VALIDATION OF BASAL DIAMETER RATIO COMPETITION INDEX FOR LODGEPOLE PINE-ASPEN

THIRD YEAR POST-TREATMENT FINAL REPORT

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DISCLAIMER

The project/study on which this report is based was funded by the Foothills Model Forest under the Partners in Sustainable Development of Forests initiative delivered by the Canadian Forest Service of Natural Resources Canada and funded by Canada's Green Plan for a Healthy Environment.

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"to develop and recommend an approach to sustainability and integrated resource management through research and technology developed by means of collaborative partnerships".

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ABSTRACT

In 1993, a four-year Foothills Model Forest study was initiated to verify the use of the recently-developed Basal Diameter Ratio Competition Index in stand tending decisions for juvenile lodgepole pine-aspen competition in west-central Alberta. A mixed-nested experiment with three blocks and four levels of aspen removal (treatments) was designed. In 1993, initial vegetation and conifer measurements and aspen removal within 1.8 m of the conifer was completed. These were followed by growth response measurements in 1994, 1995 and 1996. This final report details the analysis of the third year lodgepole pine growth response.

Three years after treatment, there were significant and accelerating differences in radial growth response between treatments. The control plots consistently had the smallest radial growth; best growth was achieved under low levels of aspen competition with the BDR>0.75 removal, followed closely by full removal. Height increments were smallest in the plots that had no aspen removal, although the difference between treatments was not significant. In the first two years following treatment, there had been no noticeable differences in height increment between treatments.

Two years after treatment there was a trend toward higher mortality and mechanical and pest damage in plots where all the aspen have been removed, although the differences were not statistically significant. In the final year of measurement, these differences had almost disappeared.

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INTRODUCTION

Performance expectations for juvenile conifers were incorporated into free-to-grow regeneration standards in Alberta in 1991 and extensive conifer release programs are implemented annually to bring regenerated stands to the provincially targeted standards. Selecting stands for the best response to and economic return from release treatments is difficult because of the high cost of treatment and limited information available on biological efficacy. Current treatment decisions are generally subjective or arbitrary and foresters require quantitative tools to assist in these decisions.

In 1993, the Canadian Forest Service completed a project on lodgepole pine-aspen competition. The objective of this study was to select or develop a competition index for quantifying the level of aspen competition that best predicts lodgepole pine growth. An index was required that would be easy to use in the field and applicable to release decisions. Based on this study, a new competition index, called the Basal Diameter Ratio (BDR) was developed (Navratil and MacIsaac 1993) which is a simplification of Lorimer's (1983) competition index:

$$CI = \frac{\text{tallest aspen basal diameter}}{\text{lodgepole pine basal diameter}}$$

Basal diameter refers to the stem diameter measured just above the root collar. In addition to its simplicity, it was as good or better in predicting pine response than other more complex competition indices, and has the potential to be used in an operational environment. Its potential has received favourable comment from operational foresters when presented at technical sessions, and they are eager to see that it is adopted.

This index was developed for lodgepole pine-aspen regeneration in west-central Alberta, but the study did not include a release response assessment. The pine growth responses must be confirmed by field experiments. This Foothills Model Forest project was undertaken to ensure that this critical step is completed, before the index is used for stand tending decisions.

The purpose of this study was to test the application of the Basal Diameter Ratio (BDR) competition index developed by The Canadian Forest Service in tending decision to increase conifer growth. The goal of this study was to provide concrete data on how effective the BDR competition index is in guiding stand tending decisions in lodgepole pine-aspen blocks in west-central Alberta.

The study was designed to help to answer the following questions:

1. How easy it is to apply the BDR competition index in determining what sections of a block should be targeted for stand tending?

2. At what level of aspen competition control (as quantified by the BDR index), is the best conifer growth achieved?

3. How consistent is the growth improvement in pine with a given level of removal of aspen competition?

A Foothills Model Forest report summarizing the project establishment and first year post treatment results was produced by MacIsaac (1995) followed by a progress report presenting the second year post treatment growth response of lodgepole pine following different levels of aspen removal based on the Basal Diameter Ratio competition index MacIsaac (1996). This is the final report in the series, and details the third year post-treatment lodgepole pine and aspen response. Under the Foothills Model Forest agreement, three years of data collection were scheduled after treatment. While the study is now completed, subsequent measurements are possible as the plots were well marked and mapped and those portions of the blocks used in this study have been exempt from stand tending.

STUDY LOCATION

The study was located within the Weldwood Forest Management Area within the Lower Foothills natural subregion[1]. The Upper Foothills natural subregion was not suitable for this study because in that ecological zone, aspen is often not the major competitor of pine (willows, alder and balsam poplar are most dominant).

Three blocks were chosen for the study, based on field reconnaissance conducted in June and July 1993. These are in the Marlboro Working Circle, Compartment 8, Blocks 404, 378 and 378A, harvested in 1985 and 1986 (Fig 1). Specifically, these blocks met the following criteria; 1) Stand age between 8 and 13 years old (since clearcut). 2) At least 50% pine stocking. 3) At least 50% aspen stocking. 4) Not stand tended. 5) Planted within 3 years of harvest. The chosen blocks had excellent aspen and pine stocking with a minimal of other competitors. Initial field reconnaissance in 1993 indicated that the aspen were 2-3 m tall, and the pine were 0.5-1.0 m tall. All three blocks had been site prepared with a Bräcke scarifier prior to planting.

METHODS

Experimental Design

Four levels of aspen competition were established in 1993 by selectively removing aspen within 1.78 m of the pine trees (corresponding to a plot area of 10 m^2), using the BDR index as a guide. The pine

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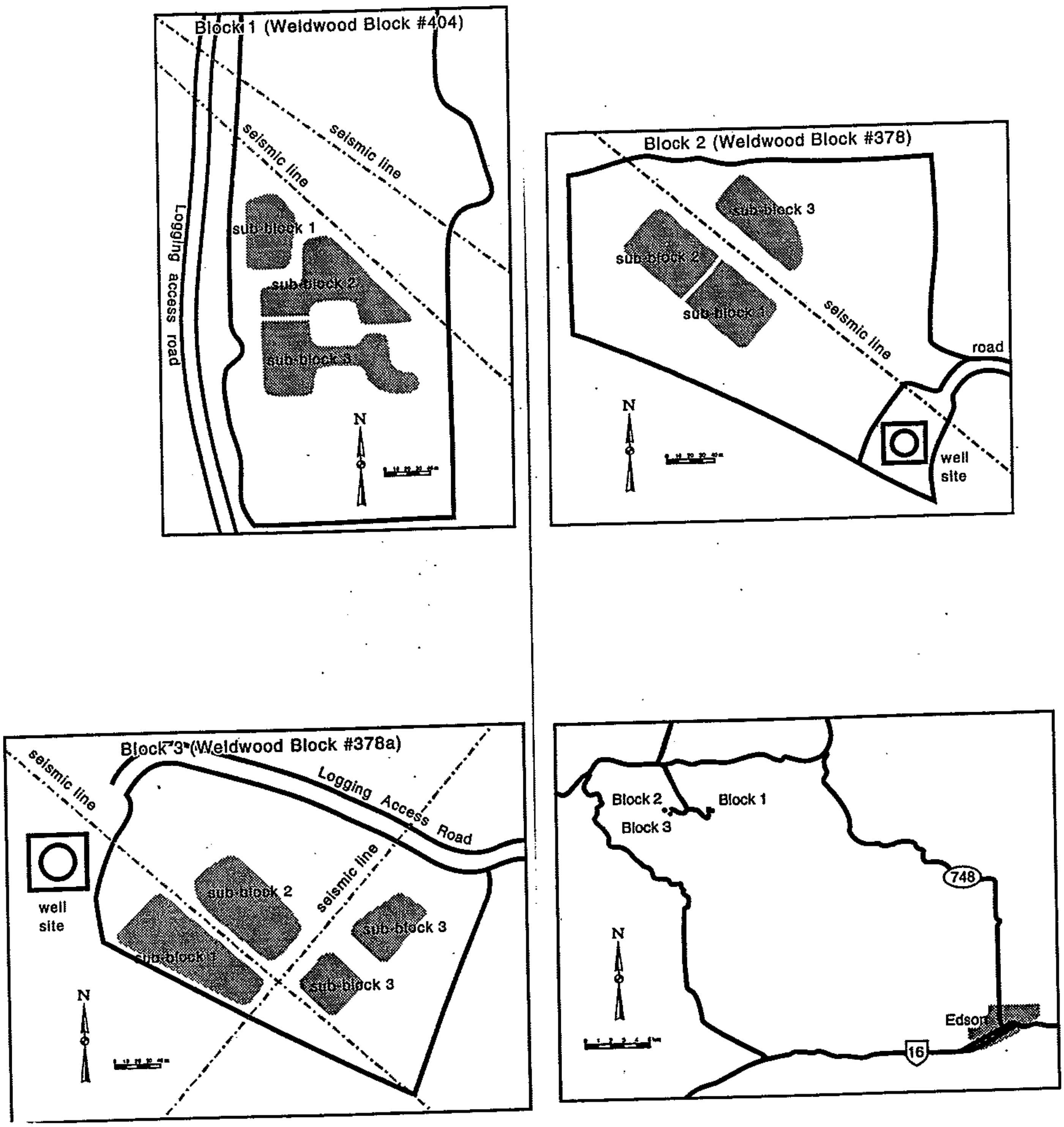
[1] Alberta natural regions from: Alberta. 1994. Natural regions and subregions of Alberta. [natural region map]. Land Information Services Division, Alberta Environmental Protection, Edmonton, Alberta. 1 sheet.

Figure 1

Study Area and Experimental Layout of Blocks and Subblocks



growth response was measured in 1994, 1995 and 1996. A randomized nested design with three blocks was used. Within each block, three well-distributed areas (subblocks) at least 1.0 ha each were sampled (Fig. 1). In each subblock, 40 lodgepole pine-centred plots (1.78m radius) were established. The four treatments (listed below) were randomly assigned to the 40 plots; 10 plots received each treatment in each subblock. Once 10 plots of one treatment type were chosen, no more of that type were used in the subblock. A randomized complete block design, in which each subblock would receive a set treatment for all plots within it was not used, because site conditions within each block were not uniform (a requirement for randomized complete block design). This randomized nested method allowed the interspersion of all four treatments throughout the blocks, thus removing bias.

Plot Selection

Placement of the permanent competition plots was based on a uniform grid within each subblock with a random starting point. Plots were spaced on a 10m by 10m grid. At each point on the grid, the closest lodgepole pine tree was used for the plot centre. If a suitable pine tree with aspen competition was not found within 5 m of the sampling grid, then there was no plot placed at that grid point. The plots had a fixed 1.78 m radius ($10m^2$). Selected saplings were replaced with the next closest pine tree if damage unrelated to competition pressure was noted. A target tree[2] was selected if it had no recent moderate to severe damage due to herbivory, the leader growth was undamaged; had at least 5 internodes (to ensure that recent arrivals not used); was not advanced regeneration; had no major insect damage; and was not subject to significant intraspecific (pine-pine) competition (i.e. no crown overlap with other pines).

There were additional selection criteria, to ensure there was sufficient aspen competition. There was at least one aspen competitor, in at least three of the four quadrants around the pine tree, with a basal diameter equal to or larger than the pine tree (BD Ratio greater than 1). An aspen density criterion was also used, with a minimum of 8 aspen on the plot. Plots were not placed within 10 m of live residual trees. All target trees were selected using the above criteria.

Treatments

Each plot received one of the four treatments listed below.

a) no aspen removal (control plot)
b) removal of all aspen within 1.8 m of the target lodgepole pine tree where the aspen basal diameter was larger than the pine (BD ratio between pine and tallest remaining aspen was less than 1.0).

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[2] In this report, the term "target tree" refers to the specific crop tree of interest in each plot centre.

c) removal of all aspen within 1.8 m of the target lodgepole pine tree where the aspen basal diameter was 75% of the pine diameter or greater (BD ratio between pine and tallest remaining aspen was less than 0.75).

d) removal of all aspen within 1.8 m of the target lodgepole pine tree, regardless of aspen size.

Aspen competition was removed using hand saws, following vegetation measurement in 1993 and was allowed to regenerate in subsequent years.

Field Measurements in 1993

Within the 1.78 m radius plots, competition data was collected in August and September, 1993. This was mostly baseline data collection, made prior to aspen removal (measurements on aspen remaining after treatment were also made, as described below).

Individual tree measurements were collected for the following trees: target lodgepole pine, the tallest conifer in the plot, the conifer in the plot that was closest to the target tree, and the tallest and closest aspen in the plot prior to treatment For the two partial aspen removal treatments, if there was a new closest and/or tallest aspen, they were also measured. Target tree measurements were: crown height, crown radius, total height, root collar diameter, estimated age based on the number of internodes, height increments for the previous five years (including the current year) and percent overtopping of the top one-third of the crown by competing vegetation. As well, any slight damage along with the causal mechanism was noted (trees were not selected for study if the damage was moderate to severe). Measurements for the nearest and tallest conifer and hardwood in the plot included: azimuth from target tree, crown radius, total height, root collar diameter, distance from the target stem-to-inside crown of competitor, distance from the target stem-to-stem of competitor, distance from target stem-to-outside crown of competitor, estimated age based on internode counts and height increments for the previous five and three years, for conifers and hardwoods, respectively (including the current year). Descriptions of the detailed tree measurement variables are in MacIsaac (1995).

Aspen competition within each plot was measured both before and after the treatments in 1993. This included: average height and cover, total density and density by quadrant. Average height and density was also measured for each tree species, all trees combined, shrubs, forbs and grass. Microsite conditions within the plots were measured for the following variables: moisture class, drainage class, microtopography, litter depth, aspect, slope, slope position, and slash abundance.

Post-Treatment Field Measurements in 1994, 1995 and 1996

Within the 1.78 m radius plots, the pine growth response to the treatments and hardwood competition data was collected in August of 1994, 1995 and 1996 after the pine growth had stopped (lammas shoot growth, which is a second period of shoot elongation late in the summer under favourable moisture conditions, was not noted in the study blocks in those two years). Detailed measurements on the target tree and closest conifer and hardwood in the plot were identical as for

1993, except that crown radius was only measured on the target tree. The measurement of closest and tallest conifer and hardwood in the plots was done independently each year. In other words, due to differential growth and mortality of individuals, a tree selected as the closest and/or tallest in one year, might not be the tallest or closest the next year.

Average cover, height and density of hardwood trees was collected in the plots. Aspen density was recorded in two ways: 1. counting all individual shoots 2. lumping any shoots coppiced from a single aspen stem cut in 1993 as one shoot. Aspen density was collected for the whole plot, and for each quadrant. In addition, a few other variables related to the target tree were collected: etiolation, herb crowding, vigour, occurrence and severity of disease, insect or mechanical damage. Density and average height and cover of each tree species in the plot was recorded, but unlike 1993, data on other growth forms and on microsite conditions was not recorded.

Descriptions of the detailed tree measurement variables are the same as for 1993 and are described in MacIsaac (1995).

Analysis Methods

There were three types of analysis used, as follows:

a) General statistical summaries and tests for normality and data transformations.
b) Analysis of covariance to test differences in pine growth response two years after treatment.
c) Multiple means tests to test for pine growth response differences and hardwood competition level differences two years after treatment.

This analysis was performed using the SAS statistical software package (SAS Institute Inc. 1989).

A variety of data transformations were used in an attempt to normalize the data prior to analysis, following the approach outlined in Sabin and Stafford (1990) and Zar (1984). The following transformations were tested: square root, square root of value+0.5, inverse of value+1, and natural log of value+1. The W-test for normality (Shapiro and Wilk 1965) as extended by Royston (1982) for sample sizes less than 2000 was used for all the variables. Tests for normality were performed on subpopulations based on stratification by treatment (n=90), and treatment by block (n=30). For all variables, there were specific transformations which consistently improved the distribution towards normality. Based on the above, the following transformations were used in the analyses: a) pine height increment and radial increment: no transformation b) pine height and root collar diameter: natural logarithm of value+1

For analysis of growth variables after treatment, covariance analysis was used, which included the size of the conifer prior to treatment (i.e., at the end of the 1993 growing season) (Woollons and White 1988). Cumulative two-year growth response was analyzed rather than treating each year's growth independently because the cumulative growth response was the primary variable of interest. Examining total growth response is a more elegant approach. It results in a more robust model,

which is not affected by problems associated with independance of sequential measurements when yearly growth is examined separately. A mixed (fixed and random effects) linear model was developed, as appropriate for the experimental design (Borders and Shiver 1989; Neter et al. 1989; SAS Institute Inc. 1991). The model was:
Growth = tree size prior to treatment+block+subblock(block)+removal+removal*block+error

In this model, subblock was considered to be a random effect. Complete model statistics are presented in this report, following the recommendation of Warren (1986).

Ryan's multiple range test (c.f., Day and Quinn 1989) was used to determine significant differences in three-year post-treatment 1994-96 pine growth response and differences in the hardwood competition levels each year before and after treatment. These tests are preferable to the more commonly used Duncan's multiple range tests (Chew 1976; Jones 1984; Mize and Schultz 1985), for this experimental situation.

In 1993, during block selection and plot layout, some minor damage to regenerating lodgepole pine trees in the area was noted (MacIsaac 1995). Target trees were then selected which had no damage or only minor damage. There was a concern, however, that the damage might become more severe over time. Based on this consideration, a subjective classification of damage severity (none, slight, moderate, severe) and the damaging agent or physical sign of damage was recorded for each target tree. Damage to trees was classified into two groups: 1) Causes and signs of damage that were known or inferred to be related to insect and disease. This included root rot (*Armillaria* sp.), needle cast, chlorosis, western gall rust (*Endocronartium harknessii*), pitch blister moth *Petrova albicapitana*, stalactiform blister rust (*Cronartium* sp.) and resinosis. 2) Damage that was known or inferred to be related to mechanical damage or browse. This included: broken/damaged leader, broken/damaged branches, damaged base/stem (girdling), damaged roots, direct evidence of browsing, double top, damaged stem or forked stem.

Non-parametric analysis was done to test whether there was a relationship between target tree damage and removal of aspen (treatment). The Kruskal-Wallis rank-sum test was used to determine if there was a difference in the target tree damage between treatments, based on an average level of damage per tree in each plot. The following rank-sum tests were performed to determine the following:

1. If the aspen removal (treatment) had an effect on the level of occurrence (for any severity level) of insect and disease damage for target pine trees.
2. If the aspen removal (treatment) had an effect on the level of occurrence (for any severity level) of physical damage for target pine trees.
3. If the aspen removal (treatment) had an effect on the severity of damage (insect, disease and physical damage combined) for target pine trees.
4. If the aspen removal (treatment) had an effect on the mortality rate (all causes combined) for target pine trees.

RESULTS AND DISCUSSION

Vegetation Competition Levels Before and After Treatment in 1993

The regenerating blocks chosen for this study had been planted to lodgepole pine. Aspen was the major competitor, with much lower amounts of shrub, forb and grass competition. Prior to treatment, the 2-3 m tall aspen was moderately-dense (ranging from 21 to 32 thousand stems/ ha), with an average cover of 38-50%. The planted lodgepole pine was one-third to one-half the aspen height (82-138 cm). The grass competition, which was primarily bluejoint (*Calamagrostis canadensis*) with lesser amounts of wild hairy rye (*Elymus innovatus*), was moderate to light, with cover ranging from 9 to 16%. The shrub strata was low, with the majority of cover below 50 cm. In terms of cover, density and height, balsam fir was the second most dominant conifer species, after pine. As well, the blocks had minor amounts of white spruce and paper birch.

Analysis of variance of aspen density, height and cover for blocks and subblocks indicated that the aspen competition was not uniform throughout the blocks prior to treatment. For density and height, aspen had more within-block variability than between-block variability. Least squares means tests showed significantly greater density (31,800 stems/ha) in block 3 compared to the other two blocks ($P < 0.05$). This was due to a high density in block 3, subblock 3 of 43,400 stems/ha, which was almost double the density for most of the other subblocks. For aspen cover, block 2 had significantly less cover than blocks 1 and 3, but the differences were not as large as for aspen density. Aspen height differences between blocks was less pronounced than for the other two aspen variables, although block 1 did have significantly taller aspen (263 cm) than blocks 2 and 3. Overall, in terms of aspen competition, the only "outlier" was for aspen density in block 3, subblock 3. These analyzed differences in aspen competition within blocks supported the decision to mix all four treatments within each of the subblocks. When all blocks were combined, there were no significant differences in aspen density before treatment, averaging around 25,000 stems/ha.

When mean values were generated based on treatment type (with plots of each treatment evenly distributed throughout each subblock), there were only small differences in pre-treatment aspen competition levels. Removal of aspen based on the BDR of 1.0 (i.e., all aspen with a root collar diameter greater than that of pine), resulted in a 47-66% decrease within blocks in aspen density, and 50-66% decrease in average aspen height within blocks. For aspen cover, the post-treatmentdecrease within blocks was more pronounced (87-92%), because the removal took out the larger trees. Using a more stringent BDR of 0.75 as a guide did not result in an appreciably greater removal of aspen. This is because, on average, the dominant aspen competitors would have a greater root collar diameter than the pine, due to faster growth rates of aspen as compared to pine in regenerating stands (and so for a given plot, using a BDR of 1.0 would achieve similar post-treatment levels of aspen as would thinning based on a BDR of 0.75). Using a more stringent removal criteria of 0.75 would result in a large number of smaller stems to be removed, which would not influence the average remaining competition very much.

An analysis of variance was performed on the average aspen competition after removal, to quantify the amount of variation within and between treatments and blocks. As expected, removal (treatment) had a very significant effect on aspen density, height and cover (Figs. 2 to 4). This was mostly due to the effect of the two extreme treatments (all removal versus no removal). Least squares means tests indicated, that, in most blocks, there were no significant difference in the remaining level of aspen for the two intermediate treatments.

Aspen Competition Levels Three Years After Treatment

Figures 2-4 provide a graphical summary of aspen density, average aspen height and average aspen cover before and after treatment. Aspen density counts which include coppiced stems showed significant regeneration in the first year after removal, with densities approaching the pre-harvest levels, especially for the plots with all aspen removed (Fig.2). However, by the third year, densities in all three treatments had fallen significantly below that of the control plots. In all three aspen removal treatments, aspen densities had declined consistently each year compared to the year before, whereas, in the control plots, post-treatment aspen regeneration had caused a slight increase in aspen density to approximately 20,000 stems/ha.

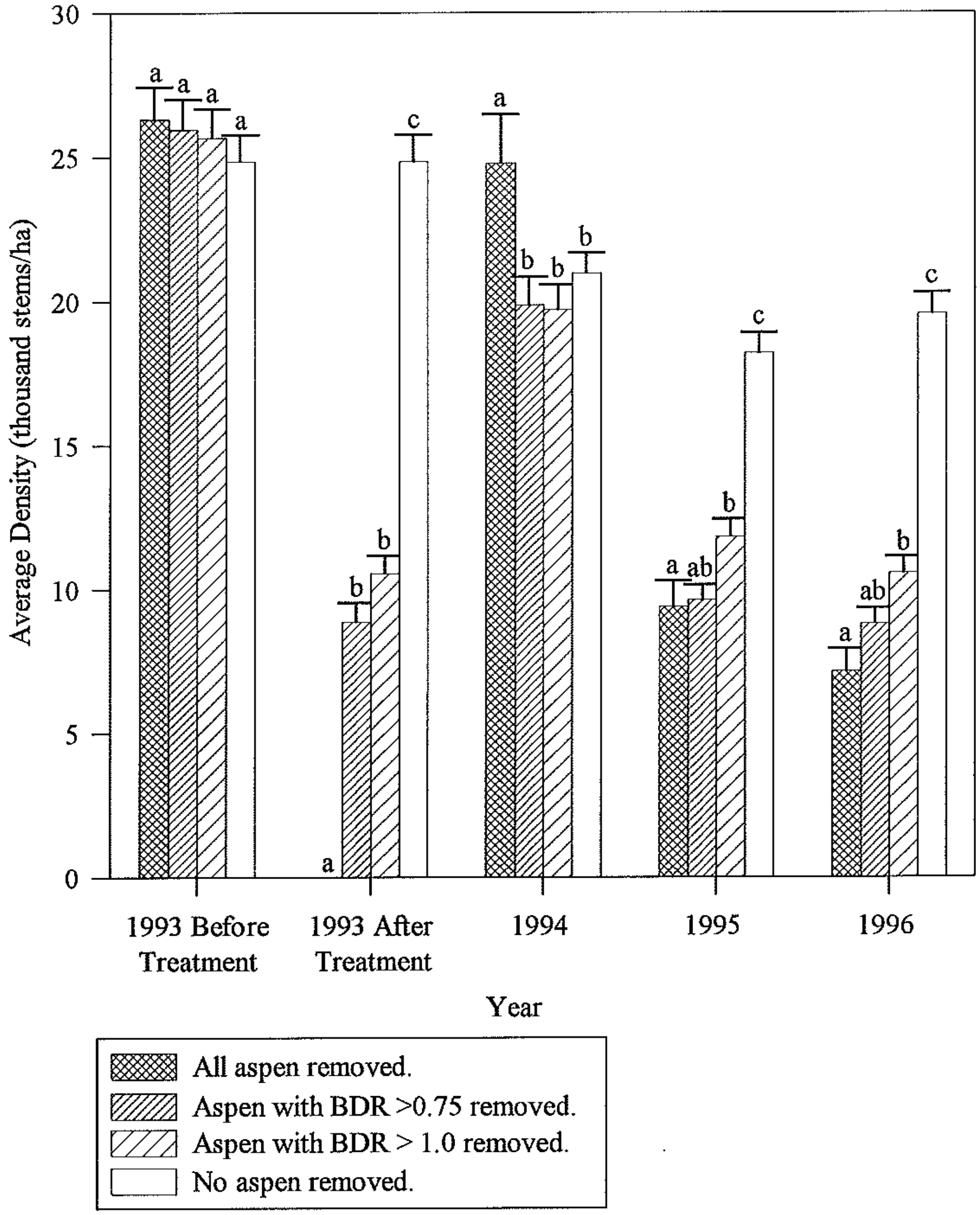
In contrast to density, after an initial steep decline the year after treatment, average aspen height increased slightly each year from 1994 through 1996, although average height remained well below the levels recorded in1993 before treatments (Fig. 3). Cover was the most strongly reduced attribute of aspen competition, declining from near 50% in all plots prior to treatment to less than 10% in all years following treatment (Fig. 4). Cover increased slightly in 1994 compared to 1993, and then stayed at constant levels in the following two years.

Pine Growth Response Three Years After Treatment

The post-treatment analysis is presented using three complementary techniques: 1. covariance analysis, 2. Graphical representation of the growth trajectories, and 3. multiple means tests. Because of the effect of the conifer tree size prior to treatment, analysis of covariance was required when analyzing the third year growth response to treatment.

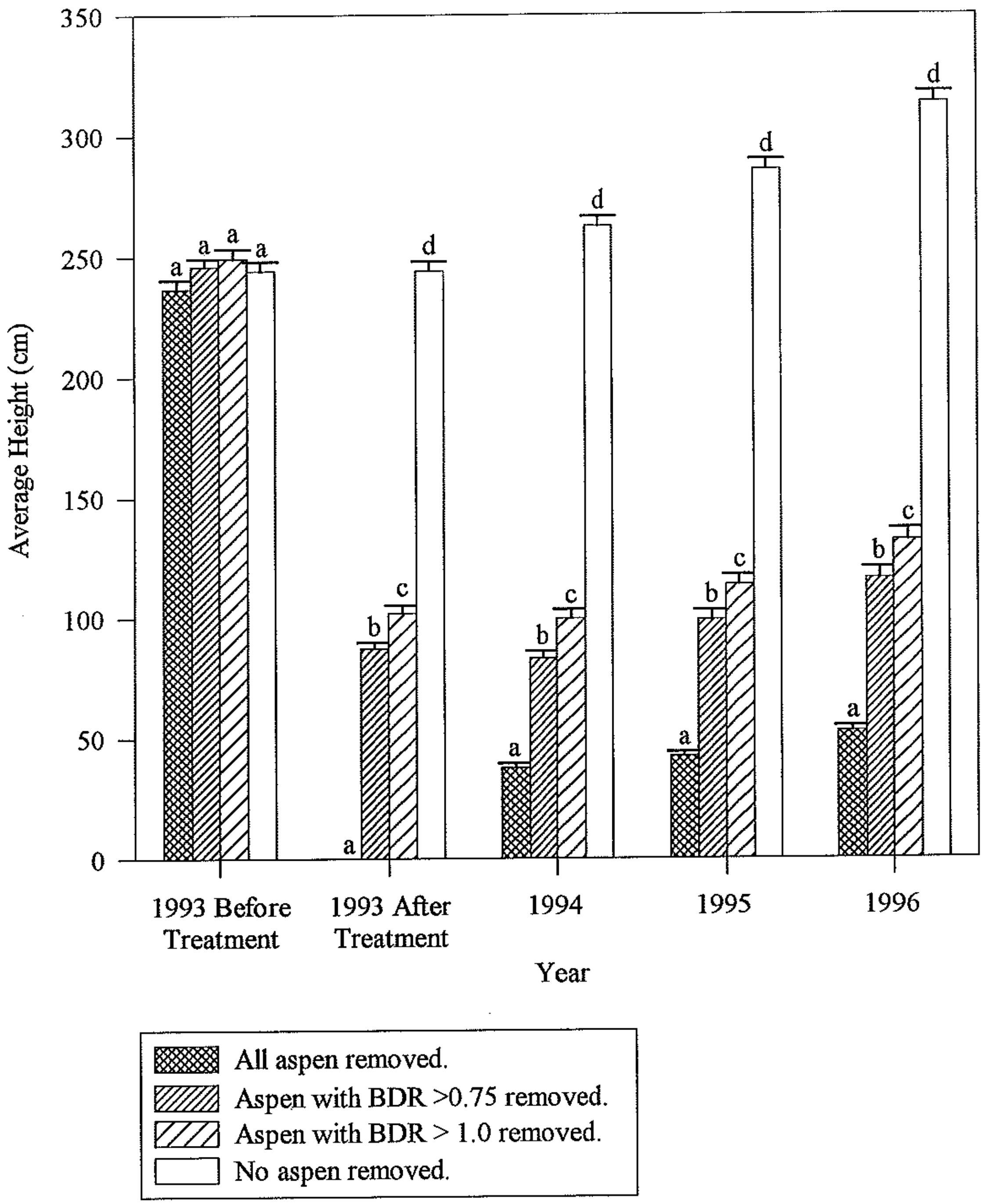
The results of analysis of covariance, which controlled for differences in the initial size of the pine, are presented in Table 1. As expected, the covariant (pre-treatment pine size) had a significant effect on all growth variables ($P < 0.0001$). For 1996 height and cumulative 1994-96 height increment, there were no treatment effects in the overall model ($P > 0.05$), although differences between blocks was significant ($P = 0.0006$ for 1996 height and $P = 0.0121$ for cumulative 1994-96 height increment). In contrast to the overall model, least squares means tests did indicate significant differences between treatments for the 1996 pine height for Block 2 and all blocks combined. For block 2, the intermediate treatment where plots with aspen greater than a BDR of 0.75 was removed had significantly larger total height ($P < 0.05$) and the treatment where plots with aspen greater than a BDR

Figure 2
Aspen Density Before and After Treatment - For All Blocks Combined



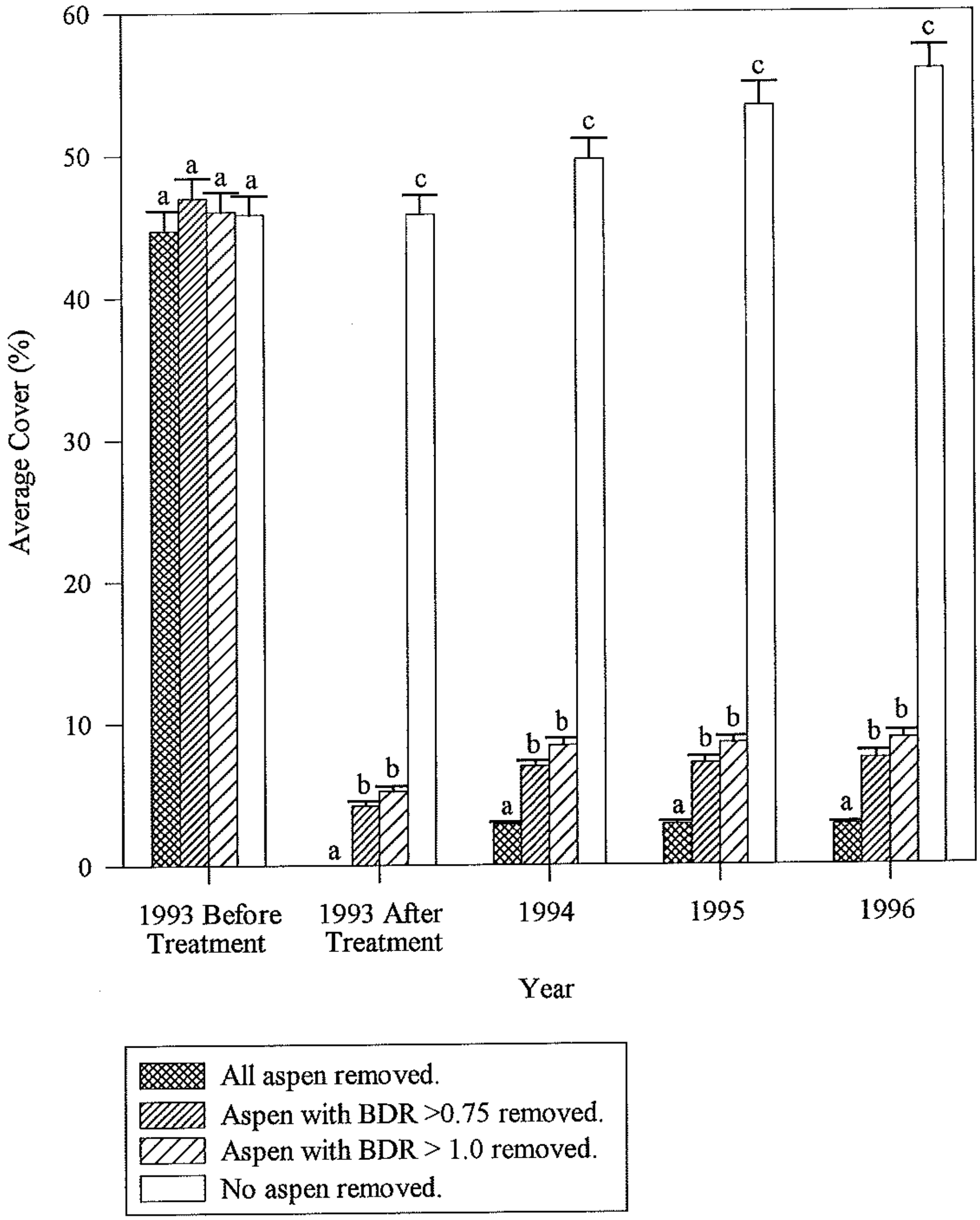
Analysis based on all blocks combined (n= approx. 90 - 1.78 m radius plots for each treatment).
Standard error of the mean shown (upper limit only).
Similar letters for the same year indicate means not significantly different, at P=0.05 using Ryan et al's Multiple Range Test (SAS Institute Inc. 1990).

Figure 3
Aspen Height Before and After Treatment - For All Blocks Combined



Analysis based on all blocks combined (n= approx. 90 - 1.78 m radius plots for each treatment).
Standard error of the mean shown (upper limit only).
Similar letters for the same year indicate means not significantly different, at P=0.05 using Ryan et al's Multiple Range Test (SAS Institute Inc. 1990).

Figure 4
Aspen Cover Before and After Treatment - All Blocks Combined



Analysis based on all blocks combined (n= approx. 90 - 1.78 m radius plots for each treatment).
Standard error of the mean shown (upper limit only).
Similar letters for the same year indicate means not significantly different, at P=0.05 using Ryan et al's Multiple Range Test (SAS Institute Inc. 1990).

Table 1

Analysis of Covariance of Lodgepole Pine Growth in 1996
Using Pretreatment Size as a Covariant

1996 Height[1]

Source	DF	Mean Sq.	F Value	Pr > F
1993 Height[12]	1	20.59	1484	0.0001
Block[2]	2	0.11	12.5866	0.0006
Subblock (Block)[3]	6	0.01	0.3716	0.8967
Removal	3	0.04	2.0802	0.1029
Block * Removal	6	0.01	0.6346	0.7025
Error	302	0.02	-	-

Least Squares Means[4] (Values are means (cm) ± standard error of the mean)

Removal	All	0.75	1.00	None
Block 1	245.31 ±10.12a	254.48 ±14.38a	263.15 ±12.46a	235.92 ±12.73a
Block 2	188.36 6.48ab	202.31 8.63a	168.21 8.18b	178.28 9.51ab
Block 3	183.50 9.38a	196.92 7.61a	183.93 8.08a	184.93 8.34a
All Blocks Combined	205.85 5.88ab	218.37 6.80a	203.49 7.16ab	197.50 6.38b

Cumulative 1994-1996 Height Increment[1]

Source	DF	Mean Sq.	F Value	Pr > F
1993 Height[12]	1	65902.07	101.0062	0.0001
Block[2]	2	4733.22	7.4168	0.0121
Subblock (Block)[3]	6	631.66	0.9471	0.4615
Removal	3	934.44	1.4010	0.2426
Block * Removal	6	208.35	0.3124	0.9303
Error	301	666.97	-	-

Least Squares Means[4] (Values are means (cm) ± standard error of the mean)

Removal	All	0.75	1.00	None
Block 1	104.69 ±7.16a	112.33 ±5.60a	111.42 ±5.85a	102.63 ±7.17a
Block 2	100.25 4.12a	107.54 5.49a	89.03 5.88a	93.17 6.08a
Block 3	94.13 5.09a	103.96 5.53a	99.12 4.57a	95.59 5.40a
All Blocks Combined	99.85 3.21a	108.00 3.18a	99.46 3.30a	96.79 3.54a

1. Analysis performed with natural log (value+1) transformation for height and RCD; sqrt(value) transformation for radial increment; and no transformation for height increment.
2. Tests of hypotheses use the Type I MS for Subblock(Block) as an error term.
3. Subblock is designated as a random effect.
4. Means in each row followed by the same letter do not differ significantly ($P \geq 0.05$) in least squares means test.

Table 1 (concluded)

1996 Root Collar Diameter[1]

Source	DF	Mean Sq.	F Value	Pr > F
1993 RCD[12]	1	16.20	552.481	0.0001
Block[2]	2	0.02	0.6546	0.5486
Subblock (Block)[3]	6	0.03	1.1660	0.3244
Removal	3	0.65	22.9065	0.0001
Block * Removal	6	0.01	0.4669	0.8326
Error	301	0.03		

Least Squares Means[4] (Values are means (mm) ± standard error of the mean)

Removal	All	0.75	1.00	None
Block 1	40.77 ±1.84a	42.63 ±2.33a	42.65 ±1.87a	35.92 ±2.12b
Block 2	38.57 1.60a	37.62 1.73a	31.00 1.41a	30.45 1.71b
Block 3	33.38 1.78a	37.42 2.90a	32.67 1.69a	28.76 1.42b
All Blocks Combined	37.71 1.05a	39.27 1.38a	35.24 1.10a	31.45 1.04b

Cumulative 1994-1996 Radial Increment[1]

Source	DF	Mean Sq.	F Value	Pr > F
1993 RCD[12]	1	8.12	32.30	0.0001
Block[2]	2	0.31	1.2370	0.3452
Subblock (Block)[3]	6	0.25	1.0026	0.4237
Removal	3	5.69	22.63	0.0001
Block * Removal	6	0.09	0.3598	0.9039
Error	301	0.25		

Least Squares Means[4] (Values are means (mm) ± standard error of the mean)

Removal	All	0.75	1.00	None
Block 1	9.02 ±0.65a	9.07 ±0.48a	9.19 ±0.57a	6.44 ±0.47b
Block 2	9.32 0.62a	9.65 0.47a	7.88 0.48a	5.98 0.53b
Block 3	8.42 0.49a	9.96 1.50a	8.24 0.42a	6.07 0.42b
All Blocks Combined	8.94 0.34a	9.56 0.54a	8.41 0.29a	6.15 0.28b

1. Analysis performed with natural log (value+1) transformation for height and RCD; sqrt(value) transformation for radial increment; and no transformation for height increment.
2. Tests of hypotheses use the Type I MS for Subblock(Block) as an error term.
3. Subblock is designated as a random effect.
4. Means in each row followed by the same letter do not differ significantly (P≥0.05) in least squares means test.

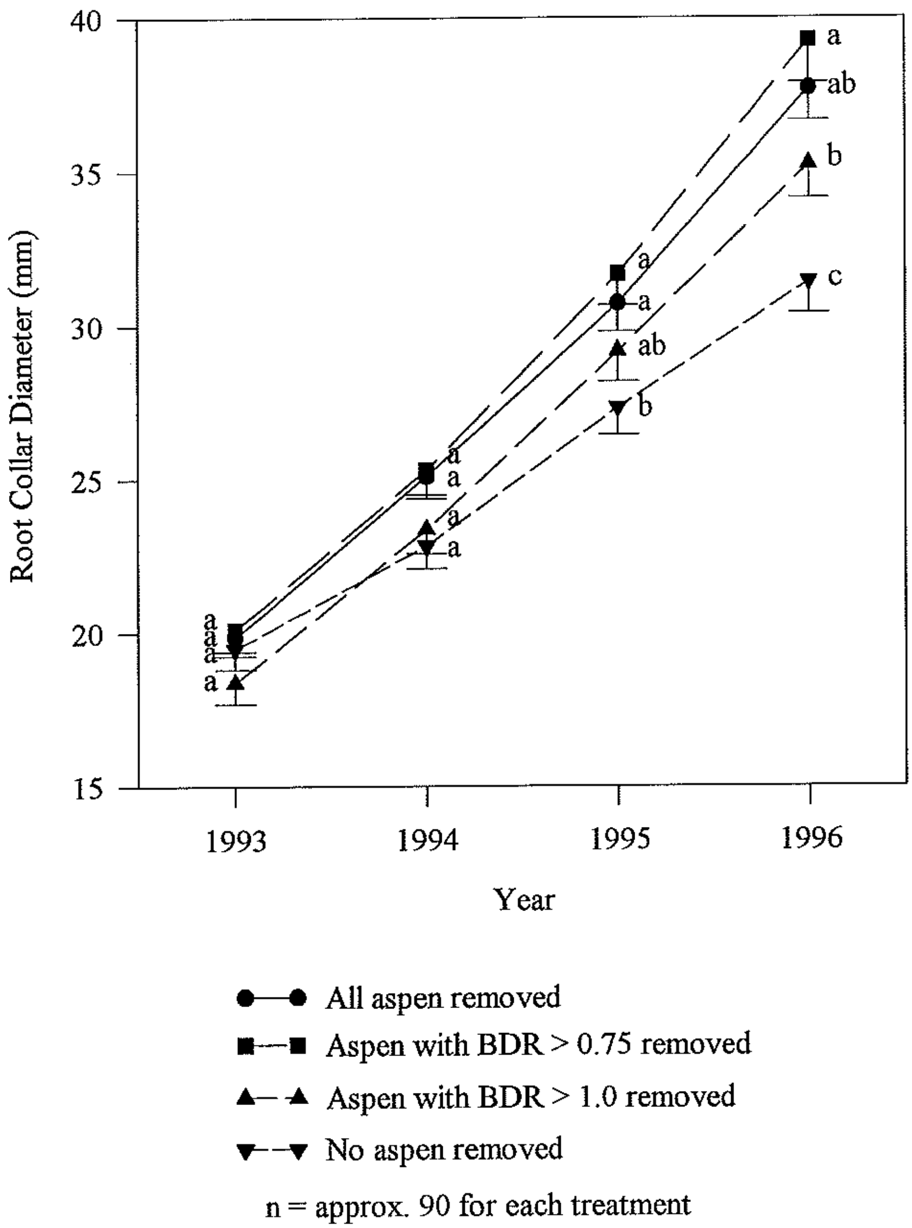
of 1.0 was removed had significantly smaller height growth ($P<0.05$). For all blocks combined, the treatment where plots with aspen greater than a BDR of 0.75 was removed had significantly larger total height ($P<0.05$) and the control with no removal had significantly smaller height growth ($P<0.05$). The least squares means test did not indicate any significant differences between treatments for cumulative 1994-96 pine height for any of the blocks.

For pine 1996 root collar diameter and cumulative 1994-96 radial increment, there were significant removal effects ($P<0.0001$) (Table 1). The least squares means tests indicate that the significant differences were consistently due to lower growth response for the control (no removal) compared to the other treatments ($P<0.05$). There were no differences in growth response from the intermediate removals based on BDR values of 1.0 and 0.75 as well as total removal of all aspen within 1.78 m of the target tree. This was corroborated by the results of Ryan's Multiple means tests (results not shown). For increment in root collar diameter, in all three blocks, the average rate of radial growth was least for the treatment where no aspen was removed.

Figures 5 to 8 present a graphical perspective of the three year post-treatment growth response for pine root collar diameter. The trends which were evident in the first year post-treatment response (MacIsaac 1995) and second year post-treatment response (MacIsaac 1996) continued and accelerated during the third year of post-treatment growth. Consistently, in 1996 for all blocks combined, and each block separately, the smallest root collar diameter growth was in the control plots with no aspen removal. For all blocks combined and in blocks 2 and 3, this difference was significant ($P<0.05$). The best root collar diameter growth was in plots where there was a low level of aspen retained (aspen with BDR > 0.75 removed), although the differences with the other treatments was not significant in most blocks. The level of aspen associated with this treatment was quite modest: three years after treatment, the average aspen height was only half that of the pine (116 cm vs 218 cm), with an associated aspen cover of only 7.5%. This can hardly be considered high aspen competition. The critical factor is whether the remaining aspen will eventually overtop the pine. Trends indicate that the regenerated aspen within the treatment plot will not, however aspen outside the plot will overtop the target trees over time.

Pine height growth has not responded significantly to the different levels of aspen removal three years after treatment, except for block 2. In that case, pine height in 1996 was greater in plots where aspen with BDR> 0.75 was removed). Pine in this treatment were significantly taller in 1996 compared to trees from plots where the aspen with BDR> 1.0 was removed ($P<0.05$). In general, the relative performance after three years was mostly a function of the differences in average size prior to treatments (Figs.9-12). The height growth curves had not diverged in the first two years after treatment and were not significantly different after three years. These results clearly indicate the effect of initial pine size on the short term average growth response of pine height growing under post-treatment conditions. There was, however, a decrease in the rate of height growth in the third year after treatment for aspen growing in the control plots compared to the other treatments. This trend, while not statistically significant, was consistent in each of the three blocks and in all blocks combined (Figs.9-12).

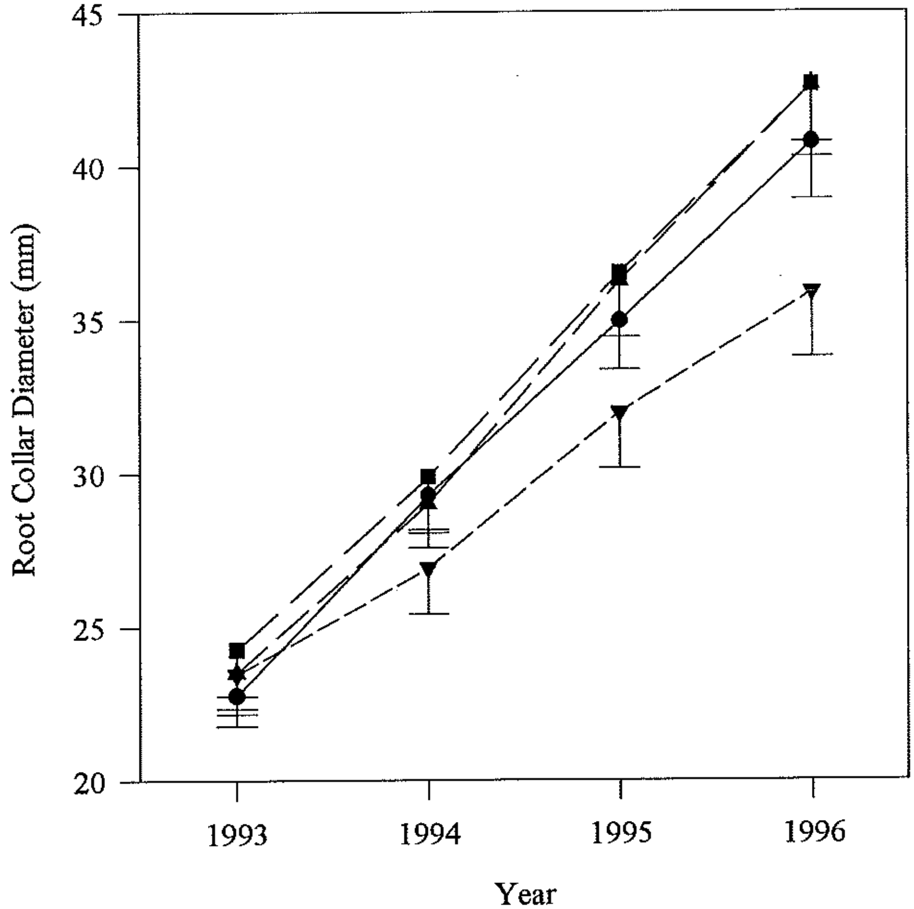
Figure 5
Lodgepole Pine Root Collar Diameter Growth for All Blocks Combined - By Treatment



Standard error of the mean shown (lower interval only).
Similar letters for the same year indicate means not significantly different, at P=0.05 using Ryan et al's Multiple Range Test.

Figure 6

Lodgepole Pine Root Collar Diameter Growth for Block 1 - By Treatment



●—● All aspen removed

■—■ Aspen with BDR > 0.75 removed

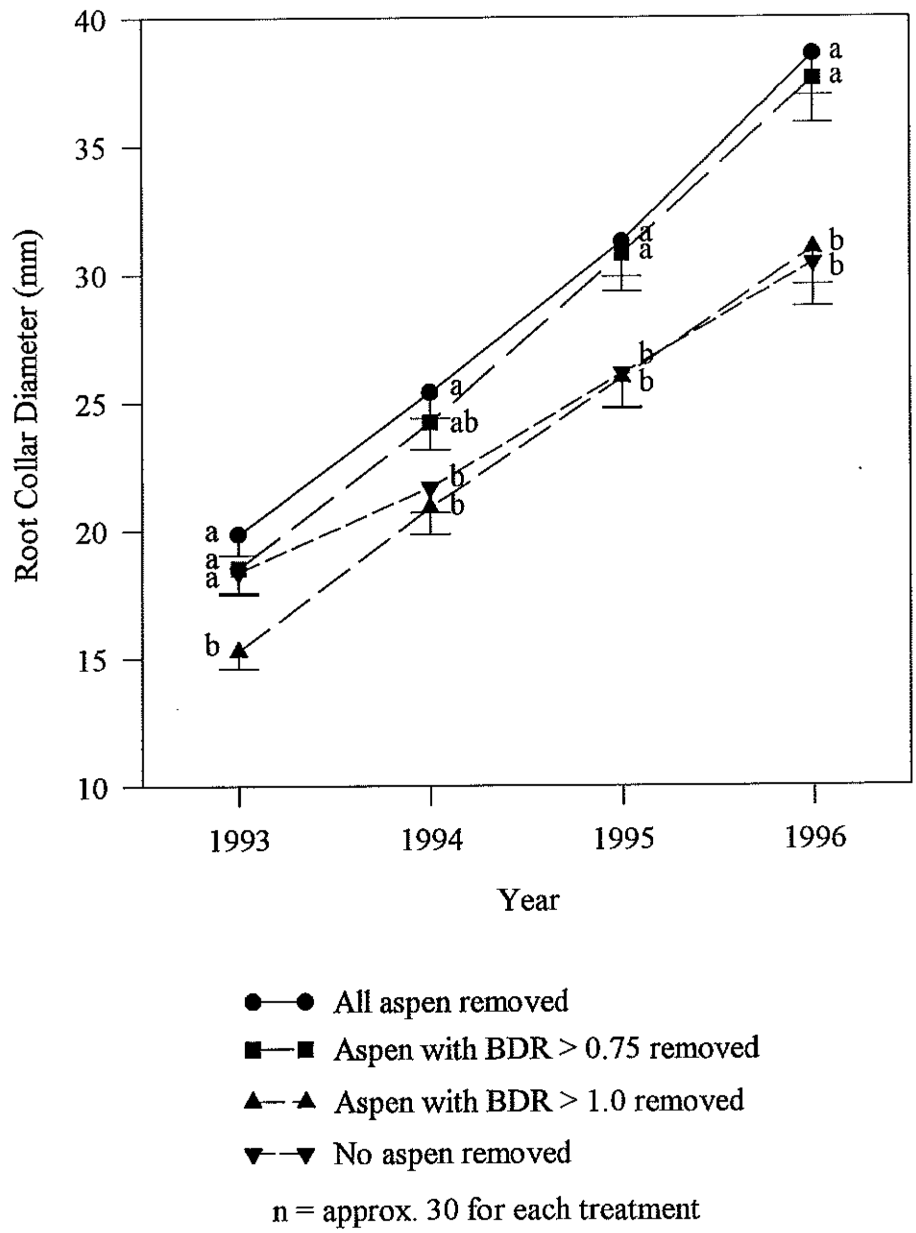
▲- -▲ Aspen with BDR > 1.0 removed

▼- -▼ No aspen removed

n = approx. 30 for each treatment

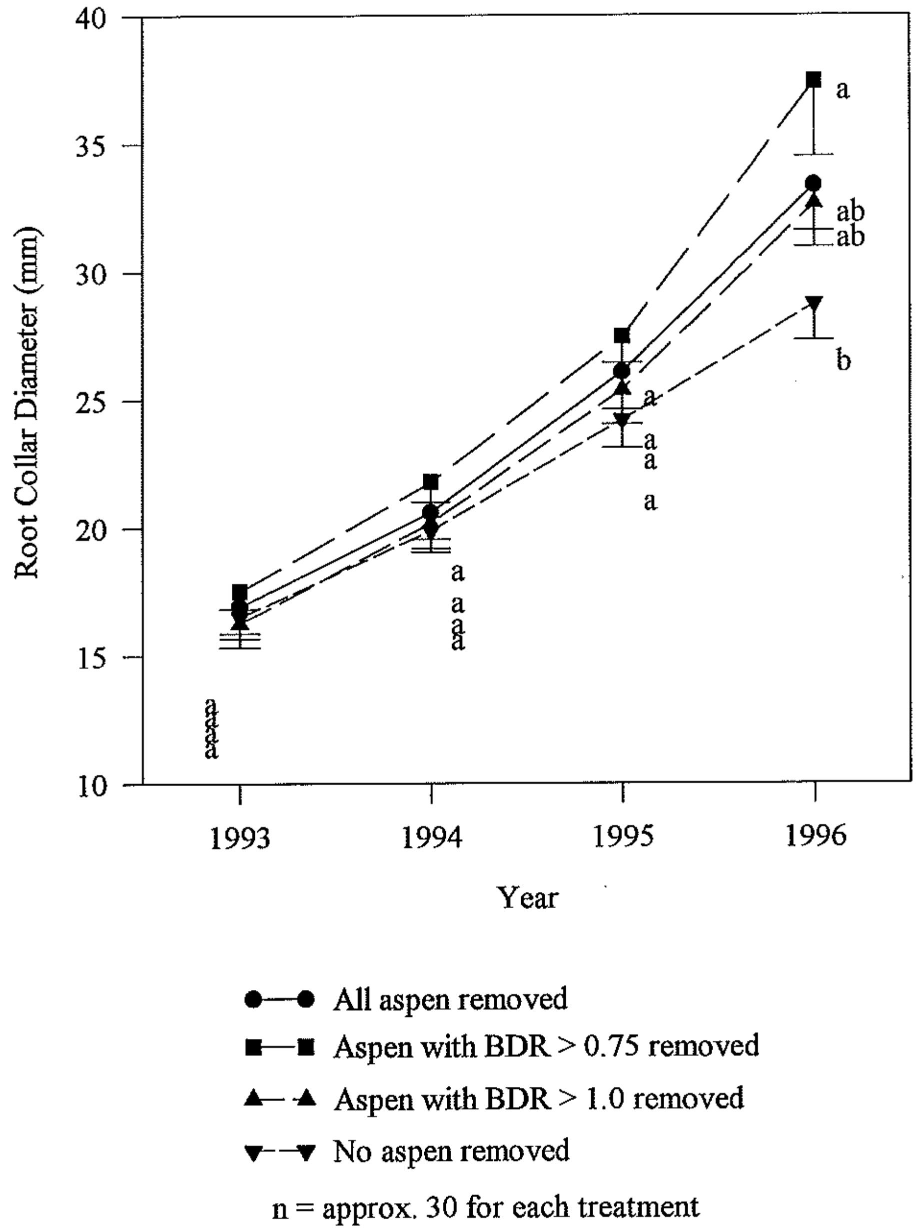
Standard error of the mean shown (lower interval only).
Means not significantly different for removal type in all years shown,
at P=0.05 using Ryan et al's Multiple Range Test (SAS Institute Inc.1990).

Figure 7
Lodgepole Pine Root Collar Diameter Growth for Block 2 - By Treatment



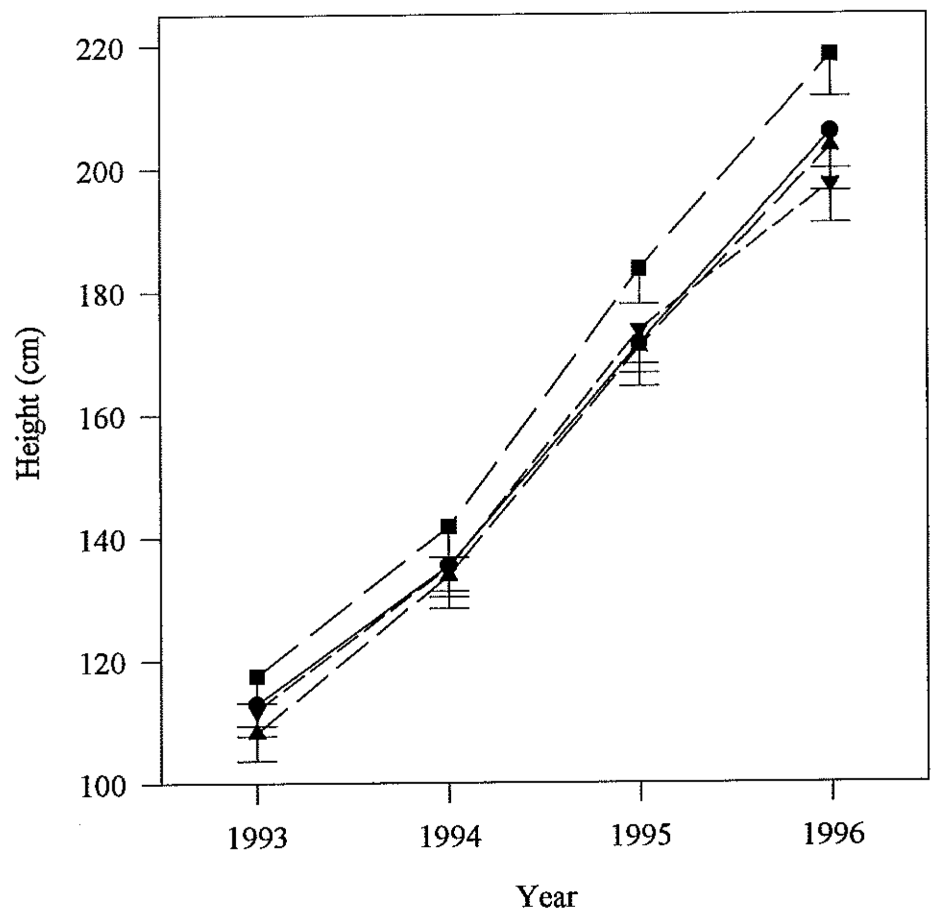
Standard error of the mean shown (lower interval only).
Similar letters for the same year indicate means not significantly different, at P=0.05 using Ryan et al's Multiple Range Test.

Figure 8
Lodgepole Pine Root Collar Diameter Growth for Block 3 - By Treatment



Standard error of the mean shown (lower interval only).
Similar letters for the same year indicate means not significantly different, at P=0.05 using Ryan et al's Multiple Range Test (SAS Institute Inc.1990).

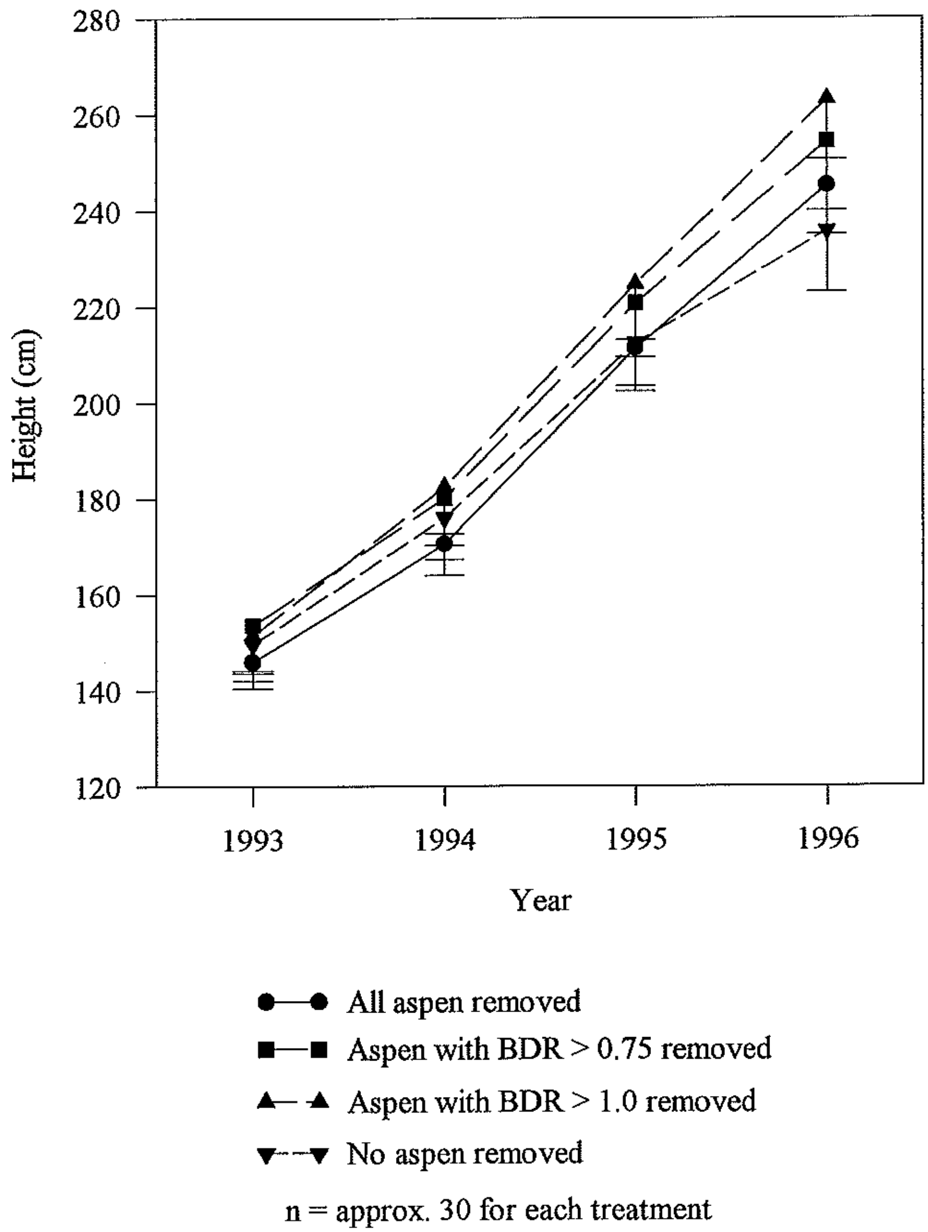
Figure 9
Lodgepole Pine Height Growth for All Blocks Combined - By Treatment



●—● All aspen removed
■—■ Aspen with BDR > 0.75 removed
▲- -▲ Aspen with BDR > 1.0 removed
▼—▼ No aspen removed
n = approx. 90 for each treatment

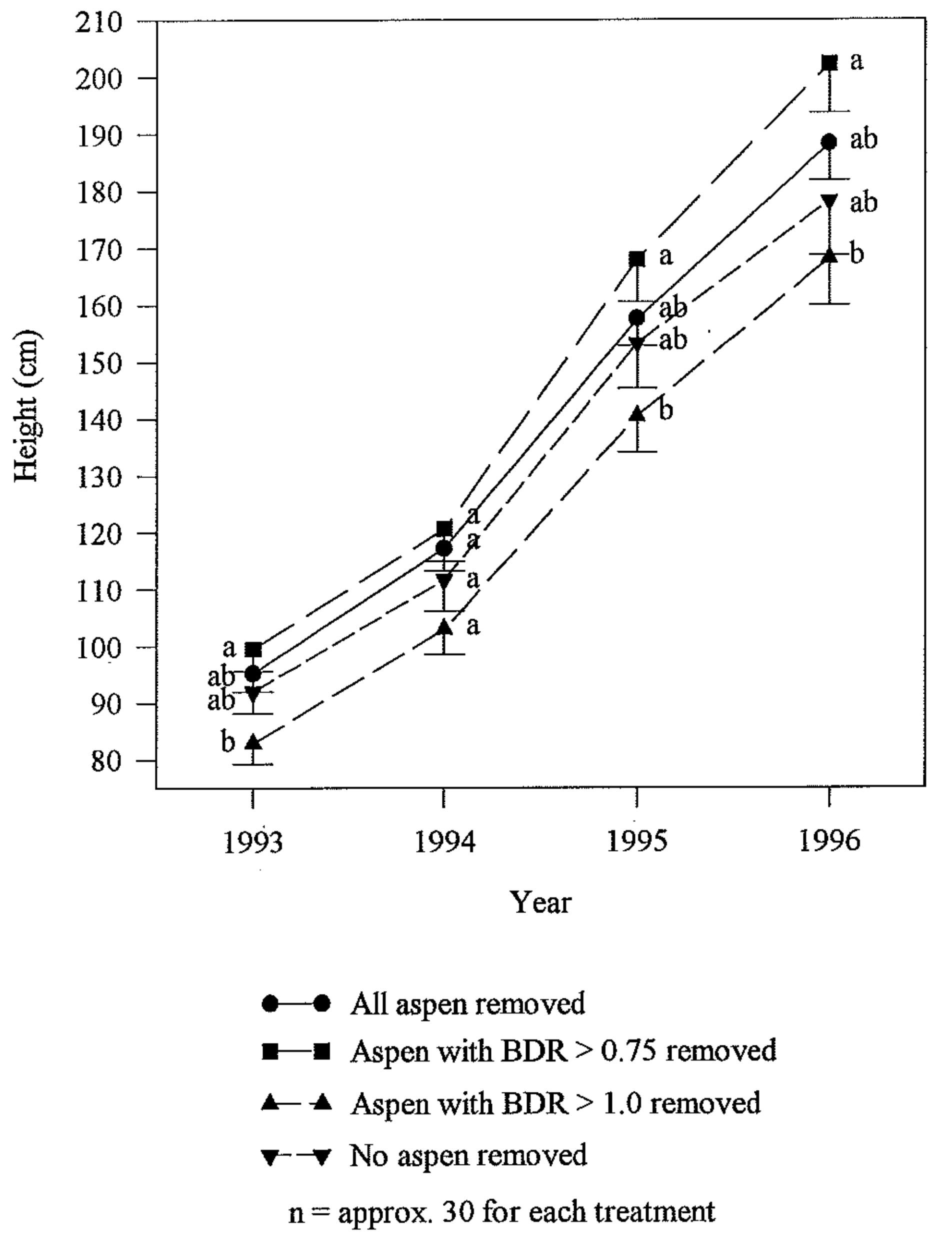
Standard error of the mean shown (lower interval only).
Means not significantly different for removal type in all years shown, at P=0.05 using Ryan et al's Multiple Range Test (SAS Institute Inc.1990).

Figure 10
Lodgepole Pine Height Growth for Block 1 - By Treatment



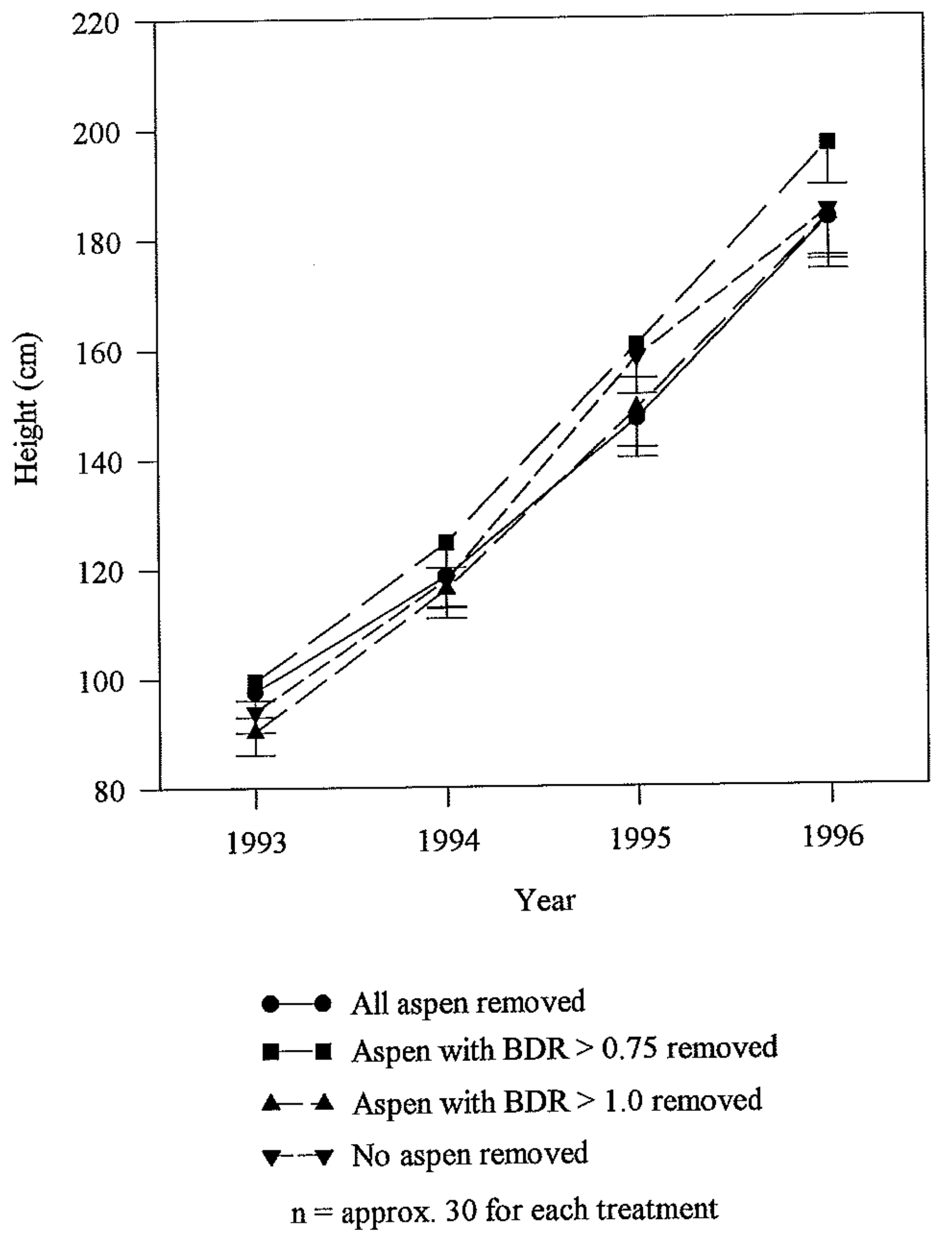
Standard error of the mean shown (lower interval only).
Means not significantly different for removal type in all years shown, at P=0.05 using Ryan et al's Multiple Range Test (SAS Institute Inc.1990).

Figure 11
Lodgepole Pine Height Growth for Block 2 - By Treatment



Standard error of the mean shown (lower interval only).
Similar letters for the same year indicate means not significantly different, at P=0.05 using Ryan et al's Multiple Range Test.

Figure 12
Lodgepole Pine Height Growth for Block 3 - By Treatment



Standard error of the mean shown (lower interval only).
Means not significantly different for removal type in all years shown, at P=0.05 using Ryan et al's Multiple Range Test (SAS Institute Inc.1990).

The results for radial growth clearly indicate that the divergent growth trajectories that were initiated in the first year after treatment have become more pronounced after the third year. For example, Figure 5 and 6 show there was divergence in average root collar diameter for trees growing under no aspen removal, compared to the other treatments. The fact that radial increment showed an increasing treatment response after three years year while height increment had not is consistent with findings from other studies on aspen-pine competition. Navratil and MacIsaac (1993) indicate that released pine respond with increased radial growth prior to any observed increase in height growth. Juvenile spacing trials in the region show that spacing improves diameter growth on all sites types, but that height growth is enhanced only on poor to medium sites (Johnstone 1981, Yang 1991). These Marlboro sites are similar to other locations in the region that would be considered to be of good site quality (Duffy 1964). As the pines respond to release, carbon allocation would be directed to roots and radial growth before height growth.

It is also intuitive that the differences in growth response would be significant when comparing the controls against the aspen removal treatments, as the three aspen removal treatments have resulted in aspen abundances that are much more alike then the controls. It will probably take more time for growth responses to become noticeable with the intermediate treatments. The lack of differences in growth response between the two intermediate treatments may also be because, in some cases, there was not a significant difference in the remaining aspen competition between the two intermediate treatments.

Mortality and Damage to the Target Lodgepole Pine

The amount, severity and type of damage to target lodgepole pine trees is summarized in Table 2. Sixty-six percent of all target trees in the three blocks combined did not show any signs of damage or disease. In damaged trees, *Armillaria* root rot fungus was noted as one of the major causes of damage (11.7% of the total target trees). Between the 1993 and 1994 field seasons, 11 target trees died. From 1994 to 1995 an additional 25 target trees died, and from 1995 to 1996 a further 20 target trees died for a cumulative mortality of 15.5% in three years. Most of the mortality and severe damage was due to *Armillaria* root rot, with lesser amounts due to western gall rust and physical damage (Table 2). This mortality rate was approximately five times greater than the average for lodgepole pine growing on medium to high productivity sites in the area (Ives and Rentz 1993).

There is a concern that this mortality could increase substantially over time. While the major *Armillaria* food source was probably stumps from the preharvested stand, the aspen cut in 1993 could exacerbate this trend, through the inclusion of dead aspen stumps and stems as an additional food source for the fungus (Dr. Ken Mallet, pers. comm). Over the three year period of the study the additional dead aspen material may not have substantially influenced the spread of *Armillaria*.

Other causes or signs of damage were (in decreasing incidence): physical damage to the leader, western gall rust, chlorosis (undefined cause), browse damage and damaged base or stem (girdling). The major diseases found in these blocks has been reported for similar regenerating pine stands in the region (Bella 1985a, Ives and Rentz 1993).

Table 2
Amount, Type and Severity of Damage to Target Lodgepole Pine Trees in 1996 for All Blocks Combined

Most Prevalent Damage[3]	Damage Severity[1,2]				Total		Dead Trees
	None	Slight	Moderate	Severe	N	%	
No Damage	239	.[4]	.	.	239	66.4	.
Root Rot (*Armillaria* sp.)	.	.	.	42	42	11.7	42
Broken/Damaged Leader	.	5	6	1	12	3.3	.
Broken/Damaged Branches	.	4	.	.	4	1.1	.
Needle Cast (Undifferentiated)	.	1	1	1	3	0.8	.
Damaged Base/Stem (Girdling)	.	4	3	1	8	2.2	.
Chlorosis (Cause not defined)	.	2	5	3	10	2.8	.
Roots	.	.	.	4	4	1.1	4
Western Gall Rust (*Endocronartium harknessii*)	.	3	2	6	11	3.1	.
Double Top	.	4	.	.	4	1.1	.
Petrova albicapitana	.	4	.	1	5	1.4	1
Stalactiform Blister Rust (*Cronartium* sp.)	.	.	.	4	4	1.1	4
Browsed	.	5	2	1	8	2.2	1
Stem	.	.	.	.	.	.	.
Forked	.	.	1	.	1	0.3	.
Resinosis	.	1	.	.	1	0.3	.
Unknown (Dead)	.	.	.	4	4	1.1	4
Total	239	33	20	68	360	100	56

1. Based on a subjective evaluation.
2. Intermediate categories were moved up to the higher category.
3. While trees may have had damage from multiple sources, only the dominant damage was recorded.
4. A "." indicates none in that category.

The four Kruskal-Wallis rank-sum tests all indicated that the amount of damage or mortality of target trees was slightly greater (though still not widespread) for the plots where all the aspen was removed, compared to the control plots. However, there was a lot of variation in this relationship, as is shown by the non-significant probability level associated with each rank-sum test:

1. H_0: Aspen removal (treatment) had an effect on the level of occurrence (for any severity level) of insect and disease damage for target pine trees (not significant: P=0.73).
2. H_0: Aspen removal (treatment) had an effect on the level of occurrence (for any severity level) of physical damage for target pine trees (not significant: P=0.81).
3. H_0: Aspen removal (treatment) had an effect on the severity of damage (insect, disease and physical damage combined) for target pine trees (not significant: P=0.65).
4. H_0: Aspen removal (treatment) had an effect on the mortality rate (all causes combined) for target pine trees (not significant: P=0.38).

Thinned stands may lead to increased incidence of pest damage (e.g., Bella 1985a, 1985b), possibly through such mechanisms as increased wind dispersal of spores. It is possible that removal of all aspen adjacent to the pine may exacerbate similar pest problems. The factors that influence damage to pine may act in different ways. For instance, Bella (1985a) and Ives and Rentz (1993) indicate that mammal damage in young lodgepole pine is greater in more dense stands than in less dense ones, however, pest damage may be greater in thinned stands (Bella 1985a). There is some early evidence from this study that retention of low levels of aspen may be associated with optimal growth of pine, in cases where the aspen is shorter than the pine. As the aspen crowns develop, second removal may be required to ensure optimal pine growth.

CONCLUSIONS

1. The aspen competition levels prior to treatment in 1993 were uniform, except for subblock 3 in block 3 which had a significantly greater density of aspen.

2. The third year of post-treatment pine growth showed a continuation of trends seen one and two years after treatment. After three years of post-treatment growth, radial increment and total root collar diameter was significantly lower in the control plots. The largest radial growth was associated with plots under low levels of aspen competition with aspen with a BDR of more than 0.75 removal, followed closely by full removal.

3. After three years of post-treatment growth, there were no significant differences in height growth between any of the treatments, although there was a decreased rate of height growth in the third year following treatment.

4. There was a trend toward higher mortality and mechanical and pest damage in plots where all the aspen have been removed, although three years after treatment it was not statistically significant.

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