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Assessment of regeneration stocking standards used in Alberta

by I.E.Bella

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FRONT COVER - An example of a relatively open pine-spruce stand of around 30 years of age. Stands like this will be much more common in the future because of logging.

BACK COVER - The area in the foreground was logged about 10 years ago and now has a thrifty but open (on the average about 10-12-ft or 4-m spacing) pine regeneration that would likely develop into a stand of higher merchantable yield at harvest than that of the mature, overdense pine-spruce stand in the background. This portion of the original stand was left uncut because the trees were of submerchantable size.

ASSESSMENT OF REGENERATION STOCKING STANDARDS USED IN ALBERTA

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ABSTRACT

The implication of the 40% stocking standard (by 1-milacre quadrats) that was adopted over a decade ago in Alberta was examined using data from the Foothills and Mixedwood on regeneration and expected growth, development, and yield of stands after logging. New minimum stocking standards were derived for the two most important commercial conifers, requiring at least 220 well-dispersed lodgepole pine (Pinus contorta Dougl. var. latifolia Engelm.) trees per acre (560/ha), or 300 well-dispersed white spruce (Picea glauca (Moench) Voss) per acre (750/ha).

Seedling spatial pattern for both species was generally clumped. To ensure the minimum required number of well-dispersed seedlings on an area, a larger quadrat should be used in place of the 1-milacre quadrat in regeneration surveys. A 10-m^2 (1 millihectare, approx. 2.5-milacre) quadrat is suitable for spruce and 12-m^2 for pine. The corresponding minimum stocking percentages for the two species should be around 75% and 70%, respectively.

While these recommended minimum numbers of trees may seem low compared to the existing standard, they were derived to ensure full stocking halfway through the rotation on medium or better sites, thus ensuring acceptable yield at harvest at a reasonable level of safety. Open stands on less productive sites may serve other important functions such as recreation and wildlife habitat.

Problems arising from the present use of stocked quadrat surveys are discussed and recommendations given for further study of the problem.

RESUME

Il y a plus d'une décennie, on a adopté en Alberta une norme de 40% (par quadrats de 1 milli-acre), et on a étudie, à l'aide de données locales des fôrets mixtes et des Foothills sur la régénération, la crois-

sance prévue, le développement et le rendement des peuplements après exploitation. On a dérivé de nouvelles normes minimales de reproduction à propos des deux résineux commerciaux les plus importants, exigeant au moins 220 arbres bien éspaces de Pin tordu latifolié (Pinus contorta Dougl. var. latifolia Engelm.) soit (560/ha) ou au moins 300 Épinettes blanches (Picea glauca (Moench) Voss) bien espacées à l'acre (750/ha).

Le mode d'espacement pour les semis de ces deux espèces était généralement trop serré. Afin d'assurer le nombre ci-dessus mentionné de semis bien distancés dans un emplacement donné, un quadrat plus vaste devrait être substitué au quadrat de 1 milli-acre dans les études de régénération. Un quadrat mesurant 10 m^2 (1 milli-hectare ou approximativement 2.5 milli-acres) convient à l'Épinette et un quadrat de 12 m^2 pour le Pin. Les pourcentages minimums correspondants pour le matériel de reproduction des deux espèces devraient approcher 75% et 70% respectivement.

Alors que ces chiffres minimums que l'on recommande peuvent sembler faibles en comparaison de la norme existante, ils furent tout de même dérivés pour assurer un matériel sur pied normal à mi-chemin de la période de révolution sur des stations moyennes ou meilleures, permettant ainsi un rendement acceptable lors de la récolte, tout en conservant un niveau raisonnable de sécurité. Les peuplements moins denses sur des stations moins productives peuvent remplir d'autres fonctions importantes comme les loisirs en forêt et l'habitat de la faune.

Les problèmes qui surgissent de l'utilisation actuelle des relevés des quadrats reboisés sont exposés et l'auteur recommande d'étudier plus à fond ces problèmes.

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1. *INTRODUCTION*

At present, the Alberta Forest Service uses 40% stocking (based on 1-milacre stocked quadrat survey) by established seedlings of desirable species as a general minimum standard for assessing regeneration on cutover areas. A quadrat is considered stocked if it contains at least one seedling of obvious vigor which has grown on the area a minimum of 3 years, two 2-year-old seedlings, or any undamaged coniferous advance growth, 30 years old or less, with potential for merchantable yield at the next harvest. Surveys are conducted in year 7 after logging so that required stocking may be ensured by the end of year 10. This standard was adopted over a decade ago and was based mainly on prevailing standards and practices elsewhere in North America, particularly in British Columbia and the U.S. Pacific Northwest. Although this standard served reasonably well in the ensuing period, several factors have brought into question its suitability and adequacy: (1) recent upswings in forest utilization, (2) increasing public interest in forestry, especially the greater concern about the adequacy of restocking on clear-cut areas, (3) the possibility of overly stringent and hence costly minimum stocking requirements, and (4) concern that the stocked quadrat system of survey is inefficient for assessing yield potential on certain areas.

This study was undertaken in response to a request by the Alberta Forest Service for a critical assessment of their 40% stocking rule. 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 this study was to evaluate the suitability of the present standard from the viewpoint of a desirable minimum stocking and to recommend, if justified, a new and possibly flexible minimum standard that would ensure an acceptable, although not necessarily potential maximum, wood fiber production. A critical look at regeneration standards is presently underway in other provinces (from personal communications with R.M. Dixon, Ontario Ministry of Natural

Resources; F.W. Flavelle, Saskatchewan Department of Tourism and Renewable Resources; E. Knight, British Columbia Forest Service), and in the U.S. Pacific Northwest (e.g. Stein 1974).

The first phase of this study was concentrated on two of the most important conifers in the region, lodgepole pine (Pinus contorta Dougl. var. latifolia Engelm.) and white spruce (Picea glauca (Moench) Voss). As this study is concerned with minimum standards, appropriate information from a sample of open-growing trees was pieced together to derive the minimum number of trees per unit area that would ensure complete crown closure at reference age of half rotation, which was so specified by the AFS. The second part of this report contains an examination of seedling spatial pattern and densities in the region, based on regeneration sampling in the Foothills and Mixedwoods. Seedling pattern has a direct bearing on the choice of the quadrat size in stocked quadrat surveys; seedling density gives information on the number of "reserve trees" available on an area to counteract tree mortality.

2. BACKGROUND

In evaluating the adequacy of regeneration, two of its characteristics have particular importance: (1) spatial dispersion over the area (i.e., stocking) and (2) density, as expressed by number of trees per unit area.

Stocking is simply the proportion of the area occupied by tree seedlings. This proportion is usually expressed as a percentage of survey quadrats of a certain size stocked with one or more desirable trees. Haig (1931) stated the basic premise for this expression as follows:

> The system used, the stocked-quadrat method, is based on the assumption that if a given area is divided into squares of such size that one established seedling or tree per square will fully stock the square at maturity, then the percentage of units so stocked, regardless of the total number of seedlings per acre, indicates the proportion of land being utilized by tree growth.

This means that if a square, or quadrat, is unoccupied (i.e., unstocked) there should be proportional loss in yield. And furthermore, since one tree is enough to fully stock a quadrat, it is implied that a good many of the "surplus" trees on a stocked quadrat will succumb through mortality by the time the stand reaches rotation age.

Several workers have noted that the success of this method depends upon the selection of proper-sized quadrats. Consequently, the introduction of this system precipitated lengthy discussions about the size of quadrats to be used, with practical values ranging between 1 and 4 milacres (4 and 16 m^2). The milacre was finally adopted, as Haig stated, "because of its convenience in field use and office compilations". But even then it was regarded by many foresters as too small a unit, requiring a minimum of 1000 seedlings/acre (2500/ha) for 100% stocking.

It was also noted that with certain species considered for sawtimber production, as few as 250-300 trees/acre (620-750/ha) would be sufficient to produce full merchantable volume yield at rotation (Haig 1931). This roughly corresponds to 100% stocking by 4-milacre (16-m^2) quadrats. Haig therefore recommended the use of 4-milacre quadrats for assessment of regeneration of this type of forest. It is implicit in the above that in such open stands, even a relatively minor drop from 100% stocking will likely result in some reduction of volume yield at harvest.

For a given species of regeneration on an area, there is a relationship between different stocking percent values based on various quadrat sizes. (It is also obvious that larger quadrat size means higher stocking percent for the same stand of regeneration.) It has been inferred from this that surveys may be done with quadrats of practically any size and results converted as desired. It has also given rise to a number of empirical studies to define such relationships for given species in certain geographic areas (Wellner 1940, Lynch and Schumacher 1941, Bever 1949, Parker and Potter 1951, Trousdell 1954). Grant (1951) concurrently derived a theoretical conversion formula based on the assumption of random seedling dispersion pattern. Generally, these conversions gave satisfactory answers if seedling patterns were close to random and particularly if the relations were used for switching average values in summary statistics of regeneration surveys.

However, subsequent studies (e.g. Gill 1950, Grant 1951, Ker 1954, Warren 1965) found that tree seedlings are rarely dispersed randomly over an area. Grant (1951) noted also that the error in his conversion increased with increase in heterogeneity. Heterogeneity of seedling pattern may also have implications regarding sampling error of stocked quadrat surveys, a point which will be touched upon later in this report.

3. DESCRIPTION OF THE STUDY AREA

Sampling was undertaken in west-central Alberta and was concentrated mainly in the Edson Forest. These forests are in the Foothills Section (B19a - Lower, and B19c - Upper; Rowe 1972) where 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. Limited amount of sampling was also done in the Mixedwood Section (B18a) in the Whitecourt Forest, where 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 encountered 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, probably the most important variable is soil moisture.

Sampling for growth of open-growing pole-size trees and sampling of regeneration were conducted at different locations. Open-growing trees were sampled in the vicinity of Hinton, Edson, along the Forestry Trunk Road between the Clearwater Ranger Station and the Red Deer River Junction, and at the Kananaskis Forest Experiment Station. Elevation at sampling locations varied between 2700 ft (820 m) and 4600 ft (1400 m).

Regeneration sampling after logging was conducted around Hinton and northwest of Edson between 3700 to 4500 ft (1130 and 1370 m) elevations, and just south of Carson Lake in the Whitecourt Forest at 2700 ft (820 m) elevation. Generally, all the 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 scarification and drags, 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 N.F.R.C.) of pine regeneration following a wildfire near the Upper Saskatchewan Ranger Station (Rocky-Clearwater Forest, elevation 4500 ft or 1370 m) were included in this study.

4. GENERAL RESEARCH STRATEGY

The initial step in the study was to determine the number of trees necessary for the species of interest growing on specific sites to achieve complete crown closure at half rotation of 40 years of age, without any prior significant intertree competition in the stand. Then these number of trees per acre (ha) values had to be regressed to stand age of 10 years--which is the cutoff point for the regeneration phase--by allowing for any mortality in the interim period.

Ideally, growth and development data from open stands should be used to derive minimum stocking standards. Because of the lack of such stands and data, this study made use of growth and size information from individual open-growing trees, then derived minimum number of trees per acre (ha) and associated stocking percentages using a crude stand model. The first step in this procedure was the derivation of DBH over Age relations by site classes, so that average DBH for open-growing trees might be estimated at reference age for each site class. The second step was the derivation of Crown Width (CW) over DBH relationships, from which crown areas could be estimated from average DBH values. The third step was the calculation of the number of well-distributed trees per acre (or ha) required for the desired crown closure and the derivation of appropriate stocking percentages.

Thus the first part of this report is essentially about the derivation of rational minimum stocking standards. However, the application of these standards is linked with stocked-quadrat surveys. Using this survey system, the selection of an appropriate quadrat size is of critical importance if seedling dispersion is anything but random. Therefore, the second part of the report contains an examination of seedling spatial pattern and density based on detailed sampling of different 10-year-old lodgepole pine and white spruce regeneration in the region. Although actual seedling density together with stocking percentage is a useful statistic for describing spatial pattern, the principle value of density in this study lies in indicating the number of "reserve trees" available on an area 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 pattern or density, yet it is essential to consider these characteristics of regeneration when developing or assessing stocking standards.

5. GROWTH-SIZE RELATIONS OF OPEN-GROWN TREES

5.1. METHODS

5.1.1. Field

Healthy lodgepole pine and white spruce trees without apparent competition from neighboring trees (full crown and no neighboring tree crowns overlapping sample trees' branches) were selected between ages 20 and 50 years. DBH to 1/10 in. (2.5 mm), Height, and CW (average of two measurements taken at 90^0 to each other) to 1/10 ft (3 cm); an increment core through the pith at breast height for growth determination and a core at 1 ft, 30 cm (stump) height for ring count were taken. Number of years required to reach 1-ft (30-cm) height was estimated from advance growth present in the area. In addition, altitude was estimated and site conditions described from a brief assessment of physiographic features and vegetation.

5.1.2. Analysis

Current DBH over bark and increment cores taken at breast height from each tree were used to estimate former DBH_{ob} in 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.

5.2. RESULTS AND DISCUSSION

5.2.1 DBH in Relation to Age

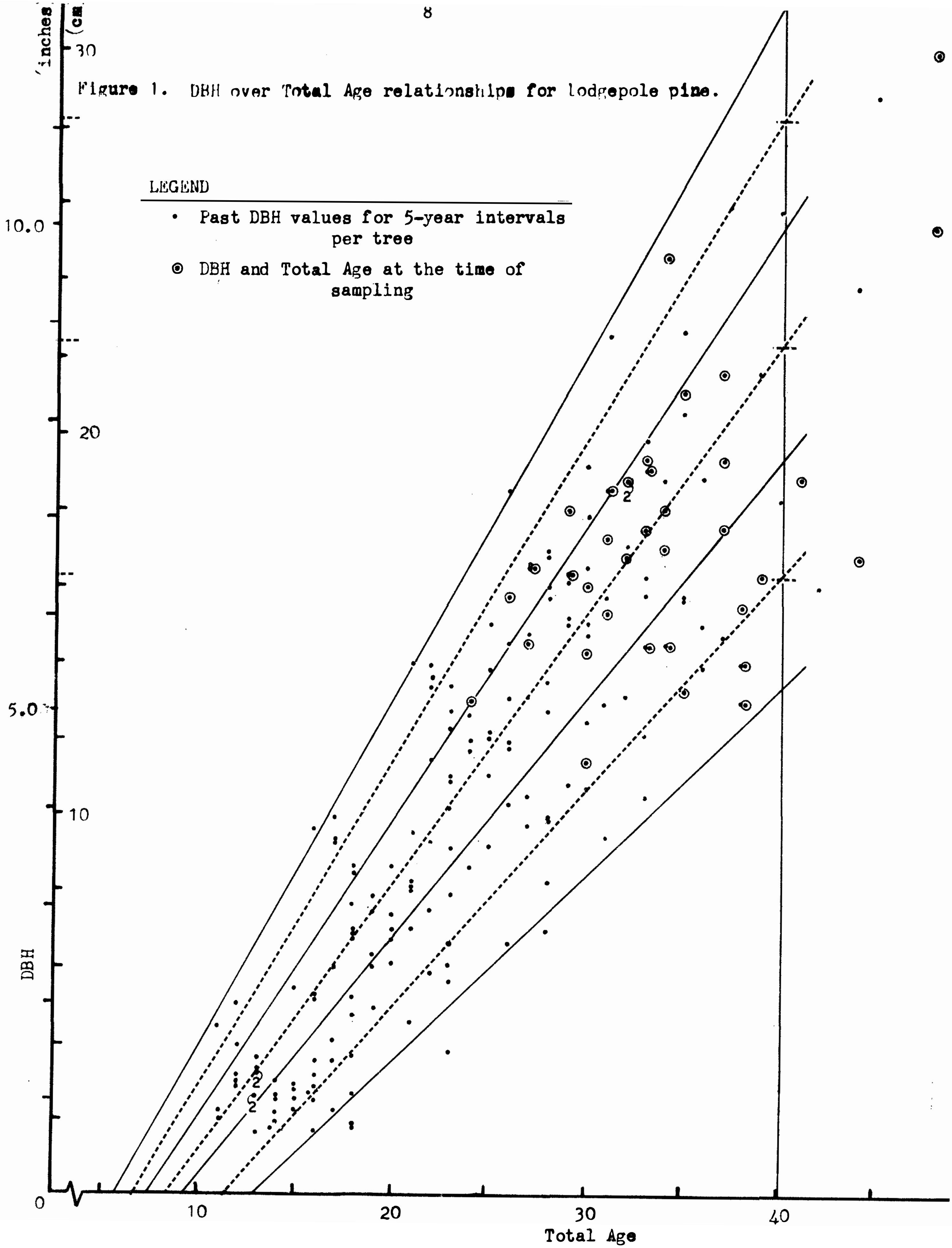
DBH values were plotted over total age for the two species (Figs. 1 and 2). The DBH values in these two scattergrams are believed to cover the range of site conditions present in the region. The range of data was partitioned into three arbitrary but proportional site classes (poor, medium, good) as shown in Figs. 1 and 2. After drawing in the class centers, the average expected DBH, at reference age of 40 years, for each site class was:

Species/Sites	Good		Medium		Poor	
	in.	(cm)	in.	(cm)	in.	(cm)
Lodgepole pine	11.1	(28.2)	8.8	(22.4)	6.4	(16.3)
White spruce	9.1	(21.3)	6.8	(17.3)	4.4	(11.2)

These diameter relations (Figs. 1 and 2) were verified through comparisons with independent data collected in the Edson Forest on lodgepole pine and white spruce 20 years after logging (made available by W.D. Johnstone, N.F.R.C.). (The set of six data points in Fig. 2, well above the upper limit of the best class, originated from a genetically superior white spruce that was growing on somewhat better then medium site.) This comparison generally confirmed that the growth trends and the range of site conditions covered by the present sample are reasonably representative of these two species in the area.

These DBH over Age trends in Figs. 1 and 2 afford some interesting comparisons of tree growth for the two species under open-growing conditions. For example, it takes pine about 6 years less than spruce to reach breast height on medium sites (9 vs. 15 years), and at least the same advantage in DBH is maintained by open-growing pine over spruce at 40 years. At that age, this means a difference of 2 in. or 5 cm (9 vs. 7 in. or 23 vs. 18 cm) in DBH.

Figure 1. DBH over Total Age relationships for lodgepole pine.



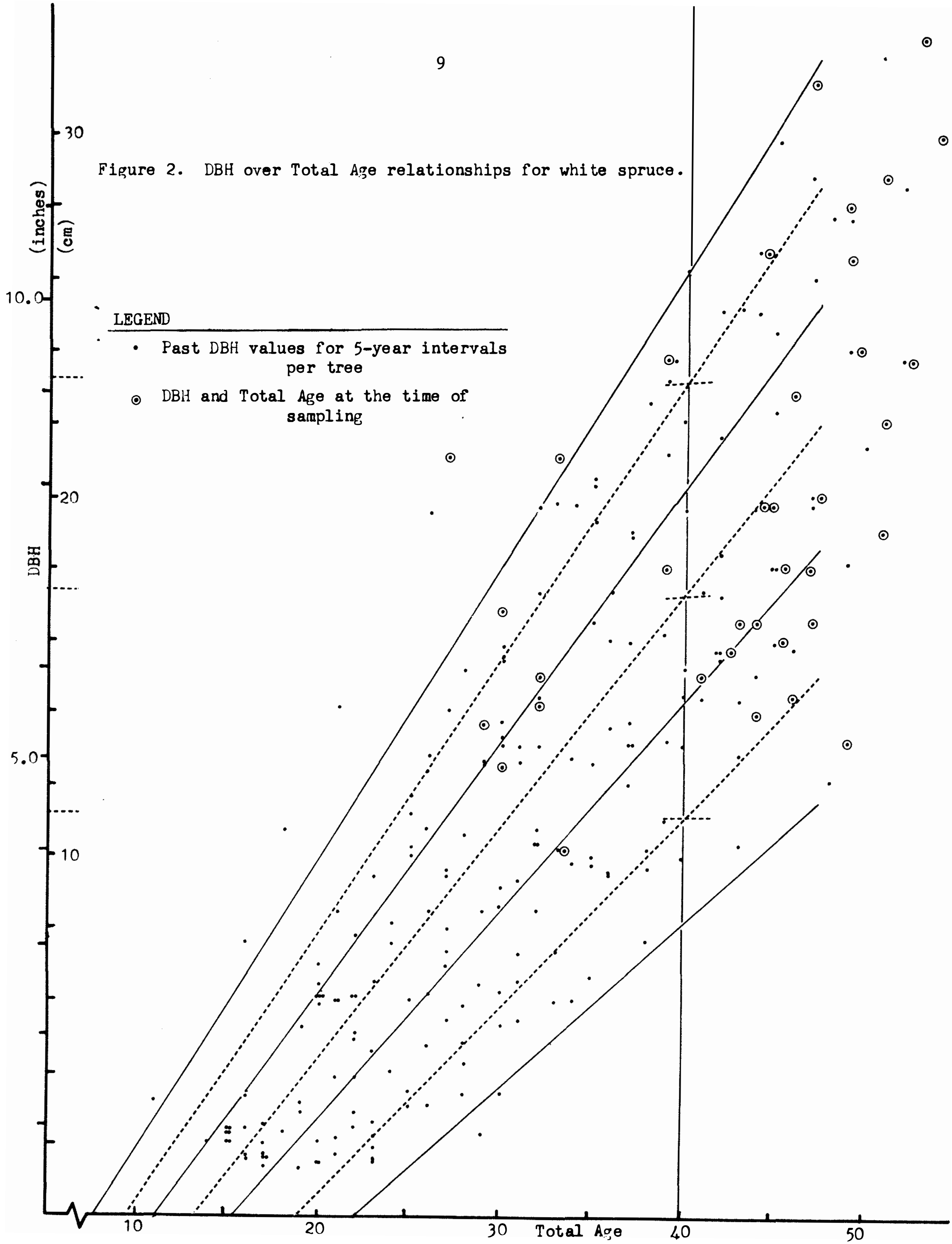


Figure 2. DBH over Total Age relationships for white spruce.

5.2.2. Crown Width in Relation to DBH

Regression equations developed for the two species and related statistics (r^2 and n) are presented in Fig. 3. Regressions for both species were highly significant, with DBH accounting for 75% of the variation in CW for lodgepole pine and 80% of that for white spruce.

Initially, individual CW over DBH regressions were fitted to the data, grouped by site classes, on the basis of height-over-age trends for each species. However, covariance tests between these individual regressions showed no significant separation, indicating that CW-DBH relationships were essentially independent of site. Thus, a common trend was fitted and used for each species. Similar results were published for jack pine in Manitoba (Bella 1967). Tree age as a second independent variable had no significant effect on CW after the effect of DBH was removed by the regressions.

It was found, rather unexpectedly, that open-growing lodgepole pine had wider crowns than white spruce for similar diameters over 6 in. (15 cm) (Fig. 3). A comparison of CW-DBH relationships suggest that spruce stands can support a greater number of similar-size trees then pine, although spruce may take several years longer to achieve the same DBH.

The growth data on open-growing white spruce originated in the Foothills Forest Section and thus may not be directly applicable to spruce in the Mixedwood. In the Foothills a western variety of white spruce (*Picea glauca* (Moench) Voss var. *albertiana* (S. Brown) Sarg.) is common. This variety has a narrow crown, and the present sample may well have included individuals of this variety. This may have influenced the CW over DBH regressions. No comparable published information could be found for this species to verify the present results. On the other hand, it was possible to compare the CW over DBH regression for lodgepole pine with that derived by Lee (1967) for the same species from British Columbia data. The two regressions appeared similar, although Lee's regression indicated a slightly greater CW, which may have resulted from the greater age of the B.C. sample and possibly other causes.

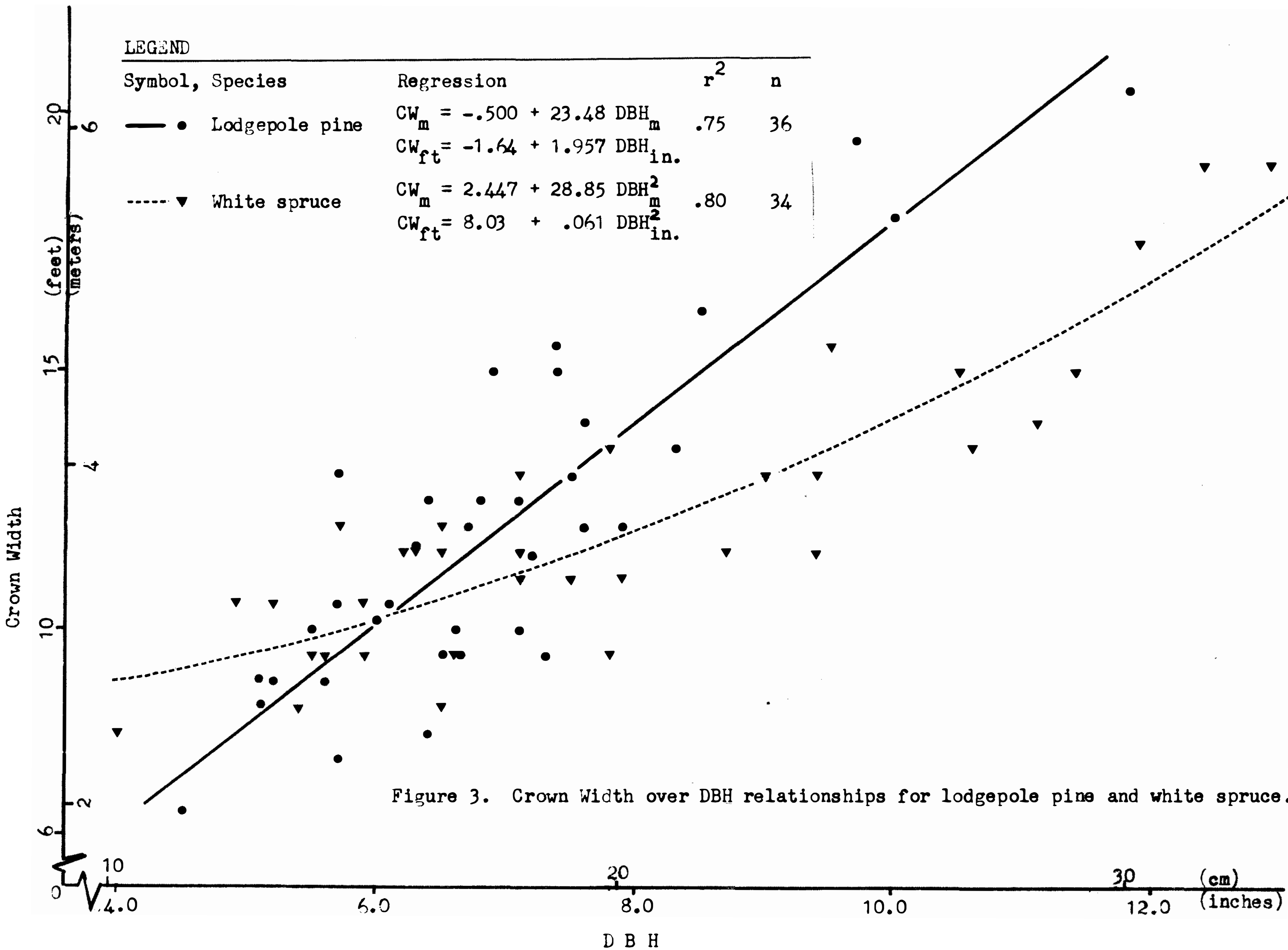


Figure 3. Crown Width over DBH relationships for lodgepole pine and white spruce.

5.2.3. Number of Trees Required for Full Stocking

This was determined in three steps:

1. Estimating average DBH at reference age
2. Estimating CW from DBH, then calculating average crown projection areas
3. Calculating the number of full-crowned trees that would be required for complete stocking based on maximum potential crown closure.

Average DBH of free-growing lodgepole pine and white spruce was estimated at 40 years for three site classes from the relationships presented in Figs. 1 and 2. From these DBH values (page 9), average CW was estimated using the regressions shown in Fig. 3. Then these CW values were used to calculate crown projection areas.

To estimate the number of full-crowned trees at reference age of 40 years which were assumed to develop without significant intertree competition to that age would require knowledge about potential maximum crown closure. Unfortunately, actual crown closure information at present is very scarce in this region, and practically nonexistent for young open stands of these two species. This writer observed that vigorous young trees in open stands of lodgepole pine or white spruce can develop so that the branches of neighboring individuals may touch or even overlap. Under such conditions it is entirely feasible that stands of either species approach 100% crown closure.

This means that it may be reasonable to specify 100% crown closure for full stocking. Specifying such a high level of closure would mean erring on the conservative side (requiring too many trees), a prudent procedure until reliable data become available on crown closure, tree growth, and stand development under the conditions described.

Based on the above, the number of open-growing pine and spruce trees required for complete crown closure at 40 years of age was estimated for the three site classes (Table 1). Only about 140 lodgepole pine trees/acre (340/ha) were required on good sites, whereas on poor sites close to 470 trees/acre (1150/ha) were necessary. Comparable statistics were roughly double for spruce: 320 trees/acre (800/ha) on good sites, 650 trees/acre (1610/ha) on poor sites.

Table 1. Number of open-growing pine or spruce per unit area required for complete crown closure at age 40 years by site class

Species	Site Class[1]	Average DBH[1] in.	(cm)	Average Crown Width[2] ft	(m)	Average Crown Area sq ft	(m^2)	Number of Trees per acre	(ha)
Lodgepole Pine	good	11.1	(28.2)	20.1	(6.13)	317.3	(29.51)	137	(339)
	medium	8.8	(22.4)	15.6	(4.75)	191.1	(17.72)	228	(564)
	poor	6.4	(16.3)	10.9	(3.32)	93.3	(8.66)	467	(1155)
White Spruce	good	9.1	(23.1)	13.1	(3.99)	134.8	(12.50)	323	(800)
	medium	6.8	(17.3)	10.8	(3.29)	91.6	(8.50)	476	(1177)
	poor	4.4	(11.2)	9.2	(2.81)	66.5	(6.20)	655	(1613)

[1]From Figs. 1 and 2

[2]From Fig. 3

This approach to the problem indicates that considerably more spruce than pine are required for full crown closure at reference age of 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 calculated for the two species at 40 years for the conditions described in Table 1. These estimates, presented in Table 2, indicate similar volumes for lodgepole pine and white spruce on medium sites, although for spruce this volume was distributed on nearly twice as many trees. On good sites spruce would outproduce pine by about 25%, 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. Naturally, these volumes will change after age 40 in absolute as well as relative terms.

Number of trees thus derived may be used as a guide in assessing the old stocking standard and developing a new one. It would be feasible, although impractical from an operational viewpoint, to adopt minimum standards for each species by site classes. Alternatively, a single standard could be adopted for each species, or a common standard for both.

5.2.4. Redefining the Standard

If a single standard by species were adopted, the question would be whether to have a relatively high minimum stocking value to achieve full occupancy even on the poor sites, or a low value, with greater weight given to better sites. A higher standard would ensure complete site utilization even on the poor sites; but there would be crowding, reduced individual tree growth, and also better self-pruning on good sites. This option would generally require higher establishment costs, whether from postlogging treatment or from planting. The second option could result in incomplete crown closure and site utilization and

Table 2. Stand volume estimates for open-growing pine and spruce having complete crown closure at age 40 by site class

Species	Sites	DBH in.	Tree: Height[1] ft	Tree: Volume Total ft³	Tree: Volume Merch. ft³	Stand statistics per acre: Number of trees	Stand statistics per acre: Volume[2] Total ft³	Stand statistics per acre: Volume[2] Merch. ft³
lP	good	11.1	48	15.679	14.799	137	2148	2027
	medium	8.8	38	7.948	7.391	228	1812	1685
	poor	6.4	28	3.157	2.790	467	1474	1303
wS	good	9.1	41	8.462	7.892	323	2733	2550
	medium	6.8	33	3.916	3.512	476	1864	1672
	poor	4.4	26	1.326	.937	655	868	614

[1]Estimated from open-growing tree data

[2]From Honer 1967. Merchantable volume to .5 ft stump and 3 in. top.

some reduction in yield on poorer sites, but it would ensure generally faster tree growth on all sites. It would also mean reduced establishment cost.

A compromise standard would fall somewhere in between, close to values derived for medium sites: 220 trees/acre (560/ha) for lodgepole pine and roughly twice that many, 470/acre (1170/ha), for white spruce. This number of trees should be adequate in stands with 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 tree pattern is heavily clumped the same number of trees would be insufficient. (This situation is discussed later.)

Number of trees required for white spruce could be lowered if the arbitrary reference age of 40 years for crown closure and complete site occupation were raised to compensate for the initial slower growth of this species. On the average, spruce takes between 5 and 10 years longer than pine to reach breast height on medium sites, and this same lag in development persists at least up to 40 years of age (see Figs. 1 and 2) and probably beyond. As it may be feasible to manage spruce stands on a somewhat longer rotation than pine, it would also be reasonable to specify crown closure for the purpose of this study at a somewhat later age than for pine, at 50 rather than 40 years. At age 50 on medium sites, spruce would have an average DBH of 9.5 in. (24 cm) and CW 13.5 ft (4.1 m); and 305 trees/acre 753/ha) would be required for crown closure. So it would be safe to accept 300 trees/acre (750/ha) as standard stocking for white spruce as compared to 220 trees/acre (560/ha) for lodgepole pine.

The use of crown closure as the basis of the present decision model and the assumption that young, open, vigorously growing pine and spruce stands approach 100% crown closure, 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 level of safety and if anything, they err on the conservative side.

Although the required number of trees seems relatively low, there is little danger of significant yield loss. Volume yield in any area is heavily concentrated on medium and better sites (see also Table 2), where these standards would ensure full stocking at 40 or 50 years. Initially open stands, however, would mean improved forage production for ungulates, and are more attractive areas for hunting and other recreational uses. After full crown closure, crowding on better sites would somewhat reduce tree growth, but it would also enhance self-pruning and result in reduction of stem taper. On poor sites, which contribute a small proportion of the yield, any understocking and related loss in yield would be of minor importance. Open stands on these less productive sites might provide desirable habitat for wildlife and areas for more intensive recreational use.

If one accepts the above number of trees per unit area as a reasonable minimum for the two species, the next step is to express or define those values in terms of stocking percent. Assuming one tree per quadrat--as in stocked-quadrat surveys--one can derive stocking percent values for different quadrat sizes that would ensure at least the minimum specified number of trees per unit area (Table 3). If one can assume random seedling pattern as well, then it is possible to estimate from available theory (Blackman 1935) the mean expected stocking percentages for these two specified densities (Fig. 4 and Table 3).

These two sets of stocking percentages are justifiably different. The first set of estimates--which is always larger (Table 3)--will ensure at least the minimum specified number of trees (but generally more, unless the spatial pattern is very regular) at the average spacing implied by the quadrat size and over the proportion of the area indicated by stocking percent. The difference between the two sets of stocking percentages increases with greater quadrat size because with increased incidence of two or more trees per quadrat counteracts the expected increase in stocking percent.

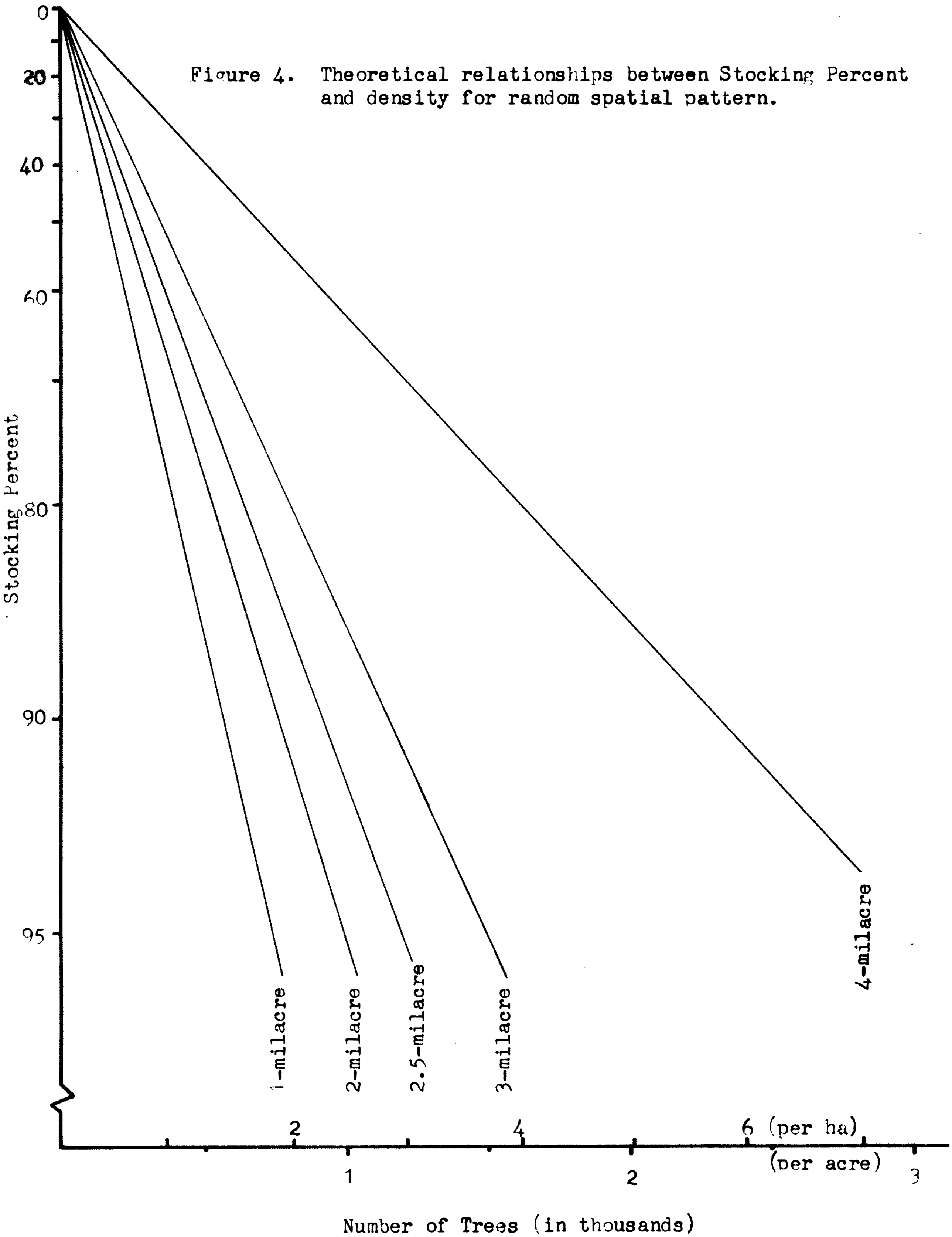
Now the problem is choosing the minimum stocking percent and related quadrat size for the two species. For reasons given earlier, a

Table 3. Estimated stocking percentages based on different quadrat sizes for two specified stand densities

Stand min. number of trees per acre	Stand min. number of trees per ha	Quadrat size (milacre)	Stocking percentage with at least one tree/quadrat	Stocking percentage random pattern for minimum number of trees
220	560	1	22	20
		2	44	35
		2.5	55	42
		3*	66	48
		4	90	58
300	750	1	30	26
		2	60	45
		2.5*	75	53
		3	100	59
		4	100	70

* Recommended

Figure 4. Theoretical relationships between Stocking Percent and density for random spatial pattern.



quadrat size of around 3 milacres (12 m^2) would be desirable, although it could be smaller if the spatial pattern of seedlings were truly random over the area. Because it is unjustified simply to assume random pattern (more about this in the next section) one should proceed on the basis of the more conservative, i.e., higher minimum stocking percent (Table 3, column 4). Then, to ensure at least 220 well-distributed lodgepole pine per acre (560/ha) would require 90% stocking by 4-milacre quadrats. If one accepted not-quite-so-well distributed 220 trees/acre and 2-milacre quadrat-size, the required stocking percentage would be reduced to 44%. Similarly, to ensure at least 300 reasonably well distributed spruce trees per acre (750/ha) on a cutover area would require 60% stocking by 2-milacre quadrats.

Because of the forthcoming general conversion to metric (SI) units in Canada, it is appropriate to adopt a quadrat size for regeneration surveys that will readily fit into the new system. From the results above it seems that a 10-m^2 [1-millihectare (mha) roughly equivalent to 2.5-milacre] quadrat would admirably suit this purpose, particularly for spruce, with minimum stocking of 75% to ensure at least 750 trees/ha. For pine, a quadrat size of 1 mha may be somewhat small, as the necessary minimum of 560 trees/ha would require only 56% stocking which may be too low to ensure homogenous stocking in a stand. Therefore, a quadrat size of 12 m^2 (approximately 3 milacres) may be more suitable, for which 67% stocking or roughly 70% would be required to ensure a minimum of 560 trees/ha. Naturally some compromise would have to be worked out when regeneration is made up of more than one acceptable species. This problem should be tackled when these results are used at the next revision of the Alberta Regeneration Survey Manual.

6. SEEDLING SPATIAL PATTERN AND DENSITY-STOCKING PERCENT RELATIONSHIPS

Because the spatial pattern of seedlings--particularly any departure from randomness--has important implications on the use of the stocked quadrat system of regeneration surveys (viz., in selecting proper quadrat size and minimum acceptable stocking percentage), a brief examination to explore the nature of seedling pattern was conducted using data from detailed sampling of different 10-year-old lodgepole pine and white spruce regeneration in the region. These data were also used to provide background information on actual seedling densities at different stocking levels, as an indication of the number of "reserve trees" that may be expected on an area with potential for filling gaps created by mortality.

6.1. METHODS

6.1.1. Field

Sampling in the three main study areas was conducted by selecting cutover blocks 10 growing seasons after logging, so that they represented a range of stocking and stand conditions in the area. On a cutover, generally three square sample plots 0.1 acre (.04 ha) in size were established to represent low, average, and high stocking levels. One hundred and nineteen plots were used from the Edson Forest and 13 from the Whitecourt Forest. The conditions described on each plot included stand type, aspect, slope, elevation, soil moisture and texture, amount of slash, competition from lower vegetation, depth of duff, and postlogging treatment.

The sample plots were subdivided into a grid of 10 x 10, 1-milacre (approx. 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.

In addition, data collected by J. Soos in 1966 in 8-year-old lodgepole pine near the Upper Saskatchewan Ranger Station (Rocky-Clearwater Forest) were used. This was a complete tally (100% sample) by 1-milacre quadrat of a 38.4-acre (15.5-ha) area, where the original stand had been destroyed by fire 8 years earlier. For the present analysis, the sample stand was partitioned into contiguous 118.8 x 118.8 ft (36.21 x 36.21 m) sample plots (i.e. an 18 x 18 matrix of 1-milacre, approx. 4-m^2, quadrats). A total of 86 plots was used in the analysis. Plots that had roads or logging trails that prevented the establishment of regeneration were excluded from this analysis.

6.1.2. 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 (e.g., n = 0, 1, 2, 3, ...). Random seedling pattern was indicated if the observed frequency distribution resembled a Poisson series (e.g., the observed distribution and the expected Poisson were not significantly different on the basis of Chi-squre test); or if the Variance/Mean ratio of the distribution was not significantly different from 1 (based on appropriate Standard Error, as in Greig-Smith 1964).

Regression techniques were used to describe relations between seedling density, as the dependent variable, and stocking percent, site (aspect, slope, height increment), and ground conditions (the amount of slash, lower vegetation, duff, and postlogging treatment) on the sample plots as independent variables.

In all the above analyses, relationships were described and spatial patterns studied on the basis of quadrat size, 1- and 4-milacres. Data for quadrat size of 4-milacres were obtained by combining four adjacent quadrats.

6.2. RESULTS AND DISCUSSION

6.2.1. Analysis of Seedling Spatial Pattern

For this analysis the data were subdivided into two main groups: (1) pine type and (2) spruce type. The analyses were conducted on individual plot data, but the presentation of results to such detail is beyond the scope of this paper.

Pine types: The analysis of data from the Edson Forest was done on a species basis: (1) pine only, (2) pine and spruce, and (3) all conifers. For both quadrat sizes (1- and 4-milacres), over 95% of the sample plots tested indicated clumpy seedling pattern; this was so for all species considered.

Rather unexpectedly, a similar clumpy pattern was found in the Clearwater-Rocky Forest pine regeneration data for tests based on both quadrat sizes, although the degree of clumping was generally lower than for the previous pine group.

Spruce types: This type was further broken down into two groups, known to be meaningful in terms of regeneration characteristics: (1) spruce-fir type in the Foothills (Edson Forest) and (2) spruce in the Mixedwood (Whitecourt Forest).

Considering spruce, and spruce and pine for the entire spruce type, seedling pattern for this type approached random on about 20% of the plots. The tests showed no effect of quadrat size.

In the spruce-fir type, the test statistics indicated random seedling pattern for spruce, spruce and pine, spruce and fir, and for all conifers combined for nearly 30% of the plots and this value was unaffected by quadrat size. If only the fir component was considered, 7% of the plots showed random seedling pattern from 1-milacre quadrat data, but this increased to nearly 30% for the 4-milacre data.

In the Mixedwood type, spruce exhibited an extremely clumpy pattern on all the sample plots. Again, a change in quadrat size did not have an appreciable effect on perceived spatial pattern.

The relationships in Fig. 4 can also be used for describing the nature of spatial pattern in a sample for which stocking and density estimates are available. If a stocking percentage for a given density falls below the appropriate trend line (e.g., the stocking percentage is actually greater; note reverse direction of change in values on the ordinate) then the pattern tends toward regular, whereas if it falls above the line it indicates clumping in the pattern. Plotting of sample estimates of stocking percentages over number of trees per acre in Fig. 4 confirms heavy clumping of seedlings for both pine and spruce.

In summary, seedling pattern for lodgepole pine and white spruce, in this region at least, is generally nonrandom and characterized by a greater or lesser degree of clumping. Only the fir component in the Foothills (spruce-fir type) came even close to a random pattern (especially when the tests were based on 4-milacre quadrats). In part, the reason for this may be that fir seedling establishment is not much dependent on ground treatment and that the necessary seed is usually dispersed by air. In addition, a good proportion of established fir seedlings are usually made up of advance growth already present (and fairly well dispersed) on the area at the time of logging, which would tend to give seedling spatial pattern a random character.

On the other hand, most spruce and pine regeneration originates following logging, when seed source and ground conditions have critical importance on abundance and spatial pattern of seedlings. These factors generally seem to operate to produce heavy clumping: (1) because of the spotty nature of suitable seedbed, and (2) specifically for pine, because of the uneven dispersion of seed over the area.

There are several implications of this clumpy spatial pattern. First and most obvious is that there will be a far greater number of trees in certain patches over the area than would be expected with a random spatial pattern. 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 clumpy seedling pattern 40% stocking by 1-milacre quadrat--as specified by the present standard--will not likely ensure a minimum of 400 well-dispersed trees per acre (1000/ha). The use of larger quadrat sizes and stocking percentages close to 100%, as advanced in the first part of this report, is a simple solution for ensuring adequate stocking in a new stand.

Because a random spatial pattern is generally assumed in the application of the stocked quadrat system of regeneration survey, and because this assumption seems hardly ever fulfilled, the usefulness of sample estimates may justifiably be suspect. Heavy clumping may also have an effect on actual sampling error and may contribute to the differences that arise in stocking percent estimates between independent samples (e.g. company vs. the Forest Service check surveys). It was hoped that increasing the quadrat size to 4-milacres (16 m^2) would result in a trend towards randomness in perceived spatial pattern. However, results so far do not confirm this expectation.

6.2.2. Number of Trees in Relation to Stocking Percent

Logarithmic regressions of Number of Trees (NT) over Stocking Percent (S%) developed for pine and spruce by stand types, for the two quadrat sizes are presented in Figs. 5 and 6, and Figs. 7 and 8, respectively. Table 4 lists a summary of relevant regression statistics. These regressions provide estimates of average expected tree numbers of specified stocking percentages. Generally, they indicate a substantially greater number of trees over what is implied by a given stocking percentage. These "reserve trees" may then be enough to counteract mortality effects in these stands.

The highlights of the results are as follows:

1. Pine types. Elevation, as represented by four separate geographic locations, had no significant effect on the NT over S% regressions. In other words, seedling density at specific stocking percentages was essentially the same at different elevations. Therefore one set of regressions is applicable for the entire study area.

2. The inclusion of spruce with pine in pine types had no effect on the basic relationships, although average stocking percentage increased 4-5%, while the tree numbers increased about 15% from an average of 2450 to 2824/acre (6050 to 6980/ha) (Table 5).

3. There was a considerably greater number of trees per unit area after logging (Edson Forest) than after a burn (Clearwater-Rocky Forest) at similar stocking levels.

4. For spruce types, NT over S% relationships were much weaker than in pine types, presumably because of the greater variation in spruce numbers over the area at given stocking levels, and because of the narrower range of data. Particularly large variation occurred in tree numbers in the Mixedwood, where seedling establishment seems strongly dependent on seed source and ground treatment, particularly on the amount of exposed mineral soil. The treatment used generally produced a patchy and irregular pattern of mineral seedbeds, which partially explains the large variation in number of trees.

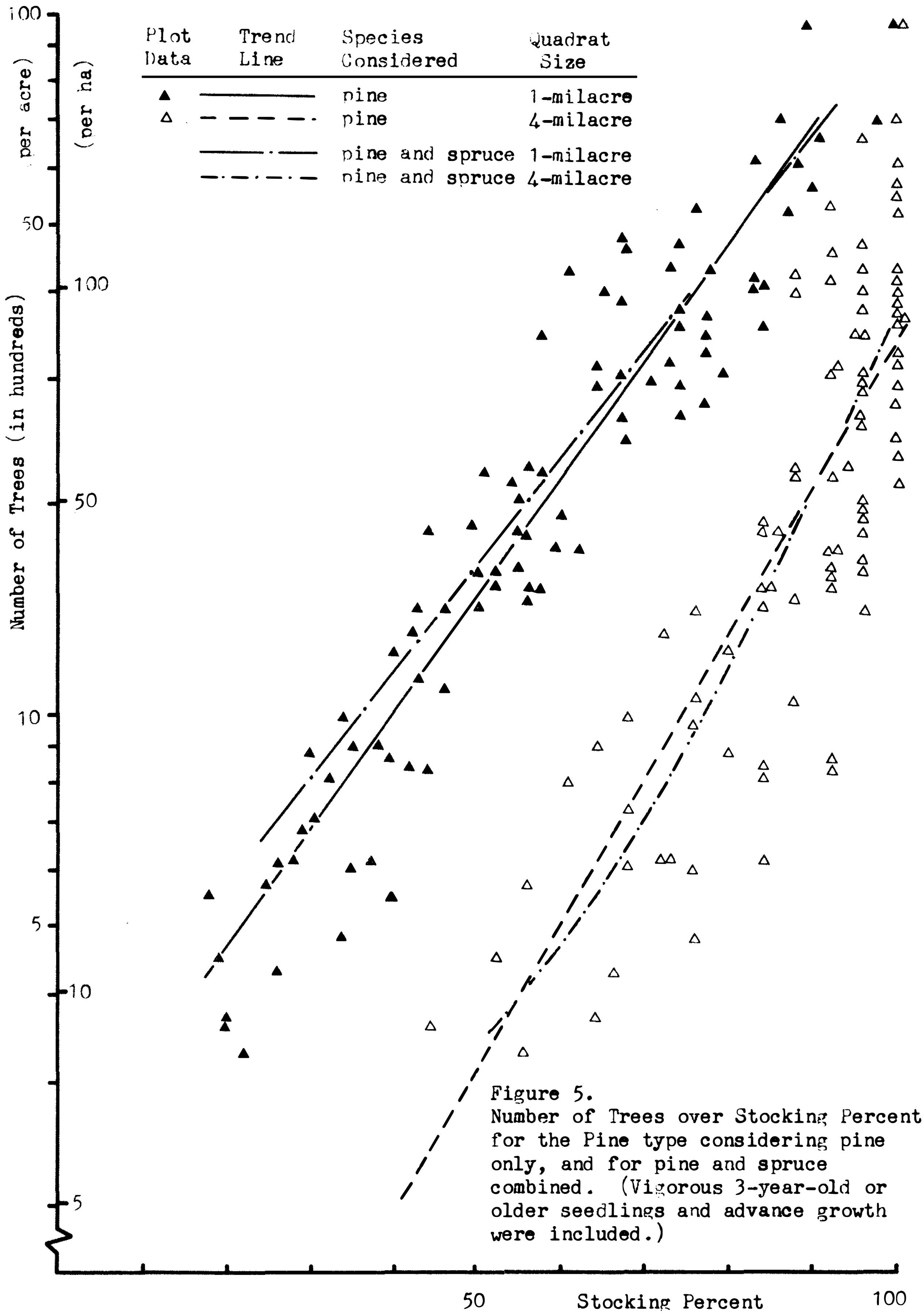


Figure 5.
Number of Trees over Stocking Percent for the Pine type considering pine only, and for pine and spruce combined. (Vigorous 3-year-old or older seedlings and advance growth were included.)

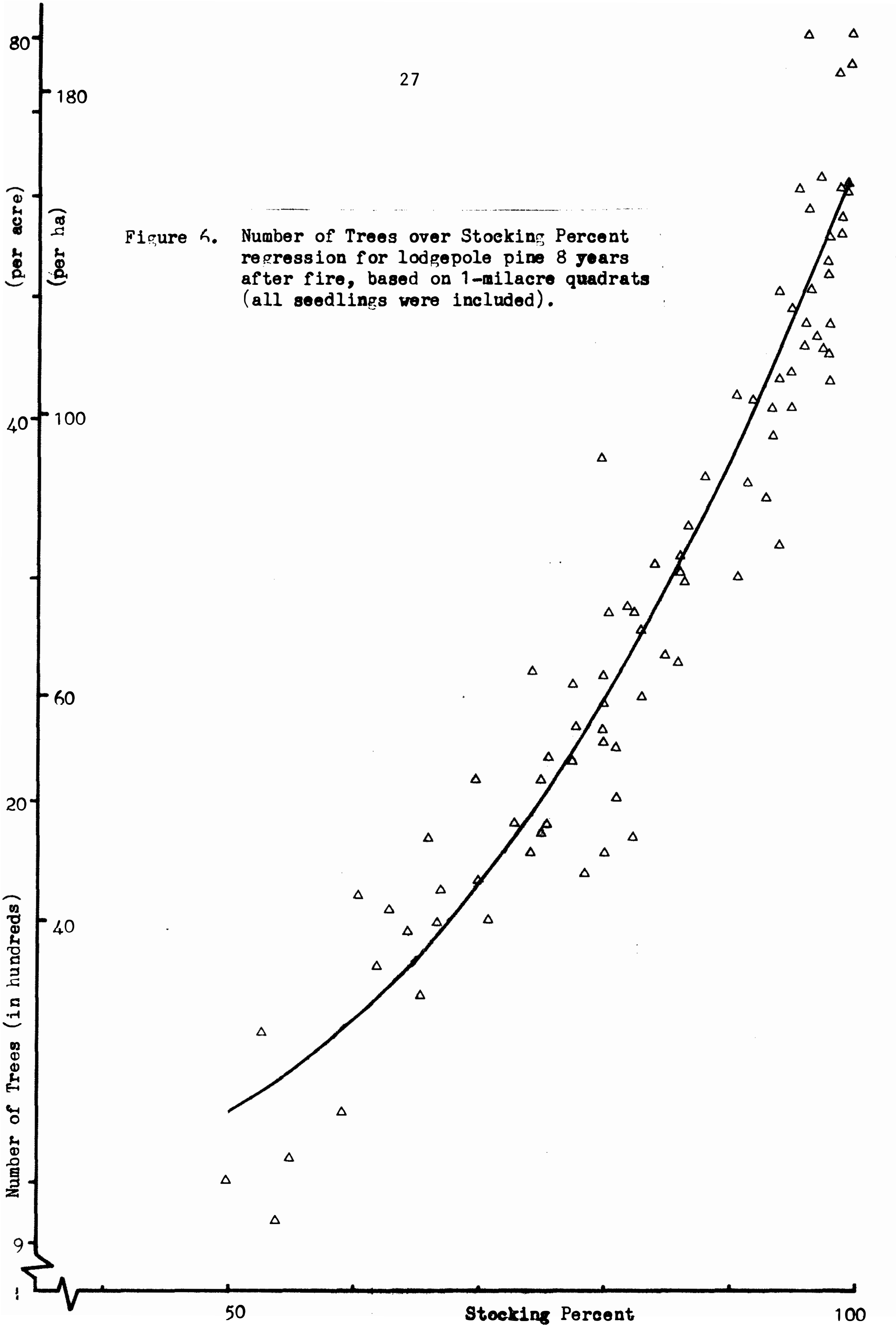


Figure 6. Number of Trees over Stocking Percent regression for lodgepole pine 8 years after fire, based on 1-milacre quadrats (all seedlings were included).

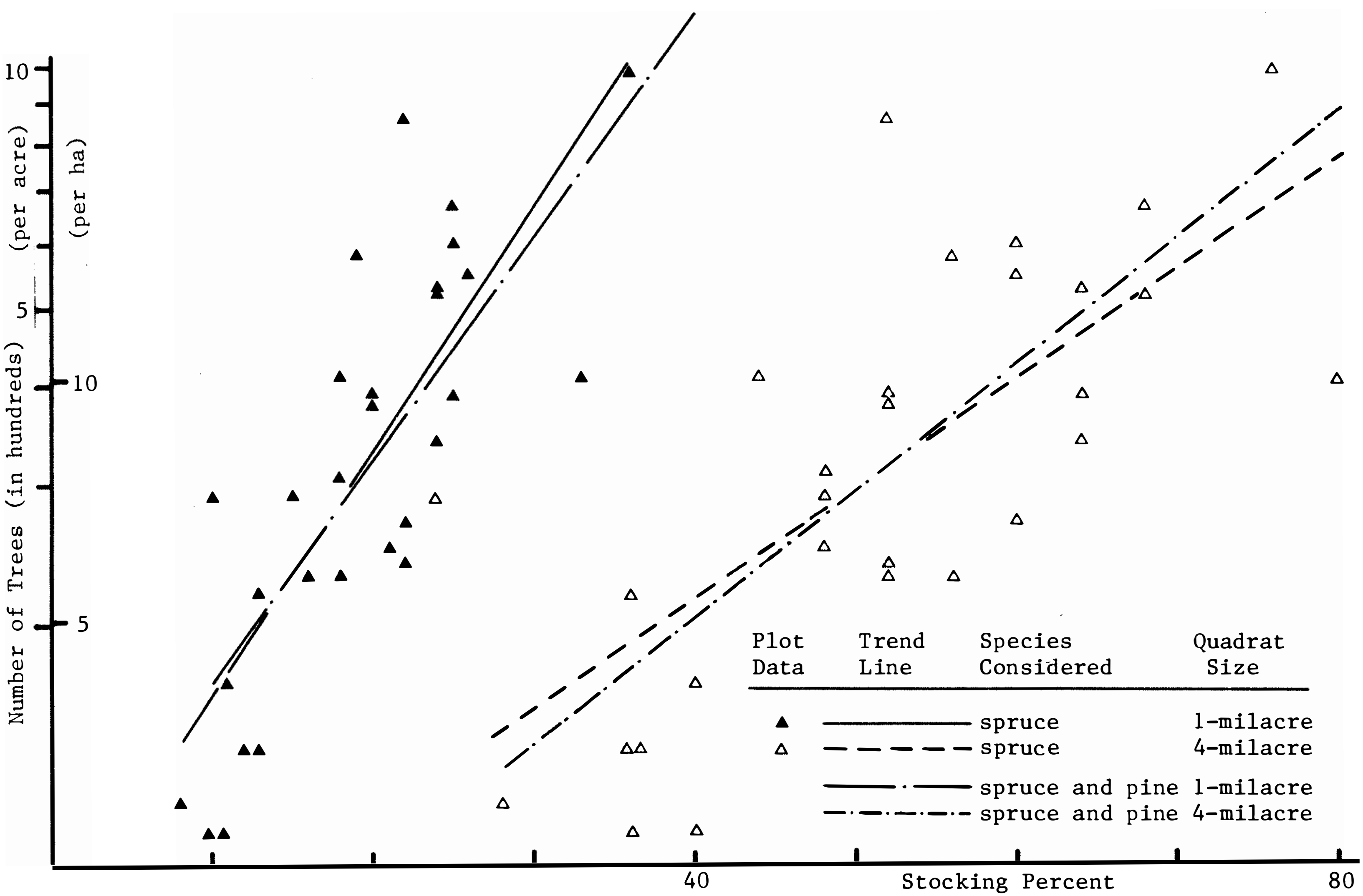


Figure 7. Number of Trees over Stocking Percent for the Spruce-Fir type considering spruce only, and for spruce and pine combined. (Vigorous 3-year-old or older seedlings and advance growth were included.)

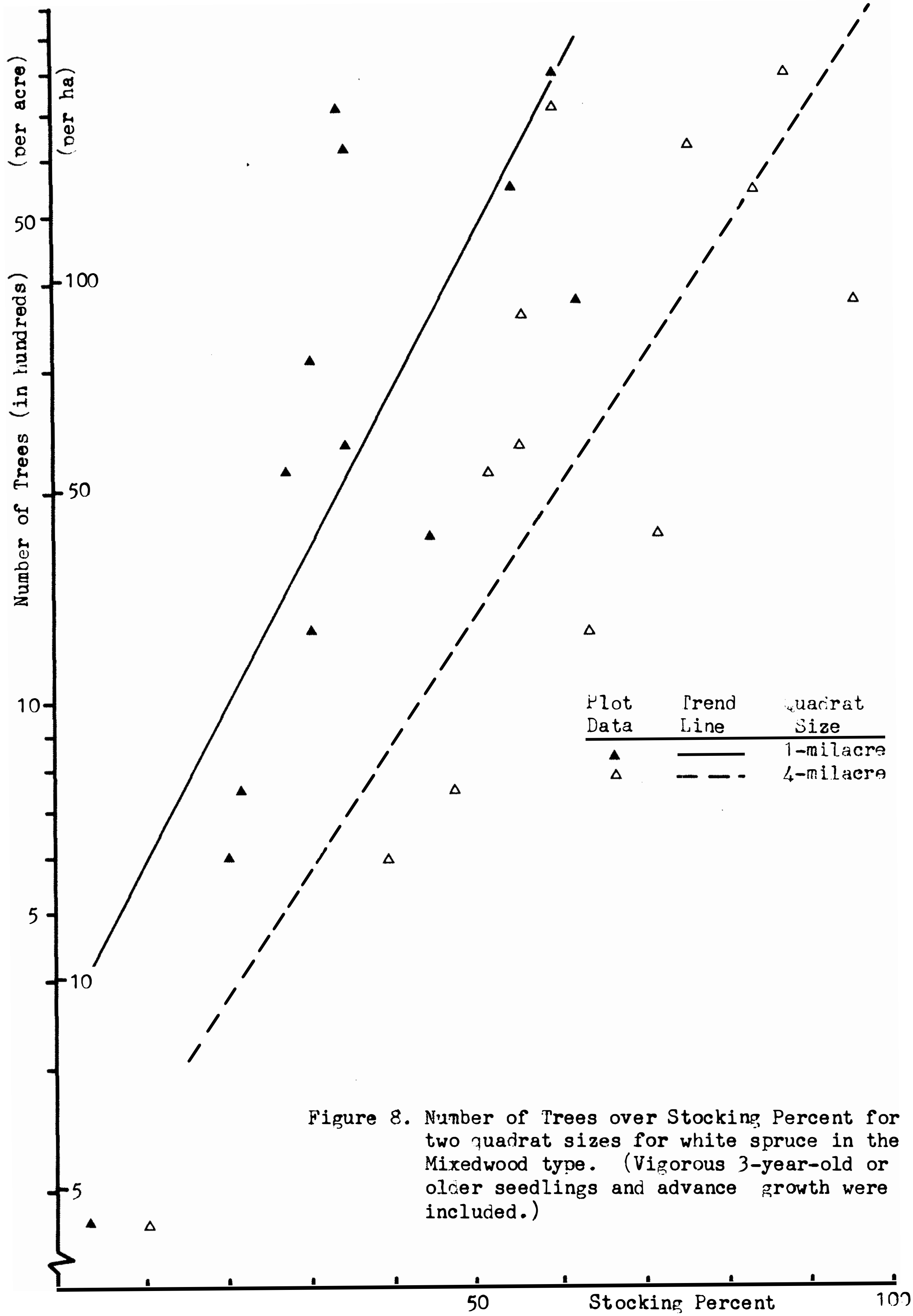


Figure 8. Number of Trees over Stocking Percent for two quadrat sizes for white spruce in the Mixedwood type. (Vigorous 3-year-old or older seedlings and advance growth were included.)

Table 4. Number of trees over stocking percent regression statistics for lodgepole pine and white spruce by stand types (vigorous 3-year-old and older seedlings and advance growth were included)

Stand Type	Species Considered	Quadrat Size (milacres)	Regression	N	r^2
Foothills: Pine, Edson Forest	pine	1	[1] $\log_n NT = 3.068 + .03820\ S\%$	88	.91
		4	$\log_n NT = 0.991 + .04837\ S\%$	88	.67
	pine and spruce	1	$\log_n NT = 3.145 + .03726\ S\%$	88	.88
		4	$\log_n NT = 2.682 + .00033\ (S\%)^2$	88	.58
Foothills: Pine, Clearwater-Rocky Forest	pine	1	[2] $\log_n NT = 7.587 - .03333\ S\% + .00045\ (S\%)^2$	85	.91
		4	$\log_n NT = 44.013 - .87656\ S\% + .00519\ (S\%)^2$	85	.55
Foothills: Spruce-Fir, Edson Forest	spruce	1	[1] $\log_n NT = 2.08 + .07040\ S\%$	29	.65
		4	$\log_n NT = 1.81 + .03153\ S\%$	29	.52
	spruce and pine	1	$\log_n NT = 2.176 + .06427\ S\%$	29	.75
		4	$\log_n NT = 1.560 + .03648\ S\%$	29	.65
Mixedwood Spruce, Whitecourt Forest	spruce	1	[1] $\log_n NT = 3.522 + .05215\ S\%$	13	.60
		4	$\log_n NT = 2.748 + .04240\ S\%$	13	.67

[1] Per 1/10 acre [2] Per acre

Table 5. Stocking percent and number of trees per-acre summaries (mean, minimum, maximum) by stand types

	Stand Type	Number of Plots	Quadrat Size (milacres)	Species Considered	Stocking % Avg.	Stocking % Min.	Stocking % Max.	Number of trees, 3-yr and older per acre Avg.	Min.	Max.
Foothills	Pine Edson Forest	90	1	P	56.2	18	91	2450	330	9530
				P+S	61.0	28	93	2824	570	10650
			4	P	87.3	40	100	2450	330	9530
				P+S	91.1	60	100	2824	570	10650
	Pine Clearwater-Rocky Forest	86	1	P	83.7	50	100	3414	938	8083
			4	P	97.2	76	100	3414	938	8083
	Spruce-Fir Edson Forest	29	1	S	19.3	8	36	370	110	990
				S+P	22.2	10	40	448	110	1260
			4	S	51.7	24	80	370	110	990
				S+P	56.1	28	80	448	110	1260
	Mixedwood Spruce Whitecourt Forest	13	1	S	35.7	4	63	3341	180	8030
			4	S	62.2	16	96	3341	180	8030

P - Lodgepole Pine

S - White Spruce

A comparison of NT over S% relations for the two spruce types in Figs. 7 and 8 reveals a much greater number of spruce trees per unit area in the Mixedwood than in the Foothills at the same stocking level (e.g., at 30% stocking based on 1-milacre, the estimated average number of spruce trees per acre would be around 1600/acre in the Mixedwood, and only about 750/acre in the Foothills, or 3950 and 1850/ha, respectively).

5. The inclusion of pine with spruce in the spruce type (Foothills) caused no significant change in the relationship, although average stocking increased 3-4%, while number of trees increased 21%, from 370 to 448/acre, or 910 to 1110/ha (Table 5).

The lack of significant change in the NT over S% relations after the inclusion of secondary species (e.g., pine may be the primary and spruce the secondary species, or vice versa) would suggest that both species are dispersed over the area in a similar pattern, although they tend to complement each other rather than occupy the same niche. This is especially evident in pine types with spruce as a secondary species (Fig. 5).

6. The inclusion of 2-year-old seedlings (in addition to the 3-year-old and older) had no appreciable effect either on the regressions or on variable means.

These NT over S% regressions (Figs. 5-8 and Table 4), can be used for estimating expected number of trees for specified minimum stocking percentages for the two quadrat sizes (Table 3). For example, 90% stocking by 4-milacre quadrats, which ensures 220/acre (560/ha) well-distributed lodgepole pine, would mean an average total of over 2100 trees/acre (5190/ha) for the present sample.

7. MORTALITY

In deriving minimum acceptable stocking percent for regeneration standards, it is important to consider irregular mortality caused by insect and disease during the life of the stand. (Regular, or suppression mortality may be ignored for these relatively open stand conditions). However, a brief review of relevant literature revealed no serious widespread insect or disease damage that could cause significant understocking which would have to be compensated for in these minimum standards. Thus, the many "surplus" seedlings that are present in the stocked quadrats should be enough to fill in any small openings created by mortality. This eliminated any need to allow for mortality in the period between age 10 and reference age halfway through rotation (viz., 40 or 50 years).

8. CONCLUSIONS AND RECOMMENDATIONS

1. Trends of DBH in relation to Age, and Crown Width in relation to DBH were derived from open-growing lodgepole pine and white spruce data collected in the Foothills Forest Section of west-central Alberta. These trends were used to derive minimum number of trees per acre (ha) and associated stocking percentages for stands of the two species, considering full site occupation--but no significant competition--by trees about halfway through rotation (at 40 years for pine 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 6 inches. This, along with generally smaller tree-size at reference age, points to considerably higher minimum stocking requirements for spruce than for pine.

2. Analysis of seedling spatial pattern indicated various degrees of clumping of the entire seedling population sampled 10 years after logging. Spruce in the Mixedwood was the most clumpy, while the fir component in the spruce-fir type was the least clumpy.

3. Number of Trees over Stocking Percent regressions for quadrat sizes 1- and 4-milacres were developed for different stand types of the two

study species. Within any one stand type, the inclusion of secondary species (e.g., spruce) with the principal species (e.g., pine, or vice versa) had no significant effect on these relations, although average stocking and density did increase. This suggests that both species are dispersed over the area in a similar pattern, although they tend to complement each other rather than occupy the same niche.

4. Greatest variation in number of trees at a particular stocking level was found for spruce in the Mixedwood, where seedling establishment was strongly dependent on seed source and ground treatment, both of which may be rather patchy over an area.

5. The conclusion from these analyses is that the present 40% stocking rule ensures a more than sufficient number of trees per acre (ha) for both lodgepole pine and white spruce. However, it is doubtful whether the 1-milacre quadrat size presently used in regeneration surveys ensures a desirable dispersion of seedlings over the area. Seedling spatial pattern for pine and spruce showed at least some clumping. This implies a surplus of seedlings (generally more than the required one seedling per quadrat) in stocked areas and gaps in between, which may render sample estimates, including sampling error, somewhat suspect in surveys which presuppose a homogeneously random seedling pattern. It is recommended that an in-depth assessment of the effect of clumpy spatial pattern on sampling efficiency be conducted, and possibly alternative methods of regeneration surveys explored that would also yield information about the nature and degree of clumping as well as about actual seedling density.

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 quadrat size. However, the clumpy nature of seedling pattern in this region prevents reliable conversions. Therefore, to enhance the usefulness of stocking percent estimates and bring regeneration survey practice more in line with theory, the use of 1-milacre (4-m^2) quadrats should be discontinued and a larger

quadrat adopted. This would also automatically mean a higher minimum stocking percent requirement.

7. Accepting complete crown closure halfway through the rotation (40 years for lodgepole pine and 50 years for white spruce) as basic stocking criteria, it was derived that 220 well-dispersed pine per acre (560/ha) or 300 well-dispersed spruce per acre (750/ha) are sufficient to ensure acceptable yield at harvest. Although the appropriate stocking percentages and survey quadrat sizes(s) should be arrived at after discussion between the agencies responsible for forest management, the Forest Service and the forest companies, it is recommended that priority be given to the adoption of a 10-m^2 (1 mha, approximately 2.5-milacre) quadrat as the survey unit for spruce and a 12-m^2 (approximately 3-milacre) quadrat for pine. The suggested corresponding minimum stocking percentages for the two species should then be around 75% and 70% respectively.

8. It is reemphasized however, that this study was conducted to derive minimum acceptable stocking standards using full utilization of the site as the criterion, rather than maximum fiber yield. Admittedly, the standards derived were based on rather crude methods and limited data and should therefore be verified and possibly revised when improved methods and more data become available.

9. Although the recommended number of trees may seem relatively low in light of the existing standard, there is little danger of significant loss in yield. The required number of trees was derived so that full stocking would be ensured halfway through the rotation, at least on medium and better sites where most volume yield is expected. Generally, open conditions in young stands would result in improved forage production for ungulates; also, allowing such 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.

10. This study did not confirm the hypothesis that increasing quadrat size from 1- to 4-milacres (4- to 16-m^2) would result in a trend towards random spatial pattern of seedlings as perceived through appropriate statistical tests. Further studies would be required for conclusive

answers on this problem at different levels of stocking in regeneration having various degrees of clumpiness.

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