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Effects of spacing 7-year-old lodgepole pine in west-central Alberta

W.D. Johnstone

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EFFECTS OF SPACING 7-YEAR-OLD LODGEPOLE PINE

IN WEST-CENTRAL ALBERTA

W.D. JOHNSTONE[1]

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NORTHERN FOREST RESEARCH CENTRE
CANADIAN FORESTRY SERVICE
ENVIRONMENT CANADA
5320 - 122 STREET
EDMONTON, ALBERTA, CANADA
T6H 3S5

[1] Present address: Research Branch, B.C. Ministry of Forests, 1450 Government Street, Victoria, B.C. V8W 3E7

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ABSTRACT

The effects of spacing 7-year-old fire-origin lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) are reported 13 growing seasons after treatment. Five spacing levels of 494, 988, 1977, 3954, and 7907 trees per hectare (200, 400, 800, 1600, and 3200 trees per acre) were established on plots at three sites in west-central Alberta. Data were analyzed in terms of the entire stand and portions of it. Wide spacing had a significant effect on stand growth and development, resulting in greater diameter increment and average stand diameter. The effects on crop-tree development were inconclusive. Spacing specifications are recommended for young lodgepole pine.

RESUME

Les effets, 13 ans plus tard, du dépressage d'un peuplement de pin tordu latifolié (*Pinus contorta* Dougl. var. *latifolia* Engelm.) de 7 ans établi après un incendie sont décrits. Des densités de 494, 988, 1977, 3954 et 7907 arbres à l'hectare (200, 400, 800, 1600 et 3200 à l'acre) avaient été établies sur des parcelles, à trois endroits dans le centre-ouest de l'Alberta. Les données ont été analysées en fonction du peuplement entier et de ses parties. Un dépressage prononcé a un effet significatif sur la croissance et le développement du peuplement, qui se traduit par des valeurs plus élevées pour l'accroissement en diamètre et pour le diamètre moyen. Les effets sur le développement des arbres du peuplement final ne sont pas concluants. Des recommandations sont faites concernant le dépressage des jeunes peuplements de pin tordu latifolié.

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INTRODUCTION

One of the potential solutions to Canada's decreasing timber supply (Reed 1978) is the practice of more-intensive forest management. Early spacing control appears to be particularly well suited to the management of lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.), which tends to regenerate overabundantly following both wildfire and scarification. Excessive stand density has been shown to reduce stand and tree growth of this species (Johnstone 1976). By concentrating stand growth on a desired number of stems, juvenile spacing offers the forest manager some degree of control over tree size and quality, stand yield, rotation length, and therefore allowable cut, without incurring additional harvesting costs. This report presents the effects, for the first 13 growing seasons after treatment, of various spacings on the development of dense, fire-origin stands of 7-year-old lodgepole pine.

METHODS

STAND SELECTION AND SITE DESCRIPTION

The area chosen for this study lies south of Hinton, Alberta (53°25′, 117°34′), on the Forest Management Agreement area of St. Regis (Alberta) Ltd. The area is known locally as the Gregg Burn. The study area is within the Upper Foothills Section (B.19c) of the Boreal Forest Region (Rowe 1972). The spacings were carried out during the fall of 1963 and the spring of 1964 in pure, even-aged, 7-year-old stands of lodgepole pine that regenerated naturally following a 1956 wildfire.

Three sites judged to be of low, intermediate, and high productivity were chosen for the study. The site of low productivity was situated on a level terrace. The soil there was a rapidly drained eluviated eutric brunisol developed on glaciofluvial terrace gravels with an aeolian veneer and a very thin organic layer (Gregg series). The intermediate productivity site was located on a moderately well-drained brunisolic gray luvisol developed on clay loam-textured cordilleran till with a silt loam-textured fluvioeolian veneer (Mercoal series) and had a south aspect. The high productivity site varied in aspect from southwest to northeast. There the soil varied from a rapidly drained eluviated eutric brunisol developed on fluvial sands and gravels with a loamy sand till veneer to a moderately well-drained brunisolic gray luvisol developed on clay loam cordilleran till with a loamy sand eolian veneer. Although both soils are in the Mercoal series, the latter soil may be more favorable for tree growth because the sand allows a large rooting volume, while the finer-textured till prevents excessive drainage. Detailed descriptions of these soil series have been presented by Dumanski *et al.* (1972). In all three sites the vegetation is of the Black spruce-lodgepole pine/Labrador tea/bog cranberry type of Krumlik *et al.*[1], analogous to the Lodgepole pine/Labrador tea/feathermoss type of Corns (1978).

STUDY DESIGN AND ESTABLISHMENT

Five spacing levels, referred to as levels of growing stock (LGS), were established on variable area plots consisting of 100 treatment trees per plot (Table 1). Two blocks, each sufficiently large enough to accommodate the five spacings, were chosen as close together as the uniformity of site conditions would permit within each productivity area. Thus the study is based on a total of 3000 treatment trees on three sites, each containing two blocks of five plots each. The allocation of treatments was made by dividing each block into two and randomly assigning to one half the spacing that required the largest plot (LGS 1). The remaining half of the block was again divided into two, and the spacing requiring the second-largest plot (LGS 2) was randomly assigned to one half. This procedure was repeated until all plots were assigned. After treatment assignment, a

[1] Krumlik, G.V., J.D. Johnson, and L.D. Lemmen. Unpublished progress report for 1977-78 on the biogeoclimatic ecosystem classification of Alberta. Northern Forest Research Centre, Canadian Forestry Service. Edmonton, Alberta.

Table 1. Spacing, grid intervals, and variable-plot sizes for the treatment plots

Levels of growing stock (LGS)	Spacing		Grid interval		Plot size	
	Trees/ha	Trees/acre	m	ft	ha	acre
1	494	200	4.50	14.76	0.200	0.500
2	988	400	3.18	10.44	0.101	0.250
3	1977	800	2.25	7.38	0.051	0.125
4	3954	1600	1.59	5.22	0.025	0.063
5	7907	3200	1.12	3.69	0.013	0.031

square (10 × 10) grid was established on each plot, and all trees except the healthiest and most vigorous tree within 46 cm (18 in.) of each grid intersection were removed. The grid distances and variable-plot sizes were determined by the various spacings (Table 1).

TREE MEASUREMENT AND COMPILATION

In the fall of 1964, after the first growing season following spacing, all treatment trees were tagged and their total height and location were recorded. During the falls of 1966, 1971, and 1976 all treatment trees were remeasured and their diameter at breast height, total height, crown width, and crown length were recorded. In addition, any damage to the treatment trees caused by insects, diseases, or animals was recorded. During the 1971 remeasurement all invading conifers were removed from the plots.

All measurements and compilations were performed in Canadian yard/pound units, and these values were subsequently converted to the Système International d'Unités (SI) using the conversion factors recommended by Bowen (1974). Breast-height measurements were taken at 1.37 m (4.5 ft), not 1.30 m. The total volume of each tree was calculated from the following equations[2]:

1. Trees ⩽8.9 cm (⩽3.5 in.) dbhob:
   $V = 0.0232 + 0.00253\, D^2 H$

2. Trees 9.1-21.6 cm (3.6-8.5 in.) dbhob:
   $V = -0.0949 + 0.00272\, D^2 H$

where V = volume in cubic feet (stump and top included, bark excluded)

D = diameter at breast height outside bark (dbhob) in inches

H = total height in feet.

ANALYSES

In lieu of treatment surrounds the analyses were based only upon data from sample trees, which were the 64 inner trees in each plot. Data from all trees in the first and last rows and from the first and last trees in the remaining rows of each plot (i.e., the perimetrical trees of each plot) were not used in the analyses. Data were analyzed for three stand components:

[2] Kirby, C.L. Unpublished file report on tree volume equations and volume basal-area ratios for white spruce and lodgepole pine in Alberta, 1973. Northern Forest Research Centre, Canadian Forestry Service. Edmonton, Alberta.

1. stand data for all sample trees,

2. largest (dbhob) 25% of the sample trees in 1976, and

3. sample trees representing the 494 largest dbhob stems per hectare in 1976, irrespective of spacing.

Because of the varying sampling intensities (Table 2), pure spacing effects were best evaluated by comparing the same proportion rather than the same number per unit area.

The average and per-hectare stand values of each plot were analyzed for each measurement period. Per-hectare values are net values (i.e., exclude mortality) and were determined for each plot by multiplying the mean value of the sample trees (volume or basal area) times the spacing level times the number of live sample trees as a decimal fraction of 64. Similar methods were used to derive net per-hectare values for the largest 25% and largest 494 stems per hectare in 1976, chosen from the 64 sample trees. The following randomized complete-block analysis of variance was used for all average and per-hectare value comparisons:

Source	Degrees of freedom
Site (S)	2
Spacing (T)	4
Site × spacing (S × T)	8
Block within site (B wi S)	3
Spacing × block within site (T × B wi S)	12
Total	29

Comparisons of treatment means were made using Duncan's new multiple-range test.

RESULTS AND DISCUSSION

There were no significant differences between the blocks within each productivity site. Consequently, data from both blocks in each site were combined for ease of presentation. The effects of site and spacing and their interaction on dimensional and growth characteristics for stand components are summarized in Table 3. In all cases, site productivity had a significant and direct effect upon the development of the stand components. Detailed comparisons of treatment means for the stand components are presented in Appendix 1.

HEIGHT

Spacing had a significant effect on mean stand height of 20-year-old lodgepole pine (Table 3). As can be seen in Fig. 1, the effect of spacing on stand height was more pronounced for the low and intermediate productivity sites than for the high productivity site. This probably reflects the more-intense competition for nutrients and moisture on the low and intermediate sites compared to the high site, where the supply of these factors has not yet limited growth. The uniformity of the stand heights just after treatment (Fig. 1) indicates that current differences are a response to the spacing and are not the result of removing shorter trees and leaving only the taller ones (analysis of variance of 1964 heights showed no significant differences between treatments within sites). Spacing also had a significant and direct effect on the mean height of the largest 25% of the 20-year-old trees (Table 3), and this effect was least pronounced on the high site (Fig. 2). Spacing did not affect the mean height of the 494 largest trees per hectare (Table 3), and no consistent pattern between their mean heights and spacing occurred for all sites (Fig. 2).

The effects of spacing upon periodic height growth from ages 15 to 20 years were significant (Table 3). These effects were most pronounced on the low site and practically nonexistent on the high site (Fig. 3). Spacing significantly affected the periodic height growth of the 494 largest trees per hectare but not the largest 25% of the trees (Table 3). The greatest periodic height growth of the 494 largest trees per hectare was observed at LGS 3 on all sites (Fig. 3).

Table 2. Numbers of sample trees analyzed and their areal equivalents for each level of growing stock (LGS)

	All trees			Largest 25%			Largest 494/ha		
	No. sample	Area equivalents		No. sample	Area equivalents		No. sample	Area equivalents	
LGS	trees	Trees/ha	Trees/acre	trees	Trees/ha	Trees/acre	trees	Trees/ha	Trees/acre
1	64	494	200	16	124	50	64	494	200
2	64	988	400	16	247	100	32	494	200
3	64	1977	800	16	494	200	16	494	200
4	64	3954	1600	16	988	400	8	494	200
5	64	7907	3200	16	1976	800	4	494	200

DIAMETER

The most dramatic effect of spacing on stand development occurred in diameter development (Fig. 4). Spacing had a highly significant effect on mean stand diameter (Table 3) and, unlike the effect on stand height, this effect is apparent on all sites. The mean diameter of the largest 25% of the trees also decreased significantly from the widest spacing to the closest spacing (Table 3), and this pattern was consistent on all sites (Fig. 5). The mean diameter of the 494 largest trees per hectare was not affected by spacing (Table 3).

Differences in periodic diameter growth during the past 5 years were highly significant for all stand components (Table 3) and, as shown in Fig. 6, a large decline in growth occurred in the closest spacings on all sites. The significant site × spacing interaction in periodic diameter growth for all trees and for the largest 494 trees per hectare (Table 3) indicates a differential response to spacing on the various sites. Although the interdependence of response to site and spacing is not readily apparent in Fig. 6, this rate of decline in diameter growth with closer spacing is greatest on the high site and least on the low site.

BASAL AREA

Wider spacing resulted in lower basal area of all trees and of the largest 25% of the trees at 20 years of age. The smaller average tree size at closer spacings has been more than compensated for by the disproportionately higher numbers of trees. No significant differences in basal area per hectare were obtained when an equal number (494) of the largest trees per hectare were compared (Table 3). The significant site × spacing interaction in basal area for the largest 25% of the trees arose because the rate of increase in basal area with closer spacing was faster on the high site than on the lower sites.

Spacing also had a significant effect on periodic basal area growth per hectare for all stand components (Table 3). Basal area growth was greater with closer spacing for both the entire stand and the largest 25% of the trees. When the largest 494 stems per hectare were considered, the largest basal area growth occurred at LGS 2 and the smallest growth occurred at LGS 5 (Appendix 1).

VOLUME

Despite significantly larger and faster-growing trees at wider spacings (Appendix 1), both volume and volume growth per hectare were significantly lower at wider spacings for both all trees and the largest 25% of the trees (Figs. 7 and 8). As with basal area, this results from the disproportionately higher number of stems at the closer spacings. The prospect of closing the resulting total volume gap is,

Table 3. Effects of site and spacing on the development of lodgepole pine stands (* significant at p = 0.05 level; ** significant at p = 0.01 level)

Characteristic	Source of variation[1]	Stand component		
		All trees	Largest 25%	Largest 494/ha
Mean height	S	**	**	**
(Age 20)	T	*	*	
	S X T			
Mean periodic height growth	S	**	*	**
(Age 15-20)	T	*		*
	S X T			
Mean dbhob	S	**	**	**
(Age 20)	T	**	**	
	S X T			
Mean periodic dbhob growth	S	**	**	**
(Age 15-20)	T	**	**	**
	S X T	*		*
Basal area/ha	S	**	**	**
(Age 20)	T	**	**	
	S X T		*	
Periodic basal area growth/ha	S	**	**	**
(Age 15-20)	T	**	**	*
	S X T			
Mean total volume/tree	S	**	**	**
(Age 20)	T	**	**	
	S X T			
Mean periodic total volume growth/tree	S	**	**	**
(Age 15-20)	T	**	**	*
	S X T			
Net total volume/ha	S	**	**	**
(Age 20)	T	**	**	
	S X T		*	
Periodic net total volume growth/ha	S	**	**	**
(Age 15-20)	T	**	**	
	S X T		**	

[1] S = site, T = treatment (spacing).

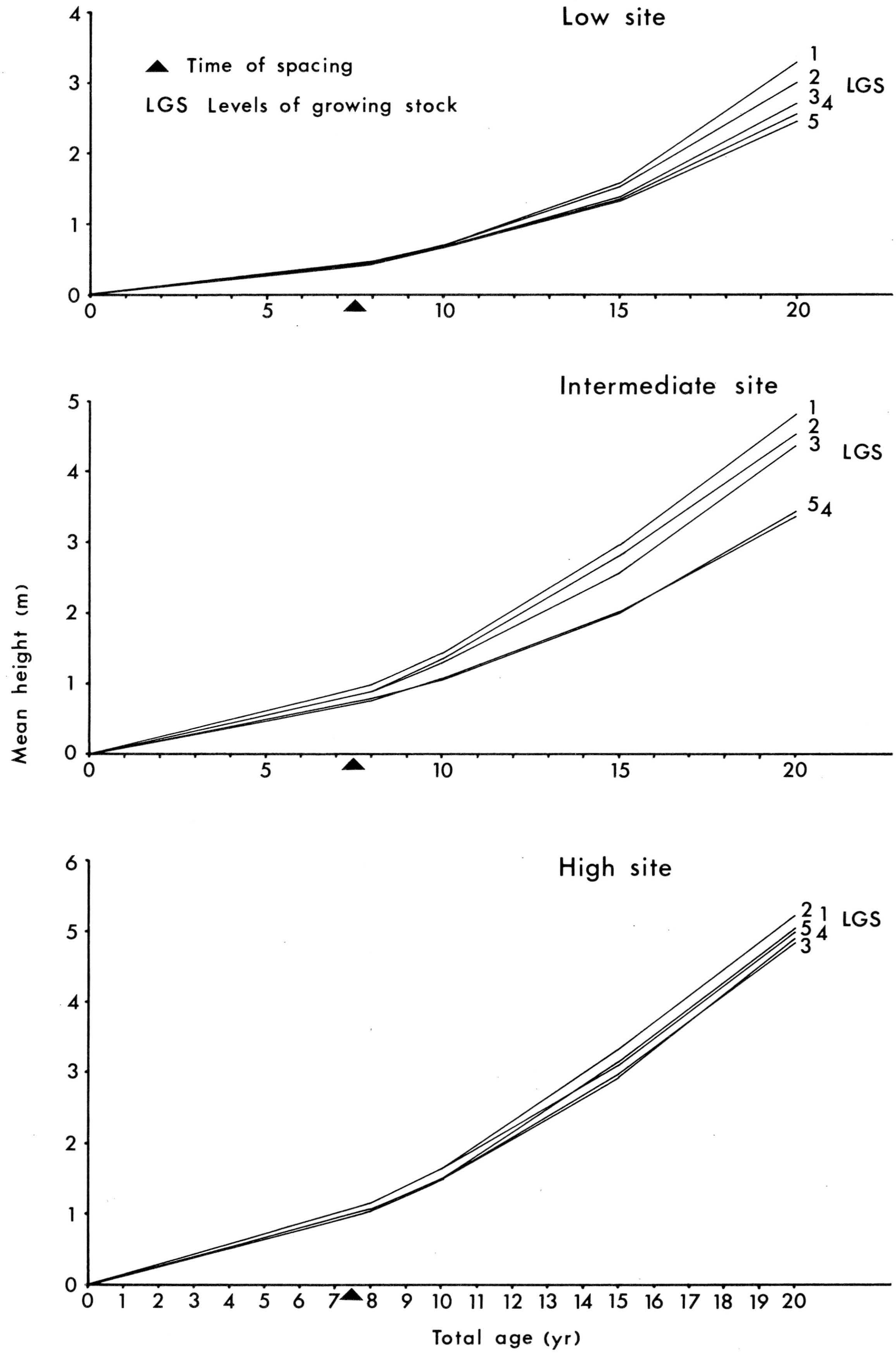

Figure 1. Height development of spaced lodgepole pine.

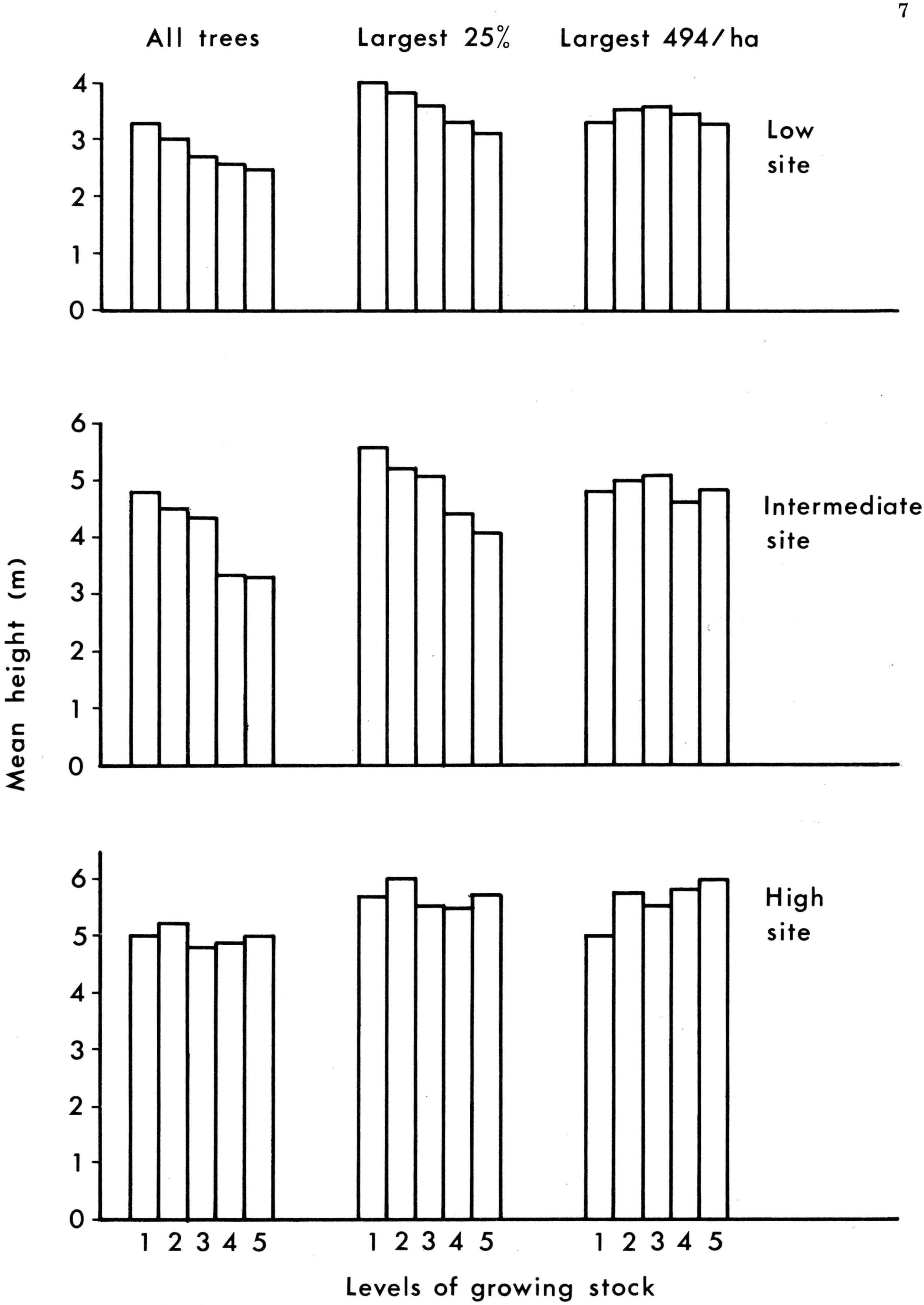

Figure 2. The effect of spacing on mean height of 20-year-old lodgepole pine.

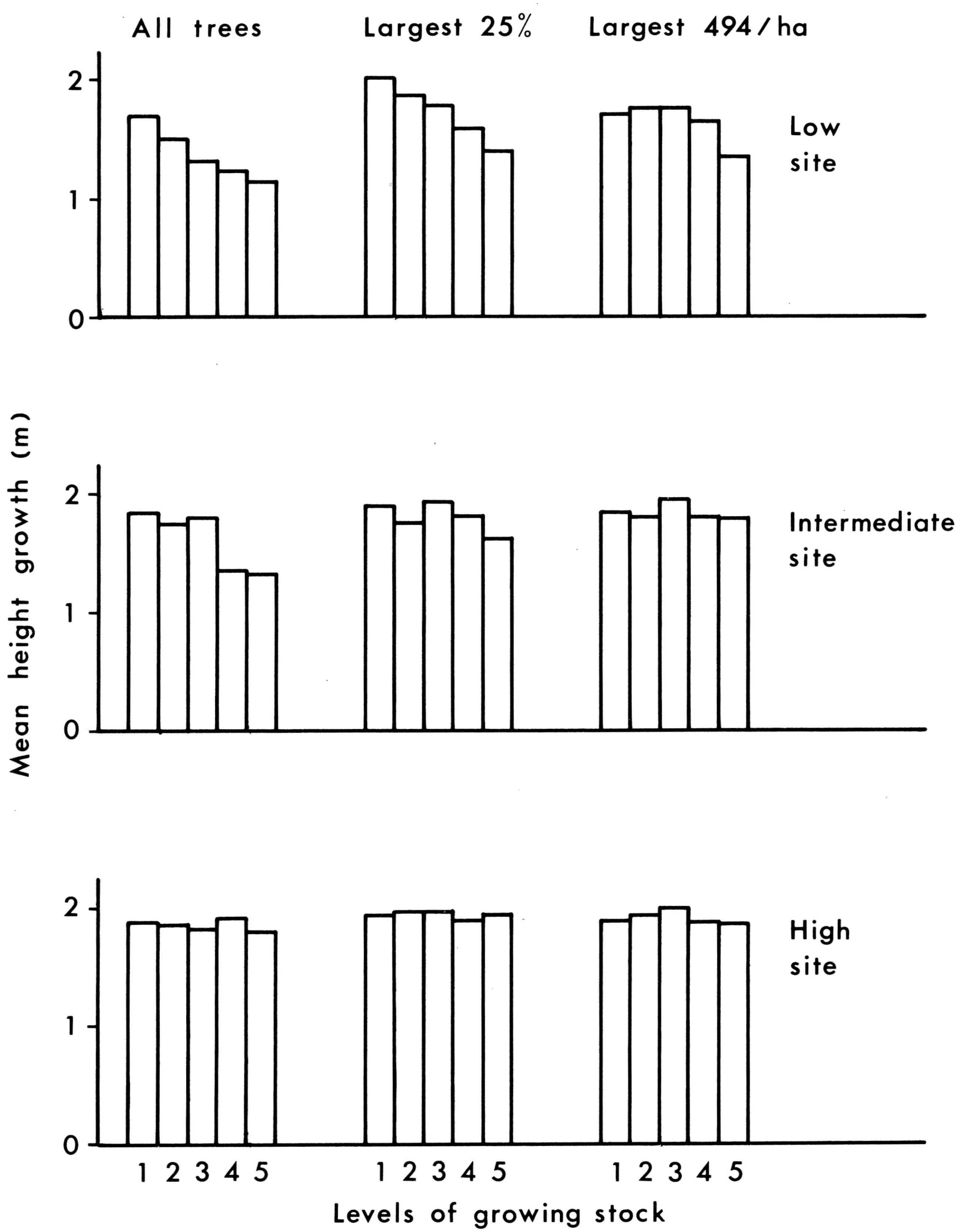

Figure 3. The effect of spacing on periodic height growth of lodgepole pine from ages 15 to 20 years.

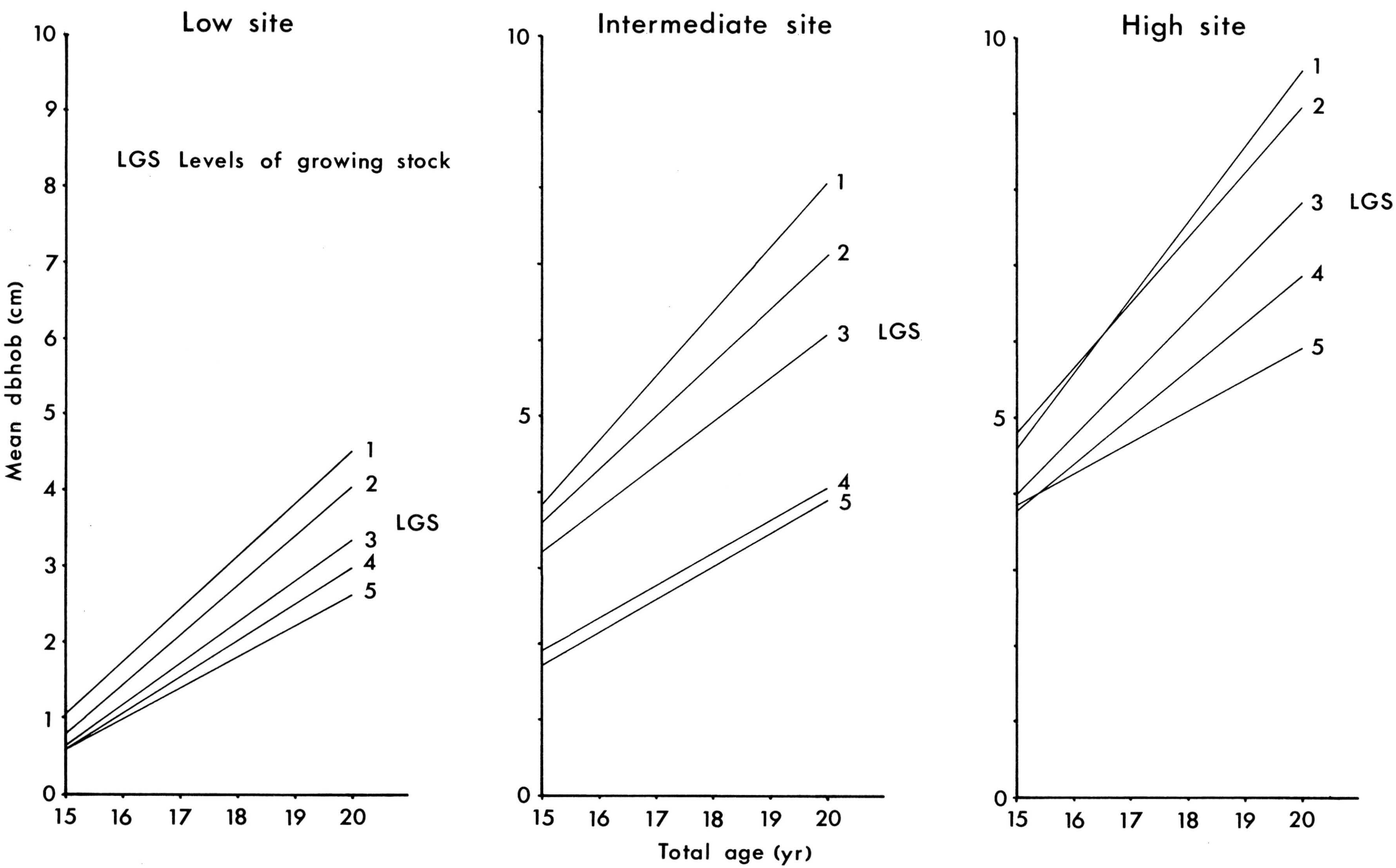

Figure 4. Diameter development of spaced lodgepole pine.

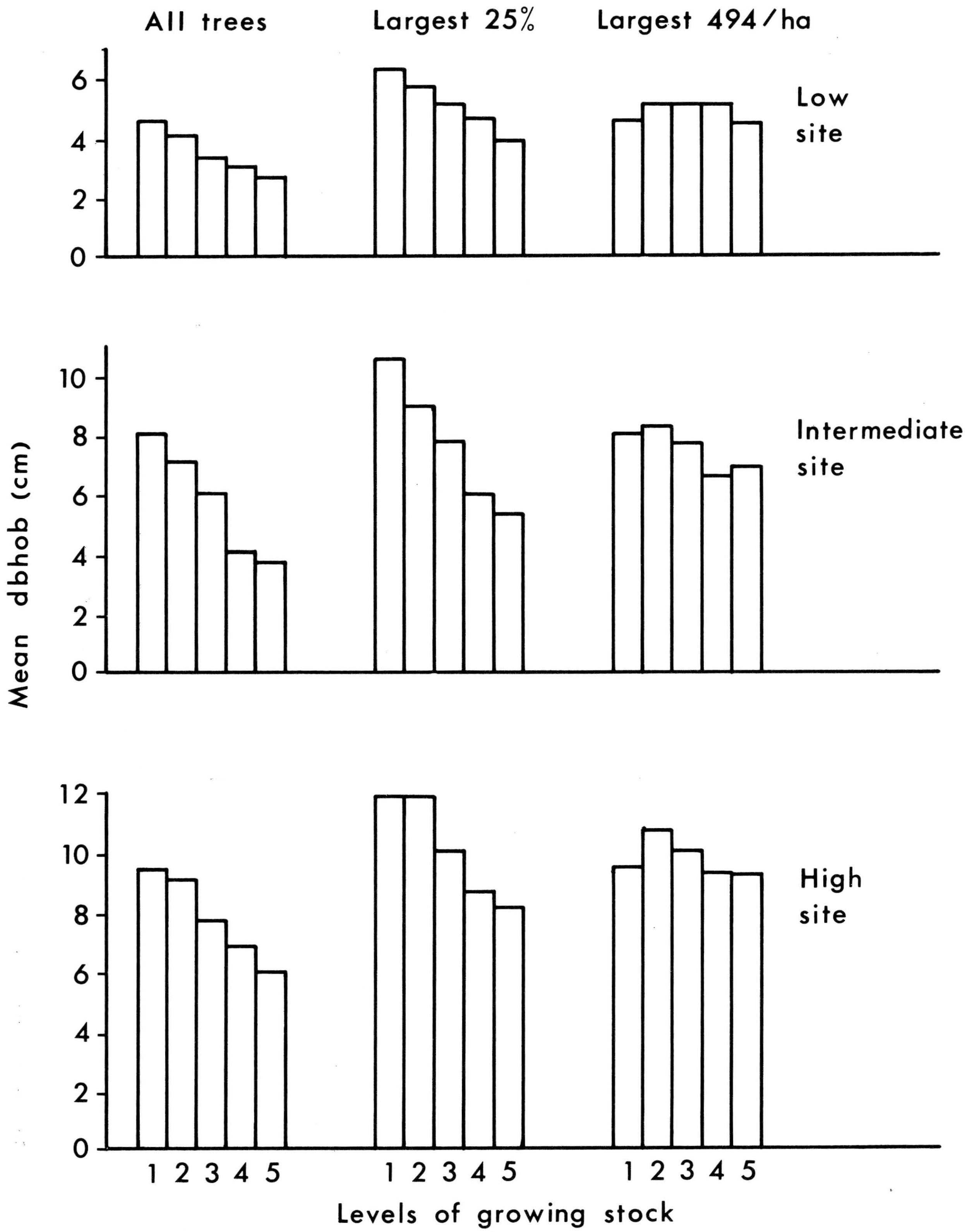

Figure 5. The effect of spacing on mean diameter of 20-year-old lodgepole pine.

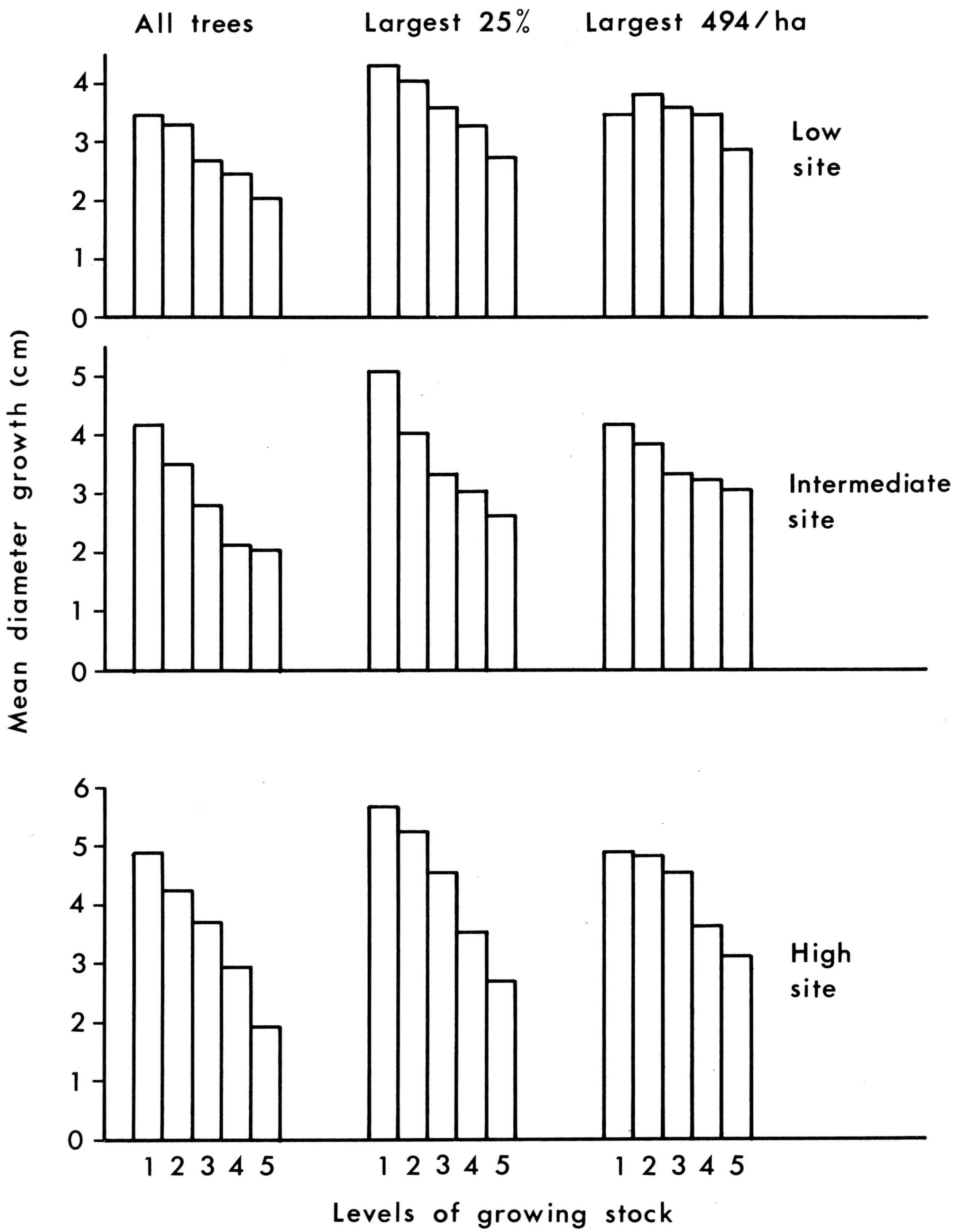

Figure 6. The effect of spacing on periodic diameter growth of lodgepole pine from ages 15 to 20 years.

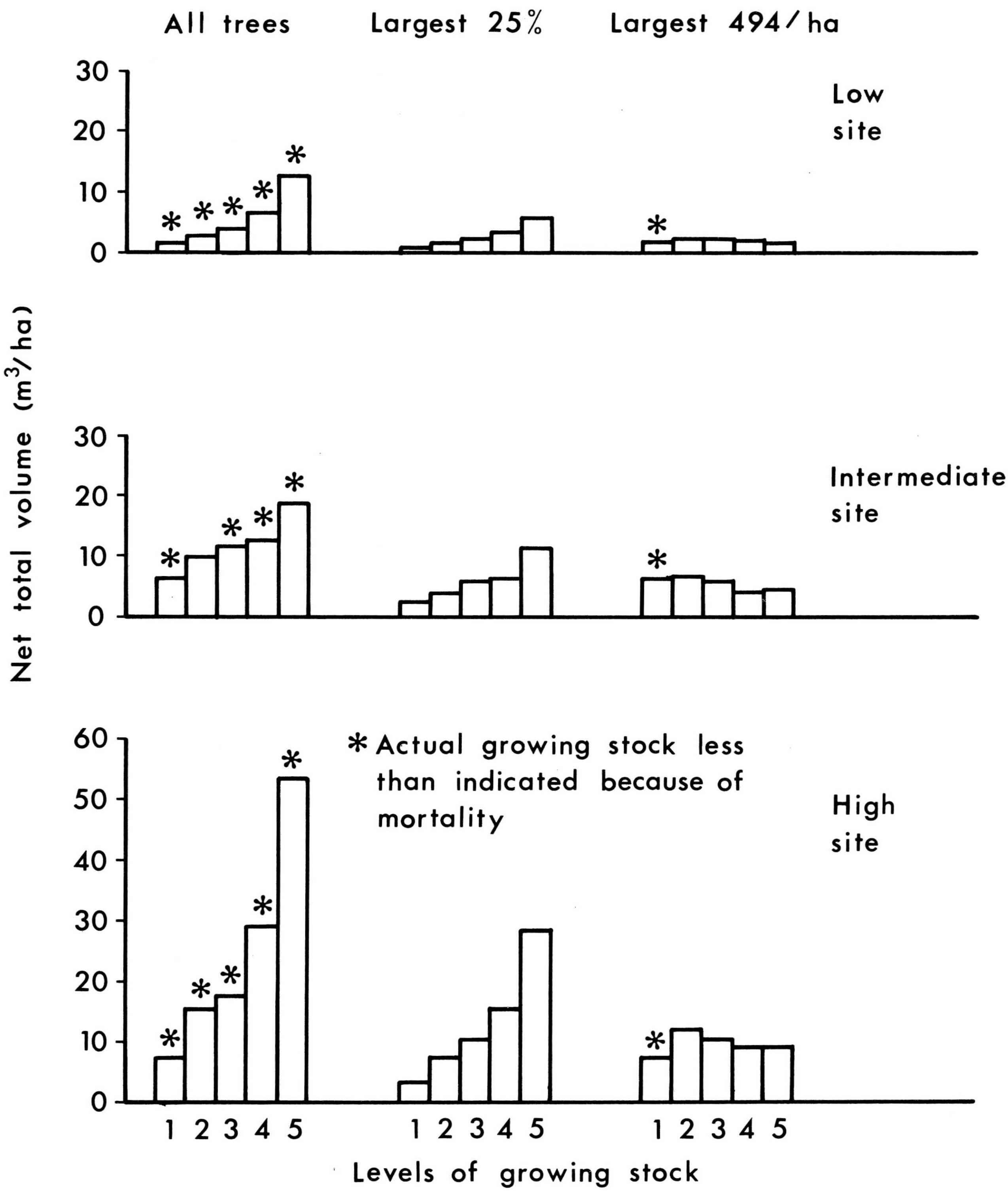

Figure 7. The effect of spacing on total volume per hectare of 20-year-old lodgepole pine.

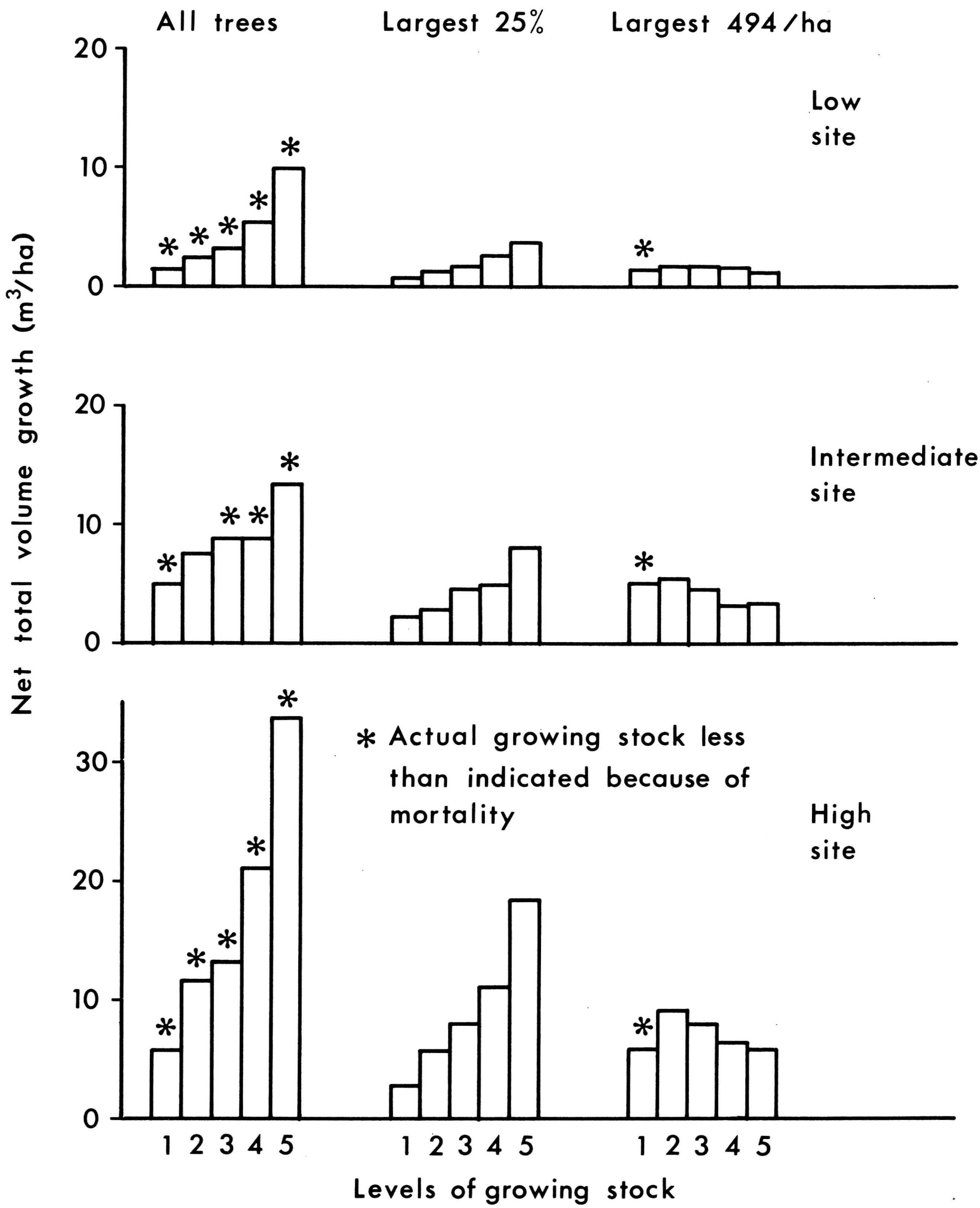

Figure 8. The effect of spacing on periodic total volume growth of lodgepole pine from ages 15 to 20 years.

as yet, uncertain. The significant site × spacing interaction in both volume per hectare and volume growth per hectare for the largest 25% of the trees (Table 3) indicates that their rate of change with respect to spacing varies with site productivity. When an equal number (494) of the largest trees per hectare were compared, only the mean volume growth per tree was significantly affected by spacing, and only the growth at LGS 2 was significantly higher than the growth at LGS 4 and 5 (Appendix 1).

DAMAGE TO TREES AND MORTALITY

An analysis of variance indicated that percentage mortality, which varied from 3% to 44%, was not significantly related to either site or spacing; however, a trend to higher mortality on the higher productivity site appears to be developing. Although numerous damaging agents are present in the plots, shoestring root rot (*Armillaria mellea* (Vahl. ex Fr.) Kummer) has been the main cause of mortality (Fig. 9a). Because the root rot infections spread from central foci with time, large open patches are now developing in some plots (Fig. 9b).

A large proportion of the sample trees are infected by western gall rust (*Endocronartium harknessii* (J.P. Moore) Y. Hiratsuka). The rust is less devastating than the root rot, but if it infects the bole it can reduce growth and quality and increase wind-break susceptibility (Fig. 9c). Fortunately, most of the infections are limited to the branches (Fig. 9d). Because the rust spores are transported by wind, this organism's areal rate-of-spread may be increased with wider spacing.

Numerous sample trees have also been attacked by lodgepole pine terminal weevil (*Pissodes terminalis* Hopp.). These attacks not only result in a loss of height growth but also cause forked tops and an associated reduction in stem quality (Fig. 9e).

Since the 1976 remeasurement, portions of the stem bark of several sample trees have been stripped by small mammals (Fig. 9f). Mortality can result if the stem is fully girdled, but even partial removal of the bark may be a problem because it provides paths-of-entry for other damaging agents (i.e., stains and decays). The full extent of the damage will not be known until the next measurement; however, the potential impact of damage caused by small mammals (i.e., porcupines (*Erethizon expixanthum* Brandt), snowshoe hares (*Lepus americanus*), and red squirrels (*Tamiasciurus hudsonicus*)) may be equal to the damage realized from root rots.

CONCLUSIONS AND RECOMMENDATIONS

The short-term results obtained in this study to date are very encouraging. Spacing has had a major effect on stand growth and development. This effect was most dramatic on average stand diameter and diameter growth, thus agreeing with earlier results reported by Alexander (1965), Cole (1976), Dahms (1967), Daniel and Barnes (1958), and Smithers (1957). Averaged over all sites, LGS 1 achieved increases of 78% in average stand diameter and 109% in average stand diameter growth compared to LGS 5. The impact of spacing on average stand height and average stand height growth was less dramatic and only of major consequence on the low and intermediate productivity sites. Despite faster individual tree growth at wider spacings, optimization of individual growth rate with the level of growing stock is required to maximize the yield per unit area.

The results generally indicate that, for the range of spacings tested, closer spacing may not result in a reduction in the average size of a large number of crop trees (about 500 per hectare). Although the significant effect of spacing on crop-tree growth rate does suggest that crop-tree size differences may eventually develop, this current lack of effect does offer the forest manager some flexibility in planning his juvenile spacing operations. This flexibility is indeed fortunate in view of the high risk from damaging agents observed in the present study.

Based upon the results to date, the following recommendations can be made:

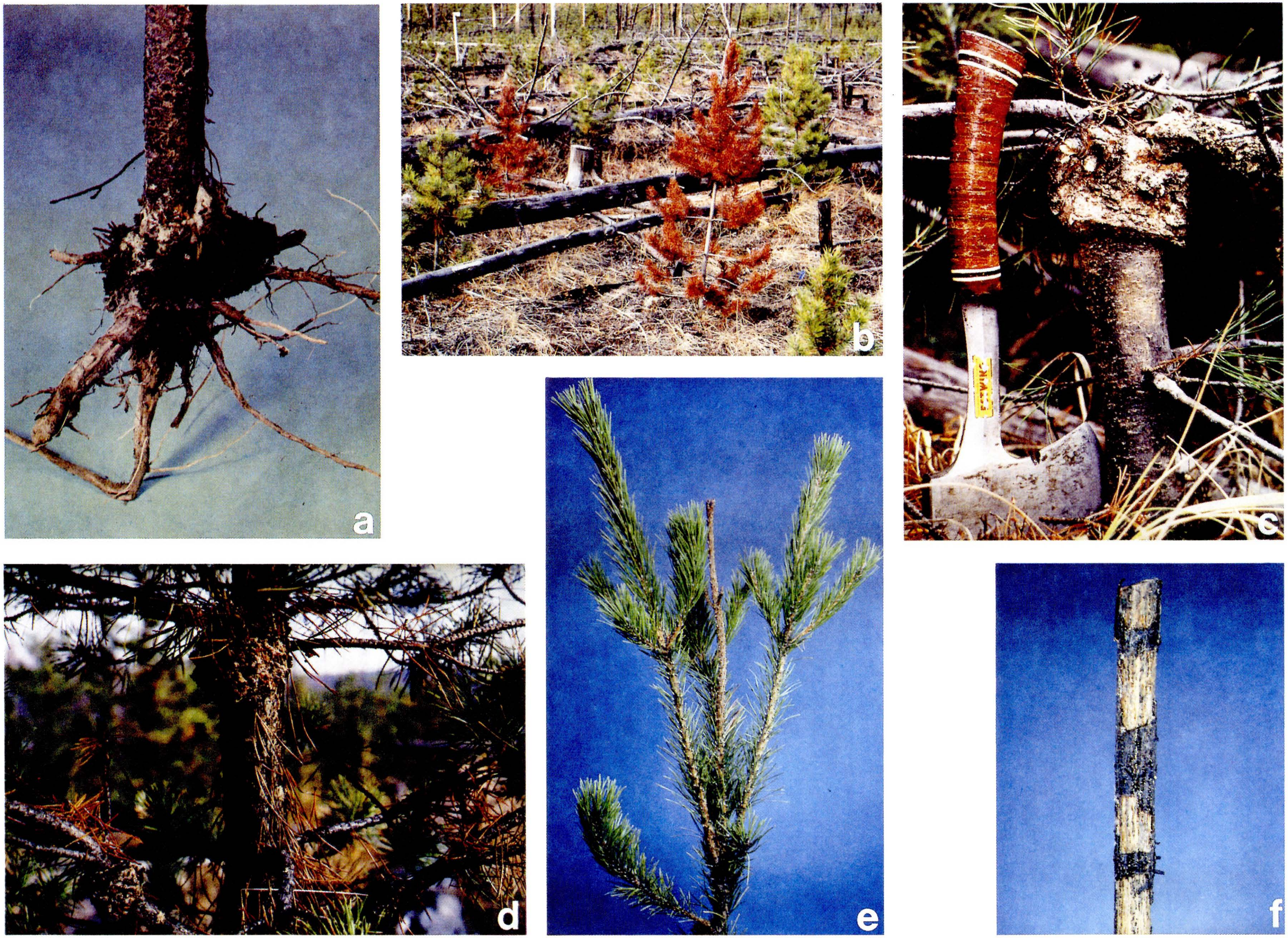

Figure 9. Damage to spaced lodgepole pine. a. Shoestring root rot. Note characteristic resinosis at root collar. b. Root rot pocket developing. c. Stem broken as a result of weakness at gall location. d. Stem and branch galls. e. Terminal leader killed by weevil. Note formation of forked top. f. Stem bark stripped by small mammals.

1. Young stands containing under 8000 stems per hectare (about 3200 per acre) should be given a low priority for treatment.

2. A post-treatment density of 2000-2500 stems per hectare (about 800-1000 per acre) is reasonable in young stands.

3. A somewhat wider spacing should be used on poor productivity sites.

4. Stand tending operations should not be undertaken in areas with a high incidence of root rot.

5. Avoid spacing stands that are heavily infected with gall rust, and selectively remove diseased trees when treating stands.

6. If practical, time stand tending to coincide with declines in small mammal populations.

Incorporation of these recommendations into stand tending guidelines should ensure vigorous early growth yet provide a hedge against the depredations of animals, insects, and diseases. Continued periodic remeasurement and analysis of this study will verify and expand the conclusions reached to date.

ACKNOWLEDGMENTS

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APPENDIX 1

COMPARISON OF TREATMENT MEANS[1]

Characteristic	Stand component	Level of growing stock				
Mean height:	All trees	5	4	3	2	1
(Age 20)	Largest 25%	5	4	3	2	1
	Largest 494/ha	2	3	5	4	1
Mean periodic height growth:	All trees	5	4	3	2	1
(Age 15-20)	Largest 25%	5	4	2	3	1
	Largest 494/ha	5	4	1	2	3
Mean dbhob:	All trees	5	4	3	2	1
(Age 20)	Largest 25%	5	4	3	2	1
	Largest 494/ha	5	4	1	3	2
Mean periodic dbhob growth:	All trees	5	4	3	2	1
(Age 15-20)	Largest 25%	5	4	3	2	1
	Largest 494/ha	5	4	3	2	1
Basal area/ha:	All trees	1	2	3	4	5
(Age 20)	Largest 25%	1	2	3	4	5
	Largest 494/ha	5	4	1	3	2
Periodic basal area growth/ha:	All trees	1	2	3	4	5
(Age 15-20)	Largest 25%	1	2	3	4	5
	Largest 494/ha	5	4	1	3	2
Mean total volume/tree:	All trees	5	4	3	2	1
(Age 20)	Largest 25%	5	4	3	2	1
	Largest 494/ha	4	5	1	3	2
Mean periodic total volume growth/tree:	All trees	5	4	3	2	1
(Age 15-20)	Largest 25%	5	4	3	2	1
	Largest 494/ha	5	4	1	3	2

APPENDIX 1 continued

Characteristic	Stand component	Level of growing stock				
Net total volume/ha:	All trees	1	2	3	4	5
(Age 20)	Largest 25%	1	2	3	4	5
	Largest 494/ha	4	5	1	3	2
Periodic net total volume growth/ha:	All trees	1	2	3	4	5
(Age 15-20)	Largest 25%	1	2	3	4	5
	Largest 494/ha	5	4	1	3	2

[1] Treatments are arranged in *ascending* order of means. Treatments underscored by the same line are not significantly different at $p = 0.05$.