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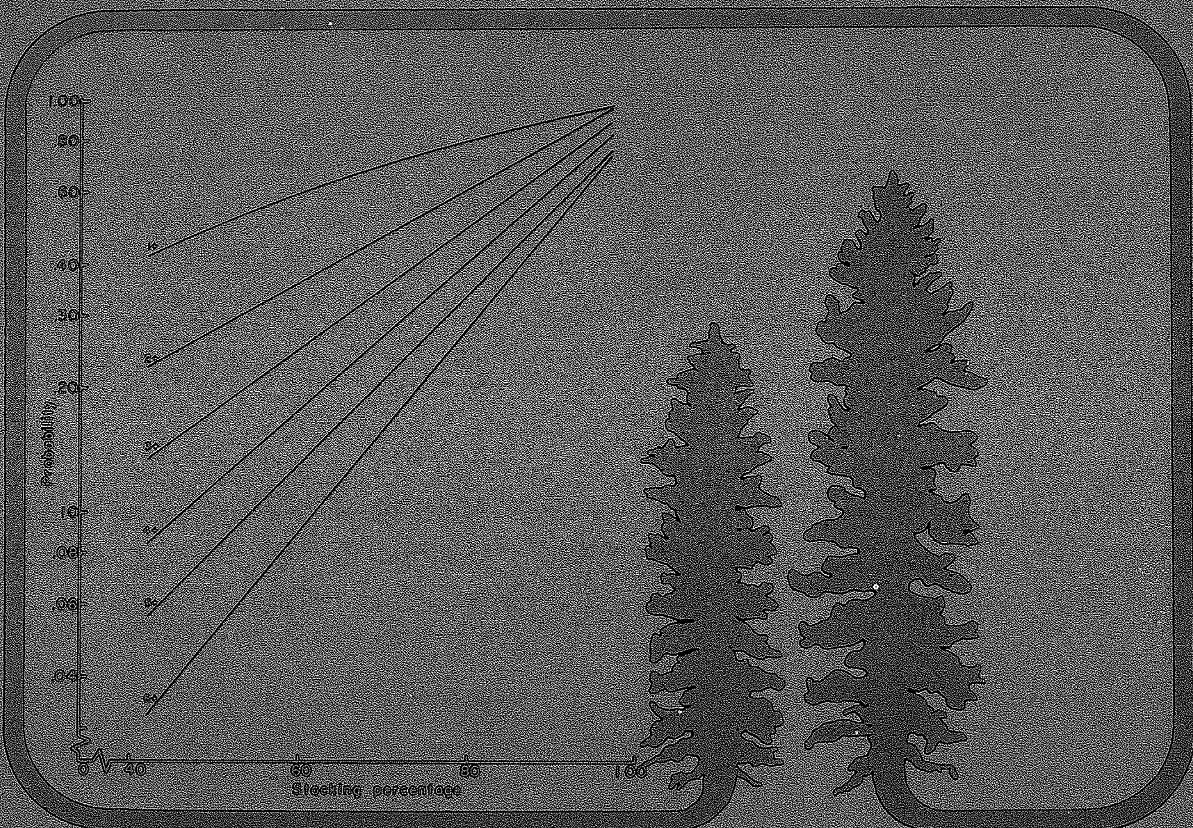

I.E. Bella and J.P. De Franceschi

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ASSESSMENT OF REGENERATION STOCKING STANDARDS USED IN ALBERTA: A FOLLOW-UP

BY

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ABSTRACT

This is the second phase of a study conducted to update reforestation standards used in Alberta. The analysis was based on growth and size information of open-growing lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) and white spruce (*Picea glauca* (Moench) Voss) to estimate the minimum number of well-dispersed trees and stocking percentage required for complete site utilization at reference age of half rotation (40 years for lodgepole pine, 40 or 50 years for white spruce). The minimum numbers of well-dispersed trees per hectare required were 575 pine (233/acre) in the Foothills, 610 spruce (247/acre) for sawlog stands in the Mixedwood, 720 spruce (291/acre) for sawlog stands in the Foothills, 900 spruce (364/acre) for pulpwood stands in the Mixedwood, and 1100 spruce (445/acre) for pulpwood stands in the Foothills.

Seedling spatial pattern and density were examined in regeneration 10 years after logging, sampled over a wide geographical area in the important forest types of Alberta. Seedling pattern for both species was generally clumpy. Therefore, to ensure at least the minimum required number of well-dispersed seedlings on an area, the use of suitably large quadrats (10 m^2 or more) and high stocking levels is necessary. Relationships were developed to show, by stocking percentage classes, the relative frequencies of stocked quadrats with at least 1, 2, 3, etc. seedlings.

Appropriate minimum stocking percentages (by 10-m^2 quadrats) derived were 65% for pine, 70 and 80% for spruce sawlog stands in the Mixedwood and the Foothills respectively, and 90% for spruce pulpwood stands. Because the two species have different stocking potentials, procedures are presented for adjusting survey results when regeneration is a mixture of pine and spruce.

Because of clumping and ingress, the many extra seedlings present on stocked areas

RESUME

Voici la seconde phase d'une étude conduite afin de mettre à jour les normes utilisées après coupe. Les auteurs fondèrent leur analyse sur la croissance et la grosseur d'arbres sis à ciel ouvert et appartenant au Pin lodgepole (*Pinus contorta* Dougl. var. *latifolia* Engelm.) et à l'Epinette blanche (*Picea glauca* (Moench) Voss) pour estimer le nombre minimal d'arbres bien espacés et le matériel sur pied relatif nécessaires pour compléter l'utilisation de la station à l'âge de référence d'une demie-révolution (40 ans pour le Pin lodgepole, 40 ou 50 ans pour l'Epinette blanche). Les nombres minimals requis d'arbres bien dispersés par hectare furent dérivés comme étant 575 pins (233/acre), 610 épinettes (247/acre) dans les peuplements à grumes mélangés, 720 épinettes (291/acre) dans les peuplements à grumes des Foothills, 900 épinettes (364/acre) dans les peuplements à pâte mélangés, et 1100 épinettes (445/acre) dans les peuplements à pâte des Foothills.

Les auteurs examinèrent la densité et le mode d'espacement des semis de régénération 10 ans après coupe ça et là dans les types importants de forêts albertaines. Chez les deux espèces, les semis n'étaient pas bien espacés. Pour y remédier, on devra utiliser d'assez grands quadrats (10 m^2 ou plus) et un matériel sur pied relatif plus dense. Les auteurs établirent des relations qui montrent, par classe de matériel sur pied relatif, les fréquences relatives de quadrats ensemencés avec au moins 1, 2, 3, etc. semis.

Les pourcentages minimals de matériel sur pied relatif approprié (par quadrats de 10 m^2) furent dérivés comme étant 65% pour le pin, 70 et 80% chez les peuplements à grumes d'épinettes en forêt mixte et dans les Foothills respectivement, et 90% chez les peuplements d'épinette à pâte. Vu que les deux espèces peuvent avoir un matériel sur pied relatif différent, on indique comment ajuster les résultats d'inventaire lorsque la régénération est un mélange de pin et d'épinette.

constitute a good reserve of potential crop trees should some of the "first" seedlings die. However, because present knowledge is rather scanty on mortality between age 10 and half-rotation age, definitive results must await the availability of more and better information. Relatively open conditions at younger ages and generally more open stands on less productive sites implied by these standards may be advantageous for recreation and wildlife.

Après 10 ans, vu le groupement et l'invasion, les nombreux semis additionnels présents dans le matériel sur pied relatif constituent une bonne réserve d'arbres possiblement du peuplement final si des "premiers" semis venaient à mourir. Cependant les auteurs en savent peu sur la mortalité depuis l'âge de 10 ans jusqu'à la moitié de révolution et les résultats définitifs doivent attendre la disponibilité d'informations meilleures et plus amples. Jeunes et clairsemés, ou, généralement plus clairsemés en station moins productive, les peuplements pourraient servir à la récréation et à la faune.

CONTENTS

1. INTRODUCTION

This study was begun in response to a request by the Alberta Forest Service (AFS) for a critical assessment of its 40% stocking rule (based on l-milacre stocked quadrat survey). The assessment was to be based upon local data on regeneration and expected growth, development, and yield of second-growth stands following logging in the major commercial forest types and stand conditions in the region. The main objective of the study was to evaluate the success of the current standard in achieving a desirable minimum stocking and to recommend, if justified, a new and possibly flexible minimum standard that would ensure acceptable, although not necessarily maximum, wood fiber production.

The results of the first phase of this study (Bella 1976) presented new minimum stocking standards for use in regeneration surveys. These standards were based on complete crown closure and full utilization of the site by trees halfway through the rotation, 40 years for pine and 50 years for spruce. The recommended stocking percentages were 75% by 10-m^2 quadrats for spruce and 70% by 12.5-m^2 quadrats for pine. Because the report had a somewhat limited data base, senior foresters in the AFS suggested postponing full implementation of its recommendations until they were confirmed by additional data from sampling a wider geographic area and altitudinal range.

The additional data were collected between May and September 1977 and are used in this report to verify earlier published results (Bella 1976). In addition, relationships were developed to show, by stocking percentage classes, the relative frequencies of stocked quadrats with at least 1, 2, 3, etc. established acceptable seedlings. This information about actual seedling densities per quadrat may be particularly useful for describing "surplus" trees with future growth potential.

2. BACKGROUND

The first report (Bella 1976) presented a brief review and evaluation of stocked quadrat surveys and their theoretical bases. The importance of selecting proper quadrat size was emphasized, particularly for areas with a nonrandom seedling pattern.

General research strategy for the study as a whole had two main objectives. The first was to determine the minimum number of well-dispersed pine and spruce growing on specific sites required to achieve complete crown closure at half rotation without any prior significant intertree competition in the stand. The second main objective was to examine seedling spatial pattern and density based on detailed sampling of 10-year-old lodgepole pine and white spruce regeneration in the region.

To fulfill the first objective, growth and size information from individual open-growing trees was used to (1) derive Dbh over Age relations by three arbitrary site quality classes for estimating average Dbh at reference age, (2) derive the Crown Width-Dbh relationships to estimate crown areas for average Dbh values, and (3) calculate the number of well-distributed trees per hectare required for desired crown closure and deriving appropriate stocking percentages. Number of trees and stocking percentages were then regressed to stand age of 10 years—the cutoff point for the regeneration phase—by allowing for any mortality in the interim period.

The application of stocking standards is linked to stocked quadrat surveys. Using that system, the selection of an appropriate quadrat size is of critical importance if seedling dispersion is anything but random. The second objective of the study was to provide information on seedling spatial pattern and density. The principal value of density in this study lies in indicating the number of "reserve trees" available to fill any gaps created by mortality during the life of the stand. This part of the study was required because standard stocked quadrat surveys provide no information on seedling patterns or density, yet these are essential characteristics of regeneration to consider when developing or assessing stocking standards.

3. DESCRIPTION OF THE STUDY AREA

Sampling was undertaken in the Foothills Section (B19a-Lower, and B19c-

Table 1. Summary of sample tree locations

Location	Species	Number of trees	Range of elevation (m) Min.	Max.
Bow-Crow Forest	P[1]	25	1362	1829
	S[2]	7	1362	1692
Rocky-Clearwater Forest	P	2	1295	1295
	S	2	1295	1295
Edson Forest	P	26	1067	1341
	S	31	1000	1311
Grande Prairie Forest	S	8	792	945
Whitecourt Forest	P	3	808	808
Slave Lake Forest	S	8	579	610
Lac La Biche Forest	S	8	518	716
Total sample	P	56	808	1829
	S	64	518	1692

[1] Lodgepole pine
[2] White spruce

Upper; Rowe 1972) and in the Mixedwood Section (B18a). In the Foothills Section, lodgepole pine, white spruce, black spruce (*Picea mariana* (Mill.) B.S.P.), balsam fir (*Abies balsamea* (L.) Mill.), and alpine fir (*A. lasiocarpa* (Hook.) Nutt.) are the major coniferous species. In the Mixedwood Section, the principal coniferous tree species are white and black spruce and balsam fir.

Because sampling was spread over an extensive area, soil and site conditions varied considerably from wet organic soils to well-drained gravelly or sandy soils, and clays. Although variations in climate and soil nutrient status likely have some effect on tree growth, the most important variable is probably soil moisture.

Sampling for growth of open-growing trees was conducted at various locations over the two forest sections. Elevation at sampling locations varied between 808 and 1829 m for lodgepole pine and 518 and 1692 m for white spruce. Table 1 contains a summary of sample-tree locations and elevations by species.

The general location of the regeneration sample is shown on Fig. 1. All logged areas had received some ground treatment after logging. In the coniferous cover types of the Foothills, which were generally clear-cut, the treatment consisted of blade and drag-type scarification using a bulldozer; in the Mixedwood, where the hardwood component was left standing, spot scarification ("dip and dive") was done with bulldozers.

In addition, data available from an earlier survey (by J. Soos, on file at the Northern Forest Research Centre) of pine regeneration following a wildfire near the

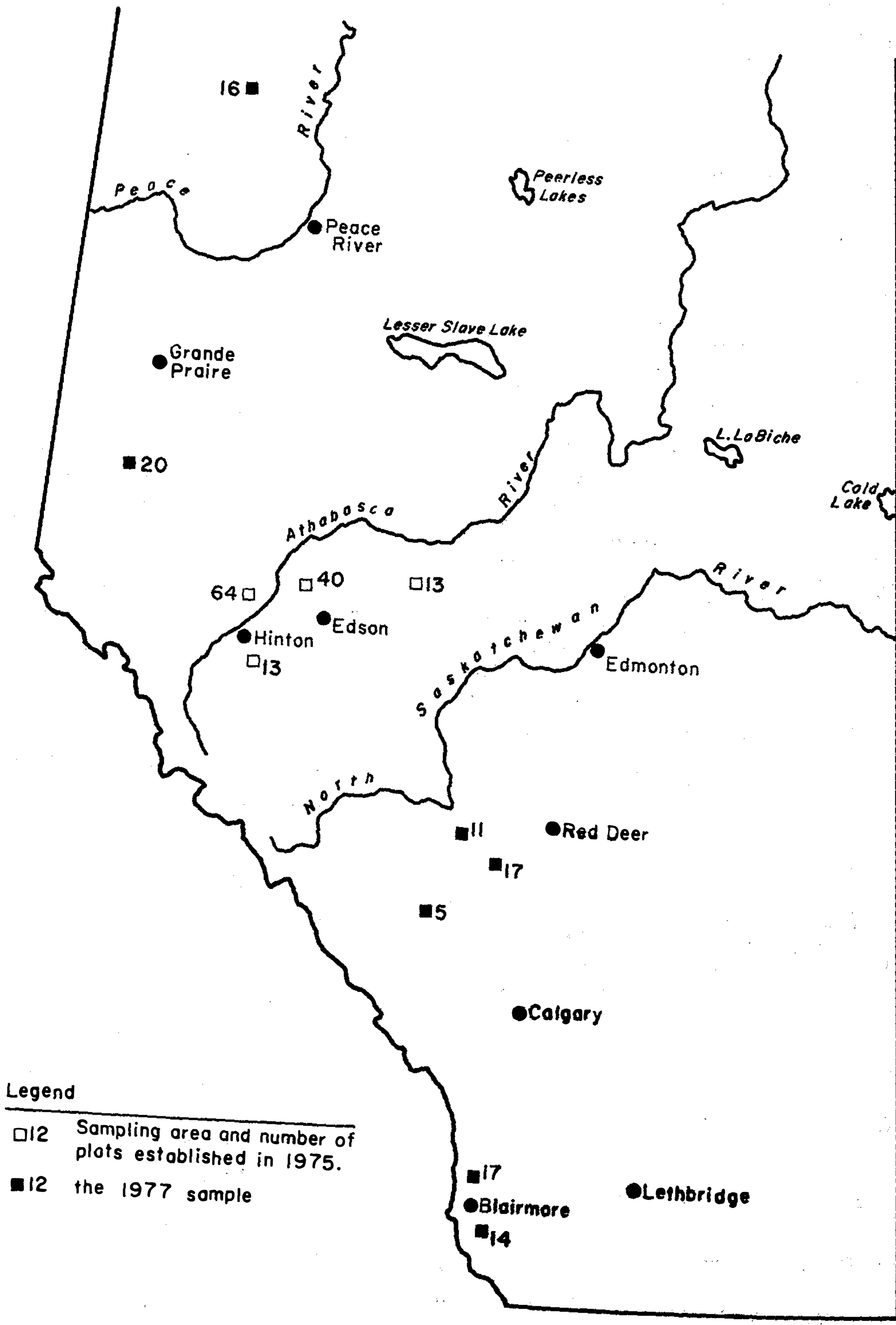


Figure 1. General location of sample plots

Upper Saskatchewan Ranger Station (Rocky-Clearwater Forest, elevation 1370 m) were also included in this study.

4. GROWTH-SIZE RELATIONS OF OPEN-GROWING TREES

4.1. Methods

4.1.1. Field

Healthy lodgepole pine and white spruce trees without apparent competition from neighboring trees (full crown and no neighboring tree crowns overlapping the sample trees' branches) were selected between ages 20 and 50 years. Dbh to 2.5 mm (0.1 in.), Height, and CW (average of two measurements taken at 90° to each other) to 3 cm (0.1 ft), an increment core through the pith at breast height for growth determination, and a core at 30-cm (1-ft stump) height for ring count were taken. Number of years required to reach stump height was estimated from advance growth present in the area. Altitude was obtained and site conditions were described at each sample tree.

4.1.2. Analysis

Current Dbh over bark and increment cores taken at breast height from each tree were used to estimate former Dbh_{ob} at 5-year intervals. Total age was estimated for each of these Dbh values using the number of years required to reach breast height. Tree growth and size relationships were developed based on freehand curves and regression techniques.

4.2. Results and Discussion

4.2.1. Dbh in Relation to Age

Figures 2 and 3 show Dbh values plotted over total age for pine and spruce. These figures include sample data from both 1975 and 1977. An examination of these figures reveals reasonable similarity between the two sets of data, so the original partitioning into three proportional arbitrary site quality classes was retained (Bella 1976). Thus, expected average Dbh in centimetres at reference age of 40 years for pine and 40 and 50 years for spruce are:

Species	Reference age	Sites: Good	Medium	Poor
Lodgepole pine	40	28.2	22.4	16.3
White spruce	40	23.1	17.3	11.2
	50	31.2	24.0	16.8

Diameter growth relations (Figs. 2 and 3) were verified by comparison with independent data collected by other researchers at the Northern Forest Research Centre. These comparisons generally confirmed that the growth trends and the range of site conditions covered by the present sample are reasonably representative for these two species in the area.

The trends indicate that pine takes about 6 years less than spruce to reach breast height on medium sites (9 vs. 15 years) and maintains at least the same advantage in Dbh over spruce at 40 years. At that age, this means a difference of 5 cm (22 vs. 17 cm) in Dbh.

4.2.2 Crown Width in Relation to Dbh

Regression equations developed for the two species and related statistics (r^2 and n) are presented in Fig. 4. Regressions for both species were highly significant. The inclusion of new data caused no significant change in the regression for lodgepole pine, where Dbh accounted for 75% of the variation in CW. For spruce, extending the sampling range in elevation downward to include a good representation from the Mixedwood (below 900 m or 3000 ft; Table 1) resulted in Elevation being highly significant as a variable. Dbh and Elevation together explained 73% of the variation in CW, of which Elevation contributed a highly significant 14%.

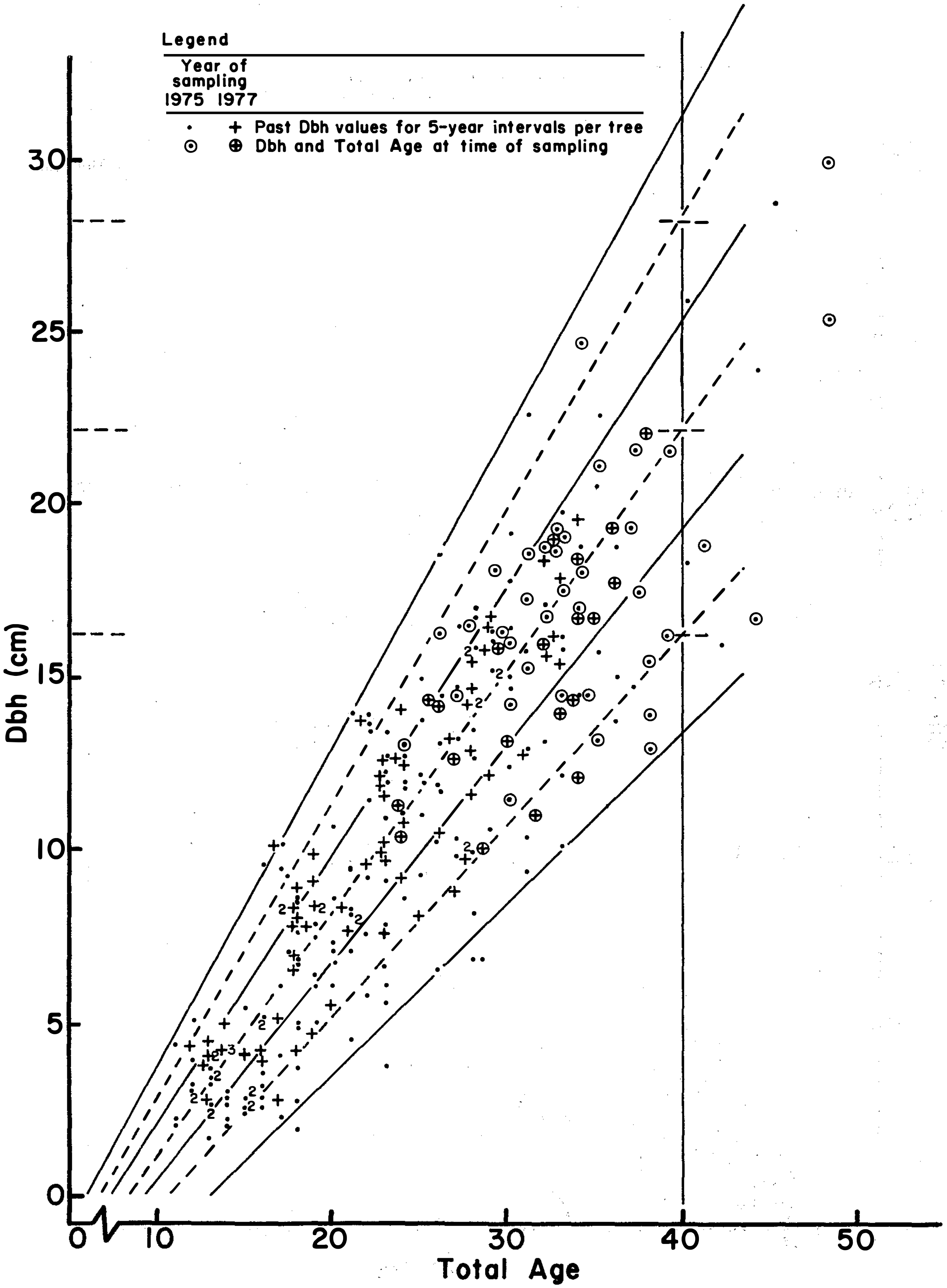


Figure 2. Dbh over Total Age relationships for lodgepole pine

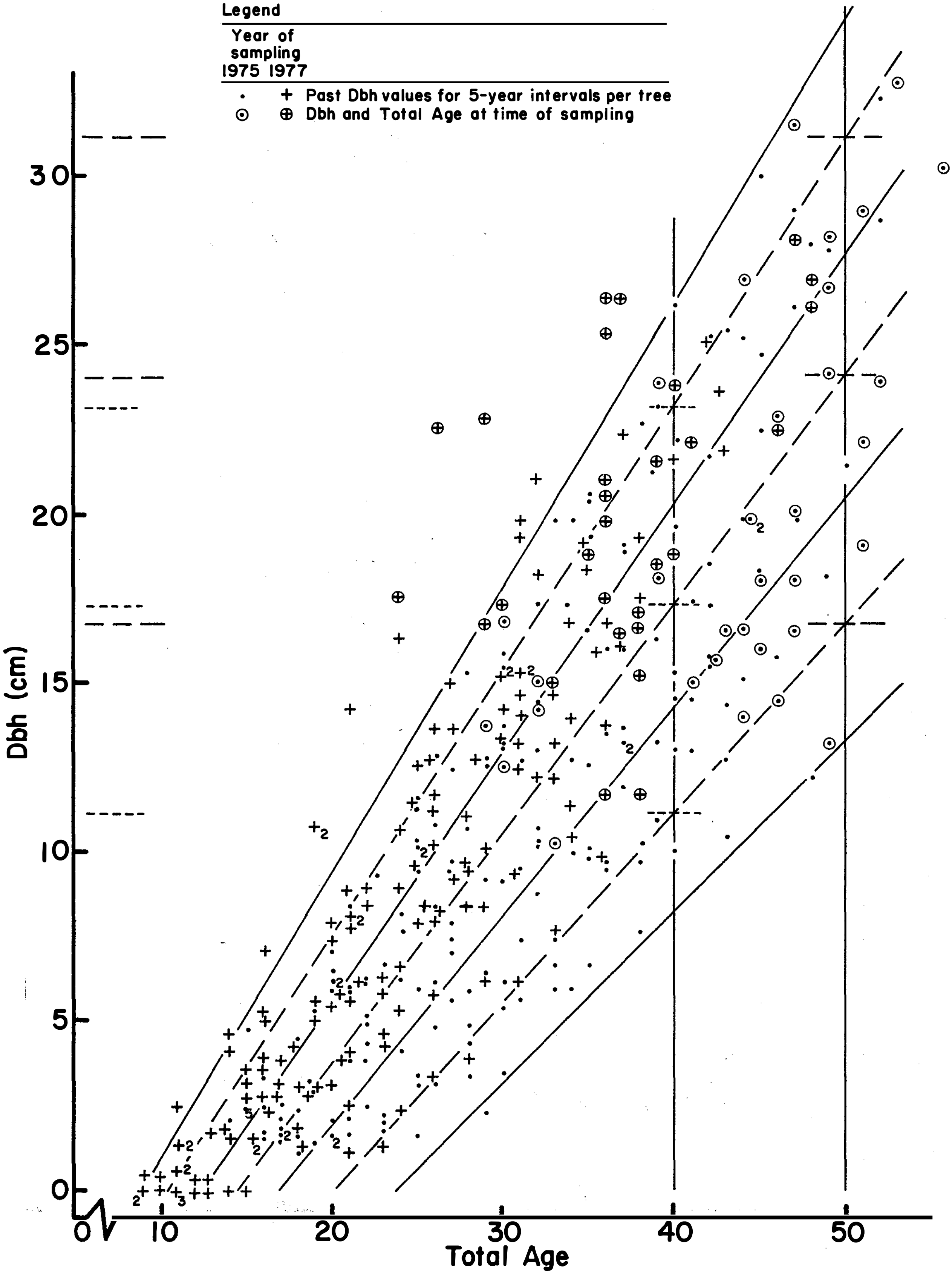


Figure 3. Dbh over Total Age relationships for white spruce

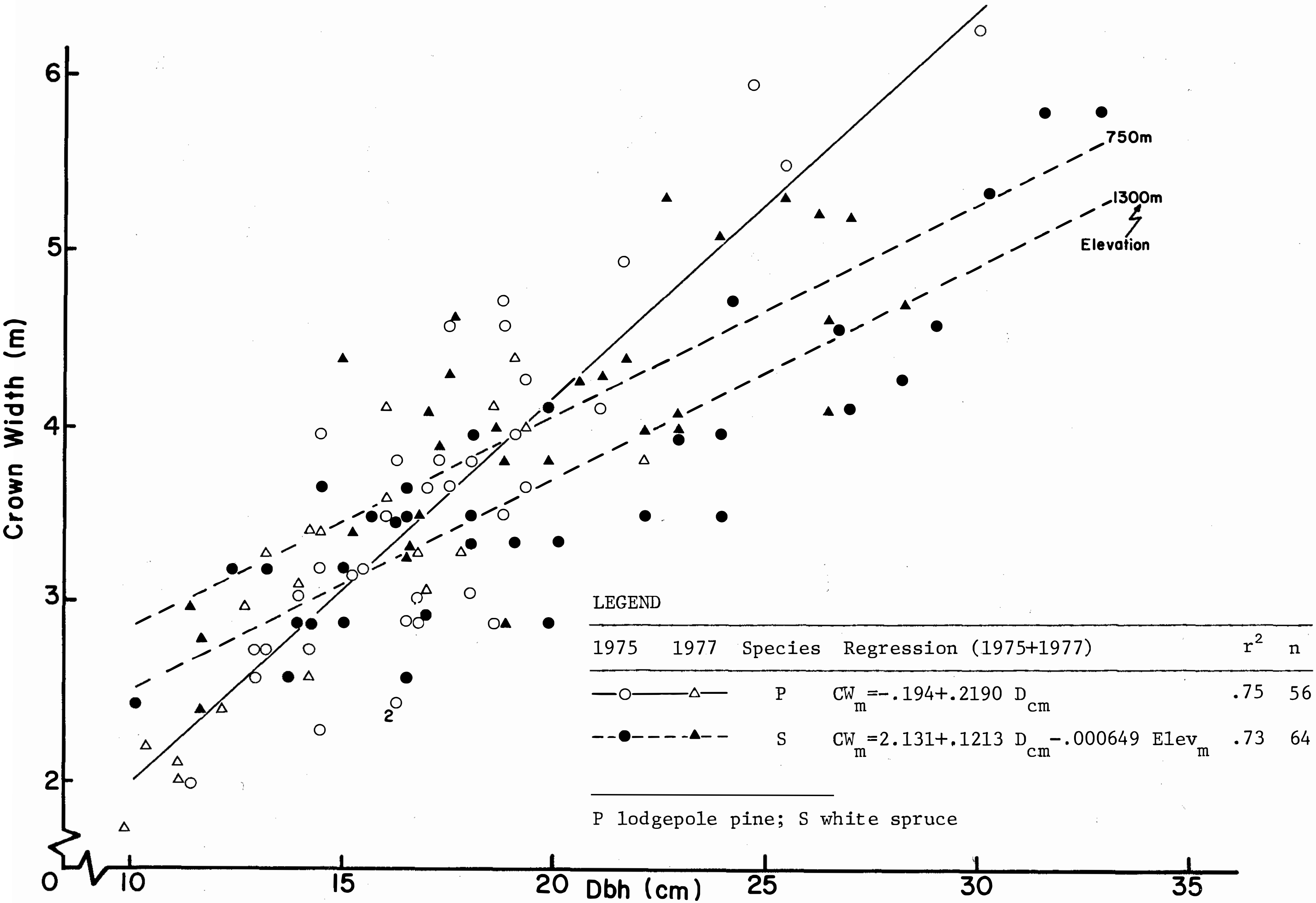


Figure 4. Crown Width over Dbh relationships for lodgepole pine and white spruce

The smaller relative CW for spruce was expected among the western variety of white spruce (*Picea glauca* (Moench) Voss var. *albertiana* (S. Brown) Sarg.) at higher elevations. This indicates that a greater number of trees of a certain diameter, and thus greater yield, may be grown on a given area at higher than at lower elevation in this region, if a similar level of crown closure is assumed. However, if narrower crowns at higher elevation coincide with a more open canopy, then number of trees and stand volume might be similar to those at lower elevations. Additional data would be required to test this hypothesis.

4.2.3. Number of Trees Required for Full Stocking

Average Dbh of free-growing pine and spruce was estimated at 40, and at 40 and 50 years, respectively, for three site classes as described in section 4.2.1. Average CW was estimated using the regressions shown in Fig. 4, and then these CW values were used to calculate crown projection areas.

From crown projection areas, the number of full-crowned, open-growing pine and spruce trees required for complete crown closure at 40, and 40 and 50 years of age, respectively, was estimated for the three site classes (Table 2). Specifying complete (100%) crown closure may appear overly optimistic, although it is not uncommon for vigorous young lodgepole pine or white spruce trees in open stands to develop so that the branches of neighboring individuals touch or even overlap. On this basis, as few as 356 well-distributed, vigorous pine trees/ha would be sufficient to provide complete crown closure at 40 years on good sites, and 574 on medium sites, whereas on poor sites slightly over 1100 would be required. These statistics are similar to the earlier results based on the 1975 data (Bella 1976).

Separate estimates of required number of trees per hectare were derived for spruce in the Foothills and the Mixedwood using median elevations of 1300 m (4250 ft) and 750 m (2450 ft), respectively (Fig. 4). This was done to consider the effect of elevation on spruce crown width and thus on number of trees per hectare. The analysis indicated that nearly 20% more trees would be needed for complete crown closure on medium sites in the Foothills, where spruce has more slender crowns, than in the Mixedwood. Because of this smaller Dbh and crown size, full crown closure in the Foothills at age 40 would require nearly twice as many well-distributed spruce than pine trees, viz., 1115 vs. 574, while in the Mixedwood it would require 910. These estimates for number of spruce in the Foothills agree well with former estimates based on the 1975 data, which originated entirely from the Foothills.

This approach to the problem indicates that considerably more spruce than pine are required for full crown closure at reference age 40 years, but the difference in tree numbers between sites is less pronounced for spruce. This can be explained by the generally smaller tree size (Dbh and CW) at reference age because of spruce's slower juvenile growth and somewhat narrower crowns.

To illustrate what the above stand densities could mean in terms of productivity, rough estimates of stand volumes were derived for the two species at 40 years for pine, and 40 and 50 years for spruce for the conditions described in Table 2. These estimates, presented in Table 3, indicate similar volumes for lodgepole pine and white spruce in the Foothills on medium sites at 40 years, although for spruce this volume was distributed on twice as many trees. On good sites spruce would outproduce pine by about 20% because of the much greater number of spruce trees. On poor sites pine would do much better than spruce, probably because of substantially greater Dbh.

Similar comparisons can be made between pine and spruce productivity where the latter is managed primarily for sawlog production (i.e., 100-year rotation). Even then, spruce should be grown at somewhat higher densities (in terms of number of trees per hectare) than pine (Table 3). This example, however, suggests that volume production in spruce at 50 years may be substantially higher than that in pine at 40 years.

Table 2. Number of open-growing trees per hectare required for complete crown closure at age 40 years for pine and 40 or 50 years for spruce by site class (from 1975 data and from all data combined, 1975-77)

Species	Half Rotation	Site Class	Forest Type[1]	Avg. Dbh[2] (cm)	Average Crown Width[3] (m) 1975	Average Crown Width[3] (m) 1975-77	Average Crown Area (m^2) 1975	Average Crown Area (m^2) 1975-77	Number of Trees/ha 1975	Number of Trees/ha 1975-77
Lodgepole Pine	40	Good	Fh	28.2	6.13	5.98	29.51	28.09	339	356
		Medium	Fh	22.4	4.75	4.71	17.72	17.42	564	574
		Poor	Fh	16.3	3.32	3.38	8.66	8.97	1155	1115
White Spruce	40	Good	Fh	23.1	3.99	4.09	12.50	13.14	800	761
			Mw			4.45		15.55		643
		Medium	Fh	17.3	3.29	3.38	8.50	8.97	1177	1115
			Mw			3.74		10.99		910
		Poor	Fh	11.2	2.81	2.65	6.20	5.51	1613	1815
			Mw			3.00		7.07		1414
	50	Good	Fh	31.2	5.25	5.07	21.65	20.19	462	495
			Mw			5.43		23.16		432
		Medium	Fh	24.0	4.11	4.20	13.27	13.85	754	722
			Mw			4.56		16.33		612
		Poor	Fh	16.8	3.26	3.32	8.35	8.66	1198	1155
			Mw			3.68		10.64		940

1 Fh Foothills; Mw Mixedwood
2 From Figs. 2 and 3
3 From Fig. 4

4.2.4. Defining the Standard

The previous report (Bella 1976) presented pros and cons for relatively high and also low minimum stocking standards, depending on whether the objective was complete site utilization at half rotation even on poor sites or only on better sites. A higher standard would ensure complete site utilization even on the poor sites; there would be crowding, reduced individual tree growth, and better self-pruning on good sites. This option would generally require higher establishment costs from postlogging treatment and/or from planting. The lower standard could result in incomplete crown closure and site utilization, and some reduction in yield on poorer sites, but it would ensure faster tree growth and larger tree size on all sites and would be generally more suitable for growing stands intended for sawlog production. It would also mean reduced establishment cost.

A compromise standard would fall somewhere in between, close to values derived from medium sites. In the previous report, 560 trees/ha were recommended for lodgepole pine at 40 years and 750 trees/ha for white spruce at 50 years. These values were generally confirmed by the additional data collected in 1977. In light of these new data, the minimum number of trees would be slightly increased for pine to 575 and somewhat reduced for spruce, say to 720/ha (Table 2), if one specifies the more conservative, higher minimum tree numbers derived for

Table 3. Yield estimates by site class for pine stands at age 40 and for spruce stands at age 40 and 50 years that were growing in open conditions and assumed to reach complete crown closure at these ages

Species	Half Rotation	Site Class	Forest Type[1]	Avg. Dbh[2] (cm)	Avg. Height[3] (m)	Tree Volume[4] Total (m^3)	Tree Volume[4] Merch. (m^3)	Stand Statistics per ha Number of Trees	Stand Statistics per ha Volume (m^3) Total	Stand Statistics per ha Volume (m^3) Merch.
Lodgepole Pine	40	Good	Fh	28.2	13.8	.4210	.3974	356	149.9	141.5
		Medium	Fh	22.4	11.5	.2245	.2088	574	128.9	119.8
		Poor	Fh	16.3	9.1	.0955	.0845	1115	106.5	94.2
White Spruce	40	Good	Fh	23.1	12.5	.2394	.2232	761	182.2	169.8
			Mw					643	153.9	143.5
		Medium	Fh	17.3	10.3	.1136	.1019	1115	126.7	113.6
			Mw					910	103.4	92.7
		Poor	Fh	11.2	7.0	.0337	.0238	1815	61.2	43.2
			Mw					1414	47.6	33.6
	50	Good	Fh	31.2	14.1	.4834	.4581	495	239.3	226.8
			Mw					432	208.8	197.9
		Medium	Fh	24.0	12.8	.2636	.2466	722	190.3	178.0
			Mw					612	161.3	150.9
		Poor	Fh	16.8	10.1	.1053	.0938	1155	121.6	108.3
			Mw					940	99.0	88.2

[1] Fh Foothills; Mw Mixedwood
[2] From Figs. 2 and 3
[3] Estimated from open-growing tree data
[4] From Honer 1967. Merchantable volume to 15 cm (0.5 ft) stump and 7.6 cm (3 in.) top

spruce in the Foothills. In the Mixedwood, the number of spruce could be as low as 610 trees/ha and still approach complete crown closure at 50 years on medium or better sites.

If pulpwood production is the main objective, the 80-year rotation may be more desirable for spruce as well. This would naturally mean a considerably higher stocking requirement for spruce: around 1100 trees/ha in the Foothills and 900 in the Mixedwood on medium sites. This is nearly double the number of trees required for pine.

These numbers of trees should be adequate in stands with a fairly regular, or at least random, spatial pattern. Complete regularity of pattern is not essential, because both the crowns and the roots are quite opportunistic in utilizing available growing space and thus would make use of gaps arising from small irregularities of spatial pattern. However, where trees are heavily clumped, the same number of trees would be insufficient, as shown later.

The use of 100% crown closure as the basis of the present decision model may be open to criticism. Therefore, the standards derived here should be verified and possibly revised when improved models and more data become available. The present standards, however, were derived to provide a margin of safety, and if anything, they err on the conservative side.

Table 4. Estimated stocking percentage based on different quadrat sizes for specified stand densities

Minimum Number of Trees/ha	Applicable Stand Type[1]	Quadrat Size m^2	Stocking Percentage: With at Least One Tree/Quadrat	Stocking Percentage: Random Pattern for Minimum Number of Trees
575	P,Fh,pt-st	5	29	25
		10	58	44
		12.5	72	51
		15	86	58
610	S,Mw,st	5	30	26
		10	61	46
		12.5	76	53
		15	91	60
720	S,Fh,st	5	36	30
		10	72	51
		12.5	90	59
		15	—	66
900	S,Mw,pt	5	45	36
		10	90	59
		12.5	—	68
		15	—	74
1100	S,Fh,pt	5	55	42
		10	— (88 by 8 m^2)	67
		12.5	—	75
		15	—	81

[1] P lodgepole pine; S white spruce; Fh Foothills; Mw Mixedwood; pt pulptimber; st sawtimber

If these numbers of trees per hectare are accepted as a reasonable minimum for the two species, the next step is to express or define those values in terms of stocking percentage. By specifying at least one seedling per quadrat—as in the stocked quadrat surveys—one can derive stocking percentages for different quadrat sizes that ensure at least the minimum specified number of trees per unit area (Table 4). For comparison, we present the mean expected stocking percentages for these specified numbers of randomly distributed trees (Fig. 5 and Table 4), which were estimated using available theory (Blackman 1935).

The first set of estimates, which is always larger (Table 4), will ensure at least the minimum specified number of trees, unless the spatial pattern is regular at the average spacing implied by the quadrat size and over the proportion of the area indicated by stocking percentage. The difference between the two sets of stocking percentages increases with greater quadrat size because the increased incidence of two or more trees per

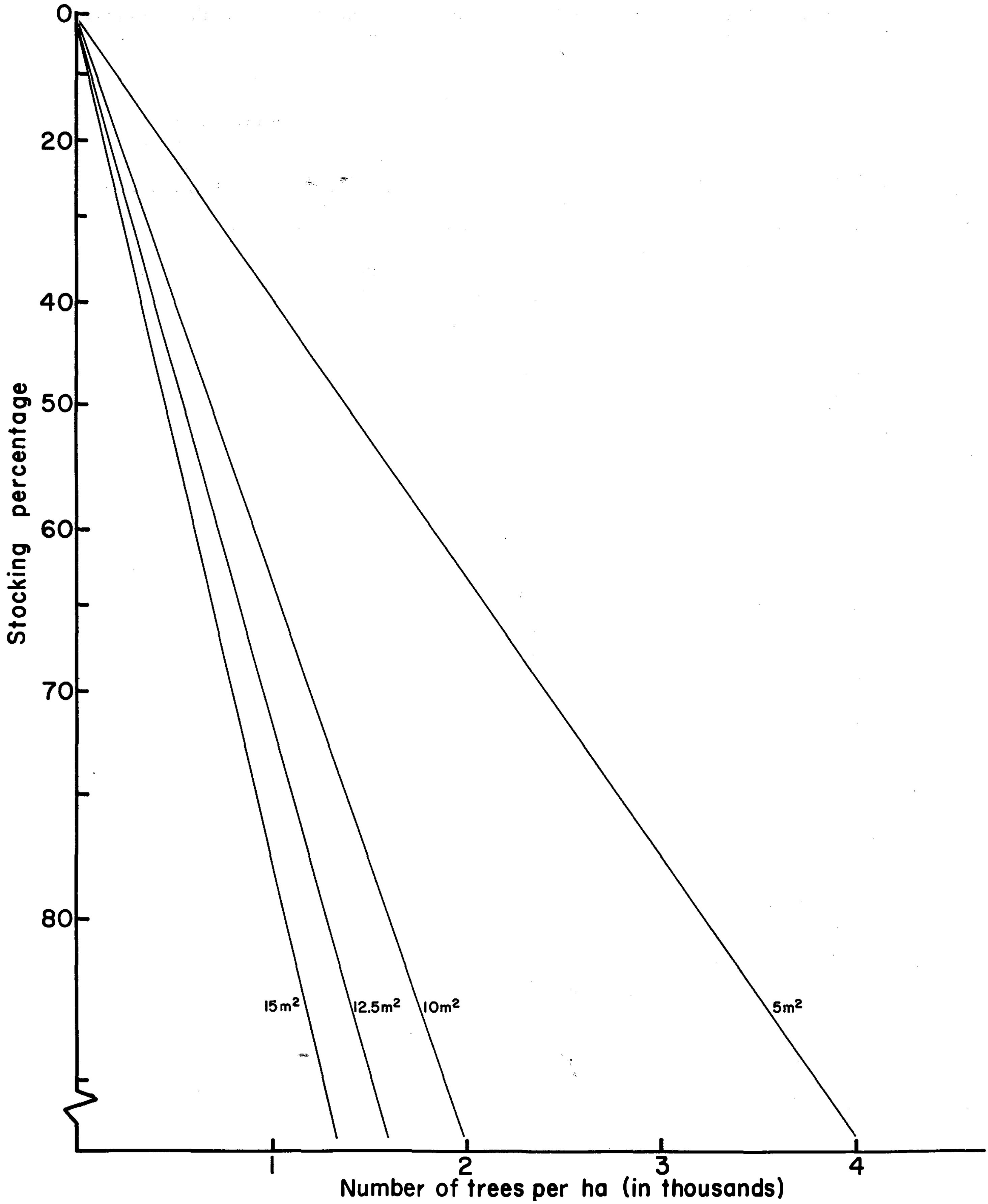


Figure 5. Theoretical relationships between stocking percentage and stand density for random spatial pattern

quadrat counteracts the expected increase in stocking percentage.

Choosing the minimum stocking percentage and related quadrat size to ensure at least the minimum desired number of well-distributed trees over an area depends largely on the spatial pattern of seedlings. Using large quadrats (10 m^2 and over) that can support a vigorous tree at reference age and high stocking percentages will ensure full crown closure and site utilization halfway through rotation even where seedling spatial pattern tends to be clumpy. Conversely, smaller quadrats (4 m^2) and relatively low stocking percentages would be adequate if the spatial pattern of seedlings was either truly random or regular over the area. Because it is unjustified simply to assume a random pattern, it seems prudent to proceed on the basis of the more conservative first alternative (Table 4, Column 4). Then, to ensure at least 575 well-distributed lodgepole pine/ha would require 86% stocking by 15-m^2 quadrats. If one accepted not-so-well distributed 575 trees/ha and 12.5-m^2 quadrat size, the required stocking percentage might be reduced to 72%.

To ensure reasonably full crown closure at 40 years in spruce would require at least 900 well-distributed trees/ha in the Mixedwood and 1100 in the Foothills, which in turn would require 90% stocking by 10-m^2 quadrats and 88% stocking by 8-m^2 quadrats, respectively. However, from an operational viewpoint, a single quadrat size for both conditions would be advantageous. Because of the tendency toward a generally more open canopy for spruce in the Foothills it may be reasonable to specify somewhat less than full crown closure, 90% stocking by 10-m^2 quadrats. With a sawlog rotation and 50-year reference age, the required stocking should be around 76% in the Mixedwood and 90% in the Foothills by 12.5-m^2 quadrats.

Because of the forthcoming general conversion to metric (SI) units in Canada, it is desirable to adopt a quadrat size for regeneration surveys that fits well into the new system. The 10-m^2 [1-mha (millihectare)] quadrat admirably suits this purpose and would be a particularly suitable quadrat size for sampling spruce intended for pulpwood production. For pine and for sawlog stands of spruce, a larger quadrat size, 12.5 m^2, is more suitable to ensure a good distribution of trees over the area. If operational convenience requires the use of a single survey quadrat size of 1 mha, the minimum required stocking percentage should be increased slightly above the table values (Table 4) shown for 1 mha to compensate for the inherent weakness of surveys arising from the use of smaller than ideal quadrat size in regeneration with a clumpy seedling pattern. Thus, the adjusted minimum stocking requirements are 65% for lodgepole pine, 70% for spruce sawlog stands in the Mixedwood, and 80% for spruce in the Foothills.

When different standards are specified for pine and spruce, as well as different standards for spruce according to Forest Region and utilization, the implementation of these standards becomes somewhat complicated, as might be expected as forest management becomes intensified. The use of different standards creates problems in surveying mixed regeneration. A solution is to adjust stocking percentage of the minor species by expressing it in terms of the major one and then using the latter's minimum standard for reference. If pine is the major species and the stand is grown for sawlogs, spruce stocking may be considered at a lower value because it requires more trees and higher minimum stocking than pine to ensure adequate stocking on an area. For example, spruce stocking of 1% in sawlog stands in the Foothills would be roughly equivalent to 0.8% pine stocking. This is based on the relation between minimum stocking of 80% for spruce vs. 65% for pine. Conversely, in predominantly spruce sawlog stands in the Foothills, pine may be considered at a 20% premium; in other words, 1% pine stocking would be worth 1.2% spruce stocking, and 80% would be used as the minimum standard.

Similarly, rough adjusting factors can be developed for pulpwood stands in the Foothills based on 90% minimum stocking for spruce and 65% for pine by 1 mha. Then if pine is the major species, spruce stocking should be considered at a 30% discount (i.e., multiply spruce stocking component by 0.7), and 65% stocking should be used as the

Table 5. Summary description of the regeneration sample

Location		Stand Type	Sampling Date	Number of Plots	Years After Logging
Edson Forest	N of Hinton	Spruce-Fir	1975	29	10
	N of Hinton	Pine	1975	35	10
	S of Hinton	Pine	1975	13	10
	NW of Edson	Pine	1975	40	10
Rocky-Clearwater Forest	Prairie Creek	Pine	1977	11	9-10
	Upper Sask. Ranger Sta.*	Pine	1966	85	8
Bow-Crow Forest	James River	Pine	1977	17	11-13
	Fallen Timber Creek	Pine	1977	5	10
	N of Blairmore	Spruce-Fir	1977	17	11-13
	S of Blairmore	Spruce-Fir	1977	14	11-12
Grande Prairie Forest	Kakwa Tower	Spruce-Fir	1977	20	9
Whitecourt Forest	S of Carson Lake	Mixedwood	1975	13	10
Peace River Forest	Squirrel Mountain	Mixedwood	1977	16	10

* Data collected by J. Soos

minimum. If spruce is the major species, pine should be considered at a 40% premium (i.e., multiply pine stocking component by 1.4), and 90% stocking should be used as the minimum.

5. SEEDLING SPATIAL PATTERN AND DENSITY

The spatial pattern of seedlings, particularly any departure from randomness, has important implications for both proper quadrat size and minimum acceptable stocking percentage in the use of the stocked quadrat system of regeneration surveys. Therefore, the nature of seedling pattern was examined using data from detailed sampling of different 10-year-old lodgepole pine and white spruce regeneration in the region. These data also included actual seedling density information, which was used to provide estimates of the number of "reserve trees" that may be expected on an area with potential for filling gaps created by mortality.

5.1. Methods

5.1.1. Field

Sampling was conducted by selecting cutover blocks 10 growing seasons (or near that) after logging, so that they represented a range of stocking and stand conditions in the region. Ground treatment on a cutover had generally followed logging within a year. On each cutover, three square sample plots .04 ha in size were established to represent low, average, and high stocking levels. The initial sample in 1975 included 117 plots from the Edson Forest and 13 from the Whitecourt Forest. Sampling in 1977 was extended to the Rocky-Clearwater, Bow-Crow, Grande Prairie, and Peace River Forests, with a total of 100 plots (Table 5 and Fig. 1). The conditions described on each plot included original stand type, physiography, amount of duff and slash, and the coverage of the area by shrubs and herbs.

The sample plots were subdivided into a grid of 10 x 10, 4-m^2 quadrats. On each quadrat, all seedlings 1, 2, and 3 years old or older and vigorous advance growth were tallied by species, and health of each individual was recorded.

Data collected by J. Soos (on file at the Northern Forest Research Centre) in 1966 in 8-year-old lodgepole pine near the Upper Saskatchewan Ranger Station (Rocky-Clearwater Forest) were also used. This was a complete tally (100% sample) by 4-m^2 quadrat of a 15.5-ha area where the original stand had been destroyed by fire 8 years earlier. For this analysis, this sample was partitioned into contiguous 36 x 36 m plots (i.e., an 18 x 18 matrix of 4-m^2 quadrats). A total of 85 plots was used in the analysis. Plots that had roads or logging trails that prevented the establishment of regeneration were excluded from the analysis.

5.1.2. Analysis

Seedling spatial pattern was analyzed using seedling frequency distributions compiled from quadrat tallies on each plot. These frequency distributions showed the number of quadrats in which "n" seedlings occurred (n = 0, 1, 2, 3, ...). Random seedling pattern was indicated if the observed frequency distribution resembled a Poisson series (i.e., the observed distribution and the expected Poisson were not significantly different on the basis of a Chi-square test), or if the Variance/Mean ratio of the distribution was not significantly different from 1.0 based on an appropriate Standard Error, as in Greig-Smith (1964, p. 62).

Regression techniques were used to describe relations between number of extra trees per quadrat (2+, 3+, etc.) and stocking percentage.

In these analyses, relationships were described and spatial patterns studied on the basis of quadrat sizes of 4, 8, and 16 m^2. Data for quadrat sizes larger than 4 m^2 were obtained by combining adjacent quadrats.

5.2. Results and Discussion

5.2.1. Analysis of Seedling Spatial Pattern

For this analysis the data were subdivided into three main types: (1) pine, (2) spruce-fir, and (3) spruce-mixedwood. The analyses were conducted on individual plot data, but in this report, only average values for each type and species are presented (Table 6).

Pine Types: The analysis of data was done on a species basis: (1) pine only, (2) pine and spruce, and (3) all conifers (Table 6). The analysis of seedling frequencies from 4-m^2 quadrats showed that on the whole, about 95% of the sample plots had a clumpy seedling pattern. The inclusion of spruce and fir in addition to pine had no influence on seedling pattern. The percentage of plots with a clumpy pattern was about 10% lower (85%) on the basis of 16-m^2 quadrats, with a slight tendency toward greater clumping when spruce and fir were also considered. Generally, the initial sample showed a somewhat higher percentage of clumpy pattern than the new sample.

Rather unexpectedly, a similar clumpy pattern was found in pine regeneration that originated after a wildfire (data from the Upper Saskatchewan Ranger Station). There was a clumpy pattern over 95% of the plots for both quadrat sizes.

Spruce-Fir Types: Nearly 90% of the plots showed a clumpy pattern for spruce and pine on the basis of 4-m^2 quadrats; this increased to 95% when fir was also included in the analyses. Based on 16-m^2 quadrats, the percentage of plots with a clumpy pattern was around only 75% for spruce and pine, and also for all conifers. Thus, larger quadrat size resulted in a 15-20% higher proportion of plots showing random seedling pattern. Fir showed the least clumpy pattern among the three conifers and approached random dispersion, on the basis of 16-m^2 quadrats, on

Table 6. Percentage of plots with clumpy seedling pattern by stand type and species for two quadrat sizes based on 1975, 1977, or all data combined

		Quadrat Size								
		4 m²						16 m²		
	Species[1]	1975		1977		1975-77		1975	1977	1975-77
Stand Type	Considered	NP[2]	% C[3]	NP	% C	NP	% C	% C	% C	% C
Pine	P	88	97.7	33	85.2	121	94.3	78.4	75.8	77.7
	P+S	88	98.9	33	85.2	121	95.2	88.6	69.7	83.4
	P+S+F	88	98.9	33	85.2	121	95.2	90.9	72.7	85.9
Spruce-Fir	S	29	72.4	51	92.2	80	85.0	46.2	82.4	69.3
	S+P	29	79.3	51	94.1	80	88.7	58.6	86.3	76.3
	F	29	82.8	51	76.5	80	78.8	37.9	62.8	53.8
	S+F	29	86.2	51	100.0	80	95.0	62.1	94.1	82.5
	S+P+F	29	86.2	51	100.0	80	95.0	58.6	84.3	75.0
Mixedwood	S	13	100.0	16	100.0	29	100.0	100.0	100.0	100.0
	S+P	13	100.0	16	100.0	29	100.0	100.0	93.8	96.6
	F	13	92.3	16	43.7	29	65.5	76.9	43.8	58.6
	S+F	13	100.0	16	100.0	29	100.0	100.0	100.0	100.0
	S+P+F	13	100.0	16	100.0	29	100.0	100.0	100.0	100.0

1 P, Lodgepole pine; S, white spruce, also black and Engelmann, if present; F, balsam fir, also alpine fir, if present

2 Number of plots

3 Percentage of plots with clumpy seedling pattern

nearly 50% of the plots. For all combinations of conifers considered, the use of larger quadrats resulted in a greater proportion of observed random seedling pattern: up to about 20% for the entire spruce-fir type. For this type, in contrast to the pine type, a slightly higher percentage of the 1977 than the 1975 sample had a clumpy pattern.

Spruce-Mixedwood Types: Spruce showed an extremely clumpy pattern on all the sample plots. Fir in this type again was generally less clumpy. A change in quadrat size had no appreciable effect on perceived spatial pattern.

In summary, seedling pattern for lodgepole pine and white spruce in this region is generally nonrandom and characterized by various degrees of clumping. Only the fir component in the Foothills (spruce-fir type) came close to a random pattern, and then only when the tests were based on 16-m² quadrats. The reason for this may be in part that fir seedling establishment does not depend much on ground condition (especially the depth of organic matter). In addition, a good proportion of established fir seedlings is usually made up of advance growth already present and regularly dispersed on the area at the time of logging.

On the other hand, most spruce and pine regeneration originates following logging, when seed source and ground conditions critically influence abundance and spatial pattern of seedlings. Because of the spotty nature of suitable seedbed, on account of the uneven dispersion of seed over the area (especially for pine), heavy clumping is usually the result. The differences noted in spatial pattern between the 1975 and 1977 samples could have arisen from differences in postlogging treatment and the age of the regeneration sampled. In the pine types, for instance, the 1977 sample was taken up to 13 years following logging because of the lack of 10-year-old cutovers; also, site preparation had not been nearly as thorough and intensive as in the 1975 sample that originated from the Edson Forest.

There are important implications of this clumpy spatial pattern. First and most obvious is that there will be a far greater number of trees in the stocked patches over the area than would be expected with a random spatial pattern. These extra trees constitute a reserve to fill in possible gaps created by mortality. However, an excessive surplus of trees would likely mean intensive crowding and reduction in tree growth, and possibly a reduction of merchantable yield at harvest.

Secondly, because of the clumpy seedling pattern, the use of small quadrats coupled with a relatively low stocking percentage will not ensure the implied number of well-dispersed trees per unit area; for example, a 4-m^2 quadrat with 40% stocking would not guarantee 1000 well-distributed stems/ha. The use of larger quadrat sizes and higher stocking percentages will ensure adequate stocking in a new stand.

Heavy clumping may also affect sampling error and may contribute to the differences that arise in stocking percentage estimates between independent samples. The use of relatively large quadrats (i.e., 16 m^2 vs. 4 m^2) should result in a consistent tendency towards randomness in perceived spatial pattern and thus lessen this problem of differences between samples. Results so far do not confirm this expectation.

5.2.2. Number of Extra Trees (2+, 3+, etc.) per Quadrat in Relation to Stocking Percentage

These relationships provide information on the average number of extra trees that may be expected per stocked quadrat. The trends, shown in Fig. 6 for quadrat sizes 8 and 16 m^2, were derived by linear regression techniques using logarithmic transformations when appropriate. All regressions shown were significant at the 0.05 probability level, although, as one would expect, the residual variation increased as the number of trees considered (2+, 3+, etc.) increased. Also, there was a tendency towards poorer fit of the regression model at the two extreme (low and high) stocking levels. Nevertheless, the regressions were reliable enough to provide information of general usefulness for the purpose of this analysis. Regressions presented describe seedlings 3 years and older, plus healthy advanced growth. The inclusion of 2-year-old seedlings resulted in only a minor change in the regressions, so they were therefore excluded from the analysis.

Regressions developed here are believed to be more useful than the number of trees/stocking percentage relationships presented earlier (Bella 1976), because these regressions give actual seedling frequency on a quadrat basis rather than the "diluted" number of seedlings per unit area values calculated from sample plot summaries. [The importance of the sample quadrat as a basis of reference has been discussed in detail by Bella (1976).] However, Table 7 is included to provide summary statistics on the regeneration sampled in terms of stocking percentage and number of trees per hectare for different quadrat sizes and species by stand types.

These relationships (Fig. 6) generally indicate a substantially greater number of trees per unit area than that implied by a given stocking percentage. Although this surfeit of seedlings at given stocking levels occurred for all coniferous regeneration, it was particularly striking in the Mixedwood for spruce (Figs. 6f and g; Table 8). For example, at 75% stocking on 8-m^2 quadrats, the expected minimum number of trees per hectare is 937, while our sample had as many as 3400 spruce/ha, if up to four seedlings per quadrat were counted. If these are expressed in relative frequencies as shown in Table 8, 62% of the quadrats would have at least four seedlings, i.e., over 80% of all stocked quadrats at 75% stocking, on 8-m^2 quadrats. Increasing the number of trees counted per

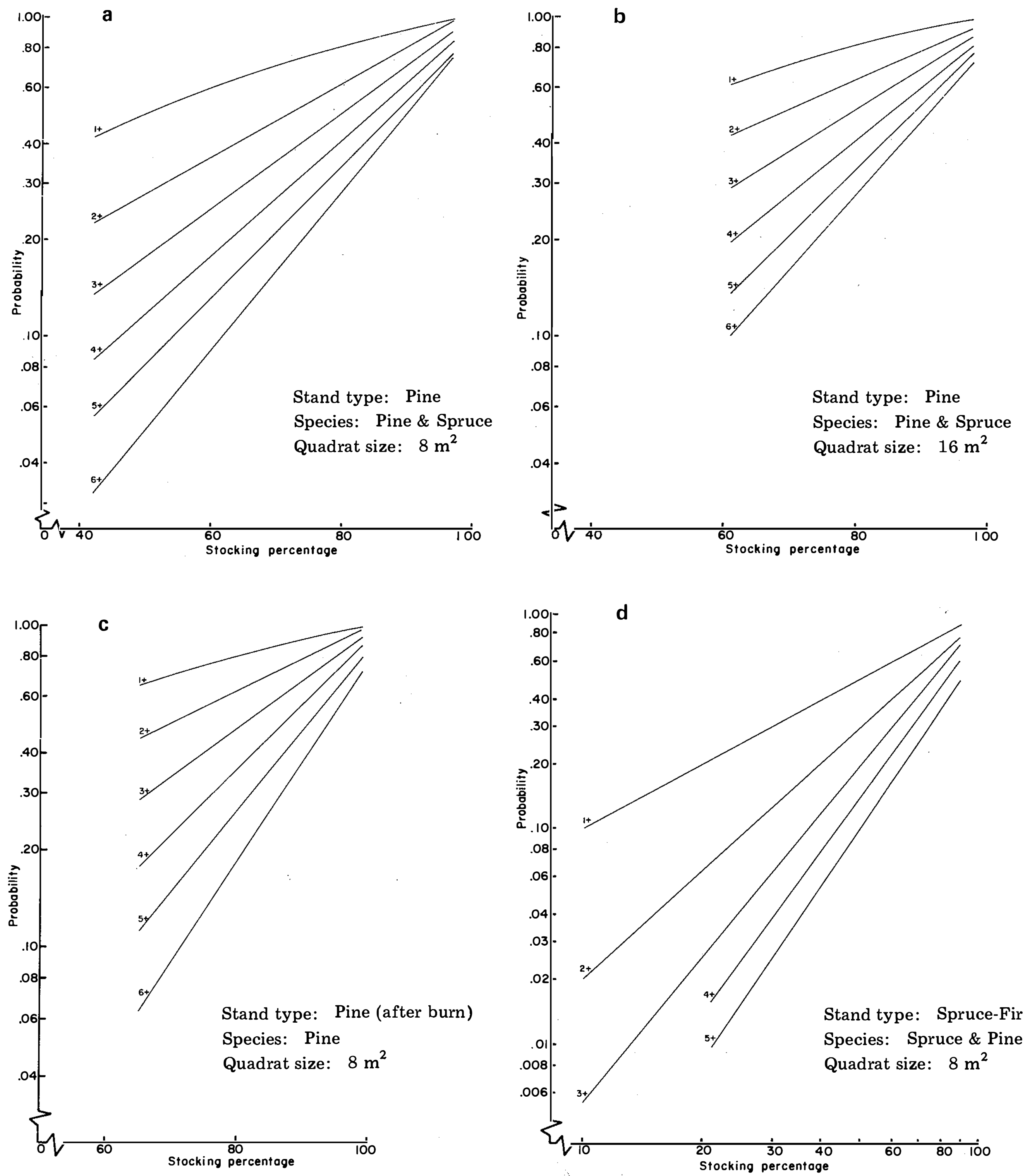
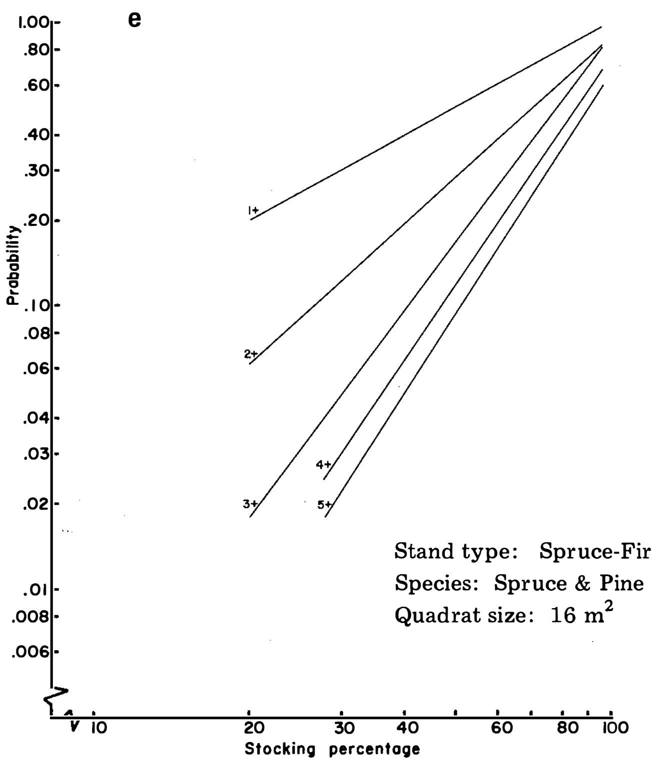


Figure 6. Expected probabilities for seedling occurrence (3 years and older) of 1+, 2+, 3+, etc. seedlings per quadrat over stocking percentage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Probability
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2+
3+
4+
5+
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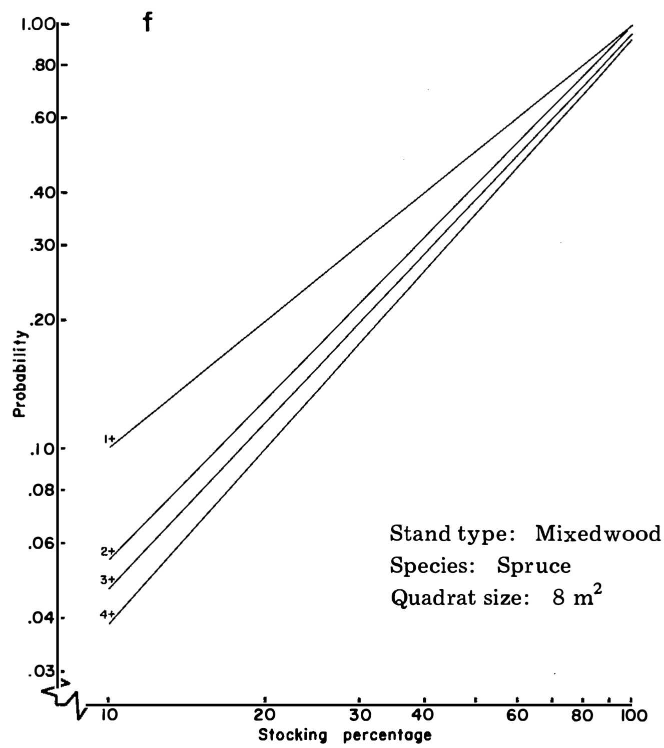
Stocking percentage
Stand type: Spruce-Fir
Species: Spruce & Pine
Quadrat size: 16 m²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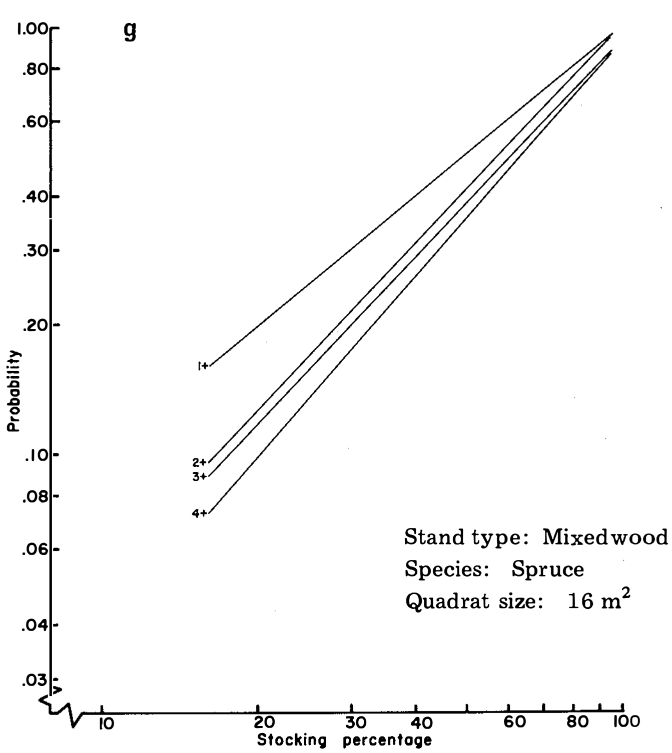
Stocking percentage
Stand type: Mixedwood
Species: Spruce
Quadrat size: 8 m²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Stocking percentage
Stand type: Mixedwood
Species: Spruce
Quadrat size: 16 m²

Table 7. Summary: Stocking percentage and number of trees per hectare by species, quadrat sizes, and stand types

Stand Type	Number of Plots	Quadrat Size in m²	Species Considered	Stocking Percentage Avg	Min	Max	Number of Trees 3 yr and Older per ha Avg	Min	Max
Pine									
1975 + 1977	121	8	P[1]	71.0	28	100	5 696	544	23 549
			P + S	76.5	40	100	6 758	914	26 317
		16	P	85.5	40	100	5 696	544	23 549
			P + S	89.7	56	100	6 758	914	26 317
Pine									
1966 sample	85	8	P	92.3	65	100	8 436	2 318	19 974
by Soos		16	P	97.2	76	100	8 436	2 318	19 974
after burn									
Spruce-Fir	80	8	S	37.0	2	88	2 196	49	31 432
			S + P	48.0	6	90	3 109	74	44 775
		16	S	53.6	4	96	2 196	49	31 432
			S + P	65.8	12	96	3 109	74	44 775
Mixedwood	29	8	S	57.8	8	100	17 162	445	53 251
		16	S	70.9	16	100	17 162	445	53 251

[1] P, Lodgepole pine; S, white spruce, also black and Engelmann if present

Table 8. Expected probabilities for seedling occurrence (3 years old and older) of at least 1, 2, 3, etc. on a survey quadrat and corresponding seedling densities per hectare

Stand Type	Species	Probability of at Least 1 Trees per Quadrat	2	3	4	5	6	Minimum Level of Stand Density per ha Based on the Probability of at Least 1 Trees per Quadrat	2	3	4	5	6
At 75% stocking based on 8 m² quadrats													
Pine	P + S	.75	.54	.42	.33	.27	.21	937	1612	2137	2550	2887	3150
Pine (Clearwater-Rocky)	P	.75	.58	.44	.33	.24	.17	937	1662	2212	2625	2925	3138
Spruce-Fir	S + P	.75	.60	.50	.41	.32		937	1687	2312	2825	3225	
Mixedwood	S	.75	.71	.64	.62			937	1825	2625	3409		
At 90% stocking based on 16 m² quadrats													
Pine	P + S	.90	.77	.68	.59	.52	.46	562	1044	1469	1838	2162	2450
Spruce-Fir	S + P	.90	.75	.69	.58	.49		562	1031	1462	1825	2131	
Mixedwood	S	.90	.87	.80	.78			565	1106	1606	2094		

quadrat would further raise minimum densities. These results clearly indicate that if a quadrat is stocked with spruce, it generally supports more than one seedling, which is also an indication of a strong clumping tendency in this type. Comparable statistics for pine were substantially lower: only 2500 trees/ha, when up to four seedlings per quadrat were considered. Expressed in terms of relative frequencies, about 33% of the quadrats would have at least four seedlings, or about 44% of all stocked quadrats; while about 54% of the quadrats would have at least two seedlings, i.e., just over 70% of all stocked quadrats. This suggests a somewhat less pronounced clumping of regeneration in the pine types.

The previous analysis (Bella 1976) indicated considerably fewer trees per unit area at similar stocking levels after a burn than after logging. The present results on seedling occurrence (1+, 2+, ... 6+; Table 7) on an 8-m^2 quadrat basis showed essentially the same minimum stand density levels for all pine. These stand densities, however, refer to minimum values associated with a specified minimum number of trees per stocked quadrat and do not include the extra seedlings that may be present. These, especially for spruce, could be very numerous indeed; it is not unusual to find as many as 100 seedlings on a 4-m^2 quadrat area where conditions particularly favored seedling establishment and survival. Therefore, the apparent differences in density values arose from the method of analysis and presentation of results and are caused by local patches (clumps) of very high seedling densities that inflate the average number of trees per unit area, which fails to show up in seedling densities when only a maximum of six seedlings per quadrat is considered.

The same general trend emerges in terms of extra trees, from statistics derived for 90% stocking based on twice as large sample quadrats (16 m^2). Again, the greatest number of extra trees was found for spruce in the Mixedwood, where there was about a fourfold increase in tree numbers (from 562 to 2094) when up to four trees, rather than only one, were counted per quadrat. This means, in terms of relative frequencies (Table 8), that 78% of sample quadrats would have at least four seedlings, or in other words, about 87% of all stocked quadrats; while about 87% of sample quadrats would have at least two seedlings, or in other words, 97% of all stocked quadrats. Comparable statistics for "extra" trees in pine and spruce-fir types were lower than for spruce in the Mixedwood, but not to the same extent as on 8-m^2 quadrats. The increase in tree numbers was slightly over threefold when up to four trees were considered per quadrat. Expressed in terms of relative frequencies at this stocking level, about 60% of sample quadrats would be expected to have at least four seedlings, or about 65% of all stocked quadrats; while about 76% of sample quadrats would have at least two seedlings, or 84% of all stocked quadrats.

For spruce, especially in the Mixedwood, these relations were much weaker than in pine types for regressions describing the higher densities per quadrat (3+, 4+, 5+, 6+ seedlings). This again suggests that spruce seedling densities per quadrat depend on the specific seed source and ground treatment, particularly the amount of exposed mineral soil, and less on the overall conditions and stocking levels of the entire cut block. Post-logging treatments presently used generally produce patchy, irregular patterns of mineral seedbeds, which would at least partly explain the large variation in number of trees per quadrat.

6. MORTALITY

In deriving a minimum acceptable stocking percentage for regeneration standards, it is important to consider irregular mortality caused by insects and diseases during the early life of the stand. Regular (suppression) mortality may be ignored for these relatively open stand conditions. In sampling regeneration for this study, we tallied dying and currently dead trees on each quadrat and noted the cause of death. The "currently dead" category was to include tree seedlings that died within the last year. With pine 2-3 years old or older, a reasonably accurate assessment was possible. This was much less so for spruce, because of the small size of young seedlings and the rapid loss of needles after death. Also, it was usually difficult to assess the cause of death of such small seedlings. Because of these limitations the present results provide only a rough approximation of the magnitude of mortality in regeneration a decade after logging.

The analysis of the results for pine showed that dying and dead trees amounted to less than 1% of all pine. It was also found that this mortality caused no significant reduction in stocking percentage in this study. Because of the inherent weakness of the spruce mortality data, no similar analysis was attempted for that species.

Although the present results are by no means conclusive, they seem to indicate that seedling mortality at an early age of the stand may not have an overriding importance in developing stocking standards. Earlier studies, although limited in scope, showed that damage by insects and diseases, particularly in young lodgepole pine over 10 years of age, may create small open patches in localized areas (Baranyay and Stevenson 1964; Powell and Hiratsuka 1973; personal communications with H.F. Cerezke in 1977 and 1978), but the many "surplus" seedlings that are present on the stocked quadrats would be enough to fill in such small openings in a young stand. These then would tend to obviate the need to allow for mortality in the period between age 10 and our reference age of half rotation (40 to 50 years). However, final decisions on this will have to wait until more and better information is available on mortality up to half rotation in similar stands.

7. CONCLUSIONS AND RECOMMENDATIONS

1. Using data extended by the 1977 sample, trends of Dbh in relation to Age, and Crown Width in relation to Dbh derived from open-growing lodgepole pine and white spruce data collected in the Foothills and Mixedwood Sections of Alberta generally confirmed initial results (Bella 1976). These trends were used to derive minimum number of trees per hectare and associated stocking percentages for stands of the two species to achieve full site occupation, without significant crowding, by trees about halfway through rotation (at 40 years for pine, 40 and 50 years for spruce). On the average, it took spruce 6 years longer than pine to reach breast height on medium sites (9 vs. 15 years). While Crown Width over Dbh trends were unaffected by site for either species, open-growing pine had wider crowns than spruce for similar diameters over 20 cm. For spruce only, Crown Width became smaller with increasing elevation—a trend that proved significant from the enlarged sample. While slower initial growth and generally narrower crowns for spruce would tend to increase minimum stocking requirements for this species in contrast to pine, growing spruce for sawtimber on a longer rotation (100 years) would result in very similar minimum stocking standards for the two species.

2. Analysis of seedling spatial pattern indicated high and various degrees of clumping of the entire seedling population sampled. Spruce in the Mixedwood was the most clumpy, while the fir component in the spruce-fir type was the least clumpy.

3. Greatest variation in tree numbers at all stocking levels was found for spruce in the Mixedwood, where seedling establishment was very strongly dependent on the amount of exposed mineral soil, which is usually rather patchy because of the postlogging treatment used.

4. On all cutovers, there was usually a surfeit of seedlings in excess of the number of trees per unit area that is indicated by the stocking percentage. Although this generally applied to all coniferous regeneration, it was particularly striking for spruce in the Mixedwood. For example, at 75% stocking (by 8-m^2 quadrats) the minimum number of trees per hectare is 937, while the present sample from the Mixedwood supported an average expected number of 3400 spruce/ha, if up to four seedlings per quadrat were counted. This means that over 80% of all quadrats had at least four seedlings. Comparable statistics for pine types were lower: 2500 seedlings, with about 44% of the stocked quadrats having at least four seedlings at 75% stocking (8-m^2 quadrats). Although further increasing the number of trees counted would likely result in greater estimated densities per unit area,

the "extra" trees would obviously be of very limited value as potential crop trees. This indicates, however, that if a quadrat is stocked with a conifer, it generally supports more than one seedling, usually a clump, and this means a good reserve of potential crop trees on stocked quadrats should the "first" seedlings die.

5. The results of these analyses indicated that although a 40% stocking rule using 4-m^2 quadrats would ensure more than sufficient number of trees per hectare for both lodgepole pine and white spruce, it may not ensure a desired level of stocking (dispersion of seedlings on a cutover) because of the clumpy nature of regeneration.

6. A basic premise of stocked quadrat surveys is that the quadrat used should be of sufficient size to support a mature tree near the end of rotation. Using smaller quadrats would be justified if a reliable method were available to convert stocking percentages based on small quadrats to equivalents based on a larger and theoretically appropriate quadrat size. However, the clumpy seedling pattern that generally prevails in this region prevents reliable conversions. A solution for getting useful stocking percentage estimates is to use suitably large survey quadrats and require high stocking levels.

7. With complete crown closure halfway through the rotation (40 years for lodgepole pine, 40 and 50 years for white spruce) as a criterion, a minimum of 575 well-dispersed pine/ha (233/acre) would provide sufficient stocking. This would require a minimum of 65% stocking by 10-m^2 quadrats. For spruce, the minimum numbers of well-dispersed trees required, depending on forest type and mangement objectives, are 610/ha (247/acre) for sawlog stands in the Mixedwood, 720/ha (291/acre) for sawlog stands in the Foothills, and 900/ha (364/acre) in Mixedwood and 1100/ha (445/acre) in the Foothills for pulpwood stands. The respective minimum stocking percentages by 10-m^2 quadrats are 70 and 80% for sawlog stands, and a common 90% for pulpwood stands. The report also includes procedures for using stocked quadrat survey results when regeneration is a mix of the two species.

8. Although the recommended minimum number of trees may seem relatively low, there is little danger of significant loss in yield. These standards do not explicitly consider the number of extra trees that are present on an area beyond the ones counted per survey quadrats or the additional seedlings (ingress) that may become established on an area after 10-year regeneration period (Johnstone 1976). It should also be understood, however, that this study was conducted to derive minimum stocking standards, using full utilization of the site as the criterion rather than maximum fiber yield or merchantable volume. The required number of trees was derived to ensure full stocking halfway through the rotation on medium and better sites, where most volume yield is expected, accepting less than full stocking on less productive sites. While open conditions in young stands would result in accelerated tree growth, they would also contribute to improved forage production for ungulates. Allowing fairly open conditions to the end of rotation on less productive sites may be advantageous for both wildlife and recreation. Poor sites contribute a relatively small amount of the wood fiber yield; therefore, any understocking and possible yield loss would be rather minor.

9. In no way is it implied that these standards ensure optimum stand density and yield, or that higher stocking levels are undesirable. Indeed, as forest management becomes more intensive, it will be necessary to derive and employ stocking standards that ensure optimum density and yield of individual stands for specific management objectives.

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REFERENCES

Baranyay, J.A. and G.R. Stevenson. 1964. Mortality caused by Armillaria root rot, Peridermium rusts and other destructive agents in lodgepole pine regeneration. For. Chron. 40:350-361.

Bella, I.E. 1976. Assessment of regeneration stocking standards used in Alberta. Environ. Can., Can. For. Serv., North. For. Res. Cent. Inf. Rep. NOR-X-167.

Blackman, G.E. 1935. A study of statistical methods of the distribution of species in grassland associations. Ann. Bot. (Lond.) 49:478-479.

Greig-Smith, P. 1964. Quantitative plant ecology. 2nd ed. Butterworths, London.

Honer, T.G. 1967. Standard volume tables and merchantable conversion factors for the commercial tree species of central and eastern Canada. Can. Dep. For. Rural Dev., Can. For. Serv. Inf. Rep. FMR-X-5.

Johnstone, W.D. 1976. Ingress of lodgepole pine and white spruce regeneration following logging and scarification in west-central Alberta. Environ. Can., Can. For. Serv., North. For. Res. Cent. Inf. Rep. NOR-X-170.

Powell, J.M. and Y. Hiratsuka. 1973. Serious damage caused by Stalactiform blister rust and western gall rust to a lodgepole pine plantation in central Alberta. Can. Plant. Dis. Surv. 53:67-71.

Rowe, J.W. 1972. Forest regions of Canada. Environ. Can., Can. For. Serv. Ottawa. Publ. 1300.