WORKING PAPER 63

Thinning Lodgepole Pine in Southeastern British Columbia: 46-year Results

2002

British Columbia

Ministry of Forests Forest Science Program

Thinning Lodgepole Pine in Southeastern British Columbia:
46-year Results

W. D. Johnstone

BRITISH COLUMBIA

Ministry of Forests Forest Science Program

The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the Government of British Columbia of any product or service to the exclusion of any others that may also be suitable. Contents of this report are presented for discussion purposes only. Funding assistance does not imply endorsement of any statements or information contained herein by the Government of British Columbia.

National Library of Canada Canadian Cataloguing in Publication Data
(Working paper ; 63)

Includes bibliographical references: p.
ISBN 0-7726-4695-3

1. Lodgepole pine - Thinning - British Columbia - Canal Flats Region. 2. Lodgepole pine - British Columbia - Canal Flats Region - Growth. 3. Lodgepole pine - Diseases and pests - Control - British Columbia - Canal Flats Region. 4. Mountain pine beetle - Control - British Columbia - Canal Flats Region. I. British Columbia. Ministry of Forests. Research Branch. II. Title. III. Series: Working paper (British Columbia. Ministry of Forests) ; 63

SD397.P585J66 2002 634.9'75153'0971165 C2002-960012-X

Citation:
Johnstone, W.D., 2002. Thinning lodgepole pine in southeastern British Columbia: 46-year results. Res. Br., B.C. Min. For., Victoria, B.C. Work. Pap. 63.

URL: www.for.gov.bc.ca/hfd/pubs/Docs/Wp/Wp63.htm

Prepared by
W.D. Johnstone
B.C. Ministry of Forests
Forest Science Program
Kalamalka Research Station
3401 Reservoir Rd
Vernon BC V1B 2C7

Copies of this report may be obtained, depending on supply, from:
Crown Publications
521 Fort Street
Victoria, BC V8W 1E7
Phone: (250) 386-4636
email: crown@pinc.com
URL: www.crownpub.bc.ca

For more information on Forestry Division publications, visit our web site at
URL: www.for.gov.bc.ca/hfd/pubs/index.htm

ABSTRACT

The effects of thinning 53-year-old, fire-origin lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) are reported 46 years after treatment. Five thinning treatments plus unthinned controls were established in plots in the Montane Spruce biogeoclimatic zone in southeastern British Columbia. Although tree-size responses were substantial in relative terms, the absolute responses to thinning were small. On an area basis, the response to thinning can be substantial, particularly when the net periodic annual increment of the thinned plots is compared to that of the unthinned controls. During the 46-year observation period, the plots were attacked by mountain pine beetle (*Dendroctonus ponderosae* Hopkins), and the results of the study tend to support the theory that heavy thinning may help to beetle-proof lodgepole pine stands.

ACKNOWLEDGEMENTS

This study was established by Michael Stewart and Bruce Clark, and was maintained and measured over the years by Keith Illingworth, George Lesko, Chris Thompson, and John Pollack. The assistance of Tom Braumandl in ecologically classifying the study area, and of Frank van Thienen for doing most of the data compilation and graphics, is gratefully acknowledged. I thank Louise de Montigny, Jim Goudie, and John Pollack for comments on early drafts of the manuscript. Funding for the 1988 and 1993 plot assessments was provided by the Canada-British Columbia Forest Resource Development Agreements (FRDA I and II). The 46-year measurement was funded by Forest Renewal BC.

CONTENTS

TABLES

FIGURES

1 INTRODUCTION

Lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) characteristically regenerates in extremely dense stands following fire, and this excessive stand density subsequently retards or prevents the production of large individual trees. The obvious solution is to thin these overly dense stands to a level of growing stock that will maximize the overall productivity of the stand for a particular site. Although thinning research in lodgepole pine has a long and varied history, most of the research has focused on young stands, where the largest responses are anticipated. The results of much of this earlier research have previously been reviewed and summarized by Cole (1975), Johnstone (1985), Johnstone and Cole (1988), and Stone (1996). However, there is an interest in thinning older, intermediate-aged stands in order to ensure the attainment of merchantable-tree sizes, to enhance the value of the final crop (through increased log sizes), to improve stand vigour (thereby reducing the risk of pest losses), or to enhance non-timber resource values such as wildlife habitat. This report discusses the effects, 46 years after treatment in 1952/53, of the thinning of a 53-year-old lodgepole pine stand growing in southeastern British Columbia.

2 METHODS

2.1 Site and Stand Description

This study is located at an elevation of 1050 m, on a gently sloping bench adjacent to the Kootenay River, approximately 30 km north-northeast of Canal Flats in the Invermere Forest District (Figure 1). This site (50° 24' N, 115° 39' W) is ecologically classified as being in the Dry Cool Montane Spruce (MSdk) biogeoclimatic subzone (Braumandl and Curran 1992). Some of the

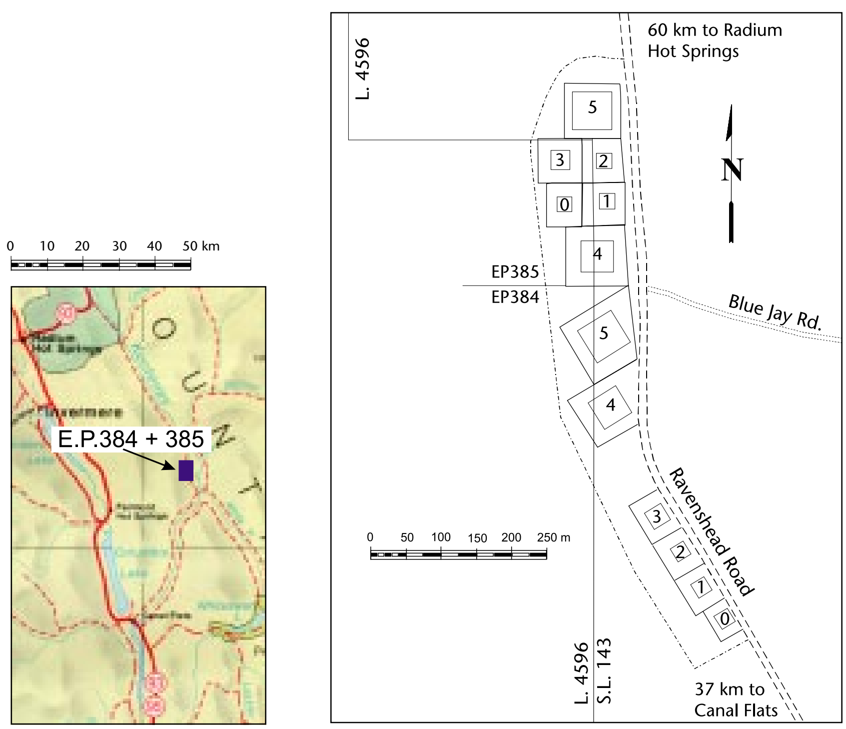


FIGURE 1 *Location and plot layout maps for Experimental Projects 384 and 385.*

plots are in the Interior spruce – Soopolallie – Grouseberry (01) site series, and the remaining plots are in the moister Interior spruce – Soopolallie – Snowberry (05) site series. The soil is a moderately well-drained, silty to silty-clay loam, and is classified as a Gleyed Brunisolic Gray Luvisol, with a rooting depth of 8 cm. The moisture regime is classified as mesic to subhygric, and the nutrient regime is classed as rich. Based on the 1953 data, the average lodgepole pine site index of the study area is 16.7 m (top height at 50 years breast high), but varied from 13.7 to 19.1 m among plots.[1] It is a predominantly even-aged lodgepole pine stand, which regenerated naturally after a fire in 1895. The stand also contains variable components of western larch (*Larix occidentalis* Nutt.) veterans in the overstory, and Engelmann spruce (*Picea engelmannii* Parry), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), and Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Bessin) Franco) in the understory. At the time of study establishment in 1952, the average total age of the lodgepole pine was 53 years. Stand conditions at study establishment are presented in Appendices 1 and 4. From 1980 to 1983, the stand came under severe attack by mountain pine beetle (*Dendroctonus ponderosae* Hopkins), and high mortality of pine was observed in some of the plots.

2.2 Study Design and Establishment

The study area was divided into two blocks (Experimental Projects 384 and 385). Each block was divided into six treatment plots, which varied in size depending on the treatment, but were large enough to accommodate a measurement sub-plot with a 15.24-m (50-foot) surrounding buffer (Table 1). The B.C. Forest Service's 1947 yield tables[2] were used to determine the normal stocking of a stand of this age (53 years) and site quality (site index 70 @ 80 years total age). The thinning treatments, defined by the number of main crop stems expressed as a percentage of normal stocking, were carried out by experienced axmen during the winter of 1952/53. Healthy larch trees were favoured over healthy pine in the thinning operation. Existing records do not explain how the treatments were assigned to the plots, but it does not appear to have been a random assignment.

TABLE 1 *Plot and treatment specifications*

Treatment no.	Treatment plot size	Measurement plot size	Treatment prescription: % normal yield	Treatment prescription: Appr. spacing	Actual trees/ha
0	0.36 ha (0.900 ac.)	0.04 ha (0.1 ac.)	No thinning		4868
1	0.50 ha (1.225 ac.)	0.08 ha (0.2 ac.)	100	2.13 m (7 feet)	2898
2	0.50 ha (1.225 ac.)	0.08 ha (0.2 ac.)	80	2.44 m (8 feet)	2218
3	0.50 ha (1.225 ac.)	0.08 ha (0.2 ac.)	60	2.90 m (9.5 feet)	1884
4	0.82 ha (2.025 ac.)	0.20 ha (0.5 ac.)	40	3.66 m (12 feet)	1325
5	0.82 ha (2.025 ac.)	0.40 ha (1.0 ac.)	20	4.88 m (16 feet)	754

1 J.W. Goudie, Biometrician, Growth and Yield, B.C. Min. For., Res. Br., Victoria, B.C., pers. comm., Oct. 2000.

2 These tables were originally distributed in mimeographed form, and were published by Smithers (1961).

2.3 Measurement and Compilation

All living trees taller than 1.37 m (4.5 feet) were tagged and measured prior to the 1953 growing season. At that time, the diameter at breast height outside bark (dbhob) and condition of all tagged trees were recorded, and a sub-sample of approximately 10% of the tagged trees was measured for height. In addition, a survey was conducted to determine the amount of fir, spruce, and balsam regeneration, less than 1.37 m tall, present in each plot. The plots were remeasured in the springs of 1958 and 1984, and the falls of 1963, 1968, 1973, 1978, 1988, 1993, and 1998. Height measurements were not taken in 1984. Additional, non-measurement surveys were carried out during the falls of 1980, 1981, and 1982 to determine to extent to which the tagged trees were being attacked by the mountain pine beetle.

Height-diameter equations were derived to estimate the heights of those trees for which only diameter was measured. Because the number of measured heights was insufficient to produce reliable height equations for some species, some grouping of data was necessary. For each assessment period, separate height-diameter equations were derived as follows:

- pine—data combined from both replications of each treatment;
- larch—data combined from all treatments; and
- other—fir, spruce, and balsam data combined from all treatments.

In the absence of height data for 1984, individual tree heights for that assessment were determined by interpolating between the heights of 1978 and 1988.

2.4 Analyses

Mean-tree and per-hectare stand values of each plot were calculated for each measurement period based on the values[3] of living trees that were tagged at study establishment. Because the species composition was highly variable among plots within blocks, and between plots within treatments (Appendix 3), the data were analyzed in two species groups: (1) all species combined, and (2) pine only. Furthermore, data from acceptable sample trees were sorted and analyzed according to two stand components: (1) whole stand, and (2) "crop trees" (the equivalent of the 200 largest [dbhob] trees per hectare after 46 years). Unless otherwise noted, per-hectare values are net values (i.e., exclude mortality and ingrowth), and were determined for each plot by multiplying the mean value of the tagged trees by the appropriate stand density of the plot. Mean-tree and per-hectare stand values from both blocks were averaged to provide the treatment values shown in this report.

Statistical analyses of the results observed in this study were not undertaken for a variety of reasons. There is uncertainty about how the treatments were assigned, and concerns about the uniformity of their application (Appendix 1). Furthermore, there was substantial heterogeneity, both between blocks and among plots within blocks, with respect to stand structure (Appendix 2), site productivity (Appendix 3), and species composition (Appendix 4). Of particular concern is the degree to which the results may have been affected by the presence of large larch trees that varied considerably throughout the study area (Appendices 2 and 4). Finally, the results of this study were greatly affected by the beetle attack, which varied in intensity throughout the study area.

3 Volumes are inside-bark volumes calculated from Kozak's taper functions. Merchantable volume is the bole volume between a 30-cm stump and a 10-cm dib (diameter inside bark) top for all trees 12.5 cm dbhob and larger.

3 RESULTS

3.1 Individual-tree Values

3.1.1 Tree diameter Figure 2 shows the effect of the thinning treatments on mean dbh over the 46-year response period. As expected, mean dbh of all species generally increased with thinning intensity and, after 46 years, the diameter of the trees in the heaviest thinning (Treatment 5) are approximately 47% larger than those in the unthinned controls (Treatment 0). Similar results were observed if only pine is considered; however, the intermediate level of thinning (Treatment 3) grew more slowly than the unthinned stand, and the mean dbh of the heaviest thinning was only 37% higher than that of the control.

3.1.2 Tree height The effect of thinning on mean height (Figure 3) was far less dramatic than its effect on mean dbh. It appears that the heaviest thinnings (Treatments 4 and 5) resulted in very modest height gains. The reason for the slight decline in the mean height of the unthinned controls during the last measurement period is unclear, but may be due either to mortality in some of the taller trees in these plots, or to the small number of height-diameter trees available for measurement at the last assessment.

Although inconclusive, the results in Appendix 3 suggest that, during the last 46 years, the trees in the more heavily thinned plots were able to maintain a higher rate of top height growth (the height growth of the 100 largest dbhob trees/hectare) than the trees in the control and in the most lightly thinned plots.

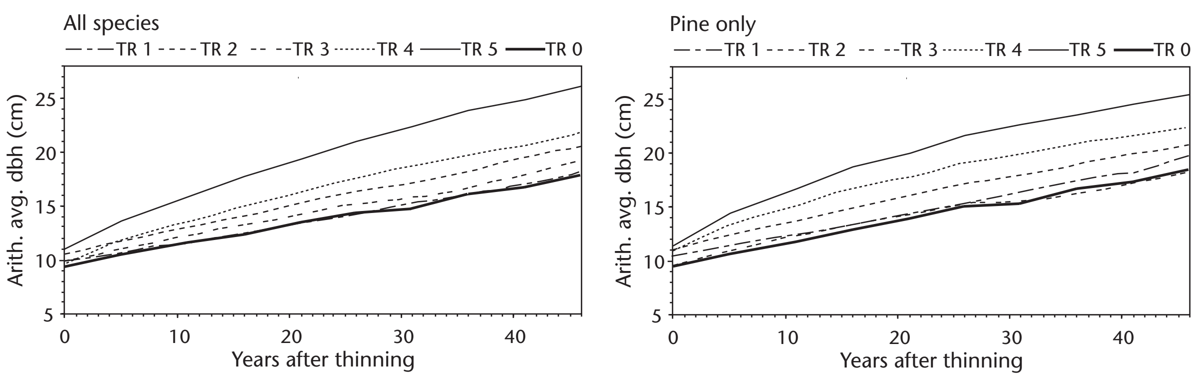


FIGURE 2 *Diameter development following thinning for all species combined and for pine only.*

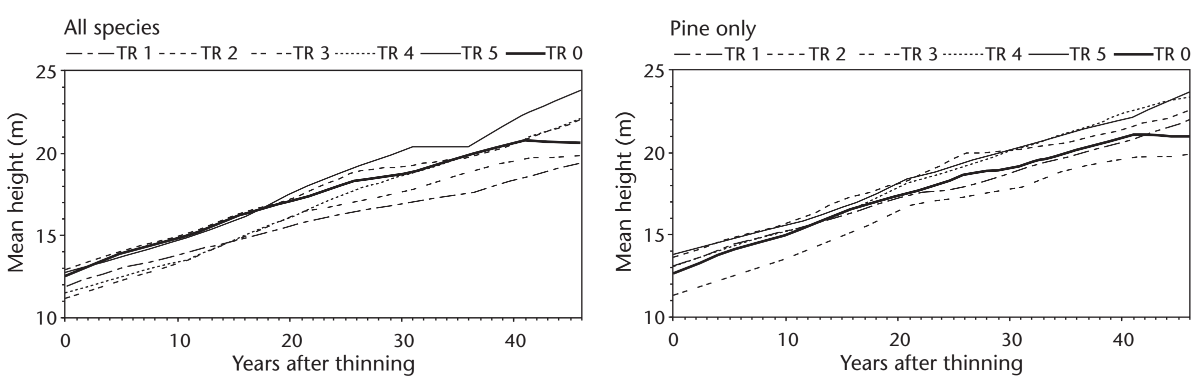


FIGURE 3 *Height development following thinning for all species and for pine only.*

3.1.3 Tree volume The combined effects of thinning on diameter and height are best expressed in terms of individual-tree volume (Figures 4 and 5). For all species, thinning resulted in larger and, presumably, more valuable trees. The trees in the widest spacing (Treatment 5) were 123% larger, in terms of total volume, than those in the controls (Treatment 0). For pine only, the trees in Treatment 5 contained 96% more total volume, on average, than the trees in the unthinned plots. These differences are even larger if individual-tree, merchantable volumes (bole volume of trees 12.5 cm dbhob and larger, between a 30-cm stump and a 10-cm dib top) are compared. In that comparison, the mean trees in Treatment 5 were 146% and 115% larger than in the unthinned plots for the all-species and pine-only components, respectively.

3.2 Stand Values

3.2.1 Survival The results in Figure 6 show the change in the levels of growing stock of the plots over the last 46 years. The distribution of the 1998 growing stock, by diameter class, is shown in Appendix 5. High and

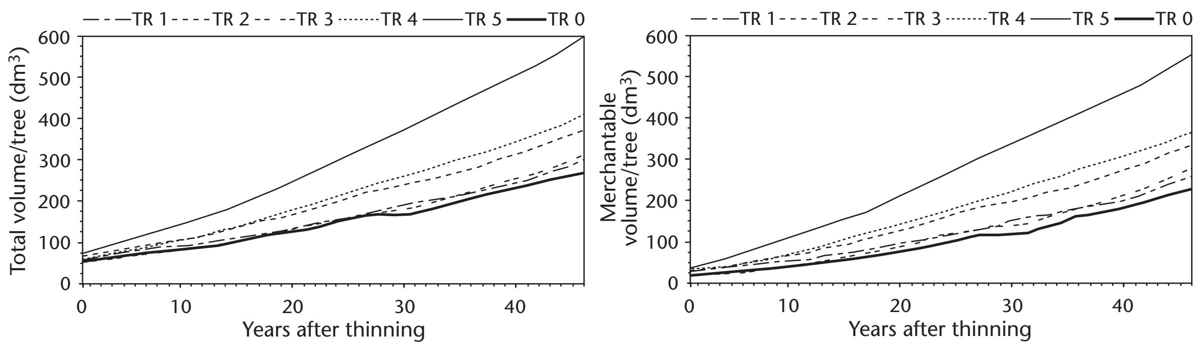


FIGURE 4 *Individual-tree total and merchantable volume development following thinning for all species combined.*

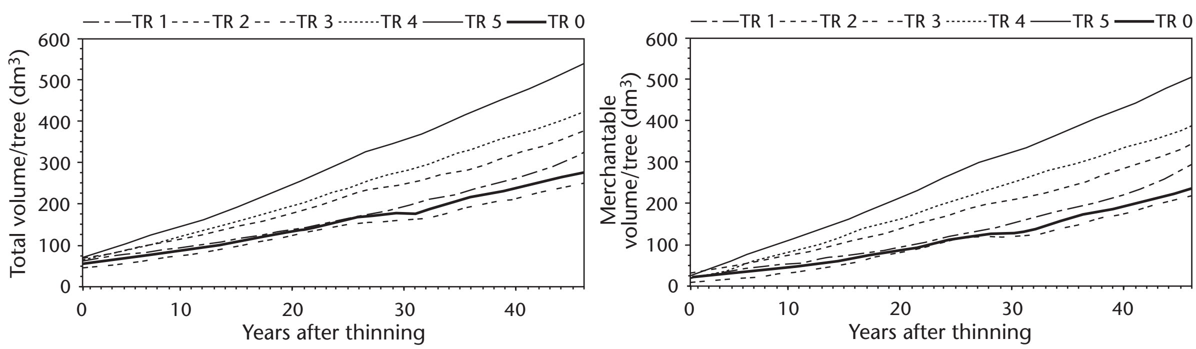


FIGURE 5 *Individual-tree total and merchantable volume development following thinning for pine only.*

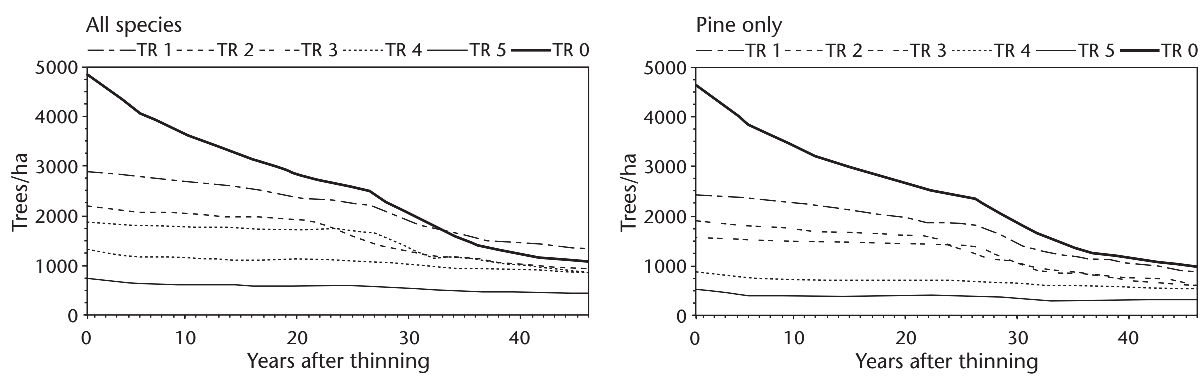


FIGURE 6 *Stand density following thinning for all species combined and for pine only.*

consistent mortality of the pine component in the unthinned plots (Figures 7 and 8), which varied from a low of 9.3% between 1973 and 1978 to a high of 26.5% between 1978 and 1984, has reduced the stand density of the controls to below that of the most lightly thinned plots (Figure 6). The high mortality immediately following treatment, observed in the most heavily thinned plots (Treatments 4 and 5), was due to snow press. Mortality in Treatments 4 and 5 stabilized at low levels thereafter. High (greater than 100) height-diameter ratios (slenderness coefficients), particularly at wide spacings, indicate a high susceptibility to wind and snow damage (Wilson and Oliver 2000). The results (Figure 9) show that, at the time of thinning, these ratios were very high and, except for the heaviest thinnings, have remained high since treatment. The decline in the ratios of the unthinned plots is a result of the trees' adjustments following high mortality.

The very high rates of mortality observed in all treatments between 1978 and 1984 (26–31 years after thinning) were due to the mountain pine beetle outbreak. Figure 7 provides a comparison of pine survival in Block 384, which, in general, had a much lower pine component than Block 385 (Appendix 3). These results show a much lower rate of pine mortality in Block 385 compared to Block 384 over all treatments, suggesting that a certain level of

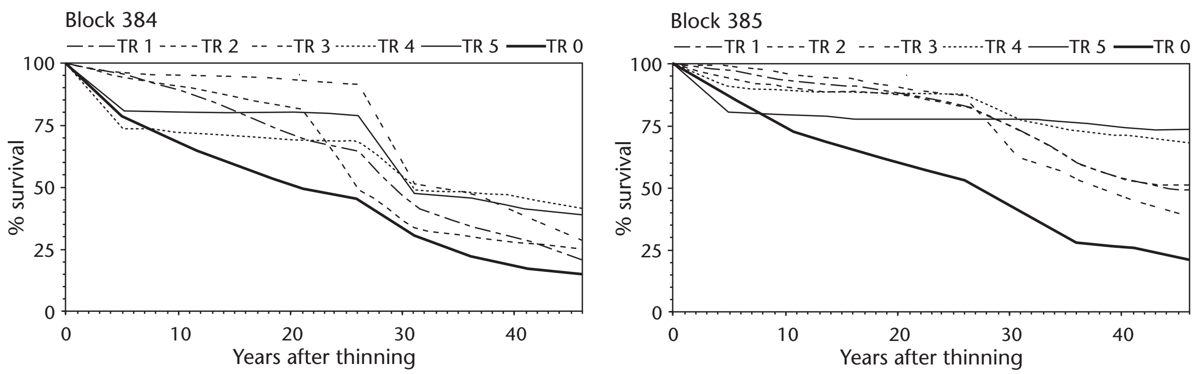


FIGURE 7 *Survival (% of number of trees at establishment) of lodgepole pine following thinning, by block and treatment.*

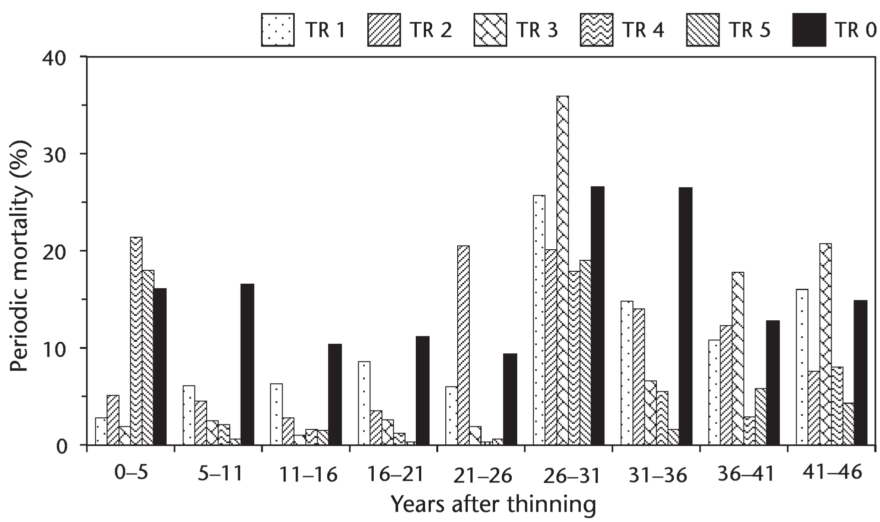


FIGURE 8 *Periodic mortality (% number of trees at start of each period) for pine following thinning.*

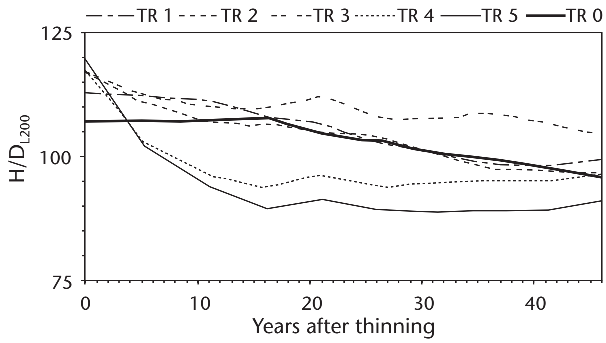


FIGURE 9 *Height (cm)/diameter (cm) ratios of the 200 largest pine (H/D_{L200}) following thinning.*

pine growing stock is required to maintain the beetle population during the outbreak. These results also show that, in both blocks, the most heavily thinned plots had substantially higher rates of pine survival. A comparison of the diameter and diameter growth of the trees that were killed during the outbreak with those that survived failed to show any conclusive relationship between tree size and mortality, or between tree vigour and mortality. It should be noted that, as with all of the results shown in this report, the presentation of treatment means masks much of the variation observed in the mean-tree and per-hectare response variables. For example, during the 1978–1984 period, mortality in Treatment 5 of Block 384 was 38.0% compared to 0.0% for the same treatment in Block 385, resulting in the a 19.0% periodic mortality rate for Treatment 5. The results (Figure 8) suggest that the beetle outbreak began prior to 1978 in Treatment 2 of Block 384, which accounts for the high mortality shown for Treatment 2 during the period 1973–1978. The higher rate of mortality in all treatments after 1983 compared to before the outbreak suggests that many of the trees that survived the initial beetle attack may have eventually died because of their weakened condition. Despite this high mortality, pine still remains a major component of the species composition of most of the plots (Appendix 3).

3.2.2 Stand basal area As can be seen in Figure 10, the thinned plots were accumulating basal area at a faster rate than the unthinned plots prior to the mountain pine beetle attack. However, because of the attack, it is not possible to predict when, if ever, the more heavily thinned plots would attain levels of basal area similar to those of the unthinned plots. Currently, only the two

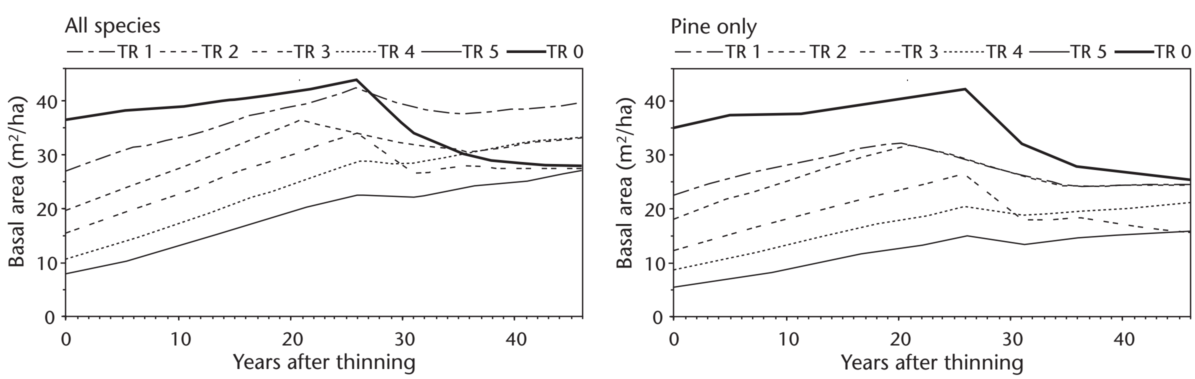


FIGURE 10 *Stand basal area following thinning for all species combined and for pine only.*

heaviest thinnings (Treatments 4 and 5) support basal areas higher than their pre-outbreak basal areas. The important contribution of species other than pine can be seen by comparing graphs for all species with those for pine only.

3.2.3 Stand volume As expected, the total volume response to treatment (Figures 11 and 12) was similar to that observed for basal area. With the exception of Treatment 3, all of the thinnings have a stand total volume equal to or higher than the unthinned controls, if all species are considered. If only the pine component is considered, the two lightest thinnings (Treatments 1 and 2) have equal or higher standing total volumes after 46 years. Tables 2

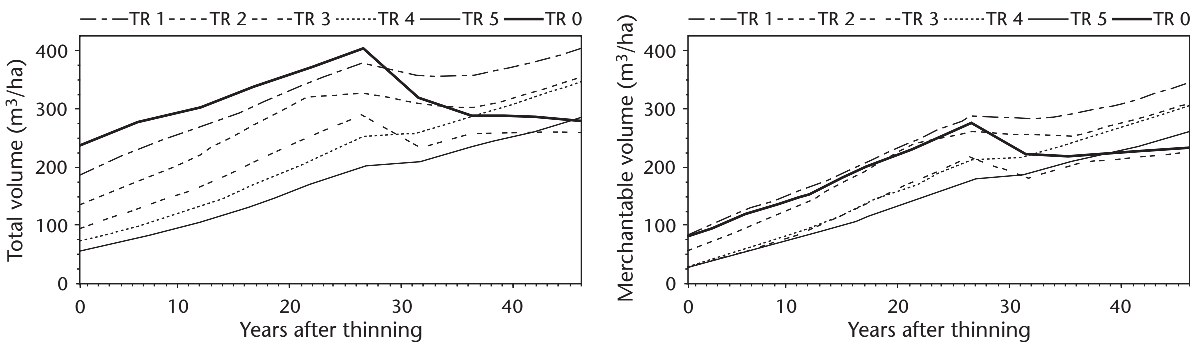


FIGURE 11 *Stand total and merchantable volume following thinning for all species combined.*

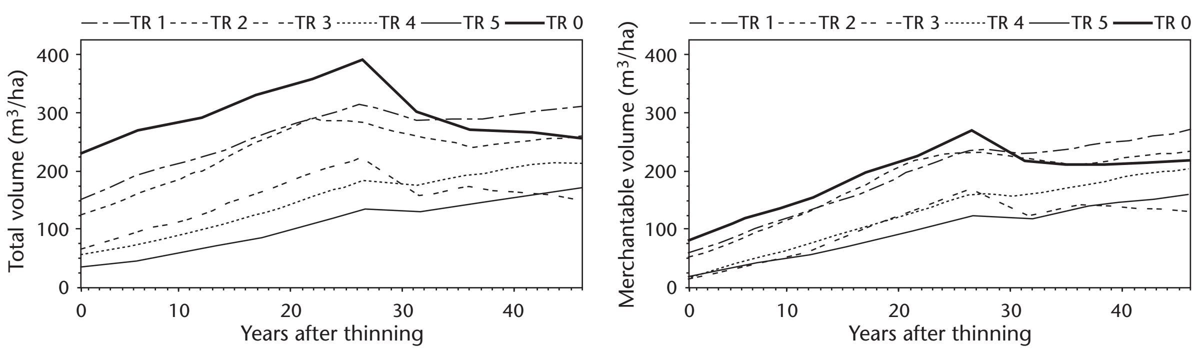


FIGURE 12 *Stand total and merchantable volume following thinning for pine only.*

TABLE 2 *Net and gross increments in stand total volume (m^3/ha) for all species combined*

	Treatments					
Measurements	0	1	2	3	4	5
1952 total volume after thinning	235.29	185.33	134.97	92.68	71.39	56.59
1997 total volume[a]	277.44	396.63	343.57	260.76	338.45	282.41
Net increment 1952–1997[a]	42.15	211.30	208.60	168.08	267.06	225.82
Net periodic annual increment	0.92	4.59	4.53	3.65	5.81	4.91
Mortality 1952–1997	275.84	147.45	184.52	151.39	65.12	55.33
Gross increment 1952–1997[b]	317.99	358.75	393.12	319.47	332.18	281.15
Gross periodic annual increment	6.91	7.80	8.55	6.95	7.22	6.11

a Excludes mortality and ingrowth.
b Includes mortality, but excludes ingrowth.

and 3 show the net and gross periodic increments for stand total volume of the thinned and unthinned plots for all species and for pine only, respectively. These results indicate the degree to which thinning increased the net periodic annual increment of the plots, and the degree to which most of the gross increment in the unthinned plots was lost to mortality. A comparison of the net and gross periodic increments in merchantable volume (Tables 4 and 5) indicates that only roughly half of the gross growth of the unthinned

TABLE 3 *Net and gross increments in stand total volume (m^3/ha) for pine only*

	Treatments					
Measurements	0	1	2	3	4	5
1952 total volume after thinning	229.86	152.35	124.55	68.89	55.73	36.84
1997 total volume[a]	256.19	309.50	260.00	152.86	220.78	172.56
Net increment 1952–1997[a]	26.33	157.15	135.45	83.97	165.05	135.72
Net periodic annual increment	0.57	3.42	2.94	1.83	3.59	2.95
Mortality 1952–1997	274.04	133.14	179.39	146.95	56.46	41.46
Gross increment 1952–1997[b]	300.37	290.29	314.84	230.92	211.51	177.18
Gross periodic annual increment	6.53	6.31	6.84	5.02	4.82	3.85

a Excludes mortality and ingrowth.
b Includes mortality, but excludes ingrowth.

TABLE 4 *Net and gross increments in stand merchantable volume (m^3/ha) for all species combined*

	Treatments					
Measurements	0	1	2	3	4	5
1952 merchantable volume after thinning	75.68	81.71	52.14	25.46	22.25	25.52
1997 merchantable volume[a]	232.82	347.61	306.62	227.82	304.94	262.39
Net increment 1952–1997[a]	157.14	265.90	254.48	202.36	282.69	236.87
Net periodic annual increment	3.42	5.78	5.53	4.40	6.15	5.15
Mortality 1952–1997	144.16	81.94	134.53	111.14	49.05	44.45
Gross increment 1952–1997[b]	301.30	347.84	389.01	313.50	331.74	281.32
Gross periodic annual increment	6.55	7.56	8.46	6.82	7.21	6.12

a Excludes mortality and ingrowth.
b Includes mortality, but excludes ingrowth.

TABLE 5 *Net and gross increments in stand merchantable volume (m^3/ha) for pine only*

	Treatments					
Measurements	0	1	2	3	4	5
1952 merchantable volume after thinning	75.43	53.23	47.41	9.40	14.34	11.63
1997 merchantable volume[a]	216.50	273.81	232.37	132.06	201.63	160.62
Net increment 1952–1997[a]	141.07	220.58	184.96	122.66	187.29	148.99
Net periodic annual increment	3.07	4.80	4.02	2.67	4.07	3.24
Mortality 1952–1997	144.16	69.20	132.49	107.79	42.14	32.91
Gross increment 1952–1997[b]	285.23	289.78	317.45	230.45	229.43	181.90
Gross periodic annual increment	6.20	6.30	6.90	5.01	4.99	3.95

a Excludes mortality and ingrowth.
b Includes mortality, but excludes ingrowth.

stand is available for harvest compared to more than 80% in the most heavily thinned plots. A more comprehensive comparison of net and gross total and merchantable volume increments over the 46-year period is presented in Appendices 6–9. The devastating effects of the beetle outbreak on these variables are clearly shown.

3.3 Crop-tree Values

Direct comparisons of individual-tree size between thinned and unthinned plots can be misleading because the thinning, particularly when done from below, removes the smaller trees and thereby directly increases the mean tree sizes of the thinned plots. The results presented in Table 6 provide a direct comparison among treatments that is limited to the 200 largest (dbh) trees/ha in each plot. When all species are considered, all of the thinning treatments produced larger trees than the unthinned plots, and the increase in size was usually directly related to thinning intensity. With the exception of Treatment 3, this pattern generally holds true if only lodgepole pine is compared, but the between-treatment differences are marginal.

TABLE 6 *Mean-tree and per-hectare crop-tree (largest 200 trees/ha) characteristics, for all species and for pine only, 46 years after study establishment*

	Treatment					
Characteristic	0	1	2	3	4	5
All species:						
dbhob (cm)	25.0	28.9	29.3	28.1	29.8	32.3
Height (m)	24.1	26.1	26.2	25.5	26.2	26.8
Total volume / tree (dm^3)	0.53	0.73	0.76	0.67	0.76	0.90
Crop-tree basal area (m^2/ha)	9.9	13.5	13.9	13.2	14.3	16.9
Crop-tree total volume (m^3/ha)	105.7	146.7	152.0	134.7	151.9	180.5
Crop-tree merch. volume (m^3/ha)	98.1	137.9	142.9	126.1	142.8	170.5
Pine only:						
dbhob (cm)	24.6	24.9	26.0	21.4	25.3	26.7
Height (m)	23.8	24.7	25.2	22.0	24.5	24.5
Total volume / tree (dm^3)	0.53	0.56	0.63	0.39	0.58	0.65
Crop-tree basal area (m^2/ha)	9.7	9.9	10.8	7.4	10.2	11.6
Crop-tree total volume (m^3/ha)	105.7	112.4	125.8	77.1	115.4	130.5
Crop-tree merch. volume (m^3/ha)	98.1	105.7	117.8	70.0	107.7	122.3

4 DISCUSSION AND CONCLUSIONS

The presentation of treatment means in this report has masked much of the variation observed in the tree and stand responses to the various thinning treatments. Nevertheless, the results of this study demonstrate that older lodgepole pine will respond positively to thinning. On an individual-tree basis, if all trees are considered, the largest responses were observed in bole diameter and volume, but thinning had little or no effect on height. Although the tree-size responses were substantial in relative terms, the absolute responses were small because the growth capability of these older trees is limited. If limited to the 200 largest crop trees/ha, the individual-tree treatment differences can be substantial if all species are considered, but marginal if only pine is compared. Furthermore, the thinning intensities tested in this study were relatively light compared to present-day standards, and a more dramatic response would probably have occurred had heavier intensities been tested. The results observed in this study are similar to the responses reported for similarly aged stands by Dahms (1971).

The results of this study also demonstrate that the response to thinning can be substantial when considered on an area basis. The most notable result is the degree to which thinning increased the net periodic annual increment of the treated plots compared to the unthinned controls. In terms of total volume, thinning increased the net increment for all species from almost 300 to more than 500%, and for the pine-only component from more than 200 to more than 500% compared to the controls. The gains in merchantable volume were much more modest. The increment gains due to thinning were mainly the result of lower mortality losses in the thinned plots compared to the unthinned plots, and were greatly affected by the beetle attack. Although the most heavily thinned plots experienced relatively higher mortality, due to snow press immediately after treatment, they had the lowest rates of mortality thereafter compared to the lightly thinned and unthinned plots. The demonstrated ability of the trees in the most heavily thinned plots to survive and respond positively following the mountain pine beetle outbreak lends support to the theory that heavy thinning may help to beetle-proof lodgepole pine stands (Mitchell et al. 1983). The study also demonstrates the advantages of maintaining and encouraging species diversity, particularly in areas with a high potential for pest outbreaks. The decision to thin older lodgepole pine stands will depend upon the consideration of a number of factors, including the current and anticipated timber supply and market situations, the availability of capital and labour, the threat of damaging agents, and the potential economic and biological responses to thinning. The present study has provided some detailed information on the last factor.

This trial provides 46 years of remeasurement data, which is the oldest set of permanent sample plot data for thinned lodgepole pine in British Columbia. The trial suffers from a number of problems that make a comprehensive, statistical analysis of the results virtually impossible. Variations, both within and among treatments, in site and stand conditions (particularly with respect to species composition and pre-treatment stand density), and the failure to carry out the thinning treatments in a uniform and quantifiable manner, have plagued this study since its establishment. Nevertheless, although the study may have limitations from a growth and yield research point of view, it may provide some very timely opportunities for examining the accumulation of coarse woody debris, and for studying successional pathways in the Montane Spruce biogeoclimatic zone.

REFERENCES

Braumandl, T.F. and M.P. Curran. 1992. A field guide for site identification and interpretation for the Nelson Forest Region. B.C. Min. For., Nelson, B.C. Land Manage. Handb. 20.

Cole, D.M. 1975. Culture of immature lodgepole pine for timber objectives. *In* Management of lodgepole pine ecosystems. Vol. 2. D.M. Baumgartner (editor). Wash. State Univ., Pullman, Wash., pp. 536–555.

Dahms, W.G. 1971. Fifty-five-year-old lodgepole pine responds to thinning. USDA, For. Serv., Res. Note PNW-141.

Johnstone, W.D. 1985. Thinning lodgepole pine. *In* Lodgepole pine: the species and its management. D.M. Baumgartner, G.G. Krebill, J.T. Arnott, and G.F. Weetman (editors). Wash. State Univ., Pullman, Wash., pp. 253–262.

Johnstone, W.D. and D.M. Cole. 1988. Thinning lodgepole pine. *In* Proceedings—future forests of the mountain west: a stand culture symposium. W.C. Schmidt (compiler). USDA, For. Serv., Gen. Tech. Rep. INT-243, pp. 160–165.

Mitchell, R.G., R.H. Waring, and G.B. Pitman. 1983. Thinning lodgepole pine increases tree vigour and resistance to mountain pine beetle. For. Sci. 29 (1): 204–211.

Smithers, L.A. 1961. Lodgepole pine in Alberta. Can. Dept. For., Ottawa, Ont. Bull. 127.

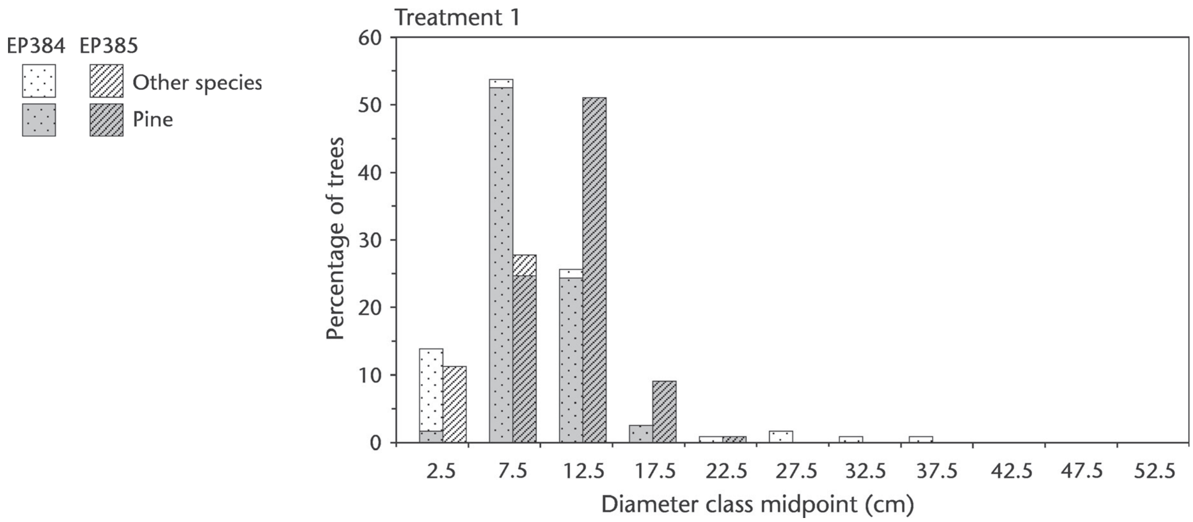
Stone, M. 1996. Commercial thinning of lodgepole pine: an economic analysis. B.C. Min. For., Econ. and Trade Br., Victoria, B.C. FRDA Working Paper 6-017.

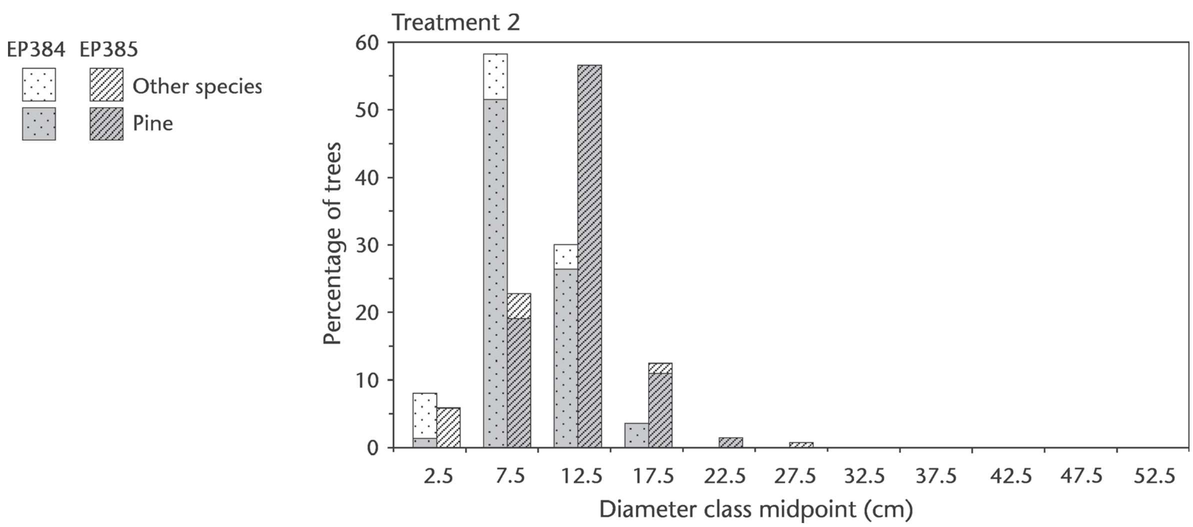
Wilson, J.S. and C.D. Oliver. 2000. Stability and density management in Douglas-fir plantations. Can. J. For. Res. 30: 910–920.

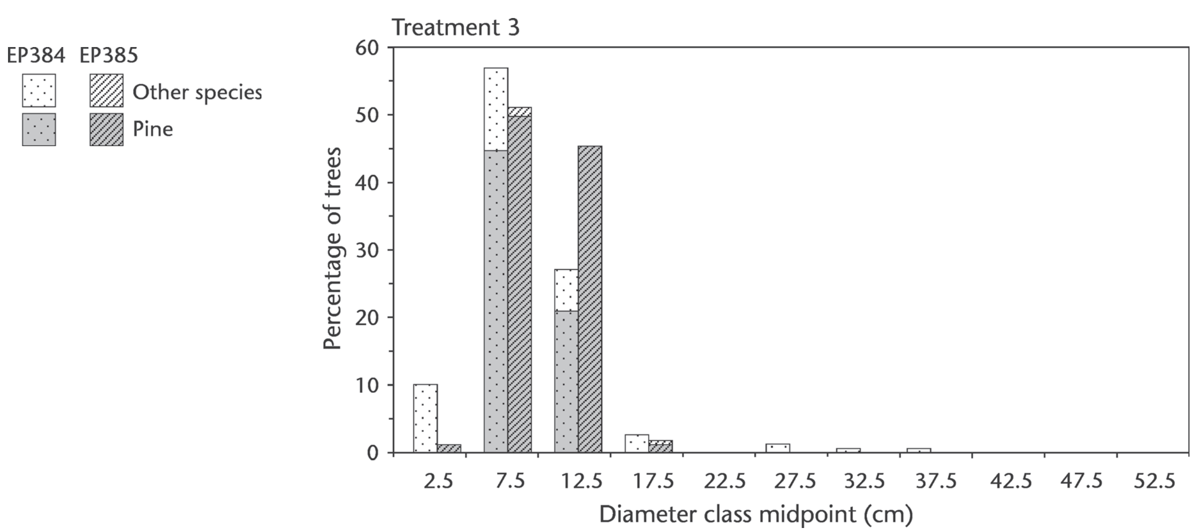
APPENDIX 1 Stand characteristics after thinning in 1952/53

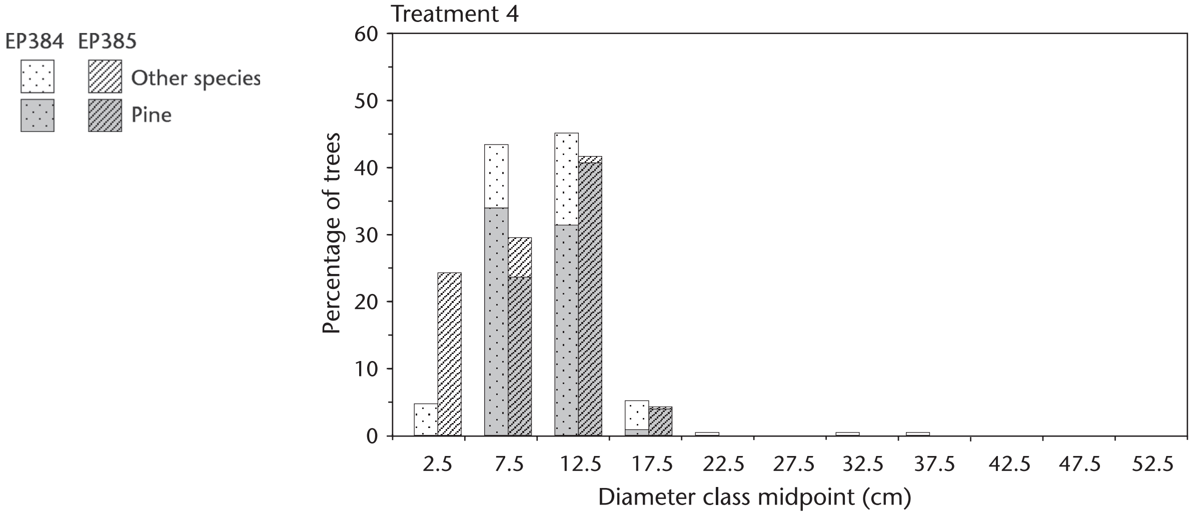
Block no.	Treatment no.	No. stems (/ha)	Arith. avg. dbh (cm)	Mean height (m)	Basal area (m^2/ha)	Total volume (m^3/ha)
384	0	5659	8.2	11.82	34.59	220.20
	1	2941	9.0	11.23	25.41	166.64
	2	2755	8.8	11.65	19.21	120.90
	3	1816	9.1	10.63	15.14	89.43
	4	1147	10.4	12.63	11.09	68.88
	5	823	11.0	12.53	9.89	66.30
385	0	4077	10.3	13.29	37.20	250.39
	1	2854	10.6	12.82	28.68	204.42
	2	1680	11.7	14.20	20.17	149.04
	3	1952	10.0	11.82	16.19	95.92
	4	1502	8.7	10.46	11.39	73.89
	5	684	10.9	13.04	7.05	46.88
Mean	0	4868	9.3	12.56	35.90	235.30
	1	2898	9.8	12.03	27.05	185.53
	2	2218	10.3	12.93	19.69	134.97
	3	1884	9.6	11.23	15.67	92.68
	4	1325	9.6	11.55	11.24	71.39
	5	754	11.0	12.79	8.47	56.59

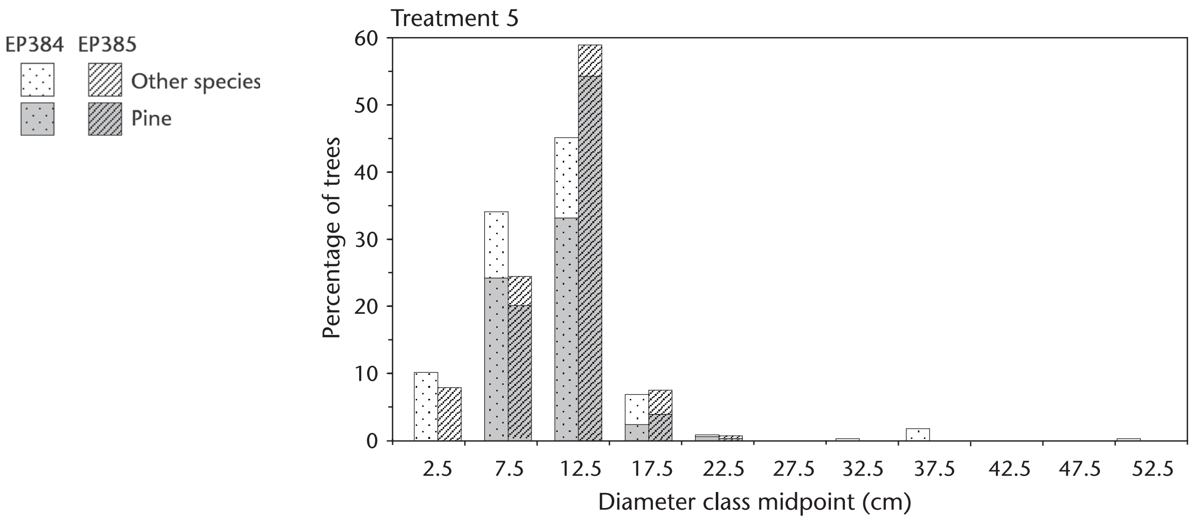
APPENDIX 2 Tree-size frequency for all species combined (pine portion in shaded areas), by block and treatment, after thinning in 1952/53

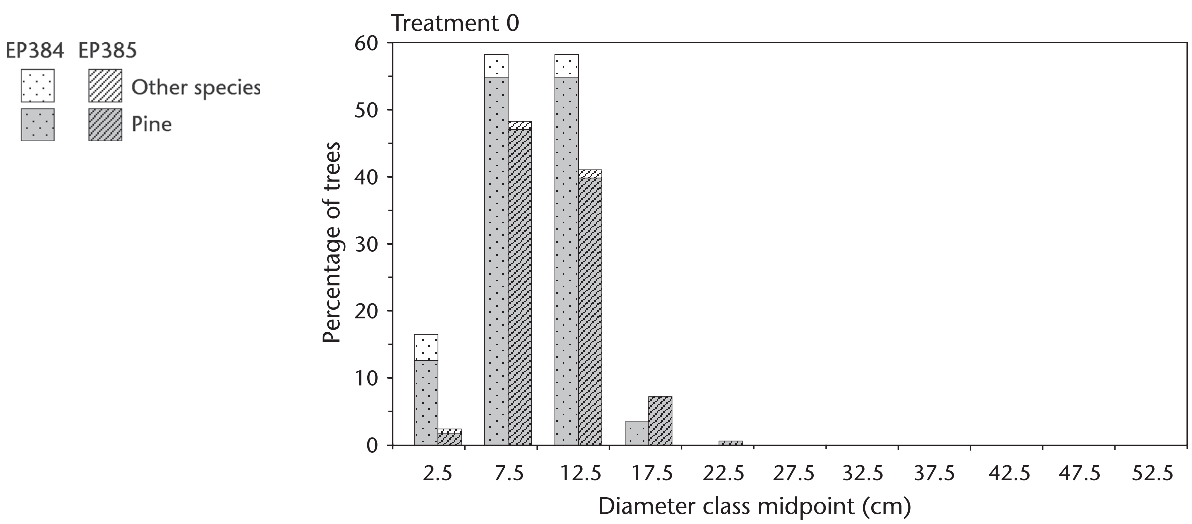







Treatment 4
EP384 EP385
Other species
Pine
Percentage of trees
0
10
20
30
40
50
60
2.5
7.5
12.5
17.5
22.5
27.5
32.5
37.5
42.5
47.5
52.5
Diameter class midpoint (cm)


Treatment 5
EP384 EP385
Other species
Pine
Percentage of trees
0
10
20
30
40
50
60
2.5
7.5
12.5
17.5
22.5
27.5
32.5
37.5
42.5
47.5
52.5
Diameter class midpoint (cm)


Treatment 0
EP384 EP385
Other species
Pine
Percentage of trees
0
10
20
30
40
50
60
2.5
7.5
12.5
17.5
22.5
27.5
32.5
37.5
42.5
47.5
52.5
Diameter class midpoint (cm)

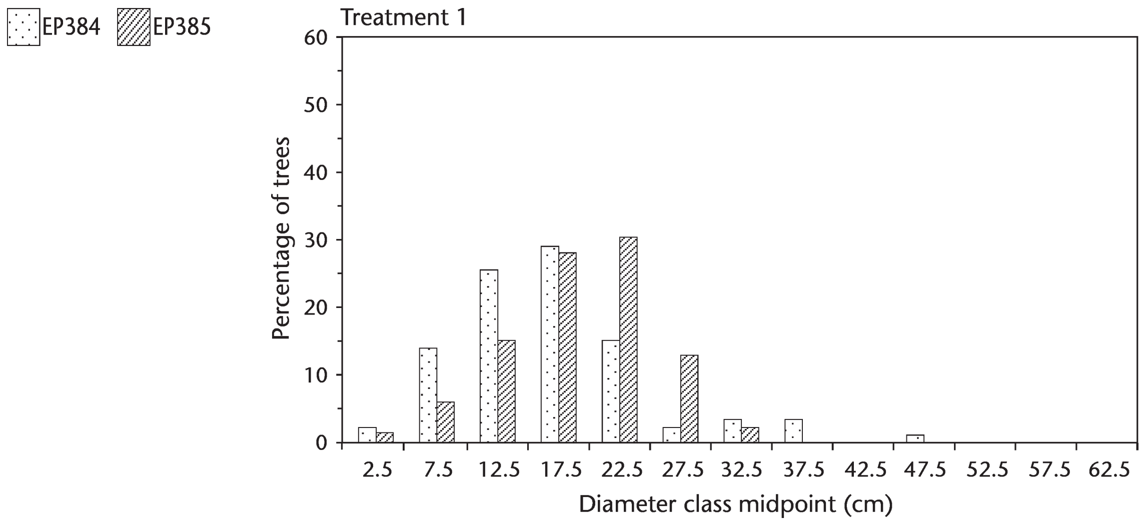
APPENDIX 3 Percent pine composition and top height, by block and plot, at study establishment (1953) and after 46 growing seasons (1998)

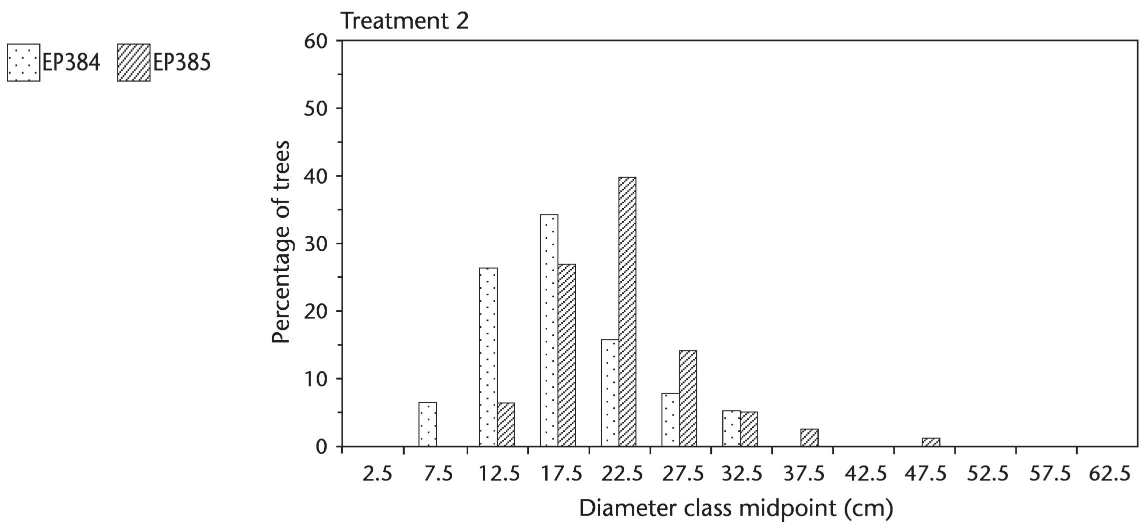
Block no.	Treatment no.	% pine of stand basal area			Top height (m)		
		1953	1998	change	1953	1998	change
384	0	96.1	91.6	4.5	17.8	23.7	5.9
	1	64.8	51.5	13.3	15.1	22.5	7.4
	2	89.2	65.5	23.7	16.3	25.4	9.1
	3	53.2	25.1	28.1	12.9	21.7	8.8
	4	58.1	39.4	18.7	14.7	24.4	9.7
	5	51.0	36.5	14.5	15.6	23.9	8.3
	Mean	68.7	51.6	17.1	15.4	23.6	8.2
385	0	97.6	90.2	7.4	16.4	24.8	8.4
	1	98.3	86.6	11.7	18.5	26.8	8.3
	2	92.1	75.7	16.4	17.7	27.0	9.3
	3	97.8	95.3	2.5	15.7	25.8	10.1
	4	93.3	77.5	15.8	15.8	25.7	9.9
	5	82.7	75.1	7.6	16.4	26.9	10.5
	Mean	93.6	83.4	10.2	16.8	26.2	9.4
Mean	0	96.8	90.9	5.9	17.1	24.3	7.2
	1	81.5	69.1	12.5	16.8	24.7	7.9
	2	90.6	70.6	20.0	17.0	26.2	9.2
	3	75.5	60.2	15.3	14.3	23.8	9.5
	4	75.7	58.4	17.3	15.3	25.1	9.8
	5	66.8	55.8	11.0	16.0	25.4	9.4
Overall mean		81.2	67.5	13.7	16.1	24.9	8.8

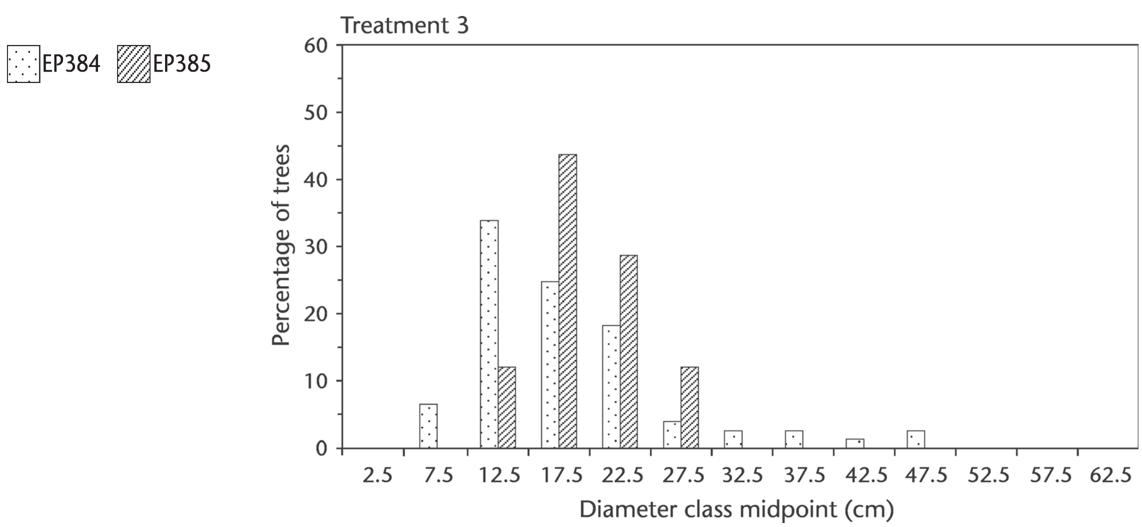
APPENDIX 4 Number of sample trees, by species and plot, after thinning in 1952/53

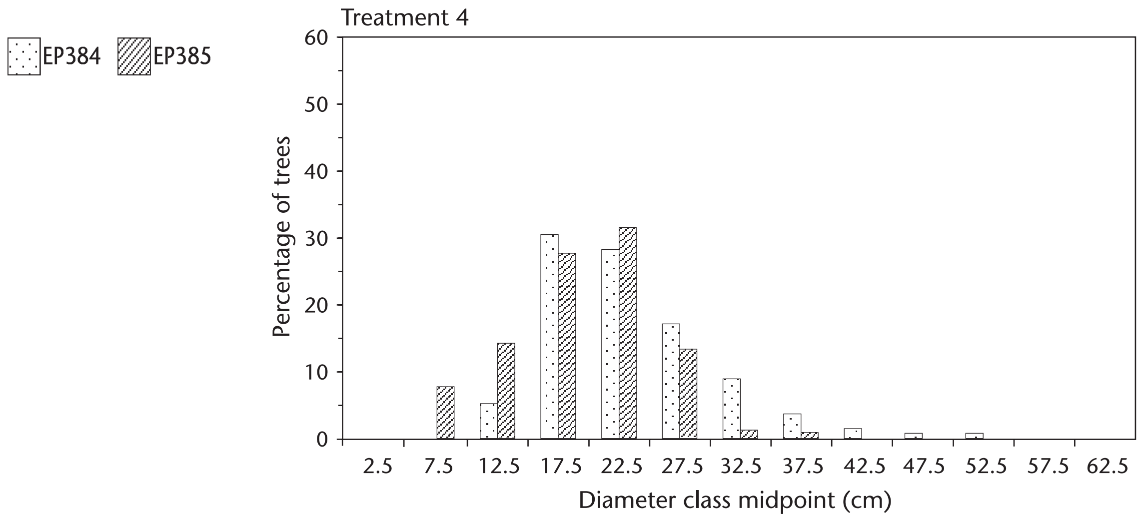
Block no.	Treatment no.	Pine	Larch	Balsam	Fir	Spruce	Total
384	0	211	17	0	1	0	229
	1	193	18	0	24	3	238
	2	185	24	0	7	7	223
	3	97	32	0	9	9	147
	4	154	65	0	5	8	232
	5	202	79	0	8	44	333
385	0	160	5	0	0	0	165
	1	198	2	0	0	31	231
	2	120	6	0	0	10	136
	3	155	2	0	1	0	158
	4	208	5	1	0	90	304
	5	219	27	1	6	24	277

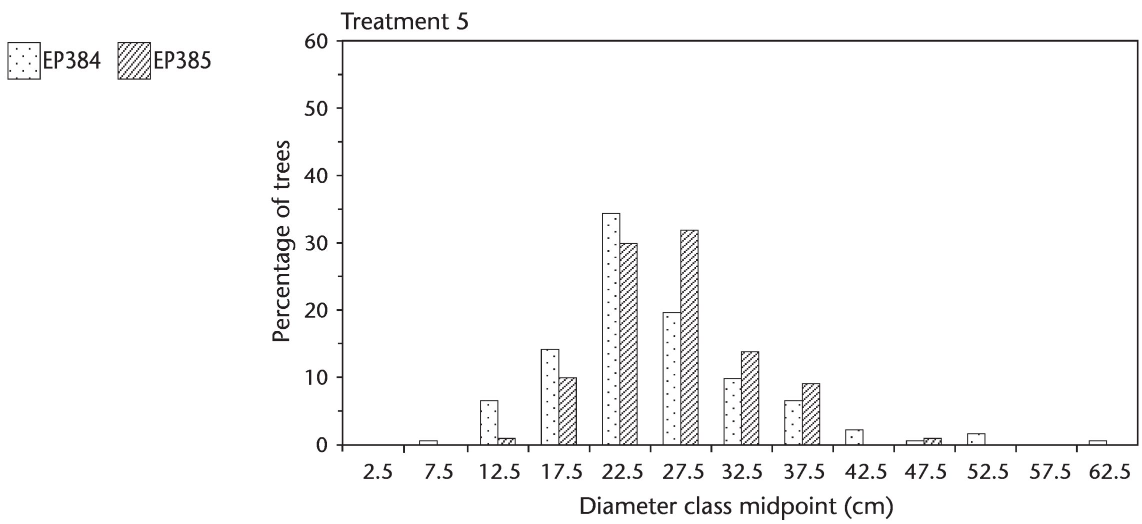
APPENDIX 5 Tree-size frequency, by block and treatment, 46 years after thinning (1998)

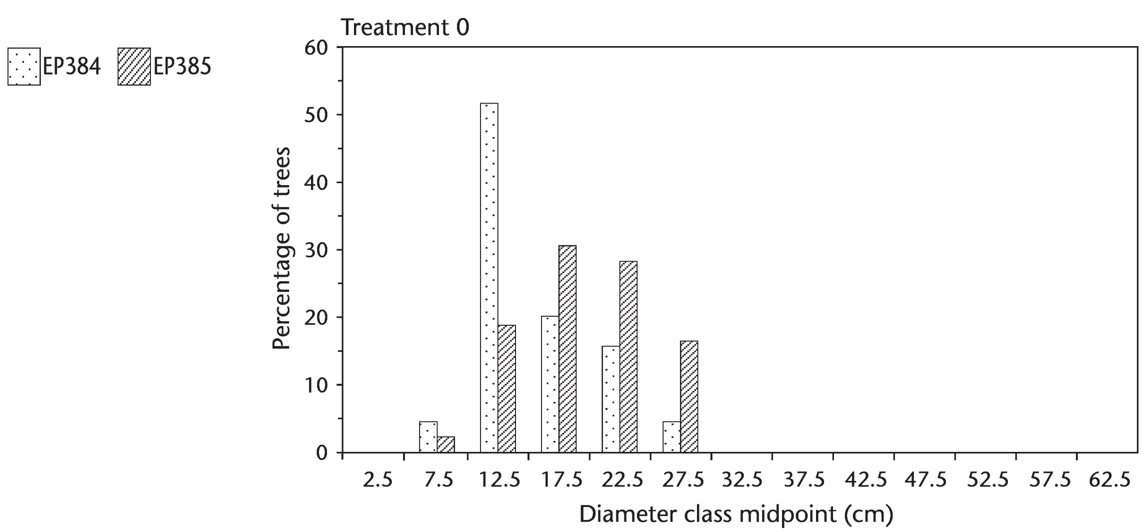




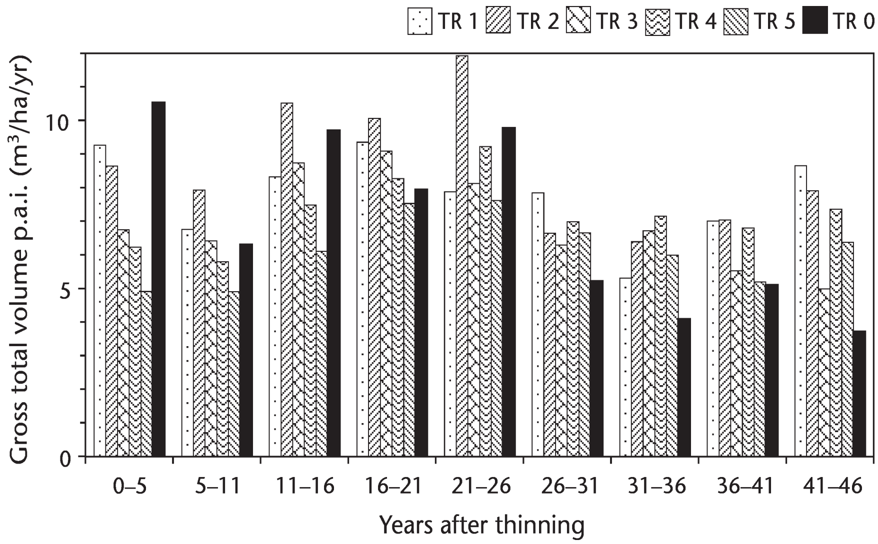


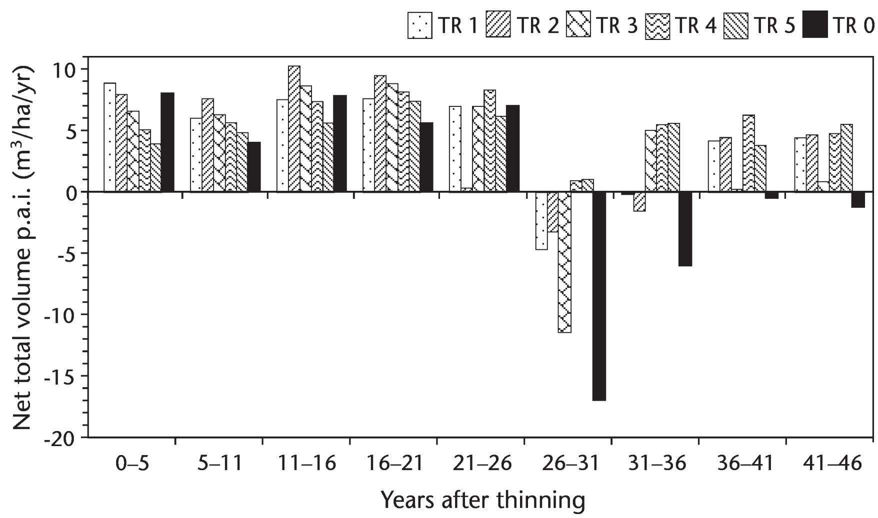

EP384
EP385
Treatment 4
Percentage of trees
0
10
20
30
40
50
60
2.5
7.5
12.5
17.5
22.5
27.5
32.5
37.5
42.5
47.5
52.5
57.5
62.5
Diameter class midpoint (cm)


EP384
EP385
Treatment 5
Percentage of trees
0
10
20
30
40
50
60
2.5
7.5
12.5
17.5
22.5
27.5
32.5
37.5
42.5
47.5
52.5
57.5
62.5
Diameter class midpoint (cm)

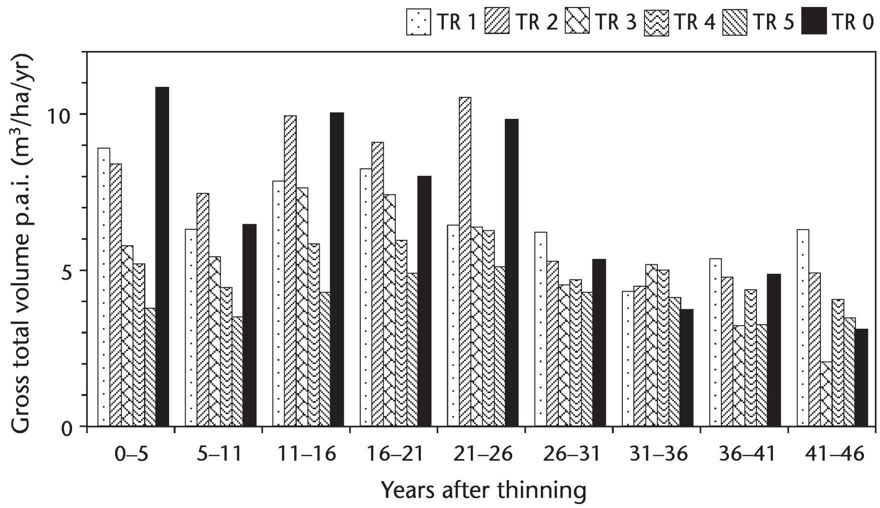

EP384
EP385
Treatment 0
Percentage of trees
0
10
20
30
40
50
60
2.5
7.5
12.5
17.5
22.5
27.5
32.5
37.5
42.5
47.5
52.5
57.5
62.5
Diameter class midpoint (cm)

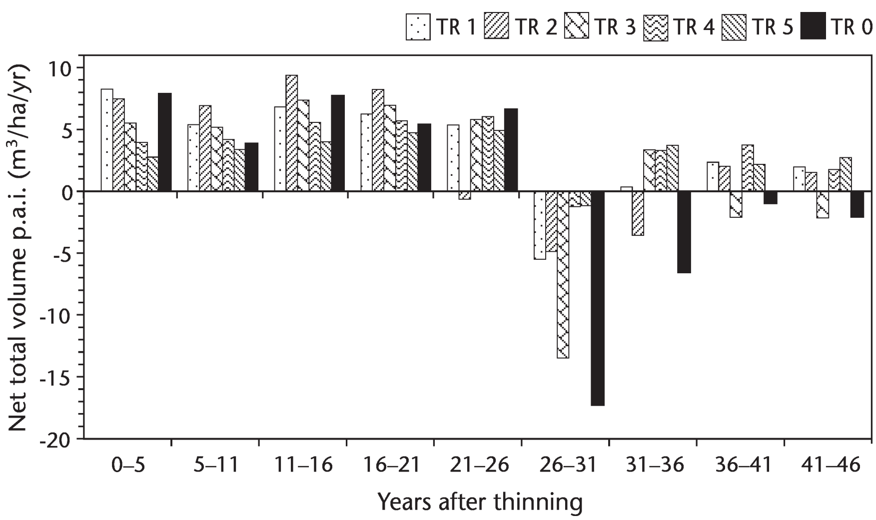
APPENDIX 6 Gross and net total volume periodic annual increment (p.a.i.) following thinning for all species combined



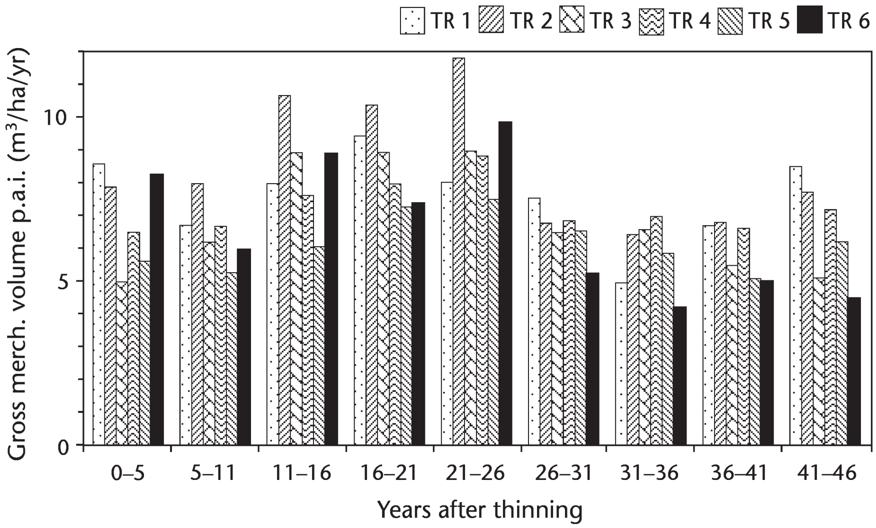


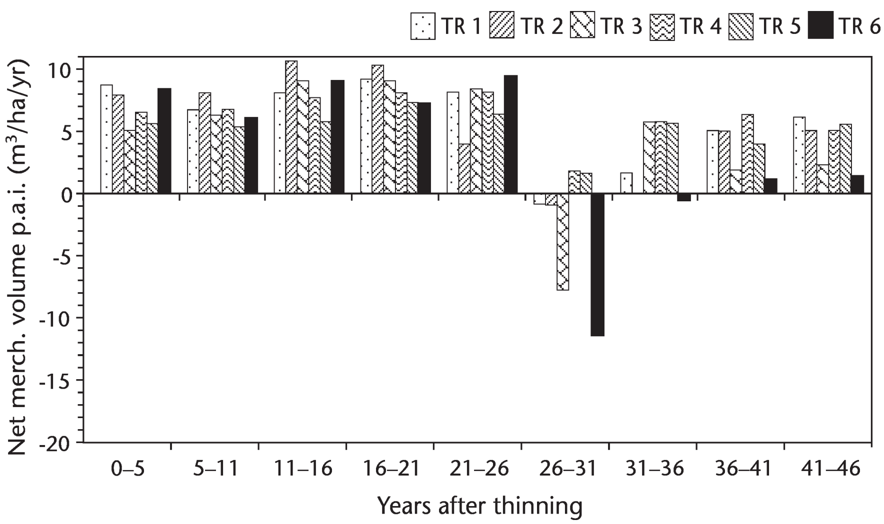
APPENDIX 7 Gross and net total volume periodic annual increment (p.a.i.) following thinning for pine only





APPENDIX 8 Gross and net merchantable volume periodic annual increment (p.a.i.) following thinning for all species combined





APPENDIX 9 Gross and net merchantable volume periodic annual increment (p.a.i.) following thinning for pine only