Early stand development of lodgepole pine spaced at age 7 in west-central Alberta

R.C. Yang

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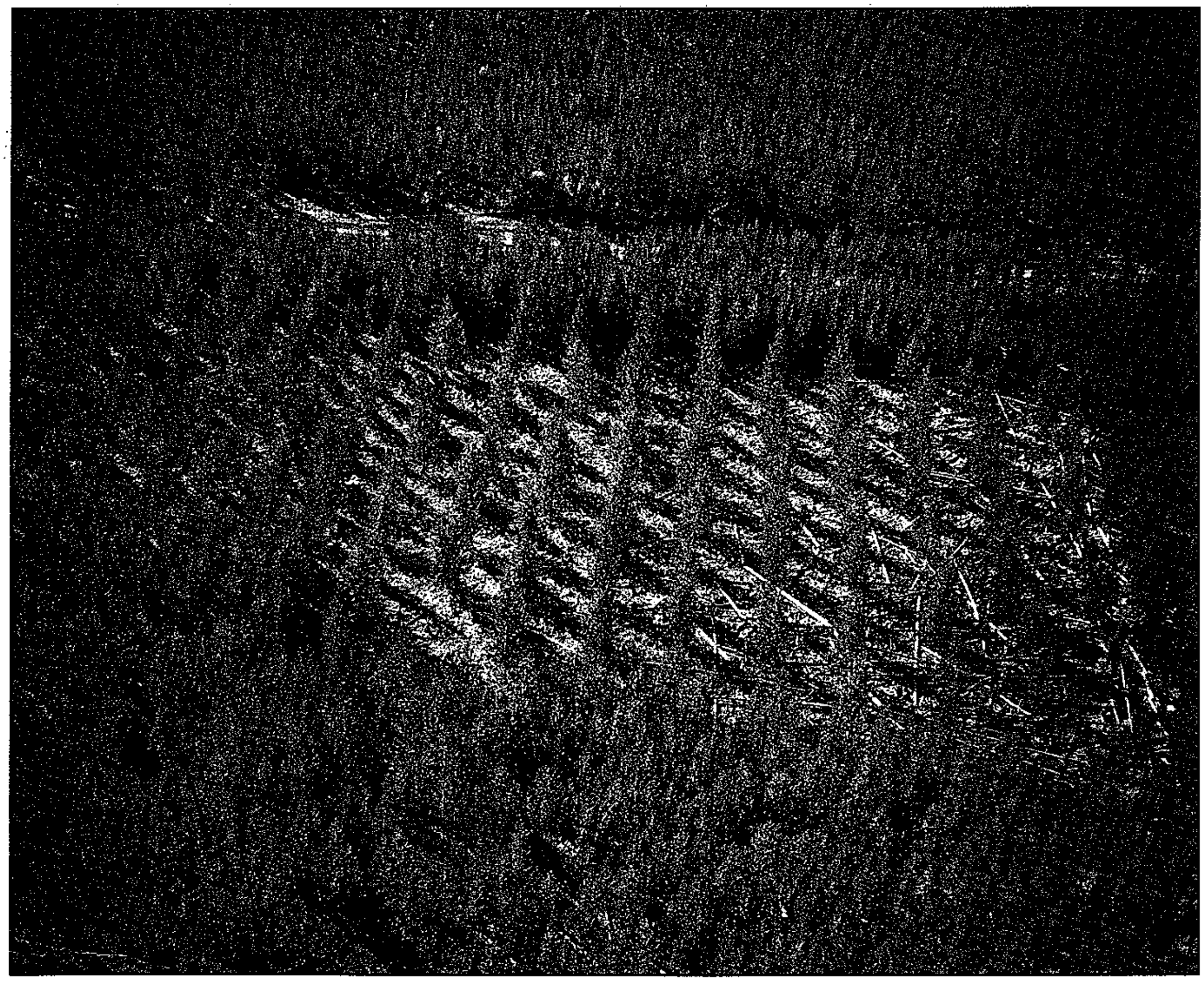

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Plots in the Gregg Burn area. Photo courtesy of S. Lux, Northern Forestry Centre, Edmonton, Alberta.

EARLY STAND DEVELOPMENT OF LODGEPOLE PINE SPACED AT AGE 7 IN WEST-CENTRAL ALBERTA

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ABSTRACT

Stands of 7-year-old, densely regenerated, fire-origin lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) were spaced at five density levels (from 1.1 to 4.5 m) on good, medium, and poor sites. The effects of spacing on stand height, diameter, mortality, crown development, and total volume were monitored. Spacing prescriptions were developed to ensure maximum utilization of growing space at different sites.

RÉSUMÉ

Une régénération dense de pins tordus latifoliés (*Pinus contorta* var. *latifolia* Engelm.) de 7 ans occupant un ancien brûlis a été espacée selon 5 degrés d'intervention (de 1, 1 à 4, 5 m) dans des stations bonnes, moyennes et pauvres. L'auteur a surveillé les effets de l'espacement sur la hauteur du peuplement, le diamètre et la mortalité des arbres, le développement du houppier et le volume total. Il a élaboré des prescriptions d'espacement destinées à s'assurer de la meilleure utilisation possible de l'espace vital dans différentes stations.

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NOTE

The exclusion of certain manufactured products does not necessarily imply disapproval nor does the mention of other products necessarily imply endorsment by Forestry Canada.

INTRODUCTION

Juvenile spacing stimulates tree growth for most species by releasing crop trees from competition, and redistributing nutrients and growing space to these stems. The treatment is relatively cost-effective, and it has often been prescribed as an operational treatment for stands of densely regenerated lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.).

The effects of stand density on lodgepole pine growth and yield have been well-documented (Smithers 1957; Dahms 1971a, 1971b; Johnstone 1981a, 1981b, 1982), and density management diagrams have been developed (McCarter and Long 1986; Long 1988). However, the relationships between site and density, which affect early tree and stand development, have not been fully explored. These relationships must be fully understood so that stands can be managed in accordance with their site quality and growth potential.

This report is based on a study of juvenile spacing of lodgepole pine that was initiated in 1963 to monitor stand development of this species in Alberta and to derive growth-density relationships for it. The three objectives of this report are: 1) to examine and update, to age 30, spacing effects on early stand development (diameter, height, basal area, and volumes) on the three sites; 2) to develop size-density and yield relationships from these data as a basis for density management guidelines; and 3) to recommend suitable spacings for juvenile stands on different sites.

METHODS

Study Area

The area—known locally as the Gregg Burn—is about 40 km south of Hinton, Alberta (legal description: 53°25′, 117°34′; Sect. 18 and 19, Tp. 49, Rng. 23, and Sect. 13 and 24, Tp. 49, Rng. 24, W5). It lies within the Upper Foothills Section (B.19c) of the Boreal Forest Region (Rowe 1972).

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 had regenerated naturally after a 1956 wildfire. Detailed descriptions of site conditions and stands, as well as the study design and establishment procedure, have been reported by Johnstone (1981a).

The established spacings were replicated on three site types: poor, medium, and good. In this study, the site types were as follows:

1) a poor site was a level, rapidly drained, Eluviated Eutric Brunisol (Gregg series) soil;

2) a medium site was a moderately well-drained, Brunisolic Gray Luvisol (Mercoal series) soil; and

3) a good site consisted of soils that varied from rapidly drained, Eluviated Eutric Brunisol to moderately well-drained, Brunisolic Gray Luvisol with a Loamy Sand Eolian Veneer (Mercoal series).

The vegetation on all sites was similar to that of the Pl-Sb/*Ledum/Pleurozium* (lodgepole pine-black spruce/Labrador tea/feather moss) ecosystem (Corns and Annas 1986).

Treatments

Plots, each comprising a 10 × 10-tree matrix, were established within the stands at five spacings: 1.1, 1.6, 2.3, 3.2, and 4.5 m, corresponding to stand density levels of 7907 (8000), 3954 (4000), 1977 (2000), 988 (1000), and 494 (500) stems ha^{-1}. Each spacing level was repeated twice on each site.

In the fall of 1964, following the first growing season after spacing, the trees on these plots were tagged and their total height recorded. These trees were remeasured in 1966 and at subsequent 5-year intervals; at each measurement, total height, diameter at breast height outside bark (dbhob), crown width, and crown length were recorded, and all damaging agents (insect, disease, or animal) were noted for each affected tree.

Data Compilation and Analyses

The height and dbhob of each surviving tree on each plot were used to obtain an average stand height and diameter, by spacing, for each measurement period.

Individual stem volumes were calculated, using volume equations[1]:

For trees ≤8.9 cm (≤35 in.) dbhob:

[1] $V = 0.0232 + 0.00253D^2H$

For trees 9.1-21.6 cm (3.6-8.5 in.) dbhob:

[2] $V = -0.0949 + 0.00272D^2H$

where V is volume (in cubic feet), D is dbh (in inches), and H is total height (in feet).

Total stand volume was the sum of stem volumes on each plot, converted to a hectare basis. For each plot, 5-year periodic increments in height, diameter, and total volume were obtained from the differences between successive remeasurements. Analyses of variance were performed on periodic increments, current stand height, current stand dbhob, and total stand volume at age 30. Periodic mortality, based on the number of stems and stand volume of surviving crop trees at the start of the measurement period, was computed and analyzed for each period, and expressed in percentages.

Stand height, stand diameter, and total stand volume at various ages were further analyzed, using ordinary, least squares regression to determine the response trend of stand growth to density. In these analyses, the terms "spacing" and "density" were synonymous, and the actual number of stems ha^{-1} at the time of a remeasurement was used, instead a nominal spacing, to eliminate an inconsistency in the number of stems ha^{-1} of a spacing. The use of nomial spacing was misleading because severe mortality from shoe-string root rot (*Armillaria mellea* [Vahl. ex Fr.] Kummer), western gall rust (*Endocronartium harknessii* [J.P. Moore] Y. Hiratsuka), and small mammal damage (Johnstone 1981a) occurred on some plots.

RESULTS AND DISCUSSION

Height

Cumulative stand height at age 30 showed a strong relationship to density ($p \leq 0.05$), despite the somewhat erratic results on good sites (Figs. 1 and 2). When averaged over all sites, the stand height for the two widest spacings (≥3.2 m) was about 1.0 m greater than for the 1.1-m spacing (8.1 and 7.1 m, respectively). The greater height growth at lower densities was in agreement with height growth observed in stands thinned at age 5 (Smithers 1957) and at age 22 (Johnstone 1981b).

Spacing improved periodic height increments (PHI) on medium ($p \leq 0.05$) and poor ($p \leq 0.01$) sites, but not on good sites (Table 1). The effect of spacing on height increments occurred before ages 15 and 20, respectively, on medium and poor sites, where the widest spacing out-grew the closest by more than 50% (Table 2). This site-dependency probably

[1] Kirby, C.L. 1973. Tree volume equations and volume basal-area ratios for white spruce and lodgepole pine in Alberta. Can. For. Serv., North. For. Res. Cent., Edmonton, Alberta. Unpublished report.

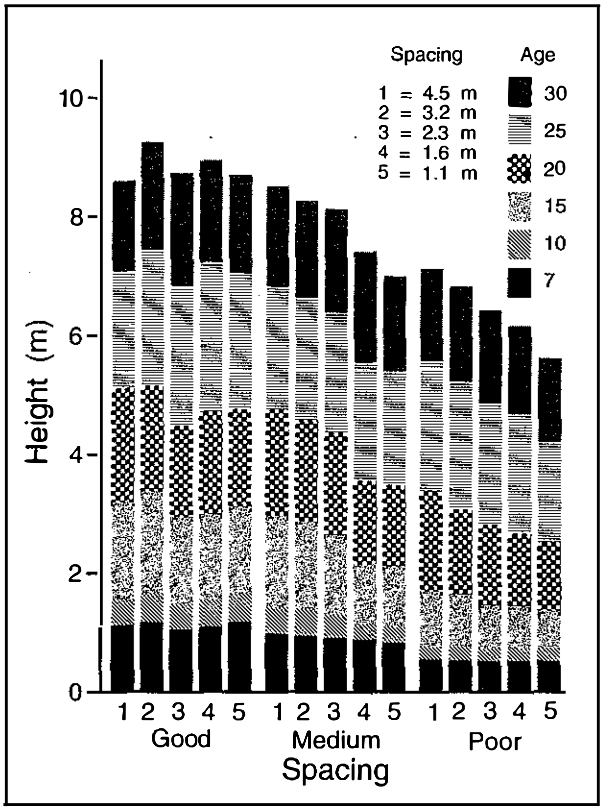

Figure 1. Average stand height by spacing, age, and site.

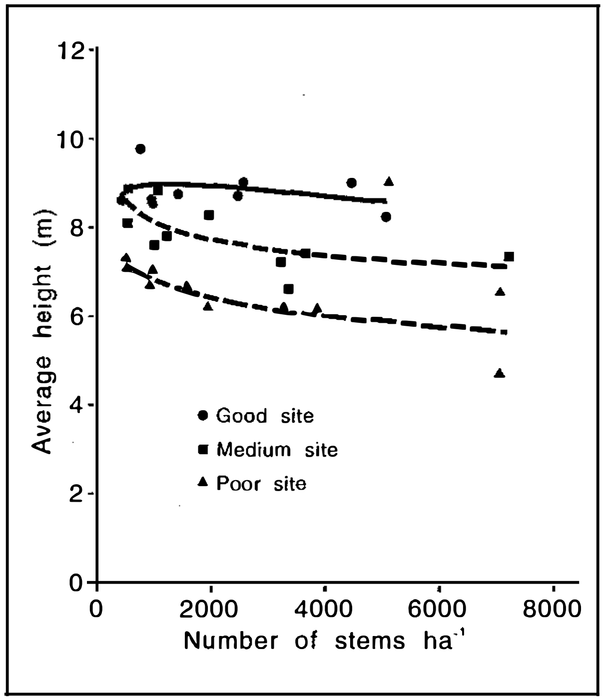

Figure 2. Average stand height at age 30 in relation to density, on three sites (good, medium, and poor).

Table 1. Effects of spacing and age on 5-year average increments[a] of lodgepole pine stands at age 30, on three sites (good, medium, and poor)

Source of variation	Height (m)		Dbhob (cm)		Total stand volume ($m^3 \cdot ha^{-1}$)	
	DF[b]	F-value[c]	DF	F-value	DF	F-value
			Good site			
Spacing (S)	4	0.88	4	53.70**	4	35.23**
Age (A)	3	20.18**	2	53.67**	2	26.85**
S x A	12	0.68	8	1.36	8	1.06
			Medium site			
Spacing	4	3.04*	4	106.19**	4	3.21*
Age	3	28.15**	2	44.81**	2	14.49**
S x A	12	1.21	8	0.62	8	0.20
			Poor site			
Spacing	4	6.06	4	26.76**	4	8.94**
Age	3	100.63**	2	5.94*	2	27.75**
S x A	12	0.51	8	0.25	8	0.69

[a] Five-year average increments are given for stand height, diameter at breast height outside bark (dbhob), and total stand volume.

[b] DF = Degrees of freedom.

[c] Where indicated, F-values are significant to the following degrees of probability: * = $p \leq 0.05$, and ** = $p \leq 0.01$.

Table 2. Periodic increments and cumulative values of lodgepole pine stands[a] at age 30 for five spacings[b], on three sites

		Good site						Medium site						Poor site					
		Spacing[b]						Spacing						Spacing					
Age (yr)	Variable	4.5	3.2	2.3	1.6	1.1	LSD[c]	4.5	3.2	2.3	1.6	1.1	LSD	4.5	3.2	2.3	1.6	1.1	LSD
								Periodic increments[c]											
7-10	Ht	0.46	0.50	0.45	0.44	0.45	0.18	0.43	0.46	0.40	0.33	0.29	0.13	0.23	0.23	0.21	0.20	0.24	0.04
10-15	Ht	1.68	1.68	1.42	1.47	1.47	0.40	1.51	1.45	1.30	0.96	0.94	0.45	0.90	0.84	0.73	0.69	0.62	0.38
15-20	Ht	1.89	1.89	1.85	1.95	1.92	0.19	1.82	1.74	1.74	1.42	1.41	0.57	1.70	1.50	1.34	1.23	1.11	0.52
	Dbhob	4.78	4.05	3.60	3.05	2.22	0.47	4.03	3.40	2.76	2.18	2.10	0.49	3.04	2.73	2.21	1.85	1.28	1.43
	Vol	6	11	12	21	33	11	5	7	9	10	14	12	1	2	3	6	9	5
20-25	Ht	2.00	2.21	2.11	2.29	2.04	0.56	2.06	2.03	2.06	2.00	1.91	0.22	2.17	2.10	2.04	2.02	1.72	0.45
	Dbhob	4.00	3.56	3.09	2.40	1.84	0.53	3.61	3.39	2.73	2.02	1.75	0.44	3.89	3.24	2.83	2.23	1.58	0.60
	Vol	13	25	24	41	57	13	11	18	20	24	30	24	6	8	12	17	22	16
25-30	Ht	1.51	1.82	1.84	1.71	1.62	0.60	1.65	1.65	1.68	1.85	1.66	0.61	1.61	1.64	1.62	1.50	1.44	0.32
	Dbhob	3.05	2.53	2.45	1.86	1.58	0.97	3.09	2.41	2.06	1.68	1.24	0.51	3.16	2.82	2.48	1.92	1.42	0.40
	Vol	15	28	29	42	48	18	16	27	27	34	36	24	11	15	22	27	32	15
								Cumulative values[c]											
30	Ht	8.58	9.22	8.68	8.90	8.66	1.15	8.44	8.22	8.06	7.35	7.01	1.44	7.09	6.78	6.39	6.11	5.56	1.62
	Dbhob	16.47	15.00	13.13	11.17	9.54	1.79	14.54	13.02	10.70	8.12	7.16	1.82	11.63	10.22	8.93	7.40	5.80	1.69
	Vol	36	68	69	112	159	44	34	55	58	71	86	62	18	26	35	51	65	38

[a] Periodic increments and cumulative values are given for average height (m), average diameter at breast height outside bark (cm), total stand volume ($m^3 \cdot ha^{-1}$).
[b] All spacings are given in metres.
[c] Least significant difference values at $p = 0.05$.

reflected the more intense competition for nutrients and moisture that occurs in young stands on poor and medium sites; on good sites these factors do not limit growth in young stands (Johnstone 1981a).

Stand age affected height increments in a similar pattern for all spacings and sites (Table 1). The increments were moderate from ages 10 to 15; they enlarged between ages 15 and 20, culminated between ages 20 and 25, and declined between ages 25 and 30 (Table 2).

The timing of spacing is critical to forest management. Late thinning has advantages over early spacing in better crop-tree selection, self-pruning, completion of seedling ingress, and detection of potential pest problems. At older ages, however, a tree's ability to respond to release declines and the size of growth response decreases. In this study the fact that increments peaked between ages 20 and 25 and showed no spacing effects thereafter is in agreement with the lack of height response to thinning in stands 25 years and older elsewhere in Alberta (Smithers 1957) and in Oregon (Dahms 1971a, 1971b). The results of this study, and of Smithers' study (1957) of 5-year-old stands, suggest that improved height growth can be achieved by spacing stands before 10 years of age. Bella and De Franceschi (1977) also recommended that lodgepole pine be thinned at a very young age, preferably before the stand is 10 years old.

Diameter

In this study, as in others (Dahms 1971a; Johnstone 1981a, 1982; Yang 1986), the effect of spacing on stand diameter development was overwhelming (Fig. 3). This effect was far more pronounced than that of age on medium and poor sites (Table 1). At age 30, stand dbhob was 73% larger at the widest spacing than at the closest on good sites, and over 100% larger on medium and poor sites (Fig. 3; Table 2).

Wider spacing improved periodic diameter increment (PDI) at all ages. The largest PDI occurred between ages 15 and 20 on good and medium sites, and between ages 20 and 25 on poor sites (Table 2). This suggests that spacing lodgepole pine later than these ages will improve diameter growth, but maximum dbhob growth potential may not be reached.

The strength of the relationship between density and stand diameter increased with age, as shown by increased R^2 on all sites (Fig. 4; Table 3). By age 30, density accounted for 95, 89, and 96%, respectively, of the variations in average stand dbhob on good, medium, and poor sites. This strong diameter-density relationship provides a guide for density management; foresters can achieve a desired final stand diameter by manipulating density.

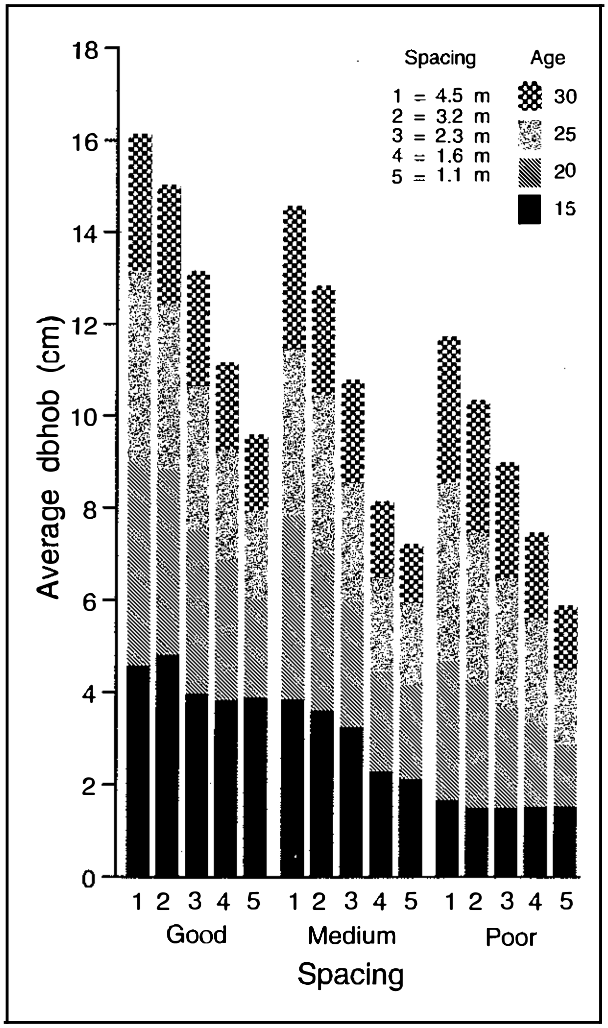

Figure 3. Average stand diameter at breast height outside bark by spacing, age, and site.

Stand Volume

Although wide spacing improved diameter growth, both stand volume and volume increment were substantially lower at wide spacings than at close spacings (Fig. 5; Table 2).

Table 3. Regression equations[a] for lodgepole pine stands at ages 15-30, on three sites

Age	Good site					Medium site					Poor site				
(yr)	b_0	b_1	b_2	R^2	$S_{y \cdot x}$	b_0	b_1	b_2	R^2	$S_{y \cdot x}$	b_0	b_1	b_2	R^2	$S_{y \cdot x}$
						Average dbhob (cm)									
15	9.048	-2.225	0.223	0.29	0.20	0.742	3.241	-0.776	0.68	0.19	6.734	-3.468	0.562	0.43	0.03
20	15.129	-1.800	-0.159	0.75	0.26	26.945	-9.561	0.927	0.82	0.26	13.210	-4.392	0.441	0.71	0.16
25	25.221	-4.343	-0.075	0.89	0.27	37.279	-12.528	1.106	0.84	0.36	18.311	-3.878	0.068	0.89	0.20
30	32.451	-6.002	-0.071	0.95	0.23	47.489	-15.906	1.366	0.89	0.37	22.056	-3.218	-0.262	0.96	0.17
						Stand total volume ($m^3 \cdot ha^{-1}$)									
15	122.18	-86.76	15.65	0.84	1.15	218.26	-13.96	2.86	0.92	0.21	25.04	-18.65	13.52	0.99	0.04
20	184.96	-140.59	28.88	0.89	2.19	99.26	-68.34	12.65	0.79	1.13	73.88	-51.52	9.23	0.79	0.75
25	263.62	-210.03	44.99	0.94	3.11	202.07	-139.48	26.63	0.74	3.00	63.66	-50.83	11.17	0.68	2.55
30	197.45	-181.57	46.39	0.92	5.01	248.75	-173.97	35.48	0.75	4.87	19.14	-29.08	10.70	0.73	4.15

[a] Regression equations are given for average diameter at breast height outside bark, total stand volume, and average stem volume, as a function of the number of stems ha^{-1}.
Model $Y = b_0 + b_1 \times \log(\text{stems/ha}) + b_2 \times [\log(\text{stems/ha})]^2$ where Y is a dependent variable, and b_0, b_1, and b_2 are estimated coefficients.

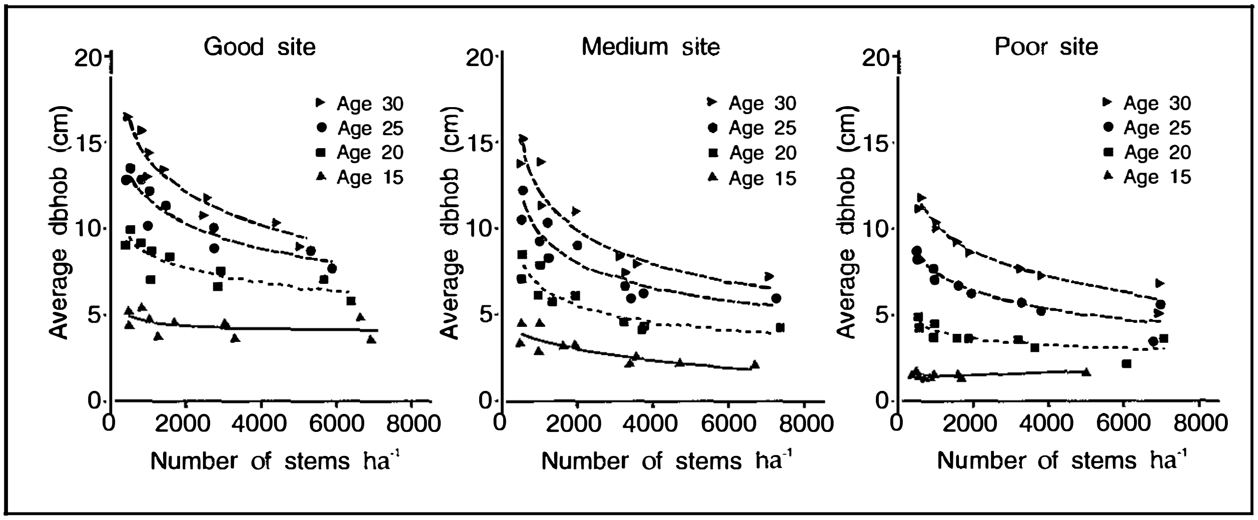

Figure 4. Average stand diameter at breast height outside bark in relation to density and age, on three sites.

The influence of spacing on total stand volume increased with age and site quality (Fig. 6; Table 1). Before 20 years of age, density had little effect on stand total volume on medium and poor sites, but increased the volume on good sites. By age 30, density accounted for 92, 75, and 73%, respectively, of variations in the stand volume on good, medium, and poor sites (Table 3).

Total stand volume was more responsive to increased density on good sites than on medium and poor sites. The volume-density curve at age 30 showed a strong upward trend for good sites, while for density beyond 3000 stems ha^{-1} the curve became flatter for medium sites and flattened more for poor sites (Fig. 6). The curve suggested an advantage in growing stands at higher densities on good sites.

Periodic volume increments (PVI) at the two closest spacings on good sites were declining or leveling off between ages 25 and 30, while PVIs on medium and poor sites were still rising (Fig. 7). The PVI decline at the closest spacing on the good site was due to overcrowding.

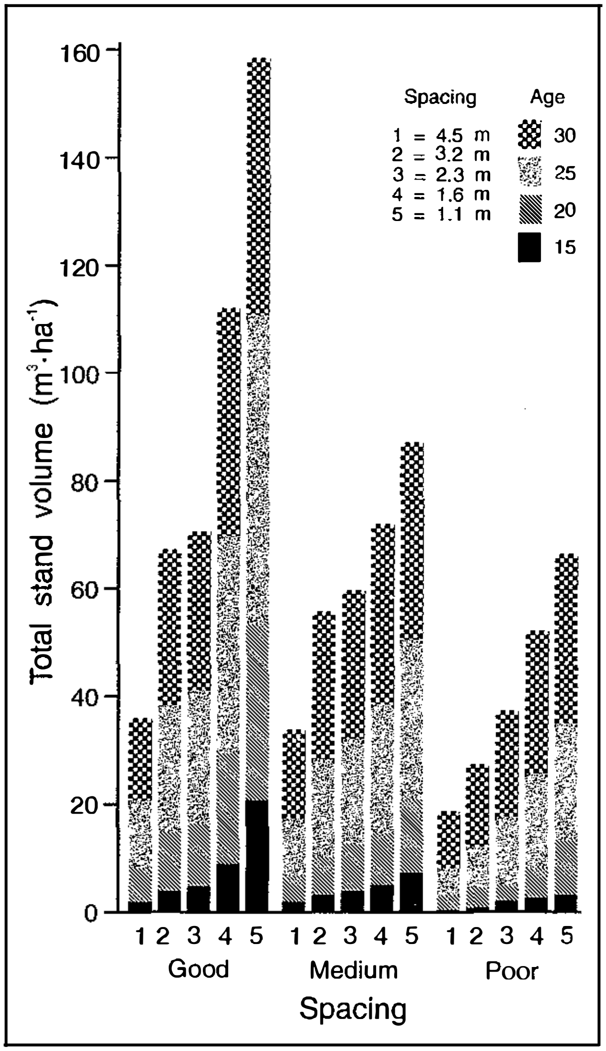

Figure 5. Total stand volume by spacing, age, and site.

Volume increments and total volumes at the 4.5-m spacing were substantially lower on all sites (Fig. 5; Table 2), despite rapid diameter growth (Fig. 3). The flattening trend of volume increment from ages 25 to 30, which was due to low density on good sites, suggests that the 4.5-m spacing has little chance of surpassing the closer spacings in total volume production.

Wide spacing improved individual tree growth (Fig. 3), but not total stand volume (Fig. 5); therefore a compromise is needed between maximum volume production per unit area and individual tree growth and size in terms of management objectives (Long 1985). The combination of high spacing costs and product premium on large tree sizes may encourage wide initial spacing; however, log quality, which determines final product values, may be adversely affected by low, initial stand density. Ballard and Long (1988) observed a strong relationship in lodgepole pine between stand density and the average diameter of the first five largest branches of each tree.

Mortality

Total stand volume mortality was higher ($p \leq 0.05$) on good sites than on medium or poor sites (Table 4). The closest spacing (1.1 m) usually resulted in the highest mortality rate on good sites, but this was not true for medium and poor sites.

Like total volume mortality, 5-year periodic mortality in terms of the number of stems was substantially higher on good than on medium or poor sites (Table 5). Many trees on good sites died between ages 10 and 15 (3-8 years after treatment). Major damaging agents included shoe-string root rot, western gall rust, terminal weevil (*Pissodes terminalis* Hopp.), and small mammals such as the porcupine (*Erethizon expixanthum*), snowshoe hare (*Lepus americanus*), and red squirrel (*Tamiasciurus hudsonicus*) (Johnstone 1981a). Trees on good sites were more vulnerable to small mammal damage than those on medium and poor sites, possibly because their vigor produced thicker, more succulent cambia that were more attractive to red squirrels[2]. At spacings ≤2.3 m on good sites, mortality was more than 10% between ages 15 and 20. Mortality subsided somewhat between ages 20 and 25, but increased again for the closest spacing between ages 25 and 30 due to overcrowding (Table 5).

Density on good sites showed rapid decline at all ages for the two closest spacings, and slow decline at all ages for more open spacings (Fig. 8). Because of differential density development trends on good sites, different densities due to spacing may be converging[3]. In contrast, the density development trends on poor sites were fairly stable; it may take a long time for densities on poor sites to converge. The medium sites had trends between those of the good and the poor sites.

[2] Personal communication from W.D. Johnstone of British Columbia Ministry of Forests, Vernon, B.C., August 1989.

[3] Personal communication from D. Walker of Weldwood Canada Ltd., Hinton Division, Hinton, Alberta, August 1989.

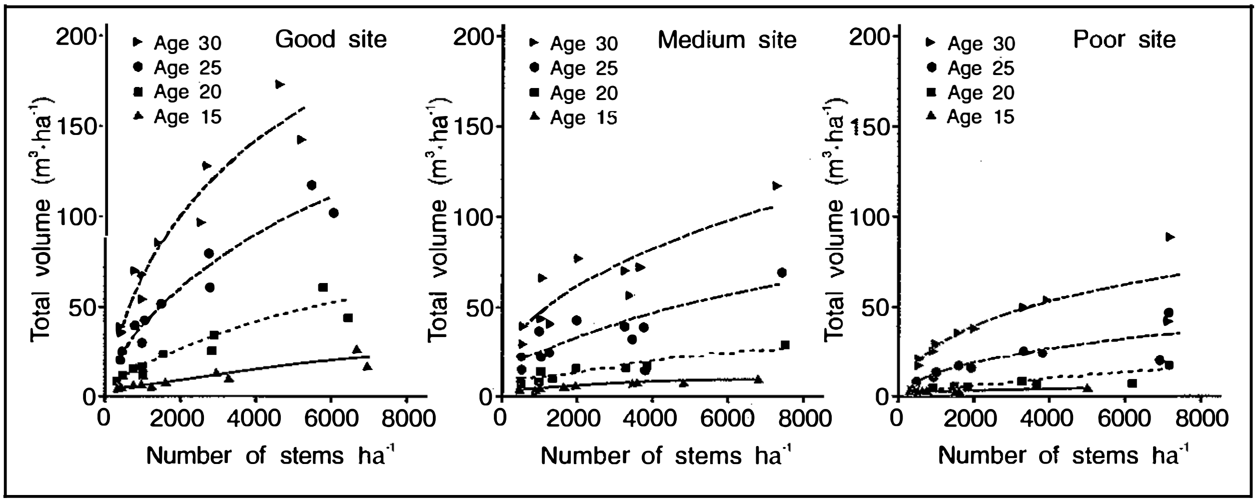

Figure 6. Total stand volume in relation to density and age, on three sites.

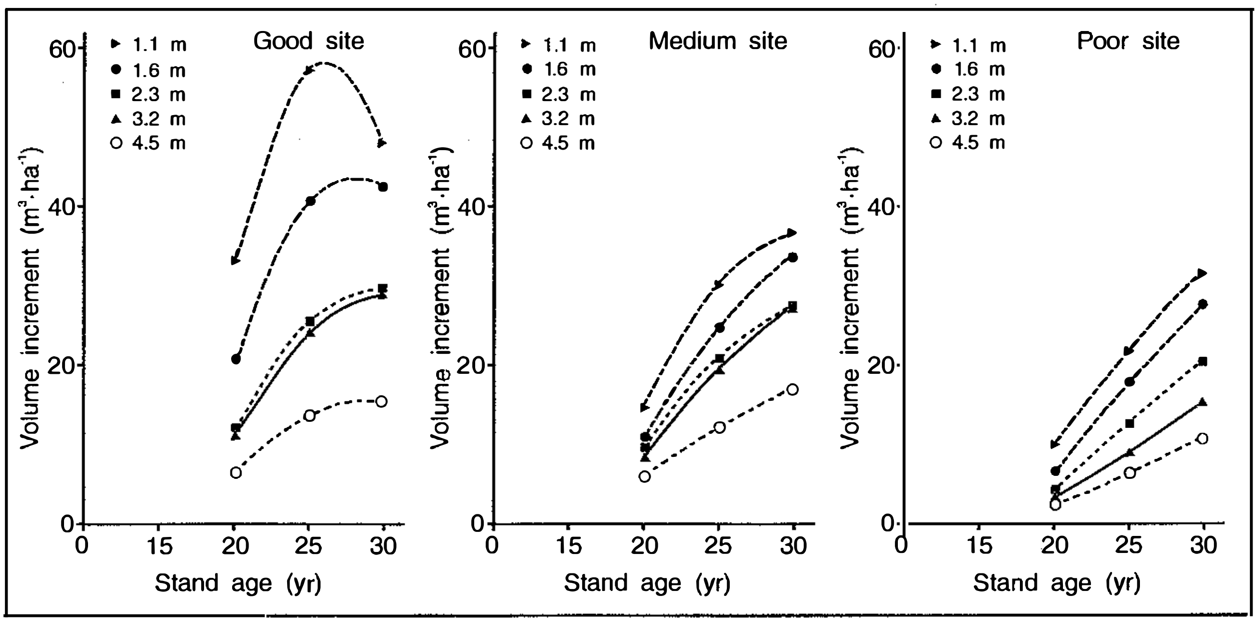

Figure 7. Five-year total stand volume increments by spacing and age, on three sites.

The above findings suggest that 1) juvenile stands on good sites should not be spaced to the expected final crop density because they require higher initial density to allow for mortality, and 2) from a biological viewpoint, spacing may be more important on poor sites than on good sites because stands on poor sites can be spaced to the expected final crop density.

Mortality reduced the number of stems at the 2.3-m spacing on the good site by more than 50% (at age 30 only 961 trees ha^{-1} survived), which also lowered total volume increments (Fig. 7). On good sites, spacing closer than 2.3 m is probably needed to ensure sufficient crop trees for optimal stand development. (In the Prince George region of British Columbia, where a high percentage of the crop trees in spaced stands have been attacked by squirrels, hares, rusts, and galls, a closer operational spacing of about 2 m is being recommended [Reid, Collins Nurseries Ltd. 1983]).

Table 4. Periodic mortality percentages (total stand volume ha^{-1}) of lodgepole pine stands, by spacing, on three sites[a]

Age (yr)	Spacing (m) 4.5	3.2	2.3	1.6	1.1	LSD[b]
			Good site			
20-25	2.0	0.8	2.8	4.0	7.1	
25-30	4.3	4.0	3.8	3.7	19.8	
Average	3.2	2.4	3.3	3.9	13.5	9.4
			Medium site			
20-25	0.5	0.1	0.6	0.6	0.7	
25-30	0.4	0.0	0.2	0.7	0.8	
Average	0.5	0.1	0.4	0.6	0.8	0.7
			Poor site			
20-25	0.2	0.0	0.1	0.3	0.3	
25-30	0.2	0.6	1.0	0.3	0.1	
Average	0.2	0.3	0.6	0.3	0.2	0.8
Overall average	1.3	0.9	1.4	1.6	4.8	3.1

[a] Spacing and age are not significant at $p = 0.05$, while site is significant at $p < 0.0002$. Overall 5-year mortality rates are 5.2, 0.5, and 0.3% on, respectively, good, medium, and poor sites.

[b] Least significant difference values at $p = 0.05$.

Table 5. Periodic mortality percentages (number of stems ha^{-1}) of lodgepole pine stands, by spacing, on three sites[a]

Age (yr)	Spacing (m) 4.5	3.2	2.3	1.6	1.1	LSD[b]
			Good site			
15	12.5	11.5	26.0	21.0	9.6	
20	5.3	1.9	13.6	10.5	12.3	
25	2.7	1.8	5.8	4.2	7.5	
30	6.4	5.8	5.8	8.9	16.5	
Average	6.7	5.3	12.8	11.2	11.5	6.9
			Medium site			
15	1.5	0.0	9.0	2.0	13.8	
20	3.0	1.0	9.6	6.2	13.4	
25	0.5	0.5	4.5	4.4	7.4	
30	2.1	0.0	1.3	3.4	4.3	
Average	1.8	0.4	6.1	4.0	9.8	8.2
			Poor site			
15	2.5	2.5	4.5	4.0	1.0	
20	2.6	3.1	4.9	3.8	1.0	
25	1.6	1.1	2.7	4.3	4.1	
30	0.5	2.2	1.9	0.6	2.7	
Average	1.8	2.2	3.5	3.2	2.2	3.0
Overall average	3.4	2.6	7.5	6.1	7.8	3.6

[a] Spacing is significant at $p < 0.01$, age is significant at $p < 0.03$, and site is significant at $p < 0.0001$. Overall 5-yr mortality rates are 9.5, 4.4, and 2.6% for, respectively, good, medium, and poor sites.

[b] Least significant difference values at $p = 0.05$.

Primary Considerations for Juvenile Spacing

The final criterion in evaluating the effectiveness of spacing is merchantable yield at harvest. In the interim, however, some tentative recommendations may be made on the basis of response data, crown development observations, and knowledge from other spacing studies on similar sites.

Full utilization of growing space is often judged by crown development. At age 30, the maximum crown width of trees at 4.5-m spacing[4] on good, medium, and poor sites averaged, respectively, 3.6, 3.1, and 2.7 m. The crown width-dbhob relationships at 4.5-m spacing were similar to the open-grown lodgepole pine relationships reported by Bella (1976) in Alberta and by Alexander (1974) in the Intermountain regions. The 20-cm open-grown trees (the average size of lodgepole pine at rotation) have crowns approximately 4.0 m wide. Because the crowns of forest-grown trees are generally smaller than those that are open-grown, and because natural mortality provides additional space for surviving trees, it is possible that 4.0-m (or wider) spacing incompletely utilizes growing space. In the upper foothills of Alberta, the crowns of lodgepole pine can almost touch and still maintain rapid diameter growth (Smithers 1961).

In contrast to the wide gap between crowns of trees at 4.5-m spacing, the crown widths at 1.1-m spacing averaged 1.72, 1.29, and 1.15 m at age 30 on, respectively, good, medium, and poor sites[5]. On good sites, crowns at 1.1-m spacing overlapped by

[4,5] Yang, R.C. 1989. Crown development of lodgepole pine in relation to spacing. For. Can., North. For. Cent., Edmonton, Alberta. Unpublished report.

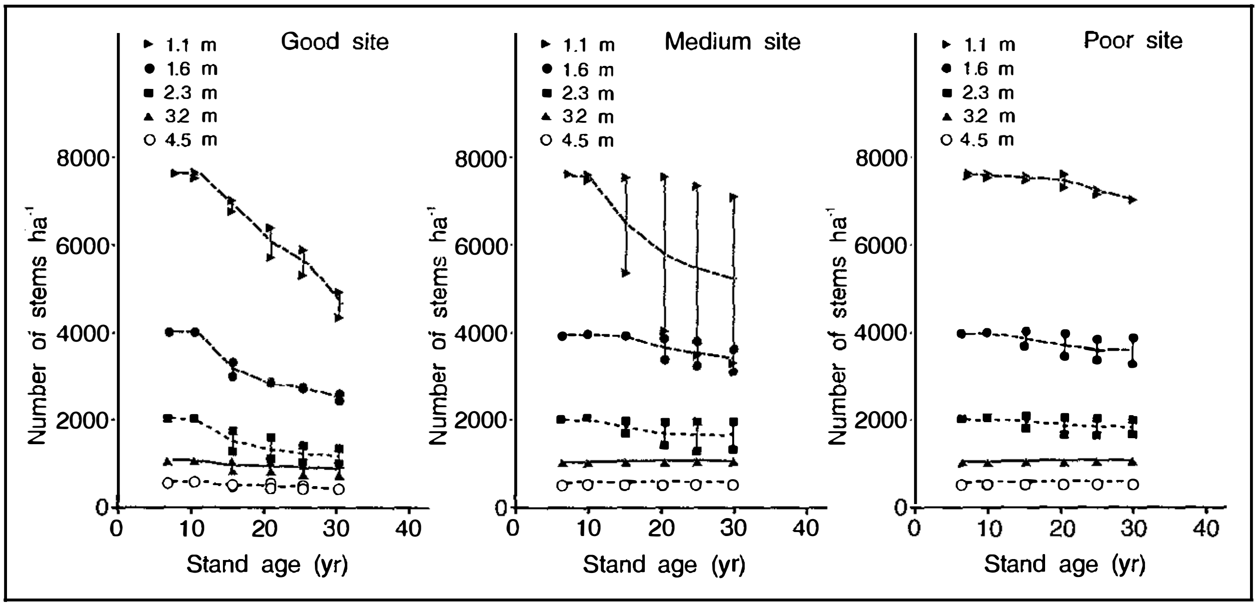

Figure 8. Number of stems ha^{-1} in relation to density, by spacing, on three sites.

more than 50%, which was a possible cause of high mortality during the preceeding five years (Fig. 8; Table 5). On poor sites, crown overlap was minimal (5%), and so was mortality.

Additional Considerations

As well as crown development, stand-level spacing decisions should consider:

1) site productivity;

2) final product objectives;

3) growth requirements of the species;

4) anticipated future treatments;

5) stand vigor and crown characteristics; and

6) anticipated future mortality (British Columbia Ministry of Forests 1983).

Additionally, risk reduction through shorter rotation should also be taken into account, as well as the possibility of improved height growth at wider spacings on medium and poor sites.

Based on observations of crown development, indications are that spacings wider than 4.0 m underutilized growing space on all sites, and that these spacings may be unsuitable for this species in this region. Indications also suggests that, on good sites, a spacing closer than 2.3 m is required because of high mortality. On medium and poor sites, increasing the spacing improved both height and dbhob growth (Figs. 1 and 3), but this action decreased stand volume at age 30 (Fig. 5). Based on the density-yield curves (Fig. 6), a density of 3000 (1.8 m), 2000 (2.2 m), and 1600 (2.5 m) stems ha^{-1} is recommended for stand spacing between ages 5 and 10 on good, medium, and poor sites, respectively.

Alexander (1974) recommended a minimum initial stocking of 2500 to 3800 stems ha^{-1} for lodgepole pine at age 10 years to ensure about 2500 stems ha^{-1} at age 30 years on good sites, while maintaining good height and diameter growth. Guidelines for juvenile spacing of lodgepole pine in the interior of British Columbia are 1300 to 2900 stems ha^{-1} (British Columbia Ministry of Forests 1983), depending on age and site quality.

The higher density in young stands on good sites ensures full site occupancy, even with mortality. Once trees express dominance, self-thinning probably reduces the density. In the absence of natural thinning, a commercial thinning between ages 50 and 60 will probably become economically feasible in the future. Stands can be managed more intensively on good sites than on medium or poor sites, because good sites offer greater potential return.

Although stand tending in general is most profitable on good and medium sites, lodgepole pine stands may be an exception. Density control of lodgepole pine may also be important on poor sites: extreme density and stagnation are more likely to occur on such sites. If left untreated, these poor sites will not yield usable volume (merchantable yield) within a reasonable rotation period. The density development trends on poor sites (Fig. 8) confirm that self-thinning of lodgepole pine is inadequate on such sites.

CONCLUSIONS AND RECOMMENDATIONS

1) Spacing improves diameter growth on all sites. Five-year dbhob increments at the widest spacing (4.5 m) are about twice those at the closest spacing (1.1 m) in all periods, and the diameter increment peaks at age 20 on good and medium sites and at age 25 on poor sites.

2) Wide spacing improves height growth on medium and poor sites, but not on good sites; this improvement occurs before age 15 on medium sites and before age 20 on poor sites. Stands should be spaced before age 10 to realize diameter and height growth potentials.

3) At age 30, stand total volume growth levels off at densities over 3000 stems ha^{-1} on medium and poor sites. These sites require wider spacing than do good sites.

4) Crown development to age 30 and crown projection to rotation age suggest that spacings over 4.0 m probably underutilize growing space and are unsuitable for lodgepole pine in this region.

5) Good sites are more susceptible to damaging agents than medium or poor sites; self-thinning also occurs at the closest spacing on good sites between ages 25 and 30. Owing to high mortality, stands on good sites require a closer spacing than 2.3 m.

6) Stand density should vary with site quality to fully utilize site potential. An initial spacing of 3000, 2000, and 1600 stems ha^{-1} on good, medium, and poor sites, respectively, is recommended. Treatment priority should depend on site quality; good sites may give the best return on investment, but treating very dense stands on poor sites may make the difference between some merchantable yield and no yield within a reasonable rotation period.

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