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A Summary of 10- to 15-year Results from Douglas-fir Thinning Experiments in the British Columbia Interior

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BRITISH COLUMBIA

Ministry of Forests and Range
Forest Science Program

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ABSTRACT

Since 1989, three long-term experiments have been established in the British Columbia interior to determine the effects of precommercial thinning (spacing) on the future growth and yield of interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco) stands under a variety of age, site, and stand conditions. This report provides a brief summary and overview of the results observed to date, and is intended to acquaint forest managers in the interior with the nature and progress of the trials. Thinning improved individual-tree growth, particularly diameter growth, with the greatest response occurring at the widest spacing. Thinning generally reduced basal area and total volume per hectare, and increased merchantable volume per hectare. The observation periods vary from 10 to 15 years, depending upon the experiment.

ACKNOWLEDGEMENTS

The establishment of these experiments was possible only because of the assistance and co-operation of staff in the Central Cariboo Forest District (and the former Williams Lake and Horsefly Forest Districts) in which the trials are located. The assistance of Ordell Steen (Research Ecologist in the former Cariboo Forest Region), in ecologically classifying the research sites, is gratefully acknowledged. Also, the collaboration of Rob Brockley is greatly appreciated. We thank Rob Brockley, Jim Goudie, and Teresa Newsome for comments on early drafts of the manuscript. Funding for the establishment, maintenance, and measurement of the trials was provided by several sources, including the Canada-British Columbia Forest Resources Development Agreements (FRDA I and II), and Forest Renewal BC. The most recent measurement of several of the trials was funded by the Forestry Innovation Investment (FII) research program.

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1 INTRODUCTION

Interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) is an important species throughout the southern and central interior of British Columbia for a variety of timber and non-timber uses. Douglas-fir is slightly to moderately shade-tolerant, and regenerates profusely following stand disturbances. According to Vyse et al. (1991), on drier interior sites, Douglas-fir typically grows in complex, multi-aged stands. These stands are commonly harvested using single-tree selection techniques, and the resulting regeneration frequently occurs in dense clumps. On moister interior sites, the stands are usually even-aged with a greater mixture of species. Following wildfire or clearcut logging, these stands commonly regenerate to dense, mixed-species, even-aged stands. The importance of controlling stand density in interior Douglas-fir stands, from both timber production and pest management perspectives, has been discussed by Lotan et al. (1988), and at the most recent symposium on the species (Baumgartner and Lotan 1991). In stands where stand density is excessive, the growth and yield of harvestable material may be well below the potential of the site, and the stand may be at greater risk of pest attack (Lotan et al. 1988; Hall 1991).

During the 20-year period from 1985 to 2004, over 385 000 ha of Douglas-fir were spaced on Crown land in the British Columbia interior.[1] Approximately 50% of the area treated was located in the Central Cariboo and Kamloops Forest Districts. However, the area treated has generally declined in recent years because of treatment costs, and concerns that the treatment is not achieving its intended yield objectives and is negatively affecting wood quality. Prior to 1982, very few studies had been carried out in the British Columbia interior to examine the effects of spacing on the growth and yield of commercially important tree species. Starting in 1982, a series of long-term experiments (Experimental Project [E.P.] 922) was undertaken to determine the effects of precommercial thinning (spacing) on the future growth and yield of various interior species growing under a variety of age, site, and stand conditions, and to provide a local data source for the calibration and validation of our growth and yield models. To date, 14 installations have been established in the interior, of which 11 were established in lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) stands (Johnstone and van Thienen 2004). The three other installations in the series (E.P.s 922.09, 922.13, and 922.14) were established in interior Douglas-fir stands in the Central Cariboo Forest District (Figure 1), and are the subject of this report. Table 1 shows distribution of the three trials with respect to their age at trial establishment, stand origin, and site classification. Although these trials are as yet too young to provide definitive answers on the optimum thinning regime(s) for interior Douglas-fir, some interesting trends are developing. The purpose of this report is to provide a brief summary and overview of the results observed to date, and to acquaint forest managers in the interior with the nature and progress of the trials.

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[1] R. Winter, Stand Management Officer, B.C. Min. For. Range, For. Practices Br., Victoria, B.C., pers. comm., Nov. 2005.

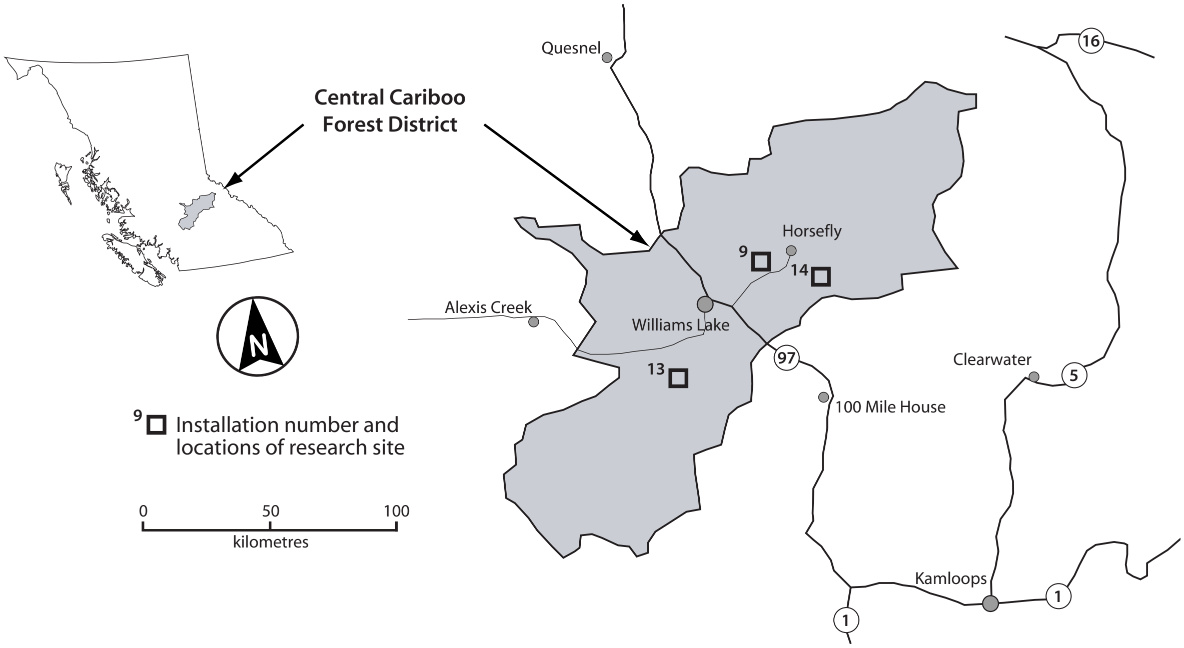

FIGURE 1 *Location of Douglas-fir precommercial thinning experiments in the Central Cariboo Forest District (the installation number is shown for each trial).*

TABLE 1 *Distribution of Douglas-fir thinning trials by stand age at trial establishment, stand origin, and biogeoclimatic ecosystem classification (BEC) variant*

E.P. number	Average tree age (yr)	BEC variant	Stand origin
922.09	63	SBSdw1	Wildfire
922.13	36	IDFdk3	Post-harvest
922.14	30	ICHmk3	Wildfire

A more detailed description of the sites, stands, methods of establishment, and progress to date is available in the establishment and progress reports for each study, which are on file at Research Branch.

2 THE TRIALS

2.1 E.P. 922.09

2.1.1 Site and stand conditions This installation was established in an essentially pure, interior Douglas-fir stand, and is located on a predominantly west-facing site, at an elevation of 990 m, approximately 2 km south-southeast of Veith Lake (Appendix 1). This site is ecologically classified as being in the SwxFd – Pinegrass (01) site series of the Horsefly variant of the Dry Warm Sub-Boreal Spruce biogeoclimatic subzone (SBSdw1) (Steen and Coupé 1997). The soil is a well-drained, gravelly sandy loam with a moderately high (35–70%) coarse-fragment content, and is classified as a Brunisolic Gray Luvisol. The rooting depth is 30–35 cm, the moisture regime is classified as mesic to submesic, and the nutrient regime is classed as medium to poor. The present stand regenerated naturally following a wildfire, and at the time of study establishment (fall of 1989), the trees had an average total age of 63 years and a quadratic mean diameter of 12.5 cm. At that time, the average stand density was 4923 stems/ha. The treatments applied were "low" thinnings (thinnings from below), which, depending upon intensity, resulted in d/D ratios ranging from 0.89 to 0.79, and v/V ratios ranging from 0.77 to 0.60.[2]

2.1.2 Methods of study establishment and measurement This installation consists of a randomized complete-block design with three blocks. Each block contains three thinning treatments: 500, 1000, and 1500 stems/ha (sph) post-thinning densities, plus an unthinned control. In a major departure from the original working plan,[3] a plot size of approximately 50 × 50 m was used for the thinned plots, and 30 × 30 m plot size was used for the unthinned controls. The stand surrounding the thinned plots was operationally spaced to approximately 1200 sph, and the control plots were surrounded by 15-m unthinned buffers.

All trees within the thinned and unthinned plots were systematically tagged with serially numbered tags, and a dbh-band was painted on each tree at 1.30 m above the point of germination. In the falls of 1989 (after thinning), 1994, 1999, and 2004, the following individual-tree measurements were taken:

a) bole diameter (outside bark) at 1.30 m (dbhob) of all tagged trees in the thinned and control plots; and
b) total height, crown length, and crown width of 60 Douglas-fir trees (20 trees randomly sampled of each third of the diameter distribution) in each plot. In addition, the heights of all non–Douglas-fir trees were measured.

At each measurement, the condition of each tree was examined, and the presence of any damage was recorded for each tagged tree. The trial was measured at establishment in 1989, has been remeasured 5, 10, and 15 growing seasons after thinning, and is due for remeasurement in 2009.

2.1.3 Compilation and analysis With the exception of the unthinned controls, the relatively large (approximately 0.25 ha) treatment plots used in this trial were established without conventional treatment buffers. In lieu of treatment surrounds, data from the two outer, perimetrical rows in the 500-sph treatment plots; the three outer, perimetrical rows in the 1000-sph treatment plots; and the four outer, perimetrical rows in the 1500-sph treatment plots were not used in the analyses of treatment effects. The elimination of these trees creates an interior buffer, approximately 10 m wide, in each of the thinned plots. Consequently, the analyses are based upon data from 49, 100, and 121 inner "sample trees" per plot for the 500-sph, 1000-sph, and 1500-sph treatments, respectively. Least-square, height/diameter equations, derived for each plot from the randomly sampled tree data described in the previous section, were used to calculate the height of sample trees that did not have a measured height. Mean-tree and per-hectare stand

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[2] Ratio of quadratic mean diameter of thinnings (d) to quadratic mean diameter before thinning (D). Ratio of mean volume/tree of thinnings (v) to mean volume/tree before thinning (V).

[3] Johnstone, W.D. and R.P. Brockley. 1983. Working plan–The effect of spacing on the growth and yield of lodgepole pine. B.C. Min. For., Res. Br., Victoria, B.C. Unpublished report.

values of each plot were calculated for each measurement period. Per-hectare values are net values (i.e., they exclude mortality) and were determined for each thinned plot by multiplying the mean value of the sample trees (volume[4] or basal area) times the spacing level times the number of living sample trees as a decimal fraction of the original (1989) number of sample trees for that plot. Net per-hectare values for the control plots were based on the area of each plot. Data from the three blocks were combined to produce the summary data shown in Figures 2–13.

2.1.4 15-year results Survival remains high in the thinned plots irrespective of spacing level (Figure 2). Mortality in the treated plots did not appear to be related to inter-tree competition. It is anticipated that competitive mortality will become increasingly important as the denser spaced plots close. Conversely, heavy competition-related mortality, particularly in the subordinate crown classes, continues in the unthinned control plots. The highest rate of mortality (over 23%) was observed in the densest control plot (Block 3). An attempt was made to retain healthy Douglas-fir trees during the selection of crop trees in the thinned plots. Fifteen years after thinning, 6.9% of the sample trees in the thinned plots displayed stem rusts or cankers compared to 26.7% in the unthinned plots. A higher proportion of sample trees in the thinned plots displayed sweep (12.0%) than in the control plots (5.2%), but 36.4% of the trees in the controls were leaning compared to 15.7% in the thinned plots. The incidence of sweep and lean in the treated plots generally decreased with increasing thinning intensity.

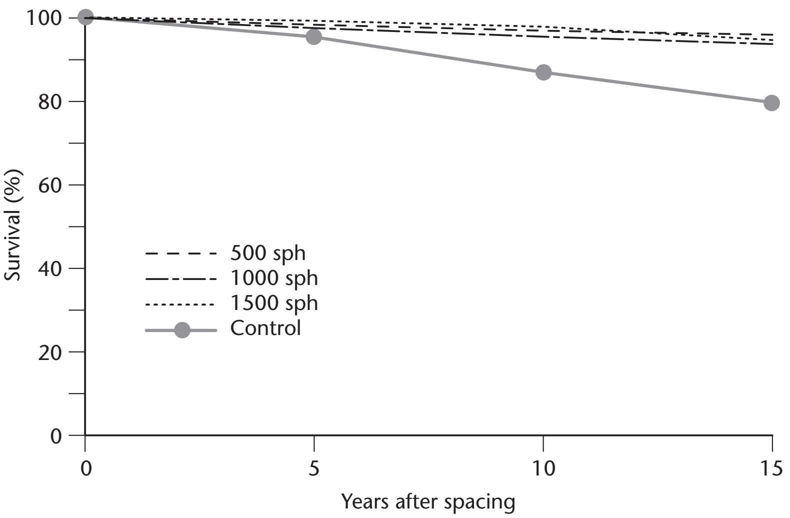

FIGURE 2 *Survival following spacing of 63-year-old Douglas-fir in the SBSdw1 (E.P. 922.09).*

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[4] Volumes are inside-bark volumes calculated from Kozak's taper function (Kozak 1997). Merchantable volume is the bole volume between a 30-cm stump and a 10-cm top for all trees 12.5 cm dbhob and larger.

In this trial, the general trend of the largest trees at the widest spacing continues to develop. Over the last 15 years, thinning intensity has had a direct effect on periodic diameter growth (Figure 3). This growth response has resulted in a major change in the diameter distributions of the plots (Figure 4). Although a small number of the largest trees in this trial were found in the unthinned stands, a far greater proportion of trees larger than 15 cm in diameter are now found in the thinned plots (98.6%, 92.2%, and 71.7% for the 500-, 1000-, and 1500-sph treatments, respectively) compared to the controls (25.0%). This has resulted in large differences in mean diameter (Figure 5) and, assuming that the trends in periodic growth continue, these differences are likely to continue to widen for the foreseeable future. Although the results in Figure 3 suggest a relatively uniform diameter-growth response

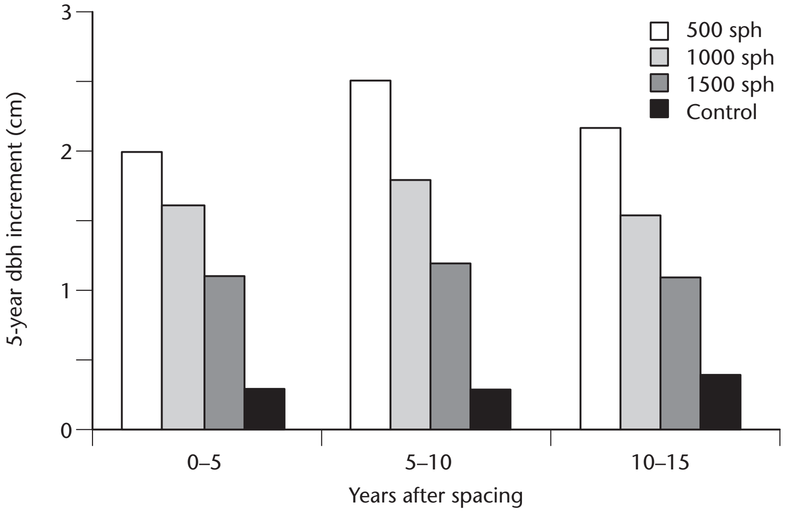

FIGURE 3 *Periodic diameter growth following spacing of 63-year-old Douglas-fir in the SBSdw1 (E.P. 922.09).*

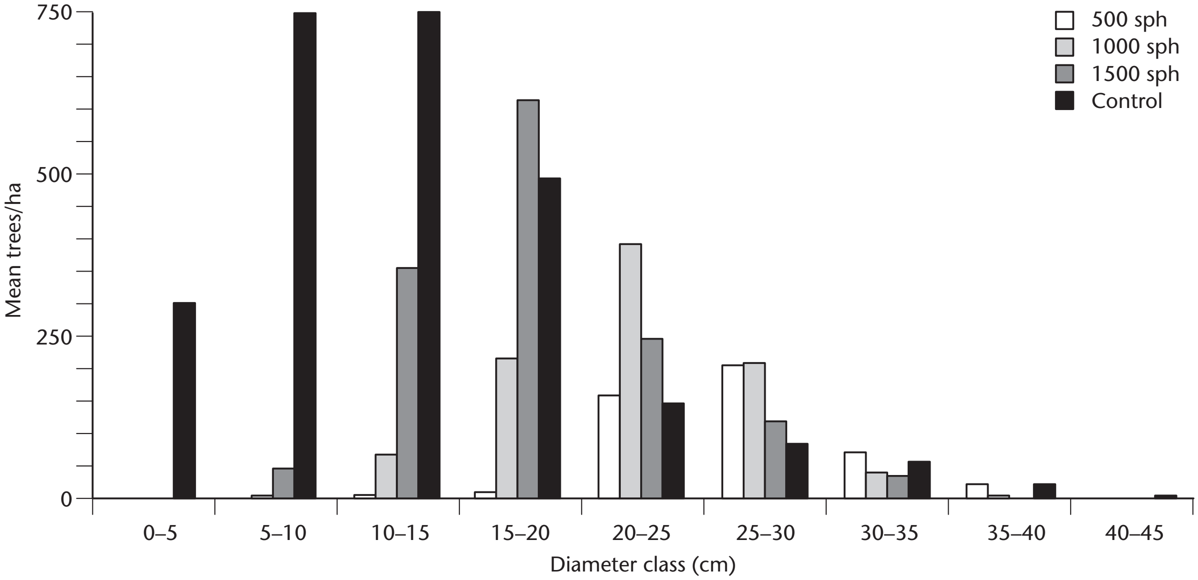

FIGURE 4 *Diameter distributions, by treatment, 15 years following spacing of 63-year-old Douglas-fir in the SBSdw1 (E.P. 922.09).*

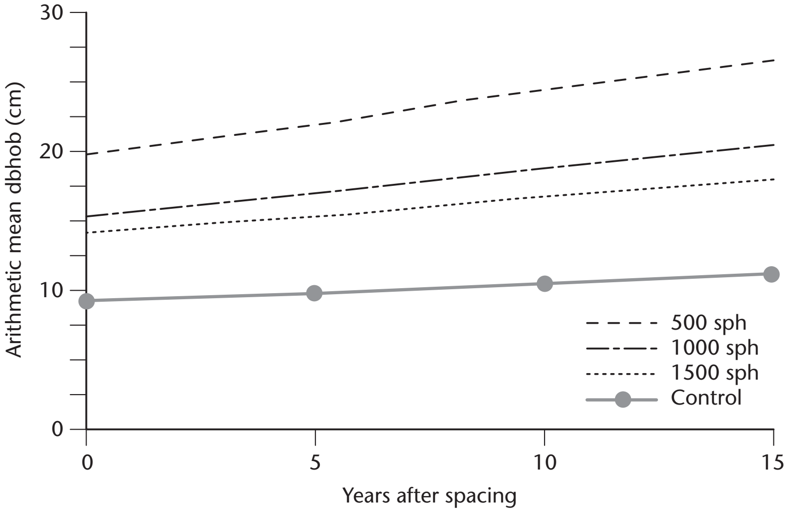

FIGURE 5 *Diameter development following spacing of 63-year-old Douglas-fir in the SBSdw1 (E.P. 922.09).*

during the last 15 years, this radial increment occurred on increasingly larger trees and, in fact, the amount of wood laid down, in terms of individual-tree basal area and volume, was much larger than during each preceding 5-year period.

Unlike diameter, spacing-related patterns in height development are less dramatic. However, the trees in the thinned plots substantially outgrew the trees in the unthinned plots (Figure 6), particularly during the last 5 years. Although some of the tallest trees observed in this trial were found in the unthinned plots (Figure 7), the slower growth and overwhelming number of small trees in these plots have resulted in much lower mean height in the controls than in the thinned plots (Figure 8).

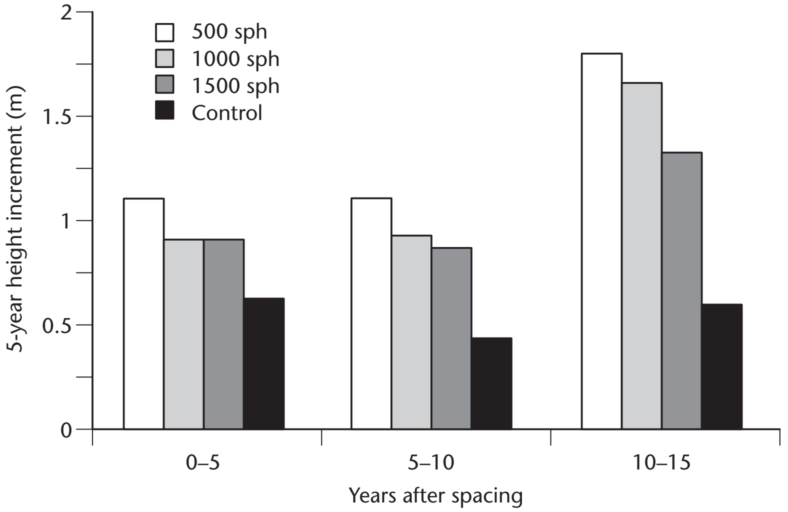

FIGURE 6 *Periodic height growth following spacing of 63-year-old Douglas-fir in the SBSdw1 (E.P. 922.09).*

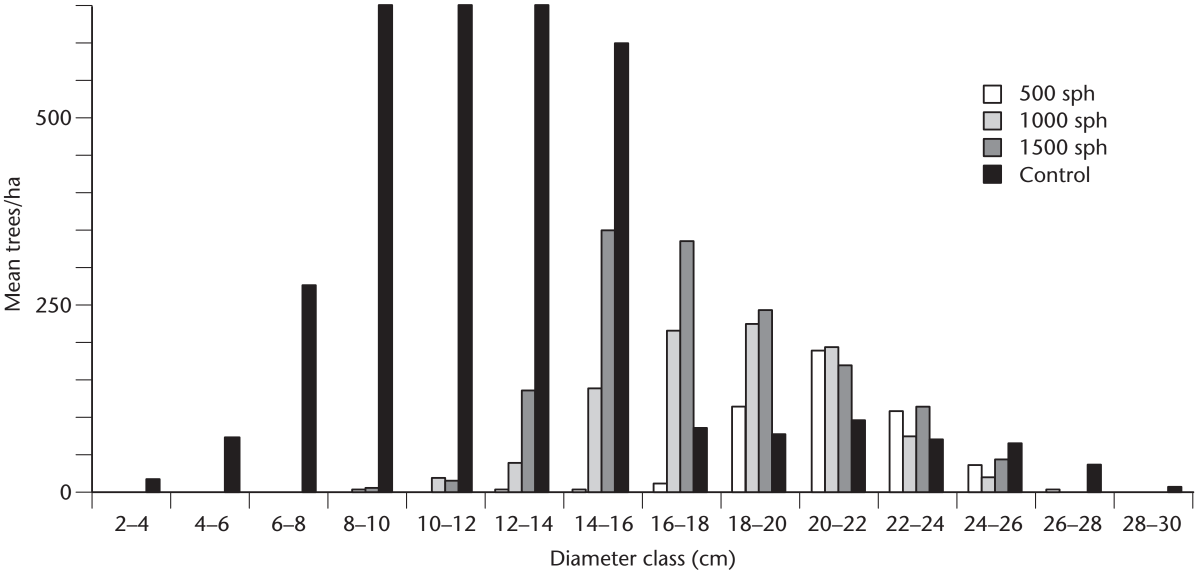

FIGURE 7 *Height distributions, by treatment, 15 years following spacing of 63-year-old Douglas-fir in the SBSdw1 (E.P. 922.09).*

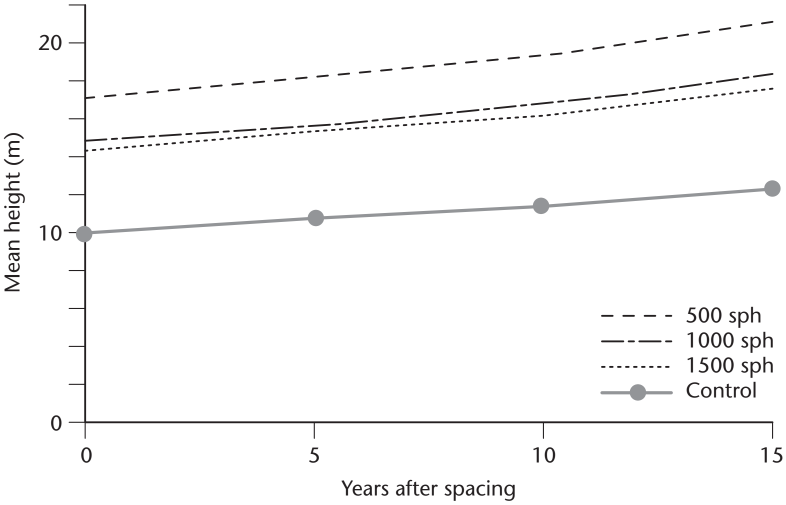

FIGURE 8 *Height development following spacing of 63-year-old Douglas-fir in the SBSdw1 (E.P. 922.09).*

Because of the larger stem diameters and heights, individual-tree total and merchantable volumes increased directly with increased spacing (Figures 9 and 10).

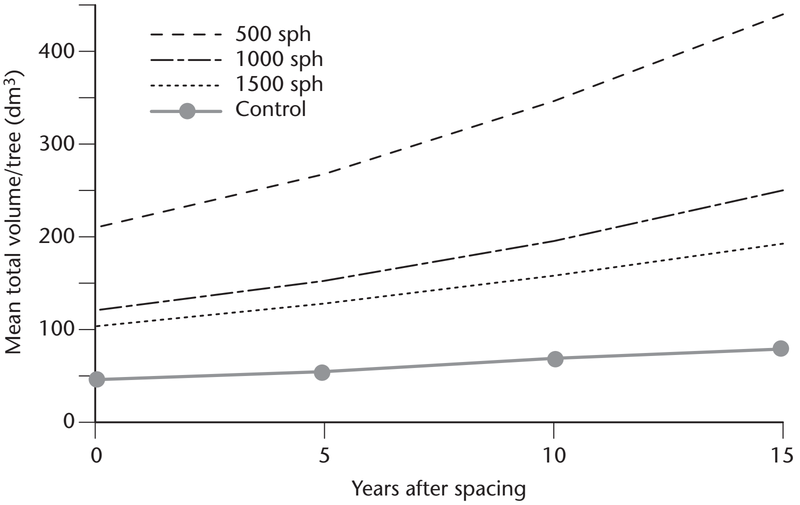

FIGURE 9 *Individual-tree total volume development following spacing of 63-year-old Douglas-fir in the SBSdw1 (E.P. 922.09).*

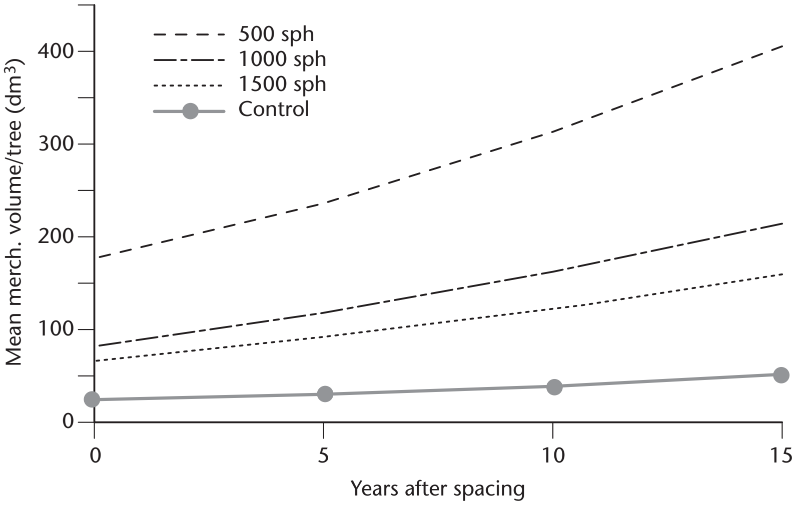

FIGURE 10 *Individual-tree merchantable volume development following spacing of 63-year-old Douglas-fir in the SBSdw1 (E.P. 922.09).*

In spite of larger and faster-growing trees, both stand basal area and stand total volume in the thinned plots are much lower than in the controls (Figures 11 and 12, respectively). However, during the last 10 years, the net, periodic increments of these characteristics have been higher in the thinned plots than in the controls. As shown in Figure 13, 15 years after treatment, the stand merchantable volume of the most closely spaced plots (1500 sph) is roughly equal to that of the unspaced plots. Except for the 500-sph plots during the first 5 years after treatment, the per-hectare increments in merchantable volume of the thinned plots have greatly exceeded the increment of the controls.

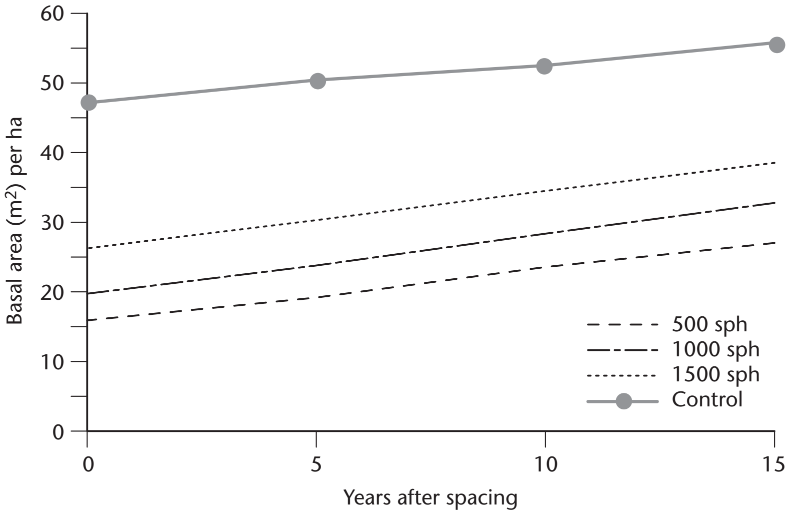

FIGURE 11 *Stand basal area development following spacing of 63-year-old Douglas-fir in the SBSdw1 (E.P. 922.09).*

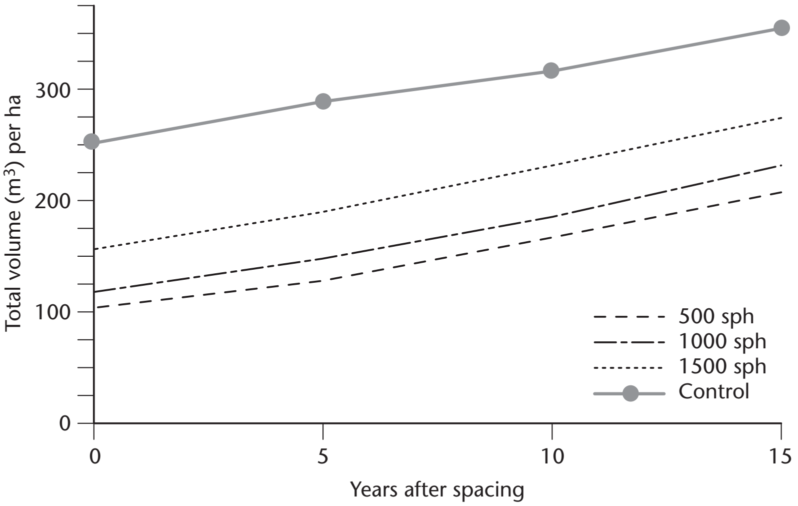

FIGURE 12 *Stand total volume development following spacing of 63-year-old Douglas-fir in the SBSdw1 (E.P. 922.09).*

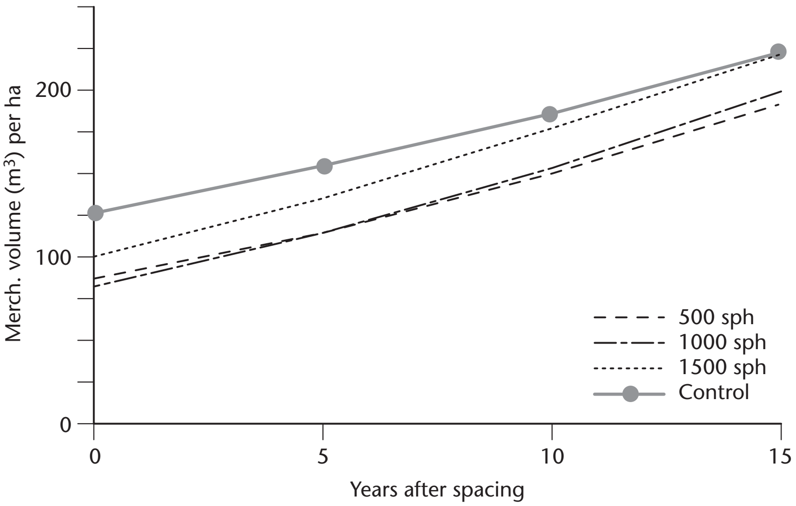

FIGURE 13 *Stand merchantable volume development following spacing of 63-year-old Douglas-fir in the SBSdw1 (E.P. 922.09).*

2.2 E.P. 922.13

2.2.1 Site and stand conditions This installation was established in a mixed stand, composed of 87% interior Douglas-fir, 10% lodgepole pine, and a balance of hybrid spruce (*Picea glauca* x *engelmannii*) and willow (*Salix* spp.). Most of the Douglas-fir appeared to have regenerated around the time of the logging, while the pine were residuals left during the logging, and, therefore, much older than the fir. This trial is located on a north- to northeast-facing slope, at an elevation of 1175 m, approximately 3.5 km southeast of Joes Lake, in the Central Cariboo Forest District (Appendix 2). The site is ecologically classified as being in the FdPl – Pinegrass – Feathermoss (01) site series of the Fraser variant of the Dry Cool Interior Douglas-fir biogeoclimatic subzone (IDFdk3) (Steen and Coupé 1997). Because the site is near the upper elevational limit of the IDFdk3, it is cooler and moister than many other parts of this subzone. The soil is a moderately well-drained, silty loam with a low (5–10%) coarse-fragment content, and is classified as an Orthic Gray Luvisol. The rooting depth is approximately 35 cm, the moisture regime is classified as mesic, and the nutrient regime is classed as medium. Very little information is available on the history of the site. The site was logged in what is believed to have been a diameter-limit cut with protection of the Douglas-fir understorey, and the site was then allowed to regenerate naturally. In 1993, at trial establishment, the average age of the Douglas-fir trees was 36 years, and the stand density was variable but averaged 24 950 stems/hectare (sph).

2.2.2 Methods of study establishment and measurement This installation consists of a randomized complete-block design with two blocks. In a departure from the original E.P. 922 working plan,[5] blocking was based on aspect, with Block 1 north-facing and Block 2 northeast-facing. Treatments were randomly assigned to each plot location, and the treatment plots were positioned to ensure homogeneous site and stand conditions within each plot. Each block contains five treatments: 500, 1000, 1500, 2000, and 2500 sph post-thinning densities, plus an unthinned control. Plot sizes varied with

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[5] Johnstone, W.D. and R.P. Brockley. 1983. Working plan – The effect of spacing on the growth and yield of lodgepole pine. B.C. Min. For., Res. Br., Victoria, B.C. Unpublished report.

treatment because, except for the controls, a constant number of 100 sample trees (10 rows of 10 trees) was contained in each plot. During the thinning, Douglas-fir trees were favoured for retention over the other species. Control-plot sizes also varied, but were sufficiently large to contain approximately 200 trees/plot. An unthinned buffer of not less than 5 m was maintained around each control plot.

All trees within the thinned and unthinned plots were systematically tagged with serially numbered tags, and a dbh-band was painted on each tree at 1.30 m above the point of germination. In the falls of 1993, 1998, and 2003, the following individual-tree measurements were taken:

a) dbhob of all tagged trees in the thinned and control plots;
b) height, crown length, and crown width of the "inner 64" tagged trees in the thinned plots; and
c) height, crown length, and crown width of all tagged trees in the control plots.

At each measurement time the condition of each tree was examined, and the presence of any damage was recorded for each tagged tree. The trial was measured at establishment, has been remeasured at 5 and 10 years after establishment, and is scheduled for remeasurement in 2008.

2.2.3 Compilation and analysis In lieu of treatment surrounds, the analyses were based only upon data from the 64 inner trees ("sample trees") in each spaced plot. Data from all trees in the first and last rows and from the first and last trees in the remaining rows of the treated plots (i.e., perimetrical trees in each plot) were eliminated from analysis. Control-plot values are based on all tagged Douglas-fir trees in these plots. The control plots in both blocks contained a small number of trees other than Douglas-fir (including lodgepole pine and interior spruce). The pine were much larger and the spruce were much smaller than the Douglas-fir and, therefore, were eliminated from the analyses. Mean-tree and per-hectare stand values of each plot were calculated for each measurement period. Per-hectare values are net values (i.e., they exclude mortality) and were determined for each spaced plot by multiplying the mean value of the sample trees (volume[6] or basal area) times the spacing level times the number of living sample trees as a decimal fraction of 64. Control plot per-hectare values were based on plot area. Data from both blocks were combined to produce the summary data shown in Figures 14–25.

2.2.4 10-year results Over the first 10 years of the study, the highest mortality rates were observed in the 1500- and 2000-sph treatments (Figure 14). This result was due to the very heavy mortality that occurred in these treatments (particularly in Block 1) during the last 5-year period. Although the reasons for this higher mortality are not clear, it did not appear to be competition-related. Virtually all of the dead trees were toppled and down, and, at all thinning levels, the survival rates were much higher in Block 2 than in Block 1. It should be noted that, at year 5, the 1500- and 2000-sph plots of Block 1

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[6] Volumes are inside-bark volumes calculated from Kozak's taper function (Kozak 1997). Merchantable volume is the bole volume between a 30-cm stump and a 10-cm top for all trees 12.5 cm dbhob and larger.

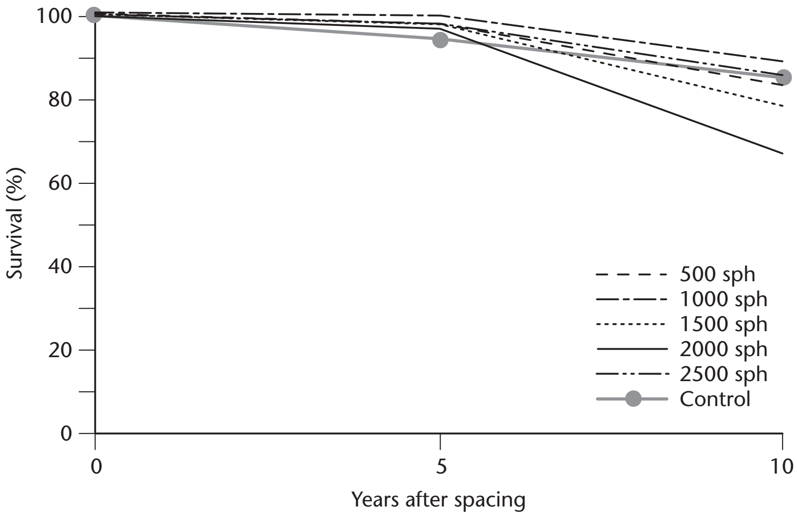

FIGURE 14 *Survival following spacing of 36-year-old Douglas-fir in the IDFdk3 (E.P. 922.13).*

had higher average slenderness coefficients (96.9 and 106.6, respectively) than the other thinned plots (this was also true in a block-to-block comparison). Ten years after spacing, the most frequently observed bole defects of the living sample trees in the thinned plots were minor and major sweeps (25.6%), minor and major leans (20.4%), and dead tops (8.2%). In addition, 42.1% of these sample trees appear to have been attacked by budworm (presumably *Choristoneura* spp.). In the controls, 3.4% of the Douglas-fir trees were attacked by budworm, 13.8% displayed stem rusts or cankers, 16.9% were leaning, and 8.4% had bole sweep.

The expected general trend of the fastest growth at the widest spacing continues to develop (Figure 15). This faster diameter growth is undoubtedly a response to the size and persistence of crowns that increased directly with available growing space. The accelerated growth has resulted in substantially more large trees in the thinned stands (Figure 16). For example, depending on the spacing, all of the thinned stands now contain between 188 (500-sph treatment) and 305 (1000-sph treatment) trees/ha larger than 12 cm in diameter compared to 0 in the unthinned stands. Assuming that the trends in periodic diameter growth (Figure 15) continue, the large differences in mean diameter between the thinned and unthinned stands (Figure 17) are likely to continue to increase for the foreseeable future.

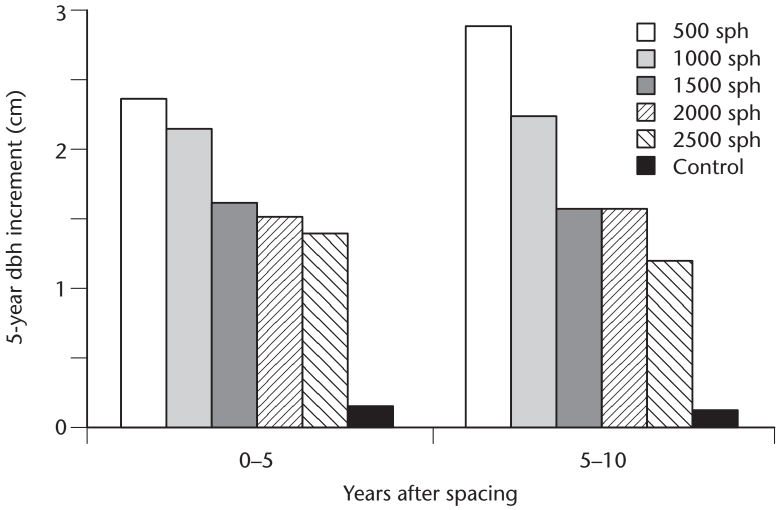

FIGURE 15 *Periodic diameter growth following spacing of 36-year-old Douglas-fir in the IDFdk3 (E.P. 922.13).*

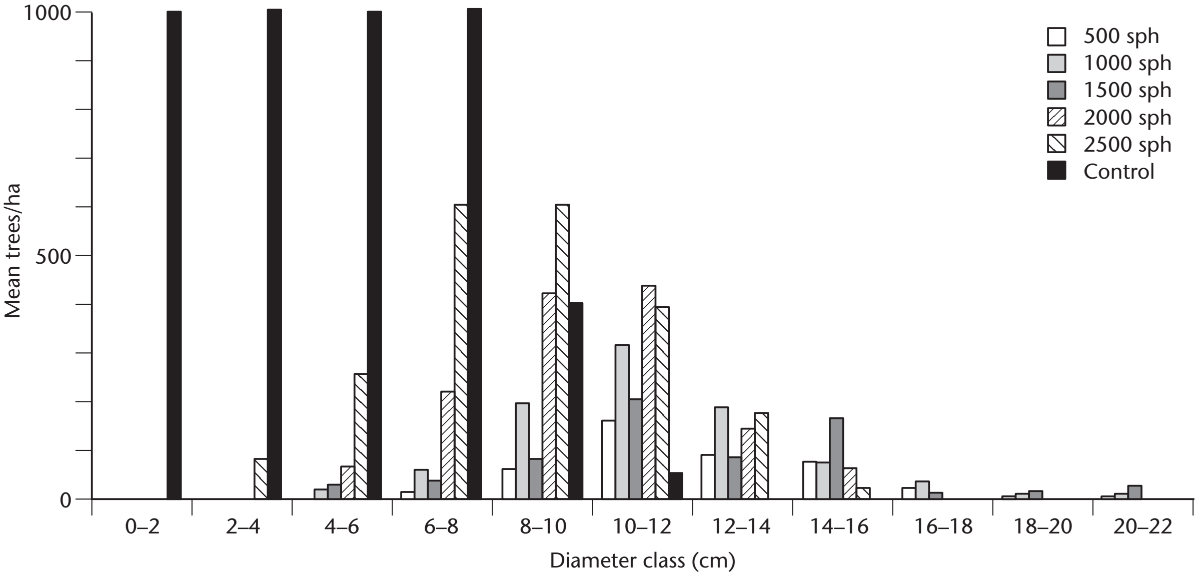

FIGURE 16 *Diameter distributions, by treatment, 10 years following spacing of 36-year-old Douglas-fir in the IDFdk3 (E.P. 922.13).*

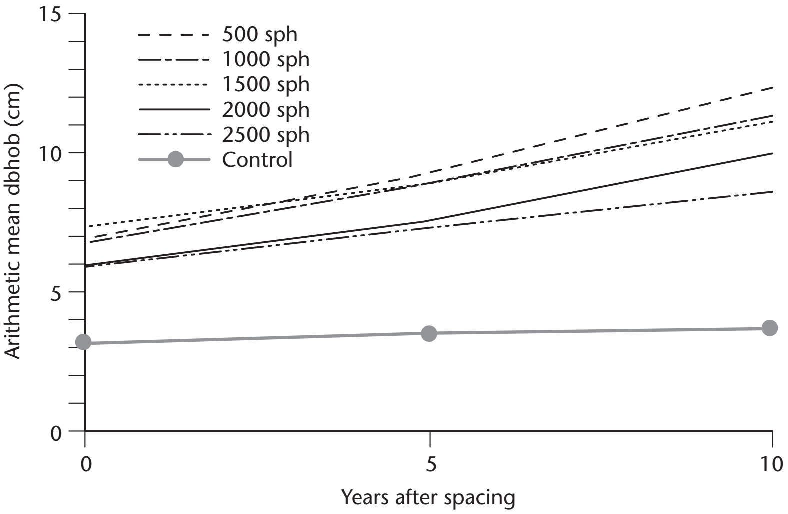

FIGURE 17 *Diameter development following spacing of 36-year-old Douglas-fir in the IDFdk3 (E.P. 922.13).*

Unlike diameter, spacing-related patterns in height growth are less clear (Figure 18). Although the trees in the thinned plots substantially outgrew the trees in the unthinned plots, trees in the most widely spaced plots were not the tallest (Figures 19 and 20) due to differences in initial height.

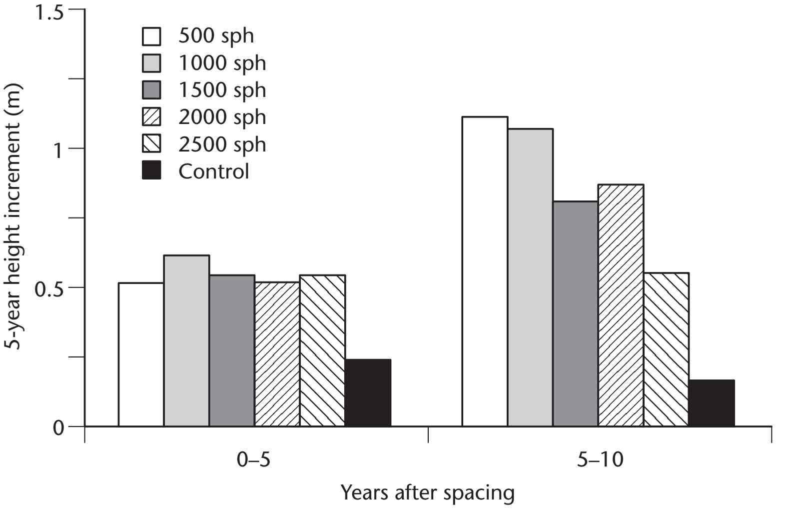

FIGURE 18 *Periodic height growth following spacing of 36-year-old Douglas-fir in the IDFdk3 (E.P. 922.13).*

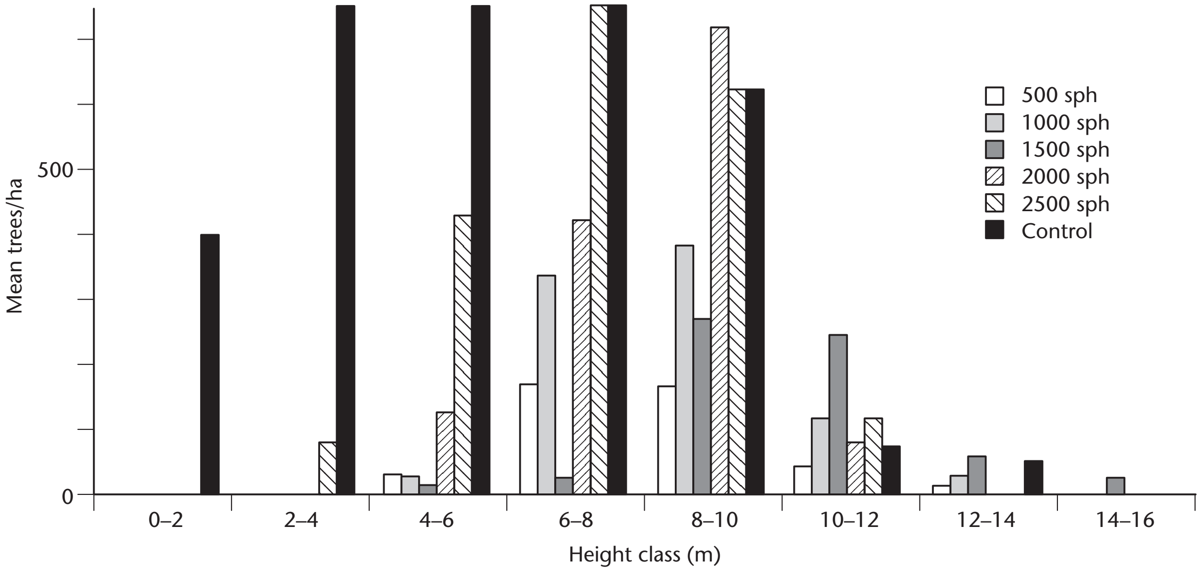

FIGURE 19 *Height distributions, by treatment, 10 years following spacing of 36-year-old Douglas-fir in the IDFdk3 (E.P. 922.13).*

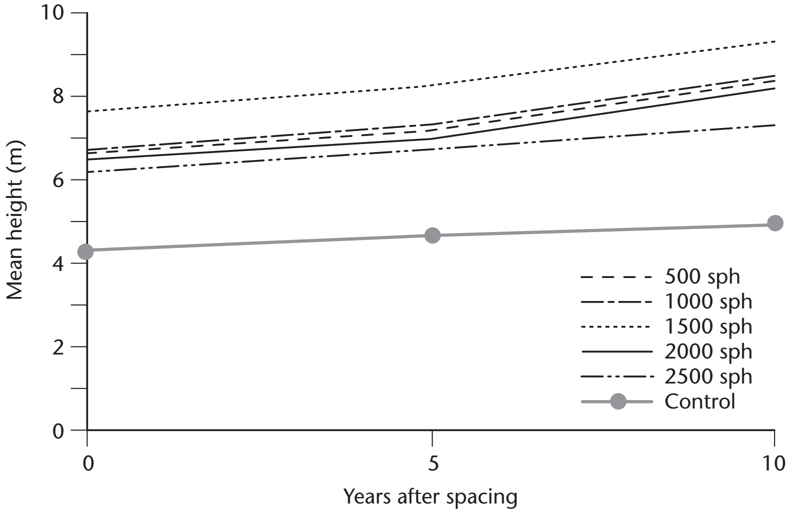

FIGURE 20 *Height development following spacing of 36-year-old Douglas-fir in the IDFdk3 (E.P. 922.13).*

Because of the larger stem diameters, and despite the lack of a clear height response, 10 years after thinning, individual-tree volumes increased directly with increased spacing (Figures 21 and 22).

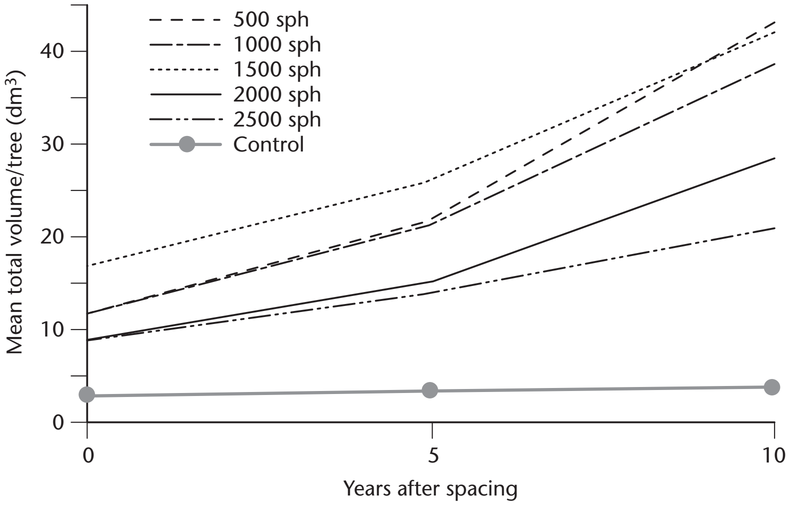

FIGURE 21 *Individual-tree total volume development following spacing of 36-year-old Douglas-fir in the IDFdk3 (E.P. 922.13).*

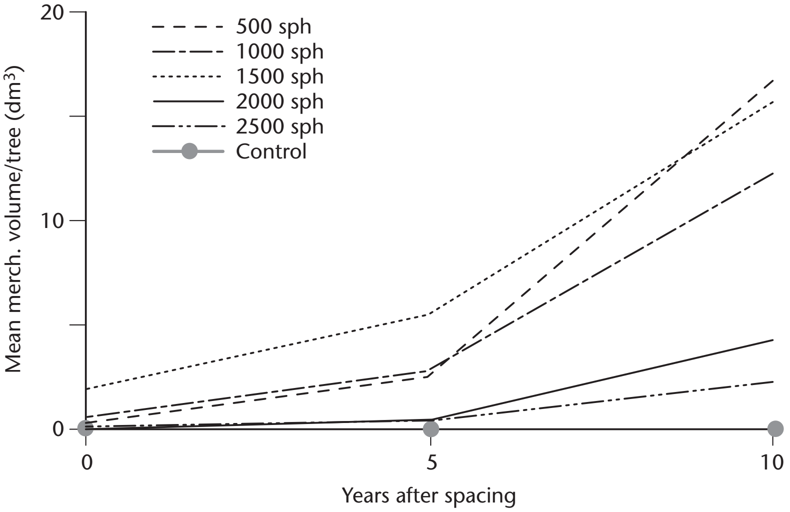

FIGURE 22 *Individual-tree merchantable volume development following spacing of 36-year-old Douglas-fir in the IDFdk3 (E.P. 922.13).*

In spite of larger and faster-growing trees, both stand basal area and total volume are much lower in the spaced compared to the unspaced plots (Figures 23 and 24, respectively). The opposite was generally true for the periodic increments in these characteristics during the last 5 years. Ten years after treatment, the optimum spacing for merchantable volume (Figure 25) appears to be 1500 sph, but this preliminary conclusion is somewhat tenuous because of the severe impact that mortality had in the 2000-sph plot in Block 1.

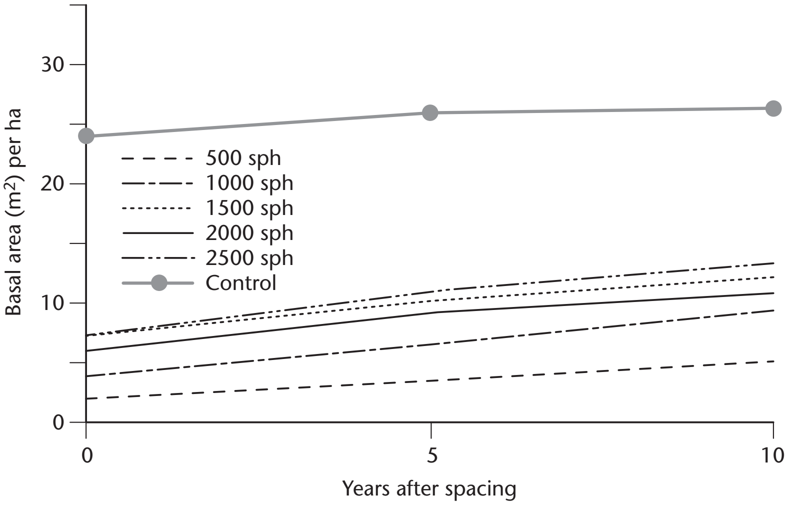

FIGURE 23 *Stand basal area development following spacing of 36-year-old Douglas-fir in the IDFdk3 (E.P. 922.13).*

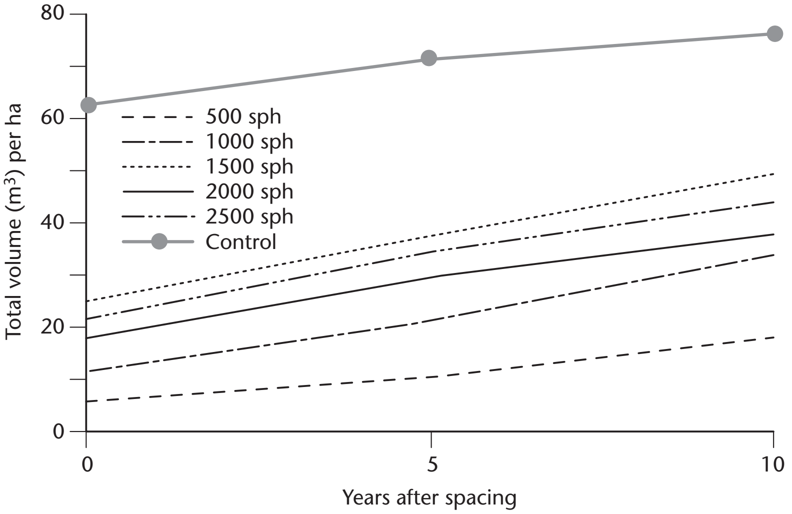

FIGURE 24 *Stand total volume development following spacing of 36-year-old Douglas-fir in the IDFdk3 (E.P. 922.13).*

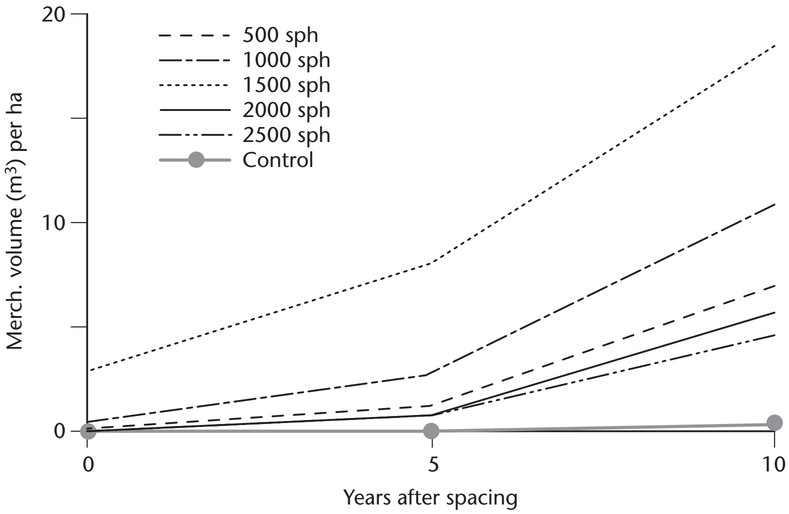

FIGURE 25 *Stand merchantable volume development following spacing of 36-year-old Douglas-fir in the IDFdk3 (E.P. 922.13).*

2.3 E.P. 922.14

2.3.1 Site and stand conditions This trial is located on a west- to northwest-facing slope, at an elevation of 1035 m, approximately 3 km west of Doreen Lake, in the Central Cariboo Forest District (Appendix 3). This site is ecologically classified as being predominantly in the CwSxw – Falsebox – Knight's plume (01) site series of the Horsefly variant of the Moist Cool Interior Cedar–Hemlock biogeoclimatic subzone (ICHmk3) (Steen and Coupé 1997). A small amount of the site was classified as being in the CwSxw – Oakfern – Cat's-tail moss (04) site series. The soils in the study area are also variable, but are predominantly well- to rapidly drained gravelly, sandy loams, and are classified as Orthic Dystric Brunisols. The moisture regime varied from subhygric to submesic, and the nutrient regime varied from poor to medium. At the time of study establishment (1994), the site was occupied by a dense, mixed stand of Douglas-fir, western redcedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), hybrid spruce, lodgepole pine, subalpine fir (*Abies lasiocarpa*), paper birch (*Betula papyrifera*), trembling aspen (*Populus tremuloides*), western yew (*Taxus brevifolia*), mountain alder (*Alnus incana*), and Scouler's willow (*Salix scouleriana*). This stand regenerated naturally following the "Vunder Fire" in 1961. The understorey vegetation was very sparse due to the dense tree canopy. At the time of study establishment, the average age of the trees was 30 years, and the mean density of the control plots was 10 733 trees/ha.

2.3.2 Methods of study establishment and measurement This trial consists of a randomized complete-block design with three blocks. Each block contains four treatments: an unthinned control, and 500, 1000, and 1500 stems/hectare (sph) post-spacing densities. Plot sizes varied with treatment because, except for the controls, a constant number of 100 sample trees was contained in each plot.

In a departure from the original E.P. 922 working plan,[7] a single control-plot size (14.14 × 14.14 m) was used in this trial, irrespective of initial stand

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[7] Johnstone, W.D. and R.P. Brockley. 1983. Working plan–The effect of spacing on the growth and yield of lodgepole pine. B.C. Min. For., Res. Br., Victoria, B.C. Unpublished report.

density. Each control plot was sufficiently large to contain a minimum of 200 sample trees. An unthinned buffer strip of not less than 5.0 m in width was maintained around the outer boundary of each control plot.

All trees within the thinned and unthinned plots were systematically tagged with serially numbered tags, and a dbh-band was painted on each tree at 1.30 m above the point of germination. In the falls of 1994, 1999, and 2004, the following individual-tree measurements were taken:

a) dbhob of all tagged trees in the thinned and control plots;
b) height, crown width, and crown length of the "inner 64" tagged trees in the thinned plots; and
c) height, crown width, and crown length of all tagged trees in the control plots.

At each measurement, the condition of each tree was examined, and the presence of any damaging agent was recorded for all tagged trees in the control and thinned plots. The trial was measured after establishment (1994), has been remeasured at 5 and 10 years after establishment, and is scheduled for remeasurement in 2009.

2.3.3 Compilation and analysis In lieu of treatment surrounds, the analyses were based only upon data from the inner 64 "sample trees" in each spaced plot. Data from all trees in the first and last rows, and from the first and last trees in the remaining rows of these plots (i.e., the perimetrical trees of each plot) were eliminated from analysis. Between 1999 and 2004, virtually all of the trees in the control plot of Block 2 were decimated by snowpress and wind damage. Consequently, all of the data for this plot, from the start of the experiment, were eliminated from the analysis. Data from all tagged, coniferous trees were analyzed for the two remaining control plots. The average and per-hectare stand values of each plot were calculated for each measurement. Per-hectare values are net values (i.e., they exclude mortality) and were determined for each spaced plot by multiplying the mean value of the sample trees (volume[8] or basal area) times the spacing level times the number of living sample trees as a decimal fraction of 64. Net per-hectare values for the control plots were based on the area of each plot. Data from the three blocks (two blocks for the controls) were combined to produce the summary data shown in Figures 26–37.

2.3.4 10-year results Survival remains relatively high in the thinned plots compared to the controls (Figure 26). Most of the mortality in the thinned plots was the result of wind damage and snowpress, and did not appear to be related to inter-tree competition. It is anticipated that competitive mortality will become increasingly important in the thinned plots as the denser spaced plots close. Although competition-related mortality, particularly in the subordinate crown classes, did occur in the unthinned control plots, here too the main cause of mortality (including the loss of the control in Block 2) was snowpress and wind damage. The risk of future damage in the unthinned plots remains high (mean height-diameter [H/D] ratio = 143.4) compared to

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[8] Volumes are inside-bark volumes calculated from Kozak's taper function (Kozak 1997). Merchantable volume is the bole volume between a 30-cm stump and a 10-cm top for all trees 12.5 cm dbhob and larger.

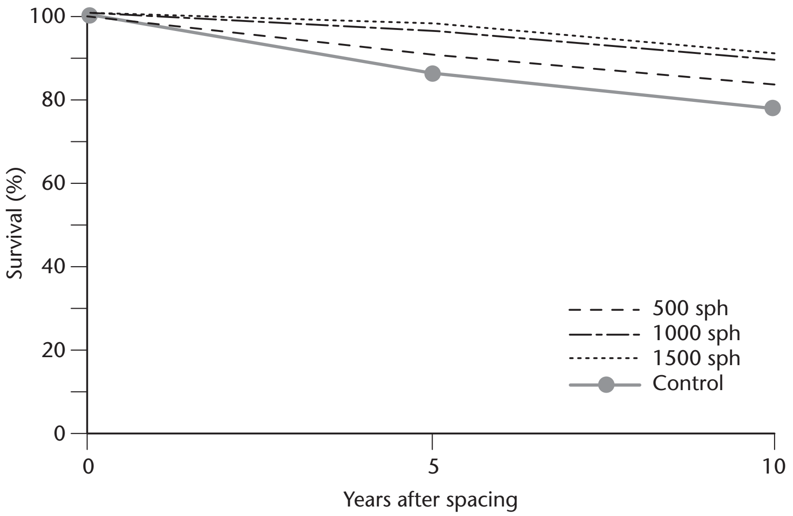

FIGURE 26 *Survival following spacing of 30-year-old Douglas-fir in the ICHmk3 (E.P.922.14).*

the thinned plots (H/D ratios of 78.3, 84.9, and 92.0 for the 500-, 1000-, and 1500-sph treatments, respectively).

During the thinning, an attempt was made to retain healthy Douglas-fir trees as future crop trees. Ten years after thinning, a smaller proportion of Douglas-fir trees in the thinned plots (14.6%) displayed rusts and cankers than did the Douglas-fir trees in the controls (22.4%). Similarly, a smaller proportion of Douglas-fir trees in the thinned plots had leans and crooks (6.3% and 9.5%, respectively) compared to Douglas-fir trees in the unthinned plots (19.1% and 11.8%, respectively). However, a higher proportion of Douglas-fir trees in the thinned plots had sweeps (12.8%), and broken, crooked, or dead tops (3.8%) compared to the unthinned controls (8.6% and 3.3%, respectively). As a general rule, the frequency of defects increased with the level of stocking in the thinned plots.

Over the last 10 years, thinning intensity has had a direct effect on periodic diameter growth (Figure 27). This growth response has resulted in a major change in the diameter distributions of the plots (Figure 28): far more larger trees are now present in the thinned plots than in the controls. For example, all of the thinning treatments had between 169 (500-sph treatment) and 359 (1500-sph treatment) trees/ha larger than 16 cm in diameter compared to 75 trees/ha in the control. This has resulted in large differences in mean diameter (Figure 29) and, assuming that the trends in periodic growth continue, these differences are likely to continue to widen for the foreseeable future. Although the results in Figure 27 suggest relatively constant growth following thinning, the radial increment during the last 5 years occurred on larger trees and, in fact, the amount of wood laid down, in terms of individual-tree basal area and volume, was much larger than during the first 5-year period.

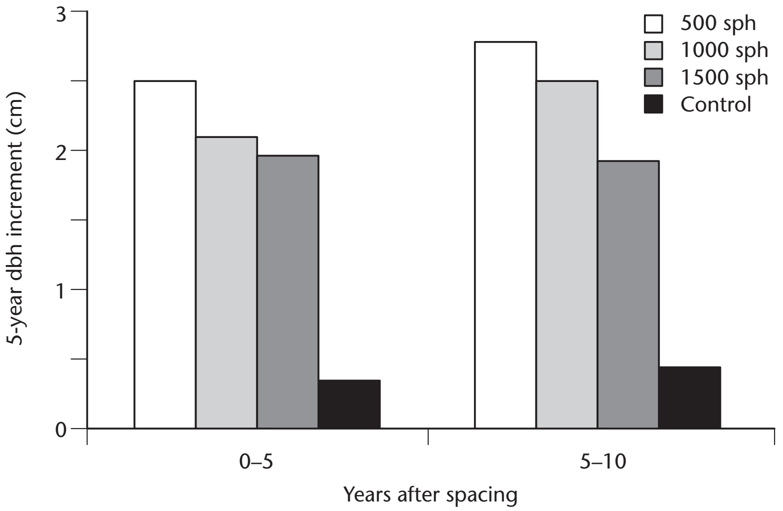

FIGURE 27 *Periodic diameter growth following spacing of 30-year-old Douglas-fir in the ICHmk3 (E.P. 922.14).*

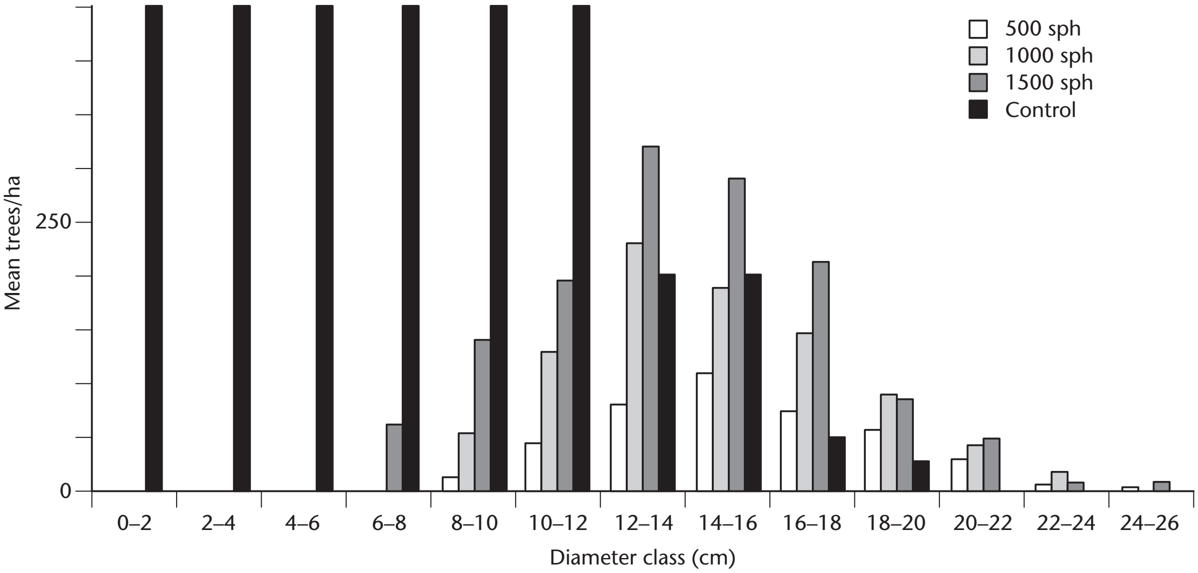

FIGURE 28 *Diameter distributions, by treatment, 10 years following spacing of 30-year-old Douglas-fir in the ICHmk3 (E.P. 922.14).*

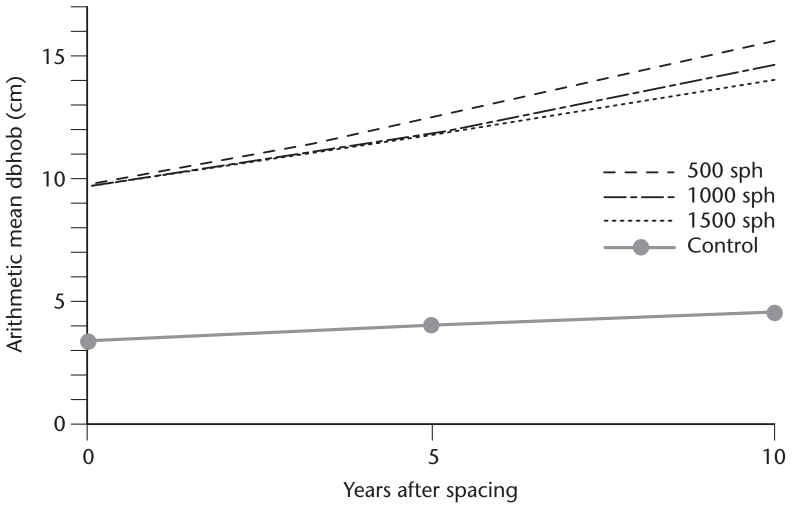

FIGURE 29 *Diameter development following spacing of 30-year-old Douglas-fir in the ICHmk3 (E.P. 922.14).*

Unlike diameter, spacing-related patterns in height development are less clear. Although the trees in the thinned plots substantially outgrew the trees in the unthinned plots (Figure 30) over the 10 years, trees in the most widely spaced plots were not the tallest (Figures 31 and 32).

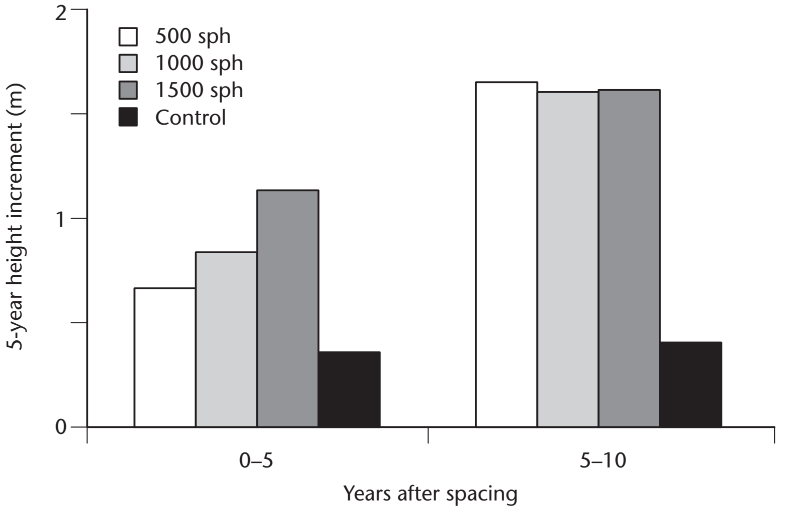

FIGURE 30 *Periodic height growth following spacing of 30-year-old Douglas-fir in the ICHmk3 (E.P. 922.14).*

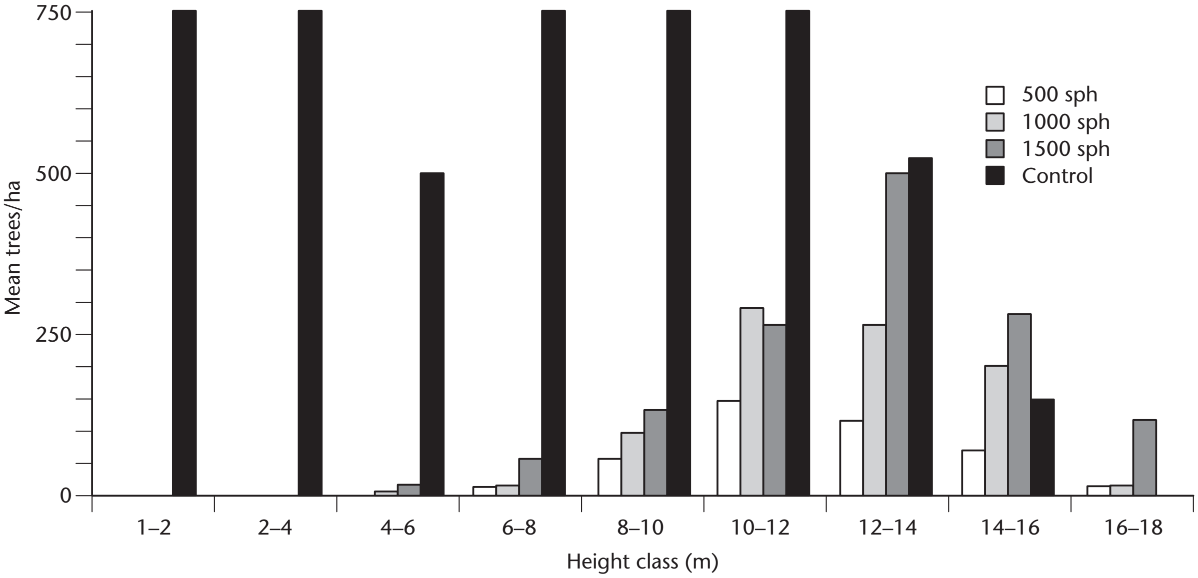

FIGURE 31 *Height distributions, by treatment, 10 years following spacing of 30-year-old Douglas-fir in the ICHmk3 (E.P. 922.14).*

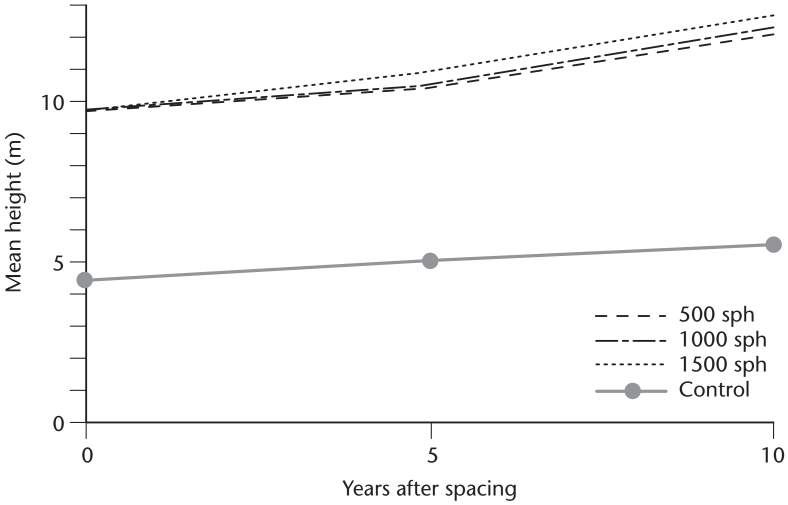

FIGURE 32 *Height development following spacing of 30-year-old Douglas-fir in the ICHmk3 (E.P. 922.14).*

Because of the larger bole diameters and taller trees, individual-tree volumes increased directly with increased spacing (Figures 33 and 34).

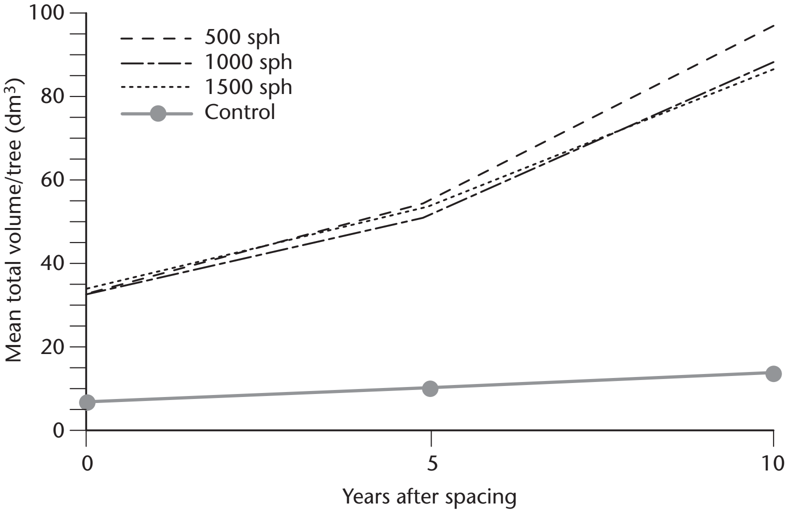

FIGURE 33 *Individual-tree total volume development following spacing of 30-year-old Douglas-fir in the ICHmk3 (E.P. 922.14).*

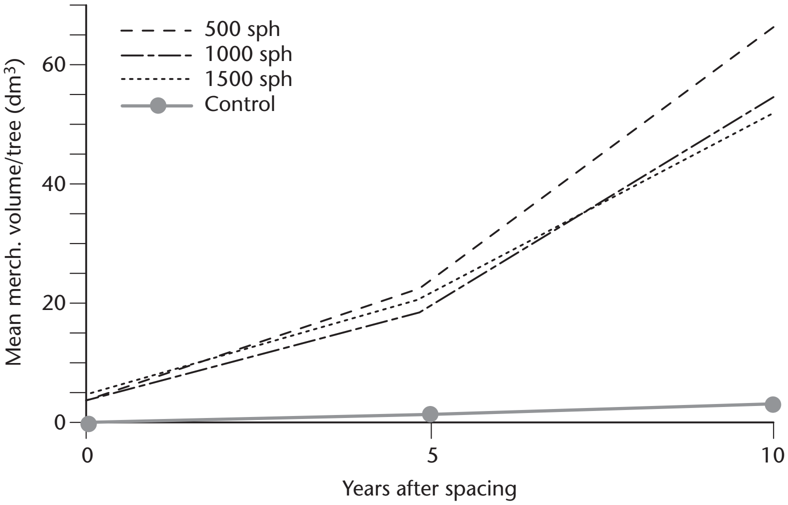

FIGURE 34 *Individual-tree merchantable volume development following spacing of 30-year-old Douglas-fir in the ICHmk3 (E.P. 922.14).*

In spite of larger and faster-growing trees, stand basal areas in the thinned plots were much lower than in the controls, especially at the widest spacing (Figure 35). This was also true for the periodic increments in basal area during the last 10 years. However, 10 years after thinning, the total volume of the 1500-sph treatment now exceeds that of the controls (Figure 36), and all of the thinned treatments have surpassed the control in terms of merchantable volume (Figure 37).

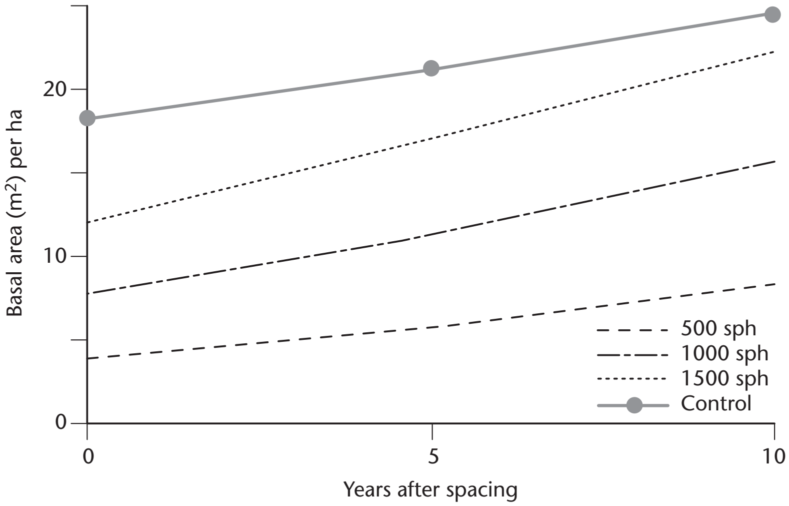

FIGURE 35 *Stand basal area development following spacing of 30-year-old Douglas-fir in the ICHmk3 (E.P. 922.14).*

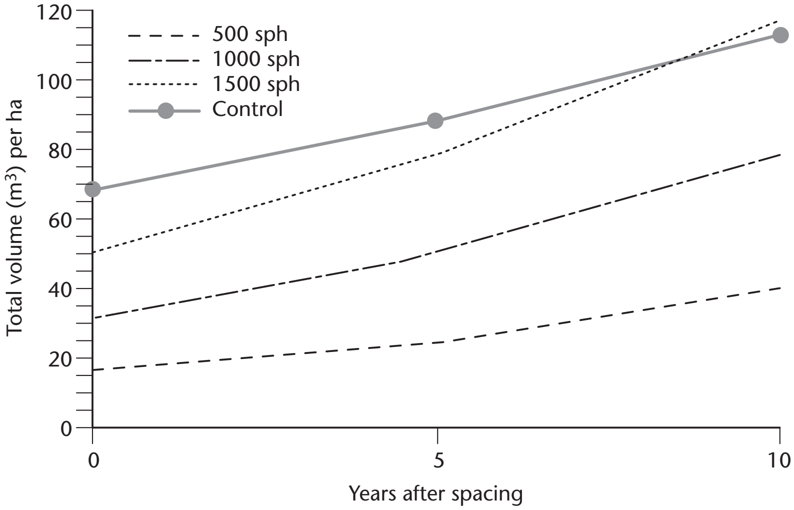

FIGURE 36 *Stand total volume development following spacing of 30-year-old Douglas-fir in the ICHmk3 (E.P. 922.14).*

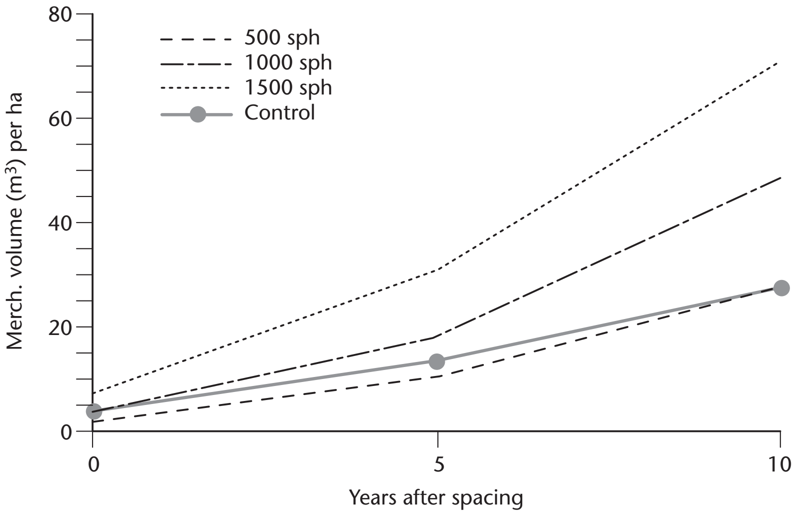

FIGURE 37 *Stand merchantable volume development following spacing of 30-year-old Douglas-fir in the ICHmk3 (E.P. 922.14).*

3 DISCUSSION AND CONCLUSIONS

In all of the trials, the most dramatic individual-tree response to thinning was observed in terms of diameter and merchantable volume, and the magnitude of this response generally increased with thinning intensity. This response is undoubtedly related to the size and persistence of crowns, which increased directly with available growing space. Direct comparisons of individual-tree size between thinned and unthinned stands can be misleading because the thinning, particularly when done from below (as in these trials), removes the smaller trees and thereby immediately increases the mean tree size of the thinned stand. Although crop-tree comparisons (a fixed number of the largest trees in each treatment) are not presented in this report, the diameter increment and stand-table results clearly demonstrate that, given sufficient time, thinning will shift the growing stock into larger diameter classes. The effect of thinning on tree height was less dramatic and less conclusive, but did not appear to be affected by age at the time of thinning. In two of three trials, the basal area and total volume of the thinned plots is well below that of the unthinned plots, but sufficient time has yet to elapse since treatment to indicate whether the thinned plots will ever catch up to their unthinned counterparts. However, in all of the trials, the more lightly thinned plots have now equalled or surpassed the unthinned plots in terms of stand merchantable volume. Here too, sufficient time has yet to elapse since treatment to indicate whether enough trees in the unthinned stands will cross the merchantability threshold to offset this thinning advantage.

The trials also provide some insight into the degree to which thinning may increase some risks and reduce others associated with managing Douglas-fir. Of considerable concern is the extent to which thinning increases risk of snow and wind damage immediately after treatment. The degree to which trees are susceptible to wind damage depends on a variety of site, stand, and tree characteristics. For example, the risk of blowdown is greatest in shallow-rooting situations characteristic of some soil types and/or species' rooting habits. A combination of stand and tree characteristics may have contributed to the higher-than-anticipated damage (including broken, leaning, and sweeping boles, and broken and dead tops) and mortality experienced in the present studies. Thinning may have altered the wind patterns within the plots and reduced the mutual sheltering and root anchoring among the individual trees. Because they were grown under high stand density conditions, which resulted in short crowns and low bole taper, the trees in these studies were highly susceptible to windthrow and breakage. The relationships between resistance to wind damage and tree and stand characteristics have been intensively studied in Europe and elsewhere, but little information is available for western North American species (Oliver and Lawson 1990; Navratil 1997; Wilson and Oliver 2000). The ratio of tree height to dbh (slenderness coefficient) appears to provide a simple estimate of a tree's potential to resist wind damage. The smaller the coefficient, the greater the wind stability and resistance to breakage of the tree. Although these studies indicate that coefficients, and thus the risks, will decline with time following thinning, the results suggest that forest managers should temper their treatment prescriptions and yield expectations when thinning dense stands in wind- or snowpress-prone areas.

The results from these studies clearly demonstrate the need for forest managers to consider the trade-off between individual-tree piece-size and per-hectare yield when prescribing thinning treatments in interior Douglas-fir stands. Furthermore, they demonstrate that thinning prescriptions must:

- be developed and applied on a site- and stand-specific basis;
- maintain an adequate level of growing stock to capture the productivity of the site; and
- provide sufficient time, prior to harvest, to allow for the accumulation of increment.

When these experiments were established, an attempt was made to ensure that they were distributed over a wide range of age, site, and stand conditions. There are still obvious gaps in this coverage. As such, these trials fall far short of achieving the goals for research trial establishment set by the Forest Productivity Councils of British Columbia.[9] The thinned plots in two of these experiments use variable-sized plots with a fixed number of trees per plot. Statistical questions aside, this makes the most efficient use of land and plant material, which are important considerations because of the significant maintenance and measurement costs associated with long-term growth and yield experiments. Although not presently of concern, the use of small control plots, necessitated by high stand density in the younger stands, may become a problem in the longer term.

Continued maintenance, measurement, and analysis of these trials will contribute to our understanding of the management of interior Douglas-fir, to the further development and refinement of our stand management prescriptions, and to the long-term growth and yield database required for adequately calibrating and validating our yield models.

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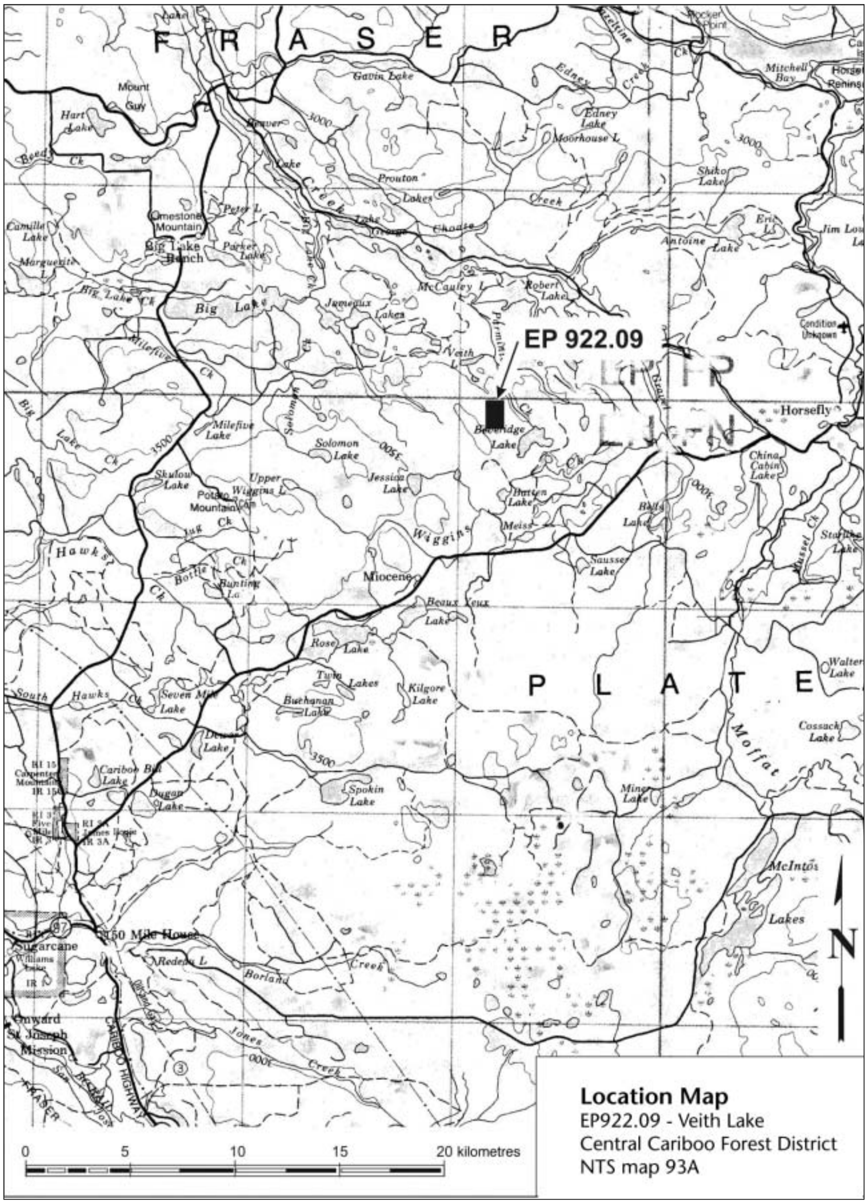
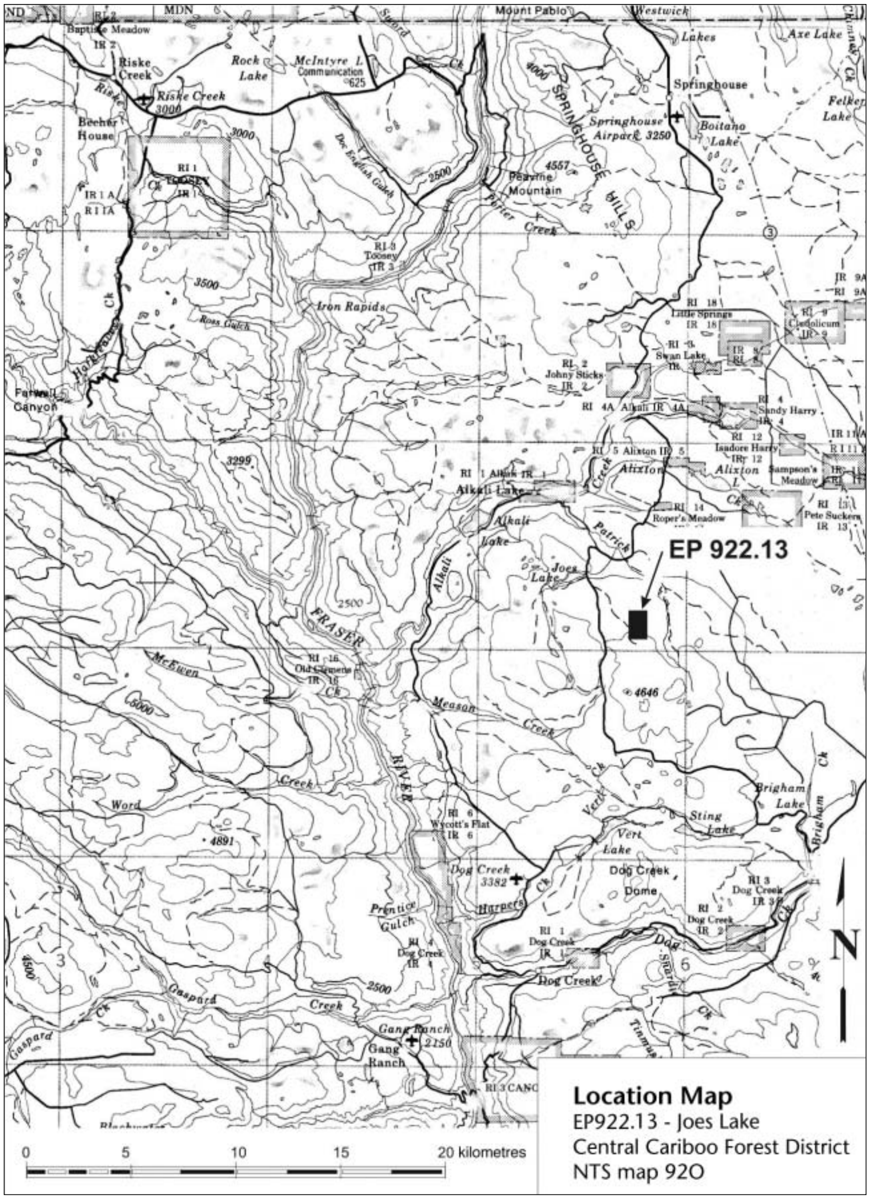
Wilson, J.S. and C.D. Oliver. 2000. Stability and density management in Douglas-fir plantations. Can. J. For. Res. 30:910–920.

APPENDIX 1 Location Map of E.P. 922.09

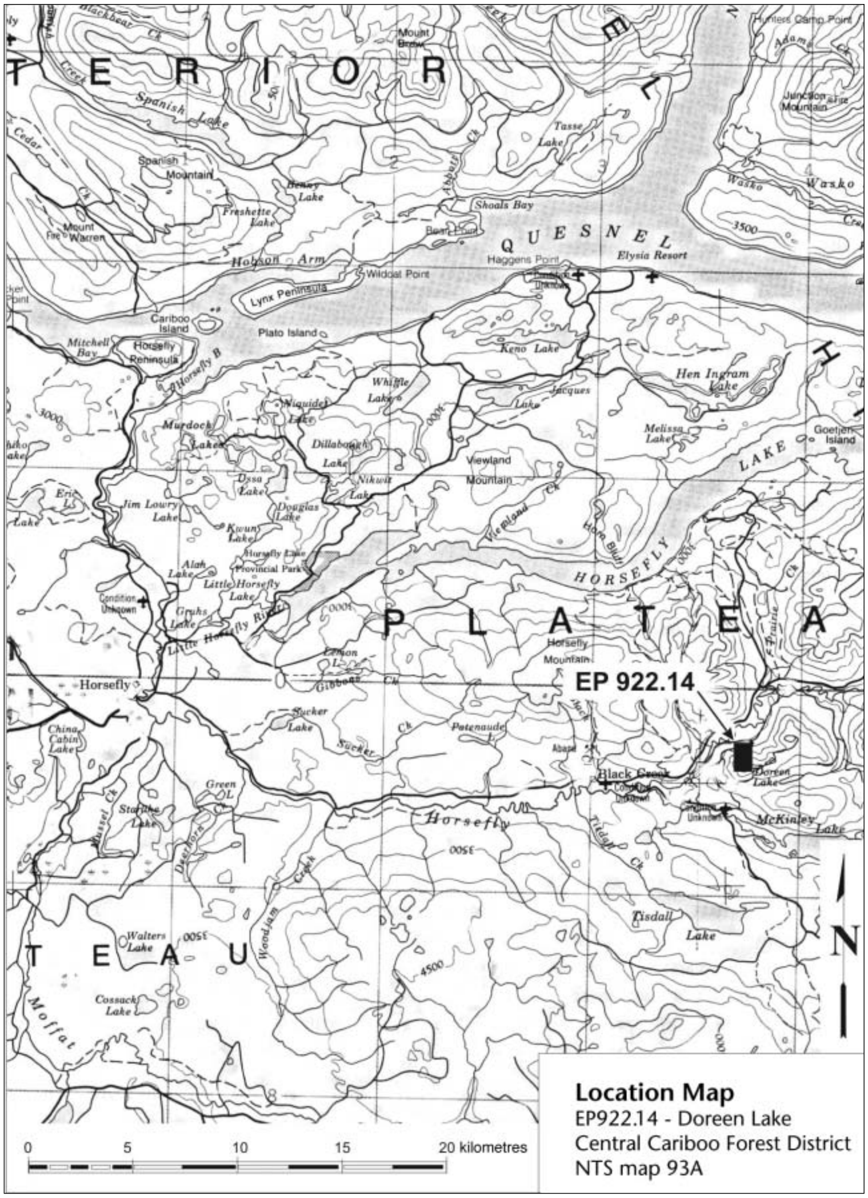


APPENDIX 2 Location Map of E.P. 922.13



Location Map
EP922.13 - Joes Lake
Central Cariboo Forest District
NTS map 92O

APPENDIX 3 Location Map of E.P. 922.14



Location Map
EP922.14 - Doreen Lake
Central Cariboo Forest District
NTS map 93A