# REGENERATION STOCKING, JUVENILE SPACING, AND FERTILIZATION OF NATURAL LODGEPOLE PINE IN WEST-CENTRAL ALBERTA

## PART II: JUVENILE SPACING

by

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## INTRODUCTION

The juvenile growth, and ultimately the harvest, of natural lodgepole pine stands can be seriously reduced when excessive stand density results in severe inter-tree competition (Johnstone 1976). Smithers (1961) warns that stands containing over 5000 stems per hectare at 90 years of age will not likely provide a reasonable merchantable yield. Although apparently unable to thin itself, lodgepole pine, particularly at young ages, will respond favorably to precommercial thinning or juvenile spacing (Alexander 1956, 1960, 1965; Barrett 1961; Cole 1975; Dahms 1967, 1971a, 1971b, 1971c, 1973; Daniel and Barnes 1958; Johnstone 1981a, 1981b, 1982; Smithers 1957, 1961). This report updates, to 18 years after treatment, a study (Johnstone 1981a) which examined the effects of various spacings on the development of dense, fire-origin stands of 7-year-old lodgepole pine.

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## METHODS

### Site Selection and Study Establishment

The study was established in an area known locally as the Gregg Burn, which is located just south of Hinton, Alberta (53°25', 117°34'). This area is within the Upper Foothills Section (B.19c) of the Boreal Forest Region (Rowe 1972). Three sites, judged to be of low, intermediate, and high productivity, were chosen within pure, even-aged stands of 7-year-old lodgepole pine which regenerated naturally following a 1956 wildfire. Detailed descriptions of these sites are reported by Johnstone (1981a).

The experimental design and methods of establishment are described in detail by Johnstone (1981a). Briefly, five spacing levels or levels of growing stock (LGS) were established on variable area plots, containing 100 treatment trees per plot (Table 1), during the fall of 1963 and the spring of 1964. A square (10 x 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. Grid distances and variable-plot sizes are shown in Table 1. Two blocks, each containing the five spacings, were established on each site. Therefore, the study is based on 3000 treatment trees from three sites, each containing two blocks of five plots each.

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 |

## Measurement, Compilation, and Analysis

In the fall of 1964, after the first growing season following spacing, and in the fall of 1966 the total height was measured and recorded for all treatment trees. The diameter at breast height, total height, crown width, and crown length of each tree were measured in the falls of 1971, 1976, and 1981. Damage to treatment trees caused by insects, diseases, or animals was also recorded. All invading conifers were removed from the plots in 1971.

All measurements 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.). The total volume of each tree was calculated from the following equations[2]:

1. Trees $\leq 8.9$ cm ($\leq 3.5$ in.) dbhob:

   $V = 0.0232 + 0.00253\ D^2H$

2. Trees 9.1-21.6 cm (3.6-8.5 in.) dbhob:

   $V = -0.0949 + 0.00272\ D^2H$

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.

Merchantable volumes, based upon a 10.16 cm (4.0 in.) diameter inside bark top and a 0.30 m (1.0 ft.) stump, were calculated for all trees $\geq 11.68$ cm ($\geq 4.6$ in.) dbhob using Honer's (1967) merchantable conversion function for lodgepole pine.

In lieu of treatment surrounds the analyses were based on the 64 inner sample trees in each plot (*i.e.*, the 36 perimetrical trees provided a buffer). Average

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[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.

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, basal area, or crown area) times the spacing level times the number of live sample trees as a decimal fraction of 64. In these calculations the tree crowns were assumed to be circular in shape. 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 x spacing (S x T) | 8 |
| Block within site (B wi S) | 3 |
| Spacing x block within site (T x B wi S) | 12 |
| Total | 29 |

Treatment means were compared using Ducan's new multiple-range test. In addition, an analysis of covariance (Zar 1974) of 1981 data, was used to determine the effect of spacing on the parabolic relationship between height and diameter over the range of sites.

# RESULTS AND DISCUSSION

Data from both blocks in each site were combined for ease of presentation in this report. This was done despite significant differences in crown width and crown closure between the blocks within each productivity site. For the first time in this experiment significant differences between blocks within sites were also observed for periodic height growth and periodic diameter growth. These differences between blocks within sites may indicate that the catastrophic mortality, which will be discussed in a later section, is beginning to compromise individual treatment responses within the overall experiment. The effects of site and spacing on growth and yield are summarized in Table 2 along with detailed comparisons of treatment means. No significant site x spacing interactions were observed 18 years after treatment indicating that site productivity was not modifying the response to spacing. In all cases, both site and spacing have significantly affected these characteristics.

## Height

Spacing had a significant effect on mean stand height of the 25-year-old lodgepole pine (Table 2) particularly on the low and intermediate sites (Fig. 1). Johnstone (1981a) previously speculated that this may reflect more-intense competition for moisture and nutrients on these lower sites. Note that, on the high site, the greatest mean height continues to occur at LGS 2 and the mean height of LGS 1 is now ranked second lowest of the five spacing levels. During the past five years, LGS 5 grew significantly slower than the remaining treatments (Table 2), and on the highest site the slowest growth was observed at LGS 1 and LGS 5 (Fig. 1).

Table 2. Effects of site and spacing on lodgepole pine stand development, and a comparison of treatment effects.

| Characteristic | Source of variation[1] | Statistical significance[2] | Level of growing stock[3] | | | | |
|---|---|---|---|---|---|---|---|
| Mean height | S | ** | 5 | 4 | 3 | 2 | 1 |
| (Age 25) | T | * | | | | | |
| Mean periodic height growth | S | * | 5 | 4 | 1 | 3 | 2 |
| (Age 20-25 | T | * | | | | | |
| Mean dbhob | S | ** | 5 | 4 | 3 | 2 | 1 |
| (Age 25) | T | ** | | | | | |
| Mean periodic dbhob growth | S | * | 5 | 4 | 3 | 2 | 1 |
| (Age 20-25) | T | ** | | | | | |
| Crown width | S | ** | 5 | 4 | 3 | 2 | 1 |
| (Age 25) | T | ** | | | | | |
| Crown closure | S | ** | 1 | 2 | 3 | 4 | 5 |
| (Age 25) | T | ** | | | | | |
| Percent live crown length | S | ** | 5 | 4 | 3 | 2 | 1 |
| (Age 25) | T | ** | | | | | |
| Basal area | S | ** | 1 | 2 | 3 | 4 | 5 |
| (Age 25) | T | ** | | | | | |
| Mean total volume/tree | S | ** | 5 | 4 | 3 | 2 | 1 |
| (Age 25) | T | ** | | | | | |
| Net total volume/ha | S | ** | 1 | 2 | 3 | 4 | 5 |
| (Age 25) | T | ** | | | | | |
| Net merchantable volume/ha | S | ** | 5 | 4 | 3 | 1 | 2 |
| (Age 25) | T | * | | | | | |

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

[2] * significant at p = 0.05 level; ** significant at p = 0.01 level.

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

Analyses of covariance detected no between-block differences in the height-diameter relationships, within each site, for each spacing. Consequently, data from both blocks within each site were combined for each treatment. Differences in the intercepts resulted in significant overall between-treatment differences on the high site even though there were no differences in the slopes of the relationships. Equations for LGS 1 and LGS 5 were not parallel on the intermediate site giving significant overall differences between spacings when combined with differences in intercepts. On the low site, differences in intercepts, plus differences in the slope of LGS 1 relative to LGS 3, 4, and 5 resulted in significant differences between spacings in the height-diameter equations. For a given diameter, tree height was inversely related to degree of spacing (*i.e.*, the wider the spacing the shorter the tree). Although these differences were consistent for all sites, the magnitude of the differences varied directly with site productivity (*i.e.*, differences between spacings on the high site were substantially larger than differences between corresponding spacings on the low site). There also appears to be a trend towards slightly taller trees, for a given diameter, on the high site than the low site.

## Diameter

Spacing continues to have a significant and dramatic effect on diameter development on all sites (Fig. 2) in that the mean diameter and diameter increment are directly related to amount of growing space. The mean diameters at LGS 4 and LGS 5 were smaller than at the remaining spacing levels, and mean diameter increment increased significantly with each increase in spacing (Table 2). The previous analysis (Johnstone 1981a) showed a significant site x spacing interaction in periodic (from ages 15 to 20 years) diameter growth, which reflected a more rapid decline in growth with respect to spacing on the high site compared to the lower sites. No significant site x spacing interaction was observed from ages 20 to 25 indicating that there is no longer a differential diameter growth response to spacing on the various sites.

## Crown Development

Site and spacing had significant effects on crown expansion and crown width (Table 2 and Fig. 3). Trees on the best site and at the widest spacings exhibited the widest crowns, and trees on the poorest site and at the closest spacing had the narrowest crowns. Consequently, the rate of crown closure is directly related to site productivity for a given level of growing stock (Fig. 4). The crowns have fully closed (crown closure of 123%) and overlap by about 11% at LGS 5 on the high site. Both site and spacing also had a significant effect on the proportion of the bole supporting live crown (Table 2). The relative rate of crown lift is faster on the higher sites and at the closer spacings (Fig. 5). Rate of crown lift is presumably directly related to rate of crown closure.

## Basal Area and Volume

Wider spacing resulted in significantly lower basal areas and total stand volumes at 25 years of age (Table 2) despite significantly larger (Fig. 6) and faster growing trees, because of the disproportionately greater number of stems at the closer spacing. Several important yield trends are developing (Fig. 7), although it is still uncertain whether the wider spacings will ever achieve the same total volume production of the close spacings. Averaged over all sites, the difference in total volume per tree at LGS 1 compared to LGS 5 has increased, during the past 10 years, from 195% to 344%, while the difference in total volume per hectare has declined from 814% to 304%. It is probable that this gap in net total volume production will continue to decline when mortality resulting from inter-tree competition becomes more severe at the closer spacings.

The production of merchantable (pulpwood) volume was also significantly affected by both site and spacing (Table 2). Except on the poorest site, where merchantable volume is essentially negligible, LGS 2 produced the highest pulpwood yield at 25 years of age (Fig. 8). LGS 2 and LGS 3 have surpassed the merchantable volume per hectare of LGS 1 on the high site because substantially more (85% and 66%, respectively) trees achieved merchantable size. Furthermore, height growth at LGS 1 is slower. It is likely that LGS 2 and LGS 3 will continue to produce higher pulpwood yields than LGS 1, particularly on the high site, because greater numbers of trees are currently approaching the merchantability-size threshold at LGS 2 and LGS 3 than at LGS 1.

## Mortality

Mortality, which varied on an individual plot basis from 0% to 66%, is of real concern in this study. The two main causes of mortality (Johnstone 1981a) are shoe-string root rot (*Armillaria mellea* (Vahl. ex Fr.) Kummer) and small-mammal girdling (*i.e.*, snowshoe hares (*Lepus americanus*) and red squirrels (*Tamiasciurus hudsonicus*)). Damage and mortality is localized within the experiment thus resulting in the significant differences between blocks within sites. An analysis of variance indicated that, mortality was not related to spacing, but was significantly higher on the most productive site than on the low site. A large proportion of the sample trees have also been infected by western gall rust (*Endocronartium harknessi* (J.P. Moore) Y. Hiratsuka), which not only reduces tree growth and quality, but also increases the risk of snow- or wind-breakage.

## CONCLUSIONS

Natural lodgepole pine stands in west-central Alberta are frequently too dense to produce merchantable yields in keeping with the productive capacity of the sites on which they grow. Excessive stand density also increases the rate and amount of mortality, the length of rotation, and harvesting cost. Juvenile spacing can drastically alter stand growth and yield, and is a valuable silvicultural tool for remedying many of the problems associated with densely-regenerated lodgepole pine. This study continues to provide the biological response data required to identify optimum management regimes for lodgepole pine.

The dramatic effects of spacing on average stand diameter and diameter increment are consistent with earlier studies of the species. The mean diameter and recent diameter growth of LGS 1 increased by 89% and 131%, respectively, relative to LGS 5 when averaged over all sites. These differences have increased since last reported at age 20 (Johnstone 1981a). Diameter growth response to selective thinning, such as studied here, will undoubtedly exceed the response to mechanical, strip thinning (Bella and De Franceschi 1982) because those trees most likely to respond favorably can be retained for future crop trees.

The effects of spacing on average height and height growth was less dramatic and less conclusive than the impact on diameter except on the low and intermediate sites. The widest spacing on the best site may even have reduced height growth. Trees at the widest spacing on the high site may be expanding their crowns so rapidly that diameter increment accelerates at the expense of height growth. This hypothesis is supported by the analyses of the height-diameter relationships. Trees grown at wider spacings were shorter than trees grown at closer spacings for a given diameter class. Consequently, bole taper will increase with increases in spacing, and both the total volume and the sawmill recovery by diameter class will be reduced. It is fortunate that this effect of spacing is less pronounced on poorer sites because wider spacing appears to be more advantageous on low sites compared to high sites. These results support other studies (Alexander 1960; Johnstone 1981b, 1982) which indicate that lodgepole pine requires a limited degree of crowding to maximize height growth.

This study demonstrates the need for forest managers to clearly identify and define their future timber objectives, preferably on a site specific basis. Despite significantly larger and faster growing trees, both total volume and total volume growth were significantly lower at the widest spacing. At the same time, the largest merchantable yield did not occur at the widest spacing. Consequently, although wide spacing may shorten technical rotation lengths (*i.e.*, the time required to grow trees of a desired size), wide spacing may also reduce total stand productivity. Obviously, some method of optimizing individual tree growth with levels of growing stock is warranted to maximize the yield of desired products on an area basis. The practice of increasing the current allowable annual cut of mature timeber in proportion to the anticipated improvement of future volume yields is often used as an incentive to encourage more intensive forest management. In order to ensure the continuity of future harvests, this method of apportionment should only be applied after the productive capacities of the sites to be managed have been duly considered. With respect to the stand density management of natural lodgepole pine, the present study shows that the largest relative gains occur on poorer sites but the actual absolute gains on these sites may be negligible.

Because of the high mortality losses caused by biotic agents in this study and by climatic causes in other studies (*i.e.*, Johnstone 1982), there is an urgent need for the comprehensive evaluation and study of the risks and uncertainties associated with the management of natural lodgepole pine stands. Quantitative risk factors developed from such a study should be incorporated into planning models and stand management regimes. Continued remeasurement and analysis of the present study will continue to contribute to the understanding of the management of natural lodgepole pine stands in west-central Alberta and elsewhere.

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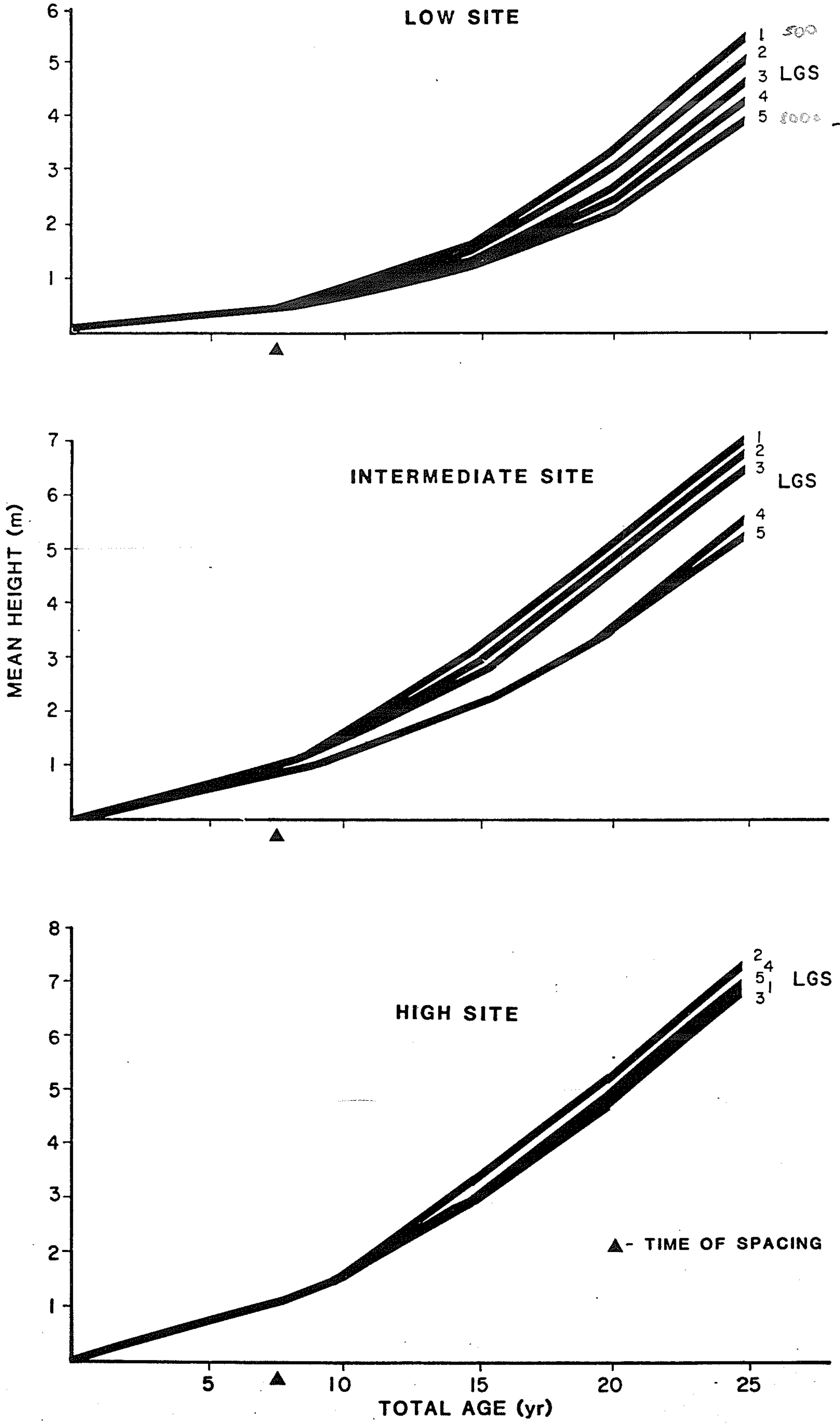
mean

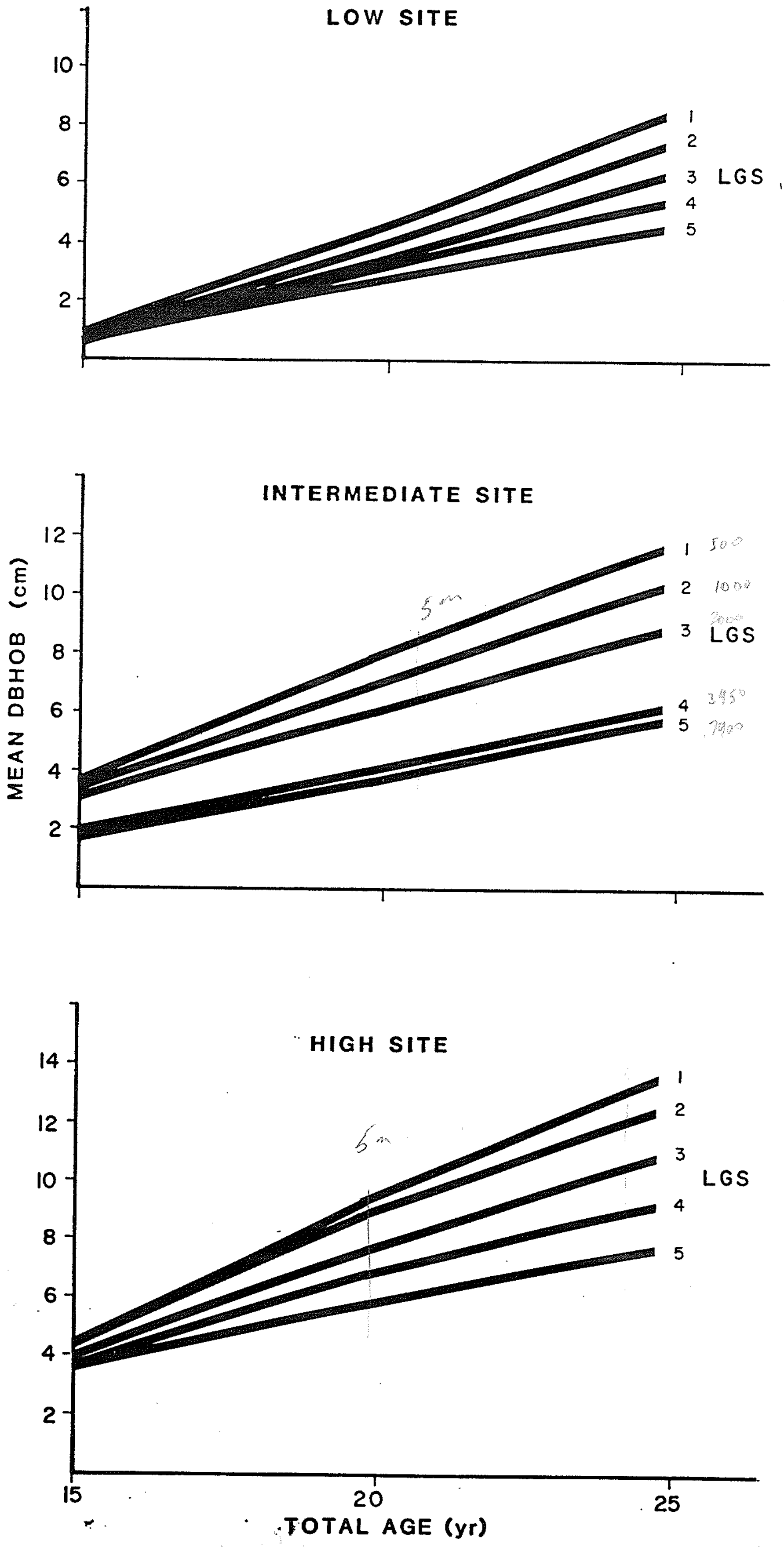
FIGURE 1: HEIGHT DEVELOPMENT OF SPACED LODGEPOLE PINE



Top Height?

Repression? not likely
should be > 30,000

FIGURE 2: DIAMETER DEVELOPMENT OF LODGEPOLE PINE



5m top h

6.5m top h

7m top ht.

FIGURE 3: CROWN WIDTH DEVELOPMENT OF SPACED LODGEPOLE PINE

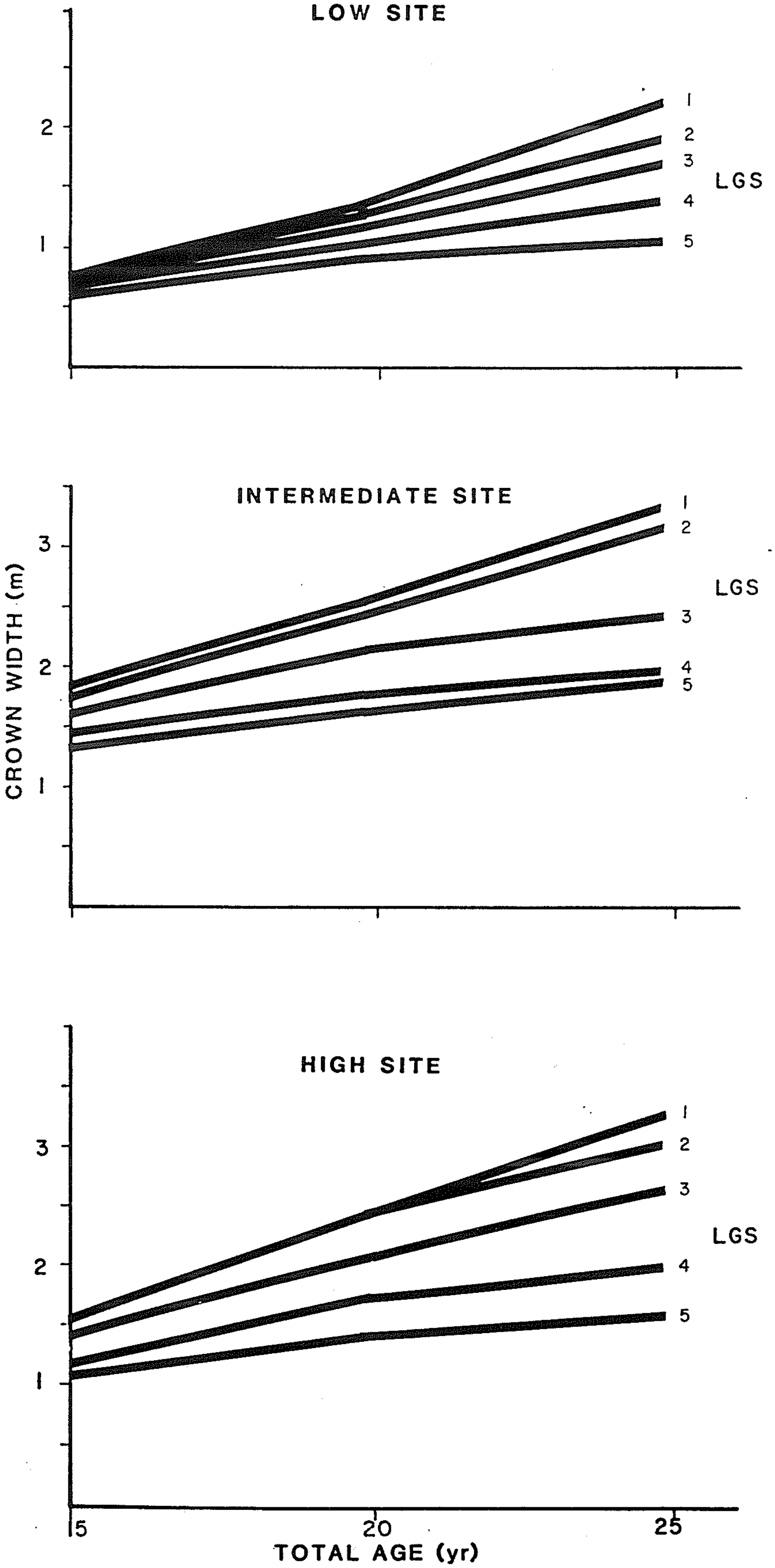


FIGURE 4: EFFECT OF SPACING ON CROWN CLOSURE OF SPACED LODGEPOLE PINE

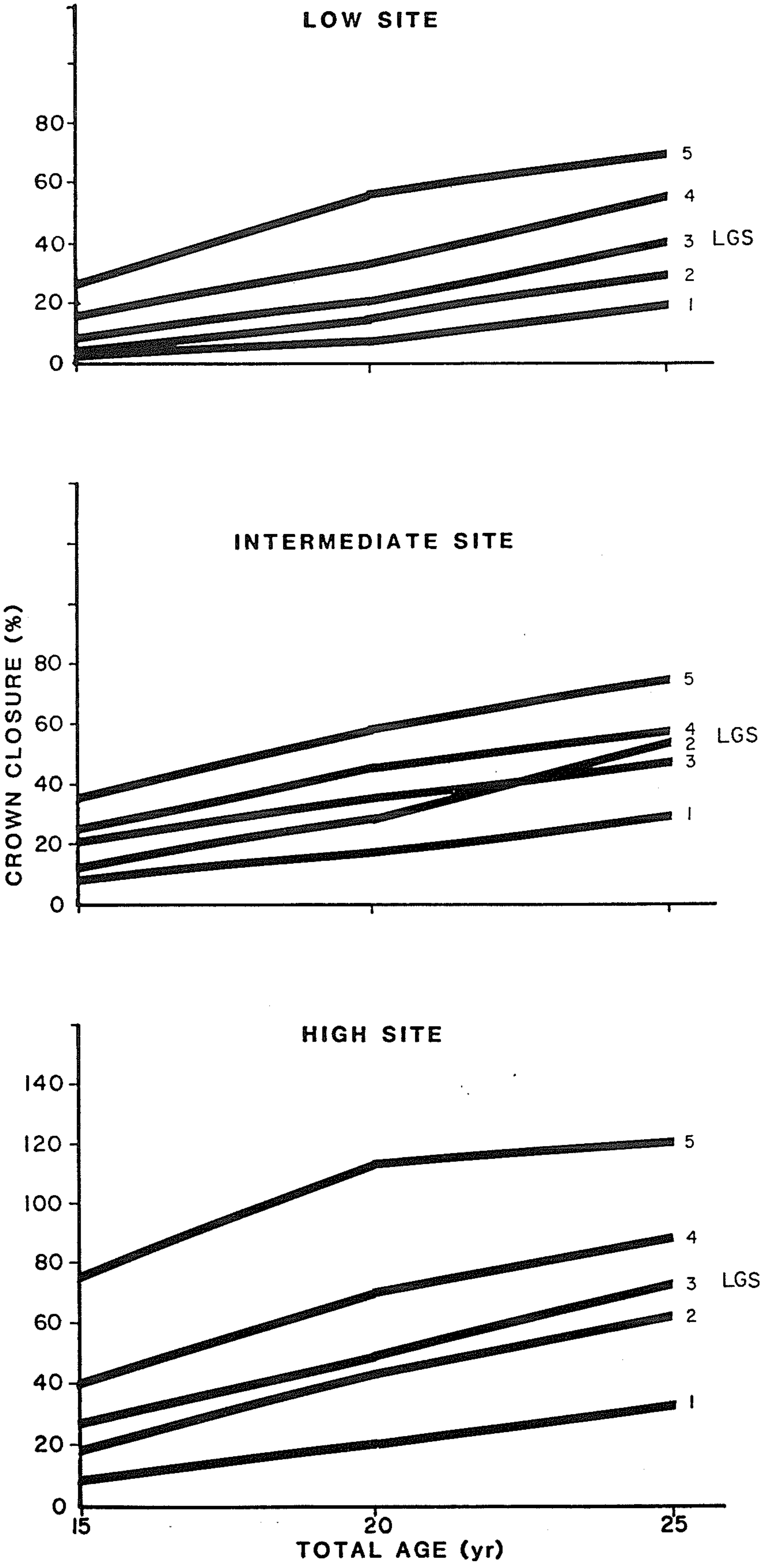
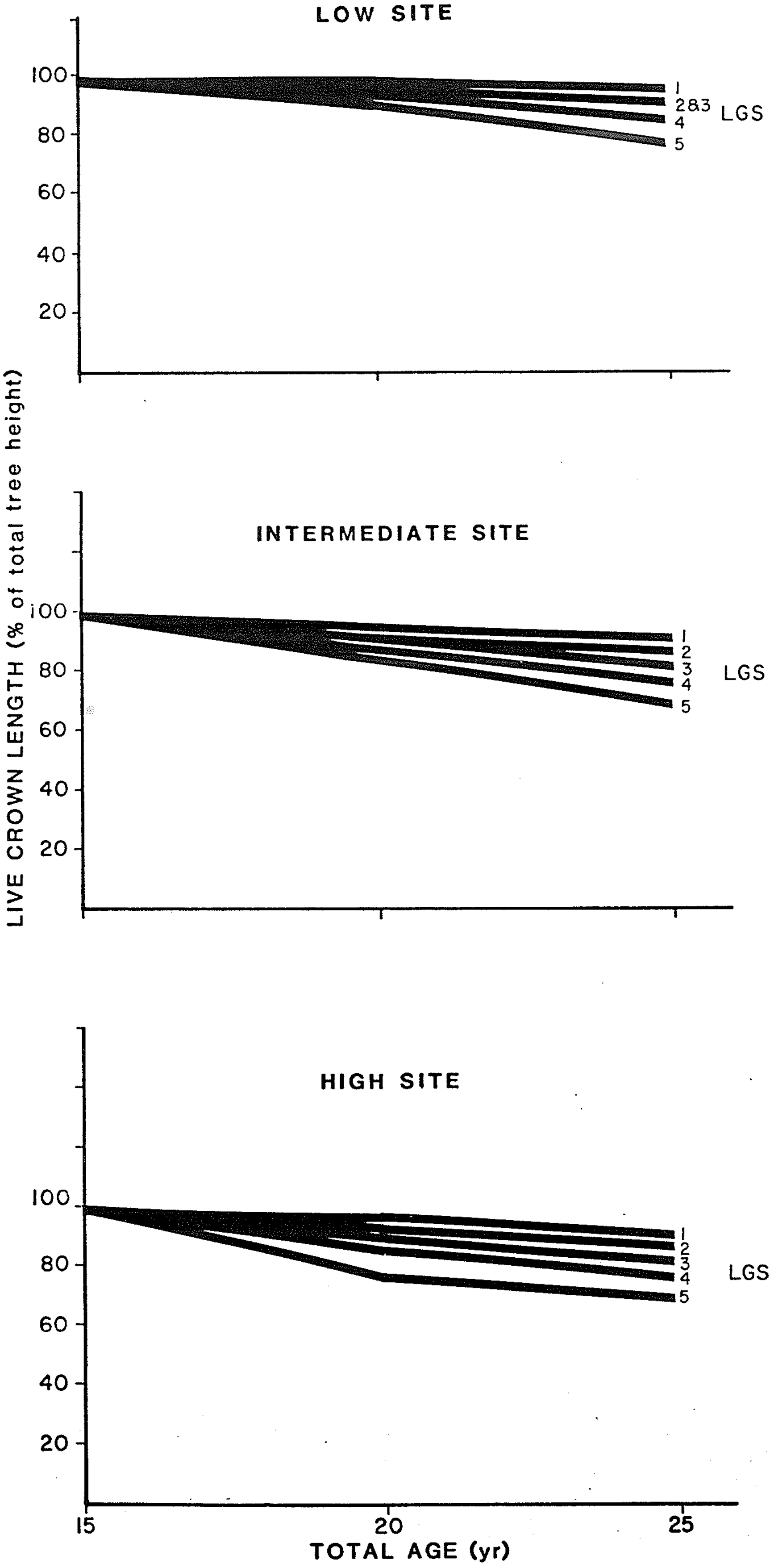


FIGURE 5: EFFECT OF SPACING ON THE CROWN LENGTH OF LODGEPOLE PINE



# FIGURE 6: EFFECT OF SPACING ON TOTAL VOLUME PER TREE OF LODGEPOLE PINE

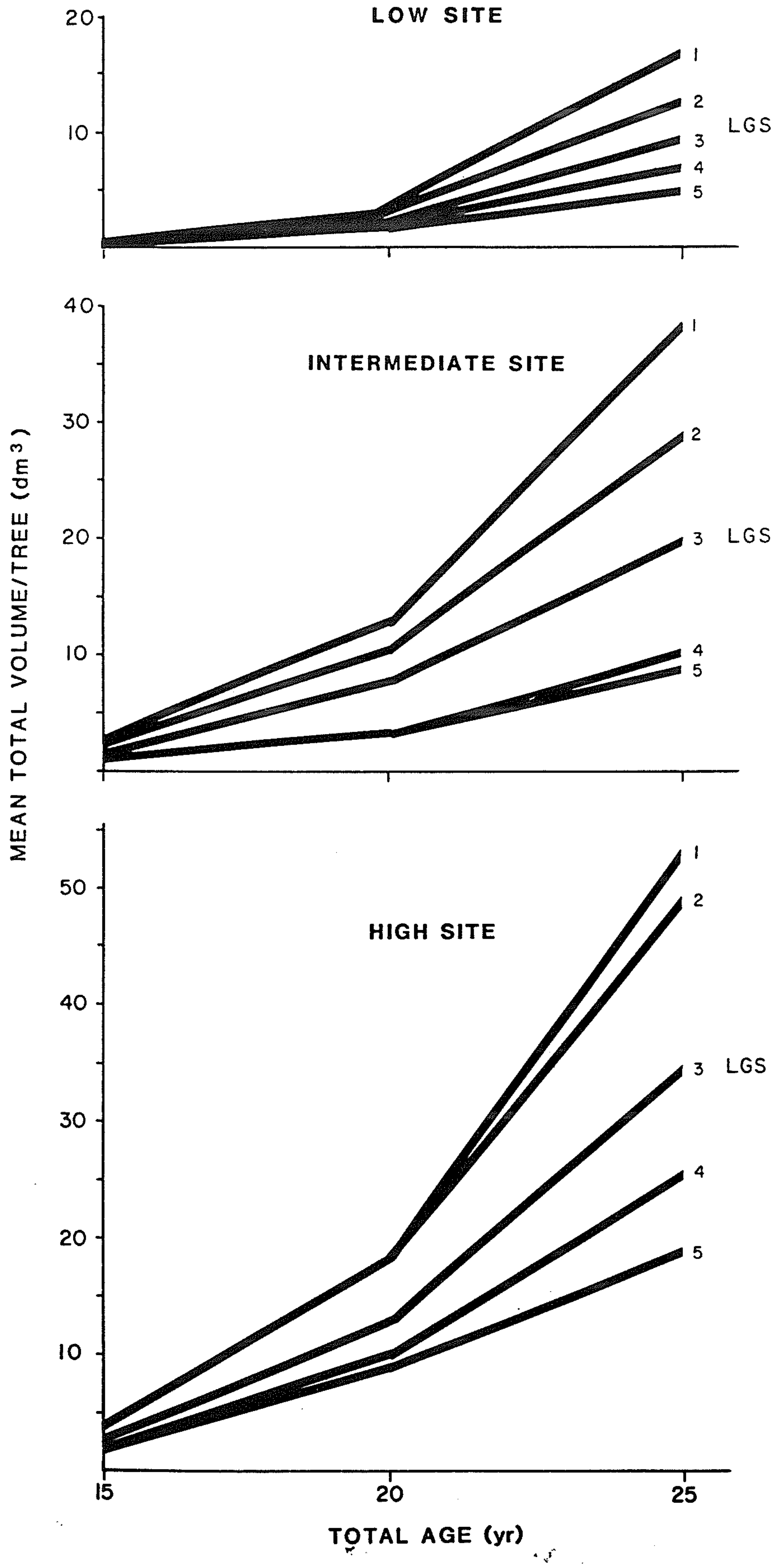


FIGURE 7: TOTAL VOLUME PER HECTARE DEVELOPMENT OF SPACED LODGEPOLE PINE

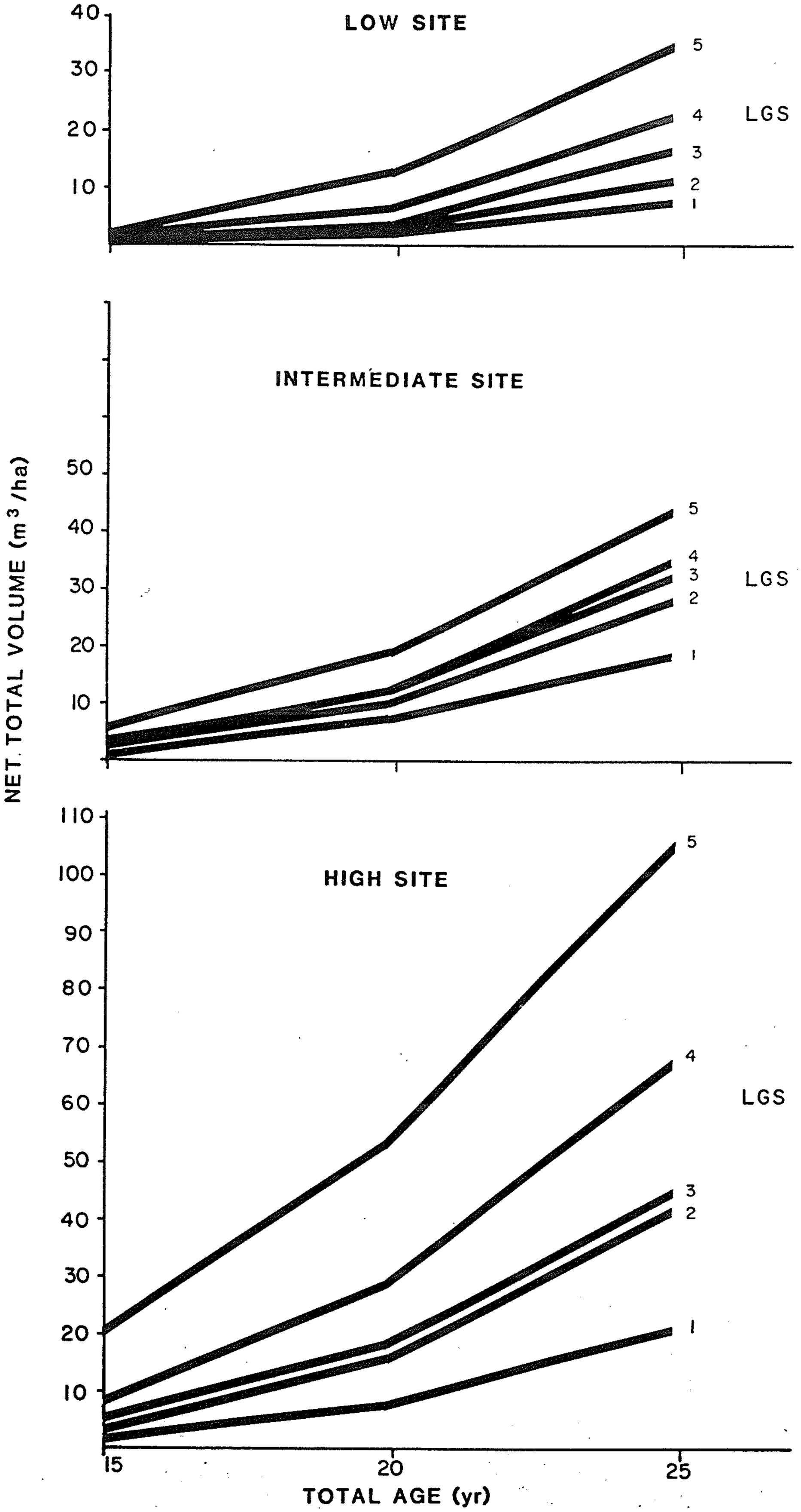


FIGURE 8: MERCHANTABLE VOLUME PER HECTARE DEVELOPMENT OF SPACED LODGEPOLE PINE