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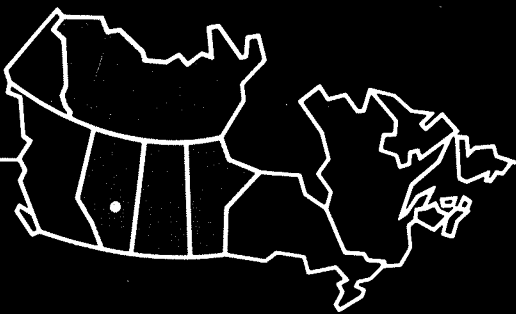

JUVENILE SPACING OF 25-YEAR-OLD LODGEPOLE PINE IN WESTERN ALBERTA

W.D. JOHNSTONE[1]

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ABSTRACT

The effects of spacing 25-year-old fire-origin lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) in western Alberta are reported 10 years 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 located on three site types. Data were analyzed in terms of the entire stand and portions of it. Spacing had a significant effect on stand and crop-tree growth and development. Wide spacing resulted in greater diameter increments and greater stand and crop-tree average diameters.

RESUME

Dix ans après le traitement, on étudie, dans l'ouest de l'Alberta, les effets de l'espacement de pins tordus latifoliés (*Pinus contorta* Dougl. var. *latifolia* Engelm.) d'origine pyrophytique. Cinq espacements soit 494, 988, 1977, 3954, et 7907 arbres à l'hectare (200, 400, 800, 1600, and 3200 arbres à l'acre) avaient été établis sur des parcelles situées sur trois types de stations. Les données ont été analysées pour l'ensemble du peuplement et pour certaines parties. L'espacement a eu un effet important sur le peuplement et sur la croissance et le développement des arbres du peuplement final. Les espacements larges ont procuré des accroissements plus grands et des diamètres moyens plus grands pour l'ensemble du peuplement et pour les arbres du peuplement final.

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INTRODUCTION

Stands of lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) are commonly overly dense following wildfires or scarification. Although excessive stand density reduces tree and stand growth (Johnstone 1976), previous studies (Alexander 1956, 1960, 1965; Barrett 1961; Cole 1975; Dahms 1967, 1971a, b, c, 1973; Daniel and Barnes 1958; Johnstone 1981a, b; Smithers 1957, 1961) have indicated that young lodgepole pine will respond favorably to juvenile spacing or precommercial thinning. This report presents the effects, for the first 10 years after treatment, of various spacings on the development of dense, fire-origin stands of 25-year-old lodgepole pine.

METHODS

STAND SELECTION AND SITE DESCRIPTION

The study area is south of the Clearwater Ranger Station, in the Bow-Crow Forest, near the junction of the Forestry Trunk Road and Tepee Pole Creek (51°53′, 115°03′). Forests in this area are within the Upper Foothills Section (B.19c) of the Boreal Forest Region (Rowe 1972) and are predominantly lodgepole pine with local patches of black spruce (*Picea mariana* Mill.). The spacings were carried out during the fall of 1967 in an even-aged, 25-year-old stand of lodgepole pine that regenerated naturally following a 1941 wildfire. Prior to spacing, stand density ranged as high as 250 000 stems per hectare (100 000 stems per acre), and the average tree height was about 3 m (9 ft.).

The study was established on three different site types. The soil of the north-facing Site 1 is a well-drained Eluviated Eutric Brunisol developed on a sandy loam-textured Cordilleran till. Sandstone bedrock of the Paskapoo formation was reached at 65 cm. A thin silt-loam fluvioeolian veneer was evident on lower-slope positions in the plot area. Although not mapped, the soil is similar to the Maskuta soil unit of Peters (1981). Vegetation on Site 1 is similar to the lodgepole pine-alder-arnica-feather moss type of Krumlik *et al.*[1] or the *Pinus contorta/Alnus crispa/Cornus canadensis* type of Corns (1978). Site 2 is on a level, well-drained Brunisolic Gray Luvisol developed on Cordilleran till with a 12-cm fluvioeolian veneer. Depth to parent material varies from 25 to 56 cm. The soils are similar to the Nordegg soil unit of Peters (1981), and the vegetation resembles that described for Site 1. Site 3 has a southerly aspect and the soil is a well-drained Brunisolic Gray Luvisol developed on Cordilleran till over sandstone of the Paskapoo formation to 60 cm. The soil is similar to Peters' (1981) Maskuta soil unit. Toward the western edge of this location there were drier soils, with truncated development due to shallow depth to bedrock. Vegetation on Site 3 is similar to that on sites 1 and 2, with exception of the more xeric western edge, where *Arctostaphylos uva-ursi*, *Amelanchier alnifolia*, and *Juniperus communis* are present.

STUDY DESIGN AND ESTABLISHMENT

The experimental design and methods of establishment used in this study are the same as those used in another lodgepole pine spacing trial reported by Johnstone (1981a). Five spacing levels (Table 1), referred to in this report as levels of growing stock (LGS) 1, 2, 3, 4, and 5, were established on variable area plots consisting of 100 treatment trees per plot. Two blocks, each containing the five spacings, were established on each site. The study therefore is based on 3000 treatment trees from three sites, each containing two blocks of five plots each. The procedure by which treatments were assigned to each plot is given by Johnstone (1981a). After treatment assignment, a 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

[1] Krumlik, G.V., J.D. Johnson, and L.D. Lemmen. Unpublished progress report for 1978-79 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

sizes were determined by the various spacings (Table 1).

TREE MEASUREMENT AND COMPILATION

In the fall of 1967, following spacing, all treatment trees were tagged and their diameter at breast height outside bark (dbhob) and total height were recorded. During the falls of 1972 and 1977, all treatment trees were remeasured, and their dbhob and total height were recorded. 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 Bowen's (1974) recommended conversion factors. 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 = dbhob in inches
   H = total height in feet.

ANALYSES

In lieu of treatment surrounds, the analyses were based only upon data from the 64 inner sample 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:

1. stand data for all sample trees,

2. largest (dbhob) 25% of the sample trees in 1977, and

3. sample trees representing the 494 largest dbhob stems per hectare in 1977, 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

[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.

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	Areal equivalents		No. sample	Areal equivalents		No. sample	Areal 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	1977	800	4	494	200

derive net per-hectare values for the largest 25% and largest 494 stems per hectare in 1977, chosen from the 64 sample trees.

Analyses of variance and covariance were used to determine the effects of site and spacing on the growth and development of the sample trees. Analysis of variance was used to detect significant differences in treatment means after spacing in 1967. It was also used to compare the effects in 1977 of the per-hectare characteristics (of all trees and of the largest 25%) that were directly influenced by the spacing. Because growth response may vary with initial tree size, covariance analysis was used to determine the effects in 1977 of spacing on those characteristics (i.e., average and largest 494 stems per hectare values) that should not have been directly affected by the spacing in 1967. In these covariance analyses, growth response or size in 1977 was adjusted for differences in initial (1967) size. The following randomized complete-block partitioning of sources of variation was used for all analyses:

Sources of variation	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 unadjusted treatment means were made using Duncan's new multiple-range test. Comparisons of adjusted treatment means were based upon 't' tests using the standard error of the difference of two adjusted means (Steel and Torrie 1960).

RESULTS AND DISCUSSION

There were no significant differences between blocks within each site. Consequently, data from both blocks within 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, except for the periodic basal area growth of the largest 25% of the trees, site had a significant effect upon component development. Detailed comparisons of treatment means for the stand components are presented in Appendix 1. The confounding of soil differences among the three sites precludes a complete comparison between aspects (i.e., site differences may not be solely due to aspect). In addition, variations in soil depth among the south-facing plots have resulted in a more-erratic treatment response on Site 3 than on sites 1 and 2. The relative ranking of site productivity, based upon stand characteristics at the time of spacing, would have been lowest, highest, and intermediate for sites 1, 2, and 3, respectively.

HEIGHT

Spacing had a significant effect on the mean height of lodgepole pine 10 years after treatment (Table 3), although the effect was inconclusive and undramatic (Fig. 1). For all

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; n.s., not significant at p = 0.05 level)

Characteristic	Source of variation[1]	Stand component: All trees	Largest 25%	Largest 494/ha
Mean height	S	**	**	**
(Age 35)	T	**	**	**
	S X T	n.s.	n.s.	*
Mean periodic height growth	S	**	**	**
(Age 25-35)	T	**	**	**
	S X T	n.s.	n.s.	*
Mean dbhob	S	*	**	**
(Age 35)	T	**	**	**
	S X T	n.s.	n.s.	n.s.
Mean periodic dbhob growth	S	*	**	**
(Age 25-35)	T	**	**	**
	S X T	n.s.	n.s.	n.s.
Basal area/ha	S	**	**	**
(Age 35)	T	**	**	**
	S X T	**	*	n.s.
Periodic basal area growth/ha	S	*	n.s.	**
(Age 25-35)	T	**	**	**
	S X T	n.s.	n.s.	n.s.
Mean total volume/tree	S	**	**	**
(Age 35)	T	**	**	**
	S X T	*	*	**
Mean periodic total volume growth/tree	S	**	**	**
(Age 25-35)	T	**	**	**
	S X T	*	*	**
Net total volume/ha	S	**	**	**
(Age 35)	T	**	**	**
	S X T	**	**	*
Periodic net total volume growth/ha	S	**	**	**
(Age 25-35)	T	**	**	**
	S X T	**	**	*

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

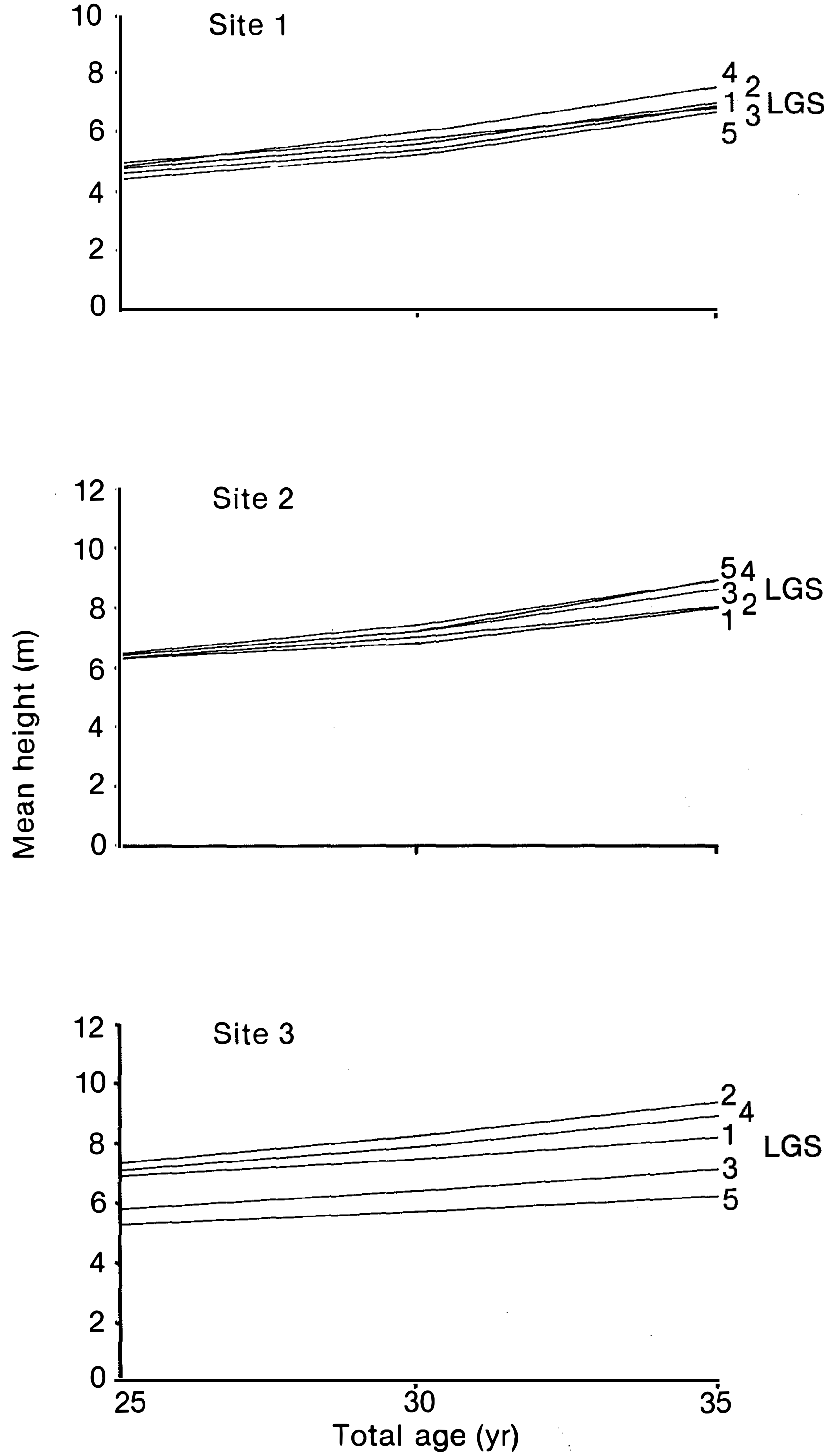

Figure 1. Height development of spaced lodgepole pine.

sites and after adjustment for initial height differences, the shortest trees were observed at LGS 1 and the tallest at LGS 4 (Appendix 1). This pattern for mean height was consistent for all stand components on all sites except for the largest 494 trees per hectare on Site 2, where the tallest trees were observed at LGS 5 (Fig. 2). This change on Site 2, plus the somewhat erratic behavior on Site 3, resulted in the significant site × spacing interaction shown in Table 3.

Spacing significantly affected periodic height growth during the past 10 years (Fig. 3). The fastest and slowest growth rates were consistently observed at LGS 4 and LGS 1, respectively (Appendix 1). Exceptions to this were observed for the largest 494 trees per hectare on Site 2, which resulted in a significant site × spacing interaction (Table 3), and for all trees on Site 3. Although Site 1 had initially shorter trees (Fig. 1), it also had the fastest periodic height growth for all components (Fig. 3).

DIAMETER

Spacing dramatically affected diameter development on all sites (Fig. 4). It also had a highly significant effect on mean stand diameter (Table 3) and, unlike the effect on stand height, this effect was apparent on all sites. After adjustment for significant initial differences in diameter, mean diameter 10 years after treatment generally decreased directly with decreased spacing (Fig. 5), although for some components slightly larger diameters were observed at LGS 2 instead of at LGS 1. For all components, LGS 1 and 2 had significantly larger mean diameters than LGS 4 and 5.

The effect of spacing on periodic diameter growth during the past 10 years was highly significant (Table 3). A large decline in diameter increment occurred at the closest spacings on all sites (Fig. 6). On all sites and for all components, LGS 1 and 2 grew significantly faster than LGS 4 and 5 (Appendix 1). If the present differences in the rate of diameter growth continue (Fig. 6), the expected widest-spacing-largest-diameter pattern will probably occur on Site 3 in the near future. The diameter growth on Site 1, where the trees were initially significantly smaller, now exceeds the growth on Site 3.

BASAL AREA

When all trees or the largest 25% of the trees were considered, wider spacing resulted in significantly lower basal areas per hectare because the smaller average tree size was more than compensated for by the higher numbers of trees at the closer spacings (Appendix 1). When an equal number (494) of the largest trees per hectare were compared, LGS 2 produced the highest basal area 10 years after spacing. The significant site × spacing interaction (Table 3) in the basal areas of all trees and of the largest 25% of the trees reflects a faster rate of increase in basal area with closer spacing on sites 2 and 3.

Periodic basal area growth per hectare for all stand components was significantly affected by spacing (Table 3). Basal area increment was greater at closer spacings for both the entire stand and for the largest 25% of the trees. Comparing the largest 494 trees per hectare, the largest basal area growth occurred at LGS 2 and the smallest growth occurred at LGS 5 (Appendix 1).

VOLUME

Both volume and volume growth per hectare were significantly lower at wider spacings for both the entire stand and for the largest 25% of the trees (Figs. 7-9). As with basal area, this occurs because of the disproportionately higher numbers of trees at the closer spacings, despite significantly larger and faster-growing trees at wider spacings (Appendix 1). Comparing an equal number (494) of the largest trees averaged over all sites, the largest volume per tree and the largest volume growth per tree were observed at LGS 2. As a result, the largest volume and volume growth per hectare also occurred at LGS 2 (Appendix 1). The significant site × spacing interaction for all volume characteristics of all stand components (Table 3) indicates the differential response to spacing on the various sites.

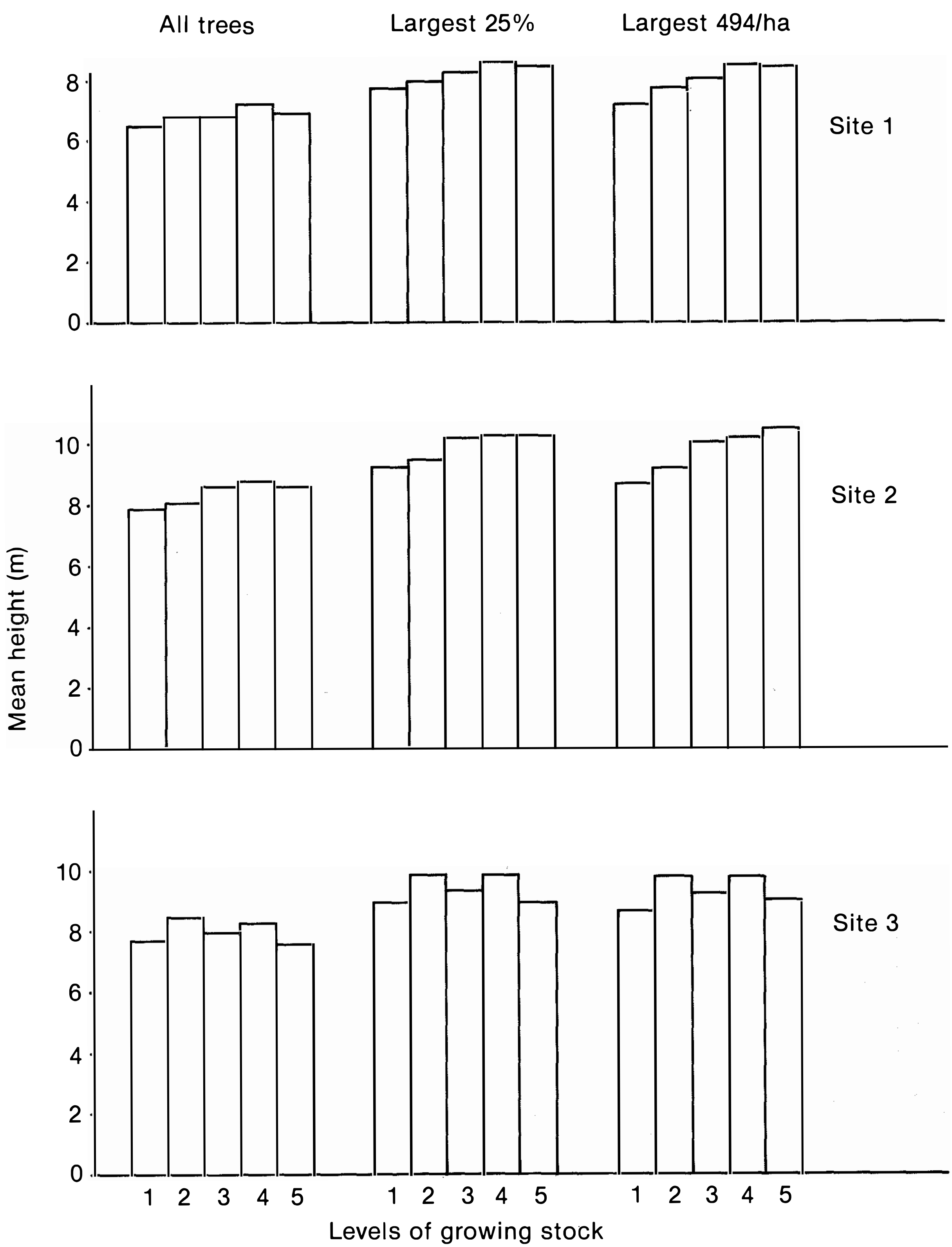

Figure 2. The effect of spacing on adjusted mean height of 35-year-old lodgepole pine.

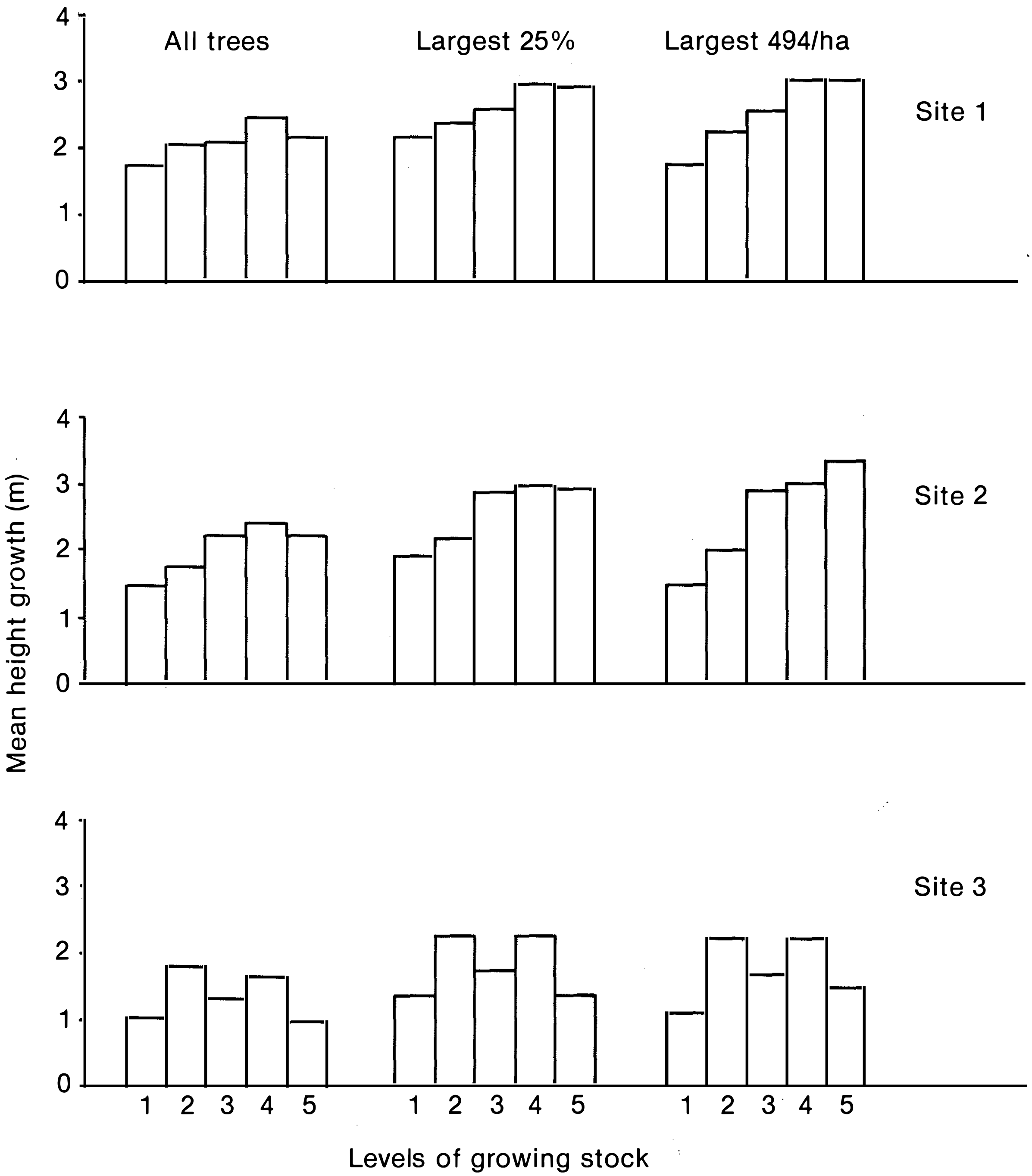

Figure 3. The effect of spacing on adjusted periodic height growth of lodgepole pine from ages 25 to 35 years.

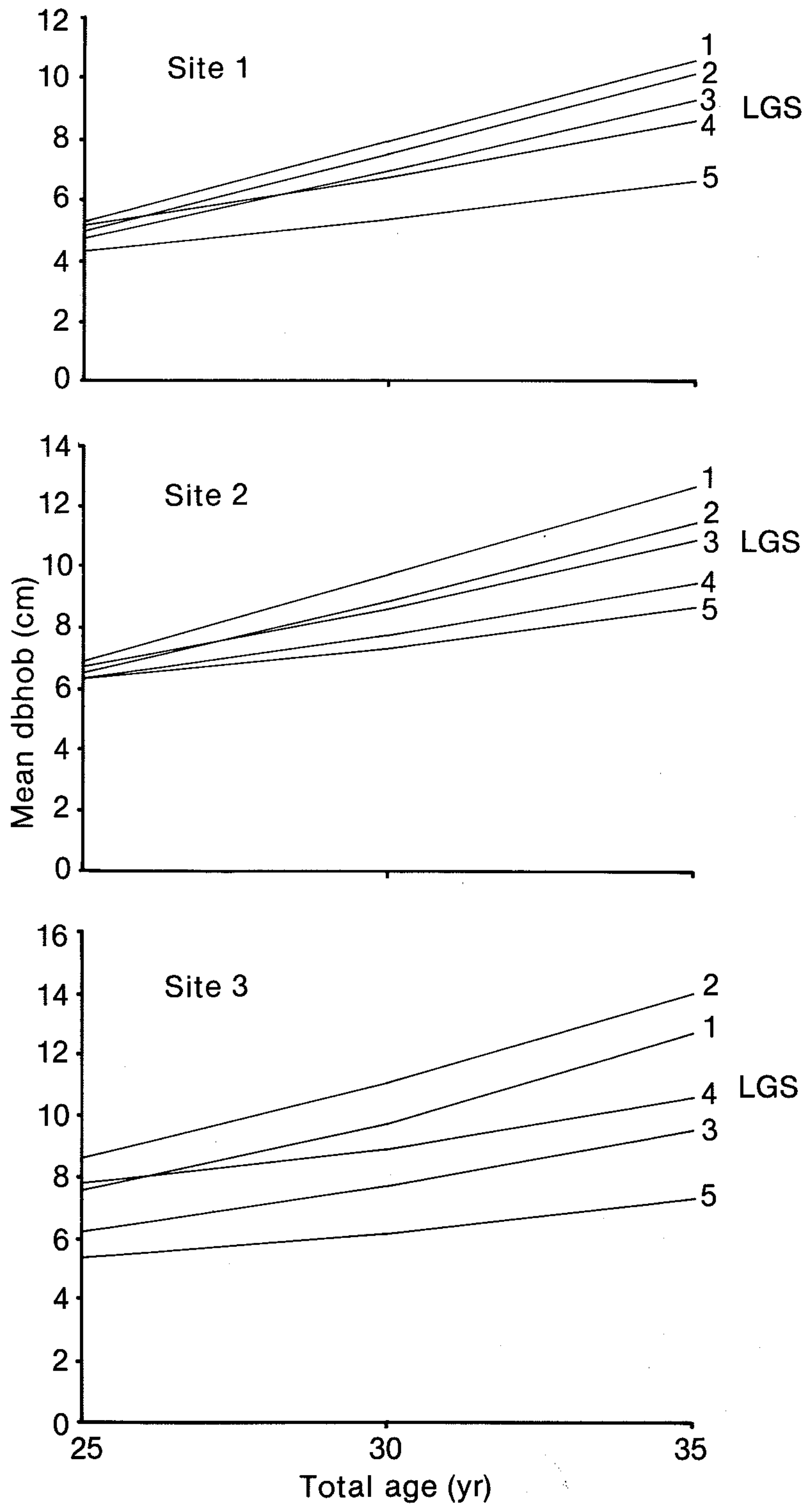

Figure 4. Diameter development of spaced lodgepole pine.

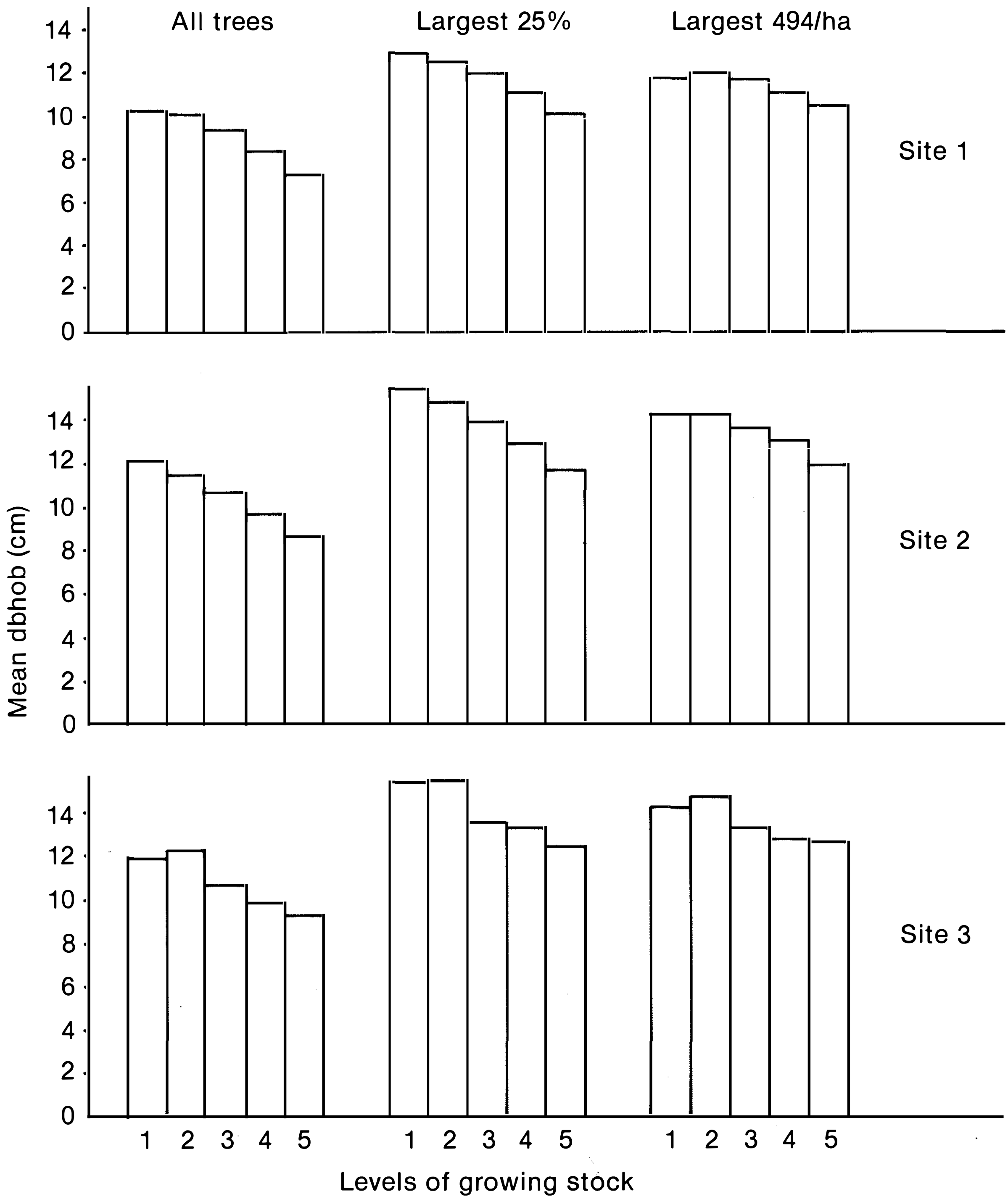

Figure 5. The effect of spacing on adjusted mean diameter of 35-year-old lodgepole pine.

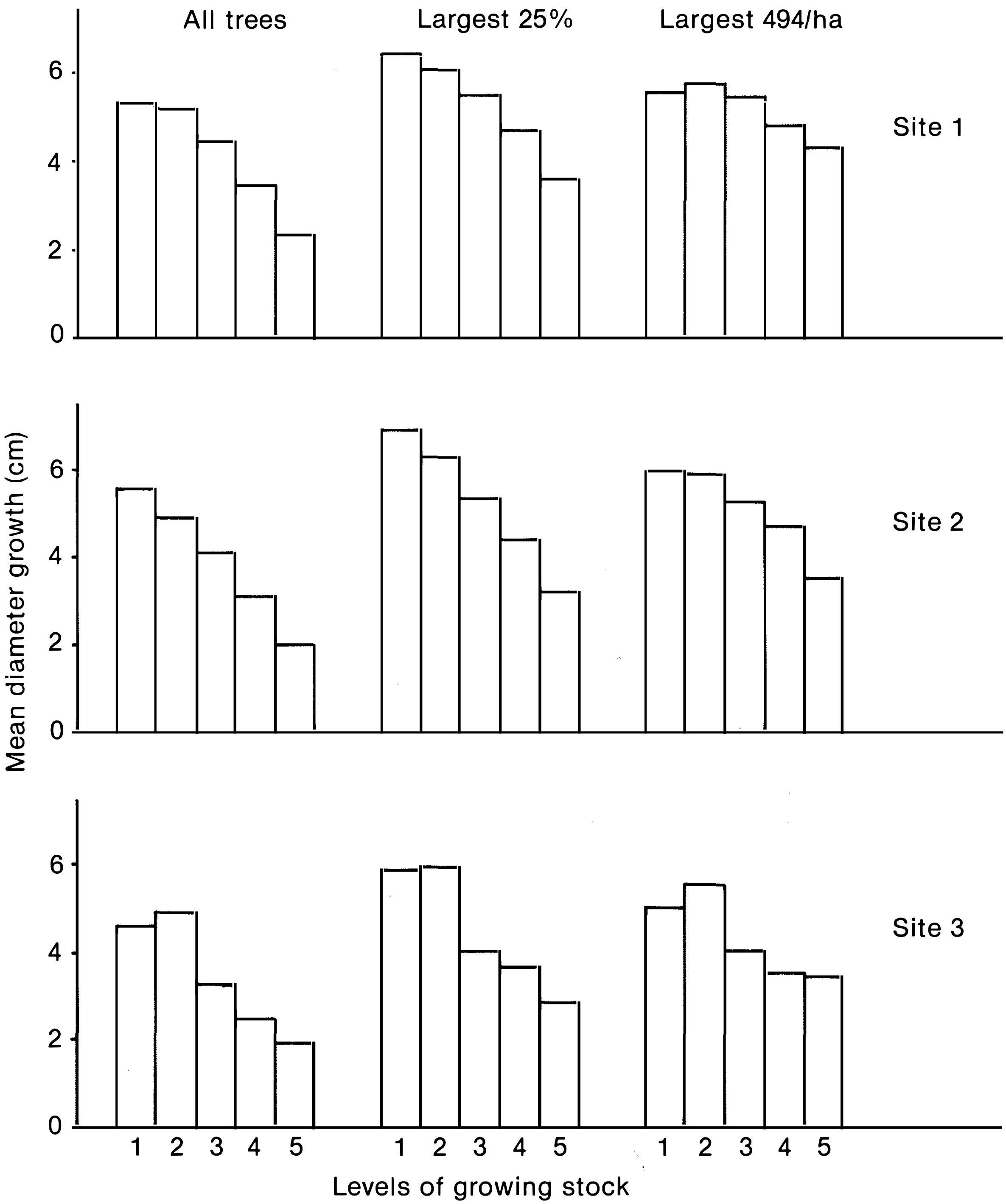

Figure 6. The effect of spacing on adjusted periodic diameter growth of lodgepole pine from ages 25 to 35 years.

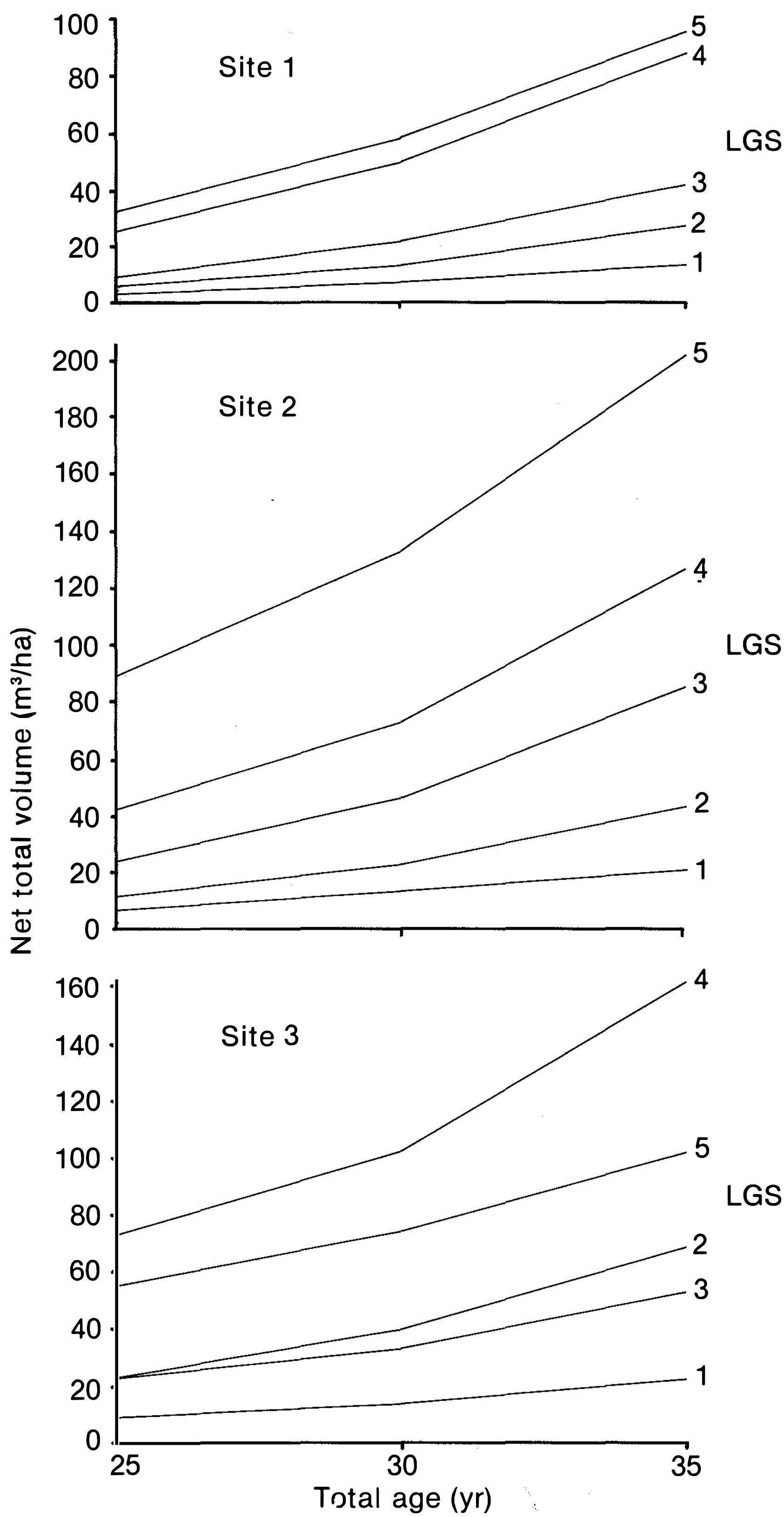

Figure 7. Net total volume development of spaced lodgepole pine.

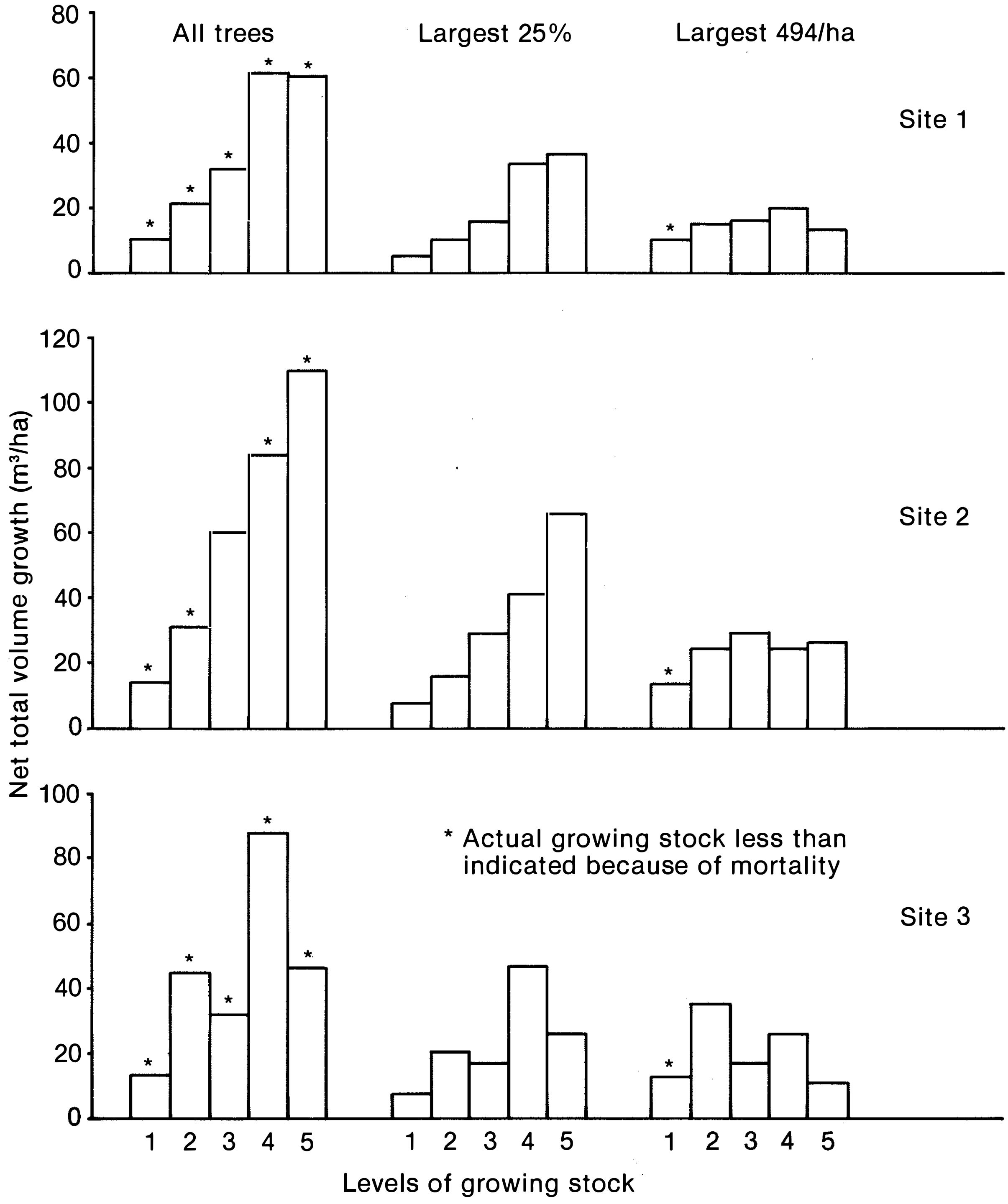

Figure 8. The effect of spacing on total volume per hectare of 35-year-old lodgepole pine.

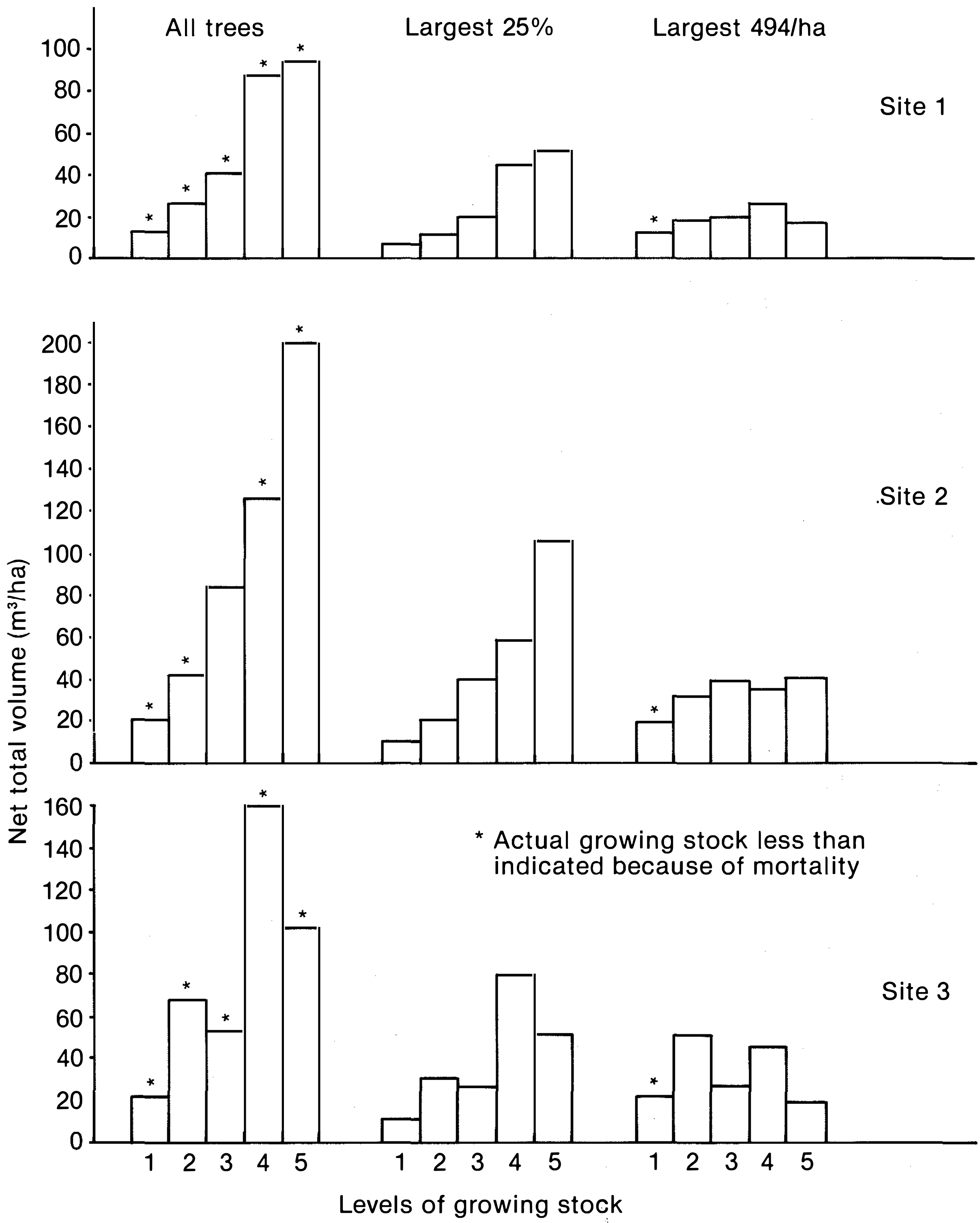

Figure 9. The effect of spacing on periodic total volume growth per hectare of lodgepole pine from ages 25 to 35 years.

MORTALITY

During the first 10 years following spacing, 10% of all trees died. An analysis of variance indicated that mortality, which varied from 0 to 33%, was significantly related only to spacing. Averaged over all sites, mortality was significantly higher at LGS 1 than at LGS 2, 3, or 4. Mortality in this study was attributable to climatic factors, mainly windthrow and snow-press, rather than biotic causes.

CONCLUSIONS

This study has clearly demonstrated that juvenile spacing has a substantial effect on stand growth and development. The response to spacing, particularly relative response, was most pronounced on the site of apparent lowest productivity. The most dramatic effect of spacing was on average stand diameter and diameter growth. This result is consistent with results from previously reported studies of spacing lodgepole pine (Alexander 1965; Cole 1975; Dahms 1967; Daniel and Barnes 1958; Johnstone 1981a, b; Smithers 1957). Averaged over all sites and after adjustment for initial differences in tree size, average diameter was 36% larger and average diameter growth was 144% greater for LGS 1 compared to LGS 5. Although the results are not directly comparable, response to the manual, selective spacing conducted in this study appears to be substantially greater than the response to the mechical strip thinning conducted in an area immediately adjacent to this study area (Bella and De Franceschi 1977).

In contrast to diameter response, a somewhat erratic and inconclusive height growth response to spacing was observed in this study. In fact, significantly lower periodic height growth was observed at the widest spacing. Reasons for the lack of a direct height-growth-spacing response are unclear, but these results add to the growing body of evidence (Alexander 1960; Johnstone 1981a, b) indicating that lodgepole pine requires a limited degree of crowding to achieve maximum height growth.

Unlike spacing in younger stands (Johnstone 1981a), close spacing in 25-year-old lodgepole pine stands may result in reduction of the average size of a large number of crop trees (about 500 trees per hectare). The significant effect of spacing on crop-tree growth rates in this study suggests that these crop-tree size differences are likely to increase in the future. It is apparent, therefore, that the forest manager's flexibility in planning juvenile spacing operations declines as the age stand increases.

The results of this study indicate the need to optimize individual tree growth rates with levels of growing stock in order to maximize yield per unit area. Despite significantly larger and faster-growing trees, both volume and volume growth per hectare were significantly lower at wider spacings. It is also apparent that any process of optimization should incorporate assumptions regarding the risks and uncertainties associated with stand management. Although the stands in the present study remain essentially free of the damaging agents that normally threaten lodgepole pine (Johnstone 1981a), unexpectedly high mortality due to climatic causes has been observed. The degree to which wider spacing affected vulnerability to climatic damage cannot be determined in this study; however, it is apparent that either regular or irregular mortality in widely spaced stands can substantially reduce expected yields and therefore must be anticipated.

The present study has provided short-term, detailed information on the effects of juvenile spacing on the growth and development of lodgepole pine. Continued periodic remeasurement and analysis of this study area will verify and expand the conclusions reached to date.

ACKNOWLEDGMENTS

This study was initiated by Harry Johnson. The author wishes to express his appreciation to Bill Chow for his assistance with data processing, Dr. Ian Corns for describing the soils and vegetation, and especially Stan Lux for his assistance with field measurement and data compilation. The author is also indebted to the British Columbia Ministry of Forests for providing the time required to complete the analysis and prepare this report.

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APPENDIX 1

COMPARISON OF TREATMENT MEANS[1]

Characteristic	Stand component	Level of growing stock				
Mean height:	All trees[2]	1	5	3	2	4
(Age 35)	Largest 25%[2]	1	2	5	3	4
	Largest 494/ha[2]	1	2	3	5	4
Mean periodic height growth:	All trees[2]	1	5	3	2	4
(Age 25-35)	Largest 25%[2]	1	2	5	3	4
	Largest 494/ha[2]	1	2	3	5	4
Mean dbhob:	All trees[2]	5	4	3	2	1
(Age 35)	Largest 25%[2]	5	4	3	2	1
	Largest 494/ha[2]	5	4	3	1	2
Mean periodic dbhob growth:	All trees[2]	5	4	3	2	1
(Age 25-35)	Largest 25%[2]	5	4	3	2	1
	Largest 494/ha[2]	5	4	3	1	2
Basal area/ha:	All trees	1	2	3	4	5
(Age 35)	Largest 25%	1	2	3	4	5
	Largest 494/ha[2]	5	4	1	3	2
Periodic basal area growth/ha:	All trees	1	2	3	5	4
(Age 25-35)	Largest 25%	1	2	3	4	5
	Largest 494/ha[2]	5	4	1	3	2
Mean total volume/tree:	All trees[2]	5	4	3	1	2
(Age 35)	Largest 25%[2]	5	4	3	2	1
	Largest 494/ha[2]	5	4	1	3	2
Mean periodic total volume growth/tree:	All trees[2]	5	4	3	1	2
(Age 25-35)	Largest 25%[2]	5	4	3	2	1
	Largest 494/ha[2]	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 35)	Largest 25%	1	2	3	4	5
	Largest 494/ha[2]	5	1	4	3	2
Periodic net total volume growth/ha:	All trees	1	2	3	5	4
(Age 25-35)	Largest 25%	1	2	3	4	5
	Largest 494/ha[2]	5	1	4	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.

[2] Comparison based upon standard error of difference between two *adjusted* means.