A LODGEPOLE PINE COMMERCIAL THINNING TRIAL IN KANANASKIS, ALBERTA: 58-YEAR RESULTS

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Weldwood

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This report has been printed on Canadian recycled paper.

This report is dedicated to the late Dave Presslee. Dave will be remembered first and foremost as a forester's forester. He embodied the art and science of forestry by combining a keen practical sense of resource with a vast knowledge of the science.

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ABSTRACT

In 1941, the Canadian Forestry Service (CFS) established a commercial thinning trial in a 77-year-old lodgepole pine-dominated stand near Kananaskis, Alberta. Seventy percent of the total volume was removed, and density was reduced from 7 166 to 1 710 trees per hectare. Sample plots established in 1949 were remeasured in 1999; these results are presented together with some earlier results. Thinning increased diameter growth and net periodic total volume increment. Twenty-two years after thinning (at age 99) the cumulative volume yield of lodgepole pine was 111 m^3/ha, or 44%, greater than that of the control treatment. This yield increase rose to 66% by age 135, 58 years after thinning. Results suggest that dense, late-rotation lodgepole pine stands can respond to thinning with increased volume growth.

RÉSUMÉ

En 1941, le Service canadien des forêts (SCF) a entamé un essai d'éclaircie commerciale dans un peuplement composé principalement de pins tordus de 77 ans situé près de Kananaskis, en Alberta. Le volume total a été réduit de 70 % et la densité, de 7 166 á 1 710 arbres par hectare. Les placettes d'échantillonnage disposées en 1949 ont refait l'objet de mesures en 1999; nous présentons ces résultats, de même que des résultats antérieurs de l'essai, dans le présent rapport. L'éclaircie a eu pour effet d'augmenter la croissance en diamétre et l'accroissement périodique net du volume total. Vingt-deux ans après l'éclaircie (à 99 ans), le rendement cumulatif en volume du pin tordu était de 111 m^3/ha, ou 44 %, plus élevé que pour le traitement témoin. Cette hausse du rendement atteignait 66 % à 135 ans, soit 58 ans après l'éclaircie. Ces résultats montrent que les peuplements denses de pins tordus en fin de révolution peuvent augmenter leur croissance en volume à la suite d'une éclaircie.

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INTRODUCTION

Current timber supply concerns in Alberta and British Columbia have generated an interest in thinning mid- to late-rotation lodgepole pine stands as a possible means of:

- providing an interim harvest without reducing final yields;
- equalizing flow in timber supply;
- preventing volume loss caused by growth suppression;
- increasing total yield by salvaging mortality;
- improving crop quality and value; and
- shortening technical rotations in low-merchantability stands where rotation age has been based on a minimum diameter.

Type and intensity of thinning are the major determinants of a stand's response, and will influence its future yield. For example, thinning from above (high thinning) has been described as unsuitable for lodgepole pine (Smithers 1957). Too low a thinning intensity will leave the stand overstocked, while an overly intense thinning produces a stand unable to fully utilize the growing space. Thinning intensity also influences the optimum thinning interval and rotation age. Smithers (1957) recommended a basal area (BA) removal for lodgepole pine of approximately 30%, with a maximum of approximately 50%. He also asserted that a heavy thinning—up to 50% of volume—at least 25 years prior to the final harvest will yield a final harvest volume equal to that of an unthinned stand plus a thinning volume of about 130 m^3/ha (Smithers 1961).

Research reviews of stand density management in lodgepole pine have noted a general lack of data for commercial thinning in mid- to late-rotation stands (Johnstone 1985; Johnstone and Cole 1988; Silfor 1997). This is a topic of considerable management interest, because large areas of dense older stands exist. Trees in such stands frequently have small crowns and high slenderness coefficients (ratio of height to diameter at breast height), potentially limiting their capacity for crown recovery and growth response (Oliver and Larson 1990).

Stands may pass through waves of density-dependent mortality (Oliver and Larson 1990), often aggravated by low stand resistance to snow and wind damage (Navratil 1995). Mortality waves in lodgepole pine stands have been observed in the growth and yield monitoring programs in Alberta (Stan Lux. Canadian Forest Service, retired. Personal communication. 1999).

There is evidence (Moller 1954; Braathe 1957) that there is no permanent loss of increment over a fairly wide range of thinning intensity. Inappropriately heavy thinning removals may, however, reduce total wood production due to inadequate site occupancy, and prolong the extent of the recovery phase.

There are only three published reports of thinning in Alberta lodgepole pine stands of age 60 years or more, and they report only short-term remeasurements (Smithers 1957; Walker and Johnston 1975; Johnstone 1982). Heavy low thinning and sanitation thinning in an 84-year-old lodgepole pine stand near Strachan, Alberta, produced periodic annual increment (PAI) increases of about 60% over the first 10 years after thinning, as compared to those of the control (Walker and Johnston 1975). The trial was not remeasured until 45 years after thinning, at stand age 130 years, when cumulative total volume gain in the best thinning treatment (sanitation thinning) was 64 m^3/ha (author's unpublished data).

Commercial thinning to reduce susceptibility to mountain pine beetle has been done in 70 to 100-year-old lodgepole pine stands in British Columbia, but no growth response data are yet available (Mitchell 1994).

There is little information on thinning in lodgepole stands 60 years of age and older in other geographical regions. Most reported thinning trials and growth and yield models of commercial thinning of lodgepole pine in Canada and the USA involve thinning of younger stands (Johnstone 1985; Yang 1998; Cole and Edminster 1985; Johnstone and Cole 1988) or thinning cycles designed to achieve target rotations (Cole and Koch 1995). Increased diameter and basal area growth after thinning 55-year-old (Dahms 1971), 65-year-old and 78-year-old (Alexander 1960) lodgepole pine were reported for stands in Wyoming and Oregon.

To address this knowledge gap, Weldwood of Canada, through its Enhanced Forest Management Program, initiated remeasurement of thinning trials established in Alberta by the Canadian Forestry Service and Alberta Forest Service from 1940 through to the 1980s. Results from one of those trials, K-57, are presented here. Despite the deficiencies of this trial as a scientific experiment, the uniqueness of the data set in terms of longevity of the trial and the supposedly extreme nature of the treatment warrant continued observation and analysis of the responses.

The main objectives of this study are

- to evaluate the effects of late-rotation thinning on stand development and yield, and
- to relate the findings to management options for thinning of late-rotation, fire-origin lodgepole pine stands.

BACKGROUND, TRIAL ESTABLISHMENT AND EARLIER ASSESSMENTS

A number of thinning trials were established in Alberta by the Canadian Forestry Service and the Alberta Forest Service between 1940 and 1990. One of these, Trial K-57, was established in 1941 in a dense 77-year-old pine-dominated stand in the Kananaskis area in southwest Alberta. The 60-year duration makes it Canada's longest-running commercial thinning trial for lodgepole pine. Earlier reports were published by Quaite (1949, 1950, 1955) and Johnstone (1982).

According to historical descriptions, the 77-year-old stand was over-dense and slow-growing prior to the 1941 thinning (Quaite 1955). The stand was nearly pure lodgepole pine (90.5% and 97.5% of basal area in the control and thinned stands, respectively in 1949), with a few large aspen and a number of small white spruce making up the remainder. Stand density averaged 7 166 trees per hectare (TPH).

The primary objective of the thinning was to produce poles and saw timber from the overstocked stand. This work was intended as an operational trial, rather than a scientifically rigorous experiment. As such, no control plots were established, nor was any replication carried out. It was predicted that "saw timber will be produced on the basis of another 50 years before the final cut. The bulk of the final crop trees will be best utilized for small poles." A final thinning was originally planned for about 1970 (Quaite 1950) but never carried out.

The 1941 thinning was "a combination of heavy thinning from above and below. . . . All the aspen, the defective pine and spruce, and nearly all the 1 and 2 inch pine were removed" (Quaite 1950). The original volume of 266 m^3/ha was reduced to about 79 m^3/ha, and density fell from 7 166 TPH to 1 710 TPH. Basal area removal was 70% for all species, and 67% for lodgepole pine. Thinning debris was removed, leaving a very clean forest floor, which could have affected nutrient cycling in the thinned treatments.

In 1949, a series of research plots were established by the CFS throughout the trial. Four 1/5-acre (0.08094 ha) plots were established in the thinned area and two 1/10-acre (0.04047 ha) control plots were established in the untreated portion of the stand (Fig. 1). Quaite (1949) noted that the untreated area and plots are on a somewhat better site than the thinned area. The control plots contained aspen trees, while all aspen was removed from the thinned area. The minimal replication and inadequate randomization of plot locations clearly limit the quantitative inferences that can be drawn from this study; nonetheless, clear patterns have emerged, justifying our continued attention. Limited inferences can be drawn from the results, and any comparison of treatment and control plots is done keeping in mind that the two areas differed at the outset and may have responded differently to treatments over time. Results are presented only for lodgepole pine, since the white spruce component was too small and unevenly distributed between control and treatment areas to allow meaningful interpretation of results, particularly in light of experimental design weaknesses.

All live trees in the plots were tagged and measured for diameter at breast height (DBH). In addition, 82 trees in the control and 99 trees in thinned plots were measured for height. A subsample was destructively sampled outside the plots to retroactively estimate 1941 height and DBH. Summaries were reported by Quaite (1950). Complete measurements were taken in 1949. The 1949 data file obtained from the CFS consisted of DBH measurements for all living trees, height measurements of a sample of trees, and designation of dead trees.

The same variables that were measured in 1949 were remeasured again in 1963 by the CFS, and these 22-year results were reported by Johnstone (1982). He reported a pronounced effect of thinning on diameter and volume growth, and concluded that thinning can stimulate the growth of older lodgepole pine trees with low merchantable volume.

Historical 1949 and 1963 measurements, as well as the 1999 measurements of height and DBH, were verified by tracking individual tree numbers. Data for 1941 and 1953 were available only in summary form from internal CFS reports (Quaite 1949, 1950, 1955). Consequently, not all stand and tree attributes could be calculated and interpreted for 1941 and 1953.

The trial site is in a unique area of the province, as the Lower Foothills, Montane, and Subalpine Subregions converge just to the north. The trial site was classified according to the *Field guide to ecosites of southwestern Alberta* (Archibald et al. 1996; Geographic Dynamics Corp. 1999). The elevation of 1 500 m would appear to place K-57 into the Subalpine Subregion; however, the vegetation in the trial plots matches the Lower Foothills Subregion. The final classification, by Geographic Dynamics Corp. (1999a), places it in the Montane Subregion (Table 1).

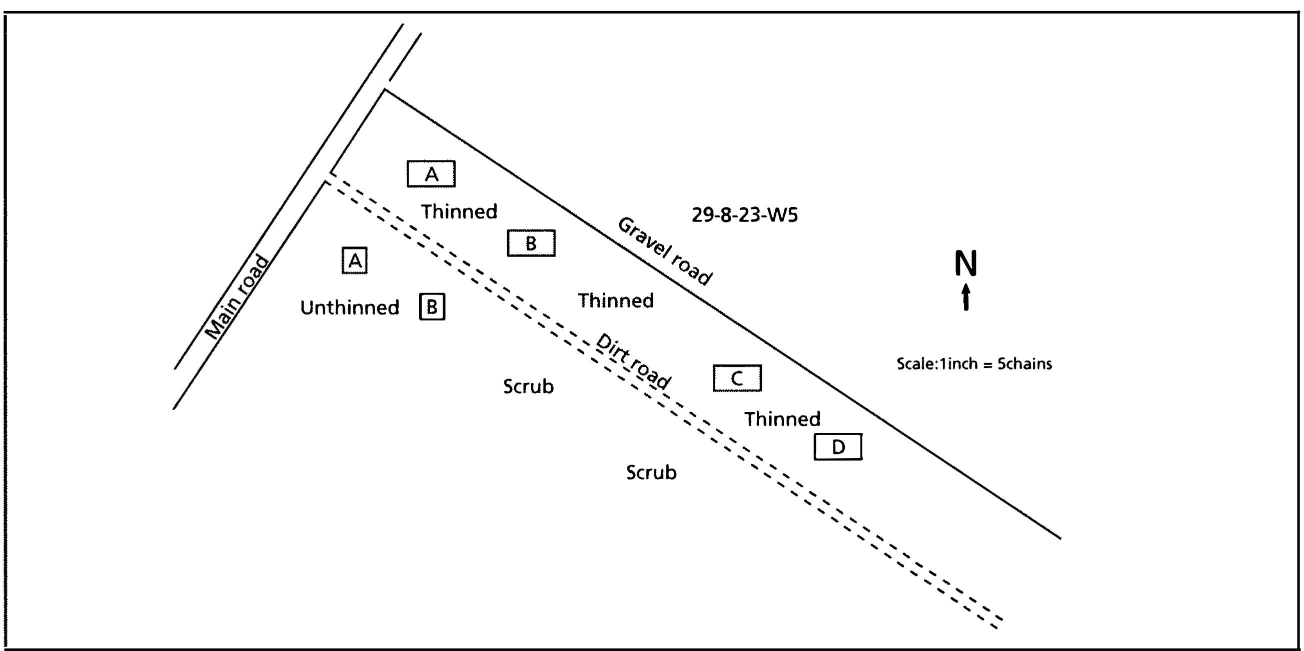

Figure 1. Plot locations in thinned and unthinned areas — the original diagram for Kananaskis project K-57.

Table 1. Ecological classification of the K-57 trial area

Ecological variable	Classification	Qualifiers
Ecosite classification	Montane-c2.1	Except thinned Plot D which is transitional between Montane-b1.1 and Montane-c2.1
Surface soil texture	Loam to Sandy Loam Sandy Loam	InIn unthinned plots With variable amount of coarse fragments in thinned plots
Moisture regime	5 (mesic) 4-5 (submesic to mesic)	In unthinned plots In thinned plots, except Plot D that had moisture regime 4
Nutrient regime	C (medium)	In all plots
Site index at 50 years	12.2	For lodgepole pine

1999 MEASUREMENTS

All live plot trees were tallied and measured for DBH. All trees with previous height measurements were remeasured for total height and height to live crown. Standing dead trees or ones assumed dead on the ground (no tag found) were recorded as dead; no measurements were taken on dead trees. Neither was any tally taken of ingress regeneration or understory, except for trees tagged in 1963.

The tracking of individual trees revealed that, in 1963, nine trees were cut for stem analysis in thinned plots; none were cut in the control plots. The lost volume was replaced in our calculations by matching the missing trees with trees that had comparable diameters in 1963, assuming that the missing trees would have grown at the same rate as their surrogates. The effect on neighboring trees is assumed to be small because of the small proportion of trees removed. Estimated volumes of these trees were added to the 1999 volume totals.

Additional height measurements were taken to compensate for trees that had died since 1963. These trees had no historical height data prior to 1999.

RETROSPECTIVE AND CURRENT ANALYSES

The 1949 data file obtained from the CFS comprised DBH measurements for all living trees, height measurements of a sample of trees, and designation of dead trees.

Height, DBH, and plot size measurements were converted to metric units and used to calculate the following stand level attributes: density (TPH), basal area (BA), total volume, merchantable volume, average stand height, top height, quadratic mean diameter (Dq), and average DBH; and tree attributes: DBH, total height, percent live crown, slenderness ratio (height/DBH), total tree volume, and merchantable tree volume.

Merchantable volumes were derived from individual tree volume tables provided by The Forestry Corp, Edmonton, employing a 10/8 utilization standard (0.3 m stump height, minimum 10 cm diameter outside bark large end, to an 8 cm top diameter inside bark) and a 15/10 utilization standard (0.3 m stump, 15 cm diameter outside bark large end, to a 10 cm top diameter inside bark).

Other measures were calculated to retroactively estimate type and intensity of the 1941 thinning. Thinning ratio DR1 is defined as d/D1, where d equals the average DBH of trees removed, and D1 is the average DBH of trees after thinning (Braathe 1957). Thinning ratio DR2 is defined as d/D2, where d is the average DBH of trees removed and D2 is the average DBH of trees before thinning (Smith 1986).

A stand density index (SDI-1) based on Reineke (1933) was evaluated by the original author (Quaite 1949) in a number of additional thinned and unthinned plots in the Kananaskis area. Quaite concluded that optimum growth resulted from thinning to a minimum SDI-1 value of 300, assuming regular thinning at 10-year intervals.

The SDI-2 values are based on the formulas from Long (1985), who estimated key SDI values for lodgepole pine at 1020 (for lower limit of self thinning), 600 (for lower limit of full site occupancy), 850 (for upper limit of thinning) and 600 (for lower limit of thinning).

The spacing factor (SF) is the ratio of spacing interval to top height, expressed as a percent. It was calculated from the density (TPH) before and after thinning, and average heights of trees in the four largest diameter classes (DBH of 5.0 to 7.4 inches) based on Quaite's (1949) data for 1941. Spacing factor values of approximately 20% are commonly recommended for managed coniferous stands. For crop plans of lodgepole pine in Alberta, Day (1998) selected a spacing factor of 17% before thinning and a spacing factor of 21% after thinning. Day (1998) also suggests that the difference in spacing factor before and after thinning should not be greater than 4%.

Site productivity was calculated in two ways. Stand density, top height, and age in 1949 were used to derive productivity index (PI) values using Johnstone's (1976) variable density yield tables. Productivity was also estimated using calculated breast height age and estimates of site index according to Huang et al. (1994). Top height of lodgepole pine was calculated using the 100 largest diameter trees per hectare from the 1949 data at stand age 85. From the map in Huang et al. (1994), the trial location was near the boundary between the Natural Region 11 and Natural Region 10; therefore, site index estimates were calculated for both Natural Regions.

The stand's self-thinning status was assessed by comparing calculated values with threshold values:

- an excessive stand density at an advanced age of > 6 000 TPH (e.g., stand density management diagrams, Farnden 1996)
- a spacing factor of <17% (Day 1998)
- a stand density index of >850 (Long 1985)
- slenderness coefficients of >100 (Klaedtke and Kenk 1997; Navratil 1995).

RESULTS AND DISCUSSION

Estimates of stand parameters at years 1941, 1949, 1953, 1963 and 1999 are given in Table 2. Table 3 shows the magnitude of changes between measurement years.

After thinning in 1941, lodgepole pine trees were taller in the control than in the thinned areas; later, this difference disappeared. The annual height increment between 1941 and 1949 was twice as great in the thinned stand (22 cm/yr) as in the control (11 cm/yr) for all diameter classes except the 2-inch class (Quaite 1955). Measurements taken in 1949 and 1963 showed little difference between heights in the thinned versus unthinned. In 1999, 58 years after thinning, mean heights were 18.4 m in the control and 19.5 m in the thinned treatment.

Basal area removal of 70% for all species and 67% for lodgepole pine indicates very high-intensity thinning. Mean diameter increases between 1949 and 1963 (ages 85 and 99) were greater in the control stand than in the thinned stand (Fig. 2); however, this is more

Table 2. Stand attributes at various times, beginning at age 77 in 1941

Attribute	1941 Stand age 77		1949 Stand age 85		1953 Stand age 89		1963 Stand age 99		1999 Stand age 135	
	Control	Thin	Control	Thin	Control	Thin	Control	Thin	Control	Thin
TPH (Pl)	6079	1554	4635	1570	3669	1534	2681	1507	1471	1192
TPH (all species)	7166	1710	5697	1721	4720	1688	3620	1652	2175	1337
DBH (cm) (Pl)	9.4	10.67	9.88	12.45	11.68	13.71	12.62	14.88	17.12	19.79
Mean height (m) (Pl)	13.28	12.13	11.98	12.00	HNM	HNM	14.55	14.00	18.44	19.47
Top height (m) (Pl)	NA	NA	16.20	14.95	HNM	HNM	18.20	17.22	21.74	22.60
Basal area (m^2/ha) pine	41.83	13.70	40.67	20.21	38.9	22.6	36.65	27.93	36.21	38.55
Basal area (m^2/ha) all species	47.27	14.01	48.24	20.7	47.6	23.25	47.84	29.03	53.6	43.08
Volume (m^3/ha) Pl	234.9	78.9	244.6	131.7	HNM	HNM	249.6	204.6	292.2	330.0
Cumulative volume (incl. thinnings)Pl	234.9	234.9	244.6	287.7	HNM	HNM	249.6	360.6	292.2	486.0
Volume (m^3/ha) all species	266.7	79.5	282.5	133.4	HNM	HNM	316.0	209.7	415.8	361.0
MAI volume (m^3/ha) Pl	3.05	3.05	2.88	3.38	HNM	HNM	2.52	3.64	2.16	3.6
MAI volume (m^3/ha) all species	NC	NC	3.64	1.48	HNM	HNM	3.19	2.12	3.08	2.67
Merch. volume (m^3/ha) Pl (10/8)	NC	NC	168.6	103.4	HNM	HNM	200.87	178.22	257.78	306.14
Merch. volume (m^3/ha)Pl (15/10)	NC	NC	89.2	58.5	HNM	HNM	134.7	136.17	236.85	276.54
SDI – 1	559	158	NA	NA	HNM	HNM	NA	NA	NA	NA
SDI – 2	1270	394	1174	537	HNM	HNM	964	694	846	846
SF%	8.4	18.3	9.1	16.8	HNM	HNM	10.6	14.9	12.0	12.7
Dq	9.4	10.6	10.6	12.8	HNM	HNM	13.2	15.4	17.7	20.2
Ht/DBH	141	113	103	62	HNM	HNM	93	78	101	108

Note:
TPH = stem density measured in trees per hectare.
Pl = lodgepole pine.
HNM = height not measured.
NC = not calculated.
NA = not available.
MAI = mean annual increment.
SDI – 1 = stand density index from Quaite (1949) calculated in English units based on Reineke's SDI.
SDI – 2 = stand density index for lodgepole pine calculated in metric units according to Long (1985).
SF = spacing factor.
Dq = quadratic mean diameter.
DBH = diameter at breast height.
Ht = height.
The 1949, 1963 and 1999 values are calculations from the historical and 1999 remeasurement data.
The 1941 and 1953 values are from summaries from Canadian Department of Resource Development (Quaite 1955).
The 1941 values were retroactively estimated in 1949 (Quaite 1949).

Table 3. Changes in stand attributes over each time period

Change in attribute	1941 Age 77 At thinning	1941-1949 Age 77–85 Control	Thin	1949-1963 Age 85–99 Control	Thin	1963-1999 Age 99–135 Control	Thin
TPH (all species)	-5456	-1469	11	-2077	-69	-1445	-315
TPH (Pl)	-4525	-1444	16	-1954	-63	-1211	-315
Mean annual mortality % (Pl)	N/A	3.0	0	1.2	0.3	1.3	0.4
%TPH (all species)	-76.0	-20.5	0.1	-36.4	-4.0	-39.9	-19.0
%TPH (Pl)	-74.0	-23.0	1.0	-42.1	-4.0	-45.1	-20.9
Basal area (all species)	33.26	0.97	6.69	-0.4	8.33	5.76	14.05
Basal area (Pl)	28.13	-1.16	6.51	-4.0	7.72	-0.44	10.62
%basal area (all species)	-70.0	2.0	47.7	-0.8	40.2	12.0	48.4
%basal area (Pl)	-67.0	-2.8	47.5	-9.8	38.2	-1.2	38.0
Volume (all species)	187	15.8	53.9	33.5	76.3	99.8	151.3
Volume (Pl)	156	9.7	52.8	5.0	72.9	42.6	125.4
% volume (all species)	-70.2	5.9	67.8	11.8	57.2	31.5	72.1
% volume (Pl)	-66.4	4.1	66.9	2.0	55.2	17.0	61.3
PAI volume (m^3/ha) Pl	NA	3.58	5.70	0.36	5.22	1.18	3.48
PAI volume (m^3/ha) all species	NA	5.37	5.78	2.39	5.45	2.19	4.2
Mortality loss (m^3/ha) Pl [a]	NA	57.2	0	110.5	3.8	112.6	42.6
SF%	9.9	0.7	-1.5	1.5	-1.9	1.4	-2.2

[a] Volume loss was calculated as the difference in TPH multiplied by the mean tree volume at the beginning of the period.
Note:
TPH = stem density measured in trees per hectare.
Pl = lodgepole pine.
NA = not available.
SF = spacing factor.
PAI = periodic annual increment.
The 1949, 1963, and 1999 values are calculations from historical and 1999 re-measurement data.
The 1941 values are from summaries from Canadian Department of Resource Development (Quaite 1955).

likely due to higher mortality of smaller trees in the control plots during this period than it is to a real increase in radial growth. Between 1963 and 1999, the diameter growth was only slightly greater in the thinned stand (4.9 cm) than in the control stand (4.5 cm).

After the period of high mortality in the control stand between 1949 and 1963, the slenderness coefficient had dropped from its 1949 value of 103 down to 93 in 1963; i.e., trees that survived were more tapered than those that did not.

Thinning ratio DR1 was calculated at 0.83, indicating a level "intermediate between low and high thinning" according to Braathe's (1957) classification. Thinning ratio DR2 was 0.938,

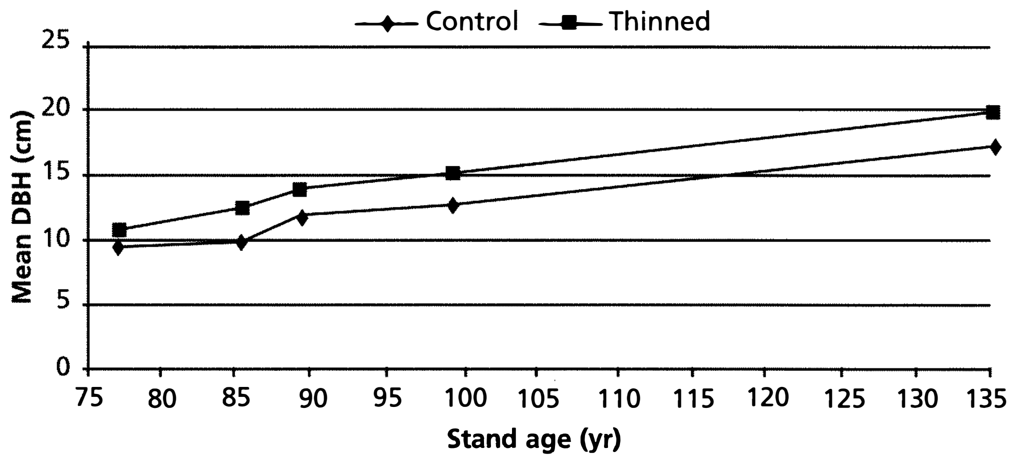

Figure 2. Mean diameter of lodgepole pine.

indicative of "severe high thinning" by Smith's (1986) classification.

The SDI-2 values were calculated for 1941 data. Based on Long's (1985) values, the control stand was well within the self-thinning zone. The thinning treatment was severe, with an SDI-2 value of 394 well below the threshold for full site occupancy (600). A post-thinning spacing factor value of 18.3% is within the range recommended by Day (1998). However the 9.9% difference between pre- and post thinning exceeds his recommended maximum of 4%, and constitutes a drastic opening of the stand.

The total volume of lodgepole pine in 1949 was 244 m^3/ha, which compares well with the total volume of 258 m^3/ha, derived for the same age in high-density stands (4 940 TPH at age 70) in Johnstone's tables (1976). Site index estimates were 12 m at age 50 for Natural Region 11, and 13 m at age 50 for Natural Region 10.

The 1999 slenderness coefficient values (101 and 108 for control and thinned treatments, respectively) are in the high risk category for wind and snow damage (Navratil 1995; Klaedtke and Kenk 1997). The consistent increase of this coefficient in the thinned stand over time (62 in 1949, 78 in 1963), implies increased intraspecific competition due to crowding, affecting crown size and diameter growth.

Based on Long's (1985) key values for SDI-2, the control stand in 1941 was well within the self-thinning zone; the thinning treatment was severe, moving the stand below the zone of full site occupancy. Other self-thinning parameter estimates (stand density, spacing factor, and slenderness coefficient) calculated for the control stand in 1941 had values on the self-thinning side of thresholds noted in the previous section. Even in 1949, 1963, and 1999, many of the thresholds were exceeded in the control stand.

Heavy thinning in 1941 improved stand density, spacing factor, and stand density index (SDI-1 and SDI-2), but the resultant shifts in quadratic mean diameter, height per diameter at breast height, and live crown were less pronounced. Based upon 1999 data, the thinned stand has once again become too dense and self-thinning, and is experiencing volume losses through mortality. The lower volume increment in the thinned stand from 1963 to 1999 than from 1949 to 1963 suggests that the stand has been self-thinning for some time. Spacing factors and SDI-2 estimates support this conclusion. A second thinning could, therefore, have been implemented to avoid mortality volume loss and to sustain high volume increments.

In the control plots, the stand density of lodgepole pine (Fig. 3) changed at different rates over

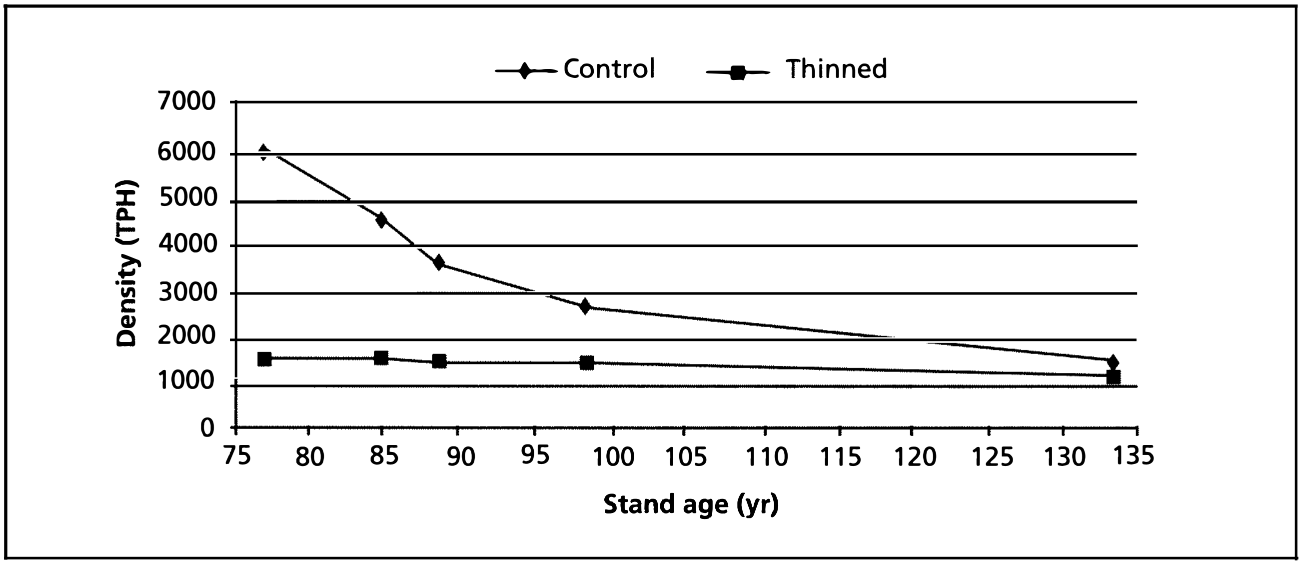

Figure 3. Stem density of lodgepole pine.

each time interval. In the 14 years between 1949 and 1963 when the control stand was between 85 and 99 years old, lodgepole pine mortality was 42%; between 1949 and 1953 it reached 5% per year. After 1963 the density curve is less steep, although high mortality may have continued beyond the age of 99 years, and levelled out only recently. Over the entire period from 1941–1999, lodgepole pine trees declined in number by 75.8%. Mortality in the thinned treatment was consistently lower than it was in the controls. Mean annual mortality was only 0.3% from 1949–1953 and 0.4% from 1941–1999.

Estimated volume losses due to lodgepole pine mortality in the control stand were 110.5 m^3/ha over 1949–1963 and 112.6 m^3/ha over 1963–1999. In the thinned stand, the mortality volume losses were much lower (3.8 and 42.6 m^3/ha, respectively over the same periods, Table 3).

In control plots individual tree growth was offset by mortality, so that net pine volume increment from 1963 to 1999 was only 42.6 m^3/ha, representing a mean periodic increment of 1.18 m^3/ha. There were consistent volume increases in the thinned stand throughout all measurement intervals (Fig. 4), with some PAIs of over 5.0 m^3/ha.

As the stand aged from 99 to 135 years old (between 1963 and 1999), net volume of lodgepole pine increased by 125.4 m^3/ha and 42.6 m^3/ha in the thinned and control, respectively. Although the volume growth rate was lower than in the previous periods, the thinned stand still produced about three times more volume than the unthinned stand during this period.

An examination of standing total volume curves (Fig. 4) provides evidence that late-rotation pine stands respond to intensive thinning. The crossover point of standing volumes (i.e., the intersection of the curves for thinned and control stands) represents the point at which wood production is the same in both treatments. Subsequent to this point, the difference between thinned and unthinned volumes represents yield gain.

The crossover point for lodgepole pine in this trial occurred about 40 years after thinning, when the volume in the thinned stand surpassed that of the control. Such an early crossover is not common unless thinning is very light, which was not the case here. The initial high-density conditions in the control caused stagnation of growth and extensive mortality volume loss, which contributed to the thinned-stand advantage.

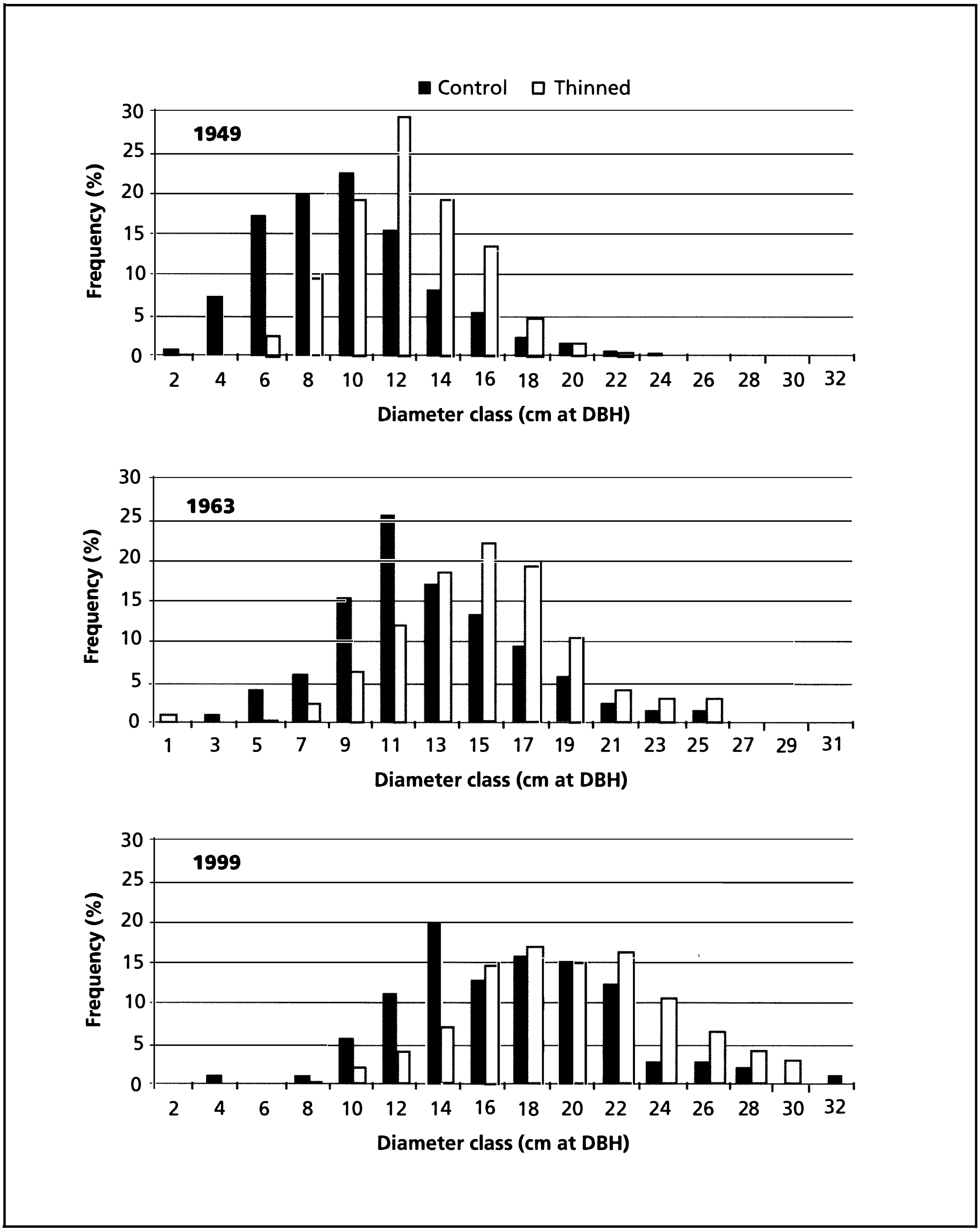

Figure 5. Lodgepole pine diameter distributions in control and thinned stands in 1949, 1963, and 1999.

Yield gains from thinning are more appropriately presented as cumulative volume, which is the sum of standing volume and thinning volume. The thinning volume was 156 m^3/ha, so that cutting the thinned stand in 1963 (at 99 years of age) would have resulted in a yield gain of 111 m^3/ha.

Average tree diameter in the thinned stands consistently exceeded that in the unthinned stands. Figure 5 illustrates differences in diameter distributions in the control and thinned stands at the three measurement dates. Most of the trees from 1999 are in diameter classes greater than 10 cm. Since trees with larger diameters produce higher relative volumes of merchantable wood, the 1999 merchantable volume yield gains were greater than gains of total volume.

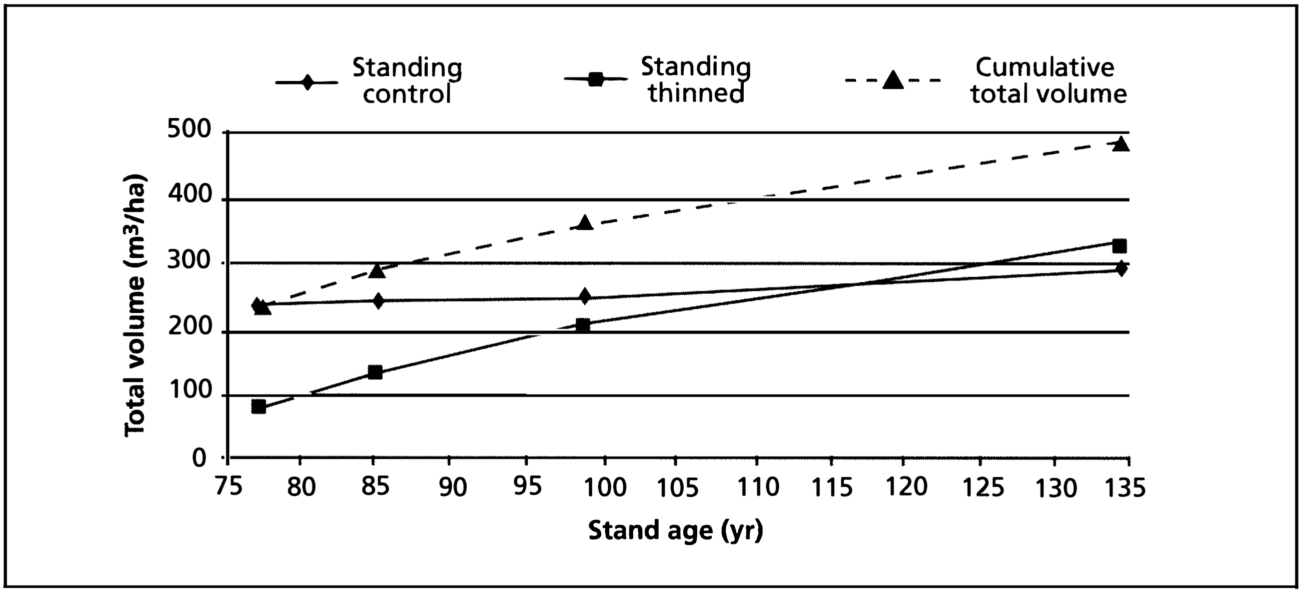

Figure 4. Standing total volume and cumulative total volume of lodgepole pine.

MANAGEMENT IMPLICATIONS AND CONCLUSIONS

This study suggests that late-rotation stands can respond to intensive thinning with increased diameter and volume growth. The delayed and intensive thinning in this dense 77-year-old stand improved the volume growth of lodgepole pine in the first 8, 12, and 22 years after thinning, tripling PAI in the thinned stand over a 36-year period (22 to 58 years after thinning). These results agree with the 21-year post-thinning findings from the same trial by Johnstone (1982), who concluded that thinning will stimulate the growth of older lodgepole pine trees with low merchantable volume. The volume gains observed in this trial resulted from both prevention of volume loss caused by growth suppression in the already self-thinning stand and recovery of merchantable volume from what would otherwise be mortality losses in older stands.

The results from this trial suggest that 66% removal of lodgepole pine volume was not excessive in this particular stand and on this particular site. Despite 67% removal of basal area, the thinned stand produced yield gains in cumulative total volume of about 150 m^3/ha about 40 years after thinning, when the standing volume of pine in the thinned stand surpassed that of the control. This supports

Smithers's (1961) assertion that "a heavy thinning—up to 50% of volume—at least 25 years prior to the final harvest will yield a final harvest volume equal to that of an unthinned stand plus a thinning volume of about 130 m^3/ha."

The K-57 trial produced a much greater growth response than the Strachan study reported by Walker and Johnson (1975). The growth response difference between these trials could be influenced by a number of factors such as stand attributes, thinning parameters, and site quality. The Strachan trial is also located in a different Natural Subregion (Lower Foothills) and on a drier site (LF c1 ecosite, moisture regime 3–4).

The original concept of the trial proposed repeated thinnings, with the final thinning to occur about 1970 (Quaite 1949). It was also assumed at the time of the final rotation cut (proposed to occur by 1990), that there should be approximately 865 trees per hectare with an average diameter of 25.4 cm. Using the current tree volume tables for lodgepole pine, this represents a total volume of 407 m^3/ha. It is interesting to note that the target is not far from the actual volume (361 m^3/ha for pine and spruce) measured in the stand in 1999. It can be assumed that if at least one more thinning had been implemented, as originally planned, the volume and DBH targets would have been reached.

Only one thinning occurred in the K-57 trial and it was delayed well into the rotation. This no doubt limited the potential value gains due to improved tree size. Despite this, the observed volume gains in the thinned stand 22 years after thinning (at a stand age of 99) and 58 years after thinning are unusually high. Growth and yield models or simulations of stand density management in lodgepole pine, although applicable to treatments at earlier ages than in K-57, do not support such a high level of response (Cole and Edminster 1985; Cole and Koch 1995; customized simulations by TASS [Tree And Stand Simulator, Forest Research Branch, BC Ministry of Forests] using the author's unpublished data). The very high initial density, which exacerbated mortality volume losses in the control stand, was probably the main reason for this observed response. Inadequacy in the trial design is another possible contributing factor.

Weaknesses in the original trial design preclude statistical analysis. Treatment plots were not randomized or properly replicated. Control plots were one half the size of those of the thinned plots and were apparently on a better site, while thinned plots were in a separate area of the stand; therefore, estimates of yield gains could be much lower or higher than presented here. Design weaknesses, together with differences in site quality and original stand composition between control and treatment areas, limit the quantitative inferences that can be drawn from this study; nonetheless, clear patterns have emerged.

Overall results confirm that thinning in late-rotation lodgepole pine stands can produce volume growth increases consistent with past reports of thinning responses in lodgepole pine stands in Alberta. The results substantiate the potential for operational thinning in high-density, late-rotation stands as a viable alternative for wood supply strategies.

A broader application of this strategy, in prediction and validation of volume response to thinning in other stands and locations, will require additional trials replicated on other sites in order to clearly define thinning strategies for meeting specific management objectives.

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