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

ESTABLISHMENT AND PROGRESS REPORT

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DISCLAIMER

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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 was completed. These were followed by growth response measurements in 1994. The initial vegetation conditions and first year growth response have been analyzed. One year after treatment, there are, in some cases, significant differences in growth response between no removal and full removal of aspen within 1.8 m of the conifer. This relationship is most pronounced for radial increment. There are, however, no significant differences in pine growth response for the intermediate removal treatments based on basal diameter ratios of 0.75 and 1.0 one year after treatment.

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INTRODUCTION

Performance expectations for juvenile conifers have been incorporated into the new free-to-grow regeneration standards in Alberta 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.

The Canadian Forest Service recently 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 actual release response assessment. The pine growth responses must be confirmed by field experiments. This Foothills 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 is 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 is to provide concrete data on how effective the BDR competition index is in guiding stand tending decisions in lodgepole pine-aspen cutblocks in west-central Alberta.

The study will help to answer the following questions:

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

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?

4. Can this approach be used in managing cutblocks for increased biodiversity, by selectively targeting release effort?

STUDY LOCATION

The study is located within the Weldwood Forest Management Area, within the Lower Boreal Cordilleran ecoregion. The Upper Boreal Cordilleran ecoregion was not suitable for this study because aspen is often not the major competitor of pine (willows, alder and balsam poplar are most dominant). Three cutblocks 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). Although younger than originally desired, they have 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 bracke prior to planting.

METHODS

Cutblock Selection

Young cutblocks (around 8 years old) with planted or naturally regenerating lodgepole pine and aspen as the main competitor were selected. High aspen competition sites were favoured. Specifically, these cutblocks 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.

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 growth response was measured in 1994, and will also be remeasured in 1995 and 1996.A randomized nested design with three cutblocks is being used. Within each cutblock, three well distributed areas (subblocks) at least 1.0 ha each were sampled (Figure 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

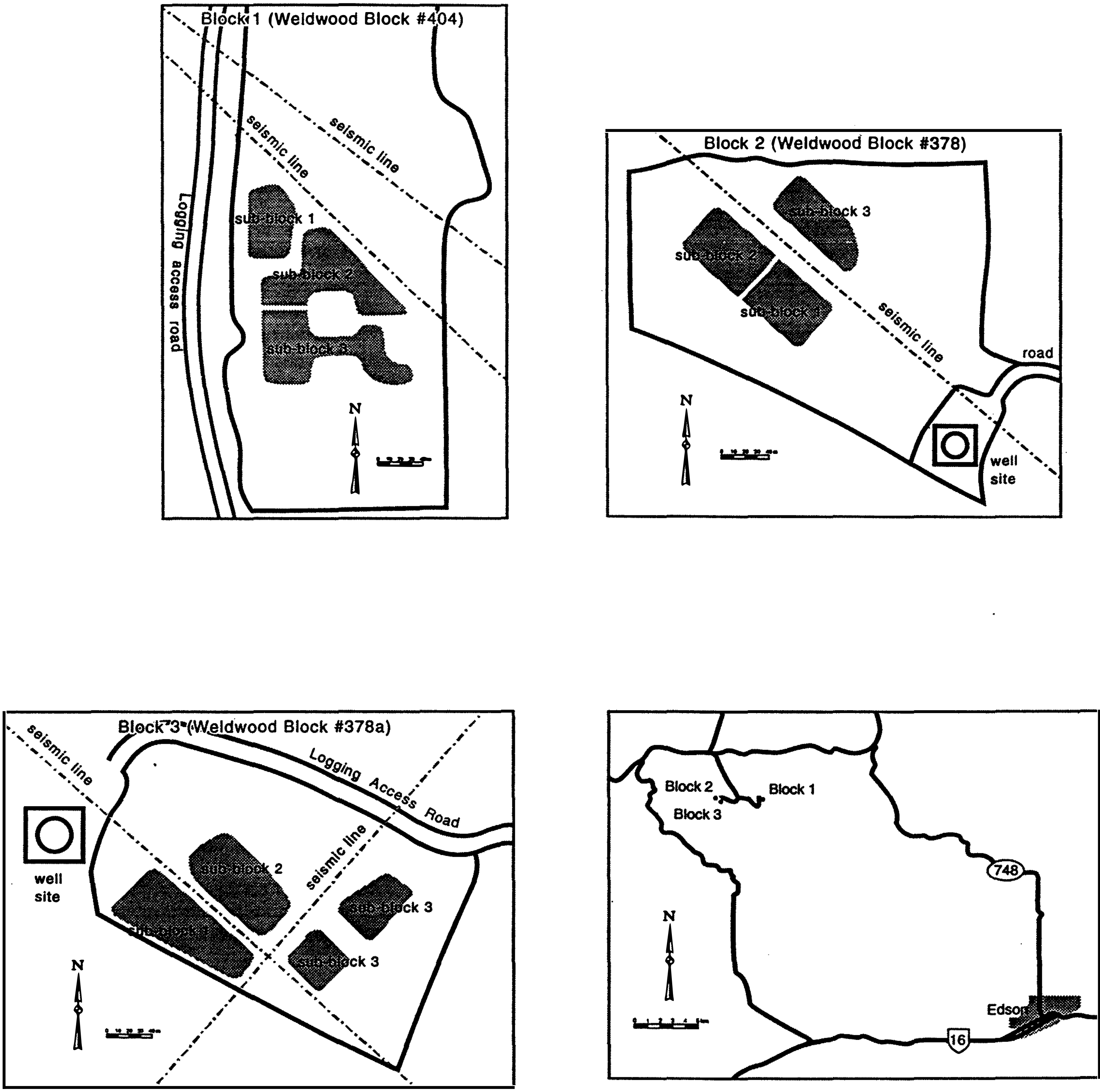


Figure 1

Study Area and Experimental Layout of Blocks and Subblocks each treatment in each subblock. Once 10 plots of one treatment type were chosen, no more of that type were used in the subblock.

The experimental design chosen, differed from the design presented in the initial study proposal, in the following manner. Initially, four, rather than three subblocks were considered per cutblock, with 40 rather than 30 plots in each. After field reconnaissance, one fewer subblock per cutblock was selected, because there was difficulty in finding enough suitable subblocks in each cutblock. This also allowed higher sampling intensity in each subblock. As well, a randomized complete block design was to be used where each subblock would have 30 plots of one treatment each, with the choice of treatment chosen randomly for each subblock. For the revised protocol, in each subblock, four treatments were assigned to 10 plots each. Originally, each subblock was to receive a set treatment for all plots within it. This change was made because, in fact, site conditions within each cutblock were not uniform (a requirement for randomized complete block design). This modified method allowed the interspersion of all four treatments throughout the cutblocks, 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. All sizes of pine tree were used, subject to the criteria listed below.

A target tree was selected if it:

- had no recent damage due to herbivory
- leader growth was undamaged
- had at least 5 (preferably 6) internodes (to ensure that recent arrivals not used)
- was not advanced regeneration
- had no insect damage
- 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 vegetation removal (control plot)
b) removal of all aspen within 1.8 m of the lodgepole pine trees where the aspen basal diameter is larger than the pine (BD ratio between pine and tallest remaining aspen is less than 1.0).
c) removal of all aspen within 1.8 m of the lodgepole pine trees where the aspen basal diameter is 75% of the pine diameter or greater (BD ratio between pine and tallest remaining aspen is less than 0.75).
d) removal of all aspen within 1.8 m of the lodgepole pine tree, regardless of aspen size.

Aspen competition was removed using hand saws, following vegetation measurement in 1993. Aspen competition will be allowed to regenerate in subsequent years, and will not be removed again.

1993 Field Measurements

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 remaining aspen after treatment were also made, as described below).

Two types of data were collected: vegetation on a plot-level basis, and measurements of individual trees. An example of the 1993 data sheet is in Appendix 1.

Vegetation Data Collected on a Plot-Level Basis

Average cover, height and density of trees, shrubs, forbs and grasses was collected in the plots. This was augmented by a few other variables, which are described below.

a) Crown Cover: Crown cover (estimated to nearest %) for the following growth forms: each tree species separately, all trees combined (all sizes), tall shrub (>50 cm), low shrub (< 50 cm), shrub species separately (if > 5% cover), forb (broadleaf, non-woody plants), graminoid.
b) Average Height: Average crown height (estimated to nearest 5 cm) for the following growth forms: each tree species separately (all sizes), all trees combined, tall shrub (>50 cm), low shrub (< 50 cm), forb, graminoid.
c) Competing Species: List of the major low shrubs and herbs in the plot
d) Density: Stem count for each tree species and shrub species (if > 5% cover).

e) Etiolation: Physical evidence of shading on the subject tree. Signs include twisted or spindly stem, poor crown development and needles cast. The options were: none, slight, moderate, severe (and intermediate classes).

f) Herb Crowding: Indication if forbs and grasses were impinging on the target tree, by covering at least 50% of the lower branches. Options were: yes, no.

g) Planted: Indication if target tree was planted based on location in relation to bracke scalp. Options were: yes, no.

h) Residual: Distance, species and condition (live or dead) of the closest residual.

Vegetation Data Collected for the Target Tree and Tallest and Closest Conifer and Hardwood

In 1993, detailed measurements were collected on the target tree. The variables were: crown height, crown radius, total height, root collar diameter, estimated age, height increments for the previous 5 years (including 1993), and damage to the tree. The nearest and tallest conifer and hardwood in the plot were also measured. Variables were: azimuth, height, root collar diameter, target stem-to-inside crown of competitor, target stem-to-stem of competitor, target stem-to-outside crown of competitor, and height increments for the previous 5 and 3 years, for conifers and hardwoods, respectively (including 1993).

Aspen competition was measured both before and after the treatments in 1993. This included: average height and cover, total density and density by quadrant, and detailed measurements on the closest and tallest aspen in the plot.

Descriptions of the detailed tree measurement variables are as follows:

a) Species Label: 2 letter code

b) Species Code: 1.target tree, 2. tallest, 3. closest, 4. tallest & closest. If the target tree was the tallest, then the second tallest was measured as well. If the tallest or closest hardwood was not an aspen, then the next tallest or closest that was an aspen was measured as well.

c) Azimuth: (nearest 5^0) Bearing from target tree stem at ground level to the competitor stem at ground level.

d) Total Height: (nearest cm): total height, including current year's growth.

e) Crown Height: (nearest cm): measured from ground to first branch whorl (3 of 4 branches intact). Used to determine live crown length.

f) Crown Radius: (nearest cm): the average radius was recorded, average of widest and narrowest crown radii.

g) Percent Overtopping: (nearest 10%): percentage of the top ⅓ of the target tree that is overtopped by crown foliage of competing tree or shrub. (ie. the crown of top ⅓ is projected upwards as a cylinder).

h) Root Collar Diameter: (nearest mm): this was the basal diameter, taken at ground level, above the root collar swelling.

i) Stem-Stem Distance: (nearest cm): Measured from centre of target tree stem to centre of competitor tree stem. In the case of shrub clumps, it was to the centre of the clump.
j) Stem-Inside Crown Distance: (nearest cm) Measured from centre of target tree stem to the nearest edge of the competitor foliage.
k) Stem-Outside Crown Distance: (nearest cm) Measured from centre of target tree stem to the farthest edge of the competitor foliage.
l) Height Increments (nearest cm): Used 5 most recent increments for confers and 3 most recent increments for hardwoods, starting with the current year.
m) Age: Estimated from a count of internodes.

1994 Field Measurements

The growth response to the treatments was measured in August 1994 after the pine had hardened off. This was to ensure that a full growing season had passed since the treatments. A reduced set of measurements was made, compared to 1993. Two types of data were collected: vegetation on a plot-level basis, and measurements of individual trees. An example of the 1994 data sheet is in Appendix 2.

Vegetation Data Collected on a Plot-Level Basis

Average cover, height and density of 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.

For three years after this release, growth response of the lodgepole pine (eg. RCD, height increments) was or will be recorded.

Analysis Methods

There were several types of analysis used. They are as follows:

a) General statistical summaries and tests for normality and data transformations.
b) Analysis of variance to test differences in vegetation between blocks before treatment.
c) Analysis of covariance to test differences in pine growth response after treatment.
d) Multiple means tests to test for growth response differences 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 among those tested: square root, arcsine, inverse and natural log of the value plus one. 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. In situations for post-treatment variables, this normality assessment was done on each treatment by block combination.

Tests for normality were performed on subpopulations based on stratification by block (n=30), subblock by block (n=40) and removal by block (n=30). For all variables, there were specific transformations which consistently improved the distribution towards normality. In general, natural log transformation normalized the data for densities while the square root transformation tended to normalize the cover data. For height data, untransformed data most approximated a normal distribution.

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: square root transformation
c) aspen and pine density: natural logarithm of value+1
d) aspen and pine average cover: natural logarithm of value+1
e) aspen and pine average height: no transformation, or square root transformation

For analysis of variance, three mixed (fixed and random effects) linear models were developed, as appropriate for the experimental design (Borders and Shiver 1989; Neter et al. 1989; SAS Institute Inc. 1991).

For analysis of variables prior to treatment, the model was:

y = block+subblock(block)+ error

For analysis of competition variables after treatment, the model was:

y = block+subblock(block)+ removal + removal*block+error

For analysis of growth variables after treatment, covariance analysis was used, which included the size of the conifer at the end of the previous growing season (Woollons and White 1988). The model was:

y = tree size in previous year+block+subblock(block)+ removal+ removal*block+error

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

Ran's multiple range test (c.f., Day and Quinn 1989) and Dunnett's one tail comparison test (SAS Institute Inc. 1989) were used to determine significant differences in growth response in

1994 for the different treatments. 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.

RESULTS AND DISCUSSION

This section details and discusses the analytical results of pretreatment aspen competition and pine size in 1993 and the first year post-treatment growth response for pine in 1994.

Competition Levels and Lodgepole Pine Growth Prior to 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 (Table 1). The 2-3 m tall aspen were 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.

Results of analysis of variance of aspen density, height and cover for blocks and subblocks indicated that the aspen did not have uniform competition prior to treatment. For density and height, aspen had more within-block variability than between-block variability (Table 2). The reasons for these results are apparent from Appendices 3.1, 3.2 and 3.3, which give block and subblock means for aspen density, cover and height, respectively. Least squares means tests showed significantly greater density (31.8 stems/10m^2 plot) in block 3 compared to the other two blocks ($P < 0.05$) (Table 2). This was due to a high density in block 3, subblock 3 of 43.4 stems/10m^2 plot, which was almost double the density for most of the other subblocks (Appendix 3.1). 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 (Table 2) . 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 cutblocks supported the decision to mix all four treatments within each of the subblocks. Notwithstanding the variations in aspen competition noted above, the range within and between blocks was incorporated in the growth response analysis of variance as described below.

For pine, analysis of variance determined the within-block and between-block variability for both average pine in the plots (Table 3) , and specific growth variables based on target pine measurements (Table 4). For both groups of variables, between-block variability was

Table 1
Vegetation Characteristics for 1993
By Block

	Aspen Before Removal	Lodgepole Pine	White Spruce	Balsam Fir	Total Tree[1]	Tall shrub (>50cm)	Low shrub (<50cm)	Forb	Grass
Density (stems/$10m^2$)									
Block 1	21.0 ±8.5[2]	1.4 ±0.8	0.7 ±1.5	3.9 ±5.1	-[3]	12.2 ±10.6	-	-	-
Block 2	23.9 11.5	2.5 2.3	0.1 0.4	1.3 2.6	-	20.4 15.1	-	-	-
Block 3	31.8 16.8	2.8 2.1	0.0 0.3	1.6 2.7	-	12.4 9.9	-	-	-
Average Cover (%)									
Block 1	50.7 19.4	1.8 1.1	0.2 0.6	2.9 3.7	53.8 19.3	2.6 3.0	5.0 5.5	19.8 14.2	8.7 13.2
Block 2	37.8 17.5	1.1 0.9	0.0 0.2	0.6 1.4	38.2 17.5	0.9 2.3	2.9 2.5	6.2 2.9	10.0 6.2
Block 3	49.0 15.5	1.7 1.2	0.0 0.0	1.4 2.9	50.7 15.0	2.1 2.8	11.6 9.0	16.0 9.1	15.6 10.5
Average Height (cm)									
Block 1	263.1 48.1	138.1 46.2	29.6 15.3	71.6 31.6	239.3 43.4	73.8 30.8	24.6 10.4	17.6 9.6	37.4 16.2
Block 2	236.7 47.3	82.4 25.0	43.4 39.4	77.9 28.8	209.0 48.3	101.5 57.4	26.5 7.9	18.9 7.0	38.8 9.5
Block 3	231.6 44.5	83.5 26.5	17.0 6.1	69.0 30.0	217.3 45.3	80.6 29.0	22.7 11.0	21.5 11.7	56.8 18.9

[1]Includes a minor component of white birch in block 1 (cover less than 1%).
[2]Standard deviation.
[3]Density data not collected.

Table 2
Analysis of Variance of Aspen Before Treatment in 1993

Aspen Density[1]

Source	DF	Mean Sq.	F value	Pr > F
Block[2]	2	4.08	3.39	0.1037
Subblock (Block)[3]	6	1.20	7.13	0.0001
Error	351	0.17	-	-
Least Squares Means (Values are means ± standard error of the mean)				
Block	1	2	3	
Density (stem/10m^2)	21.0 ±0.78a[4]	23.9 ±1.05a	31.8 ±1.53b	

Aspen Cover[1]

Source	DF	Mean Sq.	F value	Pr > F
Block[2]	2	3.58	8.51	0.0177
Subblock (Block)[3]	6	0.42	2.49	0.0224
Error	351	0.17	-	-
Least Squares Means (Values are means ± standard error of the mean)				
Block	1	2	3	
Average Cover (%)	50.7 ±1.77a	37.8 ±1.60b	49.0 ±1.41a	

Aspen Height[1]

Source	DF	Mean Sq.	F value	Pr > F
Block[2]	2	34.6	1.95	0.2223
Subblock (Block)[3]	6	17.7	9.11	0.0001
Error	351	1.95	-	-
Least Squares Means (Values are means ± standard error of the mean)				
Block	1	2	3	
Height (cm)	263.1 ±4.39a	236.7 ±4.31b	231.6 ±4.06b	

[1]Transformations as follows: density - ln(var+1)cover - ln(var+1)height - √.
[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 mean test.

Table 3
Analysis of Variance of Lodgepole Pine Average Density, Cover and Height Before Treatment in 1993

Average Pine Density in Plot[1]

Source	DF	Mean Sq.	F value	Pr > F
Block[2]	2	4.49	14.49	0.0050
Subblock (Block)[3]	6	0.31	1.72	0.1150
Error	351	0.18	-	-

Least Squares Means (Values are means ± standard error of the mean)

Block	1	2	3
Density (stems/10m²)	1.4 ±0.07a[4]	2.5 ±0.21b	2.8 ±0.19b

Average Pine Cover in Plot[1]

Source	DF	Mean Sq.	F value	Pr > F
Block[2]	2	3.02	5.08	0.0512
Subblock (Block)[3]	6	0.59	4.70	0.0001
Error	351	0.13	-	-

Least Squares Means (Values are means ± standard error of the mean)

Block	1	2	3
Average Cover (%)	1.8 ±0.10a	1.1 ±0.08b	1.7 ±0.11a

Average Pine Height in Plot[1]

Source	DF	Mean Sq.	F value	Pr > F
Block[2]	2	265.03	85.00	0.0001
Subblock (Block)[3]	6	3.12	1.15	0.3321
Error	351	2.71	-	-

Least Squares Means (Values are means ± standard error of the mean)

Block	1	2	3
Height (cm)	138.1 ±4.22a	82.3 ±2.28b	83.5 ±2.42b

[1]Transformations as follows: density - ln(var+1) cover - ln(var+1) height - √.
[2]Tests of hypotheses use the Type I MS for Subblock(Block) as an error term.
[3]Subblock is designed 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.

Table 4
Analysis of Variance of Lodgepole Pine Growth Before Treatment in 1993

1993 Height Increment[1]

Source	DF	Mean Sq.	F value	Pr > F
Block[2]	2	3311.4	37.71	0.0004
Subblock (Block)[3]	6	87.8	0.94	0.4634
Least Squares Means (Values are means ± standard error of the mean)				
Block	1	2	3	
Height (cm)	36.1 ±1.11a[4]	26.5 ±0.74b	27.6 ±0.73b	

1993 Height

Source	DF	Mean Sq.	F value	Pr > F
Block	2	251.6	85.38	0.0001
Subblock (Block)	6	2.9	1.57	0.1543
Least Squares Means (Values are means ± standard error of the mean)				
Block	1	2	3	
Height (cm)	150.3 ±3.87a	92.4 ±1.90b	95.3 ±2.02b	

1993 RCD

Source	DF	Mean Sq.	F value	Pr > F
Block	2	18.37	17.65	0.0031
Subblock (Block)	6	1.04	2.82	0.0109
Least Squares Means (Values are means ± standard error of the mean)				
Block	1	2	3	
RCD (mm)	23.5 ±0.63a	18.0 ±0.44b	16.8 ±0.44b	

[1]1993 height increment not transformed; 1993 height and rcd are square root transformed.
[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

significant for P <0.05, except for average pine cover. For subblocks within blocks the reverse was true: there were no significant differences in between-subblock growth, except for pine root collar diameter of the target trees and average cover. The pine in blocks 2 and 3 were quite similar in stature, however, block 1 had much larger pine (Table 1). This may be for two reasons: 1. Block 1 had been harvested and planted one year earlier. 2. Blocks 2 and 3 were adjacent to each other, and the pine would be growing on similar slope and aspect. These differences verified the importance of performing analysis which incorporated initial size of the pine.

Change in Aspen Competition Before and After Treatment in 1993

In the previous section, it was noted that there were some differences in aspen competition within subblocks. 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 (Table 5). 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 in aspen density, and 50-66% decrease in average aspen height. For aspen cover, the post-treatment decrease 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 appreciably greater removal of aspen. This is because of the discrepancy of aspen growth rates of aspen as compared to pine in regenerating stands. Many of the dominant aspen competitors would have a root collar diameter greater than the pine. 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.

Tables 6 and 7 illustrate the effect of different removal treatments on the proximity of the closest and tallest aspen in the plot to the target pine. Unlike the situation for aspen cover, density and height, there were large differences in the change in proximity of the tallest aspen, for BDR 1.0 versus 0.75 removal. In general, pine-stem-to-aspen-inside-crown distance changed the most with treatment, followed by pine-stem-to-aspen-outside-crown distance. For the closest aspen (Table 7), there was not a clear trend between the BDR removal of 1.0 and 0.75.

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 (Table 8). This is 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.

Table 5
Change in Aspen Competition Before and After Treatment in 1993

Comparison Change In	Block	Aspen Removal Treatment	Before Removal	After Removal	% Change
Density (stems/10m²)	1	all	22.3 ± 1.6[1]	no aspen left	.
		0.75[2]	21.4 1.6	6.4 1.0	70%
		1.00[3]	20.9 1.4	11.1 1.1	47%
		none	19.5 1.6	19.5 1.7	0%
	2	all	22.7 2.6	no aspen left	.
		0.75	22.9 1.8	7.9 1.1	66%
		1.00	24.9 1.9	8.3 1.3	67%
		none	25.0 2.0	25.0 2.0	0%
	3	all	33.6 3.2	no aspen left	.
		0.75	33.2 3.3	13.3 2.2	60%
		1.00	31.1 3.2	13.2 1.8	58%
		none	29.4 2.6	29.4 2.6	0%
Cover (%)	1	all	49.6 3.2	no aspen left	.
		0.75	52.8 3.6	4.6 0.9	91%
		1.00	50.7 4.0	6.8 0.7	87%
		none	49.5 3.5	49.5 3.8	0%
	2	all	36.3 3.6	no aspen left	.
		0.75	38.3 3.3	2.4 0.4	94%
		1.00	38.3 2.8	3.0 0.8	92%
		none	38.1 3.2	38.1 3.2	0%
	3	all	47.8 3.1	no aspen left	.
		0.75	49.3 2.8	6.0 1.0	88%
		1.00	49.1 2.7	6.2 1.0	87%
		none	49.8 2.8	49.8 2.8	0%

Table 5 (cont'd)

Comparison Change In	Block	Aspen Removal Treatment	Before Removal	After Removal	% Change
Averge Height (cm)	1	all	255.7 10.1	no aspen left	.
		0.75	265.5 6.3	103.6 6.7	61%
		1.00	265.3 9.3	133.4 9.1	50%
		none	265.7 9.2	265.7 9.5	0%
	2	all	219.8 7.3	no aspen left	.
		0.75	238.5 7.6	76.0 4.3	68%
		1.00	248.2 9.8	85.2 4.6	66%
		none	240.3 9.1	240.3 9.1	0%
	3	all	231.8 8.9	no aspen left	.
		0.75	233.0 7.6	82.7 6.1	65%
		1.00	234.7 8.1	87.9 5.3	63%
		none	226.9 8.2	226.9 8.2	0%

[1]Standard error of the mean.
[2]Removal of aspen with RCD greater than 75% of target pine RCD (i.e., BDR=0.75).
[3]Removal of aspen with RCD greater than target pine RCD (i.e., BDR=1.0).

Table 6
Change in Proximity of Tallest Aspen in the Plot to Pine Trees
Before and After Treatment in 1993

Comparison Change In	Block	Aspen Removal Treatment	Distance (cm)		
			Before Removal	After Removal	% Change
Average stem-inside crown to tallest aspen	1	all	58.6 ±9.3[1]	no aspen left	.
		0.75[2]	36.5 9.2	79.8 9.1	119
		1.00[3]	57.1 8.9	76.7 8.9	34
		none	33.5 8.7	33.5 8.7	0
	2	all	39.6 10.6	no aspen left	.
		0.75	30.2 8.5	97.1 7.8	221
		1.00	51.0 7.2	69.3 8.1	36
		none	47.9 8.8	47.9 8.8	0
	3	all	69.3 8.2	no aspen left	.
		0.75	54.8 8.7	100.8 6.5	84
		1.00	53.2 7.6	93.9 7.0	76
		none	74.8 7.6	74.8 7.6	0
Average stem-stem to tallest aspen	1	all	126.9 7.9	no aspen left	.
		0.75	105.8 7.6	96.8 8.1	-9
		1.00	124.8 7.4	106.2 9.3	-15
		none	100.4 9.0	100.4 9.0	0
	2	all	108.8 6.9	no aspen left	.
		0.75	115.4 7.6	115.8 7.5	0.3
		1.00	116.6 6.2	97.2 9.1	-17
		none	120.9 8.3	120.9 8.3	0
	3	all	126.0 6.9	no aspen left	.
		0.75	120.4 6.6	121.2 6.6	0.7
		1.00	123.6 6.5	117.9 6.2	-5
		none	134.3 7.3	134.3 7.3	0

Table 6 (cont'd)

Comparison Change In	Block	Aspen Removal Treatment	Distance (cm)		
			Before Removal	After Removal	% Change
Average stem-outside crown to tallest aspen	1	all	200.8 ± 9.6	no aspen left	.
		0.75	183.9 10.8	129.8 ±8.3	-29
		1.00	200.2 9.9	141.4 10.9	-29
		none	179.0 10.1	179.0 10.1	0
	2	all	167.3 9.2	no aspen left	.
		0.75	190.3 9.4	127.8 8.4	-33
		1.00	185.0 10.2	110.0 9.7	-41
		none	179.6 9.8	179.6 9.8	0
	3	all	191.7 7.2	no aspen left	.
		0.75	175.3 7.2	137.6 7.2	-21
		1.00	186.5 9.8	130.9 6.7	-30
		none	197.1 9.9	197.1 9.9	0

[1]Standard error of the mean.
[2]Removal of aspen with RCD greater than 75% of target pine RCD (i.e., BDR=0.75).
[3]Removal of aspen with RCD greater than target pine RCD (i.e., BDR=1.0).

Table 7
Change in Proximity of Closest Aspen in the Plot to Pine Trees
Before and After Treatment in 1993

Comparison Change In	Block	Aspen Removal Treatment	Distance (cm)		
			Before Removal	After Removal	% Change
Average stem-inside crown to closest aspen	1	all	3.5 ±4.7[1]	no aspen left	.
		0.75[2]	-4.8 6.4	43.8 ±7.2	-1007
		1.00[3]	-1.2 5.5	20.7 4.9	-1870
		none	-7.3 7.4	-7.3 7.4	0
	2	all	8.9 4.9	no aspen left	.
		0.75	20.7 6.0	60.5 7.1	192
		1.00	12.5 5.8	37.8 5.8	203
		none	8.9 5.6	8.9 5.6	0
	3	all	5.4 5.1	no aspen left	.
		0.75	5.9 5.7	42.3 6.4	617
		1.00	5.2 5.8	43.3 5.2	737
		none	5.6 4.5	5.6 4.5	0
Average stem-stem to closest aspen	1	all	38.4 4.5	no aspen left	.
		0.75	34.8 3.2	59.1 6.1	70
		1.00	33.2 4.1	44.7 4.8	34
		none	32.3 3.9	32.3 3.9	0
	2	all	46.8 3.5	no aspen left	.
		0.75	46.3 4.2	71.5 7.3	54
		1.00	40.5 4.2	53.3 6.0	32
		none	39.8 4.3	39.8 4.3	0
	3	all	40.9 4.5	no aspen left	.
		0.75	42.4 3.5	55.8 5.8	32
		1.00	42.4 3.8	57.2 5.1	35
		none	39.0 3.3	39.0 3.3	0

Table 7 (cont'd)

Comparison Change In	Block	Aspen Removal Treatment	Distance (cm)		
			Before Removal	After Removal	% Change
Average stem-outside crown to closest aspen	1	all	77.0 ±5.9	no aspen left	.
		0.75	67.3 5.7	83.6 ±7.3	24
		1.00	65.8 5.2	66.9 5.7	2
		none	80.5 7.3	80.5 7.3	0
	2	all	70.2 6.2	no aspen left	.
		0.75	72.0 5.9	81.8 7.0	14
		1.00	60.7 6.2	67.3 7.4	11
		none	60.5 6.2	60.5 6.2	0
	3	all	65.6 6.6	no aspen left	.
		0.75	66.9 6.9	64.2 6.4	-4
		1.00	70.7 8.9	67.6 5.6	-4
		none	58.9 6.8	58.9 6.8	0

[1]Standard error of the mean.
[2]Removal of aspen with RCD greater than 75% of target pine RCD (i.e., BDR=0.75).
[3]Removal of aspen with RCD greater than target pine RCD (i.e., BDR=1.0).

Table 8
Analysis of Variance of Aspen After Treatment in 1993

Aspen Density[1]

Source	DF	Mean Sq.	F value	Pr > F
Block[2]	2	3.13	1.33	0.3317
Subblock (Block)[3]	6	2.34	7.03	0.0001
Removal	2	31.50	94.49	0.0001
Block * Removal	4	1.21	3.63	0.0068
Error	249	0.33	-	-
Least Squares Means (Values are means ± standard error of the mean)				
Treatment	All	0.75	1.00	None
Block 1	-	6.4 ±0.96a[4]	11.1 ±1.06b	19.6 ±1.59c
Block 2	-	7.9 1.11a	8.3 1.38a	25.0 1.97b
Block 3	-	13.3 2.26a	13.2 1.79a	29.4 2.62b

Aspen Cover[1]

Source	DF	Mean Sq.	F value	Pr > F
Block[2]	2	7.62	4.43	0.0657
Subblock (Block)[3]	6	1.72	4.94	0.0001
Removal	2	156.62	450.86	0.0001
Block * Removal	4	0.99	2.84	0.0248
Error	248	0.35	-	-
Least Squares Means (Values are means ± standard error of the mean)				
Treatment	All	0.75	1.00	None
Block 1	-	4.6 ±0.88a	6.8 ±0.63a	49.5 ±3.51b
Block 2	-	2.4 0.43a	3.0 0.85a	38.1 3.21b
Block 3	-	6.0 0.98a	6.2 0.99a	49.8 2.82b

Table 8 (cont'd)

Aspen Height[1]

Source	DF	Mean Sq.	F value	Pr > F
Block[2]	2	61.43	6.88	0.0280
Subblock (Block)[3]	6	8.92	4.08	0.0006
Removal	2	1064.83	486.66	0.0001
Block * Removal	4	4.58	2.09	0.0825
Error	248	2.19	-	-

Least Squares Means (Values are means ± standard error of the mean)

Treatment	All	0.75	1.00	None
Block 1	-	103.6 ±6.69a[4]	133.4 ±9.10b	265.7 ±9.19c
Block 2	-	76.0 4.25a	85.2 4.60a	240.3 9.06b
Block 3	-	82.7 6.07a	87.9 5.31a	226.9 8.16b

[1]Transformations as follows: density - ln(var+1) cover - ln(var+1) height - √.
[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.

Vegetation Condition in 1994, One Year After Treatment

Tables 9, 10 and 11 provide a summary of tree density, average tree height and average tree cover one year after treatment. This can be compared to the conditions before treatment in 1993 (Table 1). Aspen density counts which include coppiced stems showed significant regeneration in the one year since removal for treatments 1.0 and 0.75 in blocks 2 and 3, with densities approaching the pre-harvest levels (Table 9). In contrast, for all removal treatments, average aspen height and cover in 1994 remained well below the levels recorded in 1993 before treatments (Tables 10 and 11, respectively).

Pine Growth Response in 1994, One Year After Treatment

The post-treatment analysis is presented using three complementary techniques: 1. covariance analysis, 2. multiple means tests, and 3. Graphical representation of the growth trajectories. Because of the effect of the conifer tree size of the previous year, analysis of covariance was required when analyzing the first 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 12. As expected, the covariant had a significant effect on all growth variables ($P < 0.05$). For height and height increment there were no treatment effects. This is confirmed with the least squares means tests which indicates no significant differences between any of the treatment responses. For root collar diameter and radial increment, there were significant removal effects ($P < 0.05$). The least squares means tests indicate that the significant differences were due to differences in the growth response for complete removal versus no removal. There were no differences in growth response from the intermediate removals based on BDR values of 1.0 and 0.75. This is 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 2 to 7 present a graphical perspective on the one year post-treatment growth response. They clearly indicate the effect of initial size on the short term average growth response of post- treatment conditions. As well, it clearly shows the divergent growth trajectories after only one year. For example, Figure 2 shows there is divergence in average root collar diameter for trees growing under no aspen removal, compared to the other treatments.

The fact that radial increment showed treatment response after only one year while height increment did 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.

It is also intuitive that the differences in growth response would be significant when comparing the two most different treatments. It will probably take more time for growth

Table 9
Tree Density in 1994

Block	Removal	Aspen[1]	Aspen (incl. coppice)[2]	Lodgepole Pine[3]	White Spruce	Balsam Fir	Balsam Poplar	Total	Total (incl. coppice)
1	all	6.6 ±0.8[4]	11.73 ±1.6	1.5 ±0.2	1.2 ±0.4	4.7 ±1.1	0.1 ±0.1	13.1 ±1.4	18.2 ±1.8
	0.75[5]	8.9 0.9	13.0 1.9	1.3 0.1	1.0 0.3	3.6 0.8	0.1 0.0	13.9 1.2	18.0 2.2
	1.00[6]	11.4 1.0	12.6 1.2	1.4 0.2	0.5 0.1	4.6 1.1	0.1 0.1	16.9 1.6	18.1 1.9
	none	17.1 1.9	17.1 1.9	1.4 0.2	1.2 0.4	3.5 0.9	0.0 0.0	22.3 2.0	22.3 2.0
2	all	13.9 1.8	28.9 4.9	2.2 0.3	0.1 0.1	1.1 0.3	0.0 0.0	16.1 2.2	31.4 5.2
	0.75	13.1 1.2	20.6 2.3	3.2 0.5	0.3 0.1	1.2 0.5	0.1 0.1	17.0 1.2	24.5 2.2
	1.00	14.2 1.4	24.3 2.5	2.6 0.5	0.3 0.1	1.7 0.5	0.0 0.0	17.8 1.6	27.9 2.6
	none	21.6 1.4	21.7 1.4	2.6 0.4	0.1 0.0	1.3 0.4	0.0 0.0	24.6 1.6	24.7 1.6
3	all	14.8 1.4	33.3 3.9	2.5 0.3	0.0 0.0	1.1 0.4	0.0 0.0	17.5 1.4	36.0 3.8
	0.75	16.7 1.2	26.2 2.2	2.7 0.4	0.1 0.1	1.5 0.5	0.0 0.0	20.1 1.2	29.5 2.2
	1.00	15.1 1.1	22.2 1.7	2.6 0.3	0.1 0.1	1.5 0.5	0.0 0.0	18.3 1.2	25.4 1.9
	none	23.4 1.4	23.6 1.4	2.8 0.4	0.0 0.0	1.8 0.5	0.0 0.0	27.0 1.5	27.2 1.5

[1]Saplings which have sprouted from a single aspen stem cut in 1993 are counted as one.
[2]Each sapling counted individually.
[3]Includes target tree.
[4]Standard error of the mean.
[5]Removal of aspen with RCD greater than 75% of target pine RCD (i.e., BDR=0.75).
[6]Removal of aspen with RCD greater than target pine RCD (i.e., BDR=1.0).

Table 10
Average Tree Height in 1994

Block	Removal	Aspen[1]	Lodgepole Pine[2]	White Spruce	Balsam Fir	Balsam Poplar	Total
1	all	36.0 ±6.3[3]	161.6 ±8.3	34.9 ±3.5	80.0 ±8.0	75.0 -	60.4 ±5.6
	0.75[4]	100.0 10.2	174.1 9.7	34.6 4.3	97.2 11.9	25.0 5.0	102.8 8.7
	1.00[5]	140.0 9.1	166.4 11.3	26.4 6.4	86.2 8.0	98.0 38.0	118.6 7.4
	none	274.8 9.2	170.3 8.6	48.9 8.9	101.8 9.9	157.0 -	233.7 10.6
2	all	40.4 3.7	107.2 5.0	47.5 27.5	97.0 13.5	51.0 -	57.5 5.0
	0.75	70.9 5.7	98.3 5.4	18.0 2.7	92.5 15.1	25.0 -	73.5 5.1
	1.00	73.3 6.7	99.1 4.6	49.6 14.1	73.7 8.7	-	77.4 5.2
	none	261.8 11.9	104.5 6.1	69.0 18.0	103.9 10.6	-	231.2 11.3
3	all	37.0 2.1	96.7 6.3	-	85.2 14.3	-	50.0 2.8
	0.75	79.0 5.8	103.7 5.1	38.3 10.3	78.6 11.8	-	81.9 5.5
	1.00	83.7 6.4	97.2 6.3	53.0 -	73.1 13.6	-	84.9 6.6
	none	250.3 8.0	100.6 5.5	148.0 -	101.0 7.7	-	217.7 8.0

[1] Saplings which have sprouted from a single aspen stem cut in 1993 are counted as one.
[2] Includes target tree.
[3] Standard error of the mean.
[4] Removal of aspen with RCD greater than 75% of target pine RCD (i.e., BDR=0.75).
[5] Removal of aspen with RCD greater than target pine RCD (i.e., BDR=1.0).

Table 11
Average Tree Cover in 1994

Block	Removal	Aspen[1]	Lodgepole Pine[2]	White Spruce	Balsam Fir	Balsam Poplar	Total
1	all	1.1 ±0.2[3]	2.5 ±0.2	0.2 ±0.1	3.3 ±0.8	0.0 ±0.0	5.8 ±1.0
	0.75[4]	6.0 1.0	2.4 0.2	0.2 0.1	3.9 0.8	0.0 0.0	9.9 1.1
	1.00[5]	9.3 1.5	2.4 0.3	0.1 0.0	3.4 0.8	0.1 0.1	12.8 1.6
	none	52.3 3.5	2.1 0.2	0.2 0.1	3.2 0.8	0.1 0.1	54.7 3.3
2	all	3.3 0.3	2.6 0.2	0.1 0.1	1.6 0.6	0.0 0.0	5.7 0.7
	0.75	5.8 0.6	2.6 0.3	0.0 0.0	1.2 0.6	0.0 0.0	8.0 0.8
	1.00	6.4 0.8	2.6 0.4	0.1 0.1	1.9 0.6	0.0 0.0	9.1 0.9
	none	47.4 3.8	2.8 0.3	0.1 0.1	1.4 0.5	0.0 0.0	51.0 3.6
3	all	4.1 0.3	2.8 0.3	0.0 0.0	1.2 0.4	0.0 0.0	8.6 2.0
	0.75	9.0 0.9	3.3 0.3	0.1 0.1	1.3 0.5	0.0 0.0	11.6 1.0
	1.00	9.4 1.0	2.7 0.3	0.1 0.1	1.4 0.6	0.0 0.0	12.3 1.2
	none	49.3 3.1	3.0 0.3	0.1 0.1	2.4 0.8	0.0 0.0	51.8 3.0

[1]Saplings which have sprouted from a single aspen stem cut in 1993 are counted as one.
[2]Includes target tree.
[3]Standard error of the mean.
[4]Removal of aspen with RCD greater than 75% of target pine RCD (i.e., BDR=0.75).
[5]Removal of aspen with RCD greater than target pine RCD (i.e., BDR=1.0).

Table 12
Analysis of Covariance of Lodgepole Pine Growth in 1994

1994 Height[1]

Source	DF	Mean Sq.	F Value	Pr > F
1993 Height[12]	1	1205.83	5559	0.0001
Block[2]	2	0.71	4.2007	0.0381
Subblock (Block)[3]	6	0.14	0.5076	0.8026
Removal	3	0.41	1.4835	0.2188
Block * Removal	6	0.16	0.5876	0.7402
Error	341	0.28	-	-

Least Squares Means (Values are means ± standard error of the mean)				
Removal	All	0.75	1.00	None
Block 1	170.6 ±6.50a[4]	180.2 ±9.86a	182.5 ±9.74a	176.1 ±8.70a
Block 2	117.2 3.96a	120.6 5.68a	103.0 4.48a	111.7 5.56a
Block 3	118.5 5.78a	124.7 4.61ab	116.1 5.29b	117.8 4.88ab
All Blocks Combined	135.4 4.1a	141.8 5.0a	133.9 5.4a	135.2 4.9a

1994 Height Increment

Source	DF	Mean Sq.	F Value	Pr > F
1993 Height	1	10564.17	130.2869	0.0001
Block	2	505.71	6.3238	0.0176
Subblock (Block)	6	79.32	0.9616	0.4512
Removal	3	48.36	0.5862	0.6244
Block * Removal	6	97.45	1.1814	0.3156
Error	341	82.49	-	-

Least Squares Means (Values are means ± standard error of the mean)				
Removal	All	0.75	1.00	None
Block 1	29.6 ±1.98a	30.9 ±1.67a	31.0 ±2.36a	28.5 ±2.42a
Block 2	25.1 1.46a	25.4 2.05a	21.9 1.59a	23.8 2.38a
Block 3	22.9 1.65a	26.4 1.50ab	26.6 1.65b	28.2 1.79b
All Blocks Combined	25.9 1.0a	27.6 1.0a	26.5 1.2a	26.8 1.3a

Table 12 (cont'd)

1994 Root Collar Diameter

Source	DF	Mean Sq.	F Value	Pr > F
1993 RCD	1	152.07	1245	0.0001
Block	2	0.67	3.2370	0.1056
Subblock (Block)	6	0.22	2.4609	0.0242
Removal	3	0.75	8.3862	0.0001
Block * Removal	6	0.11	1.2365	0.2869
Error	340	0.09	-	-

Least Squares Means (Values are means ± standard error of the mean)

Removal	All	0.75	1.00	None
Block 1	29.3 ±1.23a	29.9 ±1.73a	29.0 ±1.44a	26.9 ±1.51b
Block 2	25.4 1.00a	24.2 1.07a	20.9 1.05a	21.7 1.00b
Block 3	20.6 1.04a	21.8 0.79a	19.9 1.02a	19.9 0.85a
All Blocks Combined	25.1 0.7a	23.3 0.8a	25.3 0.8a	22.8 0.7b

1994 Radial Increment

Source	DF	Mean Sq.	F Value	Pr > F
1993 RCD	1	16.47	6.6414	0.0155
Block	2	15.16	3.5579	0.0904
Subblock (Block)	6	4.52	2.5120	0.0216
Removal	3	14.74	8.1922	0.0001
Block * Removal	6	2.17	1.2059	0.3026
Error	340	1.80	-	-

Least Squares Means (Values are means ± standard error of the mean)

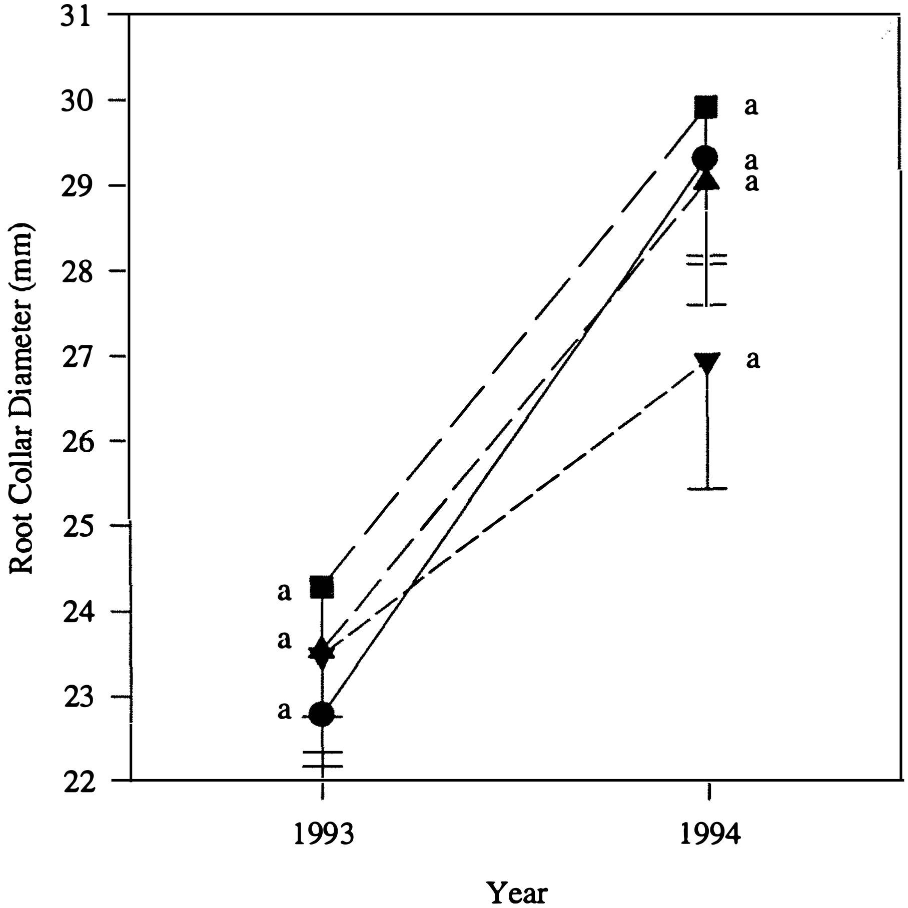
Removal	All	0.75	1.00	None
Block 1	3.3 ±0.30a	2.8 ±0.28a	2.8 ±0.28a	1.9 ±0.26b
Block 2	2.8 0.26a	2.9 0.25a	2.8 0.31a	1.8 0.20b
Block 3	1.9 0.25a	2.1 0.20a	1.9 0.16a	1.6 0.20b
All Blocks Combined	2.7 0.2a	2.6 0.1a	2.5 0.2a	1.8 0.1b

[1]Analysis performed with square root transformation for height and RCD; no transformation for ht inc and radial inc.
[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.

Figure 2

Change in Lodgepole Pine RCD - Block 1

By Treatment



All aspen removed

Aspen with BDR > 0.75 removed

Aspen with BDR > 1.0 removed

No aspen removed

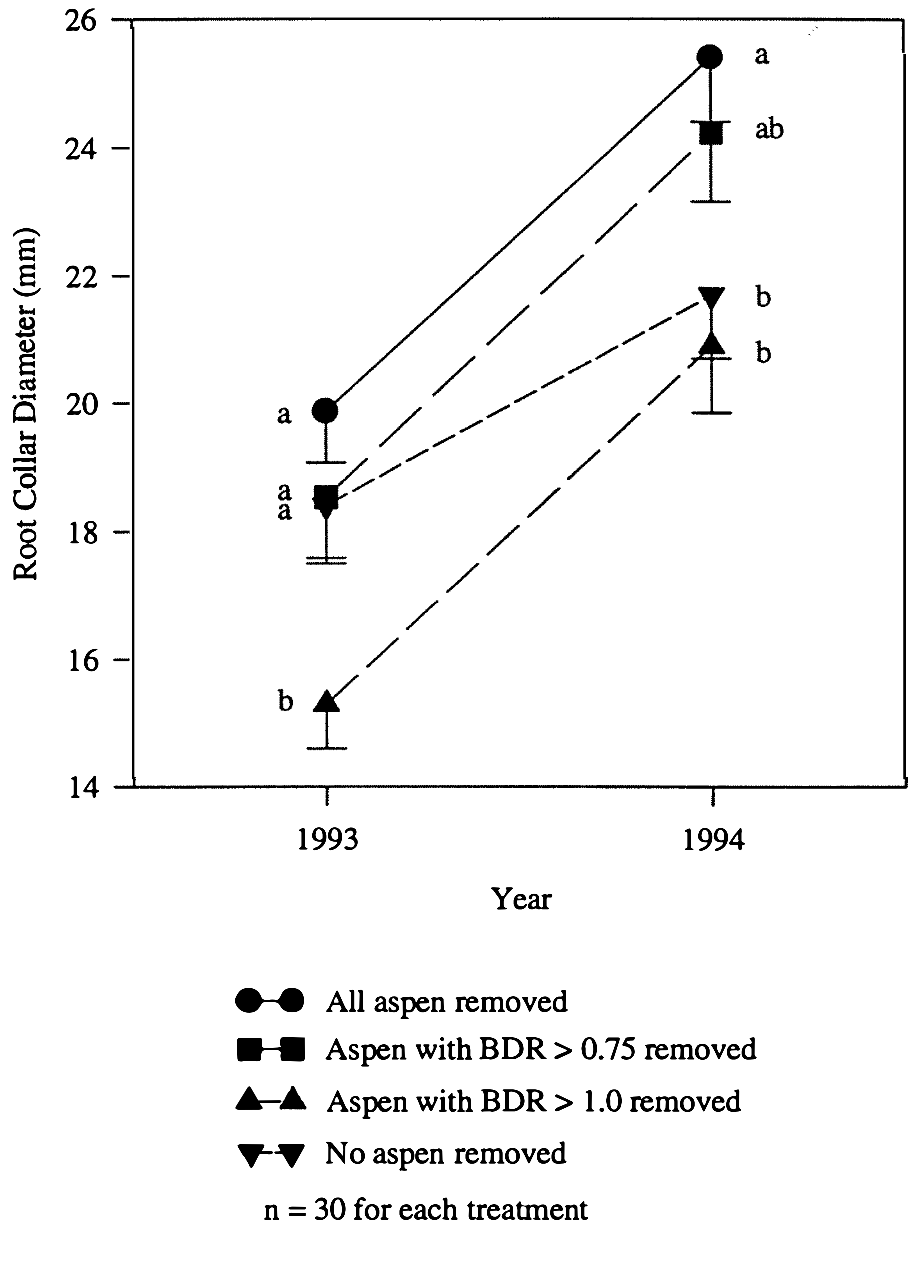
n = 30 for each treatment

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 3

Change in Lodgepole Pine RCD - Block 2

By Treatment

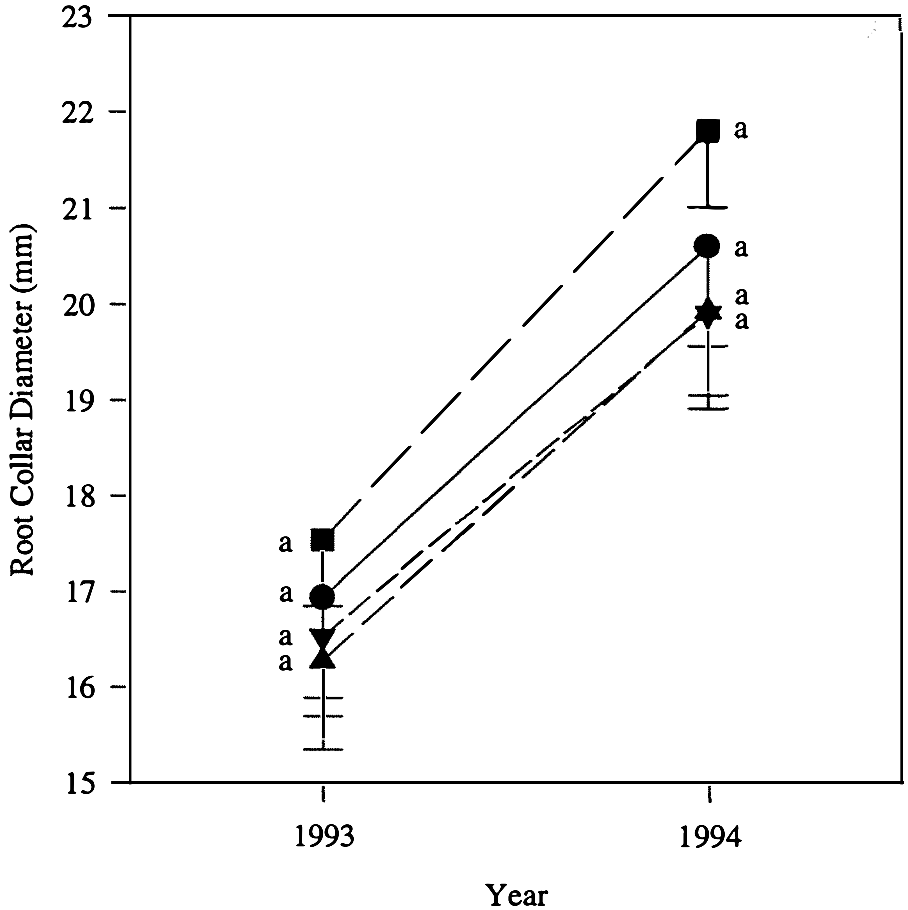


Standard error of the mean shown (lower interval only).
Similar letters for the same year indicate means not significantly different, at P=0.05 using Ryan et al's Multiple Range Test.(SAS Institute Inc. 1990).

Figure 4

Change in Lodgepole Pine RCD - Block 3

By Treatment



●-● All aspen removed

■-■ Aspen with BDR > 0.75 removed

▲-▲ Aspen with BDR > 1.0 removed

▼-▼ No aspen removed

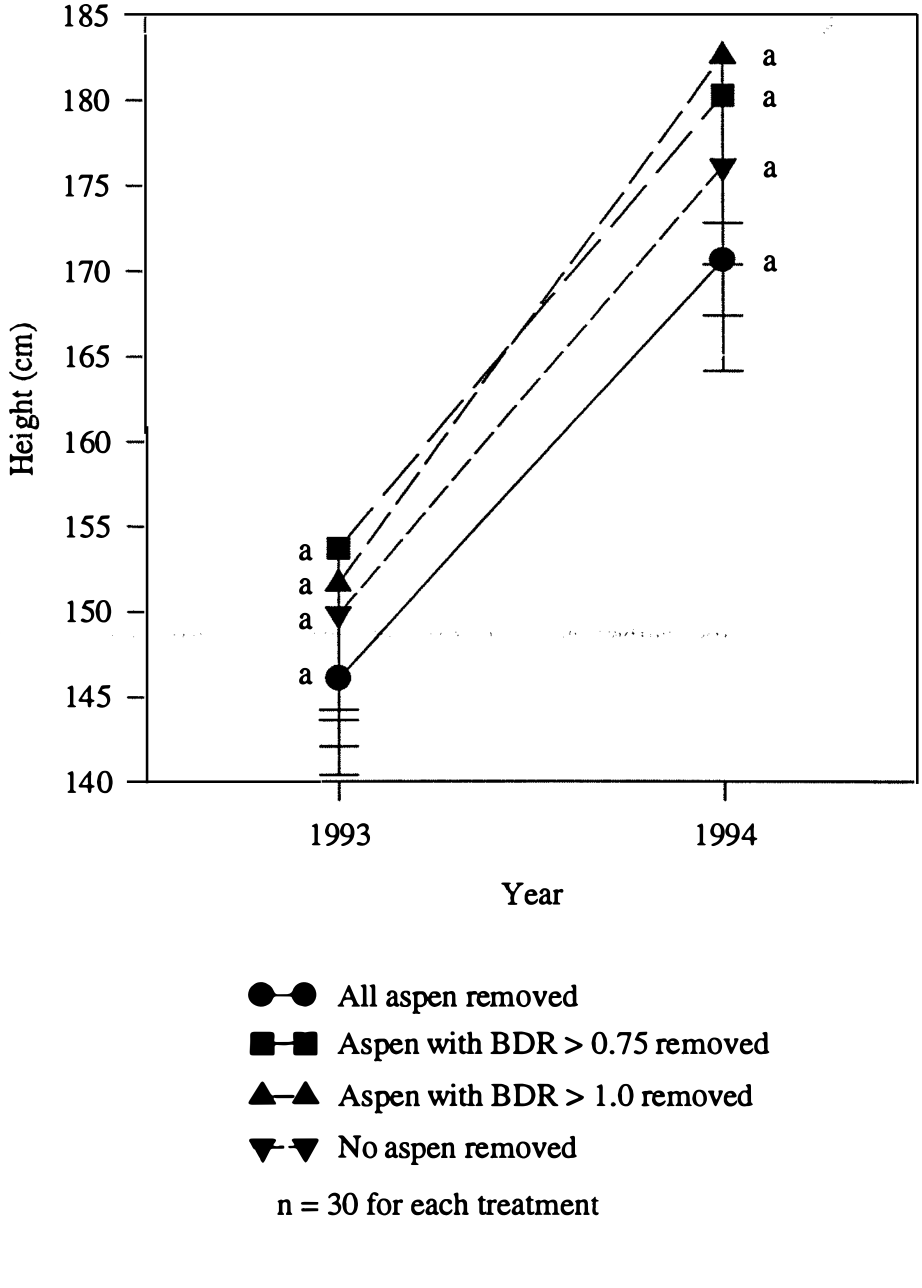
n = 30 for each treatment

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 5

Change in Lodgepole Pine Height - Block 1

By Treatment

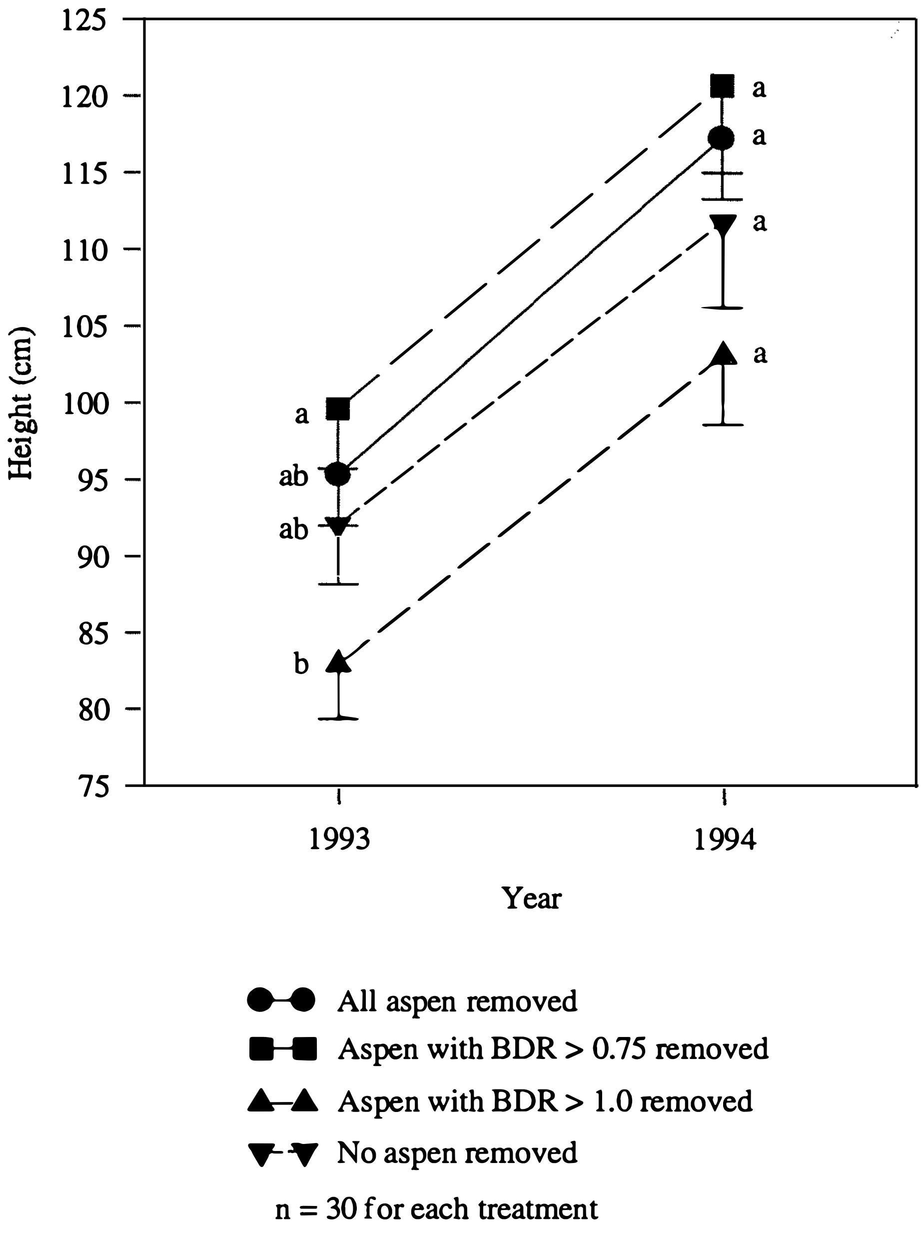


Standard error of the mean shown (lower interval only).
Similar letters for the same year indicate means not significantly different, at P=0.05 using Ryan et al's Multiple Range Test.(SAS Institute Inc. 1990).

Figure 6

Change in Lodgepole Pine Height - Block 2

By Treatment

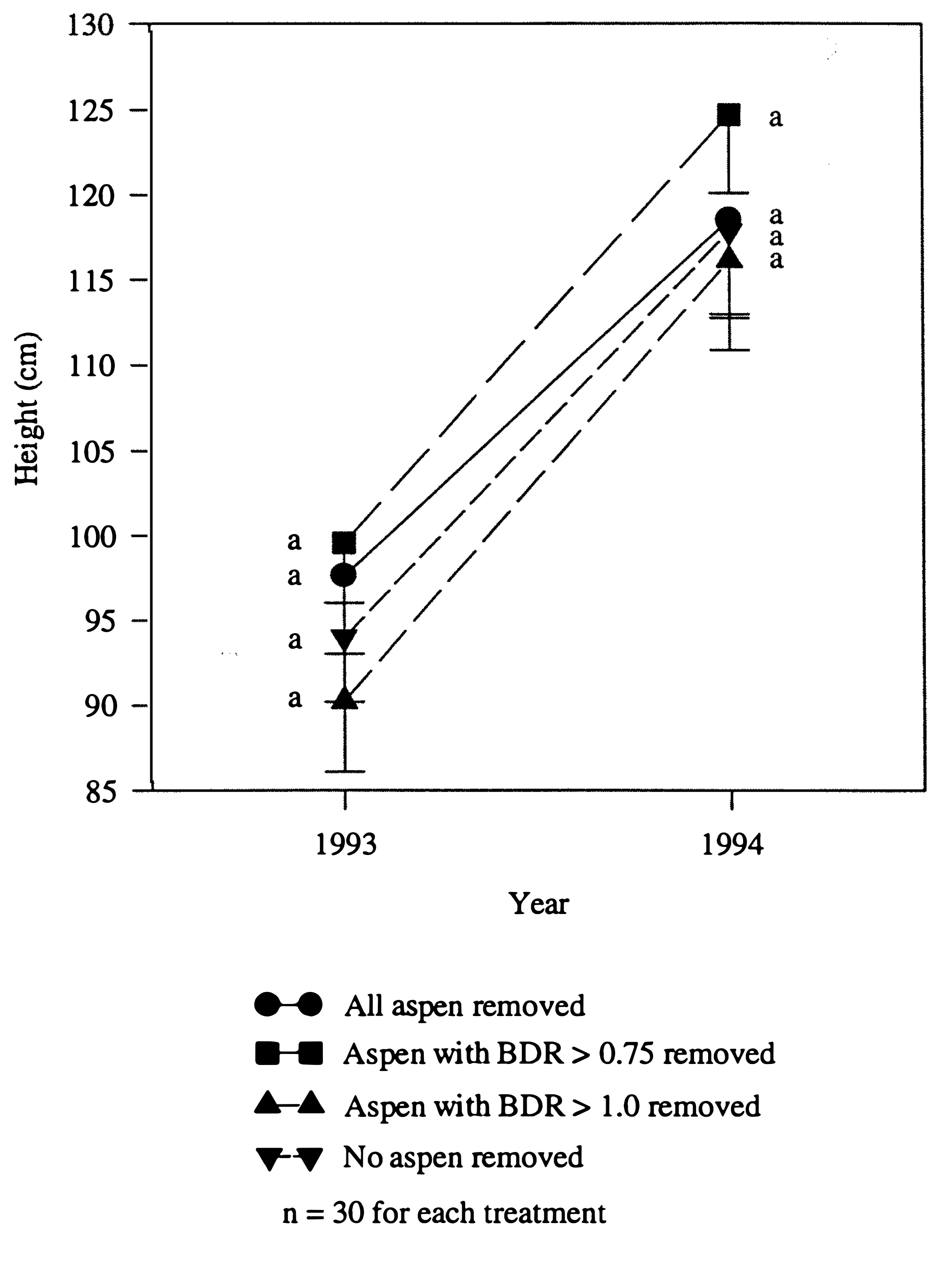


Standard error of the mean shown (lower interval only).
Similar letters for the same year indicate means not significantly different, at P=0.05 using Ryan et al's Multiple Range Test.(SAS Institute Inc. 1990).

Figure 7

Change in Lodgepole Pine Height - 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).

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.

In 1993, during block selection and plot layout, some minor damage to regenerating pine trees in the area had been noted. Target trees were then selected which did not have any visible damage. In 1994, it was observed that in fact some of the target trees had died. Based on this concern, a subjective classification of damage severity and damaging agent was recorded for each tree (Table 13). Over 70% of all trees in each block did not show any signs of damage or disease. In damaged trees, Armillaria root rot fungus was noted as one of the causes of damage. Armillaria-induced mortality had a maximum occurrence of 4% (5 trees out of 120 plots) in block 1. There is a concern that this mortality could increase substantially over time. While the major Armillaria food source is 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 substantially influence the spread of Armillaria. If more pine trees die in subsequent years, modified analysis may be required, such as analysis of variance for unbalanced data (Shaw and Mitchell-Olds 1993). As well, analysis may be required which correlates the amount of observed damage with tree vigour.

CONCLUSIONS

1. The competition in each block prior to harvest was uniform, except for subblocks 3 in block 3 which had a significantly greater density of aspen.

2. After one year of post-treatment growth, there were significant differences in radial growth response between removal of all aspen and removal of no aspen. Pine growing in plots where no aspen had been removed showed significantly less radial growth compared to all other treatments. There was no significant difference in growth response for the two intermediate treatments. This may be in part because, in some cases, the remaining levels of aspen competition were not significantly different between these two treatments.

3. After one year of post-treatment growth, there was no significant difference in height growth between any of the treatments.

Table 13
Number of Damaged Target Lodgepole Pine Trees in 1994
Block 1

Most Prevalent Damage[2]	Damage Severity[1]				Total		Dead Trees
	None	Slight	Moder-ate	Severe	N	%	
No Damage	84	.[3]	.	.	84	70.6	.
Armillaria	.	.	1	7	8	6.7	5
Broken/Damaged Leader	1	2	3	.	6	5.0	.
Broken/Damaged Branches	.	9	4	1	14	11.8	.
Needle Cast (cause not defined)	.	3	.	.	3	2.5	.
Damaged Base/Stem (girdling)	.	.	.	.	.	.	.
Chlorosis (cause not defined)	.	3	1	.	4	3.4	.
Total	85	17	9	8	119[4]	100	5

Block 2

Most Prevalent Damage	Damage Severity				Total		Dead Trees
	None	Slight	Moder-ate	Severe	N	%	
No Damage	94	.	.	.	94	78.3	.
Armillaria	.	.	.	4	4	3.3	3
Broken/Damaged Leader	1	2	3	1	7	5.8	.
Broken/Damaged Branches	.	5	.	.	5	4.2	.
Needle Cast (cause not defined)	.	.	.	.	.	.	.
Damaged Base/Stem (girdling)	.	1	.	.	1	0.8	.
Chlorosis (cause not defined)	.	6	1	2	9	7.5	.
Total	95	14	4	7	120	100	3

Table 13(cont'd)
Block 3

Most Prevalent Damage	Damage Severity				Total		Dead Trees
	None	Slight	Moder-ate	Severe	N	%	
No Damage	100	1	.	.	101	84.2	.
Armillaria	.	.	.	3	3	2.5	3
Broken/Damaged Leader	.	3	.	.	3	2.5	.
Broken/Damaged Branches	.	1	2	.	3	2.5	.
Needle Cast (cause not defined)	.	2	.	.	2	1.7	.
Damaged Base/Stem (girdling)	.	.	1	.	1	0.8	.
Chlorosis (cause not defined)	.	5	2	.	7	5.8	.
Total	100	12	5	3	120	100	3

[1]Based on a subjective evaluation.
[2]While trees may have had damage from multiple sources, only the dominant damage was recorded.
[3]A "." indicates none in that category.
[4]Damage was not recorded for one plot.

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Appendix 1
Sample Data Collection Field Sheet for 1993

1993 BASAL DIAMETER RATIO CI VALIDATION (FOOTHILLS FOREST)

BLOCK __ SUBBLOCK __ PLOT ___ DATE: ____ ____ 1993 OBSERVERS________________________________

ASPEN REMOVAL: ____(1=All 2=BDR >1.0 3=BDR >0.75 4=None) Aspen Density ___ After Removal ___
MARLBORO WORKING CIRCLE COMPARTMENT _____ CUTBLOCK _____

Site Quality _____ Planted _____ Etiolation ____ Forb Crowding ____

Dist/Dir from Prev Grid Point: ______ Prev Plot Num:___ Dist/Dir from Grid Point:_____
Closest Residual (Distance, Species, live/dead)___________

PLOT INFORMATION

	Trees				Shrubs >50cm				Other Spp			Major Herbs &Low Shrubs	
	Sp	Ht	Cov	Num	Sp	Ht	Cov	Num		Ht	Cover	Spp	Cover
Moist. ______	All	___	___	___	All	___	___	___	Low Shrub	___	___	___	___
Drain. ______	Pico1	___	___	___	___	___	___	___	Forb	___	___	___	___
Micro. ______	Pico2	___	___	___	___	___	___	___	Grass	___	___	___	___
LFH(cm) ______	___	___	___	___	___	___	___	___	Moss		___	___	___
Aspect ______	___	___	___	___	___	___	___	___	Lichen		___	___	___
%Slope ______												___	___
Position _____												___	___
Slash ______												___	___

Ht to nearest 5 cm, cover to nearest 5%. Plot is 1.78m radius. Pico1 includes subject tree, Pico2 excludes subject tree.

SUBJECT, TALLEST AND CLOSEST CONIFER AND HARDWOOD (ALWAYS INCLUDE ASPEN)

	Sp	Cd	Az	Damage Code	Ht	Crown Ht	Crown Rad	% OT	RCD	STIN Dist	STST Dist	STOUT Dist	Age *=est	Height Increments 93	92	91	90	89
Con	Pico	1		___	___	___	___	___	___	___	___	___	___	___	___	___	___	___
	___	___	___	___	___		___		___	___	___	___	___	___	___	___	___	___
	___	___	___	___	___		___		___	___	___	___	___	___	___	___	___	___
Hdwd	___	___	___	___	___		___		___	___	___	___	___	___	___	___	___	___
	___	___	___	___	___		___		___	___	___	___	___	___	___	___	___	___
	___	___	___	___	___		___		___	___	___	___	___	___	___	___	___	___
	___	___	___	___	___		___		___	___	___	___	___	___	___	___	___	___

REMAINING TALLEST AND CLOSEST ASPEN

Cd	Az	Damage Code	Ht	Crown Rad	RCD	STIN Dist	STST Dist	STOUT Dist	Height Increments 93	92	91	90	89
___	___	___	___	___	___	___	___	___	___	___	___	___	___
___	___	___	___	___	___	___	___	___	___	___	___	___	___

Tree Codes: 1-Subject 2-Tallest 3-Closest 4-Tallest & Closest.
Damage codes: 1a-frost(no growth) 1b-frost(leader growth) 1c-frost(lateral growth)
2- desiccation 3-browse 4-mechanical *** include how many years since damage
Heights, htincs, crown heights & distances to nearest cm. RCD in mm. OT to nearest 10%.
With increments, ? means can't determine, - means tree too young.

Appendix 2
Sample Data Collection Field Sheet for 1994

1994 BASAL DIAMETER RATIO CI VALIDATION (FOOTHILLS FOREST)

Block __ Subblock __ Plot ___ Date: ____ ____ 1994 Observer: _________ Recorder: _________

Aspen Removal: ____ (1=All 2=BDR >1.0 3=BDR >0.75 4=None)
Etiolation _____ Herb/Shrub Crowding _____ Subject Tree Vigour: ____
Disease/Insect/Mechanical Damage:Severity: _____ Type/Where: ______________________

PLOT INFORMATION

Trees (all sizes)								Aspen Density in Quadrants
Species	Num	Ht	Cov	Species	Num	Ht	Cov	N / E / S / W
Pl				Pb				____ / ____ / ____ / ____
Pl2				Fb				Count stems on stump as 1, then, count as individuals (in brackets).
At				Sw				
				All				
Pl includes subject tree. Pl2 and All exclude subject tree								

SUBJECT, TALLEST AND CLOSEST CONIFER AND HARDWOOD (ALWAYS INCLUDE ASPEN)

	Sp	Cd	Az	Ht (cm)	Crown Ht Rad (cm)	% OT	RCD (mm)	STIN Dist (cm)	STST Dist (cm)	STOUT Dist (cm)	Height Increments 94 93 92 91 90 (cm)
Con	Pl	1									
Hdwd											

Block __ Subblock __ Plot ___ Date: ____ ____ 1994 Observer: _________ Recorder: _________

Aspen Removal: ____ (1=All 2=BDR >1.0 3=BDR >0.75 4=None)
Etiolation _____ Herb/Shrub Crowding _____ Subject Tree Vigour: ____
Disease/Insect/Mechanical Damage:Severity: _____ Type/Where: ______________________

PLOT INFORMATION

Trees (all sizes)								Aspen Density in Quadrants
Species	Num	Ht	Cov	Species	Num	Ht	Cov	N / E / S / W
Pl				Pb				____ / ____ / ____ / ____
Pl2				Fb				Count stems on stump as 1, then, count as individuals (in brackets).
At				Sw				
				All				
Pl includes subject tree. Pl2 and All exclude subject tree								

SUBJECT, TALLEST AND CLOSEST CONIFER AND HARDWOOD (ALWAYS INCLUDE ASPEN)

	Sp	Cd	Az	Ht (cm)	Crown Ht Rad (cm)	% OT	RCD (mm)	STIN Dist (cm)	STST Dist (cm)	STOUT Dist (cm)	Height Increments 94 93 92 91 90 (cm)
Con	Pl	1									
Hdwd											

Appendix 3.1
Tree and Shrub Density for 1993[1]
by Block and Subblock

	Aspen Before Removal	Lodgepole Pine	White Spruce	Balsam Fir	Tall shrub (> 50 cm)
Block 1					
Subblock 1	19.6±9.2[2]	1.3 ±0.6	1.3 ±2.2	7.5 ±5.8	12.0 ±10.3
Subblock 2	23.6 7.7	1.3 0.5	0.1 0.3	1.6 2.8	9.8 9.2
Subblock 3	20.0 8.1	1.6 1.1	0.8 1.3	2.7 4.1	13.3 11.8
Total	21.0 8.5	1.4 0.8	0.7 1.5	3.9 5.1	12.2 10.6
Block 2					
Subblock 1	25.7 10.8	2.4 2.2	0.1 0.2	2.3 3.7	16.0 14.1
Subblock 2	24.9 13.6	2.7 2.6	0.1 0.4	0.8 1.6	28.7 19.9
Subblock 3	21.0 9.2	2.5 2.2	0.2 0.4	0.9 1.5	12.5 2.1
Total	23.9 11.5	2.5 2.3	0.1 0.4	1.3 2.6	20.4 15.1
Block 3					
Subblock 1	26.2 9.4	2.2 1.8	0.0 0.0	2.6 3.4	22.5 4.9
Subblock 2	25.9 10.7	3.2 2.5	0.0 0.0	1.1 2.2	17.3 11.4
Subblock 3	43.4 21.3	3.0 1.7	0.1 0.5	0.9 2.1	5.7 3.7
Total	31.8 16.8	2.8 2.1	0.0 0.3	1.6 2.7	12.4 9.9

[1]Density data not collected for total tree, low shrub, forb or grass. There is a minor component of white birch in block 1 (cover less than 1%).
[2]Standard deviation.

Appendix 3.2
Average Cover for 1993 by Block and SubBlock

	Aspen Before Removal	Lodgepole Pine	White Spruce	Balsam Fir	Total Tree[1]	Tall Shrub (> 50 cm)	Low Shrub (< 50 cm)	Forb	Grass
Block 1									
Subblock 1	46.4 ±19.9[2]	1.9 ±1.0	0.5 ±0.9	5.8 ±3.9	50.6 ±3.1	3.1 ±3.7	5.7 ±6.5	22.3± 14.2	4.6±7.5
Subblock 2	48.9 19.8	1.8 1.2	0.0 0.0	1.4 2.6	52.0 3.2	1.9 2.3	4.9 5.6	14.3 12.2	7.5 8.0
Subblock 3	56.6 17.5	1.7 1.1	0.1 0.2	1.5 2.6	58.8 2.8	2.7 2.7	4.4 4.1	22.7 14.6	13.9 19.0
Total	50.7 19.4	1.8 1.1	0.2 0.6	2.9 3.7	53.8 19.3	2.6 3.0	5.0 5.5	19.8 14.2	8.7 13.1
Block 2									
Subblock 1	42.6 18.3	1.2 1.1	0.0 0.0	1.1 2.0	43.9 17.7	0.8 2.8	3.1 2.3	5.3 3.2	11.6 6.9
Subblock 2	34.8 16.5	1.1 0.8	0.1 0.3	0.4 1.1	34.8 16.6	0.9 2.0	2.8 3.0	6.5 2.4	10.3 5.7
Subblock 3	35.9 17.0	0.9 0.7	0.0 0.0	0.4 0.9	35.9 17.0	0.9 2.0	2.9 2.1	6.9 2.8	8.0 5.4
Total	37.8 17.5	1.1 0.9	0.0 0.2	0.6 1.4	38.2 17.5	0.9 2.3	2.9 2.5	6.2 2.9	10.0 6.2
Block 3									
Subblock 1	47.9 16.1	1.4 0.8	0.0 0.0	2.6 3.9	50.2 15.3	2.2 2.9	12.1 9.6	13.8 8.4	17.4 10.2
Subblock 2	51.4 17.3	2.4 1.6	0.0 0.0	1.1 2.4	53.0 16.8	3.1 2.9	14.0 9.3	21.6 9.9	19.8 11.0
Subblock 3	47.8 12.9	1.2 0.6	0.0 0.0	0.5 1.5	48.9 12.7	1.0 2.0	8.7 7.5	12.5 6.0	9.7 7.5
Total	49.0 15.5	1.7 1.2	0.0 0.0	1.4 2.9	50.3 15.0	2.1 2.8	11.6 9.0	16.0 9.1	15.6 10.5

[1]Density data not collected for total tree, low shrub, forb or grass. There is a minor component of white birch in block 1 (cover less than 1%).
[2]Standard deviation.

Appendix 3.3
Average Height for 1993 by Block and Subblock

	Aspen Before Removal	Lodgepole Pine	White Spruce	Balsam Fir	Total Tree[1]	Tall Shrub (> 50 cm)	Low Shrub (< 50 cm)	Forb	Grass
Block 1									
Subblock 1	269.0[2]±43.4[3]	139.7 ±45.3	32.1 ±45.3	81.1 ±29.8	243.6±43.1	79.8 ±31.1	21.0 ±12.1	13.3±7.1	29.2±14.3
Subblock 2	243.7 43.4	142.6 41.4	22.7 4.6	74.9 38.4	230.0 41.2	58.4 13.9	27.1 8.7	21.9 11.5	44.2 17.5
Subblock 3	276.5 51.9	132.0 51.9	28.3 10.2	52.7 19.5	244.4 45.3	81.0 36.3	25.7 9.1	17.7 7.9	38.9 12.9
Total	263.1 48.1	138.1 46.2	29.6 15.3	71.6 31.6	239.3 43.4	73.8 30.8	24.6 10.4	17.6 9.6	37.4 16.2
Block 2									
Subblock 1	238.5 45.7	86.6 27.0	27.0 1.4	83.5 25.2	222.4 47.0	111.9 76.7	27.9 7.1	22.4 8.7	38.0 8.5
Subblock 2	220.0 38.0	84.6 23.3	75.0 54.5	87.6 34.6	191.6 39.0	117.7 53.1	23.2 8.1	17.3 5.8	40.0 11.7
Subblock 3	251.6 52.6	75.9 23.8	24.6 8.5	66.1 26.8	212.9 53.6	75.0 23.8	28.4 7.7	17.1 4.7	38.4 7.9
Total	236.7 47.3	82.4 25.0	43.4 39.4	77.9 28.8	209.0 48.3	101.5 57.4	26.5 7.9	18.9 7.0	38.8 9.5
Block 3									
Subblock 1	202.8 36.5	82.3 23.9	-[4]	78.9 34.2	187.9 34.0	76.6 27.6	17.1 8.5	19.2 7.4	62.9 20.0
Subblock 2	236.9 47.9	88.8 32.8	-	67.5 24.8	223.9 51.6	79.2 27.2	20.2 9.9	13.0 6.6	64.0 15.9
Subblock 3	255.2 30.8	79.4 21.2	17.0 6.1	55.1 21.7	240.1 31.5	88.3 33.2	30.8 9.7	32.4 10.7	43.4 12.7
Total	231.6 44.5	83.5 26.5	17.0 6.1	69.0 30.0	217.3 45.3	80.6 29.0	22.7 11.0	21.5 11.7	56.8 18.9

[1]There is a minor component of white birch in block 1 (cover less than 1%).
[2]NOTE: The mean and standard deviation are based on those plots for which there is a height value, so sample size does not include all plots.
[3]Standard deviation.
[4]There are no white spruce trees in this subblock.