

**JUVENILE GROWTH OF WHITE  
SPRUCE AND DECIDUOUS COMPETITION  
ON MIXEDWOOD SITES IN ALBERTA**

1996

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## 1.0 INTRODUCTION

The increase in aspen density and shift from conifer to mixed regeneration after harvesting mixedwood and softwood cover types documented by the Alberta's Juvenile Stand Survey<sup>1</sup> have raised concerns about its potential impact on softwood production and has lead to the development of regeneration standards<sup>2</sup>.

To fulfil the requirements of regeneration standards and to secure successful development of juvenile coniferous stands two knowledge pathways are necessary:

- a) Knowledge of the competition thresholds that affect free-to-grow status and juvenile growth of conifers.
- b) Vegetation management methods that can economically maintain juvenile conifer stands.

The understanding of competition thresholds can in turn be used for the justification and best design (e.g., timing and intensity) of vegetation management treatments (e.g., release). The formulation of reliable competition thresholds is, in general, difficult and very little information can be applied from the studies in other regions (Burton 1993). A previous Canadian Forest Service study had addressed aspen-lodgepole pine competition in west-central Alberta (Navratil and MacIsaac 1993). The study presented in this report expanded that work to deal with hardwood-white spruce competition. Nineteen mixedwood blocks in four geographic areas of central and west-central Alberta were sampled using a retrospective approach.

The objective of the study was to define the relationship between competition levels induced by deciduous species (aspen and balsam poplar) and white spruce growth in mixed juvenile stands. An ultimate objective was to develop measures of hardwood competition that could predict spruce growth under increasing levels of competition.

The emphasis on plantation-style management is being replaced by the increasing acceptance of mixed species regeneration and the efforts to find more ecologically-suitable regeneration methods (Brand 1992). We recognized this need. For the same reason we adopted a descriptive and detailed approach in presenting the results and findings from our study rather than offering a tool for hard and fast decisions on tending treatments. We believe that in this format information will be more useful for potential modelling of mixed stands dynamics and for adaptive management of mixed regeneration and juvenile mixed stands.

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<sup>1</sup> Transcript of talk, March 26, 1991, by C.J. Henderson to the 72nd annual meeting of the Canadian Pulp and Paper Association, Woodlands Section, held in Montreal, Quebec.

<sup>2</sup> Unpublished report, 1990, by Reforestation Branch, Alberta Forest Service, Edmonton.

## 2.0 METHODS

### 2.1 SITE DESCRIPTION

Initial block reconnaissance was conducted in conjunction with the Alberta Land and Forest Service and industry personnel in the Slave Lake, Whitecourt, Edson, Grande Prairie and Rocky Mountain forests. This was to select research sites for a variety of mixedwood stands throughout the province, and to develop information on regional competition problems. Four separate areas were selected for study: Kakwa River, Saddle Hills, Rocky Mountain House and Calling Lake (Figure 1 and Table 1), encompassing the Lower Foothills and Central Mixedwood Natural Subregions<sup>3</sup>. The chosen sites were presumed to represent the competition status of white spruce in mixed regeneration in Alberta. Blocks had been harvested in the late 1970's to early 1980's, and were mostly site prepared with the Bräcke or Leno scarifier (Table 2).

Most of the sites were mesic and moderately well-drained, and on a subjective basis, were deemed to have generally good site quality (Table 3). In terms of microtopography, many of the sites were slightly mounded and, on a subjective basis, slash abundance was light to medium (Table 4). While there was variability in microsite conditions within each block, in every block the majority of plots were within a single microsite class for a given variable.

### 2.2 FIELD DATA COLLECTION

The criteria for block selection was sufficiently high stocking levels for both conifer and hardwoods (based on the regeneration survey information from the Alberta Land and Forest Service), reasonable access, and a sufficient range of hardwood competition levels (density and cover) throughout the block (i.e., open and dense areas) to measure conifer tree response. Blocks which had been stand tended were not selected for study. In all sites, planted blocks were selected, although this was not a strict requirement in the block selection. The post-harvest ages of the sampled blocks ranged between 10 and 16 years, except for one 20 year old block in the Rocky Mountain House area (Table 2), which had been planted 10 years after harvest.

Hardwood regeneration was not uniform in most of the blocks, so specific portions of the block which contained hardwood competitors were delineated for sampling. Placement of competition plots within these subareas was based on a uniform 20m by 20m grid, with a random starting point. If the subarea was small, a 20m (between lines) by 10m (between plots) grid was used. At each point on the grid, the closest white spruce (target)<sup>4</sup> tree was used for the plot centre. If a suitable target tree was not found within 5m of the sampling grid, then there was no plot placed at that grid point. The plots had a fixed 2m radius (12.56 m<sup>2</sup>). A size larger than the standard milhectare 10 m<sup>2</sup> plot was

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<sup>3</sup> 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.

<sup>4</sup> In this report, the terms "target tree" and "crop tree" are used synonymously.

**Figure 1**  
**Study Sites**



▲ = study sites



**Table 1**  
Block Location Information

Natural Region <sup>1</sup>	Area	Blocks	Location
Lower Foothills	Kakwa River	1-2	100 km south of Grande Prairie
Lower Foothills	Saddle Hills	1-5	west end of Saddle Hills
Lower Foothills	Rocky Mountain House	1	southwest of RMH near Swan Lake
		2	15 km west of RMH on Hwy 11
		3	50 km west of RMH on Hwy 11 (Jackfish Lake)
		4	50 km west of RMH on Hwy 11 (Jackfish Lake)
		5	40 km west of RMH on Hwy 11 (Jackfish Lake)
		6	21 km south of RMH on Hwy 22, then 11 km west
Central Mixedwood	Calling Lake	1-2	10 km northeast of Calling Lake
		3-7	10 km southwest of Calling Lake

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

**Table 2**  
Harvest and Silviculture Information

Area	Block	Forestry Block No.	Plots	Harvest Year	Site Preparation Year/Type	Planted Year/Stock
Kakwa River	1	G7LIC BK 1273	47	1978	ripper or blade	1981
	2	G7LIC BK 1296	<u>33</u>	1978	ripper or blade	1979
	Total		80			
Saddle Hills	1	P&G BK 0036	29	1979	1979 none	1980
	2	P&G BK 0025	48	1977	1979 drag/Bräcke	1980
	3	P&G BK 0020	44	1979	1979 none	1980
	4	P&G BK 0023	49	1980	1980 none	1980
	5	P&G BK 0015	<u>4</u>	1981/82	1982 none	1982
	Total		174			
Rocky Mtn. House	1	R9L24 BK 4	53	1973	1982 Bräcke	1983 container <sup>1</sup>
	2	R1C45 BK 16	50	1982	1983 Bräcke	1983 container
	3	R5L25 BK 14	50	1983	1984 Leno	1984
	4	R5L25 BK 13	50	1983	1984 Leno	1985 container
	5	R5L25 BK 18	30	1983	1983 none	83/84 container
	6	R7C52 BK 20	<u>55</u>	1983	1984 Bräcke	1985 container
	Total		288			
Calling Lake	1	MOF BK6 80	50	Dec. 80	Sept 81 Bräcke	June 82 container
	2	MOF BK5 80	38	Dec. 80	July 81 Bräcke	July 81 container
	3	MOF BK1 82	43	Dec. 82	Sept 83 Bräcke	June 84 bareroot
	4	MOF BK6 82	50	Dec. 82	Sept 83 Bräcke	June 84 bareroot
	5	MOF BK3 82	42	Dec. 82	Sept 83 Bräcke	June 84 bareroot
	6	MOF BK4 81	52	Dec. 81	Aug 82 Bräcke	May 83 container
	7	MOF BK6 82	<u>52</u>	Dec. 82	Sept 83 Bräcke	June 84 bareroot
	Total		327			

1. Container seedlings from early 1980's were usually 3-0 stock.

**Table 3**  
Microsite Conditions For Moisture, Drainage and Site Quality

Location	Block	Moisture <sup>1</sup> Class		Drainage <sup>1</sup> Class		Site Quality <sup>2</sup> Class	
		dominant (%) <sup>3</sup>	secondary (%)	dominant (%)	secondary (%)	dominant (%)	secondary (%)
Kakwa River	1	mesic 66	submesic 28	mod-well 52	well 41	medium 60	good 30
	2	mesic 89	submesic 6	mod-well 50	well 49	good 77	v. good 12
	All	mesic 76	submesic 19	mod-well 51	well 46	good 49	medium 39
Saddle Hills	1	mesic 81	submesic 12	mod-well 59	well 31	good 46	medium 33
	2	mesic 71	submesic 26	well 58	mod-well 38	good 74	medium 16
	3	mesic 91	submesic 6	mod-well 66	well 35	good 75	medium 15
	4	mesic 89	submesic 10	well 52	mod-well 47	good 73	medium 18
	5	mesic 100	-	mod-well 50	well 50	good 100	-
	All	mesic 83	submesic 14	mod-well 51	well 46	good 71	medium 19
Rocky Mountain House	1	mesic 59	subhygric 21	well 66	imperfect 28	good 75	v. good 19
	2	mesic 41	submesic 32	well 56	imperfect 24	good 88	medium 6
	3	subhygric 50	hygric 34	well 54	mod-well 36	v. good 62	good 38
	4	mesic 80	subhygric 14	mod-well 68	well 26	good 98	v. good 2
	5	mesic 68	subhygric 15	mod-well 77	imperfect 13	good 76	v. good 20
	6	mesic 71	submesic 29	mod-well 100	-	good 100	-
	All	mesic 55	subhygric 17	mod-well 49	well 37	good 81	v. good 17
Calling Lake	1	mesic 59	submesic 31	mod-well 67	well 24	good 74	medium 14
	2	mesic 87	submesic 6	mod-well 89	well 6	good 86	medium 10
	3	mesic 76	submesic 12	mod-well 82	well 12	good 84	v. good 10
	4	mesic 96	subxeric 2	mod-well 94	well 4	good 89	v. good 7
	5	mesic 89	subhygric 7	mod-well 93	imperfect 6	good 88	v. good 9
	6	mesic 80	subhygric 12	mod-well 71	well 19	good 85	medium 13
	7	mesic 99	subhygric 1	mod-well 96	well 2	good 97	v. good 2
	All	mesic 83	submesic 10	mod-well 84	well 10	good 86	v. good 7

1. Classes from Describing ecosystems in the field, 2nd ed. (Luttmerding et al. 1990).

2. Classes from subjective evaluation.

3. Percentage of plots in a block with a specific microsite class.

**Table 4**  
Microsite Conditions For Microtopography, Slash Abundance and Planting Microsite

Location	Block	Microtopographic Mounding <sup>1</sup>		Slash Abundance <sup>2</sup>		Planting Microsite <sup>2</sup>	
		dominant (%) <sup>3</sup>	secondary (%)	dominant (%)	secondary (%)	dominant (%)	secondary (%)
Kakwa River	1	slightly 91	strongly 6	light 57	medium 36	* <sup>4</sup>	*
	2	slightly 73	strongly 15	light 52	medium 36	*	*
	All	slightly 84	strongly 10	light 55	medium 36	*	*
Saddle Hills	1	slightly 97	smooth 3	light 72	none 17	*	*
	2	slightly 65	strongly 31	medium 48	light 42	*	*
	3	slightly 80	strongly 16	light 57	medium 32	*	*
	4	slightly 76	strongly 22	medium 45	light 39	*	*
	5	slightly 100	-	light 75	medium 25	*	*
	All	slightly 78	strongly 19	light 51	medium 36	*	*
Rocky Mountain House	1	slightly 58	strongly 42	light 52	medium 29	*	*
	2	slightly 62	strongly 26	medium 48	light 28	*	*
	3	slightly 62	strongly 32	medium 51	light 36	*	*
	4	slightly 46	strongly 44	light 50	medium 40	*	*
	5	slightly 60	strongly 20	medium 47	light 40	*	*
	6	slightly 73	smooth 25	medium 55	light 36	*	*
	All	slightly 60	strongly 28	medium 44	light 40	*	*
Calling Lake	1	*	*	none 54	light 37	hinge 72	trench 14
	2	*	*	light 45	none 39	hinge 68	trench 16
	3	*	*	none 48	light 41	hinge 51	flat 30
	4	*	*	light 50	none 26	hinge 44	trench 22
	5	*	*	light 52	none 40	hinge 43	berm 36
	6	*	*	light 61	medium 23	hinge 67	flat 15
	7	*	*	light 67	none 21	hinge 52	trench 23
	All	*	*	light 50	none 34	hinge 57	flat 17

1. Classes from Describing ecosystems in the field, 2nd ed. (Luttmerding et al. 1990).
2. Classes from subjective evaluation.
3. Percentage of plots in a block with a specific microsite class.
4. Data not collected.

used, because inferences about the appropriate competition neighborhood could not be made *a priori*. Selected saplings were replaced with the next closest target tree if damage unrelated to competition pressure was noted.

A white spruce tree was selected as a target tree if it had at least five years of growth, and was not of advance regeneration origin. As well, it could not have major or recent damage due to mechanical agents (e.g., snow press, leader whip), herbivores, insects and/or disease. All sizes of white spruce trees were used, subject to the aforementioned criteria.

A total of 19 blocks were sampled overall. In each location, the following number of detailed white spruce-hardwood competition plots were measured: Kakwa River - 80, Saddle Hills - 174, Rocky Mountain House - 288, Calling Lake - 327.

Three types of detailed measurements were made in the 2 m radius conifer target-tree centred competition plots:

- a) Vegetation data collected on a plot-level basis. This included average heights, cover and density of different species.
- b) Microsite variables estimated on a plot-level basis.
- c) Mensuration data collected for individual trees and shrubs.

Average crown cover (% of the plot area covered by the foliage) and height was estimated for each tree species, shrubs, forbs (broadleaf, non-woody plants), grass, moss and lichen. Stem counts were made of each tree species and shrub clump in the plot. Several other "categorical" variables were collected for each plot, including physical evidence of shading on the conifer tree and the amount of crowding of the conifer tree by grasses and forbs.

Microsite variables were also measured in each plot. These included: moisture class, drainage class, slope position, slope, aspect, microtopography class, slash abundance class, site quality class, and depth of humus. For most microsite variables, the classes were derived from Luttmerding *et al.* (1990).

The following measurements were collected for specific trees and shrubs:

- a) Target tree:
  - height, crown height, crown radius, percent overtopping, root collar diameter, five most recent height increments
- b) Tallest and closest hardwood and conifer in the plot:
  - height, crown radius, stem-to-stem distance from target tree, stem-to-inside crown distance from target tree, azimuth or quadrant from the target tree, root collar diameter, height increments (five most recent for conifer, three most recent for hardwood).
- c) Other trees and shrubs in the plot:
  - height, stem-to-stem distance from target tree, stem-to-inside crown distance from target tree, azimuth or quadrant from target tree

Descriptions of the measured variables are as follows:

- a) Azimuth: (nearest 5°) Bearing from target tree stem at ground level to the competitor stem at ground level.
- b) Total Height: (nearest cm): total height, including current year's growth.
- c) Crown Height: (nearest cm): measured from ground to first branch whorl (3 of 4 branches intact). Used to determine live crown length.
- d) Crown Radius: (nearest cm): the average radius was recorded, average of widest and narrowest crown radii.
- e) Percent Overtopping: (nearest 10%): percentage of the top 1/3 of the target tree that is overtopped by crown foliage of competing tree or shrub. (i.e. the crown of top 1/3 is projected upwards as a cylinder).
- f) Root Collar Diameter: (nearest mm): this was the basal diameter, taken at ground level, above the root collar swelling.
- g) 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.
- h) Stem-Inside Crown Distance: Measured from centre of target tree stem to the nearest edge of the competitor foliage. (Nearest cm for closest and tallest, nearest 5 cm other trees and shrubs).
- i) Height Increments (nearest cm): Used five most recent increments for conifers and three most recent increments for hardwoods, starting with the current year.

As well, a basal disc was collected of the target tree and the tallest hardwood and conifer in the plot for determination of basal age and radial increments. The data was collected after maximum leaf area development of the competing hardwoods and after white spruce height growth had stopped (usually by the third week in July). As diameter growth continues later in the season (Sims *et al.* 1990), disks for root collar diameter measurements were taken in the autumn after cessation of growth.

In the spruce-hardwood systems being studied, competition is considered to be asymmetric (Cannell and Grace 1993) and it is mainly for light. For this reason, measurements of light levels were taken in Rocky Mountain House and Calling Lake. The amount of photosynthetically-active radiation in the 400-700 nm wavelength (PAR) was measured around each target seedling, using a method similar to that reported by Comeau *et al.* 1993. Radiation was recorded using a hand held Sunfleck Ceptometer, with a 40 cm probe (Decagon Devices Inc.), measured on cloudless days, within 2 hours of solar noon. Measurements were taken at the target tree leader tip, and at the mid-crown height. As well, ambient light measurements were recorded in adjacent open areas. At the Calling Lake sites, additional readings were taken 1.5 m from the target tree stem at the mid-crown height, in the following directions from the target tree: east, southeast, south, southwest and west.

## 2.3 ANALYSIS METHODS

A total of 17 conifer tree growth response variables were selected or developed for analysis. They included simple variables and ratios, both size-dependant and size-independent. Some of the variables were: height, height increment, mean 3 year periodic height increment, root collar diameter, radial increment, mean 3 year periodic radial increment, basal area, basal area increment, height:RCD ratio, crown length, and crown radius.

Three additional growth variables, based on basal area increment, were also developed. They were:

- a) ratio of basal area increment:inside bark circumference
- b) ratio of basal area increment:basal stem wood area
- c) ratio of volume increment:basal stemwood

The last variable was modified from Waring *et al.* (1980) and is a good measure of tree vigour for some species. These variables were less size-dependant than some of the more traditional growth response variables and they were more physiologically-based. They were derived from "pipe-model" theory, which states that sapwood area is important to tree vigour (Valentine 1988).

### **2.3.1 Calculation of Competition Variables and Indices**

A literature review was completed on competition indices to choose appropriate dependant growth variables, to include more recent indices in the analysis, and check for appropriate indices. The selected competition indices were further screened for their biological and operational relevance.

The amount of conifer:conifer (intraspecific) and hardwood:conifer (interspecific) competition on a plot-by-plot basis was calculated to determine if intraspecific competition indices should be used, and to determine if aspen was dominant enough in each area so that it could be used to approximate all the hardwood competition. The majority of plots had some conifer present and therefore the competition indices were generated for two data sets: a) including conifers and hardwoods (predominantly aspen) and b) including just hardwoods. The competition indices did not include shrubs, for two reasons: a) At the ages sampled, trees were the dominant competitors. b) There were other competition variables used in the analysis which incorporated shrubs. A total of 16 competition indices were tested. The formulas of the competition indices, as used in this study are in Appendix 1.

The competition indices tested in these studies included those by Daniels (1976), Lorimer (1983), Martin and Ek (1984), Braathe (1989), Brand (1986), Wagner and Radosevich (1987, 1991a, 1991b), MacDonald *et al.* (1990), DeLong (1991), Towill and Archibald (1991), Comeau *et al.* (1993), MacDonald and Weetman (1993) and Navratil and MacIsaac (1993).

Approximately 40 competition and microsite variables were selected or developed for analysis. They included intensive and extensive competition variables (ratios and sums), published and unpublished inter- and intraspecific multivariable variables and microsite variables. Many of the competition variables incorporated not just tree competitors (both hardwoods and conifers) but also shrubs, forbs and grasses (either singly or in combination with trees). They were categorized in the following groups: 10 based on stem density, 13 based on crown cover, 9 based on distance, and 13 variables based on microsite conditions.

### **2.3.2 Statistical Analyses**

A variety of data transformations were used to normalize the data prior to analysis, following the approach outlined in Sabin and Stafford (1990) and Zar (1984). 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 the data stratified by area. There were specific

transformations which consistently improved the distribution towards normality. In general, the following transformations were most appropriate: white spruce increment growth - square root, white spruce size - natural logarithm, competition indices -mostly natural logarithm, density and cover of competitors - mostly square root.

Linear regression analysis was used extensively in this study in order to determine the relationships between competitor and conifer growth. Multiple regression analysis was conducted using all 40 competition variables (assumed for this study to be the "independent" variables). Models were developed using 1 to 7 competition variables. Regression analysis was used to select those competition variables which were associated with the highest coefficient of determination ( $R^2$ ) (i.e, explained the largest amount of observed variation in conifer tree growth), and had operational potential due to ease of measurement. The competition-growth relationships which were the most promising in linear regressions were further analyzed using non-linear regression. This analysis on the selected competition-growth response variables was performed to better describe the relationship between growth and competition.

Of the 19 blocks surveyed, all except one were used in most of the analyses. The exception is Rocky Mountain House Block 1. This block was not used because it was considered an outlier, both in terms of its 20-year age (the rest of the blocks were younger than 16 years when sampled), and in the fact that it was site prepared and planted 10 years after harvest (the rest of the blocks were site prepared and planted within a few years of harvest).

As indicated in Table 2, there were only four plots surveyed in Block 5 in the Saddle Hills. Because of this small sample size, analysis which was based on a block-level basis was not done for Block 5. However, for analysis on an area basis, in which all the blocks are combined, these four plots are included in the analysis.

Most of the data development, statistical analysis and competition modelling work was performed using SAS for VMS and SAS for UNIX version 6 (SAS Institute Inc. 1990). This included linear, multiple linear and non-linear regression analysis. Additional linear and non-linear regression analysis was performed with Tablecurve 2D and 3D for Windows (Jandel Scientific). Data summary and means were generated with QuattroPro for Windows (Borland Inc.).



### **3.0 STATUS OF REGENERATION**

Regeneration information for white spruce was compiled for the 19 blocks which were used in this study, with summaries by geographic area. This information can be compared with ecosite descriptors such as moisture regime, drainage class etc. (Tables 3 and 4) and silvicultural methods such as site preparation (Table 2). The white spruce growth can also be compared with the regeneration performance of hardwood competitors such as balsam poplar (Table 5) and aspen (Table 6). Species composition in terms of density (number/ha), age and height of the conifer species was quantified. The survey grid system used precluded the quantification of information on a "block-level" basis, because plots were located in specific selected sub-areas, and not systematically over the whole block. For this reason, conclusions can only be drawn for the finding for those sub-areas. Though the blocks were specifically selected for the leading spruce regeneration, all blocks in Kakwa River and Rocky Mountain House had considerable lodgepole pine densities (approximately 50%-80% of spruce densities) in addition to deciduous species. These blocks will likely develop into mixed stands of pine and spruce and, at this stage, an as yet unpredictable aspen and balsam poplar component.

#### **3.1 WHITE SPRUCE REGENERATION IN THE SURVEYED BLOCKS**

Three types of white spruce regeneration were recognized:

- advanced regeneration established before harvest
- planted trees
- trees ingressed after harvest

Age was determined with a high level of accuracy, on sanded basal disks using a dissecting microscope in the laboratory. Ring counts were considered to represent true tree age. The regeneration type was assigned to each tree using histograms of the tree age distribution for each block. Stock types planted in the 1980's consisted primarily 3-0 bare root and 1-0 container seedlings. Thus, for example, in the blocks planted with 3-0 bare root stock, the trees with an age greater than the block age + 3 were considered to be advanced regeneration.

All 19 blocks, except one, had some advanced white spruce regeneration. The proportion of advanced regeneration varied but was largely less than 15% of the number of planted trees, with a maximum of 22.5% in Block 4, Calling Lake. As expected, the advanced regeneration trees were mostly taller and reached the 150 cm Alberta Free-to-Grow threshold height earlier than planted trees (Figures 2-11).

Ingress of white spruce after harvest was sporadic, except in several blocks in the Rocky Mountain House and Saddle Hills areas where the proportion of ingressed trees was higher (about 10%). Despite the younger age, the growth rate of ingressed trees was about the same or slightly less than that of planted trees.

The surveyed blocks were regenerated by the silvicultural system and methods (clearcut system, site preparation, planting) unfavourable to protection of advanced regeneration and/or encouragement of ingress establishment. Regardless of these limitations, our observations from 18 blocks indicate that in mixedwood cutovers 10-15 years after harvest approximately 10-20% of white spruce trees

**Table 5**  
Regeneration Performance - Balsam Poplar

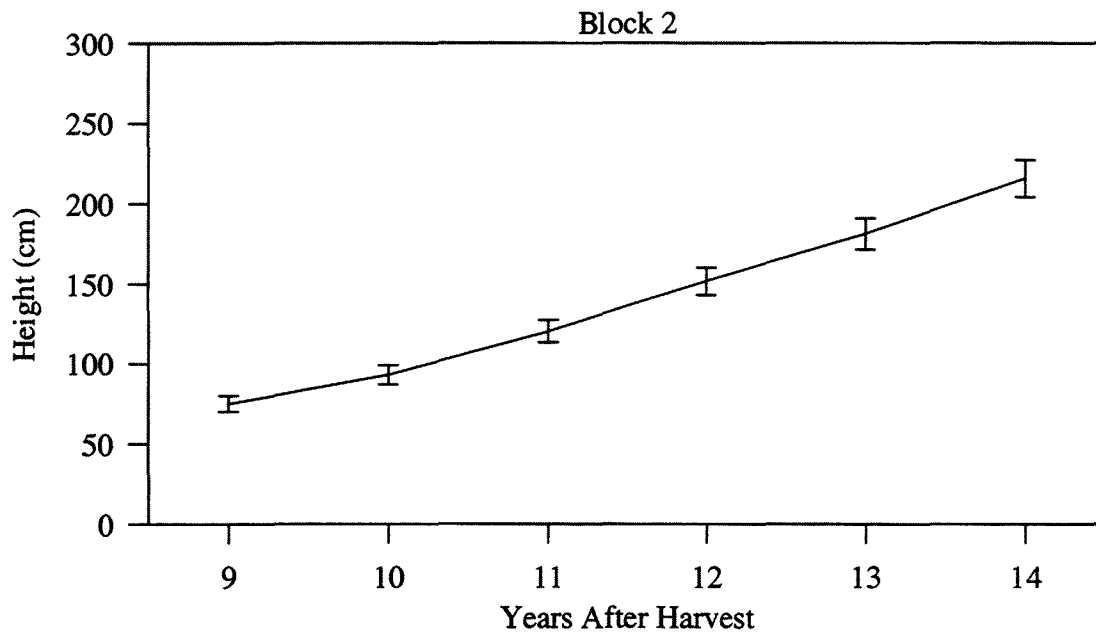
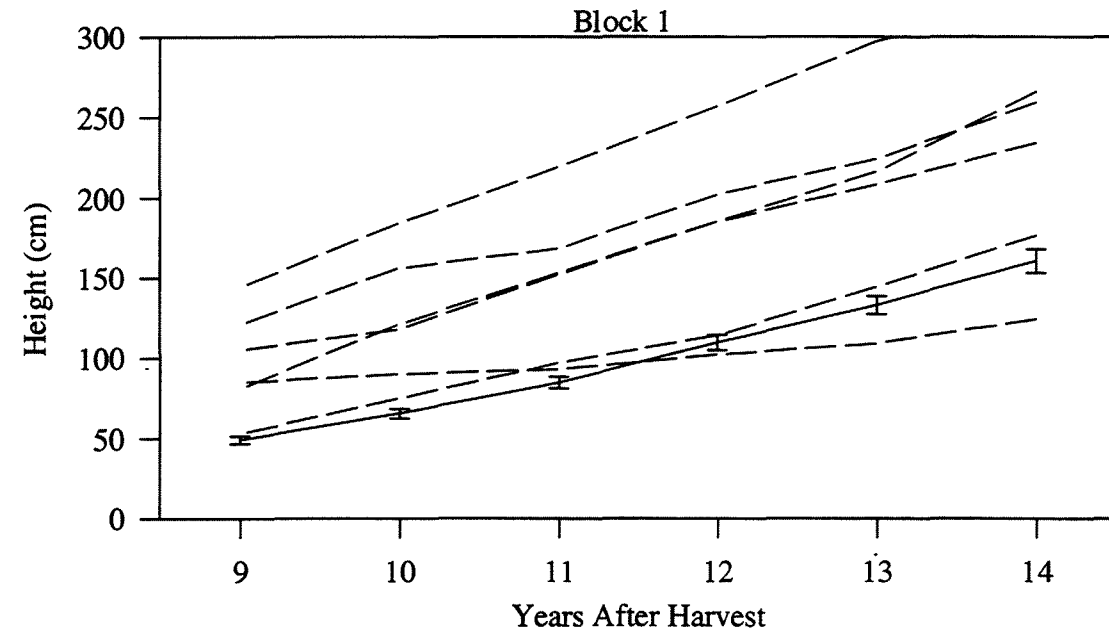
Loc.	Block/ Sample Size	Balsam Poplar				
		Age	Height	Height Increment	RCD	RADINC
Kakwa River	1 (20)	12.8 ±1.12	443.4 ±49.85	29.3 ±4.22	61.5 ±9.67	1.7 ±0.22
	2 (33)	11.5 0.26	402.4 35.51	32.5 2.83	48.6 5.45	1.6 0.19
	Total (53)	11.9 0.45	417.9 28.87	31.3 2.36	53.5 5.00	1.6 0.14
Saddle Hills	1 (30)	13.3 1.15	405.1 62.81	28.7 3.00	66.0 17.52	1.6 0.25
	2 (14)	12.3 0.97	292.1 54.43	22.9 2.63	30.6 6.38	1.1 0.25
	3 (7)	11.6 0.81	515.7 52.67	40.7 6.54	45.4 6.46	1.3 0.29
	4 (14)	11.4 0.72	436.9 63.80	37.5 5.05	52.2 9.38	1.7 0.32
	Total (67)	12.4 0.59	399.7 34.16	30.7 2.03	52.9 8.32	1.5 0.14
Rocky Mtn. House <sup>1</sup>	2 (4)	10.3 1.44	465.5 106.55	41.5 12.61	57.0 13.43	2.2 0.68
	3 (10)	7.6 0.86	341.7 62.04	33.5 4.20	44.8 9.02	2.5 0.48
	4 (50)	7.3 0.35	263.3 23.00	29.0 2.27	39.7 4.18	1.9 0.20
	5 (2)	7.0 0.00	315.5 154.50	35.0 6.00	49.5 20.50	4.1 1.71
	Total (68)	7.4 0.31	282.5 21.52	30.5 1.95	40.8 3.52	2.1 0.18
Calling Lake	1 (16)	10.8 0.63	292.0 39.54	36.3 6.93	29.7 4.05	1.1 0.15
	2 (19)	12.3 0.46	369.7 33.97	34.9 4.26	35.2 3.92	1.2 0.16
	3 (35)	10.8 0.26	462.3 29.81	55.7 5.66	51.4 4.09	2.1 0.24
	4 (29)	10.6 0.34	456.7 34.28	66.0 7.14	47.0 4.12	1.7 0.20
	5 (43)	10.4 0.17	418.7 26.54	52.0 4.98	43.0 3.06	1.7 0.15
	6 (42)	10.7 0.31	357.5 27.88	45.9 4.77	40.8 3.68	1.5 0.17
	7 (11)	10.3 0.57	428.6 69.76	64.3 12.78	48.2 9.19	2.0 0.47
	Total (195)	10.8 0.13	404.4 13.06	51.2 2.40	43.1 1.62	1.7 0.08

1. Rocky Mountain House blocks 1 and 6 not shown due to only one balsam poplar measured in each.

**Table 6**  
Regeneration Performance - Aspen

Location	Block/ Sample Size	Aspen				
		Age	Height	Height Increment	RCD	RADINC
Kakwa River	1 (23)	13.3 $\pm$ 0.97	583.6 $\pm$ 68.07	47.7 $\pm$ 3.10	60.4 $\pm$ 6.95	1.7 $\pm$ 0.18
	2 (9)	11.8 0.46	469.1 74.19	52.0 7.83	53.6 7.40	2.4 0.51
	Total (32)	12.9 0.72	553.3 53.93	48.9 3.03	58.6 5.44	1.9 0.20
Saddle Hills	1 (17)	12.1 0.64	545.1 83.06	36.7 3.84	48.2 6.80	1.3 0.22
	2 (64)	13.6 0.28	582.7 27.93	33.3 2.43	58.9 3.28	1.8 0.13
	3 (70)	12.4 0.25	564.5 27.14	40.3 2.55	51.2 2.71	1.7 0.10
	4 (75)	11.6 0.32	500.0 32.62	38.2 2.18	48.0 3.31	1.4 0.11
	Total (231)	12.4 0.17	543.3 16.89	37.5 1.32	51.8 1.74	1.6 0.06
Rocky Mtn. House	1 (82)	12.1 0.42	463.1 27.42	45.8 2.90	55.3 3.95	2.2 0.20
	2 (94)	10.2 0.26	420.7 24.88	35.1 2.58	45.0 2.72	1.5 0.11
	3 (67)	9.1 0.16	386.6 22.60	34.3 2.01	49.5 2.70	2.3 0.19
	4 (40)	9.1 0.31	316.9 32.01	29.2 2.32	41.6 4.13	1.6 0.22
	5 (49)	9.4 0.19	324.7 24.41	27.8 1.98	41.9 2.96	1.7 0.18
	6 (96)	8.5 0.18	294.4 15.46	35.2 2.26	34.5 2.01	1.7 0.12
	Total (428)	9.8 0.13	374.5 10.34	35.6 1.07	44.7 1.29	1.8 0.07
Calling Lake	1 (79)	11.8 0.23	406.8 19.36	44.8 2.73	42.0 2.42	1.9 0.14
	2 (53)	12.9 0.19	476.2 24.92	41.0 3.53	46.1 3.18	1.6 0.17
	3 (26)	10.9 0.20	420.6 37.36	47.6 7.03	42.3 3.63	1.9 0.24
	4 (50)	11.0 0.15	464.1 26.35	55.2 3.91	44.1 3.10	2.2 0.18
	5 (30)	11.3 0.34	566.4 33.86	58.6 4.65	52.6 3.93	2.4 0.25
	6 (49)	11.9 0.26	397.7 26.51	34.1 2.54	42.0 3.34	1.6 0.16
	7 (86)	11.2 0.12	439.3 20.53	51.7 2.83	43.4 2.49	2.1 0.14
	Total (373)	11.6 0.09	444.4 9.72	47.2 1.37	44.1 1.15	1.9 0.07

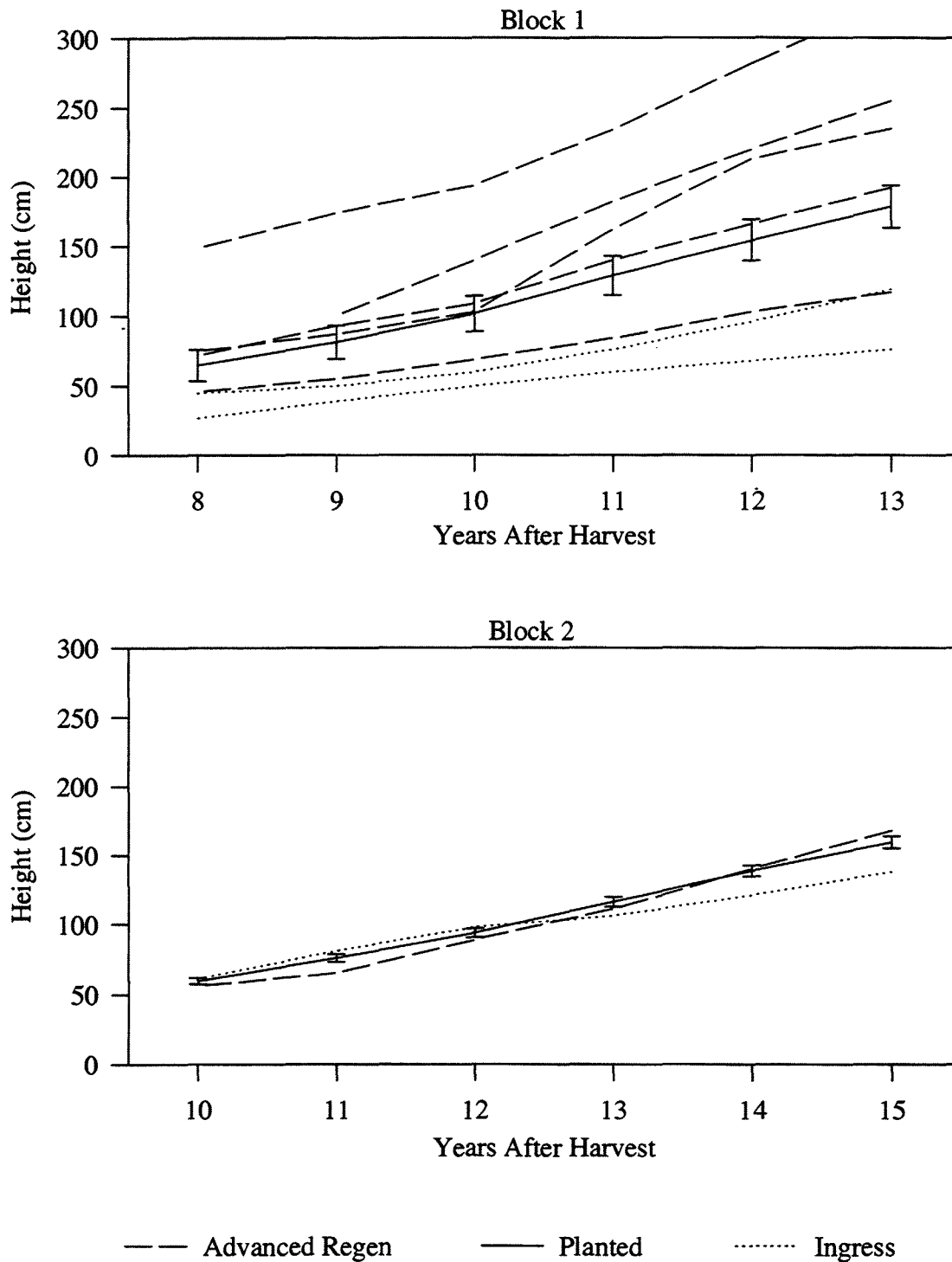
**Figure 2**  
White Spruce Height Growth - Kakwa River



— Advanced Regen      — Planted      ..... Ingress

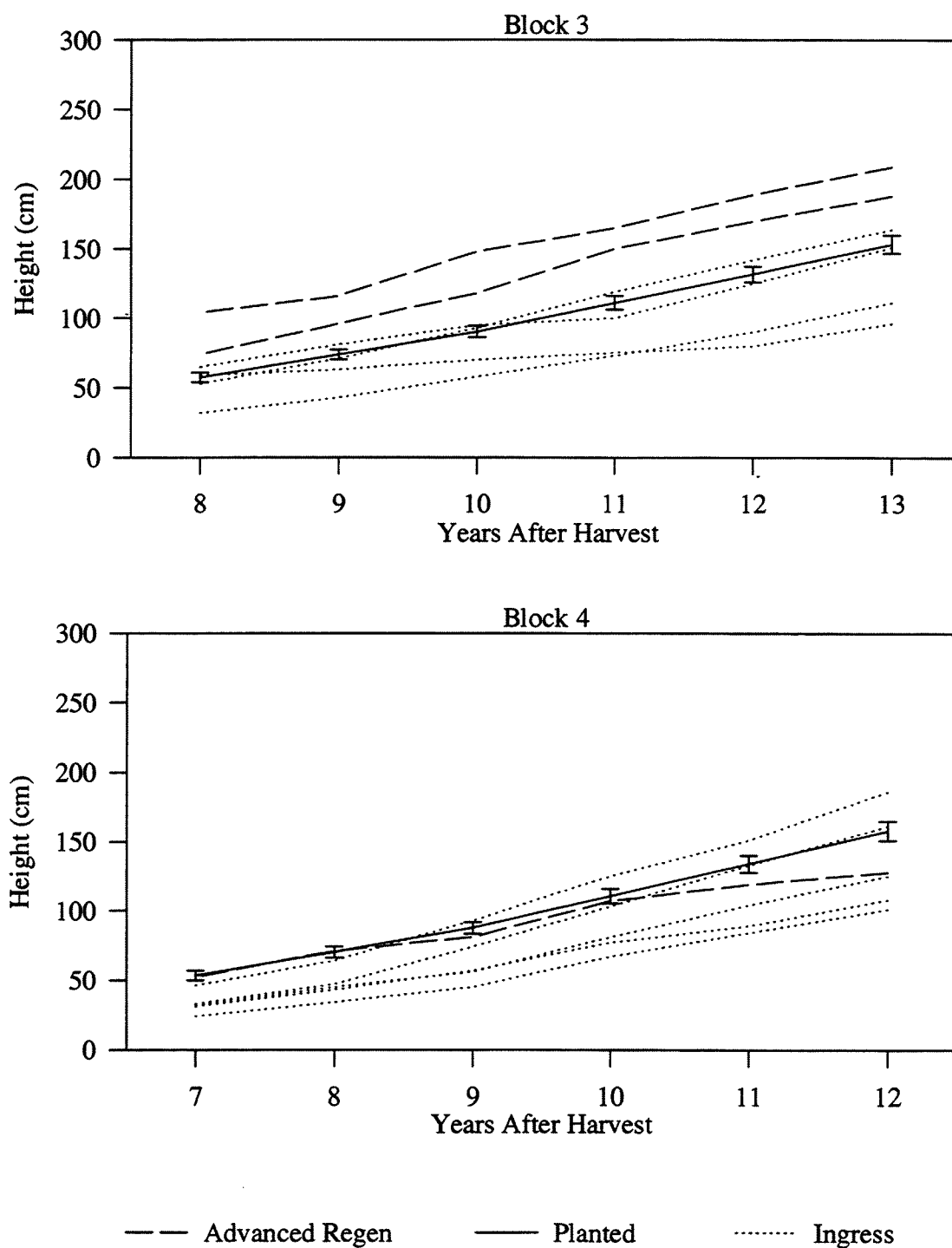
"Planted" is average curve (with standard error of the mean) for 41 (Blk 1) and 33 (Blk 2) trees. Curves for advanced regeneration and ingress are from individual trees. Some blocks do not have sampled trees of advanced regeneration or ingress origin.

**Figure 3**  
White Spruce Height Growth - Saddle Hills



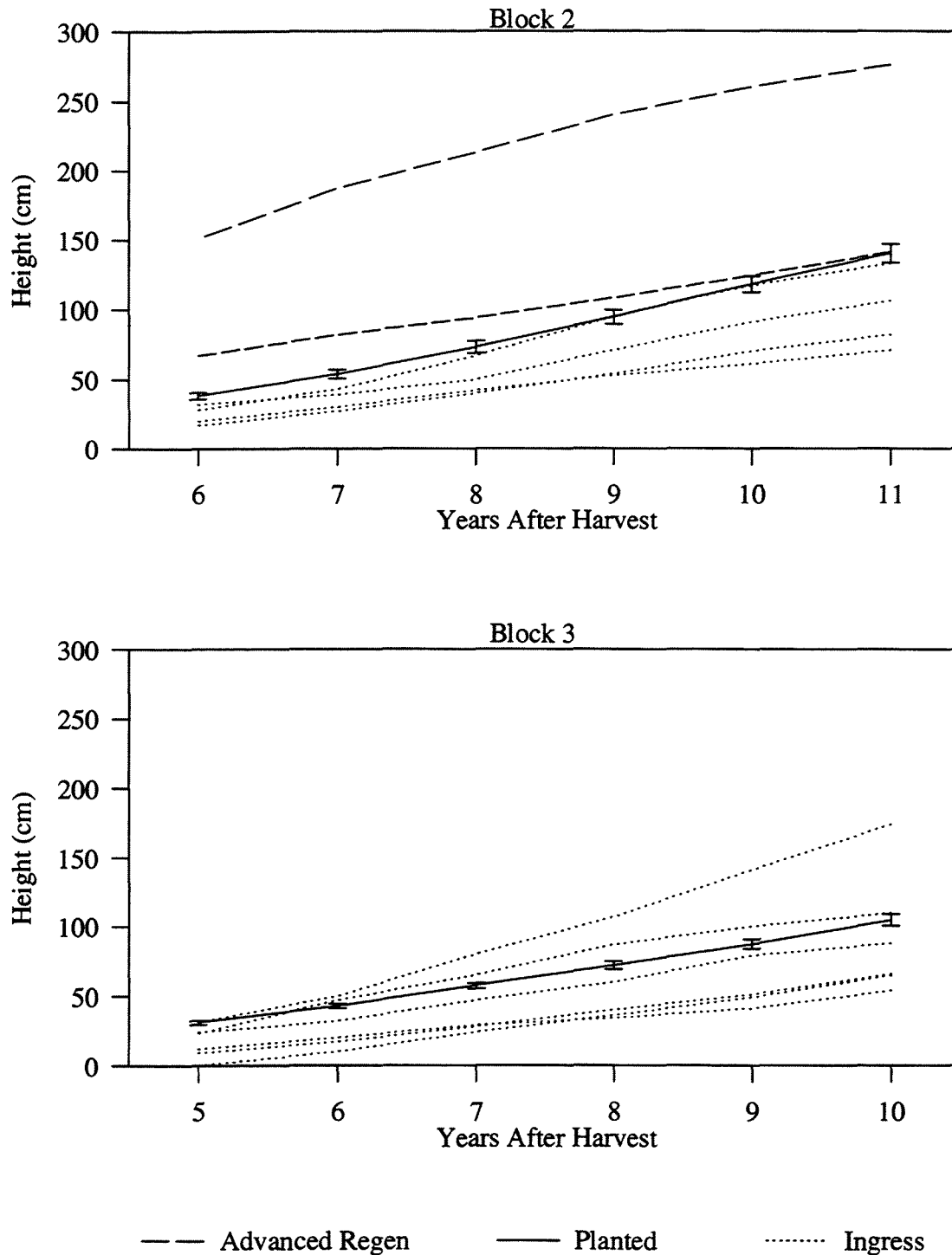
"Planted" is average curve (with standard error of the mean) for 22 (Blk 1) and 46 (Blk 2) trees. Curves for advanced regeneration and ingress are from individual trees. Some blocks do not have sampled trees of advanced regeneration or ingress origin.

**Figure 4**  
White Spruce Height Growth - Saddle Hills



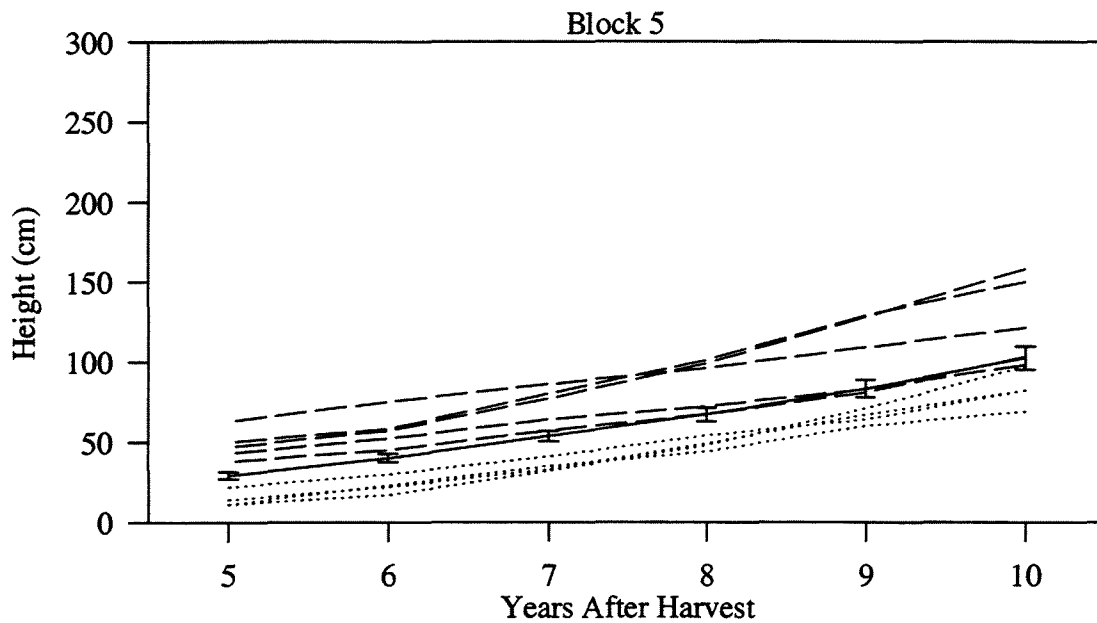
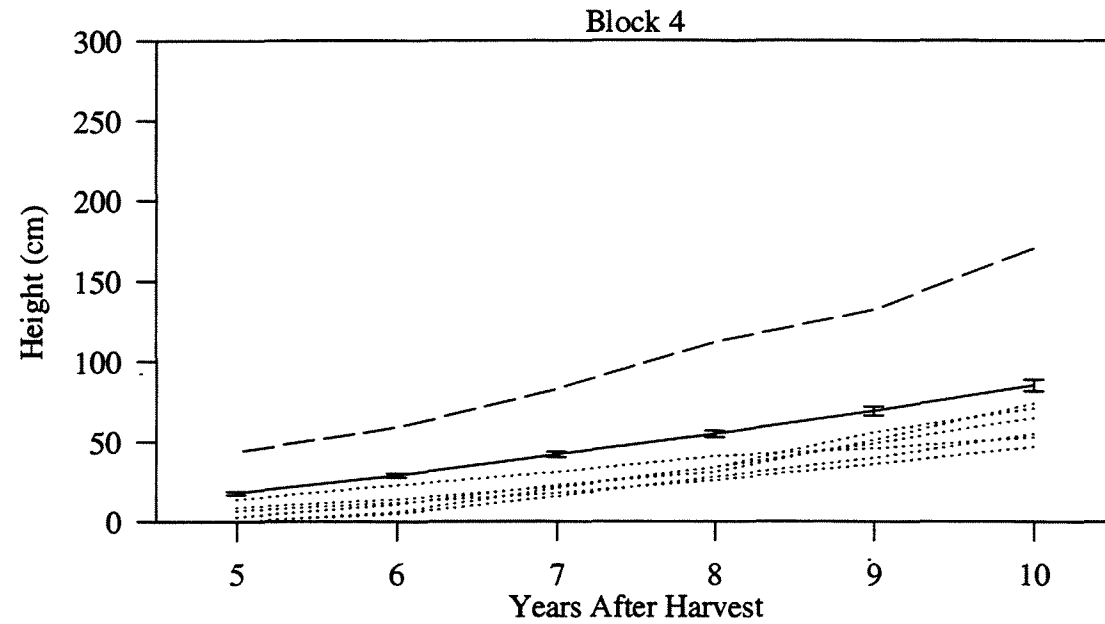
"Planted" is average curve (with standard error of the mean) for 38 (Blk 3) and 43 (Blk 4) trees.  
Curves for advanced regeneration and ingress are from individual trees.  
Some blocks do not have sampled trees of advanced regeneration or ingress origin.

**Figure 5**  
White Spruce Height Growth - Rocky Mountain House



"Planted" is average curve (with standard error of the mean) for 44 (Blk 2) and 44 (Blk 3) trees. Curves for advanced regeneration and ingress are from individual trees. Some blocks do not have sampled trees of advanced regeneration or ingress origin.

**Figure 6**  
White Spruce Height Growth - Rocky Mountain House

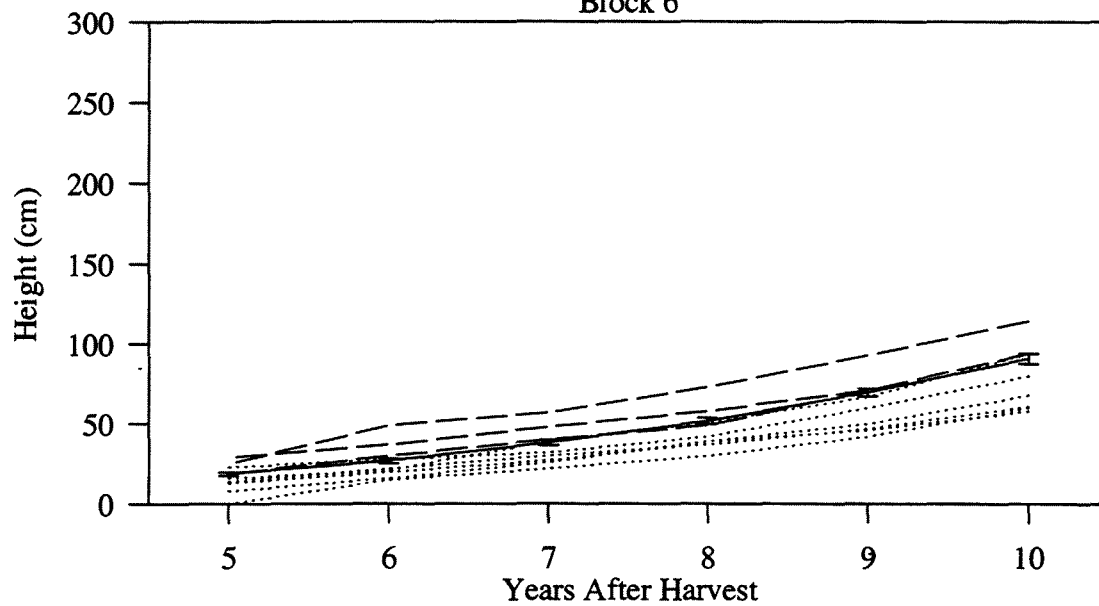


— — Advanced Regen      — Planted      ..... Ingress

"Planted" is average curve (with standard error of the mean) for 43 (Blk 4) and 21 (Blk 5) trees. Curves for advanced regeneration and ingress are from individual trees. Some blocks do not have sampled trees of advanced regeneration or ingress origin.



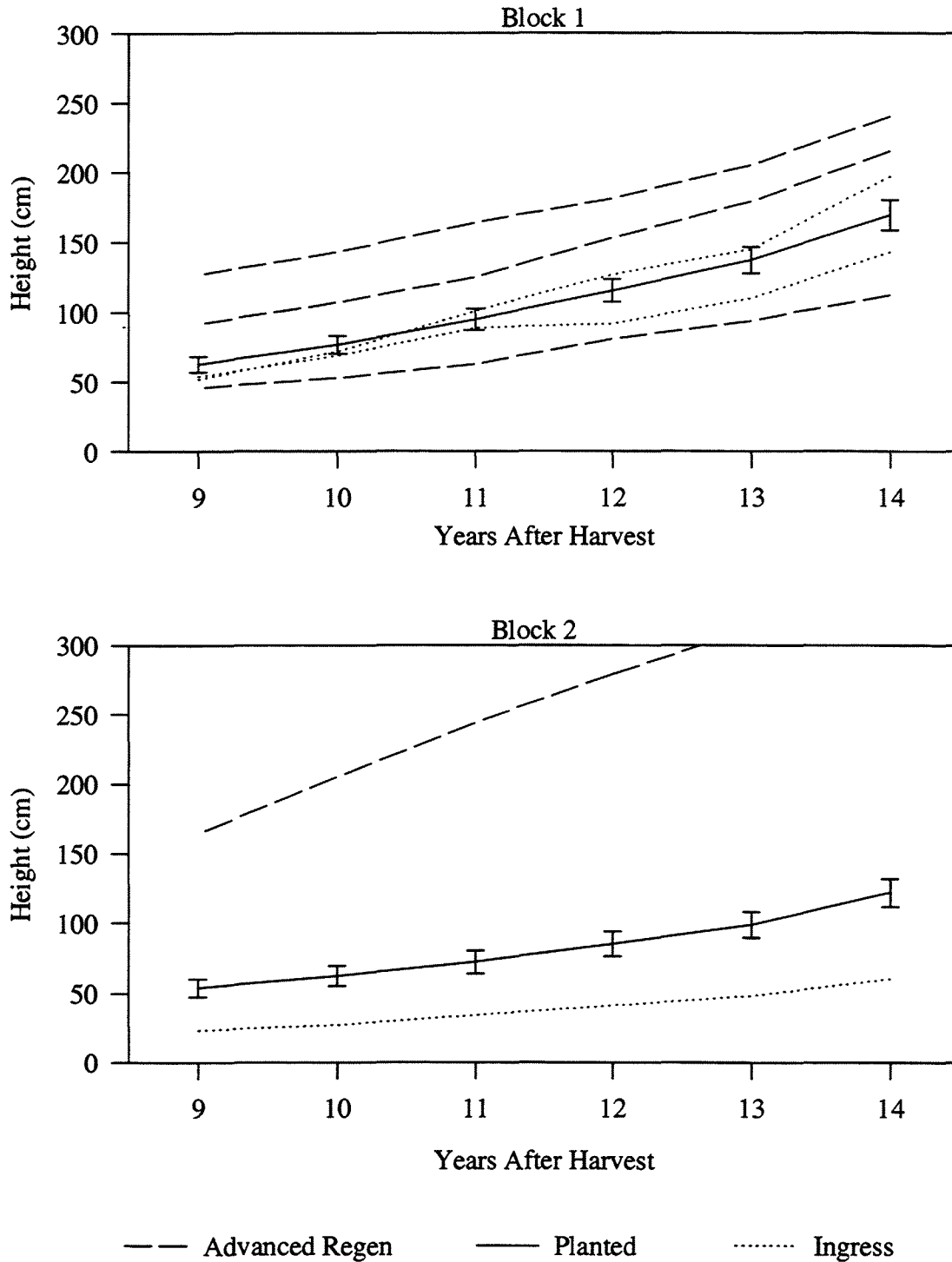
**Figure 7**  
 White Spruce Height Growth - Rocky Mountain House  
 Block 6



— — Advanced Regen      — Planted      ..... Ingress

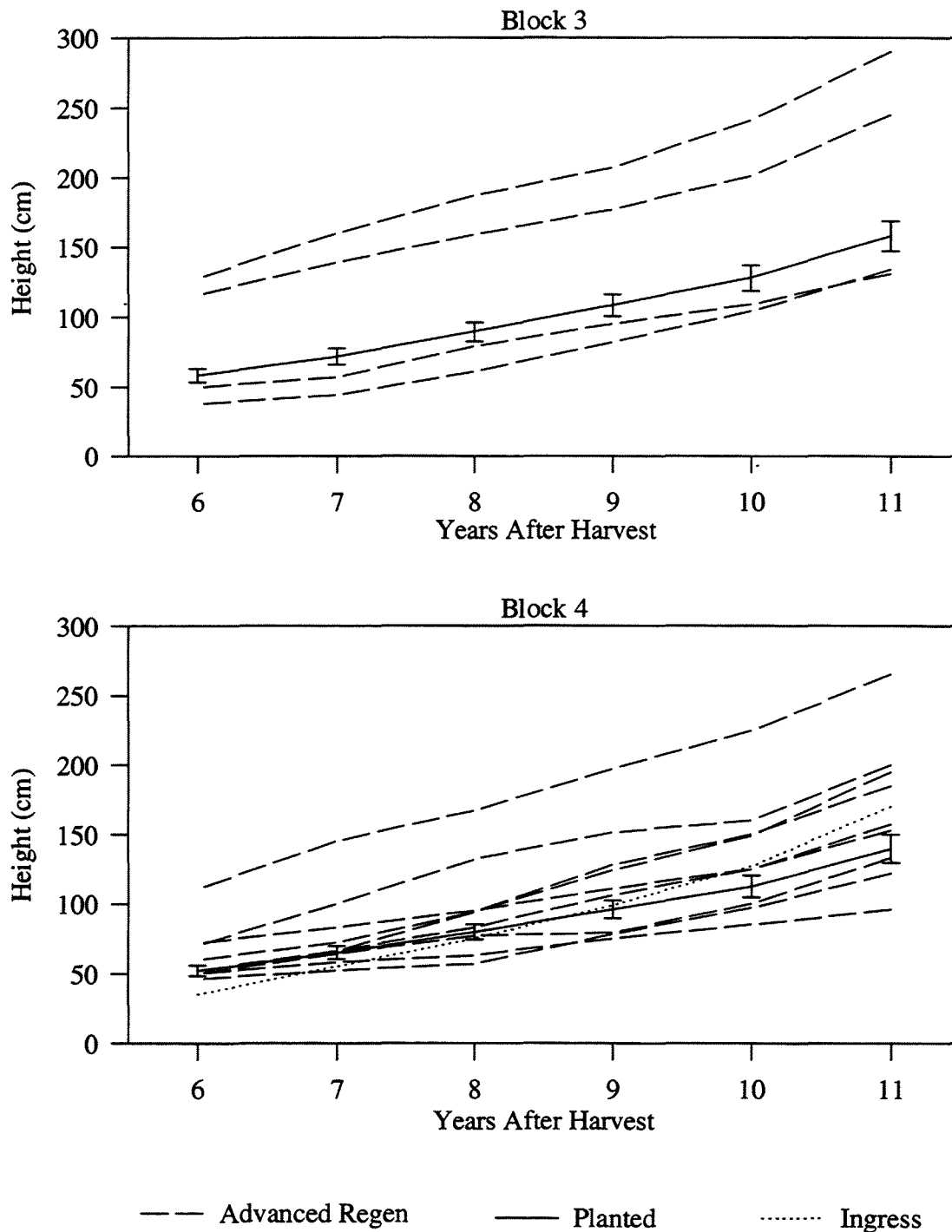
"Planted" is average curve (with standard error of the mean) for 46 trees.  
 Curves for advanced regeneration and ingress are from individual trees.  
 Some blocks do not have sampled trees of advanced regeneration or ingress origin.

**Figure 8**  
White Spruce Height Growth - Calling Lake



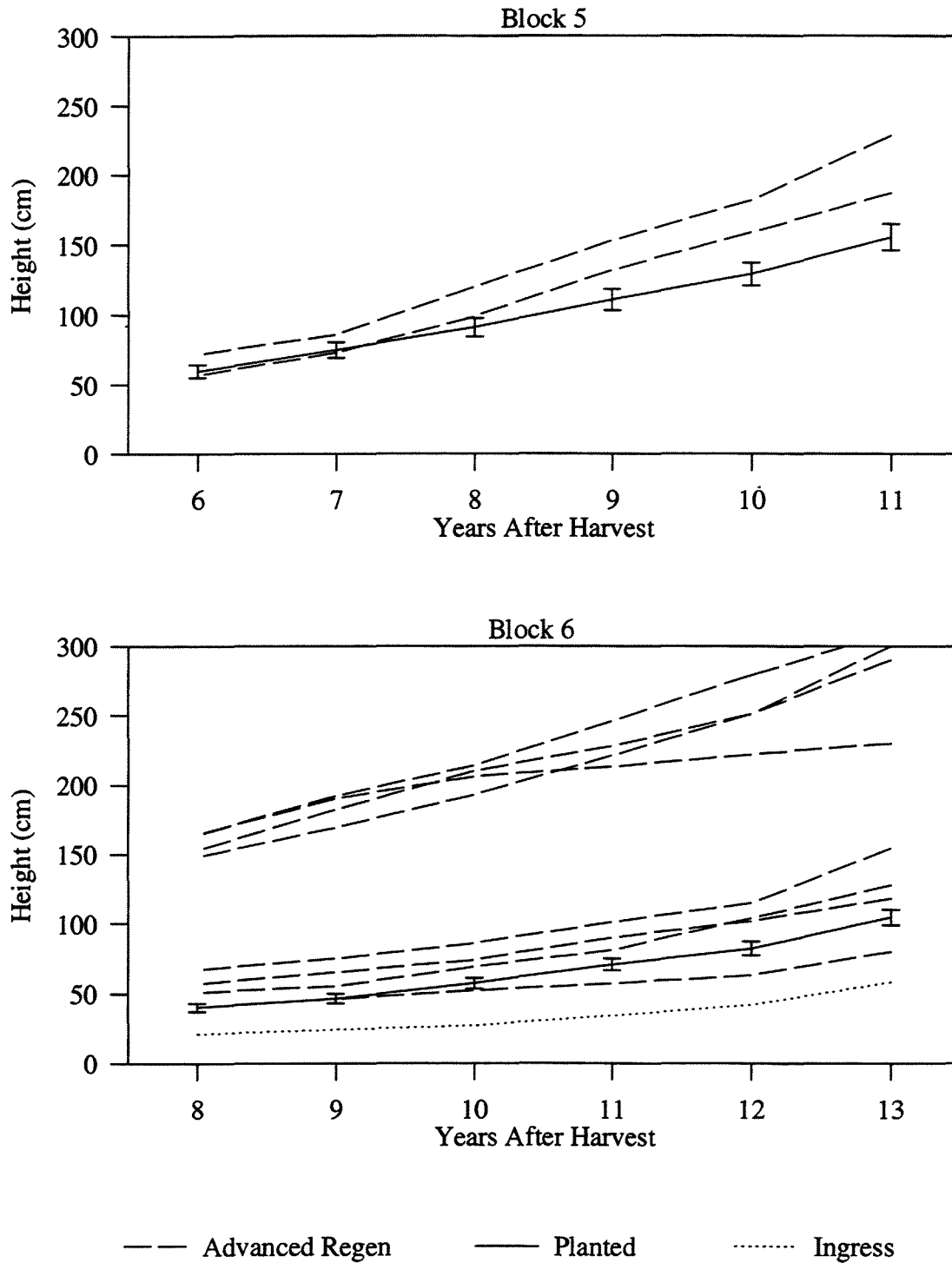
"Planted" is average curve (with standard error of the mean) for 45 (Blk 1) and 36 (Blk 2) trees. Curves for advanced regeneration and ingress are from individual trees. Some blocks do not have sampled trees of advanced regeneration or ingress origin.

**Figure 9**  
White Spruce Height Growth - Calling Lake



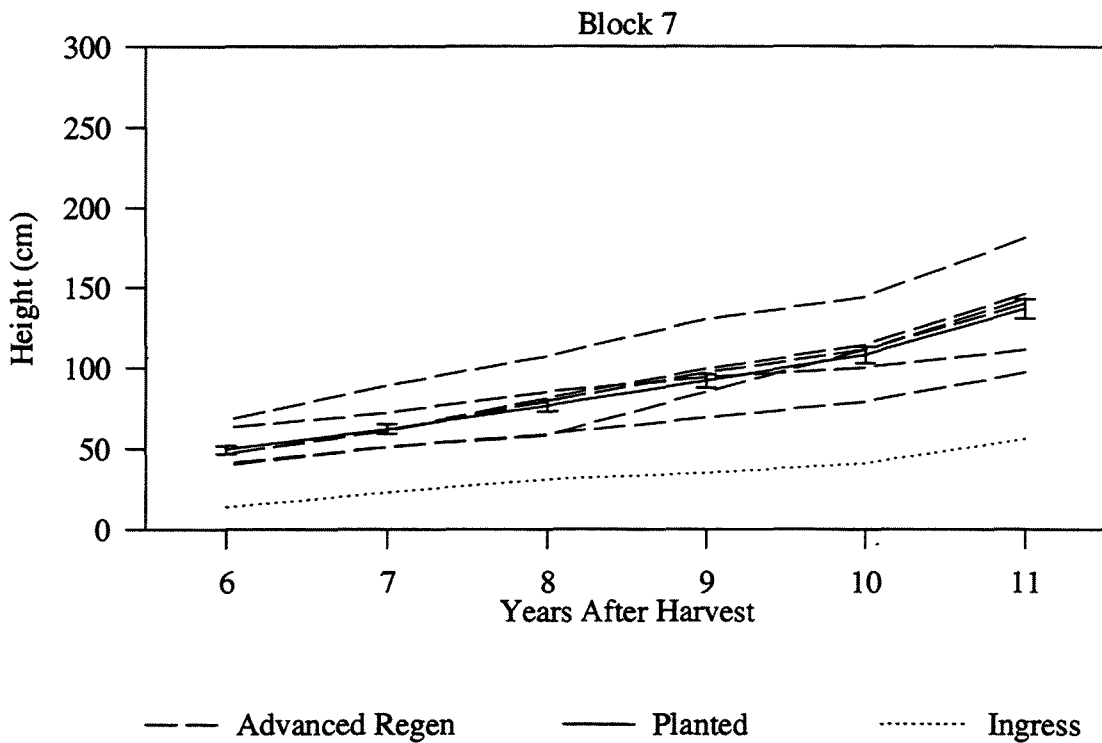
"Planted" is average curve (with standard error of the mean) for 39 (Blk 3) and 40 (Blk 4) trees. Curves for advanced regeneration and ingress are from individual trees. Some blocks do not have sampled trees of advanced regeneration or ingress origin.

**Figure 10**  
White Spruce Height Growth - Calling Lake



"Planted" is average curve (with standard error of the mean) for 40 (Blk 5) and 43 (Blk 6) trees.  
Curves for advanced regeneration and ingress are from individual trees.  
Some blocks do not have sampled trees of advanced regeneration or ingress origin.

**Figure 11**  
White Spruce Height Growth - Calling Lake



"Planted" is average curve (with standard error of the mean) for 45 trees.  
Curves for advanced regeneration and ingress are from individual trees.  
Some blocks do not have sampled trees of advanced regeneration or ingress origin.

were not of planted origin. The total density of white spruce (advanced regeneration + planted + ingress) ranged from 1,100 to 5,800 trees/ha (Table 7).

### **3.2 HEIGHT GROWTH OF PLANTED WHITE SPRUCE**

The Alberta's Free-to-Grow (FTG) reforestation standards<sup>5</sup> specify that an acceptable conifer should be 150 cm tall or taller at the performance survey 14 years after harvest.

Cumulative height growth curves show that in 33% of the blocks (6 out of 18), planted trees on average reached or exceeded 150 cm height at the block age of 11-12 years (Figures 2-11). In 61% of the blocks (11 out of 18), planted trees reached or exceeded 150 cm height at 14 years or would reach the 150 cm threshold at block age of 14 years based on their current height and growth rate at the younger age. In one block (Calling Lake Block 2) the planted trees had an average height of less than 150 cm at the block age of 14 years.

The described height growth represents an integrative response of the site, microsite, stock quality, planting, stand, and competition conditions and therefore is not equal to the potential planted tree performance. Comparison of cumulative height and diameter growth curves of FTG and Not-FTG trees showed the divergence of curves at early stages of seedling's growth. This indicates that for some trees, seedling's growth could have been slowed down due to a variety of reasons other than competition. One of the reasons could be microsite differences. Microsite variation causes trees to grow along different height-age trajectories. Hence, trees growing on poorer microsites become affected by adjacent competitors sooner than crop trees growing on productive, favourable microsites.

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<sup>5</sup>Unpublished report, 1990, by Reforestation Branch, Alberta Forest Service, Edmonton

**Table 7**  
**Regeneration Performance - Conifer**

Location	Block/ Sample Size <sup>1</sup>	White Spruce <sup>2</sup>			Conifer Density <sup>3,4</sup>		
		Age	Height <sup>3</sup>	Density <sup>3,4</sup>	Lodgepole Pine	Balsam Fir	Jack Pine
Kakwa River	1 (47)	13.9 ±0.34 <sup>5</sup>	143.0 ±11.60	1.9 ±0.17	0.39 ±0.12	0	0
	2 (33)	14.3 0.25	204.1 11.50	1.1 0.08	0.43 0.22	0	0
	Total (80)	14.0 0.24	169.1 8.93	1.6 0.11	0.41 0.11	0	0
Saddle Hills	1 (29)	12.8 0.32	128.6 9.69	5.8 1.06	0	0	0
	2 (48)	13.5 0.18	144.2 6.48	3.2 0.32	0.13 0.08	0	0
	3 (44)	12.8 0.29	129.6 7.53	3.8 0.51	0	0.02 0.02	0.02 0.02
	4 (49)	12.3 0.22	117.0 5.59	3.6 0.45	0	0	0
	Total (174)	12.8 0.12	130.3 3.55	3.9 0.27	0.04 0.02	0	0
Rocky Mountain House	1 (53)	10.4 0.21	105.3 5.90	1.4 0.14	0.29 0.07	0	0
	2 (50)	10.4 0.42	89.0 5.48	4.3 0.70	0.48 0.12	0.02 0.02	0
	3 (50)	9.4 0.19	98.0 4.79	1.3 0.13	0.03 0.02	0.4 0.14	0
	4 (50)	8.2 0.16	66.7 3.80	1.9 0.17	0.02 0.02	0	0
	5 (30)	10.9 0.58	95.6 6.21	1.3 0.17	0.32 0.09	0.88 0.27	0
	6 (55)	9.0 0.36	82.5 3.59	1.6 0.14	0.2 0.09	0	0
	Total (288)	9.5 0.14	89.1 2.14	2.0 0.15	0.22 0.03	0.16 0.04	0
Calling Lake	1 (50)	14.1 0.26	127.2 7.87	2.1 0.23	0	0	0
	2 (38)	15.0 0.20	84.7 7.72	1.9 0.19	0	0	0
	3 (43)	13.0 0.28	99.3 10.29	2.1 0.34	0	0.06 0.03	0
	4 (50)	13.0 0.25	79.0 7.81	2.1 0.28	0	0	0
	5 (42)	12.7 0.23	72.5 10.68	1.8 0.26	0	0	0
	6 (52)	14.0 0.32	56.3 5.22	1.6 0.18	0	0.09 0.05	0
	7 (52)	13.0 0.22	73.6 7.36	1.6 0.13	0	0	0
	Total (327)	13.6 0.10	83.2 3.29	1.9 0.09	0	0.02 0.01	0

1. Sample size is based on number of plots, however, white spruce age is based on measurement of target tree and tallest and closest conifer in each 12.56 m<sup>2</sup> plot.

2. Includes target trees (advanced regeneration, planted, ingress).

3. Height and density are based on all trees in each 12.56 m<sup>2</sup> plot.

4. Values converted to stems/10m<sup>2</sup>.

5. Mean and standard error of the mean.

#### 4.0 COMPETITION INTENSITY IN THE SURVEYED BLOCKS

For most of the blocks selected, the vegetation was dominated by deciduous species. Table 8 summarizes the cover of each vegetation strata for each block. In all blocks, trees comprised the most abundant strata, except for the Kakwa region (where shrub cover was based on low and tall shrubs combined). Of this, deciduous species were by far, the greatest constituent (Appendix 2). Tall shrub cover was usually less than half the deciduous cover, and varied from 3.8 to 21.2 %. Most of the tall shrub layers were less than 1.5 m in height, and were comprised mostly willows and alder. While marsh reed grass (*Calamagrostis canadensis*) was present in most of the surveyed blocks, the grass competition was generally low to moderate, with cover ranging from 1.5 to 21.8%.

Hardwood density (comprised of aspen, balsam poplar, and a very small amount of paper birch) varied considerably among the areas and to a lesser degree among the blocks within the areas (Figure 12 and Table 9). On average, the density of hardwood trees/ha was as follows:

Kakwa River	3 700 trees/ha
Saddle Hills	9 600 trees/ha
Rocky Mtn. House	9 700 trees/ha
Calling Lake	18 400 trees/ha

These stands had a corresponding hardwood:conifer mixture (based on stem density) of 1.8:1, 2.4:1, 4.1:1 and 15:1 for the four areas, respectively, thus indicating that stand initiation and stand development had been dominated by deciduous species.

The differences in aspen density (Table 9) and aspen cover were also pronounced among the areas as well as among blocks within the areas (Figure 13, Table 7). For example, in the blocks in the Rocky Mountain House area, average aspen cover ranged from 10.5% to 40.3%, and in the Calling Lake area, aspen cover varied from 8.4% to 22.9% between the blocks.

Other estimates of competitive intensity such as the proximity of aspen trees to the white spruce crop tree and frequency of overtopping also varied greatly among blocks within areas and among the areas (Figure 13, 14).

The above-mentioned estimators of competition (density, cover, overtopping) can be classified as single competition variables. When competition indices that incorporate several competition parameters were calculated, the same pattern of pronounced differences in competitive intensity among the area (Table 10) was confirmed.

The observed variability in the level of competition between areas and between blocks within areas may have both negative and positive implications for silviculture prescriptions. On the positive side it suggests that there is a reasonable potential for priority rating of vegetation management treatments, which can be used for designating which blocks and areas should be treated earlier. On the negative side it implies that the likelihood of developing a broadly-applicable competition measure or competition index (CI) is low. Because of this great diversity in early non-crop vegetation establishment and subsequently in tree species composition in regenerating stands on mixedwood sites, it may be necessary to select and test applicable competition indices for stratified classes of juvenile stand and plant community conditions.

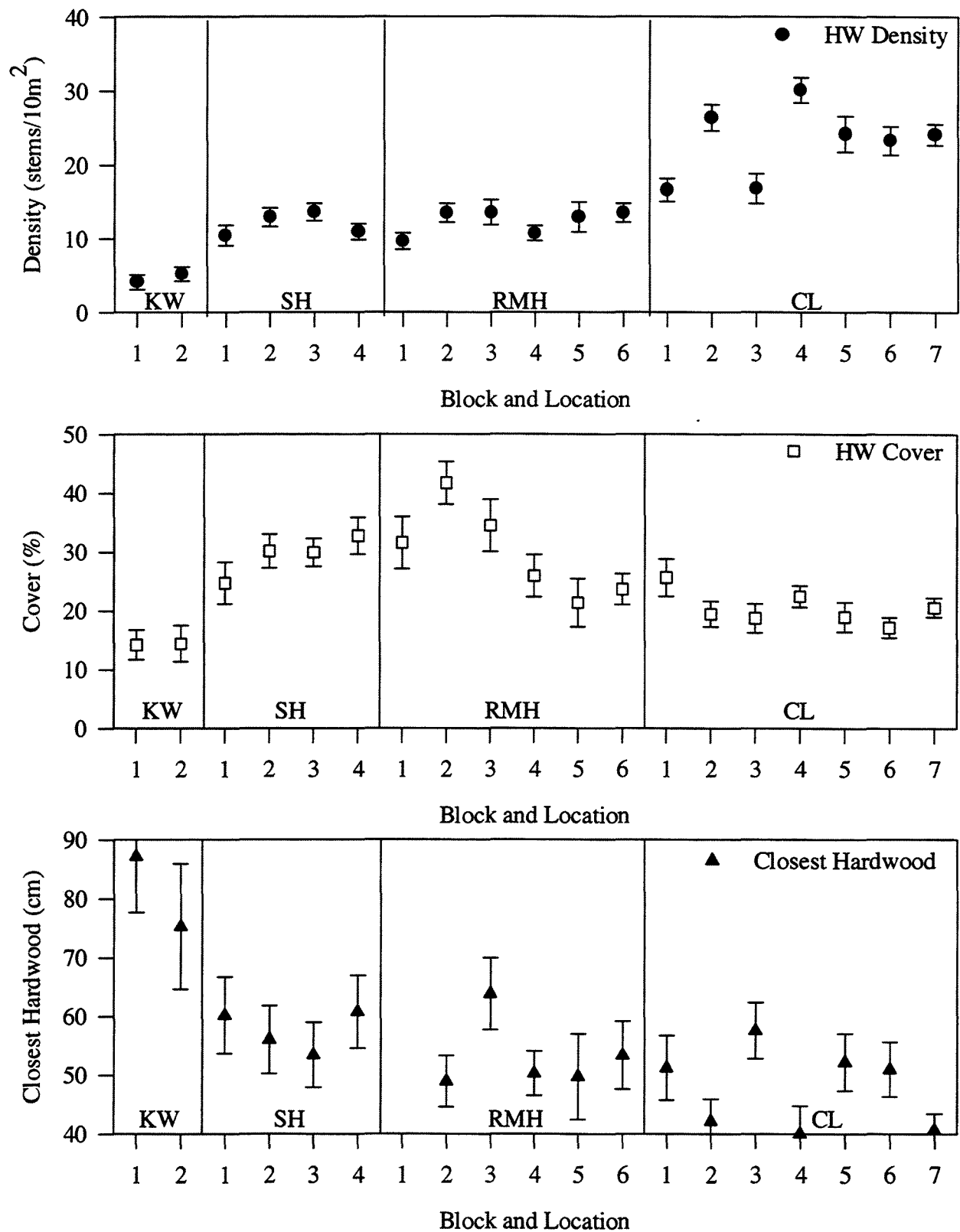


**Table 8**  
**Vegetation Cover in Each Block**

Location	Block/ Sample Size	Average Percent Cover							
		Vegetation <sup>1</sup>	Tree	Tall Shrub (>50 cm)	Low Shrub (<50 cm)	Forb	Grass	Moss	Lichen
Kakwa River	1 (47)	86.7 ±4.53	22.1 ±2.37	29.6 ±2.76 <sup>2</sup>		33.6 ±1.90	5.6 ±1.11	2.3 ±0.46	0.6 ±0.05
	2 (33)	108.2 4.85	22.1 2.83	47.8 3.39		36.7 2.28	6.0 0.97	1.0 0.23	0.4 0.05
	Total (80)	95.8 3.53	22.1 1.81	37.1 2.35		34.9 1.46	5.8 0.76	1.8 0.29	0.5 0.03
Saddle Hills	1 (29)	81.3 4.13	35.6 3.74	26.3 2.58		13.6 1.27	11.3 2.50	0.9 0.35	0.3 0.05
	2 (48)	86.6 3.18	37.1 2.46	24.4 2.02		19.9 1.57	5.7 1.11	0.6 0.06	0.5 0.05
	3 (44)	76.5 3.15	35.8 2.26	22.3 2.25		14.4 1.05	7.4 1.08	0.9 0.11	0.4 0.03
	4 (49)	83.7 3.72	37.8 2.99	19.6 1.71		17.0 1.44	10.7 1.90	1.1 0.12	0.5 0.03
	5 (4)	88.4 11.56	39.0 13.73	16.8 3.50		18.8 1.25	13.9 9.38	0.4 0.13	0.4 0.13
	Total (174)	82.3 1.76	36.8 1.39	22.7 1.04		16.6 0.70	8.6 0.83	0.9 0.07	0.5 0.02
Rocky Mountain House	1 (53)	102.4 4.92	32.3 4.17	15.9 ±2.37	5.0 ±0.65	26.9 2.54	21.8 1.57	1.8 0.30	0.1 0.01
	2 (50)	93.2 3.25	43.3 3.58	3.8 0.96	23.5 2.41	14.0 1.27	9.0 1.44	4.4 0.55	0.2 0.05
	3 (50)	96.2 4.70	35.5 4.30	11.7 1.83	8.2 1.05	26.0 1.81	15.0 1.60	1.2 0.17	0.1 0.01
	4 (50)	87.2 4.02	26.3 3.26	9.9 1.68	7.4 0.86	29.6 1.45	14.0 1.92	1.1 0.18	0.1 0.03
	5 (50)	91.1 5.43	23.1 3.89	21.2 3.08	10.2 1.89	22.3 2.76	14.0 2.39	1.8 0.21	0.1 0.04
	6 (30)	77.8 3.03	24.5 2.61	10.5 1.41	12.2 1.01	15.4 0.73	15.5 1.04	2.6 0.15	0.1 0.02
	Total (288)	91.2 1.77	31.3 1.55	11.6 0.81	11.1 0.67	22.3 0.81	15.0 0.69	2.2 0.14	0.1 0.01
Calling Lake	1 (50)	79.5 4.03	30.0 3.42	14.9 2.11	27.0 ±3.05 <sup>3</sup>	7.4 1.24	2.4 1.25	1.2 0.25	
	2 (38)	42.0 2.91	21.2 2.16	10.6 2.24	9.0 1.02	1.6 0.25	1.8 1.13	0.7 0.11	
	3 (43)	64.1 4.38	23.3 3.17	14.0 2.34	14.5 2.24	13.7 3.46	1.2 0.43	0.6 0.08	
	4 (50)	44.9 2.57	24.1 1.98	9.8 1.40	10.1 1.48	1.5 0.24	0.9 0.18	0.5 0.00	
	5 (42)	43.2 2.95	20.5 2.62	11.2 1.87	8.0 1.27	5.3 1.66	0.5 0.00	0.5 0.00	
	6 (52)	42.9 3.12	18.0 1.81	9.8 1.74	12.1 2.04	2.9 0.90	2.3 0.61	1.0 0.14	
	7 (52)	38.4 1.92	21.3 1.63	6.0 1.31	7.4 0.77	3.5 0.57	0.7 0.09	0.5 0.00	
	Total (327)	50.8 1.44	22.7 0.94	10.8 0.71	12.8 0.80	5.1 0.60	1.4 0.26	0.7 0.05	

1. Sum of all cover types (so can be greater than 100%). 2. Tall shrub and low shrub combined for Saddle Hills and Kakwa River. 3. Low shrub and forb combined for Calling Lake.

**Figure 12**  
Hardwood Cover, Density and Closest Stem to Target Tree

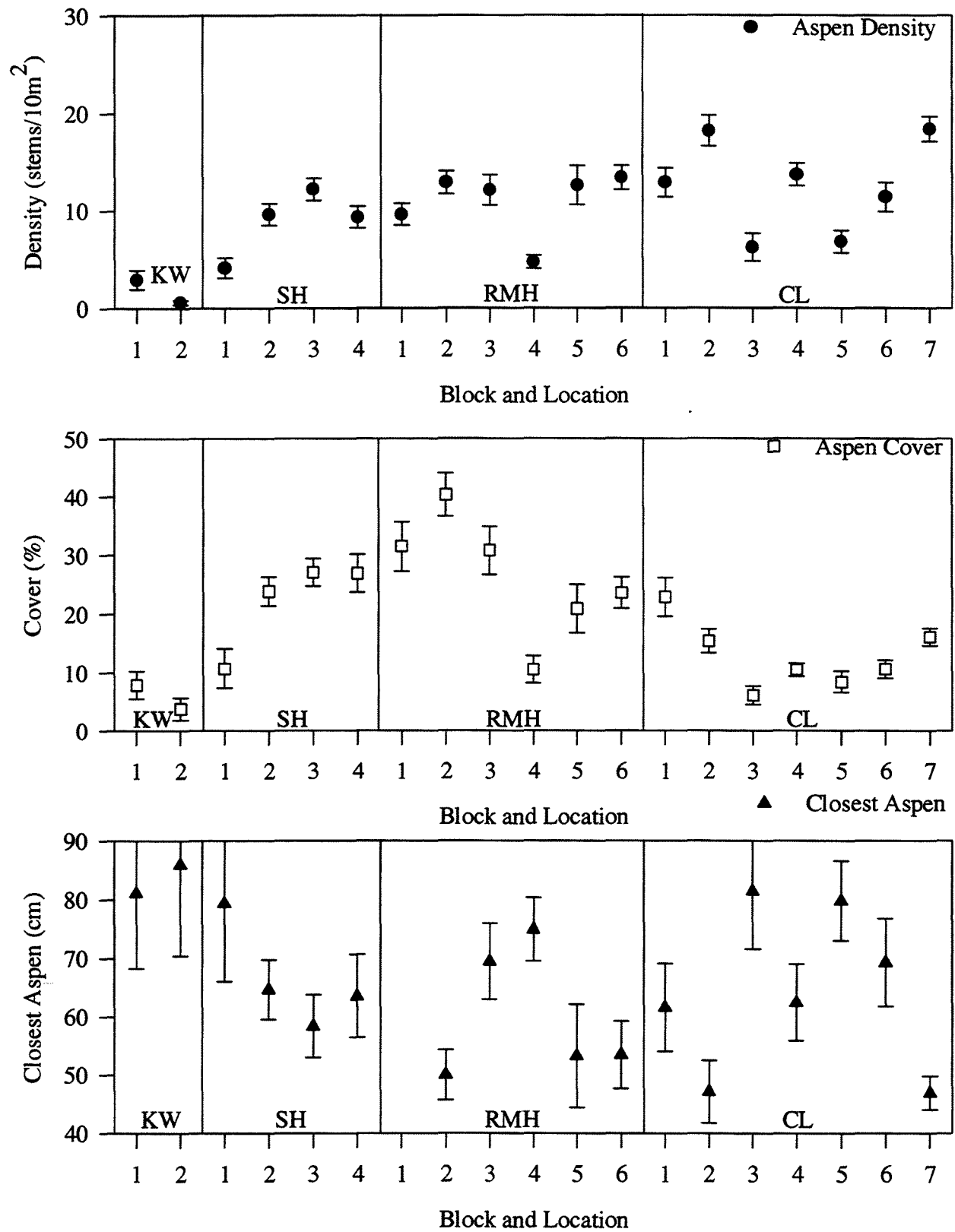


**Table 9**  
Total Hardwood, Balsam Poplar, Aspen and Conifer Density in Each Block

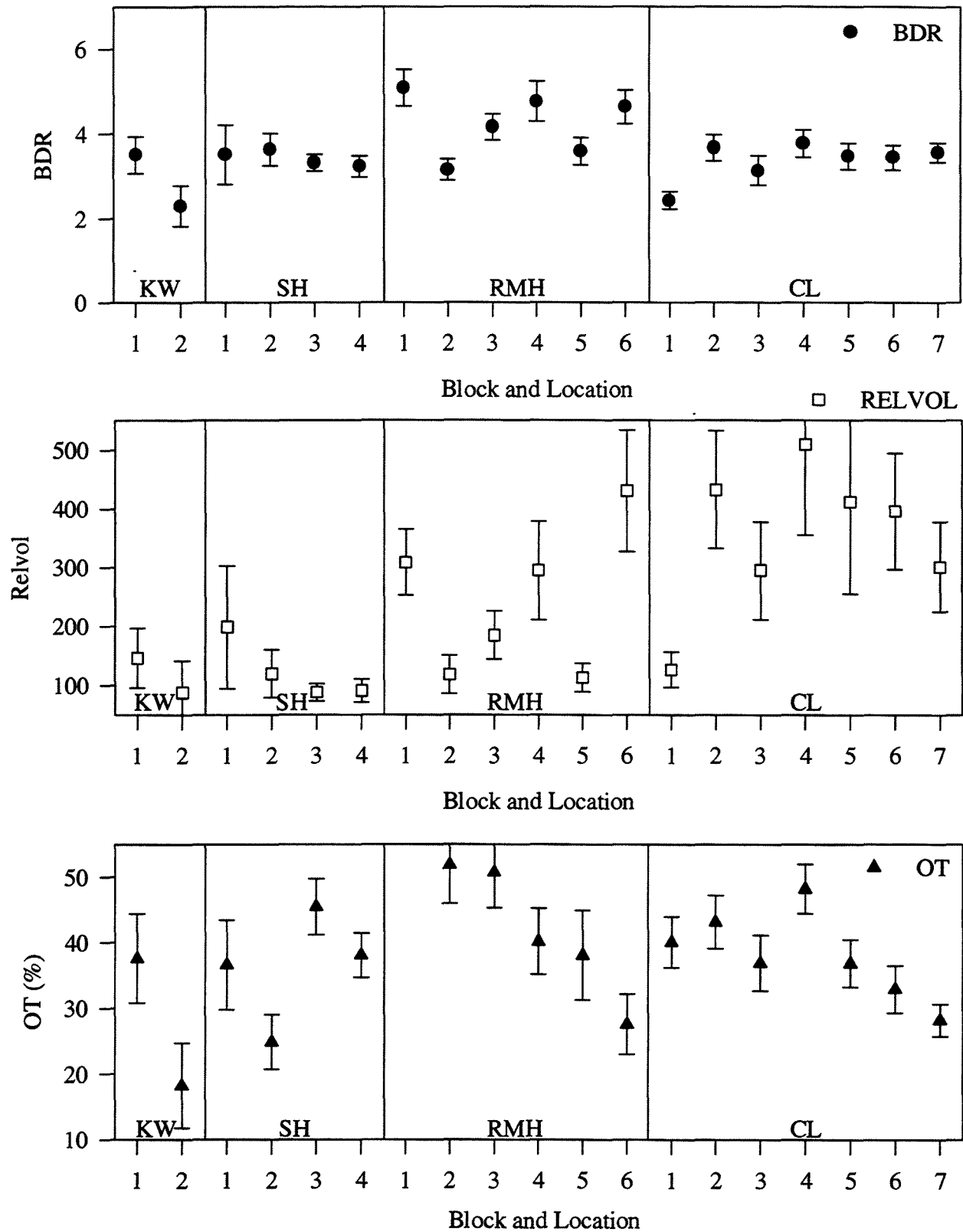
Location	Block/ Sample size	Density (converted to stems/10m <sup>2</sup> )			
		Hardwood <sup>1</sup>	Balsam Poplar	Aspen	Conifer <sup>2</sup>
Kakwa River	1 (47)	3.3 ±0.79 <sup>3</sup>	1.0 ±0.25	2.3 ±0.78	2.3 ±0.23
	2 (33)	4.2 0.76	3.7 0.78	0.5 0.18	1.5 0.25
	Total (80)	3.7 0.56	2.1 0.38	1.5 0.47	2.0 0.17
Saddle Hills	1 (29)	8.3 1.10	5.0 0.89	3.2 0.81	5.8 1.06
	2 (48)	10.3 1.01	1.9 0.44	7.7 0.88	3.3 0.31
	3 (44)	10.8 0.93	1.1 0.26	9.7 0.91	3.8 0.50
	4 (49)	8.6 0.89	1.2 0.26	7.4 0.91	3.6 0.45
	Total (174)	9.6 0.49	2.1 0.24	7.3 0.47	3.9 0.27
Rocky Mountain House	1 (53)	7.6 0.89	0.0 0.02	7.6 0.89	1.7 0.15
	2 (50)	10.7 0.99	0.5 0.28	10.3 0.95	4.8 0.70
	3 (50)	10.7 1.37	1.1 0.66	9.6 1.26	1.7 0.19
	4 (50)	8.5 0.82	4.7 0.71	3.8 0.54	1.9 0.17
	5 (30)	10.3 1.62	0.2 0.12	10.0 1.60	2.4 0.34
	6 (55)	10.8 1.00	0.1 0.05	10.6 0.99	1.8 0.16
	Total (288)	9.7 0.45	1.2 0.2	8.6 0.44	2.4 0.15
Calling Lake	1 (50)	13.2 1.24	2.7 0.64	10.3 1.19	2.1 0.23
	2 (38)	21.0 1.39	6.5 0.80	14.5 1.26	1.9 0.19
	3 (43)	13.4 1.62	6.9 1.08	4.9 1.14	2.2 0.35
	4 (50)	23.9 1.34	8.9 1.19	10.9 0.93	2.1 0.28
	5 (42)	19.2 1.94	12.7 1.82	5.4 0.91	1.8 0.26
	6 (52)	18.6 1.55	8.5 1.23	9.0 1.19	1.7 0.21
	7 (52)	19.1 1.13	3.4 0.61	14.7 1.02	1.6 0.13
	Total (327)	18.4 0.58	7.0 0.45	10.1 0.46	1.9 0.09

1. Hardwood is mostly aspen and balsam poplar, with very small amounts of paper birch.
2. Conifer density includes target trees.
3. Mean and standard error of the mean.

**Figure 13**  
Aspen Cover, Density and Closest Stem to Target Tree



**Figure 14**  
Competition Indices and Over Topping



**Table 10**  
Competition Index Levels in Each Location

Competition Index Group	Competition Index <sup>1</sup>	Kakwa River n=56	Saddle Hills n=168	Rocky Mtn. House n=273	Calling Lake n=322
Based on RCD Ratios of Target Tree and Competitor Size	Relvol	120.0 ±36.7 <sup>2</sup>	113.4 ±21.3	253.3 ±29.2	350.0 ±40.7
	BDR	3.0 0.3	3.4 0.2	4.3 0.2	3.3 0.1
	BDR2	2.5 0.3	2.6 0.2	3.0 0.1	2.1 0.1
	Lorimer	3.9 0.5	4.7 0.2	7.9 0.5	13.8 0.5
	Daniels	0.08 0.03	0.1 0.01	0.1 0.01	0.2 0.01
	Martin	2.1 0.3	2.4 0.1	4.0 0.2	6.7 0.3
CI Does Not Include Target Tree Size	Delong	110.0 22.2	121.5 7.4	98.1 6.3	16.1 0.5
	Steneck	1.7 0.5	1.5 0.1	1.4 0.1	2.8 0.1
	MACD 1	0.9 0.3	0.8 0.2	0.5 0.03	1.0 0.04
	MACD 2	3.4 0.6	5.8 0.3	5.5 0.3	8.7 0.3
	MACD 3	446.2 62.4	835.6 41.9	773.1 35.4	1498.9 48.9
	MACD 4	1100.5 154.9	2072.4 107.7	1905.6 88.4	3718.0 123.9
CI Includes Target Tree Size	Braathe	14.5 3.8	30.6 2.2	21.5 1.5	39.8 2.0
	Brand	467.7 110.0	644.3 74.3	1145.1 118.7	10.3 0.5
	Comeau	82.9 15.5	101.0 6.8	132.9 9.8	17.9 0.7
	Towill	513.3 119.3	519.8 42.3	547.9 48.9	74.5 3.6

1. Formulas for these indices are in Appendix 1.
2. Mean and standard error of the mean.

## **5.0 DECIDUOUS COMPETITION AND WHITE SPRUCE GROWTH INTERACTIONS**

Competition and growth interactions are complex and dynamic and the interactions change over time as plant communities and stands develop. Using a static one-time measurement of competition and attempting to isolate its effects on tree growth has severe limitations. Furthermore, a number of factors and processes in addition to many hidden factors interact in competition relationships. Thus it is a challenging task to choose an analytical pathway that allows for a biologically-meaningful interpretation.

We used the following steps in the analysis and interpretation of the hardwood competition-white spruce growth relationships and present the results in the same sequence:

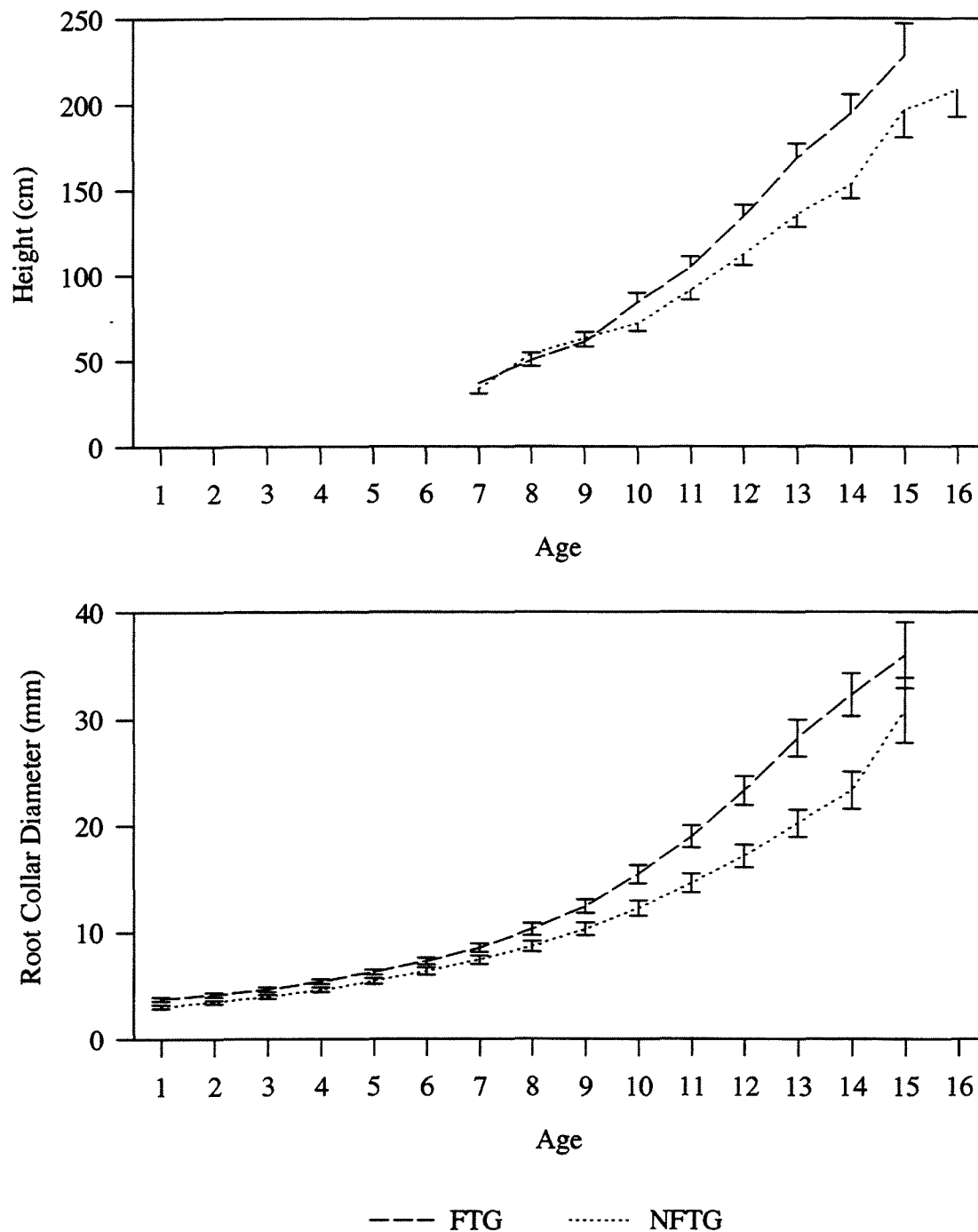
- a) Quantification of competition intensities in geographical areas (four areas) and blocks using single competition variables and selected competition indices as competition descriptors (Section 4.0).
- b) Development of single linear regressions and screening of scatterplots to determine trends in relationships for a large combination of single competition variables, competition indices, and site variables with five target tree growth variables.
- c) Ranking the regression relationships by the level of variability explained (value of  $R^2$ ).
- d) Selecting the most promising competition variables and developing multiple linear regressions. These included selected competition variables, competition indices and site variables. The competition indices included some that incorporate the size of the target tree and some that did not.
- e) Testing the effects of selected site variables separately or as a component of multiple regressions.
- f) Developing non-linear functions for the best and most promising competition index growth and competition relationships.

The basic assumption in the analyses was that current growth and cumulative growth (i.e., total size) of the target trees was affected by measurable competition. In other words, growth of white spruce is a function of deciduous competition. Of the growth response variables tested, radial increment consistently had the highest coefficient of determination in the regression analysis.

### **5.1 FREE-TO-GROW STATUS AND WHITE SPRUCE GROWTH**

The Free-to-Grow (FTG) status of each target tree was determined according to the criteria described in the 1992 version of the Alberta Regeneration Survey Manual (Alberta Forest Service 1992). The criteria were based on the proximity of a large competitor. Basically, it meant for each target tree, determining if there was overtopping by deciduous competitors, and if not, whether or not it was described as Free-to-Grow, using the currently-used Alberta standards. Average cumulative height and diameter curves of FTG and Not-FTG trees of planted origin were plotted for each of the surveyed areas (Figure 15-18).

**Figure 15**  
 White Spruce Height and Root Collar Diameter Growth For FTG and Not FTG Trees  
 Kakwa River



Average curve (with standard error of the mean) shown.

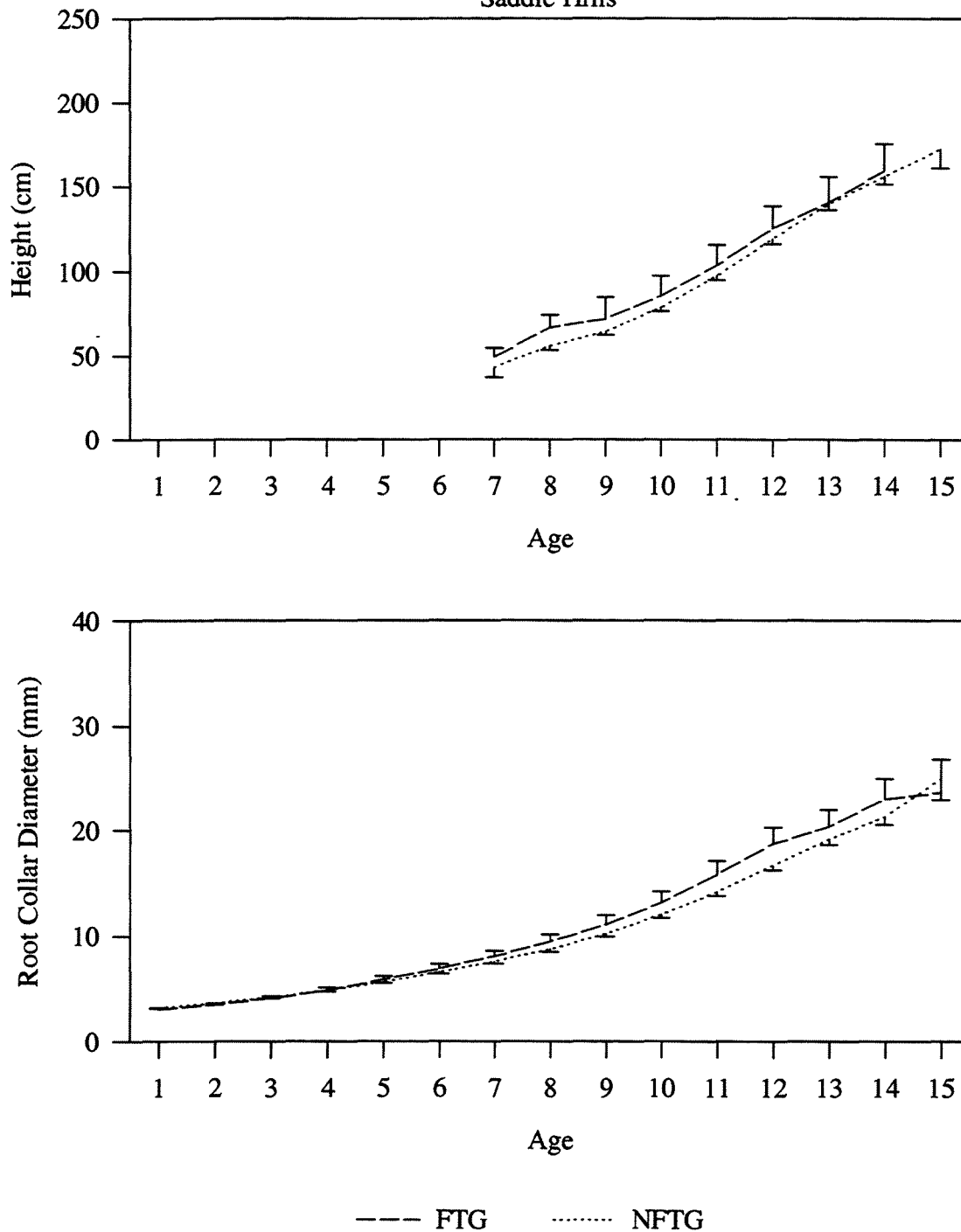
Data from planted trees (32 free-to-grow and 42 not-free-to grow).

FTG trees include acceptable (>150 cm) and conditional (100-149 cm).

Height and Diameter measured at end of growing season.

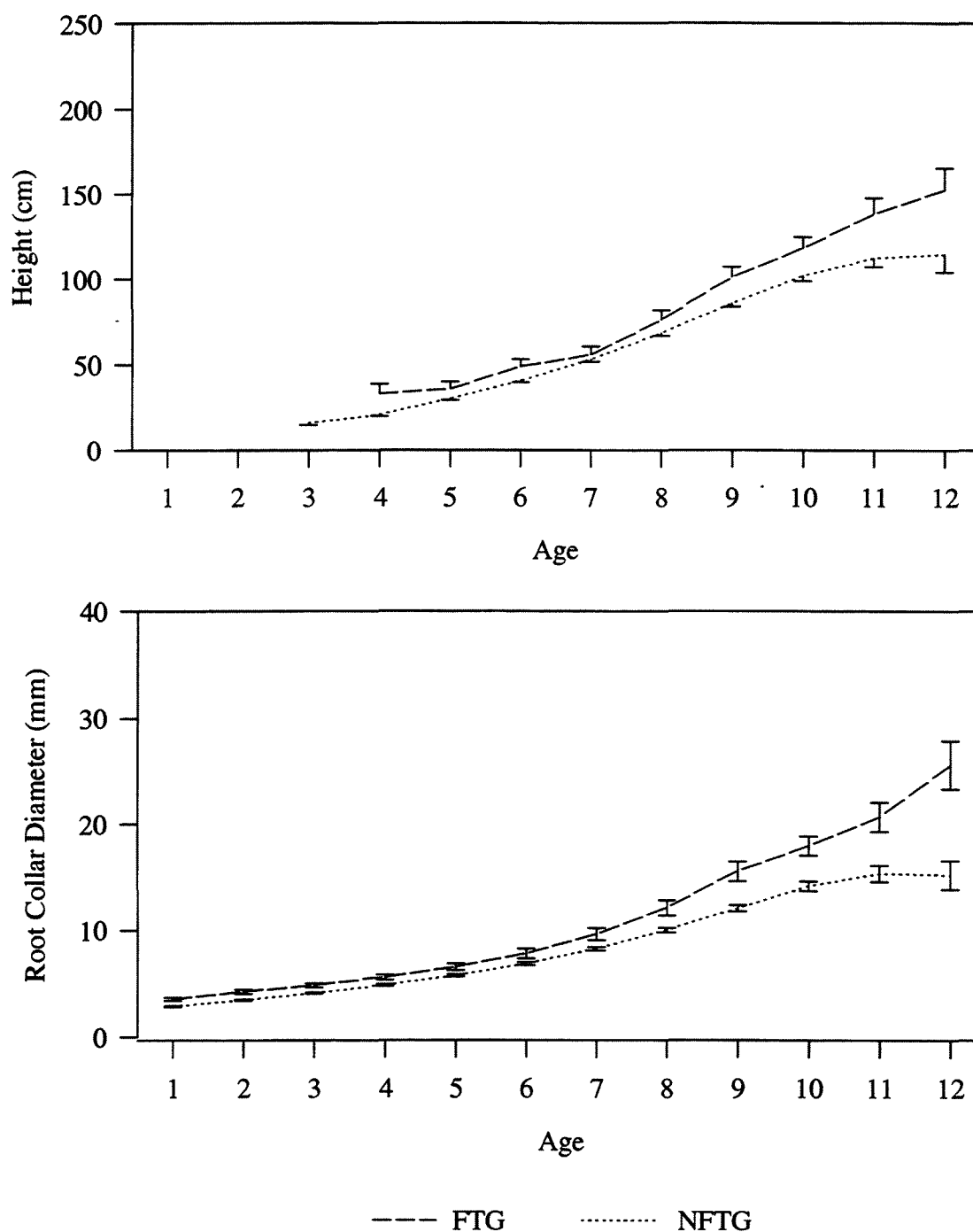


**Figure 16**  
 White Spruce Height and Root Collar Diameter Growth For FTG and Not FTG Trees  
 Saddle Hills



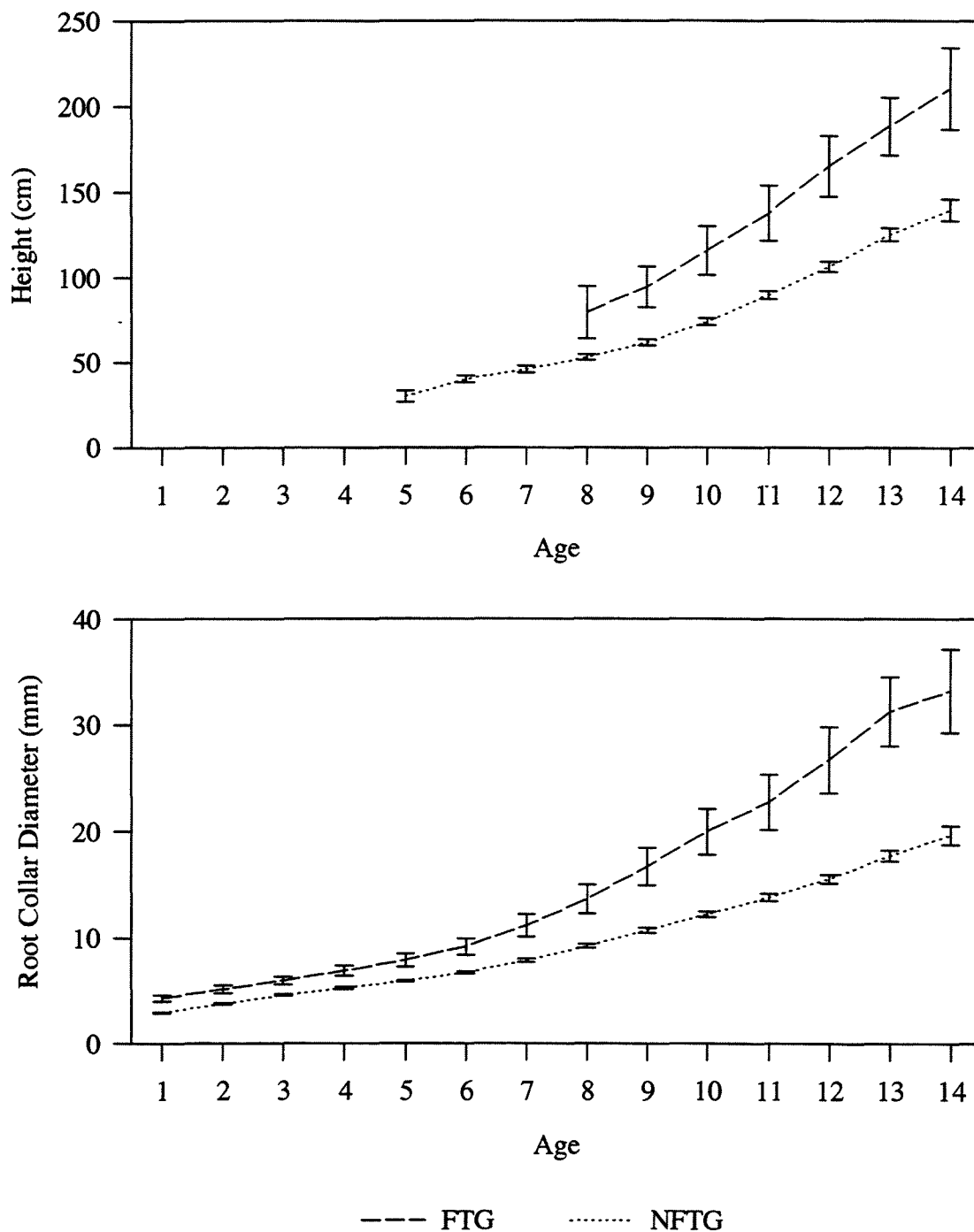
Average curve (with standard error of the mean) shown.  
 Data from planted trees (23 free-to-grow and 126 not-free-to grow).  
 FTG trees include acceptable (>150 cm) and conditional (100-149 cm).  
 Height and Diameter measured at end of growing season.

**Figure 17**  
 White Spruce Height and Root Collar Diameter Growth For FTG and Not FTG Trees  
 Rocky Mountain House



Average curve (with standard error of the mean) shown.  
 Data from planted trees (23 free-to-grow and 220 not-free-to grow).  
 FTG trees include acceptable (>150 cm) and conditional (100-149 cm).  
 Height and Diameter measured at end of growing season.

**Figure 18**  
 White Spruce Height and Root Collar Diameter Growth For FTG and NFTG Trees  
 Calling Lake



Average curve (with standard error of the mean) shown.

Data from planted trees (21 free-to-grow and 267 not-free-to grow).

FTG trees include acceptable (>150 cm) and conditional (100-149 cm).

Height and Diameter measured at end of growing season.

In the previous sections the occurrence of high competition levels in the surveyed blocks was documented. Assessments of FTG status confirmed this trend. The proportion of target trees that were Not-FTG were, on average, 86%, 91%, and 88%, in the Saddle Hills, Rocky Mountain House, and Calling Lake areas, respectively. As well, the proportion of Not-FTG trees was consistently high in individual blocks within areas (i.e., 15 of 17 blocks in these three areas had 84% or more target trees classified as Not-FTG) (Table 11). The notable exception to this trend was the Kakwa River area, where 44% and 70% of the target trees were Not-FTG, for Blocks 1 and 2, respectively. This corresponds to lower competition levels in these area compared to other areas (Figures 12-14, Table 9).

Growth changes associated with FTG status showed two distinct patterns. The first pattern indicated no change in height and diameter growth as related to the current FTG or Not-FTG status. This was the case in the Saddle Hills blocks where the cumulative growth curves were basically the same for Not-FTG and FTG trees (Figure 16). In other words, trees having a deciduous competitor equal to or taller than  $\frac{2}{3}$  of the tree height within 1 m radius, showed no growth reduction at present or in the past, based on retrospective height and root collar diameter analysis.

The second pattern present in the Kakwa River, Rocky Mountain House and Calling Lake areas suggested that the significant differences in growth of FTG and Not-FTG trees started at an age of 10 years or earlier. The most pronounced divergence of curves occurred in the Calling Lake blocks (Figure 18), with some divergence for the Kakwa River and Rocky Mountain House blocks (Figures 15 and 17). The divergence of curves also indicates that one of the two following situations may have occurred: 1. competition pressure at the early stage of seedling development could have had a lasting effect on growth, or that 2. present competition as classified by the current FTG status has existed for much of the tree's development and consequently had affected growth over most of the seedling's existence.

## **5.2 DENSITY AND COVER OF DECIDUOUS COMPETITION AND WHITE SPRUCE GROWTH**

Analysis of variance indicated that there was a significant block effect on the relationship between competition and the white spruce growth variables. For this reason, the linear regression analysis discussed in the following sections was performed on each block separately, and average results are shown.

Coefficients of determination ( $R^2$ ) for linear regressions relating white spruce growth to density and cover competition variables had the highest values between 0.18 - 0.33, varying with the area and the white spruce growth variable. The results for each area are shown in Table 12 and are described below for the four best competition variables for each location. In the Kakwa River area approximately 20% of the variation in height, basal diameter and radial increment of spruce was explained by the best performing variable - vegetation cover. The second best were Hardwood cover and Woody cover variables and explained about the same level (approximately 20%) of white spruce diameter growth, both in radial increment and total basal diameter.

**Table 11**  
Census of Free-to-Grow Target Trees in Each Block<sup>1</sup>

Location	Block	Years Since Harvest	Acceptable FTG <sup>2</sup>	Conditional FTG <sup>3</sup>	Not FTG <sup>4</sup>
			n %	n %	n %
Kakwa	1	14	20 43	6 13	21 44
	2	14	10 30	- -	23 70
	Total	14	30 38	6 8	44 55
Saddle Hills	1	13	3 10	4 14	22 76
	2	15	4 8	2 4	42 88
	3	13	2 5	1 2	41 93
	4	12	4 8	4 8	41 84
	Total	12-15	13 8	11 6	146 86
Rocky Mountain House	1	20	6 11	5 9	42 79
	2	11	4 8	- -	46 92
	3	10	2 4	3 6	45 90
	4	10	- -	2 4	48 96
	5	10	1 3	1 3	28 93
	6	10	- -	2 4	53 97
	Total	10-20	13 5	13 5	262 91
Calling Lake	1	14	6 12	- -	44 88
	2	14	1 3	- -	37 97
	3	11	5 12	2 5	36 84
	4	11	1 2	2 4	47 94
	5	11	1 2	1 2	40 95
	6	13	1 2	1 2	50 96
	7	11	- -	1 2	51 98
	Total	11-14	15 5	7 2	305 93
Total		10-20	72 8	37 4	760 88

1. Definition of free-to-grow is from unpublished report 1990, by Reforestation Branch, Alberta Forest Service. Based on target trees of all origin (planted, ingress, advanced regeneration).
2. Trees are free-to-grow from competition and are at least 150 cm tall.
3. Trees are free-to-grow from competition, but are 100-149 cm tall.
4. Trees are not free-to-grow from competition and/or are less than 100 cm tall.

**Table 12**  
Single Linear Regression for Density and cover Competition Variables

Kakwa (n=72)

Competition Variable <sup>1</sup>	Growth Variable (R <sup>2</sup> values) <sup>1</sup>				
	Radial Increment	Basal Diameter	Height Increment	Height	Basal Area Increment
Vegetation Cover	0.23 <sup>2</sup>	0.24	0.15	0.20	0.21
Hardwood Cover	0.21	0.17	0.14	0.13	0.18
Woody Cover	0.21	0.19	0.17	0.18	0.15
Crown Sum	0.21	0.13	0.11	0.10	0.16
Tree Cover	0.19	0.12	0.11	0.11	0.12
Hardwood Density	0.15	0.09	0.09	0.05	0.11
Tree Density	0.13	0.07	0.08	0.03	0.09
Aspen Cover	0.10	0.09	0.06	0.06	0.07
Moss Cover	0.10	0.08	0.01	0.05	0.09
Shrub Cover	0.07	0.09	0.08	0.10	0.05
Woody Density	0.07	0.05	0.10	0.03	0.04
Aspen Density	0.06	0.05	0.04	0.03	0.04
Shrub Density	0.03	0.05	0.07	0.06	0.03
Grass Cover	0.02	0.03	0.03	0.02	0.03
Forb Cover	0.02	0.05	0.01	0.03	0.03
Conifer Cover	0.01	0.06	0.02	0.06	0.03
Conifer Density	0.01	0.02	0.003	0.01	0.01
Herb Cover	0.01	0.03	0.01	0.01	0.01

1. Data transformed with natural log or square root transformation.
2. Based on average R<sup>2</sup> for all blocks analyzed separately.

**Table 12 (continued)**

Saddle Hills (n=165)

Competition Variable <sup>1</sup>	Growth Variable (R <sup>2</sup> values) <sup>1</sup>				
	Radial Increment	Basal Diameter	Height Increment	Height	Basal Area Increment
Aspen Density	0.33 <sup>2</sup>	0.19	0.09	0.08	0.27
Woody Cover	0.31	0.24	0.08	0.14	0.28
Hardwood Density	0.30	0.18	0.17	0.14	0.25
Aspen Cover	0.30	0.19	0.05	0.08	0.24
Hardwood Cover	0.28	0.17	0.09	0.10	0.23
Crown Sum	0.27	0.16	0.08	0.09	0.23
Tree Cover	0.27	0.16	0.06	0.07	0.22
Tree Density	0.27	0.15	0.12	0.12	0.22
Woody Density	0.20	0.19	0.18	0.26	0.18
Conifer Cover	0.19	0.13	0.07	0.04	0.18
Conifer Density	0.19	0.12	0.05	0.03	0.18
Shrub Cover	0.19	0.12	0.04	0.05	0.17
Grass Cover	0.18	0.12	0.01	0.03	0.17
Vegetation Cover	0.18	0.21	0.13	0.27	0.19
Shrub Density	0.17	0.11	0.09	0.10	0.16
Forb Cover	0.12	0.16	0.15	0.22	0.15
Herb Cover	0.09	0.07	0.03	0.04	0.09
Moss cover	0.05	0.05	0.04	0.10	0.05

1. Data transformed with natural log or square root transformation.

2. Based on average R<sup>2</sup> for all blocks analyzed separately.

**Table 12 (continued)**

Rocky Mountain House (Blocks 2-6) (n=234)

Competition Variable <sup>1</sup>	Growth Variable (R <sup>2</sup> values) <sup>1</sup>				
	Radial Increment	Basal Diameter	Height Increment	Height	Basal Area Increment
Vegetation Cover	0.18 <sup>2</sup>	0.13	0.08	0.08	0.16
Woody Cover	0.18	0.11	0.07	0.05	0.14
Hardwood Cover	0.17	0.12	0.08	0.06	0.14
Crown Sum	0.17	0.12	0.08	0.06	0.14
Tree Cover	0.15	0.10	0.07	0.05	0.12
Aspen Cover	0.14	0.10	0.09	0.05	0.13
Grass Cover	0.09	0.03	0.03	0.01	0.05
Hardwood Density	0.09	0.07	0.05	0.03	0.08
Tree Density	0.09	0.06	0.06	0.03	0.07
Aspen Density	0.08	0.07	0.06	0.03	0.07
Woody Density	0.08	0.05	0.05	0.03	0.07
Tall Shrub Cover	0.04	0.04	0.02	0.04	0.04
Forb Cover	0.03	0.05	0.02	0.04	0.05
Herb Cover	0.03	0.01	0.01	0.02	0.02
Conifer Density	0.02	0.02	0.02	0.004	0.02
Low Shrub Cover	0.02	0.03	0.02	0.01	0.03
Conifer Cover	0.02	0.03	0.04	0.04	0.03
Moss Cover	0.01	0.04	0.02	0.03	0.02
Shrub Density	0.01	0.01	0.01	0.03	0.01

1. Data transformed with natural log or square root transformation.

2. Based on average R<sup>2</sup> for all blocks analyzed separately.



**Table 12 (concluded)**

Calling Lake (n=290)

Competition Variable <sup>1</sup>	Growth Variable (R <sup>2</sup> values) <sup>1</sup>				
	Radial Increment	Basal Diameter	Height Increment	Height	Basal Area Increment
Hardwood Cover	0.26 <sup>2</sup>	0.11	0.08	0.04	0.20
Woody Density	0.26	0.11	0.09	0.06	0.20
Hardwood Density	0.25	0.09	0.07	0.04	0.19
Woody Cover	0.25	0.11	0.08	0.06	0.18
Crown Sum	0.24	0.10	0.08	0.05	0.18
Tree Cover	0.24	0.10	0.08	0.05	0.18
Tree Density	0.22	0.08	0.07	0.04	0.16
Aspen Cover	0.14	0.04	0.03	0.02	0.10
Aspen Density	0.14	0.04	0.04	0.01	0.10
Vegetation Cover	0.13	0.06	0.05	0.04	0.10
Moss Cover	0.08	0.05	0.06	0.03	0.07
Shrub Density	0.08	0.08	0.06	0.05	0.07
Conifer Density	0.06	0.10	0.05	0.10	0.08
Conifer Cover	0.05	0.09	0.05	0.10	0.07
Tall Shrub Cover	0.04	0.03	0.02	0.02	0.04
Grass Cover	0.04	0.03	0.04	0.03	0.03
Forb+Low Shrub Cover	0.02	0.02	0.01	0.02	0.02

1. Data transformed with natural log or square root transformation.
2. Based on average R<sup>2</sup> for all blocks analyzed separately.

In the Saddle Hills the strongest relationship existed between the competition variables based on the amount of aspen and hardwoods. Aspen density, Woody cover, Hardwood density, and Aspen cover explained 30% or more of the variation in radial increment of spruce. In contrast, the relationship of the same competition variables with spruce height was weak ( $R^2 = 0.08 - 0.14$ ) for the four best overall competition variables.

In the Rocky Mountain House blocks no strong regression relationship was found for height ( $R^2 \leq 0.08$ ). The highest  $R^2$  (0.17 - 0.18) for radial increment was lower than those observed in other areas and was associated with the variables representing cover such as Vegetation cover, Woody cover and Hardwood cover.

In the Calling Lake area Hardwood cover, Woody density, Hardwood density and Woody cover produced a relatively strong relationship with radial increment ( $R^2 = 0.25 - 0.26$ ). Since Aspen cover and Aspen density explained about 10% less of the variation in radial growth ( $R^2 = 0.14$ ) than did Hardwood cover and Hardwood density it is evident that balsam poplar, as an additive component of hardwood cover and hardwood density variables, contributed to a reduction in white spruce radial growth. The effects of cover and density variables on height growth were negligible and coefficients of determination explained less than 10% of the variation.

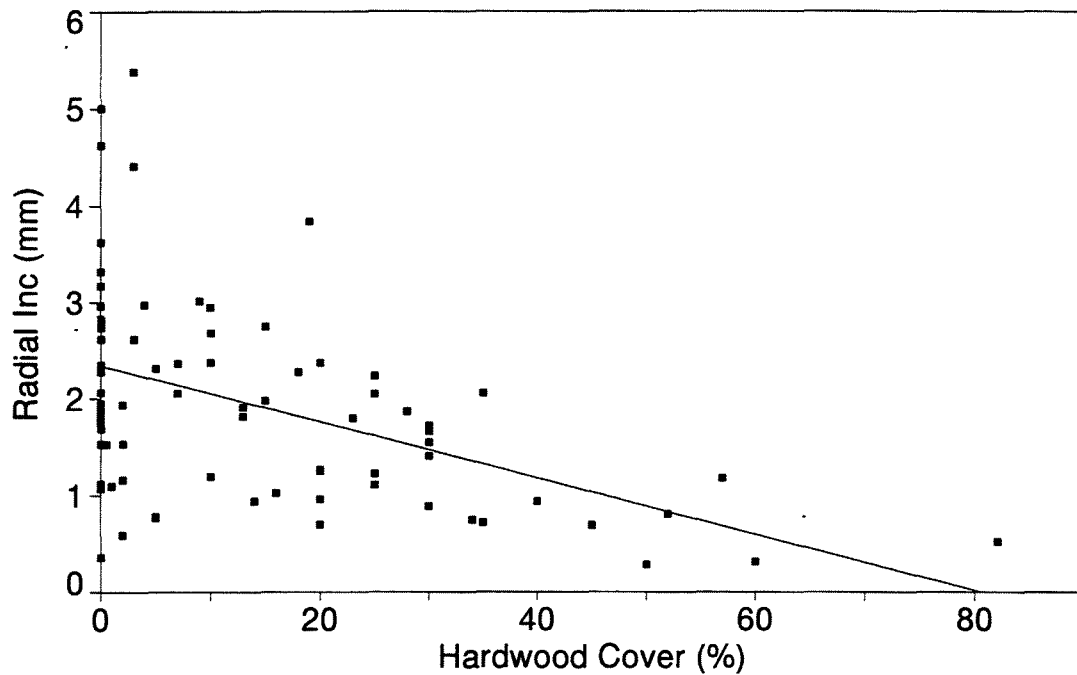
In the above paragraphs the intensity of competition versus growth relationship as expressed by  $R^2$  (coefficient of determination) was discussed. The other aspect is to ascertain the performance of seedlings as reduced by competition. Scatterplots and linear regression lines in Figures 19 and 20 illustrate that in Kakwa River and Calling Lake increasing hardwood cover was associated with reduced radial increment. In plots with 40% and greater hardwood cover the white spruce radial increment was half the amount compared to spruce growing in plots with no or very low (0 - 10%) hardwood cover. The wide range and spread of observations above the regression line in the 0 - 15% range of cover indicates that there is only a weak and inconsistently occurring negative influence of cover on spruce diameter growth, and much unexplained variation in growth at these low competition levels (a well-documented phenomenon).

In the other two areas, Saddle Hills and Rocky Mountain House, the slope coefficients were lower,  $b = -0.009$  and  $b = -0.01$ , respectively (based on transformed variables), therefore indicating even lesser negative growth response to increasing hardwood cover. These areas had a higher average and wider range of hardwood cover (mean 30%) than did Calling Lake and Kakwa River areas (mean cover 20.5% and 14.3%, respectively).

Once the non-tolerable reduction in diameter growth are defined in a management strategy, hardwood cover could serve as a rough guide for stratification of the areas scheduled for tending or selected for a more intensive competition survey. Based on regression analysis, 30% hardwood cover corresponds with approximately a 40% decrease in the rate of white spruce radial growth compared to growth on sites that had no hardwood cover (Table 13). For 50% hardwood cover, this decrease reaches over 60%. In spite of these trends, using cover estimates alone to explain differences in spruce growth, or to justify release treatment has a limited application, due to the high amount of unexplained variation.

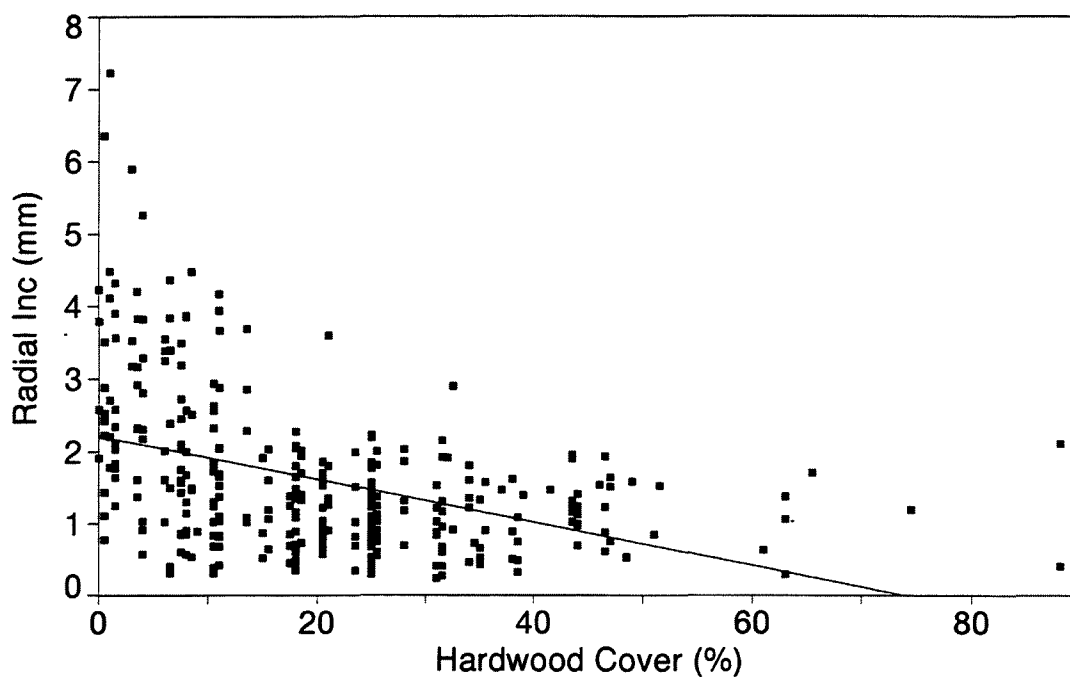
In all four areas radial growth expressed as annual radial increment in the year previous to the year of competition measurement showed the strongest regression relationship with competition. In

**Figure 19**  
 Linear Regression of White Spruce Radial Increment vs Hardwood Cover for the  
 Kakwa River Area



Radinc = 2.34 - 0.03(Hardwood Cover)  $R^2 = 0.22$  Fstat = 21.57 n = 78  
 Regression based on all blocks combined. Data not transformed. Best simple  
 regression is obtained with exponential model  $y = a + b^{-x/c}$ , with an  $R^2$  of 0.22.

**Figure 20**  
**Linear Regression of White Spruce Radial Increment vs Hardwood Cover for the**  
**Calling Lake Area**



Radinc = 2.21 - 0.03(Hardwood Cover)  $R^2 = 0.19$  Fstat = 74.45 n = 326  
 Regression based on all blocks combined. Data not transformed. Best simple  
 regression is obtained with exponential model  $y = a + b^{-x/c}$ , with an  $R^2$  of 0.33.

**Table 13**  
**Reduction of White Spruce Radial Increment at Different Hardwood Cover Levels<sup>1</sup>**

	30% Hardwood Cover	50% Hardwood Cover
Kakwa River	38% reduction <sup>2</sup>	62% reduction
Calling Lake	41% reduction	68% reduction

1. Percent reduction in radial increment compared to the predicted white spruce growth on sites with no hardwood cover.
2. Calculation based on linear regression models shown in Figures 19 and 20 for the Kakwa River and Calling Lake areas, respectively.

contrast, height growth showed to be less related to competition. This is a well-known phenomenon and conforms well to other findings discussed later.

Radial growth was consistently and strongly related to competition variables based on the overall amount of hardwood and aspen in the plot as expressed by density or cover, in all four areas. This demonstrates the importance of both balsam poplar and aspen in affecting growth of shade-tolerant white spruce.

In a separate analysis, an approach used by Newsome (1995) in aspen-lodgepole pine competition studies in the Cariboo Region, B.C. were used to test the relationship between white spruce growth and aspen density. Plots were separated into aspen density classes, based on aspen taller than the target tree. Then multiple means tests were used to determine if there was a significant difference in spruce growth in the different aspen density classes. The results showed, for almost all cases, no significant differences in growth response. This may indicate that total aspen density was more important than just the density of tall aspen in the competition dynamics.

### **5.3 PROXIMITY OF DECIDUOUS COMPETITORS AND WHITE SPRUCE GROWTH**

The relationship of competition and growth estimated by the proximity of the closest hardwood or aspen competitor to the target tree was found to be pronounced in two areas - Kakwa River and Saddle Hills, but in other two areas the same competition estimates exhibited little relationship (Table 14). In Kakwa River and Saddle Hills areas 30% or more of the variation in radial growth and more than 20% in height growth was associated with the stem-stem distance of the closest deciduous tree (variables Closest aspen stem, Closest hardwood stem). In general, the growth-proximity relationship was stronger for closest hardwood stem than for average stem-to-stem distance.

The nearness of the deciduous tree had a significant competitive effect and radial increment increased as the stem-stem distance increased. For example, in the Kakwa area, radial increment nearly doubled as the distance to the closest aspen increased from 50 cm to 150 cm (Figure 21). As previously mentioned, in two other areas (Calling Lake and Rocky Mountain House) the proximity of hardwood trees had only a small effect on spruce growth. The relationship between white spruce radial increment and the distance of the closest hardwood tree was weak in Rocky Mountain House and Calling Lake ( $R^2 = 0.14$  and  $0.09$ , respectively). In both of these areas height growth was not related to stem-stem distance. The presence of a strong relationship of the proximity of competition and spruce growth in two areas and the lack of the same relationship in two other areas illustrates the variability in the performance of this competition measurement, and competition measurements in general.

In this instance the difference in performance can likely be related to differences in the size of competitor and target tree in the studied areas. Both aspen and spruce were taller in the areas where the proximity index performed well than in the areas where the relationship was weak (Table 15). Hence, larger-sized aspen crowns cause competition by shading the spruce at an earlier age sooner and also cause more shade relative to sites with smaller aspen. The larger size of spruce also contributed to earlier and greater crown contact with aspen and possible crown overlap (but not

**Table 14**  
Single Linear Regression for Competition Distance Variables

Kakwa (n=21)

Competition Variable <sup>1</sup>	Growth Variable (R <sup>2</sup> values) <sup>1</sup>				
	Radial Increment	Basal Diameter	Height Increment	Height	Basal Area Increment
Closest Aw stem	0.39 <sup>2</sup>	0.34	0.34	0.34	0.41
Avg Aw crown distance	0.30	0.14	0.19	0.09	0.26
Avg Hw crown distance	0.22	0.09	0.15	0.06	0.18
Closest Hw stem	0.13	0.12	0.10	0.14	0.13
Avg Aw stem distance	0.11	0.06	0.08	0.03	0.15
Tallest Hw distance	0.02	0.0003	0.10	0.004	0.02
Tallest Aw distance	0.02	0.0003	0.10	0.004	0.02
Avg Hw distance	0.01	0.0001	0.05	0.002	0.003

Saddle Hills (n=132)

Competition Variable	Growth Variable (R <sup>2</sup> values)				
	Radial Increment	Basal Diameter	Height Increment	Height	Basal Area Increment
Closest Hw stem	0.32	0.25	0.23	0.22	0.28
Closest Aw stem	0.29	0.23	0.24	0.20	0.25
Tallest Hw distance	0.26	0.26	0.24	0.27	0.27
Tallest Aw distance	0.26	0.26	0.24	0.27	0.27
Avg Hw stem distance	0.22	0.23	0.21	0.21	0.22
Avg Hw crown distance	0.21	0.23	0.21	0.21	0.21
Avg Aw stem distance	0.21	0.22	0.22	0.21	0.21
Avg Aw crown distance	0.21	0.22	0.21	0.22	0.21

1. Data transformed with natural log or square root transformation.
2. Based on average R<sup>2</sup> for all blocks analyzed separately.

**Table 14 (concluded)**

**Rocky Mountain House (Blocks 2-6) (n=190)**

Competition Variable <sup>1</sup>	Growth Variable (R <sup>2</sup> values) <sup>1</sup>				
	Radial Increment	Basal Diameter	Height Increment	Height	Basal Area Increment
Avg Hw crown distance	0.14 <sup>2</sup>	0.10	0.04	0.04	0.13
Avg Aw crown distance	0.13	0.08	0.03	0.02	0.11
Avg Aw stem distance	0.07	0.05	0.01	0.03	0.06
Closest Hw stem	0.06	0.07	0.02	0.04	0.06
Avg Hw stem distance	0.05	0.04	0.01	0.03	0.05
Closest Aw stem	0.05	0.06	0.02	0.03	0.04
Tallest Hw distance	0.04	0.003	0.03	0.01	0.01
Tallest Aw distance	0.04	0.003	0.03	0.01	0.01

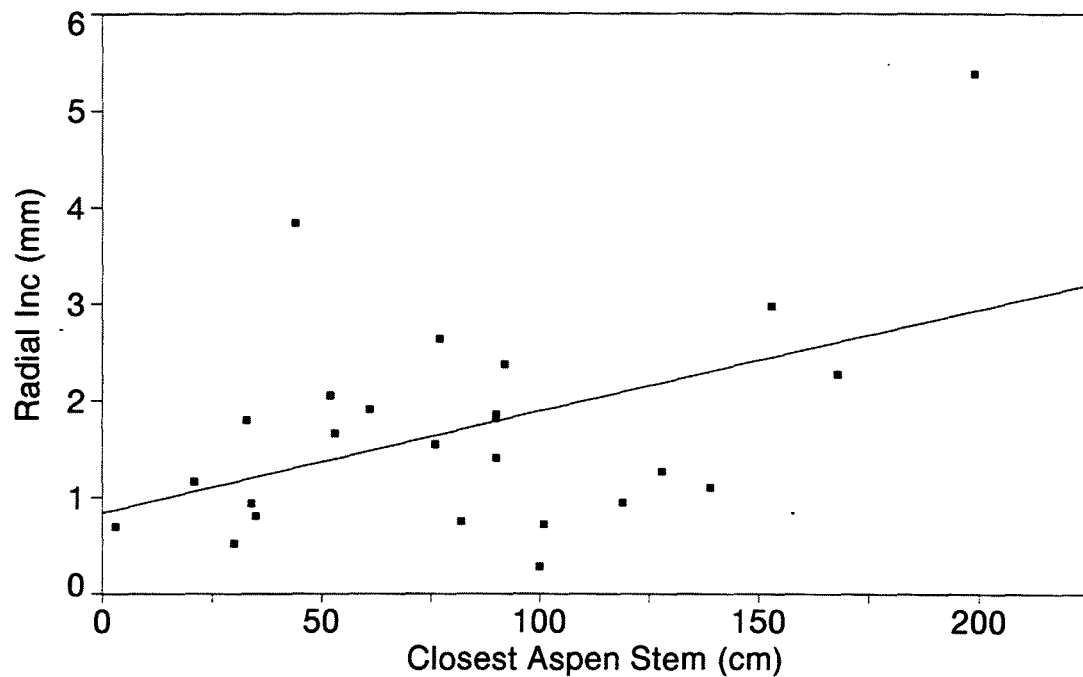
**Calling Lake (n=200)**

Competition Variable	Growth Variable (R <sup>2</sup> values)				
	Radial Increment	Basal Diameter	Height Increment	Height	Basal Area Increment
Closest Aw stem	0.09	0.06	0.03	0.01	0.09
Avg Hw stem distance	0.07	0.08	0.07	0.05	0.08
Avg Aw stem distance	0.07	0.04	0.04	0.02	0.08
Closest Hw stem	0.05	0.06	0.02	0.04	0.06
Avg Hw crown distance	0.05	0.07	0.06	0.06	0.06
Avg Aw crown distance	0.04	0.06	0.06	0.06	0.06
Tallest Hw distance	0.01	0.05	0.04	0.07	0.02
Tallest Aw distance	0.01	0.05	0.04	0.07	0.02

1. Data transformed with natural log or square root transformation.
2. Based on average R<sup>2</sup> for all blocks analyzed separately.



**Figure 21**  
 Linear Regression of White Spruce Radial Increment vs Distance to Closest Aspen for the  
 Kakwa River Area



Radinc = 0.84 + 0.01(Closest Aspen Stem)  $R^2 = 0.20$  Fstat = 5.90  $n = 25$   
 Regression is based on all blocks combined. Data not transformed. Best simple  
 regression is obtained with model  $y = a + bx^3$ , with an  $R^2$  of 0.37.

**Table 15**  
Comparison of White Spruce-Deciduous Competitor Height by Area

	Height (cm)			Ratio of Spruce/Aspen Height
	Aspen	Balsam Poplar	Spruce	
Kakwa River	553	417	169	0.305
Saddle Hills	543	399	130	0.239
Rocky Mtn. House	374	346	89	0.238
Calling Lake	444	404	83	0.187

necessarily greater shading).

In the Calling Lake, area where the ratio of spruce height/aspen height was the smallest (Table 15), the competition variables expressing the competition pressure exerted by all deciduous trees (e.g., cover and density) within a plot were more important than the proximity of deciduous competitors. It is also possible that competition was received not only from immediate neighbors. Smaller spruce trees could be affected by bigger competitors from a considerable distance. Such a competition condition related to "zone of influence" was described by Bella (1969) who concluded that in these instances competition seems to be determined largely by variables such as stand density, which is in agreement with this study and the finding of others. In fact, Calling Lake had the highest aspen density of all the areas.

In young, 4-year-old plantation of white spruce hardwood competitors more distant than the height of the young spruce seedlings had a significant competitive effect and dominant trees at greater distances were considered to be more important than small competitors close to a seedling (MacDonald 1991).

A competition index based on the sum of the target tree to aspen tree distance, developed by Newsome (1995) for aspen-pine in B.C., was tested in regression analysis against white spruce growth. Results showed that this competition index did not perform better than the other distance measurements described above.

#### **5.4 INFLUENCE OF WHITE SPRUCE AGE ON COMPETITION-GROWTH INTERACTIONS**

So far this report has presented the effects of deciduous competition on spruce growth and size without considering age-growth relationships. The influence of white spruce age on growth variables tested by non-linear regression analyses is summarized in Table 16. Results show there was only a weak to moderate relationship between size of the spruce tree and tree age (for many of the regressions this relationship was almost non-existent -  $R^2 < 0.05$ ). This is partly due to the relatively narrow range of target spruce tree ages used in the analysis (a reflection of the block ages selected for study). Not surprisingly, the relationship was stronger for those variables that integrate growth (e.g., total height or diameter) rather than one year incremental variables. While there was generally a low dependancy of spruce growth on age, there were exceptions for Diameter and Basal area increment in the Kakwa River area and Height and Diameter in the Rocky Mountain House area, where age explained over 20% of the variance in spruce size. The observed general lack of a strong relationship of spruce growth and age confirms strong influence of other factors including competition on spruce growth rather than age alone.

The age-growth-competition relationships were further tested using two-term non-linear regressions (Table 16, right column). The addition of age and non-linearity improved the predictive power where age-growth relationships were strong, but only slightly in other combinations. Age determination is difficult in the field and in an operational setting. Because of the observed lack of consistency of age-growth effects, age was not used as a component of predictive formulas in further analyses.

**Table 16**  
Test of White Spruce Age-Dependence on Growth Variables and Best Competition Variables

Location	Growth Variable	Age $R^2$	Competition Variable <sup>1</sup>	Age and Comp. Var. $R^2$
Kakwa River	Height	0.15	Hardwood Cover	0.23
	3 Yr. Periodic Htinc.	0.05	Hardwood Cover	0.20
	Diameter	0.25	Hardwood Cover	0.38
	3 Yr. Periodic Radinc.	0.11	Hardwood Cover	0.31
	Basal Area Inc.	0.26	Hardwood Cover	0.34
	Ht/Dia Ratio	0.12	Hardwood Cover	0.28
Saddle Hills	Height	0.10	Aspen Density	0.13
	3 Yr. Periodic Htinc.	0.04	Aspen Density	0.11
	Diameter	0.16	Aspen Density	0.23
	3 Yr. Periodic Radinc.	0.05	Aspen Density	0.18
	Basal Area Inc.	0.09	Aspen Density	0.19
	Ht/Dia Ratio	0.09	Aspen Density	0.24
Rocky Mountain House (Blocks 2-6)	Height	0.22	Moss Cover	0.28
	3 Yr. Periodic Htinc.	0.05	Vegetation Cover	0.15
	Diameter	0.27	Moss Cover	0.30
	3 Yr. Periodic Radinc.	0.07	Vegetation Cover	0.20
	Basal Area Inc.	0.13	Vegetation Cover	0.23
	Ht/Dia Ratio	0.02	Aspen Cover	0.13
Calling Lake	Height	0.07	Hardwood Density	0.12
	3 Yr. Periodic Htinc.	0.02	Hardwood Density	0.10
	Diameter	0.05	Hardwood Density	0.21
	3 Yr. Periodic Radinc.	0.005	Hardwood Density	0.26
	Basal Area Inc.	0.02	Hardwood Density	0.20
	Ht/Dia Ratio	0.008	Hardwood Density	

1. Competition variable is one with highest  $R^2$  from single variable linear regression for each area (all blocks combined).

## 5.5 PERFORMANCE OF COMPETITION INDICES

The competition indices summarized in the matrix of linear regression analysis for spruce growth variables (Table 17) are all based on deciduous competition present within the surveyed 2m radius plot. In general, competition indices that incorporate measurement(s) of crop tree size (e.g., RELVOL, BD Ratio, MARTIN) produced, as expected, stronger relationships of competition when tested against spruce growth. Those indices which included the basal diameter ratio between the target tree and competitors (some were distance-weighted) explained the greatest amount of variation in conifer growth response. These included Relative Volume, Martin's CI, BD Ratio and BD Ratio2 (see Appendix 1).

Competition indices which explained the highest amount of variation in regression analysis included: a) ratio of volume of target tree:sum of hardwood competitor volume (MacDonald 1991, cited by MacDonald and Weetman 1993), b) distance-weighted root collar diameter ratio of the target tree and hardwood competitors (Martin and Ek 1984), c) distance-weighted basal area of the hardwood competitor (MacDonald *et al.* 1990). However, aspen and hardwood density were often shown as important competition variables as was hardwood and total vegetation cover.

Within this group of competition indices that include crop tree size the differences in performance of CI's were very small. The performance of CI's more varied among the areas than among CI's. A 50% or better explanation of spruce growth by CI's was frequent only in one area - Calling Lake.

Comparisons of  $R^2$  values (Table 17) and ranking of the best performing CI's (Table 18) also show that two indices (BD Ratio and RELVOL) frequently occurred among the highest ranking position and that the differences between BD Ratio and BD Ratio2 were negligible. Therefore further analyses concentrated on RELVOL and BD Ratio.

## 5.6 SITE EFFECTS ON WHITE SPRUCE GROWTH AND COMPETITION INTERACTIONS

Analysis of the data from the Kakwa River and Saddle Hills areas had shown that slope and aspect were significant variables in spruce growth. Analysis for all four areas tested for differences in the strength of the regression relationship between competition level and spruce growth for plots occurring on slopes greater than 5% on north facing vs south facing slopes. The *a priori* hypothesis was that there would be a stronger negative relationship between competition levels and spruce growth (i.e., a higher  $R^2$ ) based on the subset of plots from the north facing slopes (i.e., the hardwood competitors having a greater suppression effect on tree growth). It was postulated, that on some southern aspects, greater hardwood competition would allow for better spruce growth, because solar insolation would still be high under the aspen crowns, but the hardwood cover would protect the spruce against dessication. Results indicated that, in three of the four sites, the competition-growth relationship was, in fact, most pronounced on south-facing slopes. The interaction between slope, aspect, competition and growth factors is complex and requires additional analysis beyond the scope of this report.

**Table 17**  
Single Linear Regression for Competition Indices Based on Hardwood Competitors

**Kakwa (n=54)**

Competition Variable <sup>1</sup>	Growth Variable (R <sup>2</sup> values) <sup>1</sup>				
	Radial Increment	Diameter	Height Increment	Height	Basal Area Increment
MARTIN	0.45 <sup>2</sup>	0.46	0.18	0.32	0.44
BDRATIO	0.44	0.47	0.24	0.42	0.45
BDRATIO2	0.43	0.47	0.26	0.42	0.46
RELVOL	0.43	0.46	0.24	0.42	0.43
LORIMER	0.41	0.44	0.19	0.34	0.41
COMEAU	0.41	0.37	0.22	0.34	0.34
DANIELS	0.38	0.36	0.09	0.20	0.35
TOWILL	0.37	0.34	0.21	0.31	0.31
BRAND	0.32	0.24	0.14	0.20	0.26
BRAATHE	0.27	0.22	0.16	0.23	0.27
DELONG	0.25	0.17	0.07	0.10	0.20
MACD2	0.21	0.10	0.03	0.03	0.15
MACD4	0.14	0.05	0.02	0.01	0.08
MACD3	0.14	0.05	0.03	0.01	0.08
MACD1	0.14	0.08	0.02	0.04	0.11
STENECK	0.08	0.04	0.01	0.02	0.06

**Saddle Hills (n=166)**

Competition Variable	Growth Variables (R <sup>2</sup> values)				
	Radial Increment	Diameter	Height Increment	Height	Basal Area Increment
MARTIN	0.42	0.39	0.22	0.29	0.41
RELVOL	0.40	0.38	0.29	0.37	0.39
BRAATHE	0.39	0.29	0.15	0.15	0.36
LORIMER	0.39	0.35	0.24	0.33	0.37
DANIELS	0.39	0.34	0.17	0.22	0.37
BDRATIO	0.38	0.37	0.26	0.34	0.38
COMEAU	0.37	0.25	0.15	0.16	0.31
BDRATIO2	0.36	0.38	0.25	0.34	0.37
TOWILL	0.33	0.19	0.13	0.12	0.27
MACD2	0.33	0.21	0.12	0.13	0.28
MACD4	0.29	0.18	0.14	0.15	0.25
MACD3	0.29	0.18	0.15	0.16	0.24
BRAND	0.28	0.18	0.07	0.08	0.23
DELONG	0.26	0.12	0.10	0.06	0.20
STENECK	0.24	0.15	0.11	0.08	0.21
MACD1	0.22	0.15	0.11	0.09	0.20

1. Data transformed with natural log or square root transformation.
2. Based on average R<sup>2</sup> for all blocks analyzed separately.

**Table 17 (concluded)**

**Rocky Mountain House (Blocks 2-6) (n=226)**

Competition Variable <sup>1</sup>	Growth Variable (R <sup>2</sup> values) <sup>1</sup>				
	Radial Increment	Diameter	Height Increment	Height	Basal Area Increment
RELVOL	0.44 <sup>2</sup>	0.50	0.30	0.41	0.47
BDRATIO2	0.43	0.53	0.29	0.42	0.47
BDRATIO	0.43	0.50	0.27	0.39	0.46
MARTIN	0.42	0.49	0.26	0.36	0.44
LORIMER	0.40	0.48	0.26	0.36	0.43
DANIELS	0.32	0.38	0.18	0.27	0.33
BRAATHE	0.32	0.27	0.20	0.21	0.32
COMEAU	0.30	0.26	0.19	0.22	0.27
TOWILL	0.28	0.24	0.18	0.20	0.25
DELONG	0.20	0.14	0.11	0.07	0.17
MACD1	0.19	0.11	0.11	0.08	0.13
MACD2	0.17	0.08	0.07	0.05	0.13
BRAND	0.17	0.12	0.09	0.07	0.14
STENECK	0.14	0.10	0.07	0.07	0.11
MACD3	0.12	0.07	0.06	0.04	0.10
MACD4	0.11	0.06	0.06	0.03	0.09

**Calling Lake (n=322)**

Competition Variable	Growth Variable (R <sup>2</sup> values)				
	Radial Increment	Diameter	Height Increment	Height	Basal Area Increment
RELVOL	0.69	0.72	0.43	0.57	0.71
MARTIN	0.62	0.59	0.36	0.41	0.61
LORIMER	0.62	0.58	0.34	0.41	0.61
COMEAU	0.59	0.51	0.35	0.44	0.54
BDRATIO2	0.59	0.72	0.43	0.60	0.62
BDRATIO	0.58	0.70	0.43	0.56	0.62
TOWILL	0.56	0.47	0.30	0.37	0.50
DANIELS	0.53	0.53	0.35	0.35	0.52
BRAATHE	0.51	0.42	0.29	0.34	0.56
BRAND	0.37	0.19	0.13	0.12	0.30
MACD2	0.32	0.13	0.07	0.05	0.25
DELONG	0.31	0.13	0.08	0.05	0.24
MACD3	0.30	0.12	0.06	0.04	0.23
MACD4	0.29	0.12	0.06	0.04	0.22
MACD1	0.24	0.12	0.08	0.04	0.20
STENECK	0.21	0.10	0.07	0.03	0.17

1. Data transformed with natural log or square root transformation.
2. Based on average R<sup>2</sup> for all blocks analyzed separately.

**Table 18**  
Summary of Single Variable Linear Regression for Density, Cover, Distance and Competition  
Index Variables for White Spruce Radial Increment

	Kakwa River	Saddle Hills	Rocky Mountain House	Calling Lake
Density	Hw density 0.15 Tree density 0.13	Aspen density 0.33 Hw density 0.30	Crown sum 0.17 Hw density 0.09	Woody density 0.26 Hw density 0.25
Cover	Veg cover 0.23 Hw cover 0.21	Woody cover 0.31 Aspen cover 0.30	Veg cover 0.18 Woody cover 0.18	Hw cover 0.26 Tree cover 0.15
Distance	Closest Aw stem 0.39 Avg Aw crn dist 0.30	Closest HW stem 0.32 Closest Aw stem 0.29	Avg Hw crn dis 0.14 Avg Aw crn dis 0.13	Closest Aw stem 0.09 Closest Hw stem 0.05
CI's Including Target Tree	Martin 0.45 BDRatio 0.44	Martin 0.42 Relvol 0.40	Relvol 0.44 BDRatio 0.43	Relvol 0.69 Martin 0.62
CI's Excluding Target Tree	DeLong 0.25 MACD2 0.21	MACD2 0.33	DeLong 0.20	MACD2 0.32



In addition to slope and aspect, a number of microsite variables were measured including: microtopography class, moisture class, drainage class, slash abundance and litter depth. Principle component analysis was used to determine if there was any relationships between specific groups of microsite variables, in order to determine if one or two microsite variables would sufficiently represent the effect of the greater number of microsite variables measured. This multivariate analysis indicated that there were three groups of variables which added significantly to the competition models, but only for some locations. These microsite variable groups were: a) combined slope and aspect; b) moisture and drainage; c) slash, microtopography and litter depth. All three groups may reflect moisture and nutrient microsite status. These groupings were used in further analysis not presented in this report.

## **5.7 LIGHT LEVELS, COMPETITION AND GROWTH OF THE WHITE SPRUCE**

Light transmission was measured and tests were done to relate the amount of light reaching the target seedlings with the abundance of competing vegetation and with seedling growth. In analysis of the Rocky Mountain House data, there was a strong correlation between the percentage of light reaching the seedling and hardwood abundance, with actual values shown in Table 19. Linear regressions of the percentage of full sunlight reaching the mid-crown of the seedling vs total vegetation cover produced  $R^2$  values of up to 0.38 in some blocks. When the percentage of full sunlight reaching the mid-crown of the seedling was directly related to the seedling radial growth,  $R^2$  values increased to 0.41 in some blocks.

Analyses of the Calling Lake data determined the effect of distribution of competing vegetation around the target seedling (as shown by light transmission levels), with seedling growth response. Tests were done to stratify the seedlings into shaded and unshaded groups, based on different configurations of surrounding vegetation. The greatest growth difference between shaded and unshaded target seedlings was in tests which defined unshaded seedlings as having openings 1.5 m to the east and southeast (defined as areas where there was not less than 40% of full sunlight). In these tests, there were significant growth differences between shaded and unshaded seedlings for both root collar diameter (Figure 22) and height.

The growth difference between shaded and unshaded trees was maintained, even when there were competitors in the west and southwest (i.e., the important factor was having openings to the east and southeast). Solar radiation received in the morning appears to be more critical than that received in the afternoon, perhaps due to early soil warming in the former case. This finding may have implications for mixedwood management. Stand tending could remove hardwood competitors to the east, while retaining those to the west; this would retain a mixture of hardwoods and conifers in the stand, while maintaining young conifer growth. Conifer growth could possibly be enhanced, due to a reduction in mid-afternoon sunlight which could lead to moisture stress on some sites.

**Table 19**  
Light Transmission Compared to Competition Levels

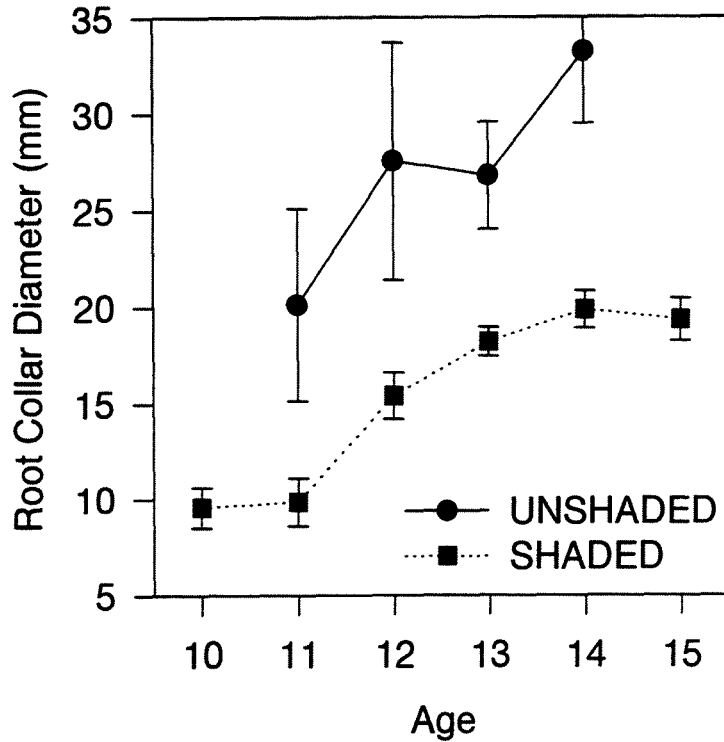
Location	Block	% of Full Sunlight at Tip of Seeding	% of Full Sunlight in 10 m <sup>2</sup> Plot (Average)	Hardwood Cover (%)	Hardwood Density (stems/10 m <sup>2</sup> )	Relative Spruce/Conifer Height (%)
Rocky Mountain House	1	43 ±5 <sup>1</sup>	- <sup>2</sup>	31.5 ±4.2	7.6 ±0.9	59 ±14
	2	61 5	-	41.7 3.6	10.7 1.0	53 8
	3	52 5	-	34.4 4.5	10.7 1.4	45 6
	4	58 5	-	35.9 3.6	8.5 0.8	45 6
	5	35 7	-	21.3 4.1	10.3 1.6	50 7
	6	60 4	-	23.6 2.7	10.8 1.0	47 6
	All	53 2	-	30.2 1.6	9.7 0.5	50 3
Calling Lake	1	44 5	41 ±4	25.6 3.2	13.2 1.2	68 10
	2	24 5	24 3	19.4 2.2	21.0 1.4	43 12
	3	58 6	44 5	18.7 2.5	13.4 1.6	57 8
	4	27 4	21 2	22.4 1.9	23.9 1.3	50 6
	5	30 4	25 3	18.9 2.5	19.2 1.9	41 4
	6	47 5	37 4	17.1 1.7	18.6 1.6	57 11
	7	36 4	29 3	20.5 1.6	19.1 1.1	37 2
	All	38 2	32 1	20.5 0.9	18.4 0.6	51 3

1. Mean and standard error of the mean.

2. Not measured.

**Figure 22**

Root Collar Diameter Growth for Shaded and Unshaded White Spruce Seedlings, Calling Lake



Unshaded trees have greater than 40% full sunlight to the south and southeast of the tree (measured by a sunfleck ceptometer, 1.5 m from the seedling at mid-crown height in late summer). Based on 22 unshaded and 99 shaded trees. Values shown are mean  $\pm$  standard error of the mean. From: MacIsaac and Navratil 1996. Note: The curves do not increase monotonically with age because the data are based on analysis of separate trees for each age.

## **6.0 SIMULTANEOUS EFFECTS OF SEVERAL COMPETITION VARIABLES - MULTIPLE LINEAR REGRESSIONS**

Up to this point the simple effects of competition variables have been presented in the groups of variables such as:

- a) density and cover of deciduous competitors
- b) proximity of deciduous competitors
- c) competition indices combining the above and in some competition indices also including crop tree size.

These steps produced a list of the competition variables presumed to be the most promising (Table 18) for each area. In this section the approach is broadened to examine the simultaneous effects of several variables using multiple linear regression models.

The first question to be answered is how many independent variables are necessary in a regression model. Stepwise procedures were used to answer this question and derive the potentially-best subsets of independent variables (Table 20). However, there are important drawbacks to the use of stepwise procedures. The inclusion and ordering of the variables is a result of numerical associations and may not reflect biologically meaningful relationships. As expected, stepwise regressions summarized in Table 20 show that there was inconsistent entry of the variables in the regression models (based on four separate models for each number of independent variables), and that this ordering did not necessarily reflect the competition relationships. Regardless of these limitations two patterns have emerged:

- a) Very little increase in the predictive power beyond four-variable models.
- b) Frequent inclusion of variables expressing abundance and proximity of deciduous competitors.

To overcome inconsistencies in the subsets of variables in the equations and ensure uniformity in interpretation, two sets of models were formulated that could potentially be used for estimating effects of deciduous competition on spruce growth. The first set of models includes the independent variables based on the abundance and proximity of deciduous competitors. Deciduous competitors were further split into hardwoods and aspen competitors. The second set of models includes the best competition index incorporating crop tree size and the variables based on the abundance and proximity of deciduous competitors. Two best performing indices, RELVOL and BD Ratio were tested against the response, dependent white spruce variables of Radial increment, Total basal diameter (RCD), and Total height.

### **6.1 MULTIPLE LINEAR REGRESSIONS OF DECIDUOUS AND ASPEN COMPETITION VERSUS WHITE SPRUCE GROWTH**

In these analyses the effects of deciduous competition were tested separately in multiple regressions for total deciduous (hardwoods) and aspen using several variables describing competition such as cover, density, and stem-stem distance.

**Table 20**

Multiple Linear Regression Models for the White Spruce Dependent Growth Variable RADINC<sup>1</sup>

<b>Calling Lake</b>						
	<u>R<sup>2</sup></u>	<u>Variables in Model</u>				
1-variable <sup>2</sup>	0.710	RELVOL				
	0.646	MARTIN				
	0.596	BDRATIO				
	0.345	MACD2				
2-variable	0.725	TREECNT	RELVOL			
	0.725	HARDWCNT	RELVOL			
	0.719	AVHWCRIN	RELVOL			
	0.716	RELVOL	BDRATIO			
3-variable	0.731	TREECNT	RELVOL	MACD2		
	0.731	HARDWCNT	RELVOL	MACD2		
	0.731	TREECNT	AVHWCRIN	RELVOL		
	0.730	HARDWCNT	AVHWCRIN	RELVOL		
4-variable	0.736	TREECNT	RELVOL	BDRATIO	MACD2	
	0.735	HARDWCNT	RELVOL	BDRATIO	MACD2	
	0.734	TREECNT	AVHWCRIN	RELVOL	BDRATIO	
	0.734	TREECNT	VEGCOV	RELVOL	MACD2	
<b>Kakwa River</b>						
	<u>R<sup>2</sup></u>	<u>Variables in Model</u>				
1-variable	0.628	BDRATIO				
	0.628	RELVOL				
	0.547	MARTIN				
	0.436	DELONG				
2-variable	0.679	AGE	RELVOL			
	0.668	AGE	BDRATIO			
	0.647	AVTACRIN	RELVOL			
	0.645	AVTACRIN	BDRATIO			
3-variable	0.762	AGE	ASPENCOV	VEGCOV		
	0.718	AGE	VEGCOV	DELONG		
	0.710	AGE	HARDWCNT	MACD2		
	0.708	AGE	TREECNT	MACD2		
4-variable	0.777	AGE	ASPENCOV	VEGCOV	BDRATIO	
	0.776	AGE	ASPENCOV	VEGCOV	RELVOL	
	0.774	AGE	ASPENCOV	VEGCOV	MARTIN	
	0.768	AGE	ASPENCOV	VEGCOV	AVHWCRIN	

1. Based on step-wise regression.

2. For each n-variable model, the four best subsets of independent variables are shown in decreasing R<sup>2</sup> value.

**Table 20 (concluded)**

**Rocky Mountain House**

	<u>R<sup>2</sup></u>	<u>Variables in Model</u>				
1-variable <sup>1</sup>	0.447	RELVOL				
	0.421	BDRATIO				
	0.350	MARTIN				
	0.148	MACD2				
2-variable	0.462	VEGCOV	RELVOL			
	0.450	HWSTCLOS	RELVOL			
	0.449	ASPENCOV	RELVOL			
	0.448	ASPENCNT	RELVOL			
3-variable	0.482	HARDWCOV	VEGCOV	RELVOL		
	0.481	ASPENCOV	VEGCOV	RELVOL		
	0.477	VEGCOV	RELVOL	DELONG		
	0.469	ASPENCNT	VEGCOV	RELVOL		
4-variable	0.486	HARDWCOV	VEGCOV	HWSTCLOS	RELVOL	
	0.485	HARDWCOV	VEGCOV	RELVOL	MACD2	
	0.485	ASPENCOV	VEGCOV	RELVOL	BDRATIO	
	0.485	HARDWCOV	ASPENCOV	VEGCOV	RELVOL	

**Saddle Hills**

	<u>R<sup>2</sup></u>	<u>Variables in Model</u>				
1-variable	0.383	RELVOL				
	0.337	MARTIN				
	0.323	BDRATIO				
	0.187	MACD2				
2-variable	0.426	HWSTCLOS	RELVOL			
	0.424	TASTCLOS	RELVOL			
	0.413	ASPENCNT	RELVOL			
	0.402	HARDWCNT	RELVOL			
3-variable	0.471	ASPENCNT	HARDWCOV	RELVOL		
	0.459	HARDWCNT	HARDWCOV	RELVOL		
	0.455	HARDWCOV	HWSTCLOS	RELVOL		
	0.454	HARDWCOV	TASTCLOS	RELVOL		
4-variable	0.513	ASPENCNT	HARDWCOV	HWSTCLOS	RELVOL	
	0.501	HARDWCOV	ASPENCOV	HWSTCLOS	RELVOL	
	0.492	ASPENCNT	HARDWCOV	TASTCLOS	RELVOL	
	0.490	HARDWCNT	HARDWCOV	TASTCLOS	RELVOL	

1. For each n-variable model, the four best subsets of independent variables are shown in decreasing R<sup>2</sup> value.

The predictive power of regressions that had multiple independent variables increased very little as compared to single linear regressions. In multiple variable regression models, more than 30% of the variation in white spruce radial increment was explained in only three out of 24 possible combinations of growth variables and hardwood and aspen competition. These three combinations were:

Kakwa River	Radial increment	$f(\text{Hardwood competition variables})$	$R^2=0.32$
	Radial increment	$f(\text{Aspen competition variables})$	$R^2=0.43$
Calling Lake	Radial increment	$f(\text{Hardwood competition variables})$	$R^2=0.31$

Examination of the equations of 3-variable models (Tables 21 and 22) further revealed that some coefficients were not significant at  $P=0.05$ . Therefore, the shortened 1-2 variable models can be accepted as follows:

Kakwa River	[2] $\text{RadInc} = 1.310 - 0.078 \text{ Hardwcov} + 0.031 \text{ ClosestHWStem}$	$R^2=0.28$
	[3] $\text{RadInc} = 1.694 - 0.116 \text{ Aspencov}$	$R^2=0.38$
Calling Lake	[1] $\text{RadInc} = 1.858 - 0.055 \text{ Hardwcov} - 0.094 \text{ Hardwcnt}$	$R^2=0.31$

The magnitude of the predicted effects of competition in the above equations is summarized in Table 23.

Aspen competition explained the radial increment response better than hardwood competition in the Kakwa River area and the opposite was true for the Calling Lake area. One of the possible explanations for this difference is that in Kakwa River area the majority of plots had no aspen or less than 10% aspen cover. Therefore, the competitive effects in plots with aspen cover greater than 30% became more clearly separated. Furthermore, in Calling Lake mean hardwood and aspen cover was almost twice as high, 13% and 20.5%, respectively, than that observed in Kakwa River. Aspen and balsam poplar density was also several times higher in Calling Lake. It is assumed that the shading effect of a higher number of small crown trees is greater, and likely created a greater competition pressure than shading by the larger crowns of fewer trees.

In broad terms, Radial increment slightly decreased with increasing hardwood or aspen abundance as expressed by cover estimates. The same trend was very weak or non-existent for height and RCD. It appears that the current, instantaneous measurements of deciduous competitors abundance could only detect the most recent growth response (radial increment in the previous year), but could not solely predict the total size of spruce formed and subjected to many influences over the tree's life.

The major differences in the prediction power of models, including complete 3-variable models, were between areas. For example, in the Saddle Hills and Rocky Mountain House areas less than 20% of the variation of any spruce growth variable could be predicted. This finding is even more relevant here than it was for simple linear regressions since it incorporates the effects based on multiple variables. Thus it can be concluded that the multiple linear models based on deciduous competition without a competition index that incorporates crop tree size had a limited overall predictive capacity, as the  $R^2$  values varied substantially between areas. The competition-growth relationships apparently varied with stand conditions.

**Table 21**  
Multiple Linear Regression of White Spruce Growth vs Deciduous Competition Variables  
Kakwa River<sup>1</sup>

Model Based on Hardwood Competition Variables						
Hardwood Competition Variables	White Spruce Growth					
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.30		0.15		0.19	
	Coeff.	Prob	Coeff.	Prob	Coeff.	Prob.
Intercept	1.17	<0.001	N/A <sup>2</sup>		18.66	0.074
Hardwood Cover	-0.09	0.002			-2.79	0.021
Hardwood Count	0.05	0.323			3.77	0.099
Closest Hardwood Stem	0.04	0.030			1.62	0.031
Model Based on Aspen Competition Variables						
Aspen Competition Variables	White Spruce Growth					
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.43		0.25		0.21	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.36	0.001	5.11	<0.001	N/A	
Aspen Cover	-0.11	0.022	-0.09	0.073		
Aspen Count	0.01	0.910	0.05	0.578		
Closest Aspen Stem	0.03	0.278	0.032	0.332		

1. Square root transformation for: Radial Increment, Hardwood Cover, Hardwood Count, Closest Hardwood Stem, Aspen Cover, Aspen Count, and Closest Aspen Stem.  
Natural log+1 transformation for: Height and RCD.
2. Information not shown for models with an R<sup>2</sup> of less than 0.19, or for models that had P>0.05 for all independent variables.



**Table 22**  
Multiple Linear Regression of White Spruce Growth vs Deciduous Competition Variables  
Calling Lake<sup>1</sup>

Model Based on Hardwood Competition Variables						
Hardwood Competition Variables	White Spruce Growth					
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.31		0.03		0.10	
	Coeff.	Prob	Coeff.	Prob	Coeff.	Prob.
Intercept	1.90	<0.001	N/A <sup>2</sup>		N/A	
Hardwood Cover	-0.06	<0.001				
Hardwood Count	-0.10	<0.001				
Closest Hardwood Stem	-0.0004	0.512				

Model Based on Aspen Competition Variables						
Aspen Competition Variables	White Spruce Growth					
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.19		0.03		0.08	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.54	<0.001	N/A		N/A	
Aspen Cover	-0.02	0.257				
Aspen Count	-0.09	<0.001				
Closest Aspen Stem	0.0005	0.408				

1. Square root transformation for: Radial Increment, Hardwood Cover, Hardwood Count, Aspen Cover and Aspen Count.  
Natural log+1 transformation for: Height and RCD.
2. Information not shown for models with an R<sup>2</sup> of less than 0.19, or for models that had P>0.05 for all independent variables.

**Table 23**  
**Predicted White Spruce Radial Increment (mm) as a Function of**  
**Hardwood Cover, Density and Proximity**

**Kakwa River**

		Hardwood Cover (%)			
		20	40	60	80
Closest Hardwood Stem (cm)	50	1.39 <sup>1</sup>	1.07	0.86	0.69
	100	1.62	1.27	1.03	0.85
	150	1.80	1.43	1.18	0.98

$$1. \text{Radinc} = (1.310 - 0.078\sqrt{\text{Hardwood Cover}} + 0.031\sqrt{\text{Closest Hardwood Stem}})^2 \quad R^2=0.28$$

**Kakwa River**

Aspen Cover (%)	20	40	60	80
Radial Increment (mm)	1.38 <sup>2</sup>	0.92	0.63	0.43

$$2. \text{Radinc} = (1.694 - 0.116\sqrt{\text{Aspen Cover}})^2 \quad R^2=0.38$$

**Calling Lake**

		Hardwood Cover (%)			
		20	40	60	80
Hardwood Count (stems/10 m <sup>2</sup> )	5	1.96 <sup>3</sup>	1.69	1.49	1.34
	10	1.73	1.47	1.29	1.14
	20	1.42	1.19	1.02	0.89

$$3. \text{Radinc} = (1.858 - 0.055\sqrt{\text{Hardwood Cover}} - 0.094\sqrt{\text{Hardwood Count}})^2 \quad R^2=0.31$$

## 6.2 MULTIPLE LINEAR REGRESSION MODELS WITH THE BEST COMPETITION INDEX AND DECIDUOUS COMPETITION VARIABLES

Two sets of the models were developed separately for each of the best competition indices RELVOL and BD Ratio, and are summarized in Tables 24-27 and 28-31, respectively. In each table, the results are displayed separately for models which incorporate aspen competition and for models which incorporate hardwood competition (which includes both aspen and balsam poplar). Consistently, with a few exceptions, the 4-variable models containing RELVOL as the competition index performed slightly better (1-8 % increase in the explanation of variability) than the models containing BD Ratio. This was true for both sets of the models with hardwood competition and aspen competition. It is interesting to note that the largest difference in favor of RELVOL occurred in Calling Lake where the ratio of mean spruce height:aspen height was the smallest. Since the RELVOL competition index includes two more measurements of spruce size (height and diameter) than does the BD Ratio index, the increases in  $R^2$  indicating improved regression relationships most probably come from this source.

Invariably and consistently, there are no or very minimal (1-2% of variation) improvements in  $R^2$  when 3-variable and 4-variable models are compared (Tables 24-31). The variable expressing stem-to-stem distance of the closest aspen most commonly occurred in the fourth order of independent variables, and therefore improved the models very little and less significantly. From this, it follows that the distance measurements may have little value in predicting spruce growth when assessing the effects of overall deciduous competition. This was true for both hardwood and aspen competition. The improvement in model fit does not seem to warrant the extra costs incurred in taking distance measurements in the field.

Commonly the improvement from 2-variable model to 3-variable models were also minimal and therefore more simple shorter models were adopted. Further selection of the models was based on the significance level of  $P=0.05$  of the partial coefficients. The derived shortened models are summarized in Tables 24A-27A and 28A-31A, for models which incorporate the RELVOL and BD Ratio competition indices, respectively.

These models were used to answer the question "which of the models, those based on hardwood competition or those based on aspen competition, performed better in predicting spruce growth". As Table 32 shows, model response was variable. Sometimes aspen competition variables yielded higher  $R^2$  values compared to hardwood competition variables and in some cases the reverse was true; this varied between areas and white spruce growth variables. For BD Ratio models, aspen models in general performed better (a minimum 4% increase in  $R^2$ ), except for one area (Saddle Hills) where hardwood based models consistently performed slightly better.

For RELVOL models the observed inconsistencies were again apparent (Table 33). The observed weak trends, in favor of better performance of aspen models in Kakwa River and the opposite, better performance of hardwood models in Saddle Hills, are in agreement with the effects explained by simple linear regressions (Section 5). Thus there appears to be no strong argument for selecting hardwood or aspen competition for broad, regional application of competition measurements. It may be prudent to inventory the abundance of both species and consider their differential growth and stand development dynamics as related to different sites and stand composition.

**Table 24**

Four-Variable Multiple Linear Regression Models for White Spruce Growth vs RELVOL (CI)  
and Hardwood and Aspen Competition Variables - Calling Lake

RELVOL (CI) and Hardwood Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.71		0.64		0.61	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	2.13	<0.001	5.50	<0.001	41.39	<0.001
RELVOL	-0.17	<0.001	-0.22	<0.001	-5.25	<0.001
Hardwood Cover	0.01	0.366	0.07	<0.001	1.49	<0.001
Hardwood Count	-0.04	<0.001	0.03	0.033	-0.13	0.736
Closest Hardwood Stem	-0.001	0.110	-0.001	0.015	-0.02	0.229
R <sup>2</sup> for Partial Models						
1-variable	0.70		0.52		0.57	
2-variable	0.71		0.63		0.61	
3-variable	0.71		0.64		0.61	
4-variable	0.71		0.65		0.61	
RELVOL (CI) and Aspen Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.72		0.63		0.65	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	2.11	<0.001	5.62	<0.001	42.82	<0.001
RELVOL	-0.18	<0.001	-0.20	<0.001	-5.15	<0.001
Aspen Cover	0.001	0.888	0.03	0.008	1.36	<0.001
Aspen Count	-0.03	0.085	0.03	0.146	-0.43	0.362
Closest Aspen Stem	-0.0001	0.606	-0.0001	0.665	0.01	0.560
R <sup>2</sup> for Partial Models						
1-variable	0.71		0.58		0.64	
2-variable	0.72		0.63		0.65	
3-variable	0.72		0.63		0.65	
4-variable	0.72		0.63		0.65	

**Table 24A**  
**One-to-Three-Variable Multiple Linear Regression Models for White Spruce Growth vs**  
**RELVOL (CI) and Hardwood and Aspen Competition Variables - Calling Lake**

RELVOL (CI) and Hardwood Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.71		0.64		0.61	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	2.06	<0.001	5.58	<0.001	39.75	<0.001
RELVOL	-0.16	<0.001	-0.21	<0.001	-5.24	<0.001
Hardwood Cover	0.03 (HARDWCNT)	0.004	0.08	<0.001	1.54	<0.001
Closest Hardwood Stem	2-variable model		-0.002	0.001	2-variable model	
			3-variable model			
R <sup>2</sup> for Partial Models						
1-variable	0.70		0.52		0.57	
2-variable	0.71		0.63		0.61	
3-variable	n/a		0.64		n/a	

RELVOL (CI) and Aspen Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.72		0.63		0.65	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	2.05	<0.001	5.63	<0.001	43.17	<0.001
RELVOL	-0.19	<0.001	-0.19	<0.001	-5.23	<0.001
Aspen Cover	1-variable model		0.05	<0.001	1.04	<0.001
			2-variable model		2-variable model	
R <sup>2</sup> for Partial Models						
1-variable	0.71		0.58		0.64	
2-variable	n/a		0.63		0.65	

**Table 25**

Four-Variable Multiple Linear Regression Models for White Spruce Growth vs RELVOL (CI)  
and Hardwood and Aspen Competition Variables - Rocky Mountain House

RELVOL (CI) and Hardwood Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.42		0.52		0.57	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.42	<0.001	4.89	<0.001	23.10	<0.001
RELVOL	-0.11	<0.001	-0.17	<0.001	-3.62	<0.001
Hardwood Cover	0.01	0.314	0.07	<0.001	1.70	<0.001
Hardwood Count	-0.003	0.859	-0.01	0.489	-0.85	0.016
Closest Hardwood Stem	0.003	0.180	0.03	0.328	0.76	0.138
R <sup>2</sup> for Partial Models						
1-variable	0.42		0.37		0.41	
2-variable	0.42		0.52		0.55	
3-variable	0.42		0.52		0.57	
4-variable	0.42		0.53		0.57	
RELVOL (CI) and Aspen Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.45		0.56		0.56	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.50	<0.001	4.92	<0.001	22.48	<0.001
RELVOL	-0.12	<0.001	-0.16	<0.001	-3.34	<0.001
Aspen Cover	0.005	0.571	0.06	<0.001	1.42	<0.001
Aspen Count	0.01	0.708	-0.005	0.792	-0.73	0.049
Closest Aspen Stem	0.02	0.474	0.02	0.422	0.98	0.067
R <sup>2</sup> for Partial Models						
1-variable	0.45		0.40		0.42	
2-variable	0.45		0.56		0.53	
3-variable	0.45		0.56		0.55	
4-variable	0.45		0.56		0.56	

**Table 25A**  
**One-to-Three-Variable Multiple Linear Regression Models for White Spruce Growth vs**  
**RELVOL (CI) and Hardwood and Aspen Competition Variables - Rocky Mountain House**

RELVOL (CI) and Hardwood Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.42		0.52		0.57	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.56	<0.001	4.98	<0.001	23.55	<0.001
RELVOL	-0.11	<0.001	-0.17	<0.001	-3.63	<0.001
Hardwood Cover	1-variable model		0.06	<0.001	1.71	<0.001
Hardwood Count			2-variable model		-1.03	<0.001
					3-variable model	
R <sup>2</sup> for Partial Models						
1-variable	0.42		0.37		0.41	
2-variable	n/a		0.52		0.55	
3-variable	n/a		n/a		0.57	

RELVOL (CI) and Aspen Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.45		0.56		0.55	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.59	<0.001	5.00	<0.001	26.98	<0.001
RELVOL	-0.11	<0.001	-0.16	<0.001	-3.32	<0.001
Aspen Cover	1-variable model		0.06	<0.001	1.41	<0.001
Aspen Count			2-variable model		-0.96	0.007
					3-variable model	
R <sup>2</sup> for Partial Models						
1-variable	0.45		0.40		0.42	
2-variable	n/a		0.56		0.53	
3-variable	n/a		n/a		0.55	

**Table 26**  
**Four-Variable Multiple Linear Regression Models for White Spruce Growth vs RELVOL (CI)**  
**and Hardwood and Aspen Competition Variables - Kakwa River**

RELVOL (CI) and Hardwood Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.52		0.58		0.60	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.17	<0.001	4.99	<0.001	18.52	0.014
RELVOL	-0.13	<0.001	-0.19	<0.001	-6.93	<0.001
Hardwood Cover	0.01	0.787	0.07	0.033	2.72	0.032
Hardwood Count	0.04	0.376	0.09	0.044	3.04	0.064
Closest Hardwood Stem	0.04	0.012	0.02	0.979	1.61	0.004
R <sup>2</sup> for Partial Models						
1-variable	0.44		0.45		0.46	
2-variable	0.51		0.54		0.52	
3-variable	0.52		0.56		0.57	
4-variable	0.52		0.58		0.60	
RELVOL (CI) and Aspen Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.64		0.68		0.59	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.56	<0.001	5.39	<0.001	41.00	0.006
RELVOL	-0.13	0.004	-0.18	<0.001	-7.21	<0.001
Aspen Cover	-0.02	0.670	0.03	0.471	1.62	0.427
Aspen Count	0.02	0.800	0.06	0.327	1.70	0.567
Closest Aspen Stem	0.01	0.574	0.01	0.767	0.24	0.827
R <sup>2</sup> for Partial Models						
1-variable	0.63		0.63		0.55	
2-variable	0.64		0.66		0.58	
3-variable	0.64		0.67		0.59	
4-variable	0.64		0.68		0.59	



**Table 26A**

Two-to-Four-Variable Multiple Linear Regression Models for White Spruce Growth vs RELVOL (CI) and Hardwood and Aspen Competition Variables - Kakwa River

RELVOL (CI) and Hardwood Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.52		0.58		0.60	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.18	<0.001	4.99	<0.001	18.52	0.014
RELVOL	-0.12	<0.001	-0.19	<0.001	-6.93	<0.001
Hardwood Cover	0.05 (HARDWCNT)	0.285	0.07	0.033	2.72	0.032
Hardwood Count	0.04 (CLOSHWST)	0.010	0.09	0.044	3.04	0.064
Closest Hardwood Stem	3-variable model		0.02	0.979	1.61	0.004
R <sup>2</sup> for Partial Models						
1-variable	0.44		0.45		0.46	
2-variable	0.51		0.54		0.52	
3-variable	0.52		0.56		0.57	
4-variable	n/a		0.58		0.60	
RELVOL (CI) and Aspen Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.64		0.68		0.59	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.57	<0.001	5.39	<0.001	43.66	<0.001
RELVOL	-0.14	<0.001	-0.18	<0.001	-7.30	<0.001
Aspen Cover	0.01 (CLOSTAST)	0.592	0.03	0.471	1.69	0.386
Aspen Count	2-variable model		0.06	0.327	1.42	0.585
Closest Aspen Stem			0.007	0.767	3-variable model	
R <sup>2</sup> for Partial Models						
1-variable	0.63		0.63		0.55	
2-variable	0.64		0.66		0.58	
3-variable	n/a		0.67		0.59	
4-variable	n/a		0.68		n/a	

**Table 27**

Four-Variable Multiple Linear Regression Models for White Spruce Growth vs RELVOL (CI)  
and Hardwood and Aspen Competition Variables - Saddle Hills

RELVOL (CI) and Hardwood Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.48		0.41		0.46	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.24	<0.001	5.23	<0.001	31.38	<0.001
RELVOL	-0.11	<0.001	-0.14	<0.001	-4.74	<0.001
Hardwood Cover	0.06	<0.001	0.11	<0.001	3.14	<0.001
Hardwood Count	-0.07	0.001	-0.08	0.001	-2.71	0.001
Closest Hardwood Stem	0.01	0.031	0.004	0.654	0.22	0.409
R <sup>2</sup> for Partial Models						
1-variable	0.38		0.25		0.34	
2-variable	0.41		0.36		0.40	
3-variable	0.46		0.41		0.46	
4-variable	0.48		0.41		0.46	
RELVOL (CI) and Aspen Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.45		0.28		0.42	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.25	<0.001	5.25	<0.001	31.91	<0.001
RELVOL	-0.09	<0.001	-0.10	<0.001	-3.71	<0.001
Aspen Cover	0.03	0.007	0.06	<0.001	1.67	<0.001
Aspen Count	-0.06	0.007	-0.06	0.041	-1.66	0.037
Closest Aspen Stem	0.01	0.036	-0.01	0.515	0.21	0.372
R <sup>2</sup> for Partial Models						
1-variable	0.38		0.20		0.36	
2-variable	0.42		0.24		0.39	
3-variable	0.43		0.27		0.41	
4-variable	0.45		0.28		0.42	

**Table 27A**  
**Three-to-Four-Variable Multiple Linear Regression Models for White Spruce Growth vs**  
**RELVOL (CI) and Hardwood and Aspen Competition Variables - Saddle Hills**

RELVOL (CI) and Hardwood Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.48		0.41		0.46	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.24	<0.001	5.27	<0.001	33.87	<0.001
RELVOL	-0.11	<0.001	-0.14	<0.001	-4.73	<0.001
Hardwood Cover	0.06	<0.001	0.11	<0.001	3.12	<0.001
Hardwood Count	-0.07	0.001	-0.09	<0.001	-2.96	<0.001
Closest Hardwood Stem	0.01	0.031	3-variable model		3-variable model	
R <sup>2</sup> for Partial Models						
1-variable	0.38		0.25		0.34	
2-variable	0.41		0.36		0.40	
3-variable	0.46		0.41		0.46	
4-variable	0.48		n/a		n/a	
RELVOL (CI) and Aspen Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.45		0.28		0.42	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.25	<0.001	5.25	<0.001	31.91	<0.001
RELVOL	-0.09	<0.001	-0.10	<0.001	-3.71	<0.001
Aspen Cover	0.03	0.007	0.06	<0.001	1.67	<0.001
Aspen Count	-0.06	0.007	-0.06	0.041	-1.66	0.037
Closest Aspen Stem	0.01	0.036	-0.01	0.515	0.21	0.372
R <sup>2</sup> for Partial Models						
1-variable	0.38		0.20		0.36	
2-variable	0.42		0.24		0.39	
3-variable	0.43		0.27		0.41	
4-variable	0.45		0.28		0.42	

**Table 28**

Four-Variable Multiple Linear Regression Models for White Spruce Growth vs BDRATIO (CI)  
and Hardwood and Aspen Competition Variables - Calling Lake

BDRATIO (CI) and Hardwood Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.64		0.58		0.66	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	2.31	<0.001	5.75	<0.001	49.02	<0.001
BDRATIO	-0.57	<0.001	-0.76	<0.001	-20.63	<0.001
Hardwood Cover	-0.01	0.504	0.06	<0.001	1.23	<0.001
Hardwood Count	-0.06	<0.001	0.003	0.842	-0.64	0.069
Closest Hardwood Stem	-0.001	0.226	-0.001	0.047	-0.01	0.289
R <sup>2</sup> for Partial Models						
1-variable	0.60		0.51		0.63	
2-variable	0.64		0.57		0.65	
3-variable	0.64		0.58		0.66	
4-variable	0.64		0.58		0.66	

BDRATIO (CI) and Aspen Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.63		0.58		0.70	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	2.24	<0.001	5.81	<0.001	49.76	<0.001
BDRATIO	-0.63	<0.001	-0.73	<0.001	-20.97	<0.001
Aspen Cover	-0.005	0.660	0.03	0.046	1.23	<0.001
Aspen Count	-0.05	0.007	0.005	0.774	-0.84	0.048
Closest Aspen Stem	-0.0001	0.849	-0.0001	0.827	0.01	0.490
R <sup>2</sup> for Partial Models						
1-variable	0.60		0.57		0.69	
2-variable	0.63		0.58		0.70	
3-variable	0.63		0.58		0.70	
4-variable	0.63		0.58		0.70	

**Table 28A**  
Two-to-Three-Variable Multiple Linear Regression Models for White Spruce Growth vs  
BDRATIO (CI) and Hardwood and Aspen Competition Variables - Calling Lake

BDRATIO (CI) and Hardwood Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.64		0.58		0.65	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	2.25	<0.001	5.76	<0.001	46.67	<0.001
BDRATIO	-0.57	<0.001	-0.76	<0.001	-20.88	<0.001
Hardwood Cover	-0.06 (HARDWCNT)	<0.001	0.06	<0.001	1.01	<0.001
Closest Hardwood Stem	2-variable model		-0.001	0.029	2-variable model	
			3-variable model			
R <sup>2</sup> for Partial Models						
1-variable	0.60		0.51		0.63	
2-variable	0.64		0.57		0.65	
3-variable	n/a		0.58		n/a	
BDRATIO (CI) and Aspen Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.63		0.58		0.70	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	2.23	<0.001	5.80	<0.001	49.75	<0.001
BDRATIO	-0.63	<0.001	-0.73	<0.001	-21.39	<0.001
Aspen Cover	-0.05 (ASPENCNT)	<0.001	0.03	<0.001	0.66	0.001
	2-variable model		2-variable model		2-variable model	
R <sup>2</sup> for Partial Models						
1-variable	0.60		0.57		0.69	
2-variable	0.62		0.58		0.70	

**Table 29**

Four-Variable Multiple Linear Regression Models for White Spruce Growth vs BDRATIO (CI)  
and Hardwood and Aspen Competition Variables - Rocky Mountain House

BDRATIO (CI) and Hardwood Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.40		0.47		0.54	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.57	<0.001	5.11	<0.001	28.21	<0.001
BDRATIO	-0.34	<0.001	-0.57	<0.001	-12.54	<0.001
Hardwood Cover	0.004	0.654	0.06	<0.001	1.54	<0.001
Hardwood Count	-0.01	0.627	-0.02	0.288	-1.03	0.005
Closest Hardwood Stem	0.04	0.175	0.03	0.326	0.79	0.134
R <sup>2</sup> for Partial Models						
1-variable	0.40		0.36		0.41	
2-variable	0.40		0.46		0.51	
3-variable	0.40		0.46		0.54	
4-variable	0.40		0.47		0.54	

BDRATIO (CI) and Aspen Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.42		0.49		0.53	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.64	<0.001	5.11	<0.001	26.76	<0.001
BDRATIO	-0.41	<0.001	-0.55	<0.001	-11.61	<0.001
Aspen Cover	-0.001	0.883	0.05	<0.001	1.24	<0.001
Aspen Count	0.001	0.934	0.01	0.542	-0.88	0.023
Closest Aspen Stem	0.02	0.388	0.03	0.356	1.11	0.045
R <sup>2</sup> for Partial Models						
1-variable	0.42		0.38		0.43	
2-variable	0.42		0.48		0.50	
3-variable	0.42		0.49		0.52	
4-variable	0.42		0.49		0.53	

**Table 29A**

One-to-Four-Variable Multiple Linear Regression Models for White Spruce Growth vs  
BDRATIO (CI) and Hardwood and Aspen Competition Variables - Rocky Mountain House

BDRATIO (CI) and Hardwood Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.40		0.46		0.54	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.70	<0.001	5.19	<0.001	31.81	<0.001
BDRATIO	-0.40	<0.001	-0.56	<0.001	-12.55	<0.001
Hardwood Cover	1-variable model		0.05	<0.001	1.55	<0.001
Hardwood Count			2-variable model		-1.22	<0.001
					3-variable model	
R <sup>2</sup> for Partial Models						
1-variable	0.40		0.36		0.41	
2-variable	n/a		0.46		0.51	
3-variable	n/a		n/a		0.54	

BDRATIO (CI) and Aspen Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.42		0.48		0.53	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.74	<0.001	5.20	<0.001	26.76	<0.001
BDRATIO	-0.41	<0.001	-0.54	<0.001	-11.61	<0.001
Aspen Cover	1-variable model		0.05	<0.001	1.24	<0.001
Aspen Count			2-variable model		-0.88	0.023
Closest Aspen Stem					1.11	0.045
R <sup>2</sup> for Partial Models						
1-variable	0.42		0.38		0.43	
2-variable	n/a		0.48		0.50	
3-variable	n/a		n/a		0.52	
4-variable	n/a		n/a		0.53	

**Table 30**

Four-Variable Multiple Linear Regression Models for White Spruce Growth vs BDRATIO (CI)  
and Hardwood and Aspen Competition Variables - Kakwa River

BDRATIO (CI) and Hardwood Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.51		0.54		0.60	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.35	<0.001	5.25	<0.001	28.91	<0.001
BDRATIO	-0.44	<0.001	-0.62	<0.001	-24.29	<0.001
Hardwood Cover	0.01	0.826	0.06	0.068	2.77	0.029
Hardwood Count	0.03	0.467	0.08	0.085	2.64	0.107
Closest Hardwood Stem	0.04	0.016	0.02	0.151	1.51	0.006
R <sup>2</sup> for Partial Models						
1-variable	0.44		0.43		0.47	
2-variable	0.50		0.50		0.54	
3-variable	0.51		0.52		0.58	
4-variable	0.51		0.54		0.60	
BDRATIO (CI) and Aspen Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.64		0.65		0.59	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.78	<0.001	5.67	<0.001	53.24	0.001
BDRATIO	-0.45	0.004	-0.61	<0.001	-25.65	<0.001
Aspen Cover	-0.02	0.648	0.03	0.568	1.56	0.436
Aspen Count	0.01	0.901	0.05	0.442	1.22	0.677
Closest Aspen Stem	0.01	0.708	0.002	0.949	-0.02	0.990
R <sup>2</sup> for Partial Models						
1-variable	0.63		0.62		0.56	
2-variable	0.64		0.65		0.59	
3-variable	0.64		0.64		0.59	
4-variable	0.64		0.65		0.59	



**Table 30A**  
**One-to-Three-Variable Multiple Linear Regression Models for White Spruce Growth vs**  
**BDRATIO (CI) vs Hardwood and Aspen Competition Variables - Kakwa River**

BDRATIO (CI) and Hardwood Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.50		0.52		0.58	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.48	<0.001	5.51	<0.001	35.98	<0.001
BDRATIO	-0.40	<0.001	-0.63	<0.001	-25.02	<0.001
Hardwood Cover	0.03 (CLOSHWST)	0.020	0.07	0.059	3.57	0.003
Hardwood Count	2-variable model		0.05	0.230	1.11 (CLOSHWST)	0.025
			3-variable model		3-variable model	
R <sup>2</sup> for Partial Models						
1-variable	0.44		0.43		0.47	
2-variable	0.50		0.50		0.54	
3-variable	n/a		0.52		0.58	

BDRATIO (CI) and Aspen Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.63		0.61		0.56	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.87	<0.001	5.75	<0.001	55.53	<0.001
BDRATIO	-0.51	<0.001	-0.50	<0.001	-20.41	<0.001
	1-variable model		1-variable model		1-variable model	
R <sup>2</sup> for Partial Models						
1-variable	0.63		0.61		0.56	

**Table 31**

Four-Variable Multiple Linear Regression Models for White Spruce Growth vs BDRATIO (CI)  
and Hardwood and Aspen Competition Variables - Saddle Hills

BDRATIO (CI) and Hardwood Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.43		0.34		0.43	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.33	<0.001	5.34	<0.001	35.79	<0.001
BDRATIO	-0.34	<0.001	-0.41	<0.001	-15.53	<0.001
Hardwood Cover	0.06	<0.001	0.10	<0.001	3.02	<0.001
Hardwood Count	-0.07	<0.001	-0.09	0.001	-2.87	<0.001
Closest Hardwood Stem	0.02	0.017	0.01	0.462	0.33	0.230
R <sup>2</sup> for Partial Models						
1-variable	0.33		0.20		0.31	
2-variable	0.37		0.27		0.36	
3-variable	0.41		0.34		0.43	
4-variable	0.43		0.34		0.43	
BDRATIO (CI) and Aspen Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.41		0.23		0.40	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.32	<0.001	5.31	<0.001	34.88	<0.001
BDRATIO	-0.27	<0.001	-0.30	<0.001	-12.14	<0.001
Aspen Cover	0.03	0.012	0.06	<0.001	1.65	<0.001
Aspen Count	-0.06	0.004	-0.07	0.027	-1.89	0.019
Closest Aspen Stem	0.02	0.019	0.01	0.396	0.32	0.194
R <sup>2</sup> for Partial Models						
1-variable	0.32		0.16		0.34	
2-variable	0.38		0.18		0.35	
3-variable	0.39		0.22		0.39	
4-variable	0.41		0.23		0.40	

**Table 31A**  
**Three-to-Four-Variable Multiple Linear Regression Models for White Spruce Growth vs**  
**BDRATIO (CI) and Hardwood and Aspen Competition Variables - Saddle Hills**

BDRATIO (CI) and Hardwood Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.43		0.34		0.43	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.33	<0.001	5.41	<0.001	39.44	<0.001
BDRATIO	-0.34	<0.001	-0.41	<0.001	-15.40	<0.001
Hardwood Cover	0.06	<0.001	0.10	<0.001	2.98	<0.001
Hardwood Count	-0.07	<0.001	-0.10	<0.001	-3.25	<0.001
Closest Hardwood Stem	0.02	0.017	3-variable model		3-variable model	
R <sup>2</sup> for Partial Models						
1-variable	0.33		0.20		0.31	
2-variable	0.37		0.27		0.36	
3-variable	0.41		0.34		0.43	
4-variable	0.43		n/a		n/a	

BDRATIO (CI) and Aspen Competition Variables						
	Radial Increment		Height		RCD	
R <sup>2</sup>	0.41		0.22		0.39	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Intercept	1.32	<0.001	5.39	<0.001	38.28	<0.001
BDRATIO	-0.27	<0.001	-0.29	<0.001	-11.89	<0.001
Aspen Cover	0.03	0.012	0.06	<0.001	1.62	<0.001
Aspen Count	-0.06	0.004	-0.08	0.006	-2.29	0.003
Closest Aspen Stem	0.02	0.019	3-variable model		3-variable model	
R <sup>2</sup> for Partial Models						
1-variable	0.32		0.16		0.34	
2-variable	0.38		0.18		0.35	
3-variable	0.39		0.22		0.39	
4-variable	0.41		n/a		n/a	

**Table 32**  
Comparison of BDRATIO Models with Hardwood and Aspen Competition Variables - ( $R^2$ )

Area	Competition Variables	White Spruce Growth (Dependent) Variable		
		RadInc	Height	RCD
Calling Lake	Hardwood	0.64	0.58	0.66 ↓ <sup>1</sup>
	Aspen	0.62	0.58	0.70 ↓
Rocky Mountain House	Hardwood	0.40	0.46	0.54
	Aspen	0.42	0.48	0.52
Kakwa River	Hardwood	0.50 ↓	0.52 ↓	0.58
	Aspen	0.64 ↓	0.61 ↓	0.56
Saddle Hills	Hardwood	0.43	0.34 ↑	0.43 ↑
	Aspen	0.41	0.22 ↑	0.39 ↑

1. Arrow shows increasing or decreasing  $R^2$ , if the difference is greater than 0.03.

**Table 33**  
Comparison of RELVOL Models with Hardwood and Aspen Competition Variables - ( $R^2$ )

Area	Competition Variables	White Spruce Growth (Dependent) Variable		
		RadInc	Height	RCD
Calling Lake	Hardwood	0.71	0.64	0.61 <sup>1</sup>
	Aspen	0.71	0.63	0.65↓
Rocky Mountain House	Hardwood	0.42	0.52↓	0.57
	Aspen	0.45	0.56↓	0.55
Kakwa River	Hardwood	0.51↓	0.58↓	0.60↑
	Aspen	0.64↓	0.63↓	0.55↑
Saddle Hills	Hardwood	0.48	0.41↑	0.46↑
	Aspen	0.45	0.27↑	0.41↑

1. Arrow shows increasing or decreasing  $R^2$ , if the difference is greater than 0.03.

The full 4-variable models as well as their shortened versions consistently contained the positive (+) coefficient of the variables Hardwood cover and Aspen cover (Table 34). It means that these variables positively contributed to the predicted effect of spruce growth. The probability level of coefficients was significant and the addition of these terms strengthened the regression relationships and their predictive power. These positive effects only occurred for the variables expressing the total tree size - height and RCD, reflecting the cumulative growth, but not or rarely for the current growth response (RADINC). We may therefore conclude that the presence of aspen or hardwood cover was not a constraint to spruce growth, but was, in contrast, an asset (at least some of the time) during growth and biomass accumulation of spruce trees.

At what point in time when the beneficial effect occurred in the life of a tree and what level of hardwood cover was beneficial cannot be explained through the retrospective approach. Examination of simple linear regressions with scatter plots displays a wide spread of data and occurrence of large size spruce trees at low and medium levels of hardwood cover and thus provides additional support for the assumed beneficial effects.

### **6.2.1 Magnitude of the Predicted Effects**

The regression coefficients in Tables 24-31 have a direct interpretation with respect to spruce growth and represent the partial contribution of each of the independent variables to the predicted white spruce growth and size. The magnitude of the predicted effects is calculated in Table 35 and are illustrated in the following example for spruce height in Calling Lake. Two situations of competition intensity are assumed. For low competition intensity: BD Ratio = 1.2; % Hardwood Cover = 15%; Closest Hardwood Stem = 185 cm. The predicted annual basal radial increment is 2.5 mm. For high competition intensity: BD Ratio = 2.5; Hardwood Cover = 50%; Closest Hardwood Stem = 60 cm. The predicted annual basal radial increment is 1.7 mm.

## **6.3 INTERPRETATION OF THE BD RATIO COMPETITION INDEX**

Spruce growth and size decreased as deciduous competition, as measured by the BD Ratio index, increased. The relation between the BD Ratio index and spruce diameter and radial increment resembled a negative power curve with upward concavity with a steep slope at low (0.5 to 2.0) BD Ratio values (Figures 23-26 and 27-30, respectively). This steep slope of the predicted curves and lines suggests that maximum spruce growth occurred where competition was low, at about the values of BD Ratio  $\leq 1$ . However, at the same low competition level there were also many spruce trees that had low growth rate and small size about equal to the trees growing under the high level of competition with BD Ratio  $> 2.5$ . This shows clearly that for many trees deciduous competition (up to BD Ratio values of 2.5) was not important and their growth was limited by other factors. In contrast, as shown by the upper limit boundary line and distribution of data points, many spruce trees have achieved large size and have had superior growth regardless of the competition level up to BD Ratio values of almost 2.0. These two examples document that the variability in spruce responses at low competition levels is very high. As a result, we cannot reliably define the competition threshold levels that should be used for maximizing spruce growth.

**Table 34**  
Incidence of Positive Partial Coefficients for COVER Variables in Multiple Linear Regressions

BDRATIO Models				
		Dependent Variables		
		RadInc	Height	RCD
Calling Lake	Hardwoods		+	+
	Aspen		+	+
Kakwa River	Hardwoods	+ (HARDWCNT)		+
	Aspen			
Rocky Mountain House	Hardwoods		+	+
	Aspen		+	+
Saddle Hills	Hardwoods	+	+	+
	Aspen	+	+	+
RELVOL Models				
		RadInc	Height	RCD
Calling Lake	Hardwoods		+	+
	Aspen		+	+
Kakwa River	Hardwoods	+	+	+
	Aspen		+	+
Rocky Mountain House	Hardwoods		+	+
	Aspen		+	+
Saddle Hills	Hardwoods		+	+
	Aspen		+	+

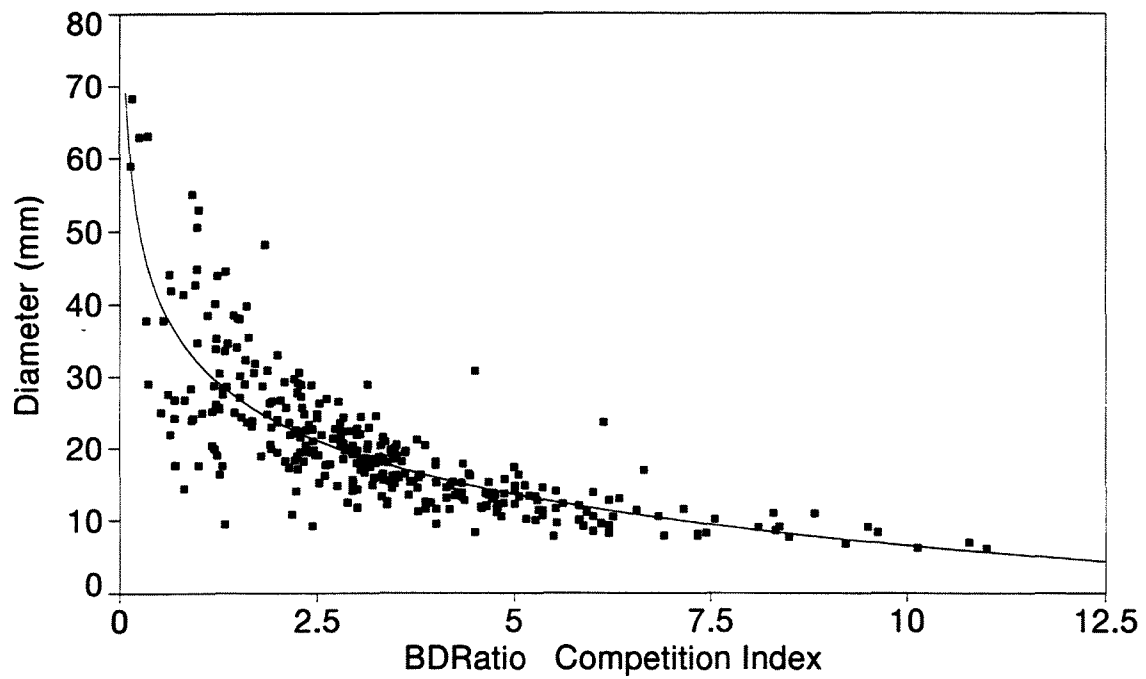
**Table 35**  
**Predicted White Spruce Radial Increment at**  
**High and Low Hardwood Competition Levels in Calling Lake**

	BDRATIO	Hardwood Cover (%)	Closest Hardwood Stem (cm)	Predicted Radial Increment(mm)
low competition	1.2 <sup>1</sup>	15	185	2.5
high competition	2.5	50	60	1.7

1.  $Radinc = (1.77 - 0.12 \ln(BDRatio + 1) - 0.05 \sqrt{Hardwood\ Cover} + 0.001(Hardwood\ Stem))^2$   
 $R^2 = 0.55$      $Fstat = 130.46$      $n = 322$

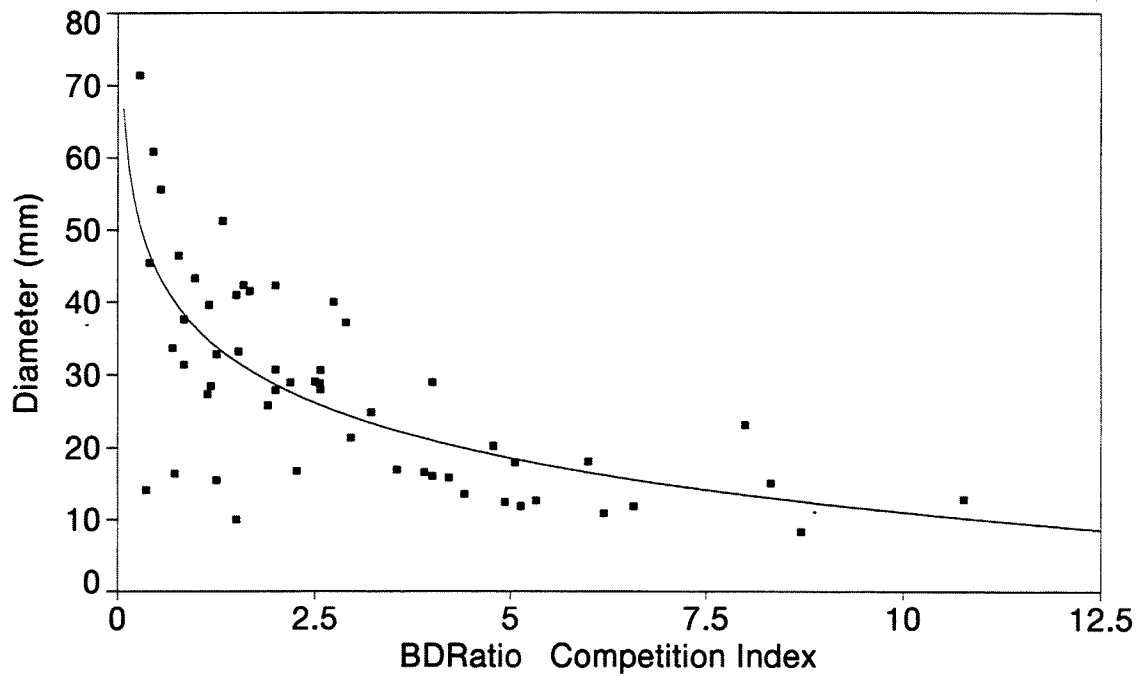


**Figure 23**  
Non-linear Regression of White Spruce Basal Diameter vs the BDRatio Competition Index for the  
Calling Lake Area



$\text{Diameter} = -94.23 + 126(\text{BDRatio})^{-0.10}$   $R^2 = 0.64$   $F_{\text{stat}} = 286.6$   $n = 322$   
Regression based on all blocks combined.

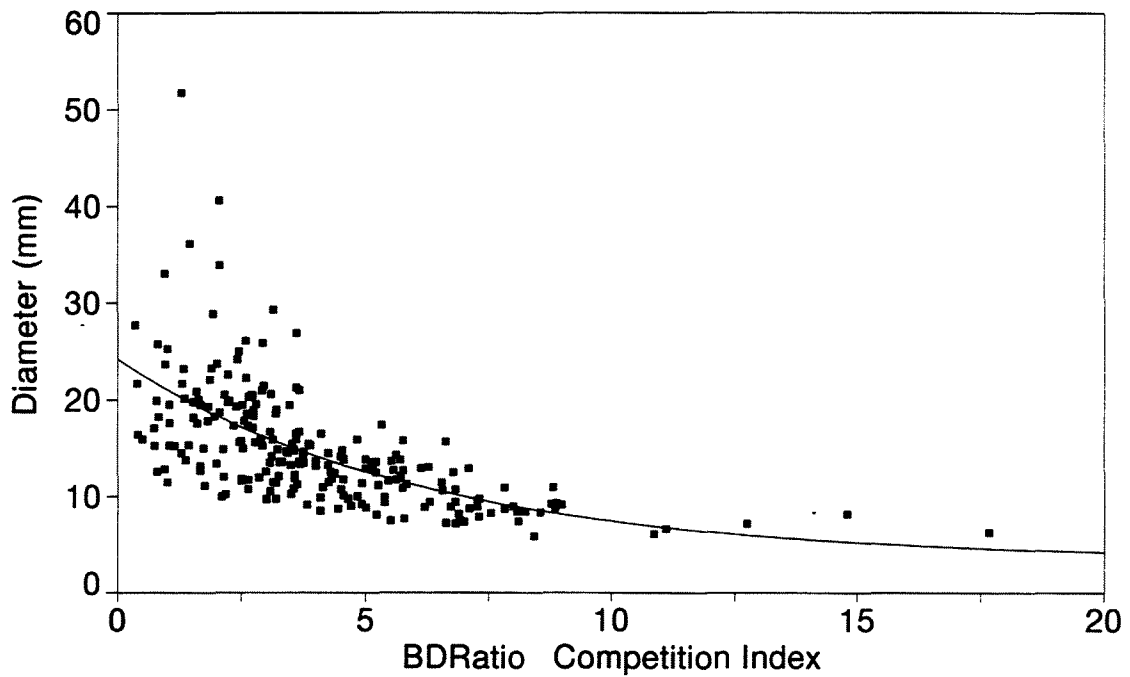
**Figure 24**  
Non-linear Regression of White Spruce Basal Diameter vs the BDRatio Competition Index for the  
Kakwa River Area



Diameter =  $-749.7 + 786(\text{BDRatio})^{-0.01}$   $R^2 = 0.48$  Fstat = 23.34 n = 54  
Regression based on all blocks combined.

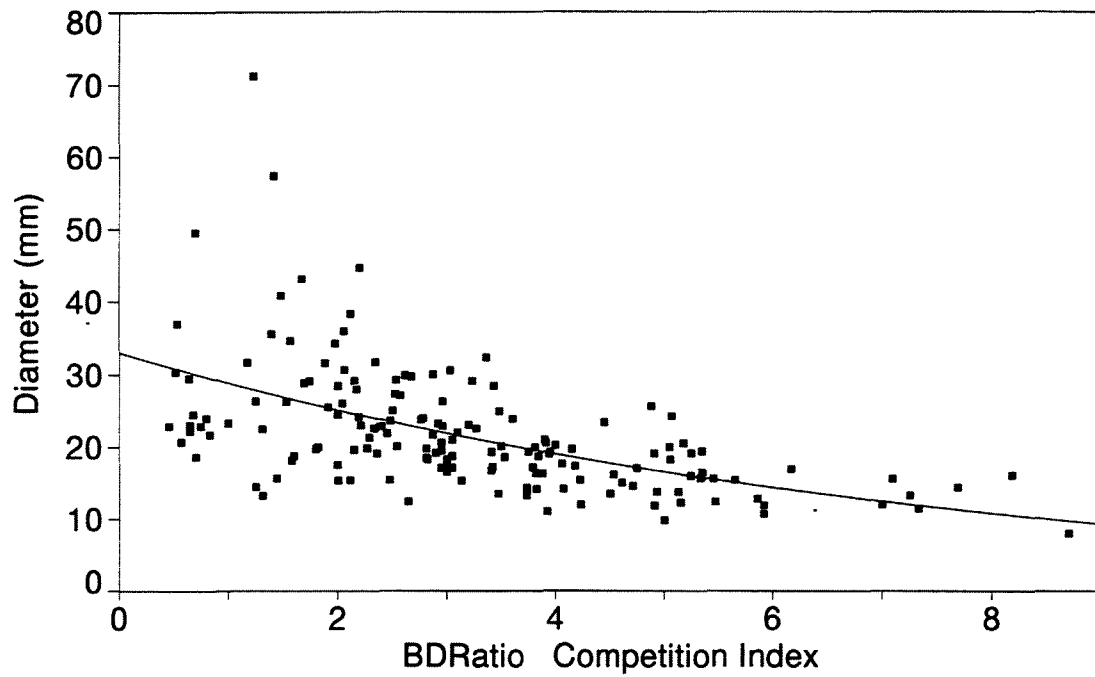
**Figure 25**

Non-linear Regression of White Spruce Basal Diameter vs the BDRatio Competition Index for the Rocky Mountain House Area



Diameter =  $3.41 + 20.78^{(-\text{BDRatio}/6.07)}$   $R^2 = 0.40$  Fstat = 73.53 n = 226  
Regression based on all blocks combined.

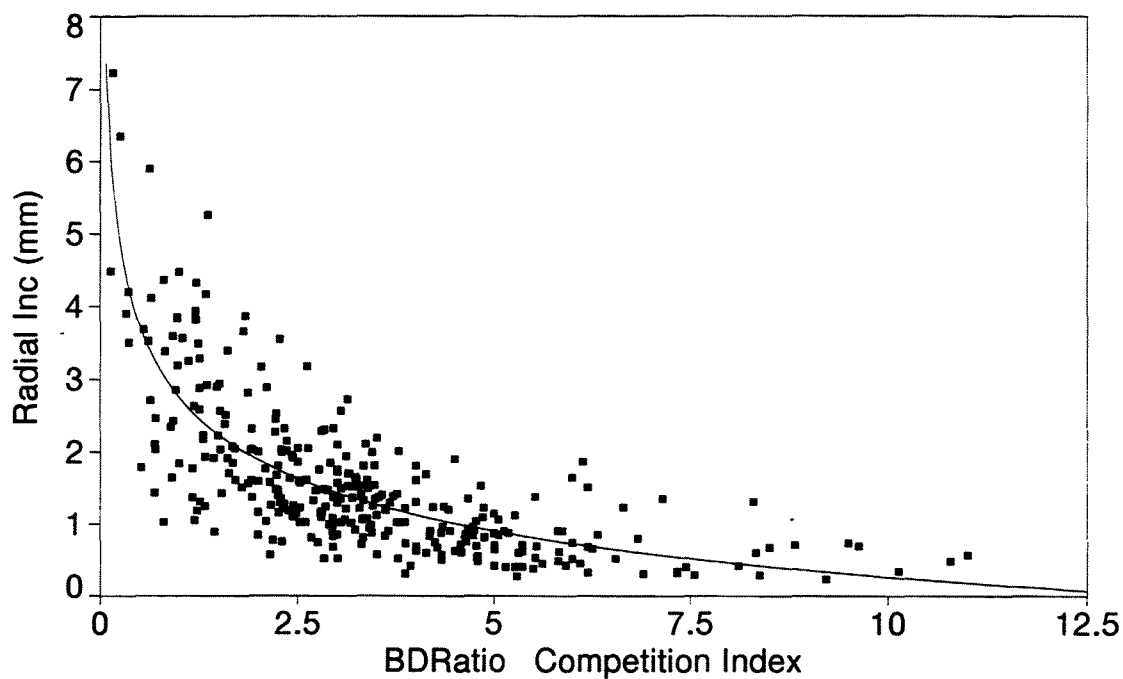
**Figure 26**  
Non-linear Regression of White Spruce Basal Diameter vs the BDRatio Competition Index for the  
Saddle Hills Area



$\text{Diameter} = -1.24 + 34.28^{(-\text{BDRatio}/7.59)}$   $R^2 = 0.30$   $F\text{stat} = 34.63$   $n = 166$   
Regression based on all blocks combined.

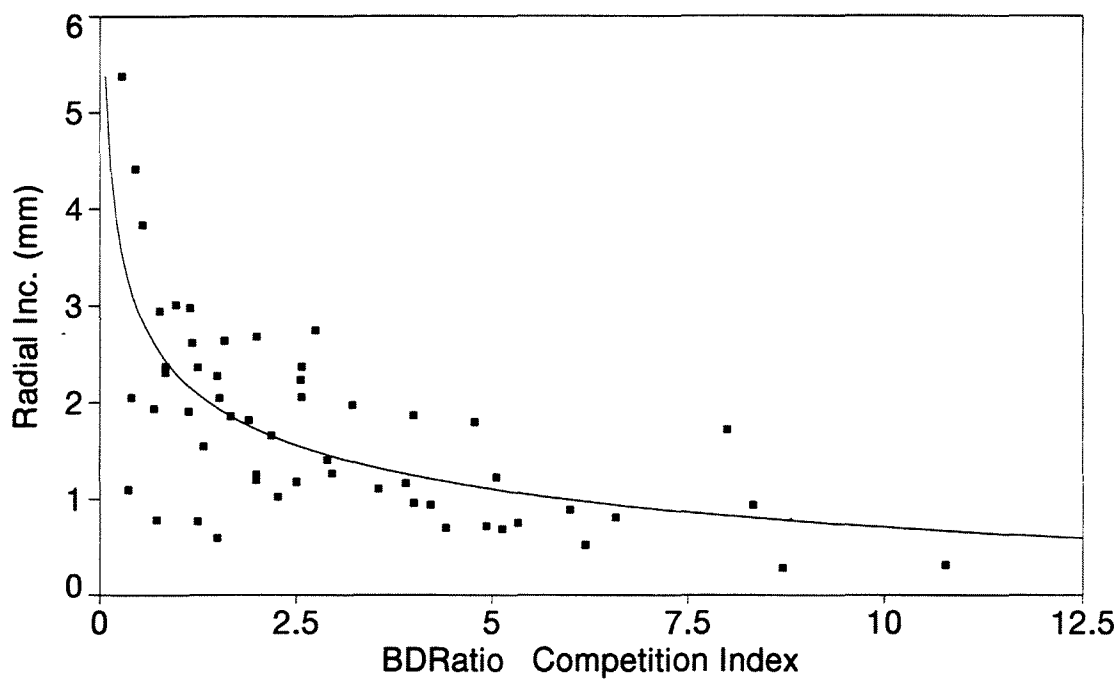
**Figure 27**

Non-linear Regression of White Spruce Radial Increment vs the BDRatio Competition Index for the Calling Lake Area



$\text{Radinc} = -4.40 + 7.15(\text{BDRatio})^{-0.19}$   $R^2 = 0.61$   $F_{\text{stat}} = 248.5$   $n = 322$   
Regression based on all blocks combined.

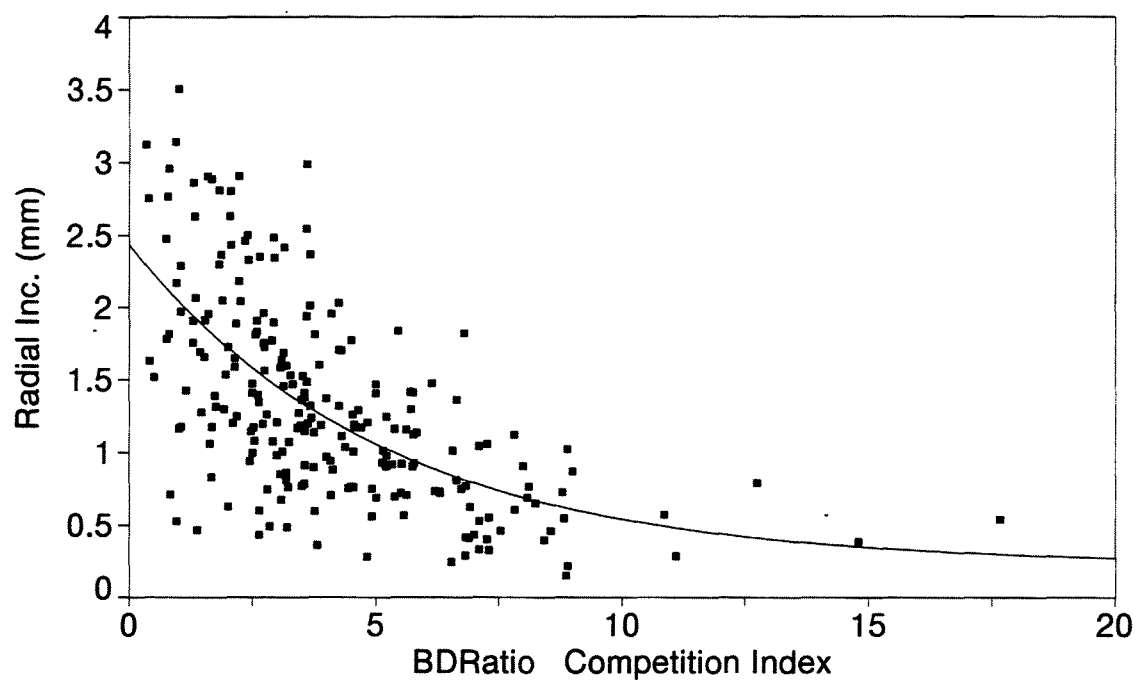
**Figure 28**  
Non-linear Regression of White Spruce Radial Increment vs the BDRatio Competition Index for  
the Kakwa River Area



$$\text{Radinc} = -1.80 + 4.07(\text{BDRatio})^{-0.21} \quad R^2 = 0.45 \quad \text{Fstat} = 20.47 \quad n = 54$$

Regression based on all blocks combined.

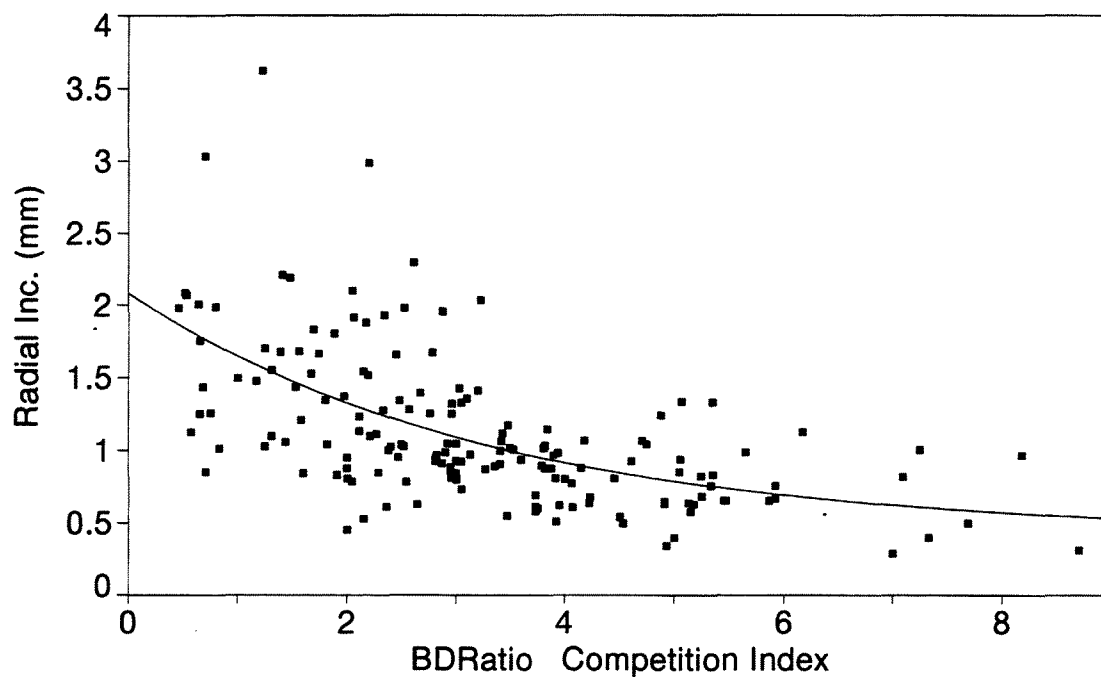
**Figure 29**  
**Non-linear Regression of White Spruce Radial Increment vs the BDRatio Competition Index for the Rocky Mountain House Area**



$$\text{Radinc} = 0.23 + 2.21^{(-\text{BDRatio}/5.11)} \quad R^2 = 0.39 \quad \text{Fstat} = 71.87 \quad n = 226$$

Regression based on all blocks combined.

**Figure 30**  
Non-linear Regression of White Spruce Radial Increment vs the BDRatio Competition Index for  
the Saddle Hills Area



$$\text{Radinc} = 0.42 + 1.66^{(-\text{BDRatio}/3.28)} \quad R^2 = 0.35 \quad F_{\text{stat}} = 43.9 \quad n = 166$$

Regression based on all blocks combined.



On the other hand, the recognition of the competition threshold that indicates substantial growth losses and the competition levels at which spruce should not be growing is more meaningful. This threshold defines a level of deciduous competition where there is an abrupt, recognizable increase in the rate of growth or in tree size. In our case, using the BD Ratio index, the growth change and better growth appears to be at the point where the curve flexes upward. BD Ratio values corresponding to this point and to the gradual growth increase were less than 2.5 and 2.5, as illustrated for radial increment in Calling Lake and Kakwa River, respectively (Figures 27 and 28). The levels of the observed threshold were not the same for all areas. The threshold was less recognizable and transitional and most likely occurred at higher values of the BD Ratio index in the Rocky Mountain House and Saddle Hills areas (Figures 29 and 30).

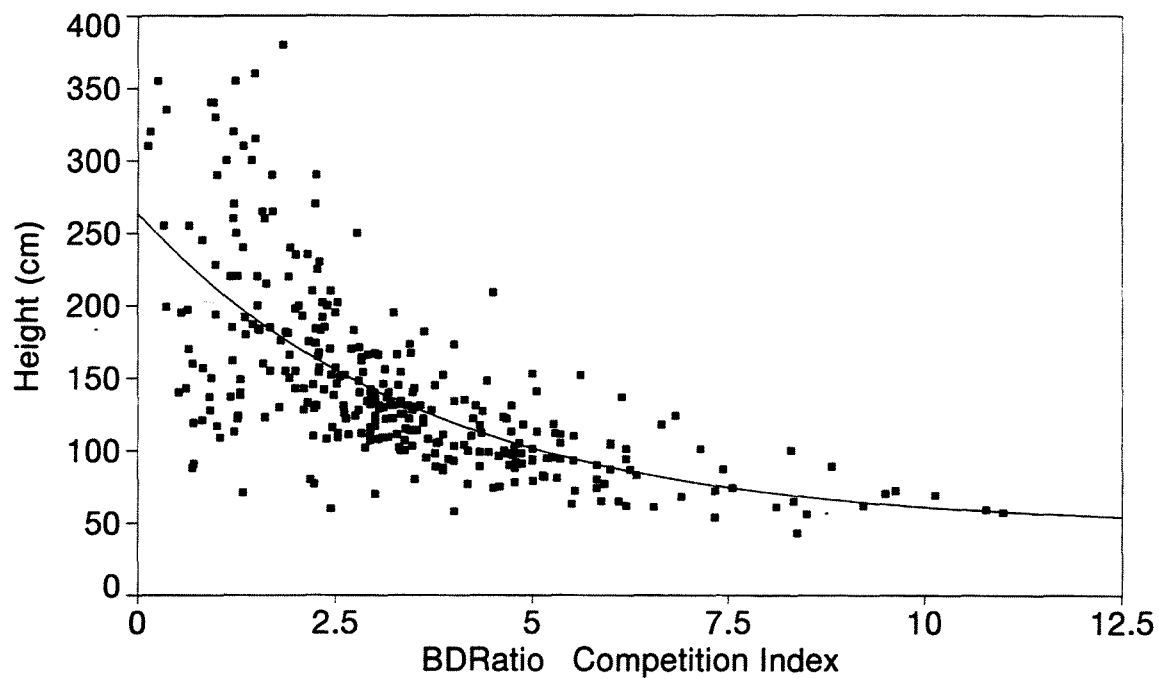
The relationship between height growth and competition as described by the BD Ratio competition index was not as strong. The strongest relationship was found in the Calling Lake area, with an  $R^2$  value of 0.46 (Figure 31). For the other three sites, the  $R^2$  values ranged from 0.23-0.39. In all four sites, a sharp change in the regression curve, corresponding to a competition threshold was not observed.

The predicted growth losses at the threshold of a BD Ratio value of 2.5 as compared to low competition represented by a BD Ratio value of 1 (Table 36) varied between areas as follows:

- 23 - 41% for radial increment
- 18 - 34% for basal diameter
- 14 - 26% for height

Since the BD Ratio index represents a measure of the proximity (within a 2 m radius) and size of the largest deciduous tree the following observations based on interpretation of Table 36 may apply: a) Competitive effects of a large deciduous tree in the vicinity of spruce appear most detrimental to the current radial growth and least to total height. b) The greatest reduction in diameter growth occurred in the Calling Lake area where the ratio of the spruce height/aspen height was the smallest. The greatest gains in diameter growth from tending treatments would be obtained by removal of all aspen and balsam poplar trees that have a diameter 2.5 times greater than that of spruce. However, to keep diameter growth losses to a minimum, or at acceptable levels of 10-15%, deciduous competition should be kept at the level before it reaches a BD Ratio of 2. In practical terms no deciduous trees with diameter equal to two times the spruce diameter should be present within 2 m radius of spruce tree for any length of time.

**Figure 31**  
Non-linear Regression of White Spruce Height vs the BDRatio Competition Index for the Calling Lake Area



$$\text{Height} = 47.02 + 216.3^{(-\text{BDRatio}/3.62)} \quad R^2 = 0.46 \quad \text{Fstat} = 136.7 \quad n = 322$$

Regression based on all blocks combined.

**Table 36**  
**Predicted Growth of White Spruce in Relation to the BDRatio Competition Index**

Location	Value of BDRatio Competition Index		
	1	2.5	5
	Radial Increment (mm) <sup>1</sup>		
Kakwa River	2.27	1.55 -32% <sup>2</sup>	1.09 -52%
Saddle Hills	1.64	1.19 -27%	0.78 -52%
Rocky Mtn. House	2.04	1.57 -23%	1.05 -49%
Calling Lake	2.75	1.62 -41%	0.89 -68%
	Basal Diameter (mm) <sup>3</sup>		
Kakwa River	36.3	26.1 -28%	18.4 -49%
Saddle Hills	28.8	23.4 -19%	16.5 -43%
Rocky Mtn. House	21.0	17.2 -18%	12.5 -40%
Calling Lake	31.8	21.0 -34%	13.5 -58%
	Height (cm) <sup>4</sup>		
Kakwa River	227.0	183.8 -19%	135.9 -40%
Saddle Hills	190.5	169.8 -11%	135.3 -29%
Rocky Mtn. House	135.9	117.5 -14%	92.5 -32%
Calling Lake	211.1	155.5 -26%	101.4 -52%

1. Model functions for radial increment are from Figures 27-30.

2. Relative decrease as compared to BDRatio = 1.

3. Model functions for basal diameter are from Figures 23-26.

4. Model functions for Height are as follows:

Kakwa River: Height =  $65.29 + 199^{(-BDRatio/4.82)}$   $R^2=0.040$  Fstat=16.82 n=54

Saddle Hills: Height =  $-6.69E 07 + 6.69E 07^{(-BDRatio/4.85E 06)}$   $R^2=0.23$  Fstat=24.2 n=166

Rocky Mountain House: Height =  $7.90 + 142.0^{(-BDRatio/9.65)}$   $R^2=0.33$  Fstat=54.18 n=227

Calling Lake function is from Figure 31.

## 7.0 DISCUSSION AND CONCLUSIONS

In general, two trends were derived from the analysis: 1. There were no consistent, broadly applicable relationships between competition measures and white spruce growth. These relationships were variable and in general, had low predictive ability of competition measurements to explain white spruce growth and size. 2. There were pronounced differences in competition levels and consequently in performance of the competition variables and indices among areas and among blocks.

Deciduous-dominated regeneration established on cutovers has a diverse structure and composition despite the silviculture treatments implemented to produce mainly conifer stands. Aspen and balsam poplar reproduce vegetatively after logging and also by seed particularly on site prepared areas. Thus, density, stocking, spatial distribution of deciduous regeneration is the outcome of many processes such as parent stand composition, intensity of site preparation, harvesting impacts, site factors and other factors (Peterson and Peterson 1992, Navratil 1993). As a result, the initial regeneration and composition of juvenile stands established on mixedwood sites is very variable.

The growth patterns and development of mixed stands vary greatly depending on the physiological predisposition of the interacting species and environmental conditions. Other sources of variability comes, for example, from microsites differences for both deciduous and coniferous species and from planting microsites for spruce (Brown and Navratil 1995). The diversity in juvenile stands in turn undoubtedly causes variable levels of competition pressure exerted on individual spruce trees.

Despite the use of a number of analytical approaches, the explainable and predicted changes in spruce growth associated with deciduous competition were at best only 30-50% of the variance in spruce growth. The maximum was 60-70% when crop tree measurements were a part of the competition index. Obviously the remaining 50-70% variation must have been associated with other limiting factors that weren't included in the analyses. This indicates that deciduous competition needs to be interpreted as one of several factors affecting spruce growth. Under variable, heterogenous stand and site conditions, competition is better viewed as one of many constraints rather than a determinant of target tree performance (Burton 1993).

A number of competition-growth relationships were tested in a step-wise fashion, using a variety of statistical procedures (not all of them are described in this report). Several functions and competition indices were selected that gave better results with the data collected from the sampling areas although the differences in their performance among the areas were pronounced. There was no definite consistent pattern applicable to all areas. Similarly, Alemdag (1978) in evaluating competition indices for prediction of diameter increment in planted spruce found no index that could be confidently adopted for any application.

While there have been several publications that deal with the competition dynamics in young mixedwood stands (e.g., MacDonald (1991), Morris and MacDonald (1991), Brand (1986), MacIsaac (1995), Alemdag (1978), Strong *et al.* (1995)), models that can predict spruce growth under various levels of interspecific competition are not widely available. Most of them point out to the difficulties in assessing the effects that the deciduous competition and population have on spruce growth. The severe limitations of the use of static measures of competition have been described by Burton (1993).

This study focused on deciduous competition measured in 10 to 14-year-old juvenile stands. Throughout the analysis there were isolated but strong signs of growth constraints assumed to be associated with grass and shrub competition in early stages of white spruce growth. This also could have contributed to the observed variability. Development of grass, forbs and shrub species competing with white spruce for growing space and particularly for moisture (Morris and MacDonald 1991) after harvesting and site preparation may have significant and long-lasting effects on spruce growth (Brown and Navratil 1995).

Rapid initial seedling growth after planting is critical for spruce responses and adaptation to deciduous competition. This critical stage of spruce seedling development at early stages may be more important limitation than deciduous competition at the age of 10-15 years.

Conifer response to increasing broadleaf competition is species-specific and differs for height growth, diameter growth and survival (e.g., Carter and Klinka 1992, Klinka *et al.* 1992). For white spruce, which is a moderately shade-tolerant species (Sims *et al.* 1990), growth of leaders and radial increment is maintained under decreasing light levels until about 40% of full sunlight (Liefvers and Stadt 1994). At lower light levels, while overall diameter and height growth is reduced, the growth of laterals is somewhat maintained, resulting in short seedlings with a relatively-large crown surface. While these seedlings may potentially survive under low light levels, their low rate of radial increment makes them susceptible to stem clipping by herbivores or to physical damage from vegetation press or snow press. However, the adaptation of white spruce to low light conditions enables the seedlings to take advantage of favorable conditions (e.g., lower transpirational stresses, reduced weevil attacks and reduced frost damage). In this way, white spruce has the ability to withstand high competition levels for long time which is another reason why the degree of statistical relationships was weak.

White spruce trees may be less responsive to changes in the surrounding deciduous competition which at some competition levels and at some stages of spruce development may even be beneficial. For example, positive effects of deciduous and aspen cover on white spruce growth were observed in multiple linear regressions (Table 34), although the effects were fairly weak and not well-defined. In a competition study in Northern Ontario, white spruce was found to have a low degree of sensitivity to competition as measured by canopy cover (Morris and MacDonald 1991).

The stronger response of diameter growth to deciduous competition compared to height growth has been reported for white spruce (Wood and Dominy 1988, MacIsaac 1995, Comeau *et al.* 1993, Delong 1991), and for several other Boreal forest tree species such as black spruce (Morris and MacDonald 1991), lodgepole pine (Navratil and MacIsaac 1993). Diameter growth is more responsive to competition than height growth due to different priority allocation of a tree's photosynthates. The first priority for photosynthates is maintenance of respiration, followed by production of roots, production of flowers and seed, growth of terminal and lateral branches, and the last priority, if still more photosynthates is available, diameter growth (Oliver and Larson 1990). Then, it follows that in trees subjected to competition or other stresses diameter growth slows down first. For this same reason our interpretations are based on the response of diameter growth and more specifically on current radial increment. In practical applications, earlier and more intensive reductions of deciduous competition would be required to maintain diameter growth than to maintain height growth.

Variable responses, or the lack of responses, at low and medium competition levels was also observed. This indicates that many trees at those competition levels are not suffering from competition which in turn means that the same trees will not benefit from broadly applied vegetation treatment. For this and other reasons (see further) competition levels and treatments for achieving the best spruce growth could not be defined and recommended. It appears that at these low competition levels spruce grows well or does not grow well regardless of the presence of deciduous trees. The changes from low and medium to high competition levels produced, however, strong negative effects as indicated by the steep slope and the deflection points of the regression curves.

Based on these interpretations the following recommendations are made:

- a) Balsam poplar was an important component of the surveyed juvenile stands and contributed to competition effects. Therefore it should be considered in competition assessment.
- b) The competition levels, and therefore tending treatments, that result in the best spruce growth could not be defined.
- c) The competition levels that produce substantial growth reduction were defined, though they varied among areas. In general, diameter growth losses of 20-40% were associated with the competition level expressed by a BD Ratio index value of 2.5. In interpretation, these growth losses occurred where a deciduous tree with the diameter 2.5 times larger than that of spruce was present within a 2.0 m distance.
- d) The importance of the neighbor competitors was greater where large competitor trees were present in relation to the target tree size. Where there was high density of competitors the abundance of competitors was more important.

The competition and growth interactions of individual trees were tested, and it proved to be difficult to isolate growth response to competition. Burton (1993), among others, concluded that quantification of individual tree growth and its constraints by competition is possible only in broad terms. Stand level descriptors rather than individual tree competition indices, could be more appropriate for diverse juvenile mixed stands.

Provided that management objectives for juvenile mixed stands are clearly defined in terms of acceptable levels of deciduous component and of associated acceptable levels of spruce growth losses, such stand level descriptors could become a decision-making tool. It would be possible to devise silviculture treatments for reducing the competition constraints to acceptable levels and then to accept the changed growth and yield trajectories of spruce. For this reason a descriptive approach was adopted in presenting the findings in this report rather than suggesting a tool for hard and fast decisions on tending treatments. In this way the information presented becomes more useful for consultation and adaptive management. If desirable, it can also serve as a background for stand dynamic modeling.

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## APPENDIX 1

### Formulas for Competition Indices Tested in Analysis

The formulas presented here are, in some cases, modifications of the original published formulas. All indices are based on a 2 m radius (12.56 m<sup>2</sup>) plot. **In this study, these indices are based on hardwood competitors within the plot (they do not include shrubs or conifers).**

**BDRATIO:** Navratil and MacIsaac (1993) - published index used a plot radius of 1.78 m.

$$BDRATIO = \frac{RCD \text{ of tallest hardwood competitor}}{RCD \text{ of target tree}} \quad \dots [1]$$


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**BDRATIO2:** Navratil and MacIsaac (1993) - published index used a plot radius of 1.78 m.

$$BDRATIO2 = \frac{RCD \text{ (avg of tallest plus closest hardwood competitors)}}{RCD \text{ of target tree}} \quad \dots [2]$$

Note: Includes only tallest and closest trees.

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**BRAATHE:** Braathe (1989) pg 270 - published index used plot radius of 3 m.

$$Braathe = \sum_{i=1}^n \frac{\text{height of hardwood competitor}_i - \text{height of target tree}}{\text{target stem-to-hardwood competitor}_i \text{ stem distance}} \quad \dots [3]$$

Where: n = number of individual hardwood trees in the plot

Note: Heights and distances can be metres or centimetres since the units cancel out.

**BRAND:** Brand (1986) pgs 25 & 26 - published index used plot radius of 1.41 m.

$$\text{Brand C.I.} = \frac{\sum_{i=1}^n \frac{Hb_i * C_i}{Ht}}{\left( \frac{Rb}{Rt} + 1 \right)^{-1}} * \sum_{i=1}^n C_i \quad \dots [4]$$

Where:

$Hb_i$	=	Average height of hardwood species <sub>i</sub>
$C_i$	=	Total percent cover of hardwood species <sub>i</sub>
$Ht$	=	Height of target tree
$Rb$	=	Average distance from target tree stem to hardwood competitor tree stems (based on all individual hardwood trees in the plot) (ie. mean or average stem-to-stem distance of all trees)
$Rt$	=	Crown radius of target tree
$n$	=	number of hardwood tree species in plot.

Note: -In this study,  $Rb$  is calculated based on stem-to-stem distances, whereas the published index used stem-to-inside crown of hardwood competitor.  
 -Average covers and heights are taken from species averages.  
 -Heights and distances can be metres or centimetres since the units cancel out.

**COMEAU:** Comeau et al. 1993

$$\text{Comeau} = \sum_{i=1}^n \frac{\text{avg cover of competing hardwood species}_i * \text{avg height of competing hardwood species}_i}{\text{target tree height}} \quad \dots [5]$$

Where:  $n$  = number of hardwood tree species in the plot

Note: Average covers and heights are taken from species averages estimated for each plot.

**DANIELS:** Daniels(1976) pg 456, cited by Mugasha (1989)  
 This was originally proposed by Hegyi (1974), using plot radius of 3.05m.

$$\text{Daniels} = \sum_{i=1}^n \frac{\left( \frac{\text{RCD of hardwood competitor}_i}{\text{RCD of target tree}} \right)}{\text{target tree stem to hardwood competitor}_i \text{ stem distance}} \quad \dots [6]$$

Where:  $n$  = number of individual tallest and closest hardwood trees in the plot

**DELONG:** Delong 1991

$$Delong = \sum_{i=1}^n \frac{\text{avg cover of competing hardwood species}_i * \text{avg height of competing hardwood species}_i}{\text{average stem to stem distance of competing hardwood species}_i} \dots [7]$$

Where: n = number of hardwood species in the plot

Note: -The published index uses proximity for the denominator, defined as average stem-to-stem.

-Average covers and heights are taken from species averages.

-Average stem-to-stem distances are calculated for each species.

-Heights and distances can be metres or centimetres since the units cancel out.

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**LORIMER:** Lorimer (1983) pg 358, cited by Mugasha (1989) Equation 18  
In the published index, the plot radius is variable to make age-independent.

$$Lorimer = \sum_{i=1}^n \frac{RCD \text{ of hardwood competitor}_i}{RCD \text{ of target tree}} \dots [8]$$

Where: n = number of individual tallest and closest hardwood trees in the plot

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**MACD1:** MacDonald et al 1990 - BACD from pg 1062

$$MACD1 = \sum_{i=1}^n \frac{\text{basal area of hardwood competitor}_i}{\text{target tree stem to hardwood competitor}_i \text{ stem distance}} \dots [9]$$

Where: n = number of individual tallest and closest competing hardwood trees in the plot

Note: RCD measurements must first be converted from mm to cm.

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**MACD2:** MacDonald et al (1990) - CVCD from pg 1062

$$MACD2 = \sum_{i=1}^n \frac{\text{crown radius of hardwood competitor}_i}{\text{target tree stem to hardwood competitor}_i \text{ stem distance}} \dots [10]$$

Where: n = all individual competing hardwood trees in the plot

crown radius = stem-to-stem minus stem-to-inside-crown of hardwood competitor

Note: Heights and distances can be metres or centimetres since the units cancel out.

**MACD3:** MacDonald et al (1990) - ANG from pg 1062

$$MACD3 = \sum_{i=1}^n \text{angle from target tree base to top of hardwood competitor}_i \quad \dots [11]$$

This angle is defined as:

$$TAN \left( \frac{\text{height of hardwood competitor}}{\text{target tree stem to hardwood competitor stem distance}} \right)$$

Where: n = all individual competing hardwood trees in the plot

Note: Heights and distances can be metres or centimetres since the units cancel out.

**MACD4:** MacDonald et al (1990) - derived from CVCD from pg 1062

$$MACD4 = \sum_{i=1}^n (\text{angle from target tree base to top of hardwood competitor}_i) * \text{hardwood competitor}_i \text{ location modifier} \quad \dots [12]$$

Where: n = all individual competing hardwood trees in the plot

Note: Heights and distances can be metres or centimetres since the units cancel out

The competitor location factor weights the angle based on location of the competitor: N: 1 E: 2 S:4 W:3.

**MARTIN:** Martin and Ek (1984) Equation 4

$$Martin = \sum_{i=1}^n \frac{\left( \frac{RCD \text{ of hardwood competitor}_i}{\text{target tree RCD}} \right)}{\text{target tree stem to hardwood competitor}_i \text{ stem distance (m)} + 1} \quad \dots [13]$$

Where: n = number of individual tallest and closest hardwood trees in the plot

Note: The published index uses a linear expansion factor which is not used here.

**RELVOL:** MacDonald (1991) cited by MacDonald and Weetman (1993)  
In the published index, the plot radius is 1.4 m.

$$RELVOL = \frac{\sum_{i=1}^n \text{basal area of hardwood competitor}_i * \text{height of hardwood competitor}_i}{\text{basal area of target tree} * \text{height of target tree}} \quad \dots [14]$$

Where: n = number of individual tallest and closest hardwood trees in the plot

BA=basal area

Note: Heights and distances can be metres or centimetres since the units cancel out.

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**STENECK:** Stenecker and Jarvis (1963)

$$STENECK = \sum_{i=1}^n \frac{RCD \text{ of hardwood competitor}_i}{\text{target tree stem to hardwood competitor}_i \text{ stem distance}} \quad \dots [15]$$

Where: n = number of individual tallest and closest hardwood trees in the plot

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**TOWILL:** Towill and Archibald (1991) pg 16

$$Towill = \sum_{i=1}^n \text{avg cov of hardwood competitor}_i * \text{avg ht of hardwood competitor}_i * \left( \frac{\text{avg HW competitor height}_i}{\text{target tree height}} \right) \quad \dots [16]$$

Where: n = number of competing hardwood tree species in the plot

Note: Average covers and heights taken from species averages.

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**WAGNER:** Wagner and Radosevich (1991)

This index is also referred to as EX11 in Wagner and Radosevich (1987)

The published index used a plot radius of 2.06 m.

$$Wagner = \sum_{i=1}^n \text{average cover of competing hardwood species}_i \quad \dots [17]$$

Where: n = number of competing hardwood species in the plot

**APPENDIX 2**  
Tree Crown Cover in Each Block

Location	Block/ Sample Size	Average Percent Cover		
		Hardwood <sup>1</sup>	Aspen	Conifer <sup>2</sup>
Kakwa River	1 (47)	14.2 ±2.55 <sup>3</sup>	7.9 ±2.35	3.6 ±0.69
	2 (33)	14.4 3.11	3.8 1.91	2.9 1.14
	Total (80)	14.3 1.96	6.3 1.61	3.3 0.63
Saddle Hills	1 (29)	24.7 3.58	10.7 3.38	4.6 0.84
	2 (48)	30.1 2.90	23.9 2.44	6.0 1.00
	3 (44)	29.9 2.37	27.1 2.33	3.6 0.64
	4 (49)	32.7 3.13	26.9 3.21	4.1 0.59
	Total (174)	30.1 1.50	23.5 1.48	4.5 0.39
Rocky Mountain House	1 (53)	31.5 4.22	31.5 4.22	1.3 0.30
	2 (50)	41.7 3.62	40.3 3.72	1.2 0.21
	3 (50)	34.4 4.45	30.8 4.09	0.8 0.19
	4 (50)	25.9 3.61	10.5 2.32	0.5 0.09
	5 (30)	21.3 4.08	20.9 4.11	2.1 0.64
	6 (55)	23.6 2.65	23.6 2.65	0.7 0.27
	Total (288)	30.2 1.59	26.6 1.55	1.0 0.12
Calling Lake	1 (50)	25.6 3.19	22.9 3.30	4.6 1.14
	2 (38)	19.4 2.18	15.4 2.06	1.3 0.20
	3 (43)	18.7 2.49	6.1 1.62	2.2 0.62
	4 (50)	22.4 1.87	10.5 1.12	1.2 0.23
	5 (42)	18.9 2.47	8.4 1.83	1.1 0.18
	6 (52)	17.1 1.70	10.6 1.55	1.1 0.21
	7 (52)	20.5 1.63	16.1 1.53	1.0 0.15
	Total (327)	20.5 0.86	13.0 0.80	1.8 0.21

1. Hardwood is mostly aspen and balsam poplar, with very small amounts of paper birch.
2. Does not include target trees.
3. Mean and standard error of the mean.