UNIFORM SHELTERWOOD CUTTING AND SCARIFYING IN WHITE SPRUCE-TREMBLING ASPEN STANDS TO INDUCE NATURAL WHITE SPRUCE REGENERATION, MANITOBA AND SASKATCHEWAN

by

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ABSTRACT

Between 1962 and 1965 a series of operational-scale trials, involving a two-stage shelterwood harvesting system and scarification, to induce natural white spruce regeneration in boreal mixedwood stands was carried out in Manitoba and Saskatchewan. This report deals with stocking, density, and height growth of the white spruce regeneration and hardwood reproduction 22 to 24 years following establishment. Impact of the 2nd cut on white spruce regeneration; stand development and biodiversity; and a comparison of alternate strip clear-cutting and scarification under the same conditions are also discussed.

Five of the six trial areas met current provincial stocking standards. Areas were, overall, 75 % stocked (on a 10-m^2 quadrat basis) with 4 600 white spruce and 2 310 hardwood stems/ha averaging 1.6 and 4.9 m in height respectively. White spruce stocking varied between 24 and 61%; averaging 44% while hardwood stocking ranged between 60 and 65%; averaging 62%. By including balsam fir regeneration and advanced growth, overall stocking increased to 77% and conifer stocking to 48%. Failure of one trial is attributed to inadequate scarification (17 vs 29 - 42%).

Criteria for successfully regenerating white spruce using the shelterwood harvesting system and scarification are presented.

Frontispiece: White spruce regeneration under a white spruce - aspen shelterwood 24 years after seedbed treatment on Area 1, Riding Mountain. Left: White spruce residual seed tree. Right: White spruce regeneration on blade-scarified seedbeds.

Page

TABLE OF CONTENTS

FIGURES

Page

TABLES

UNIFORM SHELTERWOOD CUTTING AND SCARIFYING IN WHITE SPRUCE-TREMBLING ASPEN STANDS TO INDUCE NATURAL WHITE SPRUCE REGENERATION, MANITOBA AND SASKATCHEWAN

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INTRODUCTION

A nation-wide survey of reproduction conducted by Candy (1951) revealed that the regeneration of white spruce (*Picea glauca (*Moench)Voss) was scarce in both disturbed and undisturbed stands in the Mixedwood Forest Section (B.18a) of the Boreal Forest Region (Rowe 1972). The inability of this species to regenerate adequately and to establish well-stocked stands in Saskatchewan has more recently been stated by Kabzems (1971). Among factors constraining natural regeneration is the lack of seedbeds suitable for seed germination and seedling survival (Rowe 1955). Various experiments have shown that scarification exposing humus and mineral soil results in favourable seedbeds (Phelps 1951; Crossley 1955; Lees 1963, 1964, 1970; Waldron 1966; Walker 1988; Kolabinski 1994). On such seedbeds, moisture is usually available at or near the surface, especially in the early part of the growing season when most seedlings are germinating and establishing root systems.

In 1962 the Canadian Forest Service, in cooperation with the governments of Manitoba and Saskatchewan, initiated a project (MS-228) to assess whether or not a uniform two-stage shelterwood cutting combined with mechanical seedbed preparation in mixed white spruce -trembling aspen (*Populus tremuloides* Michx.) stands would result in sufficient white spruce regeneration to ensure future well-stocked mixedwood stands. Application of the shelterwood system leaves a partial overstory which, when accompanied with scarification, is beneficial for conserving moisture at the soil surface for seed germination and the protection of seedlings from drought and lethal soil surface temperatures (Place 1955; Day 1963, 1970; Jarvis et al 1966; Waldron 1966; Lees 1970). In addition, reducing the crown cover also provides conditions for improving growth rate of establishing seedlings (Waldron 1966); under dense stands white spruce seedling development is adversely affected by heavy shade (Quaite 1956; Logan 1969).

Between 1962 and 1966, seven operational trials entailing shelterwood logging and scarification were established in Manitoba and Saskatchewan. Project establishment, post logging and preliminary treatment results covering the first five growing seasons for individual areas are contained in Project MS 228 progress reports[2]. Unfortunately the closing of the former Manitoba-Saskatchewan Region, Canada Department of Fisheries and Forestry office in Winnipeg in 1970 precluded the opportunity to carry out the second cut at the Riding Mountain Forest Experimental

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[1]Former employees Canadian Forest Service, Natural Resources Canada, residing in Sherwood Park, Alberta and Winnipeg, Manitoba respectively.

[2] Project MS-228: Shelterwood cutting and mechanical seedbed treatment in white spruce-trembling aspen stands to induce white spruce regeneration, Manitoba and Saskatchewan (Unpublished progress reports by Jarvis 1962, 1963, and 1965; Kolabinski 1964 and 1967).

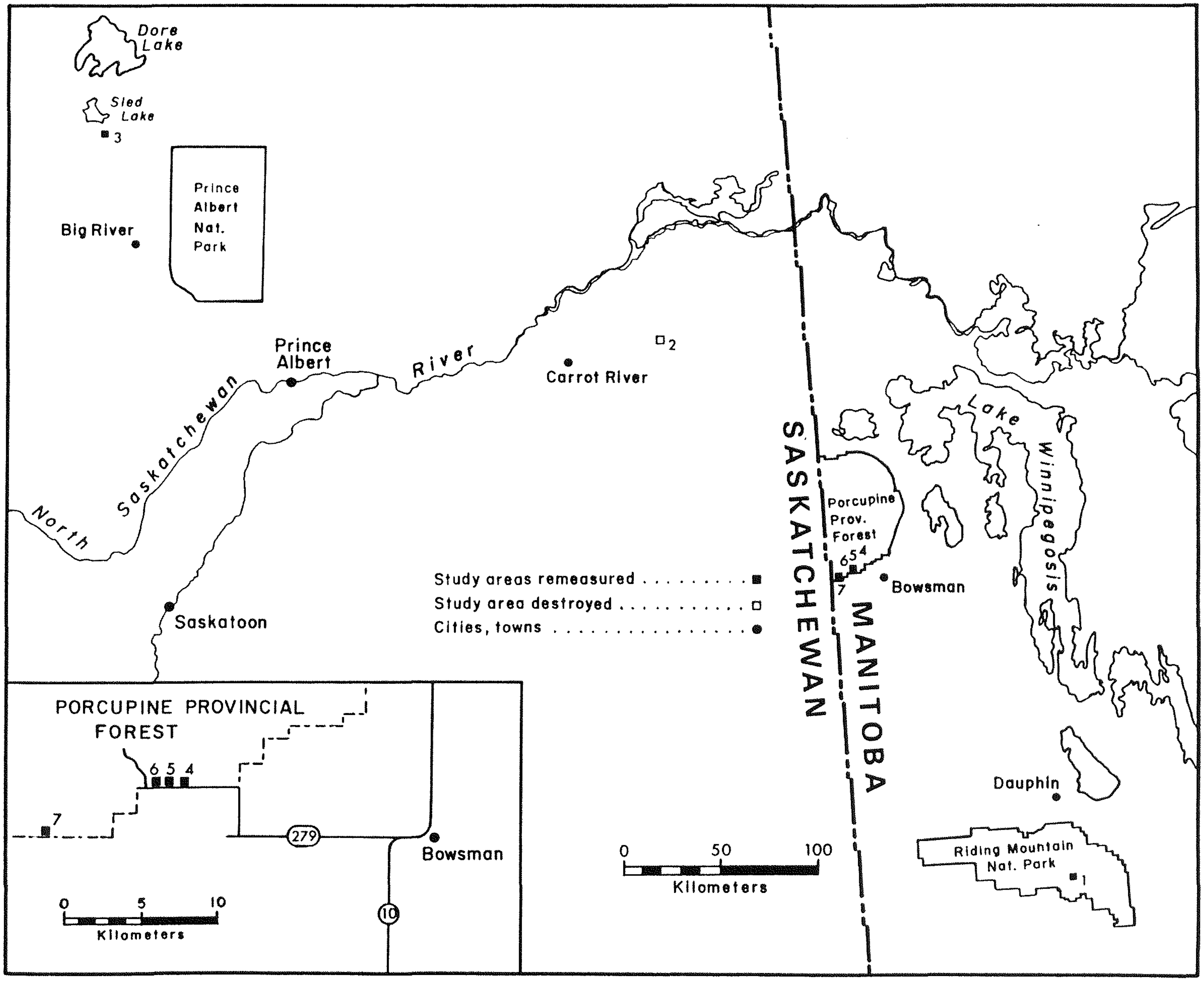

Figure 1. Location of shelterwood study areas in white spruce-aspen stands in Manitoba and Saskatchewan.

Area, Manitoba and at Sled Lake, Saskatchewan. The Canada-Manitoba Forest Renewal Agreement signed in 1984, enabled the Canadian Forest Service to remeasure the study areas. Stocking, density, and height growth of white spruce regeneration and hardwood reproduction 22 to 24 growing seasons following establishment; impact of the 2nd cut on white spruce regeneration on four areas; and stand development and biodiversity are presented.

STUDY AREAS

Between 1962 and 1966 seven study areas, varying in size from 6.1 to 40.5 ha, were established in mature white spruce-trembling aspen stands. All of the stands are within the B.18a Mixedwood Section of the Boreal Forest Region (Rowe 1972). Five areas are located in Manitoba and two in Saskatchewan. Unfortunately, Area 2 located near Carrot River, Saskatchewan was destroyed before an assessment could be undertaken (Fig. 1).

Average stand basal areas for Areas 1 and 3, prior to logging in 1963 and 1962, were 11.2 and 8.1 m^2/ha of white spruce, with 13.5 and 14.6 m^2/ha of hardwoods, respectively (Table 1). Balsam fir (*Abies balsamea* L. Mill.) was also present in the understorey of Area 3 and averaged 0.2 m^2/ha. At the Porcupine Provincial Forest, the stands in Areas 4 to 7 had been partially logged to a 21.8 cm diameter limit for white spruce saw logs approximately 20 years prior to the preparation of seedbeds in 1964 and 1965 (Steneker 1969). As a result these latter stands were made up primarily of the remaining, and now mature, white spruce, small diameter poplar reproduction, and residual hardwoods. Basal area of residual white spruce on these areas ranged from 4.6 to 11.8 m^2/ha; hardwoods from 5.0 to 14.5 m^2/ha. Stand values for all six areas varied from 14.7 to 19.1 m^2/ha (Table 1).

The terrain in Riding Mountain (Area 1) is rolling while in the others it is either flat or gently undulating. Soils from the Bt horizon were clay loam in texture and soil moisture, according to Hills' site classification system (1952), ranged from fresh to very moist (Table 2). Ground vegetation on the experimental areas (1, and 4 to 7) located in Manitoba consisted of a tall shrub-herb type. Beaked hazelnut (*Corylus cornuta* Marsh.) is the main constituent of the shrub class on predominant fresh (3) to moderately moist (4) sites. In comparison to the Riding Mountain, the relatively moister sites (4 and 5) at the Porcupine Provincial Forest characteristically supported a greater variety of other tall shrub species such as high bush cranberry (*Viburnum trilobum* Marsh.), red osier dogwood (*Cornus stolonifera* Michx.), and speckled alder (*Alnus rugosa* (Du Roi) Spreng. var. *americana* (Reg.) Fern). On Area 3 in Saskatchewan the vegetation was principally feathermoss (*Pleurozium schreberi* BSG. Mitt) and stair step moss (*Hylocomium splendens* (Hedw.) BSG) with tall shrubs such as green alder (*Alnus crispa* (Ait.) Pursh) present on the fresh to moderately moist sites and river alder (*Alnus tenuifolia* Nutt.) occupying lower lying moist to very moist areas (6).

METHODS

Logging

On Area 1 at the Riding Mountain logging of individually marked white spruce — an individual tree selection system designed to remove the largest (48 cm and up) as well as dying, defective, and high-risk trees while ensuring a uniform distribution of thrifty residuals which would survive until a proposed second cut in approximately

Table 1. Number of trees and basal area per hectare of stands by species and study area at time of establishment

Study area	Time of stand assessment	White spruce No. of trees (/ha)[b]	White spruce Basal area (m²/ha)	White spruce (%)[c]	Balsam fir No. of trees (/ha)	Balsam fir Basal area (m²/ha)	Balsam fir (%)	Hardwoods[a] No. of trees (/ha)	Hardwoods[a] Basal area (m²/ha)	Hardwoods[a] (%)
Riding Mtn. (1)	Before logging (1962)	202	11.2	45	--	--	--	178	13.5	55
	After logging (1964)	144	4.7	29	--	--	--	156	11.9	71
	% change	-28	-58	--	--	--	--	-12	-12	--
Sled Lake (3)	Before logging (1962)	206	8.1	35	156	0.2	1	240	14.6	64
	After logging (1963)	172	4.7	29	156	0.2	1	206	11.4	70
	% change	-17	-42	--	--	--	--	-14	-22	--
Porcupine For. (4)	After scarification (1965)[d]	124	9.3	63	--	--	--	345[e]	5.4	37
Porcupine For. (5)	After scarification (1965)[d]	167	11.8	70	--	--	--	235[e]	5.0	30
Porcupine For. (6)	After scarification (1966)[d]	49	4.6	24	5	>0.1	>1	564[e]	14.6	76
Porcupine For. (7)	After scarification (1966)[d]	83	6.2	32	--	--	--	745[e]	12.9	68

[a] Hardwoods includes trembling aspen, balsam poplar and white birch.
[b] Includes trees $\geq$ 1.5 cm dbh.
[c] Percent of entire stand.
[d] These areas were logged for merchantable white spruce (DBH $\geq$ 21.8cm) approximately 20 years prior to scarification.
[e] Comprised of hardwood residuals and small-diameter reproduction.

10 years[3] — took place during the winter of 1963-64. This shelterwood left 72% of the original number of white spruce, 42% or 4.7 m^2 basal area/ha, and nearly all (88% or 11.9 m^2/ha) of the hardwoods (Table 1). On Area 3 logging, which was carried out during the winter of 1962-63, left 83% of the white spruce, and 58% (4.7 m^2/ha) of the white spruce and 78% (11.4 m^2/ha) of the hardwood basal area. At the Porcupine Provincial Forest no logging was carried out in Areas 4 to 7 at the time the experiment was initiated. A further breakdown of the number of trees and basal area/ha by tree size (1.5 -9.0 cm and 9.1 cm + classes) is provided in Table 11.

Waldron (1966) has recommend that a total of 9.2 to 13.8 m^2 basal area /ha - of which a minimum of 5.7 m^2 must be white spruce - should be left after the first cut of a two stage shelterwood harvest system in boreal mixedwoods. The six trial areas (Table 1) essentially met the white spruce basal area criteria but four of the areas (1, 3, 6, and 7) had excessive amounts of residual, and presumably unmerchantable, hardwoods. Recent results from a seed tree harvesting system applied in mixedwood stands at the Riding Mountain suggest that on small cut-blocks (4 ha) even a residual stand of 4 m^2/ha of mature white spruce is adequate to successfully regenerate white spruce on mineral soil seedbeds[4].

The second cut, or final removal of the residual white spruce on Areas 1 and 3 has not, as yet, taken place. However, white spruce residuals were harvested from Areas 4 and 7 in the winter and summer of 1973 respectively, and from Areas 5 and 6 in the winter of 1985[5]. In addition, white birch (*Betula papyrifera* Marsh.) was being removed from Areas 6 and 7 at the time of the 1987 assessment.

Scarification

Crawler-type tractors equipped with hydraulically controlled straight blades were used to create mineral soil seedbeds on the experimental areas between 1962 and 1965. In Area 1 the 8.1 ha. block was divided into eight section of which four were randomly chosen and then enlarged to 1.4 ha in size prior to scarification; the other four sections (0.6 ha in size) were left untreated as controls. Scarifying, which was carried out in Area 1 in the summer of 1962 prior to logging in 1963-64, was done by scalping as many and as large-as-possible patches of mineral soil around and between the residual standing trees while avoiding areas containing significant amounts of advanced growth[6]; 42% mineral soil exposure was achieved. In contrast, on Area 3, the manner of scarifying differed in that the entire area was treated - after logging in 1963 - by bulldozing continuous strips in a corridor fashion which produced 29% exposed mineral soil and 10% mounded mineral and organic material (Table 2).

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[3]Haig, R. A. 1964. Silvicultural operations in white spruce- aspen stands on the Riding Mountain Forest Experimental Area, 1960 to 1963. Can. Dept. For., For. Res. Br., Manitoba-Saskatchewan Region, Winnipeg, Manitoba. Rept. 64-MS-4.

[4] Ball, W. J. and N. R. Walker. 1994. White spruce and aspen stand development after partial cutting mature mixed stands in Manitoba. Can. Nat. Res., Can. For. Serv., Northwest Region, Manitoba District Office, Winnipeg, Manitoba. Draft report.

[5]Personal communication from Greg Carlson, Manitoba Department of Natural Resources, Swan River, Manitoba, 1990.

[6]Pratt, M. 1978. Silvicultural operations in the Riding Mountain Forest Research Area from 1961 to 1969. Fish. Environ. Can., Can. For. Serv., North. For. Res. Cent., Edmonton, Alberta. File Rept. NOR-17-071.

Table 2. Summary of study area characteristics, scarification treatments at the time of their establishment, and logging

Study area	Size (ha)	Soil texture	Soil moisture[a] (range)	Logging: Year of first cut	Logging: Year of second cut	Scarification year	Area scarified (%)[b]: Mineral Soil	Area scarified (%)[b]: Mounds	Area scarified (%)[b]: MS + Mds	Area unscarified (%)
Riding Mtn. (1)	8.1	Clay loam	Fresh to moderately moist	1963-64	Not cut	1962	42	10	52	48
Sled Lake (3)	9.3	Silty clay-loam	Fresh to very moist	1962-63	Not cut	1963	29	10	39	61
Porcupine For. (4)	35.6	Clay loam	Fresh to very moist	Previous to[c] scarification	Winter 1973	1964	32	5	37	63
Porcupine For. (5)	11.3	Clay loam	Fresh to moist	Previous to[c] scarification	Winter 1985	1964	33	5	38	62
Porcupine For. (6)	40.5	Clay loam	Fresh to moist	Previous to[c] scarification	Winter 1985	1965	31	6	37	63
Porcupine For. (7)	39.2	Clay loam	Fresh to very moist	Previous to[c] scarification	Summer 1973	1965	17	4	21	79

[a] Hills 1952.

[b] Based on 5-m^2 quadrats having a minimum of 10% exposed bladed mineral soil (MS) or blade mounded (Mds) material.

[c] These areas were logged for merchantable white spruce (DBH $\geq$ 21.8 cm) approximately 20 years prior to scarification.

On the four study areas located in the Porcupine Provincial Forest, straight-blade scalping was done in the stands wherever it was conveniently possible to do so near to, or in the vicinity of, good white spruce seed trees. Because of stand structure in which the mature white spruce were often widely scattered, the scalping tended to be concentrated in specific areas that were often widely dispersed; mineral soil exposure averaged 32% except for Area 7 where only 17% exposure was achieved[7].

In a related study in the Porcupine Provincial Forest trial area, Steneker (1969) found that mean annual diameter increment for white spruce residuals was only minimally affected (10% loss) by scarification provided 120 m^2 of undisturbed soil surface - approximately a circle with a 3.1 m radius - was left; there was a 60% loss in diameter increment when the radius was reduced to only 2.1 m. The impact of this scarification treatment on windfirmness, particularly as it related to fungal infection, was not assessed. Pratt has reported that physical damage to both residuals and advanced growth at the Riding Mountain (Area 1) was light where 35-40% mineral soil exposure was achieved but considerably higher when scarification was more intense (up to 65%)[8]. Visual observations suggest that windfall losses of white spruce seed trees 32 year after the first cut on Area 1 at the Riding Mountain were generally light (Figure 2). However observations on windfall resulting from root and butt rot caused by wounding during scarification in operationally-harvested mixedwoods in the same general area suggested that the length of time available for seeding in between the two shelterwood cuts could be significantly reduced by poor scarification practices[9].

Seed Availability

White spruce seedfall can only be estimated since seed traps were not set out on the trial areas. However local cone crop estimates have been made in white spruce stands scattered throughout Manitoba and Saskatchewan since 1923[10]. In addition seedfall studies have been carried out at the Riding Mountain Forest Experimental Area in Manitoba (Waldron 1965)[11] and at Christopher Lake located 145 km to the southeast of Sled Lake, in Saskatchewan (Kolabinski 1994). Based on these estimates the following information was derived:

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[7]Both logging and scarification of areas in Saskatchewan and in the Porcupine Provincial Forest of Manitoba were carried out under the supervision of provincial forestry staff. Identical tasks at the Riding Mountain were supervised by Canadian Forest Service staff.

[8]Pratt, M. 1978. Silvicultural operations in white spruce-aspen stands in the Riding Mountain Forest Experimental Area from 1961 to 1969. Fish. Environ. Can., Can. For. Serv., North. For. Res. Cent., Edmonton, Alberta. File Rept. NOR-17-071.

[9]Brace Forest Services, 1992. Permanent sample plot remeasurement and regeneration surveys, Riding Mountain Forest Experimental Area - Manitoba. Can.-Manit. Partnership Agreement in Forestry, Contractor's report.

[10]Waldron, R. M. 1965. Annual cone crops of white spruce in Saskatchewan and Manitoba, 1923-1964. Can. Dept. For., For. Res. Br., Manitoba - Saskatchewan Region, Winnipeg, Manitoba. Rept. 65-MS-11.

[11]Hennessey, G. R. 1966. Seedfall and litterfall in a mature white spruce stand in Manitoba. Can. Dept. For.,For. Res. Lab., Winnipeg, Manitoba. Int. Rept. MS-35 and

Hennessey, G. R. 1970. Seedfall and litterfall in a mature white spruce stand in Manitoba. Can. Dept. Fish. For., Can. For. Serv., For. Res. Lab., Winnipeg, Manitoba. Int. Rept. MS-108.

Figure 2. Windthrown white spruce seed tree.

Study area	Basal area white spruce (m^2/ha)	Year of scarifi-cation	Years of observation	Total seedfall (M/ha)[1]	(kg/ha)
Riding Mtn. (1)	4.7	1962	1962-68(7)	5 872	11.1
Sled Lake (3)	4.7	1963	1963-66(4)	2 913	5.5
Porcupine (4/5)	10.6	1964	1964-68(5)	12 193	23.0
Porcupine (6/7)	5.4	1965	1965-68(4)	4 606	8.7

[1]M = thousands.

It would appear that white spruce seedfall was adequate at all locations especially when additional seed fell (heavy or medium white spruce cone crops occur once every two years on average; the longest interval being only four years[12]) during the remaining period that the mineral soil seedbeds were receptive to white spruce germination and seedling establishment.

Assessment Surveys

Between 1986 and 1988 the study areas were assessed for white spruce regeneration and hardwood reproduction 22 to 24 growing seasons after scarification. On each area, stocking success was measured on contiguous quadrats of two sizes - 5-m^2 (2 m x 2.5 m) and 10-m^2 (2 m x 5 m) - nested along parallel transect lines spaced at 40 m intervals. These two sizes of quadrats were used to conform to regeneration survey standards that were then in use in Saskatchewan and Manitoba. The following data were collected from these plots:

(1) A tally of the presence or absence of conifer regeneration on each quadrat by species based on live and healthy seedlings ≥3 years old.
(2) A tally of the presence of advanced growth conifer species that remained after logging and were ≥1.5 cm at breast height.
(3) Height of the tallest conifer occurring on each 5-m^2 quadrats measured to the nearest centimetre.
(4) Height of the tallest hardwood (≥ 50 cm) present on each 5-m^2 quadrat measured to the nearest centimetre.
(5) Notation of seedbed as scarified or nonscarified. Quadrats having 10% mineral soil exposure resulting from seedbed treatment were classified as scarified.
(6) A count of seedling stems by species on every fourth 5-m^2 quadrat.
(7) Classification of the quadrats by soil moisture regime (after Hills 1952).

The regeneration data were summarized and tabulated for each area to show percentage stocking, number of stems/ha and average height of dominant conifer regeneration and hardwood reproduction on treated and untreated seedbeds. Current provincial stocking standards based on 10-m^2 quadrats were used for stocking assessment (Appendix I).

[12]Waldron, R. M. 1965. Annual cone crops of white spruce in Saskatchewan and Manitoba 1923-1964. Can. Dept. For., For. Res. Br., Winnipeg, Manitoba. Rept 65-MS-11.

Table 3. Percent stocking of white spruce, balsam fir, and hardwoods by study area and site treatment (basis: 10-m² quadrats)

Study area	Establishment year	Site treatment	Growing seasons (years)	No. of quadrats (10-m²)	White spruce Regen (%)	White spruce Adv.Gr. (%)	White spruce R+A (%)	Balsam fir Regen (%)	Balsam fir Adv. Gr. (%)	Balsam fir R+A (%)	All softwoods (%)	Hardwoods[a] (%)	White spruce or hardwoods (%)	Conifers or hardwoods (%)
Riding Mtn. (1)	1962-63	Scarified	24	218	84.9	1.4	84.9	0.9	0.5	1.4	85.3	75.2	92.7	92.7
		Nonscarified		222	5.0	8.1	13.1	0.9	0.0	0.9	14.0	47.3	57.2	58.1
		All		440	44.5	4.8	48.6	0.9	0.2	1.1	49.3	61.1	74.8	75.2
Sled Lake (3)	1962-63	Scarified	23	115	85.2	0.9	85.2	41.7	0.0	41.7	87.8	66.1	92.2	92.2
		Nonscarified		167	40.1	6.6	44.9	29.9	13.2	35.9	62.9	55.1	70.6	82.6
		All		282	58.5	4.2	61.3	34.8	7.8	38.3	73.0	59.6	79.4	86.5
Porcupine For. (4)	1964	Scarified	23	111	87.4	1.8	87.4	5.4	0.9	6.3	87.4	67.6	94.6	94.6
		Nonscarified		169	13.6	14.2	23.1	2.4	0.0	2.4	27.2	58.6	69.8	69.8
		All		280	42.8	9.3	48.6	3.6	0.4	3.9	51.1	62.1	79.6	79.6
Porcupine For. (5)	1964	Scarified	23	77	94.8	0.0	94.8	15.6	0.0	15.6	94.8	75.3	97.4	97.4
		Nonscarified		115	6.1	0.9	7.0	0.9	0.0	0.9	7.8	58.3	61.7	62.6
		All		192	41.7	0.5	42.2	6.8	0.0	6.8	42.7	65.1	76.0	76.6
Porcupine For. (6)	1965	Scarified	22	96	70.8	2.1	72.9	33.3	0.0	33.3	78.1	70.8	88.5	89.6
		Nonscarified		144	8.3	1.4	9.7	6.2	2.1	7.6	17.4	57.6	61.1	66.0
		All		240	33.3	1.7	35.0	17.1	1.2	17.9	41.7	62.9	72.1	75.4
Porcupine For. (7)	1965	Scarified	22	58	87.9	0.0	87.9	1.7	0.0	1.7	87.9	89.6	98.3	98.3
		Nonscarified		198	5.0	0.0	5.0	0.0	0.0	0.0	5.0	58.1	59.1	59.1
		All		256	23.8	0.0	23.8	0.4	0.0	0.4	23.8	65.2	68.0	68.0
All areas	1962-65	Scarified	22-24	675	84.7	1.2	85.0	15.0	0.3	15.2	86.4	73.0	93.3	93.5
		Nonscarified		1 015	12.8	5.5	17.2	6.5	2.5	7.7	22.3	55.3	63.0	65.9
		All		1 690	41.5	3.8	44.3	9.9	1.6	10.7	47.9	62.4	75.1	76.9

[a] Hardwoods include trembling aspen, balsam poplar and white birch.

As a means of assessing the impact of the second cuts on white spruce regeneration on Areas 4 to 7 in the Porcupine Provincial Forest, remeasurements were carried out on sets of 10 contiguous 4-m^2 quadrat that had been randomly installed in transect lines on treated and untreated seedbeds during the initial establishment of the trial areas. Stocking and white spruce seedling density on these plots in 1987 and 1988 were compared with 5-year assessment records on file.

In each of the experimental areas, stand data were collected on permanently marked 10 m-wide (1/2 chain) tally strips; a total of 4 969 m were examined on the six areas. All living trees were recorded by species and 2.54 cm dbh classes[13]. Basal areas were calculated for trees 1.5 - 9.0 cm and 9.1 cm +.

RESULTS AND DISCUSSION

White Spruce Regeneration

(a) Stocking

Overall stocking of white spruce regeneration on scarified seedbeds averaged 85%; meeting the 10-m^2 regeneration quadrat size stocking standards in mixedwoods for all three prairie provinces (Table 3). As expected, stocking on nonscarified seedbeds was a complete failure averaging only 13%. The better performance (40%) on untreated seedbeds on Area 3 was unexpected and appeared to be due, in part, to improved moisture conditions on feathermoss and rotted wood growing mediums.

Overall, area stocking to white spruce was 42% reflecting the fact that scarification to expose mineral soil seedbeds averaged only 31%; ranging from a high of 42% mineral soil exposure and 44% stocking on Area 1 to a low of 17% mineral soil exposure and 24% stocking on Area 7 (Tables 2 and 3). Area 3 at 58% stocking of white spruce only, easily exceeded the provincial standard (45%) for mixedwood stands in Manitoba and Alberta while Areas 1, 4, and 5 just fell short at 42-44%.

Stocking data for the 5-m^2 quadrats are provided in Appendix II.

(b) Density

Seedling densities for white spruce regeneration on the blade scarification ranged from 4 720 to 16 700 and on untreated seedbeds from 0 to 950/ha (Table 4). Conditions on nonscarified seedbeds within the shelterwood were not suitable for natural regeneration of white spruce, even after 22 to 24 years. With the exception of Area 3, field observations indicated that the prevailing undisturbed litter in the stands was usually too dry for germination and survival of seedlings. In addition the presence and development of dense shrub species such as hazel, as well as poplar suckers, also limited white spruce seedling establishment.

In contrast, seedbeds in which the subsurface organic horizons were removed by blading to expose mineral soil generally supported an over abundance of white spruce seedlings. Variations in actual numbers among the experimental areas probably reflected the proximity of seed trees to the scattered scarification patches.

[13]Diameter breast height (dbh) measurements were taken at 1.37 m (4.5 feet), not at 1.30 m.

Table 4. Number of white spruce, balsam fir, and hardwood stems per hectare by study area and site treatment

Study area	Establishment year	Site treatment	Growing seasons (years)	No. of quadrats (5-m²)	White spruce Regen /ha	White spruce Adv.Gr. /ha	Balsam fir Regen /ha	Balsam fir Adv. Gr. /ha	Hardwoods[a] Reproduction /ha	All
Riding Mtn. (1)	1962-63	Scarified	24	114	8 430	20	20	0	4 360	12 830
		Nonscarified		106	0	70	0	0	1 020	1 090
		All		20	4 370	10	10	0	2 750	7 140
Sled Lake (3)	1962-63	Scarified	23	58	16 700	40	5 540	0	2 560	24 840
		Nonscarified		83	950	90	1 100	600	1 250	3 990
		All		141	7 430	70	2 930	100	1 790	12 320
Porcupine For. (4)	1964	Scarified	23	59	14 030	0	80	0	2 390	16 500
		Nonscarified		81	150	180	30	0	1 130	1 490
		All		140	6 000	110	50	0	1 660	7 820
Porcupine For. (5)	1964	Scarified	23	41	11 150	0	0	0	3 980	15 130
		Nonscarified		55	90	0	0	0	2 020	2 110
		All		96	4 810	0	0	0	2 860	7 670
Porcupine For. (6)	1965	Scarified	22	44	4 720	0	950	0	1 570	7 240
		Nonscarified		76	30	0	100	0	1 500	1 630
		All		120	1 750	0	410	0	1 520	3 680
Porcupine For. (7)	1965	Scarified	22	28	11 740	0	0	0	8 120	19 860
		Nonscarified		100	0	0	0	0	1 730	1 730
		All		128	2 570	0	0	0	3 130	5 700
All areas	1962-65	Scarified	22-24	344	10 900	20	1 080	0	3 570	15 570
		Nonscarified		501	200	60	200	100	1 400	1 960
		All		845	4 560	40	560	60	2 310	7 530

[a] Hardwoods include trembling aspen, balsam poplar and white birch.

A comparatively lower seedling count on the scarified seedbeds in Area 6 (4 720 stems/ha) was apparently due to too few residual seed trees (Tables 1 and 4). There were indications that snowshoe hare (*Lepus americanus*) browsing may have taken their toll of seedlings on this area. As well, it can be speculated that the seedling count on Area 1 (amounting to 8 430 stems/ha) at Riding Mountain in all probability would have been even higher. Data on file reveals that considerable losses of early seedling germinants were sustained due to logging of the stand the second year after seedbed preparation[14]. Some mineral soil seedbeds were buried by slash and logging debris preventing further ingress of white spruce seedlings.

The average density of spruce seedlings combining both treated and untreated seedbeds ranged from 1 750 stems (Area 6) to 7 430 stems (Area 3) per hectare. However, it can be seen that distribution of seedlings are clumped and largely confined to the scarification patches (Fig. 3).

(c) Height growth

The average height of white spruce regeneration on scarified seedbeds after 22 to 24 years was usually more than twice that of seedlings growing on untreated seedbeds. On the scarified areas mean dominant heights ranged from 0.5 to 2.1 m and on the nonscarified from 0.2 to 1.0 m (Table 5). While these seedlings currently meet Alberta's eight year minimum height requirement of 50 cm, it is doubtful that these heights would also be acceptable for 22- to 24- year-old seedlings. However, it should be noted that on scalped seedbeds at the Riding Mountain with no overstory or vegetative competition, planted white spruce of the same age only averaged 3.4 m; compared to 2.1 m for natural regeneration in the same area with a significant overstory (Ball 1990). In an adjacent operational shelterwood and scarification program undertaken by the Canadian Forest Service[15], it was noted by Brace[16] that "These patches have only begun height differentiation in the past 5 years (by age 25).......... Spruce regeneration currently ranges from 3 to 8 m tall within the clumps at age 30." This observation would suggest that more rapid height growth of white spruce on Area 1 is just beginning.

The best height growth on mineral soil seedbeds was on Areas 1, 4 and 5 where the seedlings were slightly older mainly as a result of the good initial seedling catch in the first year following scarification. On the other areas (3, 6 and 7) it was noted that seed crops were light at the time of scarification and, as a result, the influx of seedlings did not take place until the third year after treatment.

Other factors affecting seedling height growth were snowshoe hare (Radvanyi 1987) and ungulate browsing. Field examination of both white spruce and balsam fir seedlings revealed that browsing was common and prevalent at various times in most areas with the exception of Area 1 at the Riding Mountain.

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[14]Jarvis, J. M. 1965. Some effects of shelterwood logging on white spruce regeneration and seedbeds. Can. Dept. For., For. Res. Br., Winnipeg, Manitoba. Unpublished file report.

[15]Haig, R. A. 1964. Silvicultural operations in white spruce-aspen stands on the Riding Mountain Forest Experimental Area, 1960 to 1963. Can. Dept. For., For. Res. Br., Manitoba- Saskatchewan Region, Winnipeg, Manitoba. Rept. 64-MS-4.

[16]Brace, L. G. 1992. Permanent sample plot remeasurement and regeneration surveys, Riding Mountain Forest Experimental Area - Manitoba. Can.-Manit. Partnership Agreement in Forestry, Contractor's report.

Figure 3. Clumping of 22-year-old white spruce seedlings on a blade-scarified seedbed on Area 7, Porcupine Provincial Forest.

Table 5. Average height of the tallest white spruce and balsam fir regeneration, and hardwood reproduction by study area and site treatment

Study area	Establish-ment year	Site treatment	Growing seasons (years)	White spruce Regen (m)	White spruce Adv.Gr. (m)	Balsam fir Regen (m)	Balsam fir Adv. Gr. (m)	Hardwoods[a] Reproduction (m)
Riding Mtn (1)	1962-63	Scarified	24	2.1 (290)[b]	9.5 (3)	0.6 (2)	4.2 (1)	1.8 (274)
		Nonscarified		1.0 (11)	7.6(18)	--	--	4.9 (92)
		All		2.1 (301)	7.9(21)	0.6 (2)	4.2 (1)	2.6 (366)
Sled Lake (3)	1962-63	Scarified	23	1.0 (153)	1.3 (1)	1.0 (70)	--	5.4 (103)
		Nonscarified		0.4 (80)	5.6(11)	0.6 (66)	5.5 (28)	10.1 (120)
		All		0.8 (233)	5.3(12)	0.8(136)	5.5 (28)	7.9 (223)
Porcupine For. (4)	1964	Scarified	23	1.5 (160)	2.8 (1)	0.8 (5)	--	3.9 (98)
		Nonscarified		0.7 (26)	5.6(28)	1.0 (5)	--	4.8 (94)
		All		1.4 (186)	5.4(29)	0.9 (10)	--	4.4(192)
Porcupine For. (5)	1964	Scarified	23	1.3 123)	--	0.9(13)	5.0 (1)	4.8 (66)
		Nonscarified		0.2 (5)	2.7 (1)	0.9 (1)	--	6.1 (52)
		All		1.2 (128)	2.7 (1)	0.9(14)	5.0 (1)	5.4(118)
Porcupine For. (6)	1965	Scarified	22	0.5 (96)	2.2 (2)	0.9(42)	--	4.4 (81)
		Nonscarified		0.3 (10)	1.8 (1)	0.4(10)	--	7.3 (80)
		All		0.5 (106)	2.1 (3)	0.8(52)	--	5.8(161)
Porcupine For. (7)	1965	Scarified	22	1.0 (84)	--	0.8(1)	--	4.9 (64)
		Nonscarified		0.3 (11)	--	--	--	5.5 (92)
		All		0.9 (95)	--	0.8(1)	--	5.3(156)
All areas	1962-65	Scarified	22-24	1.4(906)	5.3 (7)	0.9(133)	4.6 (2)	3.5 (686)
		Nonscarified		0.5 (143)	6.1(59)	0.6 (82)	5.5(28)	6.6 (530)
		All		1.3(1049)	6.0(66)	0.8(215)	5.4(30)	4.9(1216)

[a] Hardwoods include trembling aspen, balsam poplar and white birch.
[b] Figures in brackets represent number of heights measured.

In addition, vegetative competition had a marked affect on seedling growth rate. On Area 3, in which the scalped seedbed was made by corridoring with one pass of the bulldozer, it was observed that overtopping of the seedbed by the rapid growth of shrubs growing on and adjacent to the strip edges had a particularly deleterious effect on coniferous seedling growth. Vegetation control under these conditions would have proved beneficial by reducing heavy shading and improving light conditions. However, strip scarification is not recommended for future use in securing natural white spruce regeneration under boreal mixedwood conditions.

The poor growth of the seedlings on mineral soil seedbeds prepared in patches is principally attributed to competition from tall herbs, shrubs, poplar suckers, and to apparent soil compaction (Corns 1988). However vegetation competition is variable on these bulldozed patches with most spruce clumps exhibiting sufficient vigour to ensure their long term survival and growth (Figure 3) except, perhaps, on the moist sites where competition appeared to be more severe. In most cases, vegetation management is not considered necessary nor is it recommended as a blanket treatment in these situations.

Similarly, in nonscarified areas, seedling growth was also slow due to insufficient light (Logan 1969) resulting from heavy shading by shrub species and from the crowns of the residual overstorey which should have been removed at an earlier date.

White Spruce Advanced growth

Advanced growth white spruce was generally present in only small amounts; stocking ranged from 0 to 14% in the untreated areas. The density of advanced growth white spruce among areas ranged from 0 to 180 stems/ha on the nonscarified seedbeds with the average height of the tallest saplings being 6.1 m; on the other hand, more recent (22- to 24-years-of-age) white spruce regeneration on undisturbed seedbeds, only averaged 0.5 m (Tables 3 to 5). The better growth of the white spruce advanced growth was attributed to the opening up of the crown cover as a result of partial cutting in these stands. Studies in the prairies region have shown that young white spruce up to 60 years in age responds well to reductions in competition (Lees 1966; Steneker 1967; Johnson 1986; Johnstone 1978; Yang 1989, 1991).

On scarified areas, it was apparent that blading of mineral soil seedbeds destroyed over half of this sapling component (Tables 3 and 4).

Balsam Fir

Residual tree and advanced growth balsam fir, comprised a significant proportion of the softwood component in Area 3. On nonscarified seedbeds in Area 3 advanced growth stocking was 13% with 600 stems/ha; the tallest of which averaged 5.5 m. On the other areas balsam fir was either non-existent or present as a minor species in the stand (Tables 3 to 5).

Some natural regeneration of balsam fir occurred in each of the six areas but, as expected, was particularly substantive on Area 3 in which a large seed source was present. Tables 3 and 4 show that scarified seedbeds (42 % stocking and 5 540 stems/ha) were more receptive than untreated seedbeds (30% stocking and 1 100 stems/ha) for balsam fir regeneration. Regeneration stocking on Area 3 averaged 35% overall with 2 930 seedling /ha; the tallest averaging 0.8 m in height.

The fact that the balsam fir regeneration on scarified seedbeds was the same height as the white spruce (1.0 m) suggests that the balsam fir seeded in later or has been subjected to more severe hare and ungulate browsing.

Hardwood Reproduction

(a) Stocking

Percent stocking of hardwood reproduction was consistently higher on scarified quadrats containing 10% + mineral soil than on the untreated seedbeds; ranging from 66 to 90% and from 47 to 59% respectively (Table 3). The lower values on the nonscarified areas suggest that root suckering of trembling aspen and balsam poplar (*Populus balsamifera* L.) was inhibited more by shading from residual stand trees and competing shrub growth than were those found in stand openings where blade scalping had taken place. Some of the stocking increases found on scarified quadrats was attributable to the establishment of seed origin hardwoods - namely, white birch. White birch, particularly on Areas 1 and 3, regenerated most frequently on scarified mineral soil seedbeds (Fig. 4). At the same time, stocking of aspen reproduction was proportionately greater than balsam poplar or white birch in nonscarified areas reflecting the higher initial stocking to aspen residuals and the fact that the parent root systems of residual hardwoods had not been removed or displaced by the bulldozer blade.

(b) Density

Density of hardwoods species on scalped quadrats was usually more than double that of reproduction on nonscarified areas; stem densities ranged from 1 570 to 8 120/ha and from 1 020 to 2 020/ha respectively (Table 6). The total number of hardwood stems of all species averaged over "All areas" (3 570/ha) is equivalent to approximately one half of the number found in an aspen stand of the same age following wildfire (Johnson 1957). White birch accounted for almost 50% of the hardwood species found on Areas 1 and 3.

Visual observations suggested that the abundance of regenerated hardwoods species overall reflected the hardwood component present in the parent stands. Usually stands contained more residual aspen (66%) than balsam poplar (20%) or white birch (14%) but blading did not exclude the suckering of either of the poplar species. Proportionally, aspen did better on non-scarified seedbeds than did either balsam poplar or white birch (Table 6). Untreated seedbeds were the least receptive for regenerating seed-origin white birch (150 vs 1 250/ha overall).

(c) Height growth

Mean dominant heights of hardwood reproduction on the nonscarified areas were about twice (x 1.6) that for the same species on the scalped quadrats (Table 7). The markedly reduced growth rate on treated seedbeds has been largely due to the adverse effects of blading and soil compaction by the heavy scarification equipment used in site preparation. Displacement and damage inflicted on the parent root systems by scarification can have a negative impact on both height and stem growth of suckering hardwoods (Weingartner, 1980; Basham 1982, 1988).

The average height of hardwood reproduction in both scarified and nonscarified stand conditions ranked the tallest for aspen, intermediate for balsam poplar, and shortest for white birch (Table 7). The poorest growth among areas on scarification has been on Area 1 at the Riding Mountain where there were more slower-growing white birch. In addition, poplar growth in Area 1 was also being affected by elk and moose browsing. Walker (1987) reported from an earlier study conducted in this area that repeated ungulate browsing reduced, and even prevented, the height

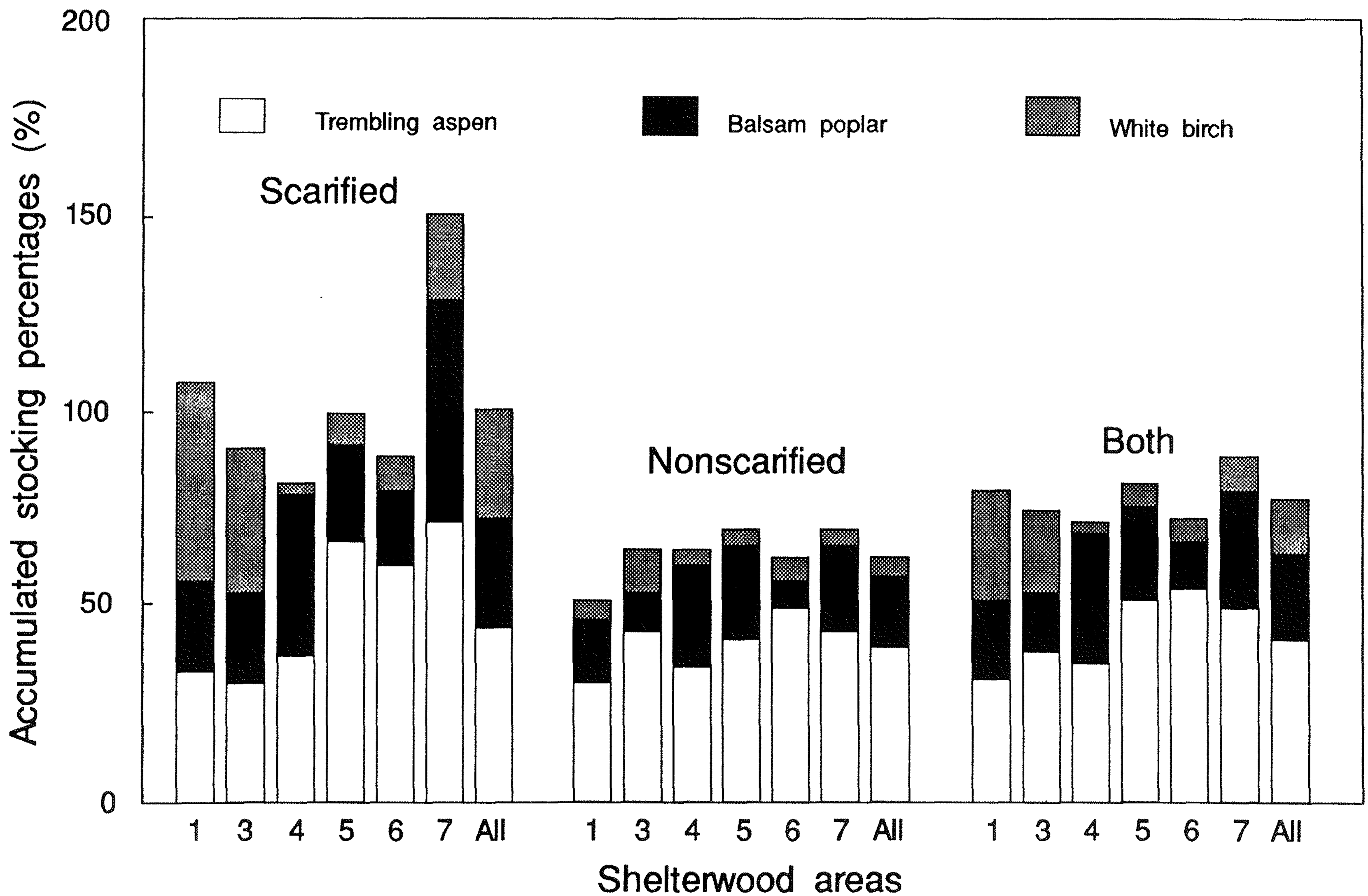

Figure 4. Frequency of hardwood reproduction by species on stocked 10-m² quadrats after 22-24 years.

Table 6. **Abundance of hardwood reproduction by species, study area, and site treatment**

Study area	Establishment (year)	Site treatment	Growing Seasons (years)	No. stems/ha[a] Trembling aspen	Balsam poplar	White birch	All hardwoods
Riding Mtn. (1)	1962-63	Scarified	24	980	950	2 430	4 360
		Nonscarified		650	300	70	1 020
		All		820	640	1 290	2 750
Sled Lake (3)	1962-63	Scarified	23	340	470	1 750	2 560
		Nonscarified		800	210	240	1 250
		All		610	320	860	1 790
Porcupine For. (4)	1964	Scarified	23	970	1 380	40	2 390
		Nonscarified		860	270	0	1 130
		All		900	740	20	1 660
Porcupine For. (5)	1964	Scarified	23	2 350	1 450	180	3 980
		Nonscarified		1 040	580	400	2 020
		All		1 600	950	310	2 860
Porcupine For. (6)	1965	Scarified	22	1 070	390	110	1 570
		Nonscarified		1 200	200	100	1 500
		All		1 150	270	100	1 520
Porcupine For. (7)	1965	Scarified	22	3 970	2 820	1 330	8 120
		Nonscarified		1 060	500	170	1 730
		All		1 700	1 000	430	3 130
All areas	1962-65	Scarified	22-24	1 240	1 080	1 250	3 570
		Nonscarified		920	330	150	1 400
		All		1 070	640	600	2 310

[a] Based on 5-m^2 list quadrats.

Table 7. Average height of the tallest hardwood reproduction by species, study area, and site treatment

Study area	Growing seasons (years)	Scarified: Trembling aspen (m)	Scarified: Balsam poplar (m)	Scarified: White birch (m)	Nonscarified: Trembling aspen (m)	Nonscarified: Balsam poplar (m)	Nonscarified: White birch (m)
Riding Mtn. (1)	24	2.5(92)[a]	1.8(73)	1.3(109)	5.6 (63)	4.3(21)	1.6 (8)
Sled Lake (3)	23	9.8(32)	5.1(25)	2.5(46)	11.0(95)	8.8(14)	3.6(11)
Porcupine For. (4)	23	4.7(43)	3.4(52)	2.5 (3)	5.3 (56)	4.2(36)	3.2 (2)
Porcupine For. (5)	23	5.3(43)	4.0(19)	2.6 (4)	6.9 (33)	4.6(17)	6.4 (2)
Porcupine For. (6)	22	4.2(59)	4.4(17)	5.7 (5)	7.7 (70)	4.4 (7)	4.1 (3)
Porcupine For. (7)	22	4.6(38)	5.0(22)	6.7 (4)	5.8 (58)	4.8(31)	6.8 (3)
All areas	22-24	4.6(307)	3.3(208)	1.9(171)	7.4(375)	5.0(126)	3.6(29)

[a] Figures in brackets represent number of heights measured.

growth of aspen and poplar suckers. Comparable heights for "free-to-grow" aspen and balsam poplar in fire-origin stands of the same age is 12 m (Johnson 1957).

Effects of Microsite on White Spruce Regeneration

Hills' (1952) descriptive soil moisture regimes are, for the silviculturalist, a simple graphic way of portraying microsites which comprise, in their simplest definition: topographic position, soil texture and profile development, and lesser vegetation on a particular landform (see Waldron 1966 for an artistic example). Microsite and lesser vegetation relationships for the Riding Mountain (Area 1) are provided in Appendix III Table 1. The impacts of scarification on microsites and natural white spruce regeneration are important when preparing preharvest silvicultural prescriptions (PHSPs) on similar landforms. Results, in terms of percent stocking and mean density of white spruce regeneration by microsite (moisture regime) for individual trial locations, are provided in Appendix III, Tables 2 and 3.

Overall, moderately moist microsites (4) proved to be the most suitable for white spruce seedling establishment on scalped seedbeds followed by fresh (3), and moist (5) microsites (Figure 5). Very moist (6) microsites were the poorest on both scarified and nonscarified seedbeds; here stocking was lowest with very few white spruce seedlings per hectare. Similar results for planting and seeding white spruce on mineral-soil strips scalped in aspen stands have been reported by Dyck (1994).

Microsite responses, which varied between and within experimental areas, were a result of various vegetative and edaphic factors. Scarified patches which exhibited failed or poor stocking were, in part, the result of vegetation competition and heavy shading from shrub growth. For example on moist and very moist microsites encroachment and rapid development of shrubs such as speckled and river alder resulted in heavy seedling losses. Drainage impediment and seasonal flooding occurred on some of the deeply scalped seedbeds. The very moist (6) microsites were particularly prone to ponding, and failure of spruce regeneration on such seedbeds was a common occurrence (Fig. 6). As a result of the low seedling densities obtained, it is recommended that these sites be excluded from the treatment area and not scarified using a bulldozer and straight blade. In addition, failed stocking on specific sites at the Porcupine Provincial Forest in some instances were confounded by seedling losses resulting from recent logging activity.

Impact of the 2nd Cut on White Spruce Regeneration

The second and final cut of the residual white spruce was carried out on Areas 4 to 7 on the Porcupine Provincial Forest. Areas 4 and 7 were cut in 1973, some 8 to 9 years after scarification. In Areas 5 and 6 final logging took place in 1985, 20 to 21 years after scarification. Examination of these areas in the summer of 1988 revealed seedbed disturbances and seedling loss had occurred from tree felling and the skidding of logs. It was found that even on the older 1973 logging (cut 15 years prior to the 1988 examination), it was still possible, through careful observation, to detect instances of logging disturbance. In addition, some of the scattered residual white birch in Areas 6 and 7 were being harvested for fuelwood at the time of this assessment. This recent cutting activity was contributing to some seedling loss and damage on the areas as well (Fig. 7).

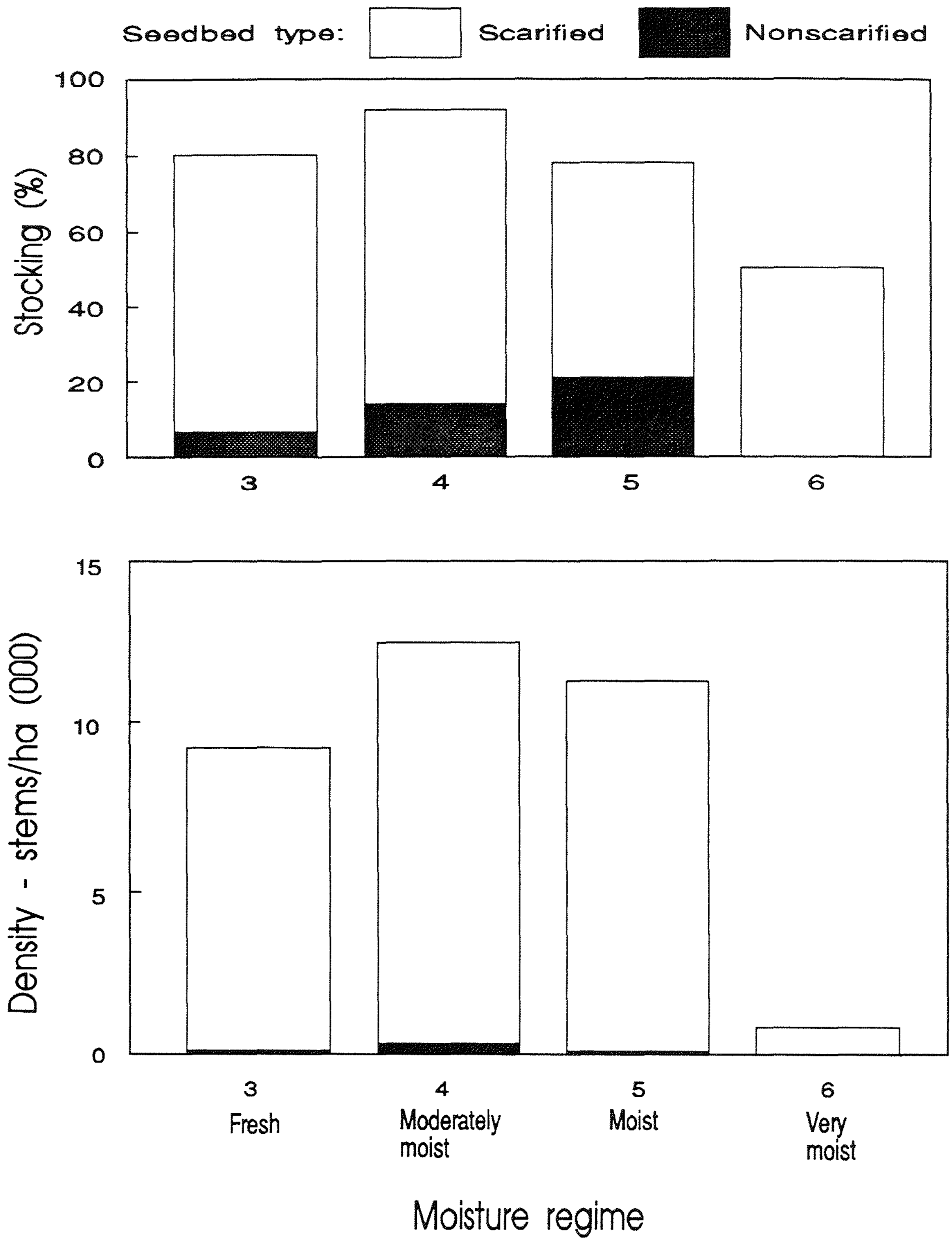

Figure 5. **Effect of soil moisture regime (Hills 1952) on stocking (10-m^2 basis) and density of 22- to 24- year-old white spruce regeneration by site treatment.**

Figure 6. Absence of white spruce regeneration on a scalped seedbed (foreground) subjected to periodic flooding on Area 3, Sled Lake.

Figure 7. Partial burial and damage to white spruce regeneration from 1-year-old white birch logging slash on Area 7, Porcupine Provincial Forest.

Table 8. Stocking of white spruce regeneration in uncut and in cut-over areas following the removal (2nd cut) of the residual white spruce

				Years after seedbed treatment					
				5 Years	22-24 years				
Study area	Year of second cut	Site treatment	Year of scarification	Stocking (%)	No. of years	Stocking (%)	Change in % stocking	Quadrats disturbed or damaged by logging (%)	No. of quadrats[a] (4-m^2)
Riding Mtn. (1)	Not cut	Scarified	1962	72	24	65	-7	0	200
		Nonscaried		5		6	+1	0	150
Sled Lake (3)	Not cut	Scarified	1963	95	23	82	-13	0	100
		Nonscarified		14		22	+8	0	100
Porcupine For. (4)	Winter 1973	Scarified	1964	100	23	76	-24	22	100
		Nonscarified		32		7	-25	19	100
Porcupine For. (5)	Winter 1985	Scarified	1964	100	23	75	-25	17	100
		Nonscarified		15		1	-14	37	100
Porcupine For. (6)	Winter 1985	Scarified	1965	86	22	52	-34	30	100
		Nonscarified		5		2	-3	35	100
Porcupine For. (7)	Summer 1973	Scarified	1965	93	22	55	-38	31	100
		Nonscarified		20		4	-16	34	100
All areas	Uncut	Scarified and	----	47	--	44	-3	0	550
	Cut-over	nonscarified	----	56	--	34	-22	28	800

[a] Includes stocking and list quadrats.

(a) Reduction in stocking

Twenty eight percent of the 4-m^2 regeneration quadrats were disturbed or damaged as a result of the 2nd cut on Areas 4 to 7 (Table 8). Regardless of seedbed type, Areas (1 and 3) which were not subjected to the 2nd cut had their quadrat stocking reduced from 47 to 44%; a drop of only 3%. Meanwhile those areas (4 to 7) which were logged a second time had their quadrat stocking reduced from 56 to 34%; a drop of 22%.

Percentage stocking of white spruce on scarified plots on all areas ranged from 72 and 100 % after the first 5 years. Decline in stocking on the unlogged areas at 23 to 24 years as a result of natural seedling mortality was 7% on Area 1 and 13% on Area 3. On Areas 4 to 7, in which the final cut took place, the comparative reductions were from 24 to 38 %.

Stocking values on nonscarified seedbeds at 5 years ranged from 5 to 32 %. The 23 to 24 year decline was from 3 to 25% on logged areas, with a slight stocking increase of 1 and 8% on unlogged areas 1 and 3, respectively.

Stocking data from Table 8 were converted to logarithms and subjected to an analysis of variance (Appendix IV). Results of this statistical analysis indicated that frequency distribution of stocked quadrats (cut vs. not cut) were significantly reduced on those areas in which logging had taken place.

(b) Reduction in density

The percent of 4-m^2 list quadrats that were destroyed on Areas 4 to 7 as a result of the 2nd cut was estimated to average 32% (Table 9). Regardless of seedbed type, Areas (1 and 3) which were not subjected to the 2nd cut had their number of seedlings reduced from 11 030 to 8 290; a 25% reduction. Those areas (4 to 7) which were logged had their number of seedlings reduced from 30 900 to 8 510; a 72% reduction (Table 9).

White spruce seedling densities in the fifth growing season on scarified seedbeds ranged from 11 370 stems/ha in Area 6 to 121 820/ha in Area 4 (Table 9). On nonscarified seedbeds the density ranged from 0 to 1 730 stems/ha. The logged areas (4 to 7) showed density reductions that were from 67 to 80% on scarified seedbeds as compared to 7 and 47% on uncut Areas 3 and 1, respectively. On the nonscarified seedbeds seedling numbers in the uncut areas increased by 22% in Area 3 and 50% in Area 1. In the areas cut, the initially low density of seedlings on nonscarified was virtually reduced to zero. Much of this seedling loss was due to felling and log skidding which had often crushed and flattened rotted wood growing mediums which frequently supported white spruce regeneration in the nonscarified portions of the stand.

Density data from Table 9 were converted to logarithms and subjected to an analysis of variance (Appendix IV) Results indicated that white spruce seedling densities were significantly reduced on those areas in which logging had taken place. However, it would appear that only a portion of the 72% reduction could be fairly attributed to logging since initial densities on the nonscarified were three times those on the uncut areas (30 900 vs 11 030) and would, therefore, be subjected to a higher natural attrition rate. A reduction in density as a result of logging somewhere between 32% (based on quadrat disturbance) and 47% (72-25%) seems plausible.

Table 9. Number of white spruce stems per hectare in uncut and in cut-over areas following the removal (2nd cut) of the residual white spruce

Study area	Year of second cut	Site treatment	Year of scarification	Years after seedbed treatment: 5 Years				Quadrats disturbed or damaged by logging (%)	No. of quadrats[a] (4-m^2)
				No. of stems/ha	22-24 years: No. of years	No. of stems/ha	% change in stems/ha		
Riding Mtn. (1)	Not cut	Scarified	1962	14 580	24	7 720	-47	0	40
		Nonscaried		490		740	+50	0	30
Sled Lake (3)	Not cut	Scarified	1963	29 650	23	27 680	-7	0	20
		Nonscarified		1 110		1 360	+22	0	20
Porcupine For. (4)	Winter 1973	Scarified	1964	121 820	23	39 660	-67	20	20
		Nonscarified		1 730		0	-100	25	20
Porcupine For. (5)	Winter 1985	Scarified	1964	79 070	23	15 440	-80	20	20
		Nonscarified		1 480		0	-100	50	20
Porcupine For. (6)	Winter 1985	Scarified	1965	11 370	22	3 210	-72	30	20
		Nonscarified		0		0	-0	35	20
Porcupine For. (7)	Summer 1973	Scarified	1965	30 890	22	9 510	-69	40	20
		Nonscarified		860		250	-71	40	20
All areas	Uncut	Scarified and	----	11 030	--	8 290	-25	0	110
	Cut-over	nonscarified	----	30 900	--	8 510	-72	32	160

[a] List quadrats only.

Meeting Provincial Regeneration Stocking Standards

Overall stocking of white spruce (including advanced growth) and hardwoods on the shelterwood cut areas averaged 75%; 5% short of the Manitoba and Alberta stocking standards for mixedwoods (Table 10). If you add in the balsam fir component and eliminate Area 7, the percent stocking increases to 79%. The white spruce component averages 43% while the standard is set at 45%. If you add in the balsam fir component and eliminate Area 7 the percent stocking to conifers increases to 51%, but more importantly, on Area 6 - which had the fewest residual seed trees at the time of treatment - coniferous stocking increases from 35 to 41%. Except for Area 7, which had only 17% mineral soil exposure, all trials met the Alberta and Manitoba stocking standards for 10-m^2 quadrats.

Overall, 10-m^2 quadrat stocking to *white spruce regeneration only* averaged 13%; stocking to *hardwood reproduction only* averaged 32%; while 30% of the quadrats were stocked to both species; a total of 75% stocking (Table 10). There were 4 600 white spruce and 2 310 hardwood stems/ha averaging 1.6 and 4.9 m in height respectively. White spruce advanced growth accounted for only 40 stems/ha and averaged 6.0 m (vs 1.3 m for the white spruce regeneration) in height; this difference would appear to support the recommended protection of white spruce understoreys when scarifying and when harvesting in mixedwood stands where the value of the advanced growth warrants the extra costs incurred (Brace and Bella 1988; Brace 1989, 1992; Navratil et al 1994). In this study white spruce advanced growth ranged from 0 to 180 stems/ha.

On scarified areas within the shelterwood, white spruce (including advanced growth) stocking was 85% with 10 920 stems/ha averaging 1.4 m in height while hardwood stocking was 73% with 3 570 stems/ha averaging 3.5 m in height. On nonscarified areas white spruce stocking was considerably less at 17% with 260 stems/ha averaging 2.1 m in height while hardwood stocking was also considerably less at 55% with 1 400 stems/ha averaging 6.6 m in height (Tables 3, 4, and 5). It is difficult to state which of these two conditions is most suitable for achieving "free-to-grow" status without the need for future silvicultural intervention. Research by Basham (1982, 1988) suggested that aspen suckers located on scarified seedbeds have been weakened by stain and decay and may succumb in the short term releasing the white spruce to form future crop trees. The development of competition indices for mixed stands of white spruce and aspen regeneration/reproduction as has been done for mixed stands of lodgepole pine and aspen for Alberta would be of value for such assessments (Navratil and MacIsaac 1993).

With respect to seedling height growth, all areas meet Alberta's eight year 50 cm rule but it is doubtful that this same height would be acceptable for 22- to 24- year-old white spruce seedlings (Appendix I). With equivalent age planted stock at the Riding Mountain averaging 3.4 m, it is apparent the white spruce are suffering the effects of soil compaction, high seedling densities, and heavy hardwood competition from the reproduction and the residual overstorey. Even the aspen reproduction is facing severe competition from the residual overstorey averaging 7.4 m in nonscarified areas and 4.6 m in scarified areas (Table 7) while free growing, dominant aspen in fire origin stands average 12 m at the same age (Johnson 1957). Browsing by elk and moose proved to be particularly heavy at Riding Mountain with aspen averaging only 2.5 m and balsam poplar only 1.8 m in height on scarified seedbeds (Table 7). Removing the residual overstorey by harvesting the spruce and perhaps poisoning the larger poplars at an earlier age would have definitely aided the hardwoods but would have been less beneficial to the white spruce. Nevertheless it is anticipated that there are sufficient numbers of white spruce present (10 900/ha) at age 23 years (Figure 3) to achieve mixedwood stands at maturity without vegetative control of the poplar suckers based upon released and control experiments in young mixedwood stands by Steneker (1967) and Yang (1989). Comparable data for an intermediate-aged mixedwood stand at Bertwell, Saskatchewan based on field records of a control plot is as follows:

Table 10. **Stocking, stems per hectare, and average height of the tallest white spruce regeneration/hardwood reproduction on the shelterwood areas 22 to 24 years following site preparation (basis: 10-m^2 quadrats)**

Study area	White spruce[a]			Hardwoods[b]			Both		Basis:
	Stocking (%)	Stems (n/ha)	Avg. Ht. (m)	Stocking (%)	Stems (n/ha)	Avg. Ht. (m)	Stocking (%)	Stems (n/ha)	Quadrats (n)
Riding Mtn. (1)	49	4 380	2.5	61	2 750	2.6	75	7 130	440
Sled Lake (3)	61	7 500[c]	1.0	60	1 790	7.9	79[d]	9 290	282
Porcupine For. (4)	49	6 110	2.0	62	1 660	4.4	80	7 770	280
Porcupine For. (5)	42	4 810	1.2	65	2 860	5.4	76	7 670	192
Porcupine For. (6)	35	1 750[c]	0.5	63	1 520	5.8	72[d]	3 270	240
Porcupine For. (7)	24	2 570	0.9	65	3 130	5.3	68	5 700	256
All areas	44	4 600[c]	1.6	62	2 310	4.9	75[d]	6 910	1 690

[a] Includes white spruce advanced growth.
[b] Includes trembling aspen, balsam poplar, and white birch.
[c] Including balsam fir regeneration/advanced growth increase overall coniferous stocking to 73% and stems/ha to 10 530 on Area 3; to 42% and 2 160 stems/ha on Area 6; and on "All areas" to 48% and 5 220 stems/ha.
[d] Including balsam fir regeneration/advanced growth increases overall stocking to 86% and stems/ha to 12 320 on Area 3; to 75% and 3 680 stems/ha on Area 6; and on "All areas" to 77% and 7 530 stems/ha.

Age (Years)	Species	Stems/ha Height (0.3 cm+)	Stems/ha Dbh (1.5 cm+)	Basal area m²/ha	Total volume m³/ha	Merchantable volume m³/ha
1	wS	30 000[1]	0	0	0	0
20		13 200	2 940	3	6	0
30		9 860	5 100	12	32	1
54		3 480	3 480	21	121	51
1	tA	3 500[1]	0	0	0	0
20		2 050	2 050	11	69	49
30		1 830	1 830	19	122	112
54		1 160	1 160	25	176	157

[1] Assuming the same discounted mortality rate $(x_n=x_1(\frac{100-y}{100})^n)$ as occurred between age 20 and 54; approximately 4% for white spruce and 2% for trembling aspen.

Based on current provincial standards in the prairie provinces, all areas except Area 7 at the Porcupine Forest Reserve, should be acceptable. Based on the results for areas 4, 5, and 6, it would seem apparent that the residual stand on areas 1 and 3 could safely have been removed after 10 years. Manual or chemical release of the white spruce seedlings from the aspen reproduction could have been effectively carried out after 15 years. Further development of provincial stocking standards to cover seedling older than 10 years of age seems warranted especially as they relate to shelterwood harvesting and the initial slower growth of natural white spruce regeneration in boreal mixedwoods.

Stand Development and Biodiversity

Following logging (1st cut) and the scarification treatments the basal area of residual white spruce ranged from 4.6 to 11.8 m²/ha. Hardwood basal areas ranged from 5.0 to 14.6 m²/ha, and balsam fir, though notably present only in Area 3, had a basal area which was less than 1.0 m²/ha (Table 11).

(a) White spruce

In the study areas at the Porcupine Provincial Forest the remaining merchantable white spruce were harvested in 1973 (Areas 4 and 7) and 1985 (Areas 5 and 6). Consequently, the basal area of white spruce on these four areas at the time of stand assessment was made up of unmerchantable and ingrowth white spruce with less than 1.0 m²/ha.

On the two areas not cut the basal area of spruce over a 23 to 24 year period increased by 42% on Area 1 and 20% on Area 3 (Table 11). These increases were attributed partly to increment of residual trees which offset the light mortality of spruce observed on these areas. In addition, some of the basal area gains were attributed to tree ingrowth. This was particularly evident on Area 1 where the favourable growth of regenerated spruce on scarified seedbeds made up the greater part of the total number of trees (1 273 stems/ha) measured in the 1.5 - 9.0 cm. diameter class (see frontispiece).

Table 11. Average number of trees and basal area per hectare of shelterwood-cut mixedwoods following initial treatment and stand development during the next 22-24 year period by study area

Stand characteristics[a]	Riding Mtn.	Sled Lake	Porcupine Forest			
	1	3	4	5	6	7
		White spruce (after logging (1st cut)[b] and scarification[c])				
No. of trees/ha						
D.B.H. 1.5 - 9.0 cm	55	32	10	4	-	12
9.1 cm+	89	140	114	163	49	71
All	144	172	124	167	49	83
Basal area (m^2)/ha						
D.B.H. 1.5 - 9.0 cm	0.1	0.1	>0.1	>0.1	-	>0.1
9.1 cm+	4.6	4.6	9.3	11.8	4.6	6.2
All	4.7	4.7	9.3	11.8	4.6	6.2
		White spruce (after 22-24 years and 2nd cut[d])				
No. of trees/ha						
D.B.H. 1.5 -9.0 cm	1 273	119	378	65	2	56
9.1 cm+	108	109	9	9	2	6
All	1 381	228	387	74	4	62
% change	+860	+32	+212	-66	-89	-25
Basal area (m^2)/ha						
D.B.H. 1.5 - 9.0 cm	1.0	0.1	0.3	>0.1	>0.1	>0.1
9.1 cm+	5.7	5.5	0.3	0.3	>0.1	0.1
All	6.7	5.6	0.6	0.3	>0.1	0.1
% change	+42	+20	-93	-97	-100	-98

[a] Sample size: Areas 1, 3 and 4 to 7 are 10 m x 2012 m, 10 m x 805 m, 10 m x 563 m, 10 m x 583 m, 10 m x 402 m and 10 m x 604 m, respectively.
[b] Area 1 was logged (1st cut) in 1963-64; Area 3 in 1962-63; and Areas 4 to 7 approximately 20 years prior to scarification.
[c] Area 1 was scarified in 1962; Area 3 in 1963; Areas 4 and 5 in 1964; and Areas 6 and 7 in 1965.
[d] Residual white spruce were logged (2nd cut) on Areas 4 and 7 in 1973; and on Areas 5 and 6 in 1985; Areas 1 and 3 were not logged.

Table 11 cont'd

		Balsam fir (after logging and scarification)				
<u>No. of trees/ha</u>						
D.B.H. 1.5 - 9.0 cm	-	151	-	-	5	-
9.1 cm+	-	5	-	-	-	-
All	-	156	-	-	5	-
<u>Basal area (m²)/ha</u>						
D.B.H. 1.5 - 9.0 cm	-	0.1	-	-	>0.1	-
9.1 cm+	-	0.1	-	-	-	-
All	-	0.2	-	-	>0.1	-
		Balsam fir (after 22-24 years)				
<u>No of trees/ha</u>						
D.B.H. 1.5 - 9.0 cm	-	462	19	4	30	-
9.1 cm+	-	133	2	-	5	-
All	-	595	21	4	35	
% change	-	+283	+100	+100	+606	-
<u>Basal area (m²)/ha</u>						
D.B.H. 1.5 - 9.0 cm	-	0.8	>0.1	>0.1	>0.1	-
9.1 cm+	-	1.8	>0.1	-	0.1	-
All	-	2.6	>0.1	>0.1	0.1	-
% change	-	+967	+100	+100	+2 383	-

Table 11 cont'd

			Hardwoods (after logging and scarification)			
No. of trees/ha						
D.B.H. 1.5 - 9.0 cm	>0.1	11	263	146	314	295
9.1 cm+	156	195	82	89	250	450
All	156	206	345	235	564	745
Basal area (m²)/ha						
D.B.H. 1.5 - 9.0 cm	>0.1	>0.1	0.7	0.4	0.8	0.8
9.1 cm+	11.9	11.4	4.7	4.6	13.8	12.1
All	11.9	11.4	5.4	5.0	14.6	12.9
			Hardwoods (after 22-24 years)			
No. of trees/ha						
D.B.H. 1.5 - 9.0 cm	163	1 061	1 074	1 222	1 045	1 593
9.1 cm+	239	327	181	237	383	342
All	402	1 388	1 255	1 459	1 428	1 935
% change	+157	+573	+364	+520	+154	+160
Basal area (m²)/ha						
D.B.H. 1.5 - 9.0 cm	0.3	2.4	1.2	2.3	2.1	1.8
9.1 cm+	10.9	5.5	6.0	5.7	12.6	13.0
All	11.2	7.9	7.2	8.0	14.7	14.8
% change	-6	-30	+33	+60	+1	+15

Table 11 cont'd

			All species (after logging and scarification)			
<u>No. of trees/ha</u>						
D.B.H. 1.5 - 9.0 cm	55	194	273	150	319	307
9.1 cm+	245	340	196	252	299	521
All	300	534	469	402	618	828
<u>Basal area (m²)ha</u>						
D.B.H. 1.5 - 9.0 cm	0.1	0.2	0.7	0.4	0.8	0.8
9.1 cm+	16.5	16.1	14.0	16.4	18.5	18.2
All	16.6	16.3	14.7	16.8	19.3	19.0
			All species (after 22-24 years)			
<u>No. of trees/ha</u>						
D.B.H. 0 - 1.4 cm	5 715	10 854	6 397	6 389	2 611	4 046
1.5 - 9.0 cm	1 436	1 642	1 471	1 291	1 077	1 649
9.1 cm+	347	569	192	246	390	348
All	7 498	13 065	8 060	7 926	4 078	6 043
<u>Basal area (m²)/ha</u>						
D.B.H. 0 - 1.4 cm	--	--	--	--	--	--
1.5 - 9.0 cm	1.3	3.4	1.5	2.3	2.1	1.8
9.1 cm+	16.6	12.8	6.3	5.9	12.7	13.1
All	17.9	16.2	7.8	8.2	14.8	14.9

Figure 8. Overmature and decadent trembling aspen residuals on Area 1, Riding Mountain.

(b) Balsam fir

Development of the relatively abundant balsam fir in nonscarified stand conditions on Area 3 showed a stem increase of 283% (595 stems/ha) and a basal area gain of 967% (2.6 m^2/ha) after 23 years. At the same time a small amount of fir reproduction (less than 1.0 m^2/ha) also came into a measurable dbh class (1.5-9.0 cm) on areas at the Porcupine Provincial Forest.

(c) Hardwoods

In the hardwood component many of the mature aspen and balsam poplar at the time of stand treatments were over-mature and decadent by the end of the 22 to 24 year study period (Fig. 8). However, in spite of significant mortality losses of over-maturing hardwoods, total number of trees on individual areas increased by 154 to 573% through reproduction and recruitment of young trees to the 1.5 - 9.0 cm dbh class (Table 11). Opening up of the stands by partial removal of the white spruce overstory 20 years prior to site preparation in 1964 and 1965 and recent logging (1973 and 1985) on the Porcupine Provincial Forest areas has stimulated hardwood ingrowth. With exception of Area 1, average number of hardwood stems in the 1.5 to 9.0 cm. diameter class ranged from 1045 to 1593/ha. In Area 1 it appears that ungulate browsing and dense hazel ground cover on nonscarified seedbeds has reduced or kept much of the hardwood suckering in check. Average number of stems per hectare (1.5 - 9.0 cm. dbh.) in this area is only 158 stems/ha by comparison.

Average basal area gain and/or decline for hardwoods varies considerably. Periodic basal area increment in Areas 4, 5, 6, and 7 ranged from 1 to 60% and is attributed largely to ingrowth of new hardwoods. At the same time, new growth in Areas 1 and 3 has apparently not yet offset mortality of over-maturing hardwood residuals. The decrease in basal area has been 30% for Area 3 and 6% in the case of Area 1 (Table 11).

Data collected on the strip cruise indicated that, overall, the species composition of the hardwoods has not changed significantly over the past 22-23 years:

Species	Strip cruise[1]				Regeneration surveys[2]	
	Time of treatment Stems/ha	%	After 22-24 years Stems/ha	%	After 22-24 years Stems/ha	%
Aspen	197	66	681	65	1 070	46
Balsam poplar	62	20	269	25	640	28
White birch	41	14	102	10	600	26
Totals	300	100	1 052	100	2 310	100

[1] All areas; includes all stems 1.5 cm + dbh.
[2] All areas; includes all stems 0.3 m + in height.

However on an individual stand basis, the number of balsam poplar stems/ha have increased by 10% with an equal decrease for white birch on five of the six areas; three areas showed a 9% increase in aspen density and three an identical decrease. At the same time the regeneration surveys reveal a proportionally lower representation of aspen and a corresponding higher representation of balsam poplar and white birch. Without continued assessment the longer term implications of the treatments on stand composition are uncertain. It does seem certain, however that white birch will be represented in those stands where it occurred before treatment.

Table 12. Stocking, stems per hectare, and average height of the tallest white spruce regeneration/hardwood reproduction on scarified and nonscarified seedbeds following strip clear-cutting and shelterwood harvesting in white spruce and mixedwoood stands 22 to 25 years following site preparation (basis: 10-m² quadrats)

Harvesting system	Site treatment	Mineral soil/humus seedbeds (%)	White spruce[a] Stocking (%)	White spruce[a] Stems (n/ha)	White spruce[a] Avg.ht. (m)	Hardwoods[b] Stocking (%)	Hardwoods[b] Stems (n/ha)	Hardwoods[b] Avg.ht. (m)	Both Stocking (%)	Both Stems (n/ha)	Basis: Quadrats (n)
Alternate strip cutting[c]	Scarified	--	62	9 160	2.0	60	2 410	6.0	80	11 570	966
	Nonscarified	--	25	760	1.7	75	3 260	9.5	80	4 020	575
	Both	44	48	6 020	2.0	66	2 730	7.5	80	8 750	1 541
Shelterwood cutting	Scarified	--	85	10 920	1.5	73	3 570	3.5	93	14 490	675
	Nonscarified	--	17	260	2.1	55	1 400	6.6	63	1 660	1 015
	Both	31	44	4 600	1.6	62	2 310	4.9	75	6 910	1 690

[a] Includes white spruce advanced growth.

[b] Includes trembling aspen, balsam poplar, and white birch.

[c] Kolabinski 1994; clear cut strips only.

(d) All species

With the death of the overmature aspen and the harvesting of the residual white spruce (Areas 1 & 3) natural stand development should occur on all six trial areas with clumps of pure white spruce regeneration (13%), hardwood reproduction (32%) and more typical mixedwood stands (30%) with a poplar overstorey and a white spruce understorey. White spruce regeneration and hardwood reproduction ranging from 3 688 stems/ha in Area 5 to 12 496 stems/ha in Area 3 (0 to 9.0 cm dbh) at age 22-24 years of age appears to be more than adequate to ensure fully stocked mixedwoods at the next rotation. Removal or death of the residual overstorey within 15 years of the 1st cut should ensure the 80% stocking (10-m^2 quadrat basis) required to meet provincial stocking standards.

Representation of white birch, balsam fir, and other conifers will vary amongst locations and are essential to ensure biodiversity of tree species, even if they are not "merchantable" according to current forestry practices.

Mixedwood rotation ages using shelterwood harvesting systems combined with scarification may well be extended by up to 10 years depending on the timing of the second cut. Results and 70 years of combined personal experience by the authors would suggest that the volume of white spruce at the next rotation will be considerably higher than in current natural mixedwood stands; however it is obvious that this increase will be at the expense of the hardwoods.

Field observations by the authors would suggest that shelterwood harvesting should have minimal impact on the biodiversity of non-woody plants. The impact on other living organisms and wildlife needs to be studied in more detail, as was recommended by Johnson and Waldron (1990), than was possible in this study.

SHELTERWOOD vs ALTERNATE STRIP CLEAR-CUTTING

Comparing shelterwood and alternate strip clear-cutting system trials carried out by the same investigators (Jarvis and Kolabinski), over the same time frame (1959-1965), and in similar stands, it is apparent that overall stocking and density of white spruce and hardwoods was somewhat less on the shelterwood than on the strip clear-cuts: 75% vs 80% and 6900 vs 8750 stems/ha (Table 12). For white spruce regeneration and hardwood reproduction clear-cut strips had slightly greater stocking, number of stems and average height. Shelterwood areas showed a greater stocking of white spruce regeneration (85 vs 62%) and stem density (10 920 vs 9 160) on scarified seedbeds reflecting higher seedfalls in mixedwood stands and the beneficial effects of shading by the residual overstorey. The negative impact of this shading is reflected in the growth of the hardwoods (4.9 m vs 7.5 m). Restocking of hardwoods was considerably better on the nonscarified seedbeds in the alternate clear-cut strips with no overstorey than on the nonscarified seedbeds in the shelterwood (75 vs 55% and 3 260 vs 1400 stems/ha). While it appears that the reverse relationship occurred on the scarified seedbeds such was not the case since white birch stocking was 9% higher on the shelterwood areas and its slower growth rate reduced the overall average of the tallest reproduction by 2-3 m.

An identical relationship exists between the two cutting treatments carried out at the Riding Mountain (Table 13). A notable difference here is that the growth of the white spruce seedlings was almost equal on the scarified seedbeds and both were about a metre shorter (- 0.6 on the alternate strip clear cut vs - 1.2 m on the shelterwood) than planted white spruce (3.4 m) on similar bladed seedbeds but with no vegetative or overstorey competition (Ball 1990).

Table 13. **Stocking, stems per hectare, and average height of the tallest white spruce regeneration/hardwood reproduction on scarified and nonscarified seedbeds following strip clear-cutting and shelterwood harvesting in mixedwood stands located in the Riding Mountain (Areas 1a and 1), 24 and 25 years respectively following site preparation (basis: 10-m^2 quadrats)**

Harvesting system	Site treatment	Mineral soil/humus seedbeds (%)	White spruce[a]			Hardwoods[b]			Both		Basis:
			Stocking (%)	Stems (n/ha)	Avg.ht. (m)	Stocking (%)	Stems (n/ha)	Avg.ht. (m)	Stocking (%)	Stems (n/ha)	Quadrats (n)
Alternate strip cutting[c]	Scarified	--	67	4 670	2.8	48	1 370	4.3	83	6 040	184
	Nonscarified	--	16	100	3.1	66	2 470	7.0	72	2 570	145
	Both	55[d]	45	2 660	2.9	56	1 860	5.7	78	4 520	329
Shelterwood cutting	Scarified	--	85	8 450	2.2	75[e]	4 360	1.8	93	12 810	218
	Nonscarified	--	13	70	5.1	47	1 020	4.9	57	1 090	222
	Both	42	49	4 380	2.5	61	2 750	2.6	75	7 130	440

[a] Includes white spruce advanced growth.
[b] Includes trembling aspen, balsam poplar, and white birch.
[c] Kolabinski 1994; clear cut strips only.
[d] 8% of exposed mineral soil and 4% of exposed humus seedbeds were covered by logging slash.
[e] Excluding white birch, stocking is 50% with 1930 stems/ha.

The biggest advantage of the clear cut strips is the ability to prepare larger scalps without causing damage to the roots of the white spruce seed trees and the better growth of the hardwoods and white spruce (Tables 12 & 13). The major advantage for the shelterwood is a larger supply of seed which could be significant if two or more failure or light seedfall occurs immediately after seedbed preparation and the resultant higher stocking to white spruce regeneration. A secondary advantage is the fact that the retarded growth of the hardwoods should be an advantage to the spruce when the second cut is made. A third advantage is the fact that there is no leave strip left to regenerate at a later date. The apparent biggest disadvantage of shelterwood cutting is the loss of white spruce seedlings resulting from the second cut. In weighting advantages and disadvantages of the two regeneration systems factors such as windfall and growth of the residual white spruce seed trees, the utilization of the aspen and poplar residuals, aesthetics, and wildlife must be factored into the decision as well.

SUMMARY AND CONCLUSIONS

Between 1962 and 1965 a series of operational-scale trials entailing shelterwood logging and mechanical seedbed preparation to induce natural white spruce regeneration in mixedwood stands was carried out in the Mixedwood Forest Section (B.18a) of Manitoba and Saskatchewan. Results from the examination of six study areas some 22 to 24 years following initial stand treatment are as follows:

1. Trial areas were, on average, 75 % stocked (on a 10-m^2 quadrat basis) with 4 600 white spruce and 2 310 hardwood stems/ha averaging 1.6 and 4.9 m in height respectively. White spruce stocking varied between 24 and 61%; averaging 44% while hardwoods ranged between 60 and 65%; averaging 62%. By including a small amount of balsam fir regeneration and advanced growth five of the six areas met current provincial stocking standards; failure of one of the trials is attributed solely to a lack of adequate scarification 17% vs 29 - 42%.

2. White spruce regeneration averaged 1.6 m at 23 years-of-age which meets Alberta's 14 year criteria but casual observation might suggest the immediate need for a manual or chemical release program in order to ensure that the coniferous regeneration is free-to-grow. However with current regeneration densities (white spruce at 4 600 and hardwood at 2 300 stems/ha) it is anticipated that natural succession alone will ensure future well stocked mixedwood stands. Hardwood reproduction (aspen, balsam poplar, and birch) has been suppressed by the residual overstorey and averaged only 3.5 m on scarified seedbeds and 6.6 on nonscarified areas; the former should prove a benefit to the further development of the white spruce regeneration over the rotation.

3. Stocking of white spruce on scarified seedbeds averaged 85% with 10 900 stems/ha and 1.3 m tall; comparable data for nonscarified seedbeds was 12% stocking with 200 stems/ha and 0.5 m in height. The impact of scarification on hardwoods was mixed; mineral soil seedbeds enhanced the regeneration of white birch but significantly reduced height growth for all hardwood species. Data are as follows: stocking on treated seedbeds averaged 73% with 3 580 stems/ha and 3.5 m in height; on nonscarified seedbeds the corresponding numbers are 55%, 1 400 stems/ha, and 6.6 m tall. Exposing mineral soil seedbeds is essential for securing natural white spruce regeneration in mixedwood stands.

4. Results from these shelterwood and site preparation trials were almost identical to white spruce and hardwood stocking obtained on scarified clear cut strips during the same time frame (Kolabinski 1994) suggesting that from a solely forestry point-of-view either silviculture system would be suitable for harvesting and renewing boreal mixedwood stands. However it is apparent that cover type management is not the same as ecosystem management

and other factors such as aesthetics, biodiversity and wildlife would have to be factored into any preharvest silviculture prescription (PHSP).

5. In order to achieve successful restocking of mixedwoods using the two-staged shelterwood harvesting system combined with scarification the following specifications must be met:

a. Mixedwood stands should be located on landforms (ecosystems) with clay loam textured soils and rolling topography with a preponderance of fresh to moist sites; landforms with similar soil types, with essentially level topographies and a preponderance of moist and very moist microsites are not suitable as they are prone to the development of excessive amounts of *calamogrostis* grass and seasonal flooding when cut and scarified.

b. A minimum of 30% mineral soil exposure is required to ensure sufficient white spruce regeneration to meet provincial stocking standards. Scarification should be carried out as soon as possible following the first cut in order to minimize the amount of hardwood reproduction required to be removed and the creation of unproductive mounds of mixed debris and soil. Seedbed treatment costs escalate rapidly with increases in the amount of forest debris that has to be moved. Seedling establishment proved to be better and less hindered by vegetative competition on larger scalped patches than on narrow bladed strips. Bladed strips had a tendency to become overtopped and heavily shaded by lesser vegetation and shrub growth.

c. The second cut must be delayed by not less than five years following scarification in order to ensure adequate seedfall; sufficient white spruce seed should fall over a 10 year period provided a minimum of 5 m^2 basal area and 70 white spruce per hectare (including dominants and co-dominants) are left. The residual hardwood component can, apparently, be as low as 5 m^2 basal area /ha where there is significant hardwood reproduction already established, but should not exceed 12 m^2 basal area where there is no or little poplar reproduction at the time of treatment. The 10 year interval should also prove beneficial to white spruce on the mineral soil seedbeds by suppressing the growth of the hardwoods.

d. General paucity of advanced growth also showed that softwood growing stock on the areas would be insufficient without the assistance and success of natural regeneration on treated seedbeds. Understorey white spruce advanced growth should be protected if numbers (250+/ha) warrant the extra costs of harvesting balanced with the reduced cost of scarification.

e. Natural white spruce regeneration in these trials appears to be in sufficient numbers to preclude the need for future manual or chemical release from the hardwoods unless there is a financial opportunity to significantly increase growth and reduce the rotation age of the next crop.

f. Care would have to be taken at the time of the second (2nd) cut to minimize losses to the white spruce regeneration from felling and skidding.

A more detailed discussion of the factors affecting natural white spruce regeneration on prepared seedbeds at the Riding Mountain Forest Experimental Area, Manitoba and operational silvicultural applications can be found in Waldron (1966).

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APPENDIX I
PROVINCIAL STOCKING STANDARDS

1. Candy's (1051) scale for assessing stocking of regeneration based on 1/1000 acre or approximately 4-m^2 regeneration quadrats.

Fully Stocked	80-100%
Well Stocked	60-80%
Moderately Stocked	40-60%
Understocked	20-40%
Failure	0-20%

2. Saskatchewan's previous stocking standard (Saskatchewan Parks and Renewable Resources, 1985) considered a minimum of 65% softwoods based on 5-m^2 to be sufficient regeneration. A four-plot cluster (16 m^2 in size) is now used and requires a minimum of 60% stocking. (Steve Hyde, Saskatchewan Natural Resources, Prince Albert, SK., pers. comm. December 1992).

3. Manitoba's previous reforestation standard required a minimum of 75% softwood stocking based on 10-m^2 quadrats (Manitoba Department of Natural Resources, 1980). The current reforestation standard in Manitoba for stocking based on circular 10-m^2 quadrats requires $\geq$75% total softwood stocking in management of softwood (S) cover types, $\geq$45% and $\leq$75% softwood for mixedwood (M)[a] cover types; $\geq$20 and $\leq$45% softwood for mixedwood (N)[b] cover types; and $\leq$20% softwood for hardwood (H) cover types (Jeff Delaney, Manitoba Natural Resources, For. Br., Winnipeg, MB., pers. comm. April 1993).

4. New regeneration standards for Alberta are based on survey assessments of 4-8 and 8-14 year old harvested stands using 10-m^2 circular sample plots (Alberta Energy/Forestry Lands and Wildlife 1992). The reforestation standards for softwood and mixedwood stands as presented in the Alberta Regeneration Survey Manual incorporates seedling density, height and "Free-to-Grow" status according to the following criteria:

   (a) <u>Softwood stands (4-8 years after harvesting)</u> 80% stocking with at least one acceptable seedling or 60% stocking with acceptable and 20% stocking with conditional seedlings that meet a minimum height requirement - White spruce, black spruce 50 cm (acceptable); larch 100 cm (acceptable); white spruce, black spruce 40 cm (conditional); balsam fir 50 cm (conditional); trembling aspen, balsam poplar and white birch 150 cm (conditional).

   (b) <u>Mixedwood stands (4-8 years after harvesting)</u> 80% stocking with at least one acceptable seedling or 45% stocking with acceptable and 35% stocking with conditional seedlings that meet minimum height requirements as requirements as outlined in section (a).

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[a] "M" cover types contain 51 - 75% coniferous basal area.
[b] "N" cover types contain 26 - 50% coniferous basal area.

(c) Softwood stands (8-14) years after harvesting) 80% stocking with one "free-to-grow" acceptable sapling or 60% stocking with free-to-grow acceptable and 20% stocking with conditional established saplings that meet a minimum height requirement - White spruce, black spruce 150 cm (acceptable); larch 200 cm (acceptable); white spruce, black spruce 100 cm (conditional); balsam fir 150 cm (conditional); trembling aspen, balsam poplar and white birch 200 cm (conditional).

(d) Mixedwood stands (8-14 years after harvesting) 80% stocking with one "free-to-grow" acceptable sapling or 45% stocking with free-to-grow acceptable and 35% stocking with conditional established saplings that meet minimum height requirements as outlined in section (c).

APPENDIX II

Table 1. Percent stocking of white spruce, balsam fir, and hardwoods by study area and site treatment (basis: 5-m^2 quadrats)

Study area	Establishment year	Site treatment	Growing seasons (years)	No. of quadrats (5-m^2)	White spruce Regen (%)	White spruce Adv.Gr. (%)	White spruce R+A (%)	Balsam fir Regen (%)	Balsam fir Adv. Gr. (%)	Balsam fir R+A (%)	All softwoods (%)	Hardwoods[a] (%)	White spruce or hardwoods (%)	Conifers or hardwoods (%)
Riding Mtn. (1)	1962-63	Scarified	24	436	66.3	0.7	66.5	0.5	0.2	0.7	66.5	53.7	80.0	80.0
		Nonscarified		444	2.5	4.0	6.5	0.5	0.0	0.5	7.0	29.5	35.1	35.6
		All		880	34.1	2.4	36.2	0.5	0.1	0.6	36.5	41.5	57.4	57.6
Sled Lake (3)	1962-63	Scarified	23	230	67.8	0.4	67.8	30.4	0.0	30.4	72.6	45.2	77.8	80.9
		Nonscarified		334	23.4	3.3	26.6	19.8	8.4	23.4	43.4	35.6	51.2	64.7
		All		564	41.5	2.1	43.4	24.1	5.0	26.2	55.3	39.5	62.0	71.3
Porcupine For.(4)	1964	Scarified	23	222	72.1	0.9	72.5	2.2	0.5	2.7	72.5	48.6	81.5	81.5
		Nonscarified		338	7.7	8.0	14.8	1.5	0.0	1.5	15.4	39.3	48.5	48.5
		All		560	33.2	5.2	37.7	1.8	0.2	2.0	38.0	43.0	61.6	61.6
Porcupine For. (5)	1964	Scarified	23	154	79.9	0.0	79.9	9.1	0.0	9.1	79.9	60.4	92.8	92.8
		Nonscarified		230	2.2	0.4	2.6	0.4	0.0	0.4	3.0	41.3	42.6	42.6
		All		384	33.3	0.3	33.6	3.9	0.0	3.9	33.9	49.0	62.8	62.8
Porcupine For. (6)	1965	Scarified	22	192	50.0	1.0	51.0	21.9	0.0	21.9	57.8	45.3	70.3	72.4
		Nonscarified		288	3.5	0.7	4.2	3.5	1.0	4.2	8.3	38.9	41.3	44.1
		All		480	22.1	0.8	22.9	10.8	0.6	11.2	28.1	41.4	52.9	55.4
Porcupine For. (7)	1965	Scarified	22	116	71.6	0.0	71.6	0.9	0.0	0.9	71.6	78.4	87.1	87.1
		Nonscarified		396	2.8	0.0	2.8	0.0	0.0	0.0	2.8	39.9	41.4	41.4
		All		512	18.4	0.0	18.4	0.2	0.0	0.2	18.4	48.6	51.8	51.8
All areas	1962-65	Scarified	22-24	1 350	67.2	0.6	67.5	9.9	0.1	10.1	69.2	53.1	80.6	81.4
		Nonscarified		2 030	6.9	2.9	9.7	4.1	1.5	4.8	13.3	36.8	43.0	45.7
		All		3 380	31.0	2.0	32.8	6.4	1.0	6.9	35.6	43.3	58.0	59.9

[a] Hardwoods include trembling aspen, balsam poplar and white birch.

APPENDIX III

TABLE 1. VEGETATION SHEET
List of lesser vegetation commonly
found on various soil moisture regimes
at Riding Mountain, Area 1

(Revised July 28/56 - J.S. Rowe)

Locality: ______________________
Area: ______________________
Date: ______________________
Notes by: ______________________

Plot No.: ______________________
Site: ______________________
Cover Type: ______________________
Aspect: ______________________
Position & Slope: ______________________

Dominant Stratum

	Prim.	Sec.
Tall Shrub (+3')	_____	_____
Med. Shrub (6"-3')	_____	_____
Tall Herb & Grass (+1')	_____	_____
Med. Herb & Grass (6"-1')	_____	_____
Low Herb & Shrub (-6") _____	_____	
Moss or Lichen	_____	_____

	Very Dry and Dry	Fresh	Moist	Very Moist	Wet
Tall Shrubs	Alnus crispa Elaeagnus commutata Salix humilis Sheph. canadensis	Amelanchier alnif. Corylus cornuta Prunus pensylvan. Prunus virginiana	Acer spicatum Sorbus decora Viburnum trilobum	Acer negundo Cornus stolon. Salix bebbiana Salix discolor	Alnus rugosa Salix petiolaris Salix pyrifolia
Medium Shrubs	+Hudsonia tomentosa Juniperus communis	Diervilla lonicera Rosa acicularis Symphor. albus Symbor. occident. +Vacc. myrtilloides	Lonicera dioica	+Ledum groenlan. Lonicera involuc. Lonicera villosa Ribes glandulos. Ribes hirtellum Ribes triste Rubus idaeus Viburnum edule	+Andro. polifolia Betula glandulosa +Chamaedaphne calyculata +Kalmia polifolia Rhamnus alnifolia Ribes lacustre Spiraea alba

Tall Herbs and Grasses	Agastache foen. Anem. cylindrica Hedysarum alpinum Hier. canadense Lathyrus venosus Lilium umbellatum Potentilla arguta	Actaea rubra Agropyron subsec. Anemone riparia Apocynum androsae. Aralia nudicaulis Aster conspicuus Chamaen. angustif. Disporum trachy. Lathyrus ochrol. Sanicula mariland. Thalictrum venul. Vicia americana	Achillea sibirica Aquil. canadensis Osmorhiza longist. Solidago lepida	Anem. canadensis Aster umbellatus Calam. canadensis Cinna latifolia Heracleum maximum Pteretis pensyl. Solidago gigantea Thalic. dasycarpum Urtica gracilis	Arnica chamis. Aster puniceus Cirsium muticum Eupator. maculat. Impatiens capen. Petasites sagit. Petasites vitifol. Sium suave
Medium Shrubs and Grasses	Achil. millefolium Aster laevis Erigeron glabellus Castil. rhexifolia Comandra pallida Elymus innovatus Equisetum hyemale Gentiana amarella Heuchera richard. Melampyrum lineare Oryzopsis asperi. Polygala senega Solidago nemoralis Zizia aptera	Aquil. brevistyla Aster ciliolatus Campanula pet. Corallorhiza mac. Corallorhiza stri. Galium septent. Prenanthes alba Schizachne purpur. Smilacina stellata Viola rugulosa	Bromus ciliatus Mert. paniculata Osmorhiza obtusa Petasites palmatus	Dryop. cristata Dryop. disjuncta Dryop. spinulosa Equisetum arvense Equisetum pratense +Geocaulon lividum Habenaria hyper. Lysimachia cilia. Poa palustris Valeriana septen.	Caltha palustris Equisetum sylv. Geum macrophyllum Geum rivale Lathyrus palust. Mentha arvensis Parnassia palus. Senecio pauper. Stachys palustris

Low Herbs and Grasses and Shrubs	Antennaria spp. +Arctos. uva-ursi Danthonia spicata Houstonia longif. Festuca ovina Juniperus horizon. +Lycopodium complan. Oryzopsis pungens Potentilla trident. Solidago hispida Spiranthes gracilis Vaccinium caespit. Viola adunca	Anemone quinquef. Corallorhiza trif. Fragaria virginiana +Lycopodium obscur. Maianthemum can. Pyrola asarifolia Pyrola secunda	Carex deweyana +Coptis groenlan. Corallorhiza trif. Cornus canadensis Fragaria vesca +Goodyera repens +Linnaea borealis Lycopodium annot. Moehringia later. Monotropa uniflora +Pyrola virens Rubus pubescens +Trientalis boreal. +Vacc. vitis-idaea +Viola renifolia	Circaea alpina +Equisetum scirp. Galium triflorum +Gaultheria hisp. +Habenaria obtus. +Habenaria orbic. +Listera cordata Mitella nuda +Moneses uniflora +Ranunculus lapp.	Carex capillaris +Carex disperma Carex gynocrates Chrysos. ioense +Drosera rotundif. Galium trifidum Ranunculus abort. +Rubus acaulis +Rubus chamaemorus +Smilacina trifol. Stellaria longif. +Vaccinium oxycoc. Viola nephrophylla Viola palustris
Mosses and Lichens	Ceratodon purpureus +Cladonia rangif. Polytrichum pilif.	Brachy. salebrosum Polytrichum junip. Rhytid. triquetrus	+Calliergon schr. +Dicranum rugosum Eurhyn. diversif. Peltigera spp.	+Hylocomium splen. +Hypnum crista-cast. Thuidium recog.	Aulacomnium palu. Campthoth. nitens Climacium amer. Drepan. uncinatus Mnium cuspidatum +Sphagnum spp.

+ - Species characteristic of coniferous types.
- Species having little indicator value so far as moisture is concerned are underlined.

APPENDIX III

Table 2. Percent stocking of white spruce regeneration by study area and soil moisture regime[a] (basis: 5-m^2 quadrats)

Study area	Stocking (%)							
	Scarified				Nonscarified			
	Fresh	Moderately moist	Moist	Very moist	Fresh	Moderately moist	Moist	Very moist
Riding Mtn. (1)	65 (316)[b]	70 (120)	0 (0)	0 (0)	2 (314)	4 (130)	0 (0)	0 (0)
Sled Lake (3)	67 (24)	75 (126)	55 (80)	0 (0)	19 (59)	26 (167)	24 (100)	0 (8)
Porcupine For. (4)	71 (34)	73 (118)	71 (70)	0 (0)	10 (58)	7 (180)	8 (88)	0 (12)
Porcupine For. (5)	86 (52)	86 (76)	65 (26)	0 (0)	2 (80)	3 (120)	0 (30)	0 (0)
Porcupine For. (6)	49 (111)	62 (61)	20 (20)	0 (0)	3 (153)	2 (111)	17 (24)	0 (0)
Porcupine For. (7)	80 (10)	77 (44)	73 (52)	40 (10)	2 (60)	2 (216)	5 (98)	0 (22)
All areas	64 (547)	73 (545)	62 (248)	40 (10)	4 (724)	8 (924)	12 (340)	0 (42)

[a] After Hills 1952.

[b] Figures in brackets represent number of measured 5-m^2 quadrats.

APPENDIX III

Table 3. Number of white spruce seedlings per hectare by study area and soil moisture regime[a] (basis: 5-m^2 quadrats)

	Numbers of stems/ha							
	Scarified				Nonscarified			
Study area	Fresh[a]	Moderately moist	Moist	Very moist	Fresh	Moderately moist	Moist	Very moist
Riding Mtn. (1)	7 910 (85)[b]	9 970 (29)	0 (0)	0 (0)	0 (72)	0 (34)	0 (0)	0 (0)
Sled Lake (3)	28 660 (5)	21 280 (31)	7 520 (22)	0 (0)	760 (13)	1 500 (43)	200 (25)	0 (2)
Porcupine For. (4)	10 870 (10)	13 180 (30)	17 040 (19)	0 (0)	160 (16)	170 (43)	130 (19)	0 (3)
Porcupine For. (5)	18 710 (14)	6 470 (21)	9 880 (6)	0 (0)	150 (17)	80 (31)	0 (7)	0 (0)
Porcupine For. (6)	3 600 (22)	9 000 (14)	310 (8)	0 (0)	60 (41)	0 (33)	0 (2)	0 (0)
Porcupine For. (7)	7 410 (1)	9 310 (13)	17 970 (11)	820 (3)	0 (14)	0 (52)	0 (26)	0 (8)
All areas	9 290 (137)	12 520 (138)	11 340 (66)	820 (3)	100 (173)	310 (236)	90 (79)	0 (13)

[a] After Hills 1952.
[b] Figures in brackets represent number of measured 5-m^2 quadrats.

APPENDIX IV

Table 1. Analysis of variance for changes in percent stocking and stems/ha of white spruce regeneration in uncut and in cut-over areas following the removal (2nd cut) of the residual white spruce

Source of variation[a]	df	% Stocking Change: Mean square	% Stocking Change: F Value	% Stocking Change: Probability >F	% Stem Change: Mean square	% Stem Change: F Value	% Stem Change: Probability >F
Treatment	1	572.70	4.11	0.0772	1827.80	1.81	0.2157
Log	1	13076.00	93.79	0.0001	15090.14	14.92	0.0048
Treat X Log	1	6847.88	49.12	0.0001	2185.04	2.16	0.1798

[a] Treatment = Scarified and nonscarified; Log = Cut and not cut.