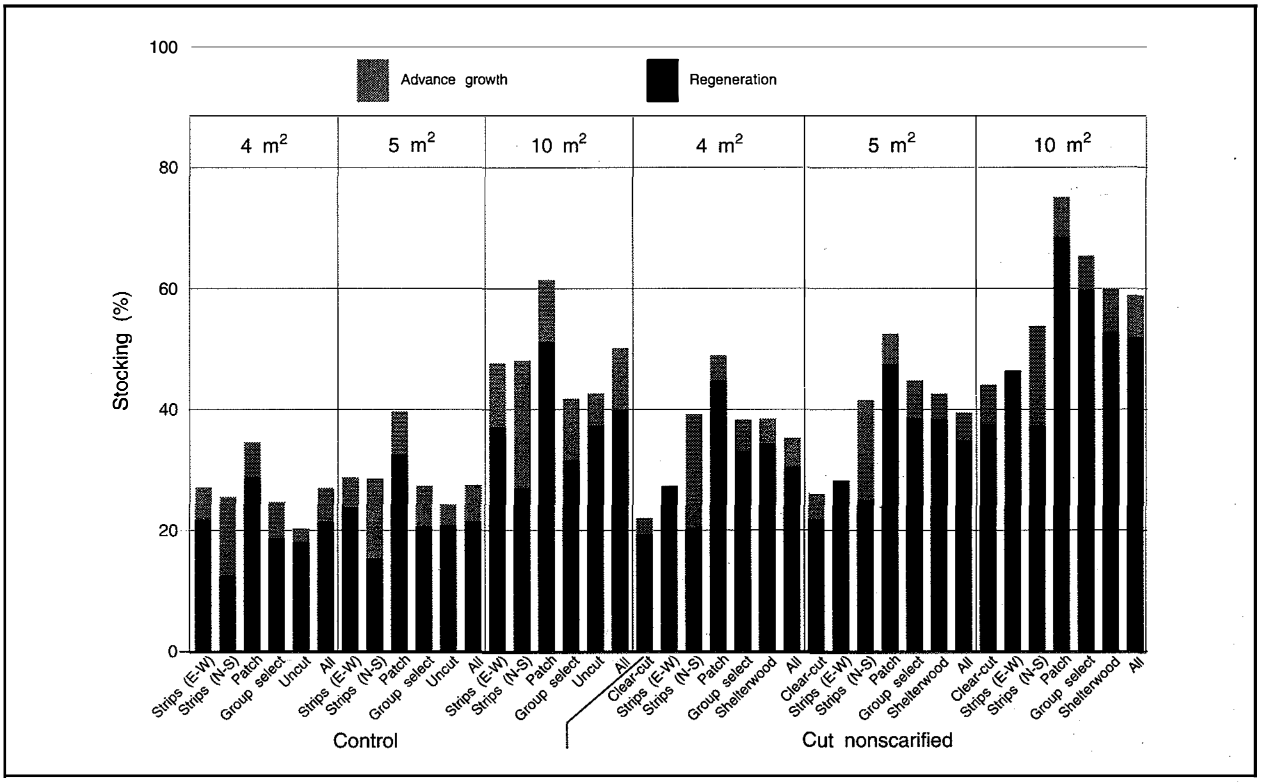

Figure 5. Percentage stocking of black spruce regeneration and advance growth on nonscarified areas.

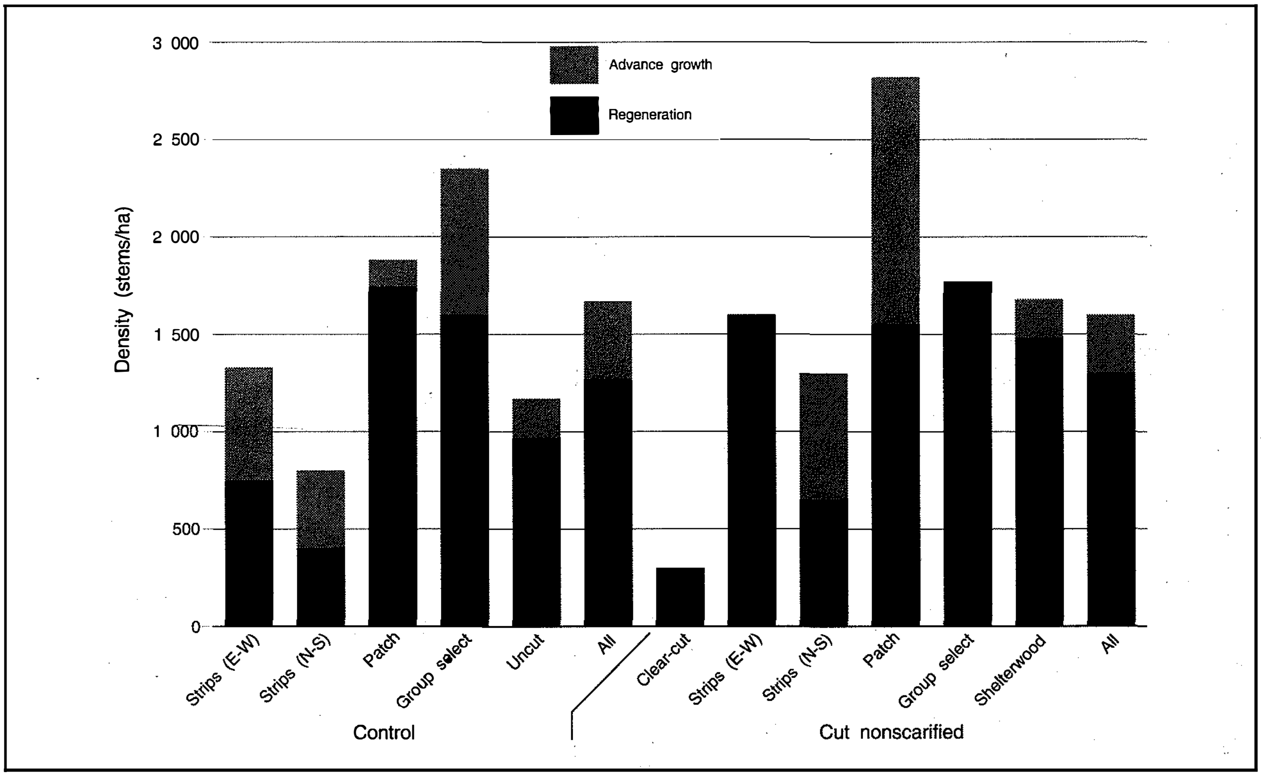

Figure 6. Stem densities of black spruce regeneration and advance growth on nonscarified areas (basis: 4-m² quadrats).

stems/ha; by 1985 the stocking of advance growth declined to 6% (4-m^2 quadrats) and 326 stems/ha.

Moisture Regime

Original moisture regime (MR) ratings in some instances were adjusted to reflect wetter conditions in 1985. Water table fluctuations were caused by beaver (*Castor canadensis*) activity, which impeded drainage.

On scarified areas percentage stocking was best on fresh (MR 3), moderately moist (MR 4), and moist (MR 5) sites. Distribution of seedlings on very moist (MR 6) sites decreased markedly, and none were established on wet (MR 7) moisture regimes (Fig. 7). Stocking failure on the very moist and wet sites was attributed to seedbed flooding resulting from deep blading, restricted drainage, and seasonal inundation (Fig. 8). Seedlings, however, were exceedingly dense (43 656/ha) on very moist scarified micro sites that were not subject to severe flooding (Fig. 9).

Regeneration on untreated seedbeds in both cut and uncut conditions was poorest on MR 6 and MR 7+. Lack of regeneration on these sites was attributed to a combination of high water tables and suppression from dense speckled alder that were growing vigorously on drainageway sites (Fig. 10). The drier areas (MR 2–5) were more favorable for regeneration but were still understocked. On average, seedling densities were greatest on MR 4 sites for all seedbeds (Fig. 9).

Moderately fresh sites (MR 2), occurring only on a small portion of the nonscarified areas, showed the greatest stocking increase for untreated seedbeds. In 1961 the increase in stocking from 3 to 39% (4-m^2 quadrats) was attributed to a general improvement in seedbed receptivity afforded by complete decomposition of logging slash, feather moss ground cover, and advanced decomposition of rotting wood seedbed mediums. It appeared that the seedlings were able to establish either under the succession of a moderate graminoid ground cover (originally occupied by feather moss) or on rotted cut tree stumps (Fig.

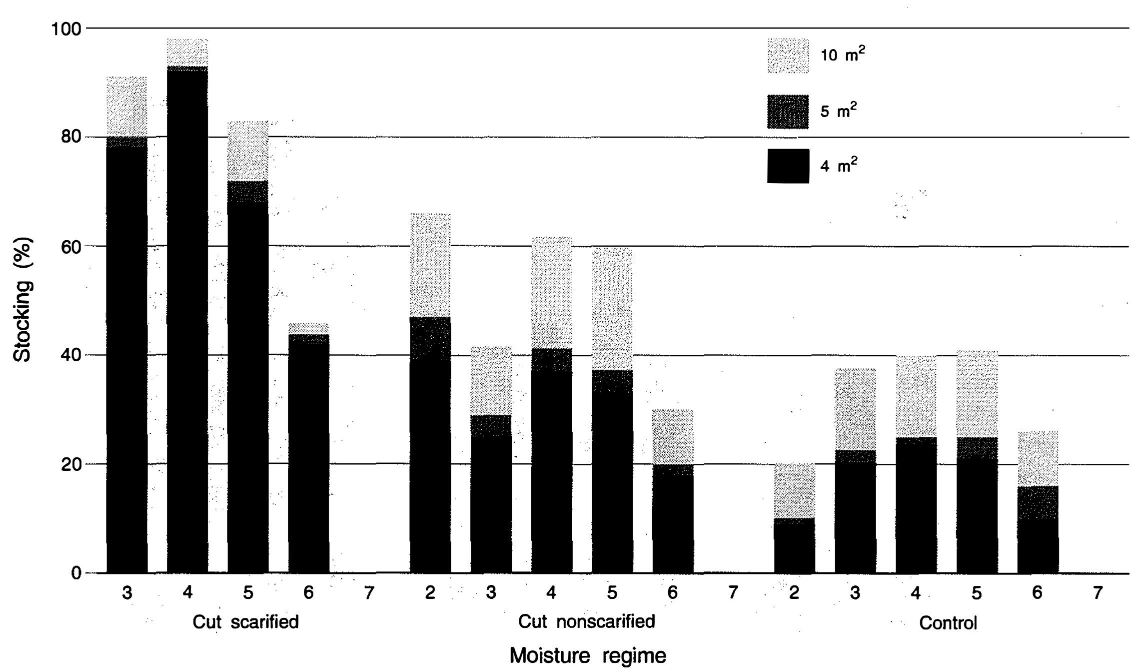

Figure 7. Percentage stocking of black spruce regeneration by moisture regime and treatment.

Figure 8. Grass and sedge growth (foreground) resulting from flooding of deep bladed moist site seedbeds.

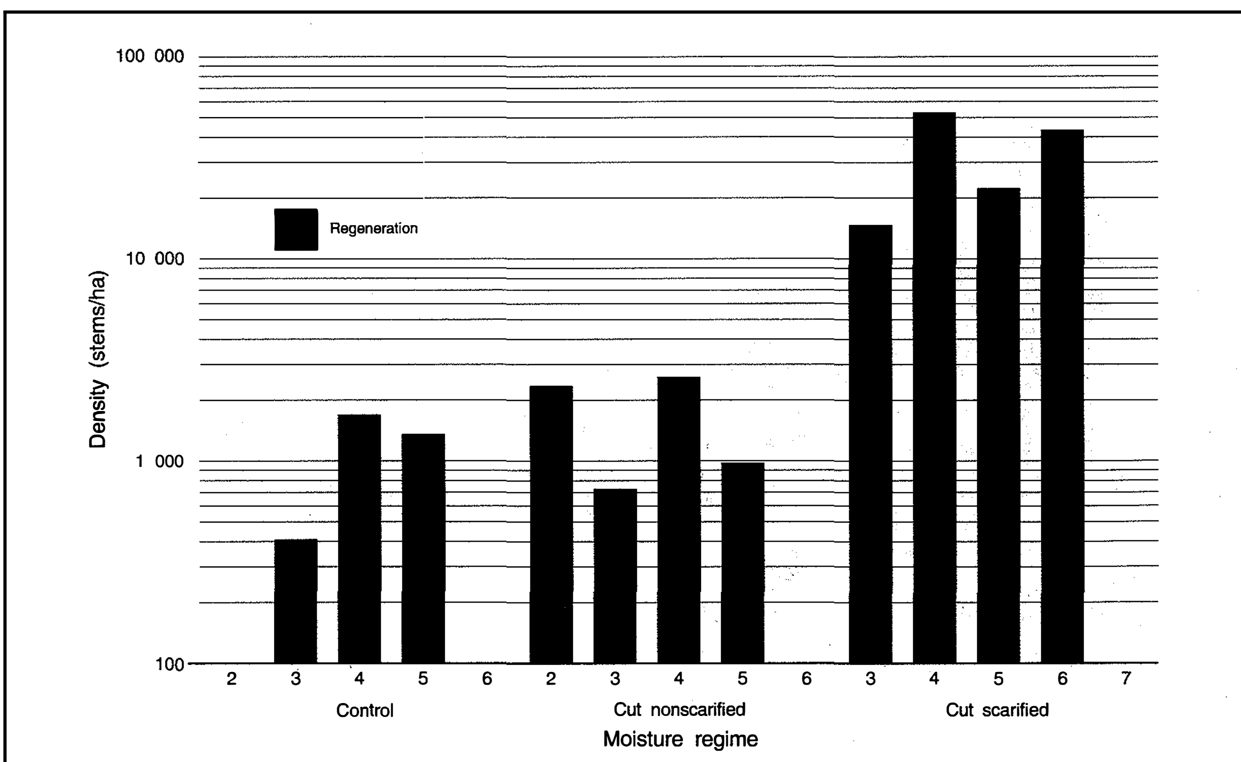

Figure 9. Density of black spruce regeneration by moisture regime and treatment (basis: 4-m^2 quadrats).

Figure 10. Speckled alder growth on wet drainageway site 29 years after logging.

11). This establishment did not take place until about 15 years after logging.

Height Growth

Height distribution of black spruce regeneration (excluding advance growth) 24 years after scarification and 29 years after logging on nonscarified areas is shown in Figure 12. This figure shows clearly that more seedlings in taller height classes were found on the scarified than on the nonscarified seedbeds. Seedling growth under a tree canopy in uncut stands was also poorer than in the corresponding cut nonscarified areas. Sixty-seven percent more of the largest seedlings (6–7 m height class) are growing on cut nonscarified areas than on cut scarified areas. This difference, however, is attributed to an existing age disparity of 5 years between the two seedling groups. The less numerous cut nonscarified seedlings were also growing under less crowded conditions than those on the more densely regenerated cut scarified areas. The data had also shown that average height of advanced growth black spruce in 1985 was 5.3 m on cut nonscarified stands and 2.8 m in the uncut stands. This has indicated that height development of this seedling component was also better in open cutovers than in uncut stands.

Other softwoods (tamarack and jack pine) were taller than black spruce. The hardwoods, averaging from 1.3 to 4.9 m in height, were taller on the older cut nonscarified (2.7 m) and uncut areas (2.5 m) than those on scarified areas (2.3 m), which were 5 years younger (Table 3).

Changes in Vegetation and Seedbeds

Seedbed and vegetation ingrowth changes occurred during the years following logging and scarification. Following the cutting operations most of the cutovers were covered with dense and heavy accumulations of logging slash, which covered from 10 to 49% of the underlying seedbeds (Jarvis 1961). Other postcut observations at that time revealed that in addition to desiccation of exposed feather mosses, logging disturbance also prompted the invasion of graminoids and various shrub species. In particular, dense raspberry (*Rubus idaeus* L. var. *strigosus* [Michx.] Maxim.) development occurred on moderately fresh, fresh, and moderately moist sites.

Figure 11. Black spruce seedling (approximately 15 years old) growing on a rotting stump.

The time lapse between logging and scarification showed certain seedbed and vegetation ingrowth changes. Most dramatic was a virtually complete decay and disappearance of slash and logging residues. A sharp decline of the once prolific raspberry growth was also evident. Seedbed conditions on certain partial-cut nonscarified areas changed very little. For example, on moderately moist to moist feather moss/Labrador tea sites, Labrador tea and mosses still persisted. In contrast, in the fully exposed clear-cut (nonscarified) areas, including sites ranging from moderately fresh to moderately moist, the feather mosses died out and were replaced usually by a complete graminoid cover with a few herbs and scattered shrub species such as wild rose, wild currant, and willow (*Salix* spp.). It was also noted that dense speckled alder growth persisted on some of the very moist and wet sites (Fig. 10).

On scarified seedbeds markedly differing conditions existed. The bulldozer blading effectively removed all vegetation and the organic mantle, leaving exposed mineral soil. Vegetation regrowth progressed at a relatively slow to moderate rate. Consequently, reduced vegetation

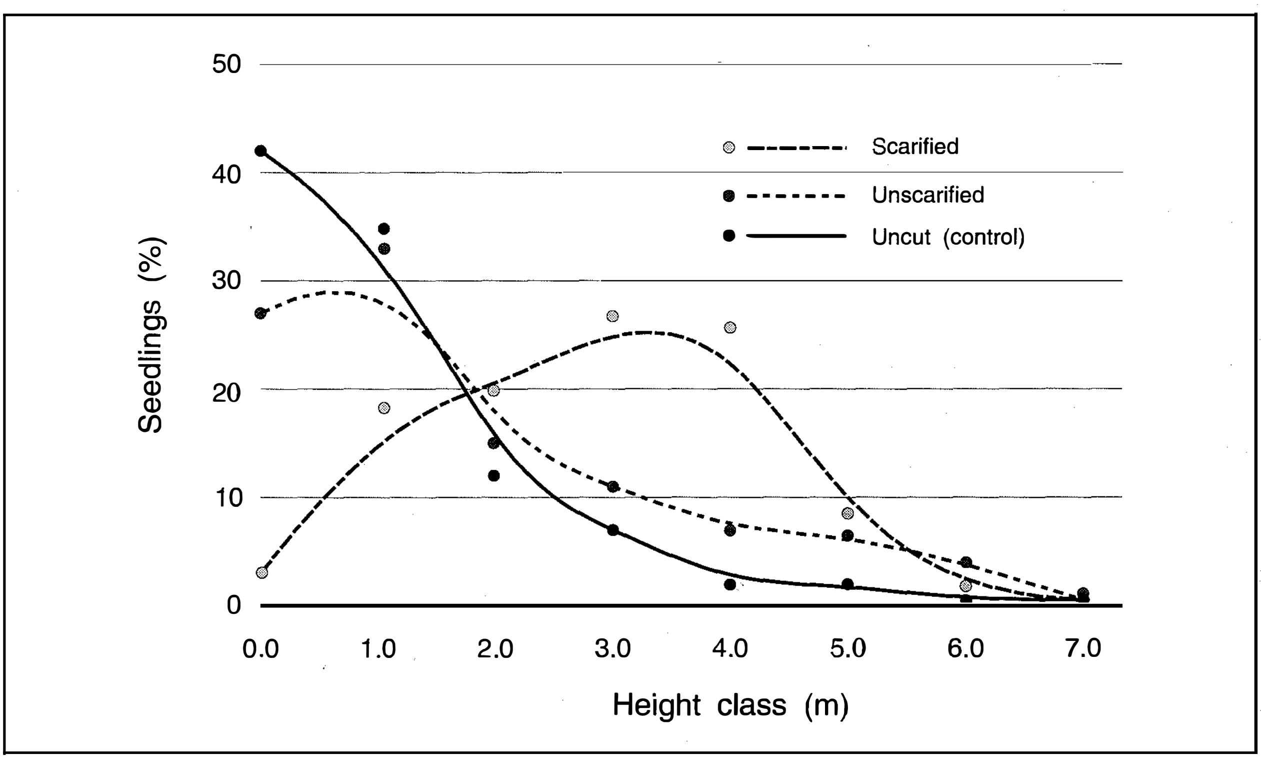

Figure 12. Height distribution of black spruce regeneration (excluding advance growth) 24 years after scarification and 29 years after logging on nonscarified areas.

Table 3. Average height of tallest black spruce regeneration, other softwoods, and hardwood reproduction per stocked 4-m^2 quadrat

Method of cutting and area	Cut and scarified[a]			Cut nonscarified[b]			Controls within treatment[b]		
	Black spruce regeneration (m)	Other softwoods (m)	Hardwoods[c] (m)	Black spruce regeneration (m)	Other softwoods (m)	Hardwoods (m)	Black spruce regeneration (m)	Other softwoods (m)	Hardwoods (m)
Clear-cut, Areas 13 & 14	2.7 (170)[d]	3.3 (36)	2.3 (105)	2.2 (38)	5.4 (2)	1.9 (73)	–[e]	–	–
Strips (E & W), Areas 1 & 10	2.7 (106)	3.6 (10)	3.2 (29)	1.7 (29)	1.3 (3)	4.9 (22)	0.9 (38)	–	2.1 (26)
Strips (N & S), Areas 8 & 11	2.6 (58)	1.7 (3)	2.7 (15)	1.4 (12)	–	1.6 (7)	1.2 (16)	–	2.7 (21)
Patch, Areas 5 & 9	3.2 (97)	5.5 (2)	1.6 (39)	2.1 (61)	0.9 (40)	4.0 (39)	1.2 (97)	1.0 (4)	2.6 (143)
Group selection, Areas 4 & 7	–	–	–	1.7 (74)	3.3 (3)	2.1 (94)	0.9 (41)	1.0 (3)	2.4 (54)
Shelterwood, Areas 3 & 6	–	–	–	1.4 (61)	2.3 (3)	3.0 (71)	–	–	–
External controls[f], Areas 2 & 12	–	–	–	–	–	–	1.1 (33)[f]	–	2.8 (31)[f]
All areas[g]	2.8 (430)	3.3 (51)	2.3 (188)	2.0 (275)	2.8 (15)	2.7 (306)	1.1 (225)	1.0 (7)	2.5 (275)

[a] Regeneration 24 years after scarification.
[b] Regeneration 29 years after scarification.
[c] Average height of hardwoods on stems > 50 cm.
[d] Figures in brackets represent number of heights measured.
[e] No data by definition.
[f] External to treated stands.
[g] Controls within cut stands except for areas 13 and 14 are averaged with areas 2 and 12.

competition permitted successful establishment of black spruce (Figs. 3 and 4). On fresh to moderately moist sites, as crown closure of the regenerated spruce occurred, lesser vegetation was increasingly being shaded out. In addition, there was some evidence based on the sparseness of the feather moss community that it was only in the early stages of succession. On moist-to-very-moist moisture regimes, the bladed seedbeds were more prone to flooding; seasonal inundation and water ponding had a degrading effect on these seedbeds, which resulted in failed stocking and diminished seedling growth (Fig. 8).

Residual Stands

Stand Development

During the 1956–85 period, losses to residual trees on treated areas and uncut controls increased as the leave time of overmaturing unharvested stands lengthened (Fig. 13). Stand attrition over 29 years, owing to initial logging disturbance and aging (134–165 years in 1985), was lower in the uncut controls than on the residuals associated with the four logged treatments (strip, patch, group selection, and shelterwood). Residual trees in the patch and strip cutting treatment had the highest volume losses (69 and 64%, respectively), while group selection and shelterwood cuts (59 and 57%, respectively) had higher losses than the uncut control (42%) (Table 4).

The number of trees per hectare before cutting and the decline after logging are shown in Figure 14. In 1956, the number of stems in uncut portions of the four cutting treatments ranged from 1 270 to 1 483/ha; 29 years later it ranged from 413 to 657/ha. During this period, the number of stems per hectare in the uncut control decreased from 3 373 to 1 315 (Fig. 14). The total number of stems in 1985, however, includes a substantial number of sapling and seedling-sized trees that entered a measurable diameter class. Most of these were in the <10 cm diameter class, and the proportion of this ingrowth to residuals indicates that actual stem losses of residuals were much higher (Fig. 15). This figure also shows that a higher proportion of regeneration occurred in the <10 cm diameter class with shelterwood cuts than with other treatments.

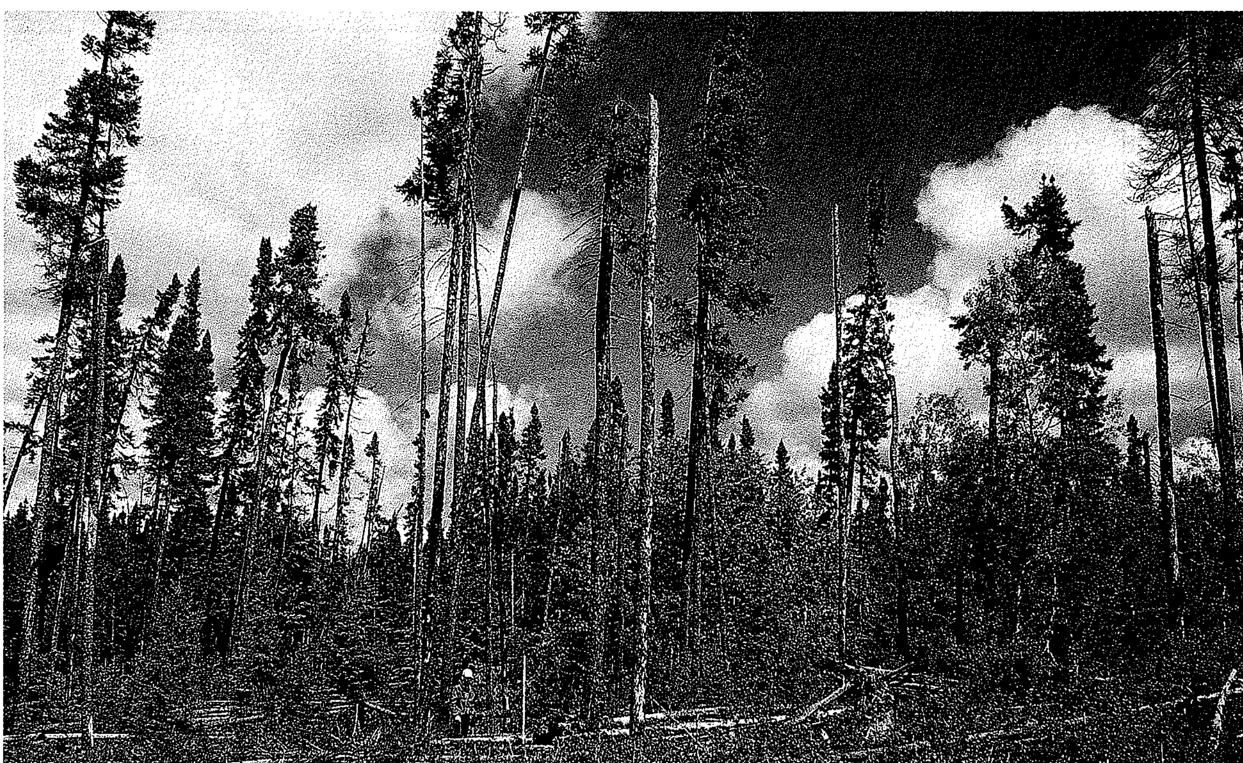

Figure 13. Residual stand and tree mortality in the group selection cut in Area 4.

Table 4. Merchantable volume and basal area per hectare before and after cutting (1956–85)

Attribute	Cutting method					
	Clear-cut	Strip[a]	Patch	Group selection	Shelterwood	Uncut (control)
Merchantable volume (m^3)						
Before cut	223.1	204.8	282.5	237.9	208.2	276.2
After cut	0.0	89.2	142.7	121.9	92.2	276.2
% removed	100.0	56.0	49.0	49.0	56.0	0.0
Basal area (m^2)						
After cut	–[b]	18.8	25.7	21.3	19.3	49.1
10 years later	–	12.4	15.4	14.2	11.2	–
% change	–	–34.0	–40.0	–33.0	–42.0	–
29 years later	–	6.6	7.6	9.0	7.6	26.9
% change	–	–65.0	–70.0	–58.0	–61.0	–45.0
Total volume (m^3)						
After cut	–	130.4	174.4	152.3	133.6	330.2
10 years later	–	87.7	106.2	102.8	78.6	–
% change	–	–33.0	–39.0	–32.0	–41.0	–
29 years later	–	47.3	54.7	63.0	57.0	190.7
% change	–	–64.0	–69.0	–59.0	–57.0	–42.0
Merchantable volume (m^3)						
After cut	–	89.2	142.7	121.9	92.2	276.2
10 years later	–	60.5	88.1	83.1	54.8	–
% change	–	–32.0	–38.0	–32.0	–41.0	–
29 years later	–	44.4	50.0	55.6	51.4	149.6
% change	–	–50.0	–65.0	–54.0	–44.0	–46.0

[a] Data for strip cut areas (E–W and N–S) are combined for comparison with Jarvis and Cayford (1967).
[b] No data.

Stand Mortality

Residual stand mortality between 1965 and 1985 in the uncut controls and in the logged areas is shown in Figure 16. In the uncut control most of the mortality was classified as dead standing (66%), which reflected suppression of lower crowned trees and deterioration of these stands in general to old age and overmaturity. In the logged areas residuals suffered more wind-related mortality (sheared off at the base, broken top, and uprooted). This appears to be attributable to the effects of logging disturbance and also stand aging.

Tree mortality for all residuals combined is shown in Figure 17. This figure indicates that most of the dead standing trees occurred in the 14-cm diameter class and that shearing, broken tops, and uprooting occurred mainly in the 14-, 17-, and 19-cm classes, respectively. Approximately 80% of this mortality, in terms of number of trees, occurred in the 10–20 cm diameter class; in terms of basal area, a similar amount occurred in the 15–25 cm diameter class.

DISCUSSION AND CONCLUSIONS

In this study, a number of cutting treatments were used in upland black spruce stands to investigate methods of logging that would be most suitable for inducing regeneration. These treatments included strip, patch, group selection, shelterwood, and clear-cutting as well as an uncut control area. In addition, seedbeds were prepared on some of these cutovers by bulldozer blade scarification 5 years after the original treatments.

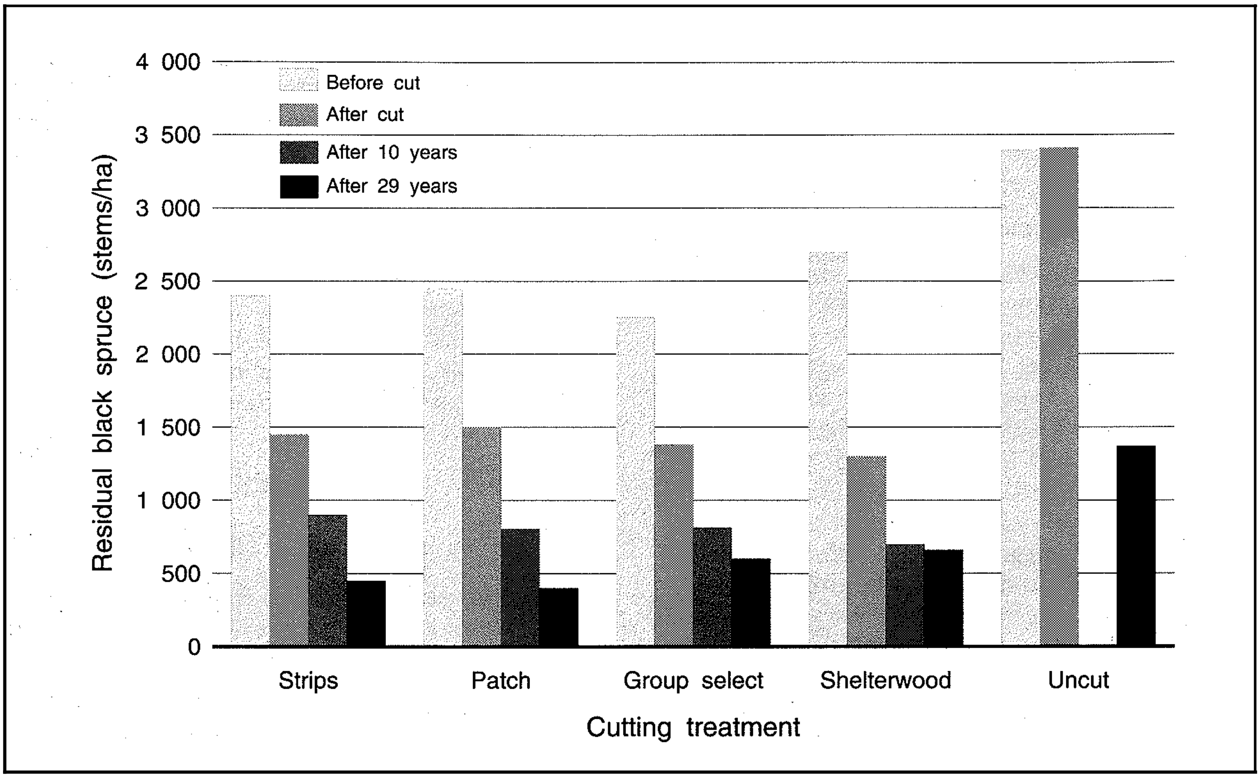

Figure 14. Number of residual black spruce per hectare before and after logging.

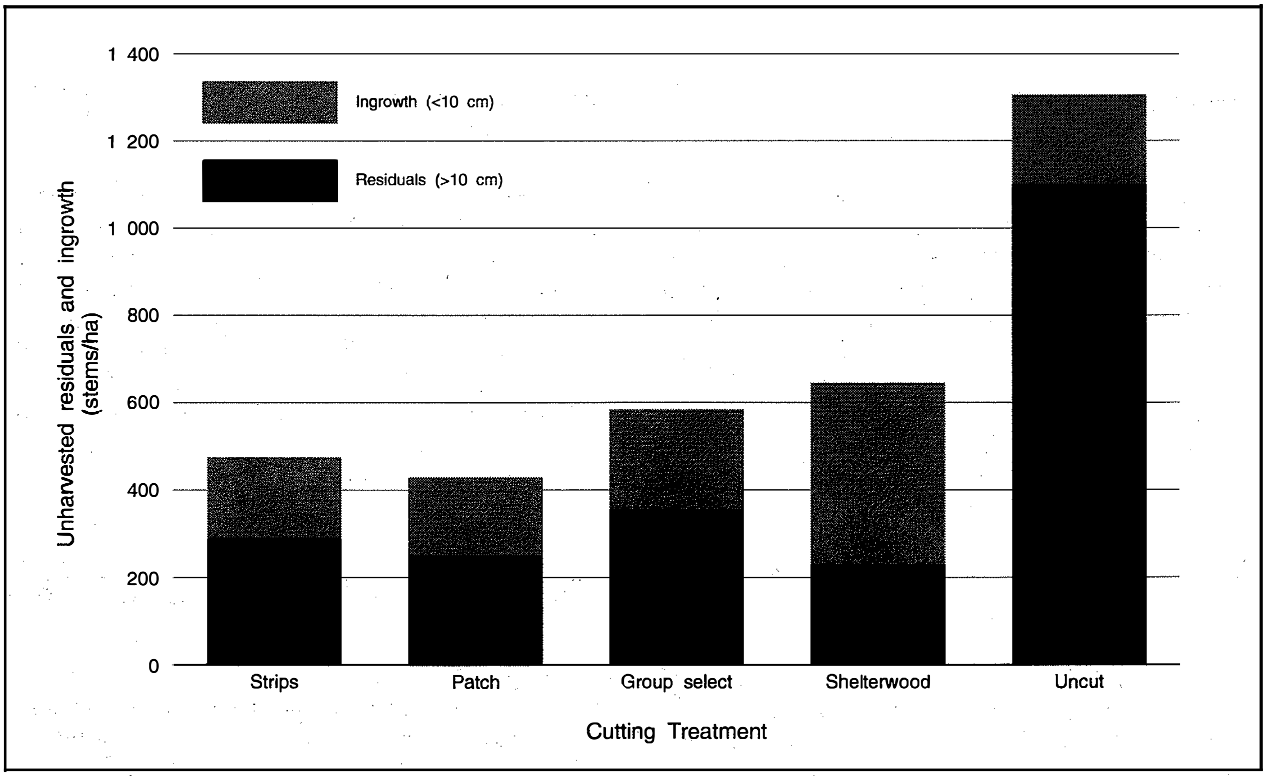

Figure 15. Relative proportion of sapling size and residual black spruce per hectare 29 years after logging.

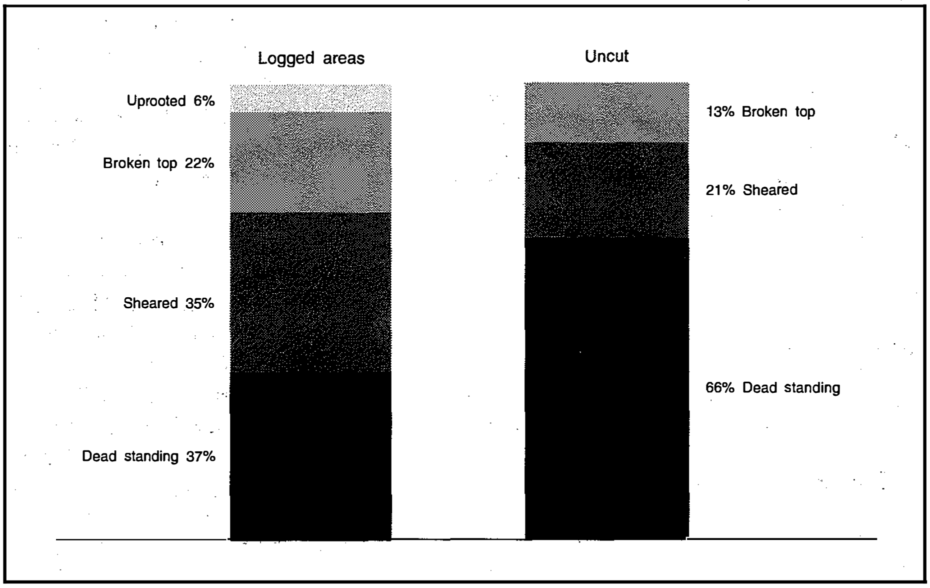

Figure 16. Types of residual tree mortality between 1965 and 1985.

The results after 29 years indicate that cutting techniques alone without seedbed treatment did not ensure adequate or well-regenerated stands. In fact, seedling influx with passage of time was slow in nonscarified areas. Stocking by 4-m^2 quadrat basis averaged 7% after the first 5 years (in 1960) and 15% after 10 years (Jarvis and Cayford 1961, 1967); it increased to 26% after 29 years. In comparison, scarified areas attained 79% overall stocking during a 24-year period.

Regeneration inducement by stand manipulation alone was generally better under patch, group selection, and shelterwood cutting than on clear-cut and cutover strips. This was probably attributable to a difference in subsurface exposure and rate of vegetative ingrowth between cutting treatments. Residual trees in the cutting treatments of the patch, group selection, and shelterwood cuttings more than likely provided better seedbed shading for maintaining a moisture regime balance for seedling germination and survival (Heinselman 1959). In addition, the rapid invasion of weed and shrub competition following disturbance from logging may have been less intense under partial shading than in clear-cuts.

Higher stocking levels were attained on the larger sized circular cuts in patch cutting (39 m in diameter) than on smaller group selection cuts (23 m in diameter). This indicates that the comparative larger openings were able to provide a protective environment for seedling germination and that the increased light intensity was probably more favorable for subsequent seedling growth than the heavier shading of smaller group selection cuts (Place 1955).

Advance growth and seedlings of layer origin occurred generally only in small and scattered amounts. As a result, their contribution to stocking was only of some importance when assessed on the basis of 10-m^2 quadrats. As an example, advance growth of 12% combined with regeneration in the case of patch cutting increased the stocking level to 75%, which is considered satisfactorily regenerated by Manitoba's minimum stocking standard (Manitoba Department of Natural Resources 1980). If, however, the second cut (harvesting of existing residual seed source trees) had been implemented within a time frame of 5–10 years, there evidently would have been insufficient regeneration even on the patch cutting. Considering that Jarvis and Cayford (1967) showed stocking on these nonscarified areas after the first 10-year period was only 19% (basis: 4-m^2 quadrats), this has served to emphasize the importance of early treatment of seedbeds following logging.

Sizeable losses of unharvested residual trees due to stand mortality subsequent to logging disturbance was evident at 10 years after cutting (Jarvis and Cayford 1967). Wind-related mortality and breaking up of stands due to old age (125–165 years in 1985) were particularly apparent after 29 years. Losses in terms of merchantable and total volume were severe for all cutting systems. Patch cutting seemed to sustain the heaviest loss; stand trees bordering and on adjoining circular cuts were particularly vulnerable to blowdown. The first 10-year mortality that occurred in shelterwood cutting was offset to some degree by the presence and favorable response of ingrowth during the post-logging interval. The tally of the many dead standing trees

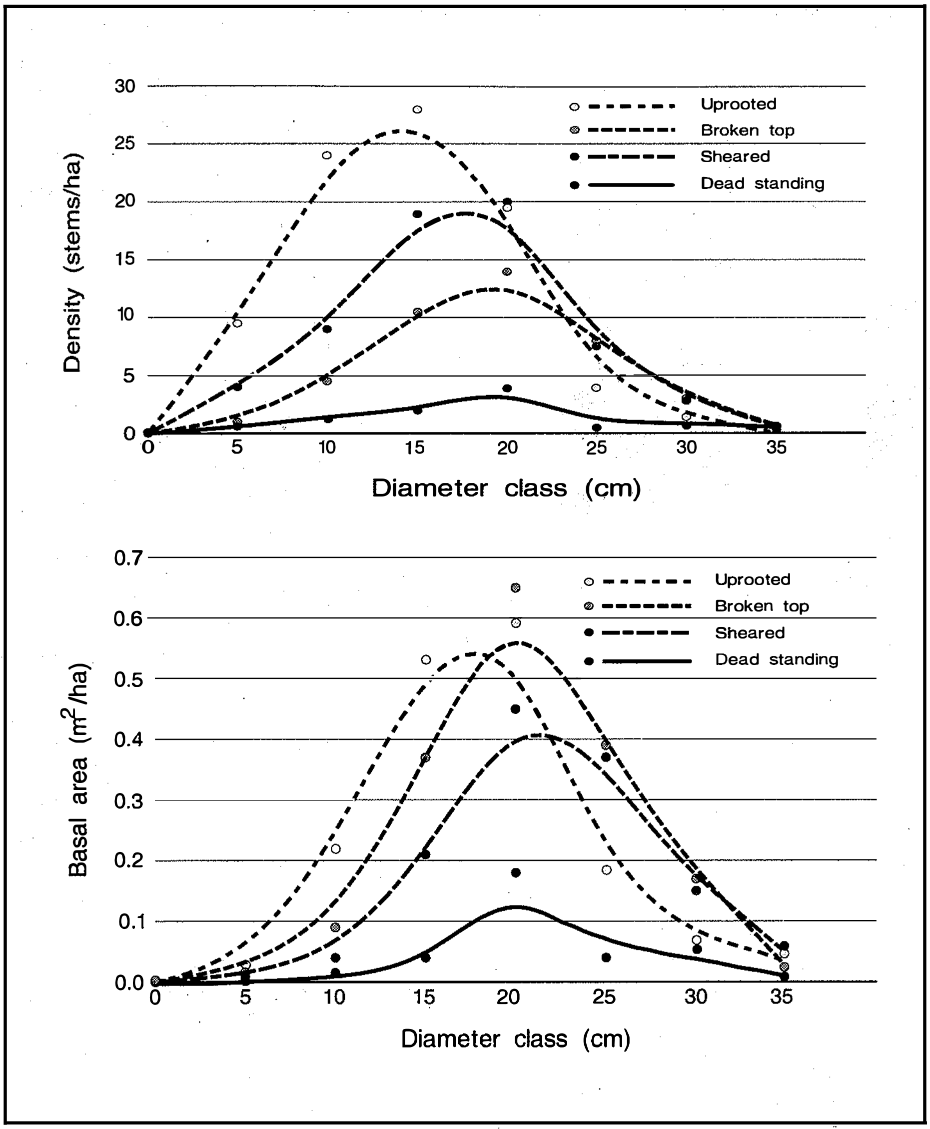

Figure 17. Mortality of residual trees by diameter class between 1965 and 1985 (all cutting treatments combined).

overall has revealed that substantial losses through natural stand attrition can also be expected as leave time lengthens (Evert 1976; Fleming and Crossfield 1983).

From the point of view of residual stand mortality, it is apparent that with a natural regeneration system (through cutting and retaining a seed supply) it becomes important to have black spruce seed on a seedbed as soon after logging as possible to allow harvesting of the residual cut before major losses occur. It follows, therefore, that some form of site preparation will be necessary to provide seedbeds that are conducive to securing natural regeneration in sufficient quantity to form the future stand. In this study, such seedbeds were provided by ground scarification and the exposure of mineral soil.

The question remains, though, as to what degree and intensity should site preparation be taken to attain a desirable stocking level. Heavy and uniform scarification by straight blading as undertaken in these trials resulted largely in an overabundance of seedlings. Densities ranged from approximately 23 000 to 58 000 stems/ha, which is too high and will require thinning for optimum growth. There are also other biological and ecological factors with blading that can have a considerable impact on the development of the regenerated stand.

The removal of top soil can affect soil fertility, and exposed mineral soils are predisposed to erosion and flooding. McMinn (1974, 1982) stated that scalping and casting aside of the organic and soil surface materials can reduce soil fertility inherent in the duff and organic substrates. It was shown that nitrogen depletion by removal of the forest floor on a fine-textured podsol had positively reduced tree growth in a jack pine ecosystem (Weber et al. 1985). Blading medium to moderately coarse-textured soils might not lower site productivity too severely since nutrient loss can be offset by reduced vegetative competition and warmer soil temperatures (McMinn 1982). The soils at the Duck Mountain area fall into the heavier soil-texture category.

Straight blade scarifying and rolling back of subsurface materials inevitably creates large volumes of accumulated mineral and organic debris. In this study, it was determined that the generally windrowed and mounded materials reduced the productive scarified area by 18%. Black spruce failed to regenerate on this seedbed medium due to the low moisture holding capabilities of the loosely piled mineral and organic substrates. Rapid and intense development of vegetative competition on mounded debris also precluded any seedling establishment. The seedbed treatment operation revealed that very moist and drainageway sites could either become lost, or not be effectively brought into production. Much of this problem is due to high water tables associated with these sites and flooding, which is often compounded by removal of the organic mantle. Blading even less moist sites (MR 5) also subjected certain seedbeds to flooding. It was observed that creation of depressions through dipping of the bulldozer blade could often cause water ponding (Fig. 8).

In summary, the less desirable aspects of bulldozer blading in the Duck Mountain experiment reveal a need to limit mineral soil exposure. Limiting the area of exposed mineral soil could provide a means of controlling overstocking and regeneration density. Shallower surface depth scalping by leaving a thin layer of humus would keep more nutrients on the site and aid in maintaining soil fertility. Humus-covered soil and the lower and nutrient rich Ah soil horizon provide good seedbeds for germination and growth (Winston 1974; Jeglum 1979). In addition, care should be exercised in the treatment of moist and very moist sites to reduce flooding problems. This can be alleviated to some measure by avoiding rutting and deep blading.

With the termination of this study, salvage logging of these unharvested residual stands has been in progress. As a result, some consideration will have to be given as to the most practical means to raise stocking levels of underregenerated final cut and previously cut nonscarified areas. Logging operations with wheeled skidders currently in use are not likely to preserve any appreciable amounts of existing advanced regeneration (Horton 1965; Arnott 1968; Stanek 1975). In addition, any further retainment of possible seed trees by a modified harvest approach (Robinson 1974; Wood and Raper 1987) is impractical due to the old age and deteriorated state of the stands. Further evidence of stand deterioration was indicated by the absence of cotyledonous seedlings in 1985, which appeared to be due to a decline in seed supply.

There are two other options open to the forest manager—to plant or seed. Each method requires some form of site preparation to assure restocking success (Armson 1975; Virgo 1975). By most accounts, planting appears to be a more reliable method than seeding (e.g., Wood and Jeglum 1984). Planted seedlings have an added advantage of requiring less intense seedbed preparation for survival and accelerated growth than the requirement usually necessary for crop establishment by direct seeding (Richardson 1973; Rudolph 1973; Fraser 1981). The underlying objective of this approach (planting or seeding) would primarily be to fill in understocked and unregenerated areas. In light of the problems that were alluded to in treating very moist and wet sites and their susceptibility to degradation, it seems logical that the effort in preparing any seedbeds should be restricted to manageable drier sites. Drier sites on these areas, ranging from moderately fresh to moist, would be more productive for tree growth and less costly to prepare.

When this study was initiated, logging practices of the period were essentially hand cutting and piling, with trees delimbed and topped at the stump. Removal of the wood was usually by horse-drawn sleighs. Current operations have been revolutionized by rubber-tired skidder logging, which has permitted the forwarding of full-length trees to a landing for delimbing and topping. This system, in effect, considerably reduces slash loadings on cutovers and thus allows for greater potential seedbed exposure and can facilitate site preparation (Horton 1965; Johnstone 1975; Smith et al. 1985). Mechanization, whether of logging or site preparation, has also meant that most mechanical equipment generally requires greater room to maneuver and that efficiency and profit margins increase with the larger-sized cuts. From an operational point of view, it is therefore evident that shelterwood and small patch cutting techniques are not practical, nor are they worthwhile from the standpoint of increasing reproduction.

Based on these results and the work of other investigators, it is recommended that logging and the silvicultural prescription should be integrated through alternate strip or small-sized block clear-cutting. Suggested guidelines for cutting these types of black spruce stands include:

1) Alternate strips should be from 40 to 60 m wide. This ensures good seed dispersal and protection for established seedlings (Auld 1975). It is also pointed out that leave strips wider than the 20-m widths used in this study can reduce leave stand mortality (Elling and Verry 1978; Fleming and Crossfield 1983).

2) Block clear-cuts should be from 1 to 5 ha in size. They could be irregular in configuration due to the topography and the relative amounts of upland and lowland of the area to be cut. They should not, however, be so wide that a maximum seed dispersal distance of about 90 m from bordering stand trees is exceeded (Haavisto 1975).

3) Pretreatment surveys should be conducted to determine the amount and distribution of advance growth so that the prescription for seedbed treatment can be confined to sites that are insufficiently stocked.

4) Effective site preparation should be carried out as soon as possible after logging to provide a measure of vegetative competition control and to capitalize on the seed supply from the retained stand trees.

5) Heavy scarification in treating very moist sites should be avoided in order to prevent seedbed degradation. Wet and drainageway sites should be left nonscarified.

The cutting method should be determined on the basis of prevailing stand size and terrain conditions.

ACKNOWLEGMENTS

The author wishes to acknowledge the work of H.J. Johnson, who planned and initiated this experiment. Acknowledgement is also made to J.M. Jarvis and J.H. Cayford, who published earlier reports from which much valuable information was obtained. Appreciation is extended to G.H. McColm and P. Borowski of the Manitoba Department of Natural Resources, Forestry Branch, for their cooperation and diligence in preserving the study area until field measurements were completed.

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