Summary of the 13-Year Results of an Interior Douglas-fir Precommercial Thinning Experiment in the Alex Fraser Research Forest, Williams Lake, British Columbia

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Abstract

A precommercial thinning experiment was established in uneven-aged interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) stands in the Knife Creek Block of the Alex Fraser Research Forest in 1990. The stands in which the experiment was conducted were logged to an approximate diameter limit of 25 cm (10 inches) in the 1950s and 1960s. Three thinning treatments and a control area were randomly assigned to adjacent areas, approximately 10 ha in size. The three thinning treatments consisted of: (1) the standard juvenile spacing rules at the time; (2) 3 m clumped spacing rules; and (4) 5 m clumped spacing rules. Two 0.05 ha plots were located in relatively uniform, dense portions of each area, prior to the treatments being applied operationally to the entire 10 ha area. The experiment was laid out on three sites, a few km apart. There was a slight elevation gradient and moisture gradient among the three sites. There are a total of 24 plots in the experiment (3 replicates × 4 treatments per replicate × 2 plots per treatment).

The plots that received the precommerical thinning treatments averaged higher levels of ingrowth, considerably less mortality, greater basal area growth, larger changes in quadratic mean dbh, and higher increased in relative density than did the control plots. Average volume per ha growth was similar between the control plots and the standard and 5 m clumped spacing treatments; however, a much larger proportion of the volume growth on the control plots occurred on trees that will not become merchantable than was the case for the treated plots. The best volume per ha growth was found for the 3 m clumped spacing treatment, averaging slightly more than 1 m^3/ha/year higher than the other treatments.

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Introduction

Stands of uneven-aged interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) are structurally complex due to a history of disturbances from partial cutting, insects, and fire. They are an important source of timber in the central and southern interior of British Columbia (Marshall and Wang 1996). As well, many interior Douglas-fir stands provide important winter habitat for mule deer (*Odocoileus hemionus*) (Armleder *et al*. 1986).

Large trees are essential to good mule deer winter range. Recruitment of sapling-sized trees to larger diameters is necessary to replace large trees which die from various causes or which are harvested. Recruitment is especially necessary in areas that meet other criteria for good winter range, but presently lack sufficient numbers of large trees, often because of diameter-limit logging in the past. Removal of some portion of the smaller trees in dense patches (precommercial thinning, sometimes called juvenile spacing) is one possibility for increasing the growth rate of individual trees. If successful, this treatment will be beneficial from both a timber and a mule deer winter range perspective.

This report summarizes the results to date of a precommercial thinning experiment (Project 88-11) carried out in the Knife Creek Block of the Alex Fraser Research Forest, near Williams Lake, BC. Some of the content of this summary has been taken from Marshall (1996, 1999) and Marshall and Bugnot (1999).

Methods

Three blocks of approximately 40 ha each were established, a few kilometers apart, from west to east across the forest. There is a slight elevation gradient, and an accompanying moisture gradient, from lower and drier in the western part of the Knife Creek (Block B) to higher and moister in the eastern part (Block D). The areas in which these blocks are found were logged in the 1950s and 1960s to some diameter limit (possibly 10 inches or 25.4 cm). Many, but not all, of the larger trees were removed at that time. The number of trees removed by harvesting appears to have varied considerably across each of the blocks, based on residual stump evidence. The disturbance created by the logging caused a subsequent flush in natural regeneration and a release of existing advance regeneration. At the time that this project began, this flush had grown into a large number of dense patches, comprised mainly of small diameter trees (< 10 cm dbh). It was this characteristic that made these areas prime candidates for pre-commercial thinning.

Each of the three blocks was divided into quarters. Three of the quarters received different spacing treatments assigned randomly, and the fourth was used as a control. Two 0.05 ha plots were established in each of the quarters resulting in 8 plots per block and 24 plots for the study. The plots were located in relatively uniform, dense areas of the stands that were sufficiently large to accommodate the plots. The conditions on the plots should not be taken as being representative of the area as a whole. The intent was to measure the response to the various spacing regimes in locations most likely to show the largest measurable response.

The plots were initially established at the end of the 1989 growing season for the western-most block and at the end of the 1990 growing season for the other two blocks. Trees greater than 1.3 m in height within the plot boundaries were tallied by diameter and species at that time to provide a record of pre-treatment conditions.

The precommercial thinning treatments applied were the 1991 standard prescription for these types of stands (S) and two clumped designs (C1 and C2). The focus of the standard prescription was to leave most larger trees (≥12.5 cm dbh) uncut, and for smaller trees to allow an average spacing of 2.5 m for Douglas-fir or spruce (*Picea engelmanni* x *glauca*) and 2.8 m for lodgepole pine (*Pinus contorta* var. *latifolia*). The object of the clumped designs was to leave clumps of trees from one height class. Four height classes were used: 1 - 3 m, 3 - 7 m, 7 - 15 m, and > 15 m. A clump was defined as 3 to 9 trees in the same height class within a 3-m radius circle. Spacing within a clump could vary between 0.5 m and 2.5 m. Trees < 25 cm dbh in the same or lower height classes were to be removed within either 3 m (3 m Clumped – C1) or 5 m (5 m Clumped – C2) of each clump.

The precommercial thinning treatments were applied in the late fall and early winter of 1990-91. The plots were re-established in the spring/summer of 1993. At that time, all trees greater than 1.3 m in height within the confines of the plot and those trees greater than 10 cm dbh within a 5 m distance of the plot boundary were permanently tagged. The species of each tagged tree was recorded, along with measures of dbh, total tree height, height to the base of the live crown (for each of four quadrants around the tree), crown width (in two directions), and vigor. The locations of all tagged trees were also mapped.

The plots were remeasured in the spring/summer of 1997 and 2004. Diameters of all living trees were measured in the early spring, prior to the onset of diameter growth; other measurements did not include current year foliage, so the measurements were inclusive of the 1996 and the 2003 growing seasons, respectively.

Results

A considerable range of densities existed among the plots prior to treatment, although all the plots were subjectively classified as dense (Table 1). Block B was the driest of the three blocks. The plots in this block were dominated by Douglas-fir (> 80% by basal area). The remaining basal area was comprised entirely of lodgepole pine, with the exception of a small percentage (< 0.5%) of aspen (*Populus tremuloides*) in plot 5.

Block D appeared to be the moistest of the three blocks. The plots in this block were dominated by mixtures of Douglas-fir, spruce, and lodgepole pine (together accounting for > 80% of the basal area). Douglas-fir was the leading species on five of the eight plots, spruce was the leading species on two plots, and lodgepole pine was leading on one of the plots. The remaining basal area was comprised of deciduous trees (aspen, white birch - *Betula papyrifera* Marsh., and willow - *Salix* spp.). Aspen and birch were approximately equally abundant. Willow was present in small amounts on only one of the plots.

Table 1. Summary of plot conditions in 1989/90 prior to spacing (from Marshall 1996).

Block	Treatment	Plot	Stems/ha	BA/ha	QMD[d]	RD[e]	% Comp.						Date
							Fd	Pl	Sx	At	Ep	W	
B	C1	1	13720	39.1	6.02	15.93	100.0						08/89
	C1	2	6840	40.7	8.71	13.81	99.4	0.6					08/89
	U[a]	3	10460	43.7	7.30	16.19	98.8			1.2			06/93
	U[a]	4	8220	39.7	7.84	14.17	96.4	3.6				0.1	06/93
	C2	5	7980	37.1	7.69	13.38	81.7	18.0		0.3			08/89
	C2	6	8320	37.6	7.59	13.66	100.0						08/89
	S	7	8060	39.2	7.87	13.97	100.0						08/89
	S	8	7540	35.4	7.73	12.73	83.4	16.6					08/89
D	S	9	5520	36.6	9.18	12.08	68.9	18.6	0.8	9.3	2.2		08/90
	S	10	6760	32.1	7.77	11.48	85.9	12.6	0.4	0.2	0.9		08/90
	C1	11	4260	38.2	10.69	11.68	39.7	9.0	42.9	8.4			08/90
	C1	12	5760	29.8	8.12	10.46	60.7	0.4	37.8			1.0	08/90
	C2	13	5620	31.5	8.44	10.84	75.5	15.9	0.1	8.5			08/90
	C2	14	9320	41.0	7.48	14.99	44.0	50.2	5.2	0.3	0.3		08/90
	U[b]	15	5480	36.0	9.14	11.91	62.3	12.4	3.7	6.0	15.6		08/90
	U[c]	16	4340	31.8	9.67	10.23	31.3	-	59.2	2.9	6.5		08/90
C	C2	17	6660	28.2	7.34	10.41	77.7		4.9	10.1	7.3		08/90
	C2	18	4640	18.8	7.18	7.02	67.3	10.0	4.9	3.4	14.5		08/90
	U	19	5500	30.0	8.33	10.39	94.5		1.6		3.9		08/90
	U	20	5660	28.4	7.99	10.05	75.6	8.9		6.9	8.5		08/90
	C1[b]	21	7280	30.7	7.53	11.34	60.4	12.6	4.3	0.6	22.0		08/90
	C1	22	5820	24.5	7.32	9.06	66.1	18.9			15.0		08/90
	S	23	6140	33.5	8.34	11.60	66.1	26.5	0.2	0.9	6.3		08/90
	S	24	9000	39.2	7.47	14.34	73.7	16.2	0.6	0.3	9.2		08/90

[a] These plots were not measured until the beginning of the 1993 growing season.

[b] The plot figures were adjusted based on the 1993 data to account for apparent missed trees in the original tally. Percent species composition was assumed to be the same as in the original (1990) data.

[c] The plot figures were adjusted based on the 1993 data to account for undocumented mortality or double counted trees. Percent species composition was assumed to be the same as in the original (1990) data.

[d] Quadratic mean diameter (i.e., the diameter of the tree of mean basal area).

[e] Relative density index calculated according to Curtis (1982).

Block C was intermediate to blocks B and D in terms of soil moisture. The plots in this block were dominated by Douglas-fir (greater than 60% by basal area in all plots). There was only a very small spruce component (< 5%). The amount of lodgepole pine differed greatly among the plots (0 to 26.5%). The deciduous component contributed slightly more, on average, than in Block D. Birch was the dominant deciduous species on most of the plots.

The conditions on the thinned plots were more alike following treatment than prior to spacing, but still varied considerably (Table 2). Basal area per ha on the thinned plots ranged from 14.75 to 36.80 m^2 and relative density ranged from 4.24 to 10.50. Generally, the plots that were spaced using the C2 regime had the lowest residual densities. There was no apparent difference in residual densities between the C1 and S regimes.

Table 2. Summary of plot conditions prior to the 1993 growing season.

Block	Treatment	Plot	Stems/ha	BA (m^2/ha)	Volume[a] (m^3/ha)	QMD (cm)	RD	% Comp. Fd	Pl	Sx	At	Ep	W
B	C1	1	2260	18.02	70.8	10.08	5.7	100.0					
	C1	2	1960	26.75	135.8	13.18	7.4	100.0					
C	C1	21	2440	24.66	129.7	11.34	7.3	60.7	13.0	4.5	0.3	21.5	
	C1	22	2800	22.68	105.6	10.16	7.1	66.8	13.1	3.9	-	16.2	
D	C1	11	3100	36.80	229.8	12.29	10.5	43.4	4.3	43.2	9.2		
	C1	12	2300	27.18	138.6	12.27	7.8	61.3		38.7			-
B	C2	5	2060	25.20	153.3	12.48	7.1	75.2	24.7		-		
	C2	6	1400	22.37	126.2	14.26	5.9	100.0					
C	C2	17	1160	15.48	67.2	13.04	4.3	68.7	14.0	5.3		12.0	
	C2	18	1280	14.75	61.3	12.11	4.2	70.5	12.6	7.8	0.1	9.0	
D	C2	13	1500	18.95	90.5	12.68	5.3	80.5	19.4		0.1		
	C2	14	1240	18.40	117.0	13.74	5.0	23.8	67.0	9.2			
B	S	7	1940	26.29	120.9	13.14	7.2	100.0					
	S	8	1720	22.91	123.9	13.02	6.4	83.6	16.4				
C	S	23	1740	28.08	194.9	14.33	7.4	74.2	23.6	0.2	-	1.9	
	S	24	1440	21.24	121.7	13.70	5.7	75.8	24.2			-	
D	S	9	2300	23.21	149.4	11.34	6.9	85.2	14.8		-		
	S	10	1860	23.70	120.3	12.74	6.6	89.0	11.0			-	
B	U	3	10460	43.74	187.8	7.30	16.2	97.8	1.0		1.2		
	U	4	8220	39.67	166.4	7.84	14.2	96.4	3.6				0.1
C	U	19	5580	32.58	126.2	8.62	11.1	95.4		2.7		1.9	
	U	20	5480	32.45	130.4	8.68	11.0	78.0	9.2		6.3	6.5	
D	U	15	5480	36.15	180.0	9.16	11.9	64.8	11.4	3.7	5.8	14.2	
	U	16	4340	33.99	195.3	9.99	10.8	31.3	-	59.2	2.9	6.5	

[a] Total volume of living trees as determined using Ministry of Forests volume equations (B.C. Forest Service 1976).

A large majority of the cut trees were in the smaller diameter classes. The impact of this was to modify the shape of the diameter distribution from an inverse-J shaped curve to more of a bell-shaped curve. There did not appear to be a consistent pattern among the distribution of the trees removed by the pre-commercial thinning treatments. The number of trees and basal area removed by spacing appeared to be as much a function of the previous diameter and spatial distribution on the plots as it was a function of the spacing method.

The plot conditions prior to the 1997 growing season are summarized in Table 3. Response to the thinning on an area basis over the first remeasurement period (incorporating the 1993 to 1996 growing seasons – Table 3 values minus Table 2 values) is given in Table 4. The thinned plots averaged more ingrowth, less mortality, higher basal area growth, slightly higher volume growth, a greater increase in quadratic mean diameter (QMD), and a higher rate of increase in relative density than did the control plots. The C1 and S treatments showed similar average responses. The C2 treatment averaged lower growth rates than the other thinning treatments on all of the variables except QMD; for this variable, the highest response was found for the C2 treatment. These differences among the thinning treatments were expected since the C2 treatment resulted in a lower residual density than either of the treatments. Only small changes occurred in the percentage species composition (determined according to basal area) over this growth period (Table 4). Generally, the percent composition of Douglas-fir increased slightly, and the composition of trembling aspen and white birch decreased slightly.

Table 3. Summary of plot conditions prior to the 1997 growing season.

								% Comp.					
Block	Treatment	Plot	Stems/ha	BA (m^2/ha)	Volume[a] (m^3/ha)	QMD (cm)	RD	Fd	Pl	Sx	At	Ep	W
B	C1	1	2260	22.92	98.3	11.36	6.8	100.0					
	C1	2	1960	29.89	158.5	13.93	8.0	100.0					
C	C1	21	2380	27.93	153.6	12.22	8.0	60.1	14.6	4.7	0.2	20.3	
	C1	22	2720	25.89	132.5	11.01	7.8	67.4	14.7	4.1		13.8	
D	C1	11	3040	39.72	259.8	12.90	11.1	44.0	4.2	43.1	8.8		
	C1	12	2280	30.84	168.9	13.12	8.5	62.2		37.8			
B	C2	5	2040	28.56	173.7	13.35	7.8	77.2	22.7		0.1		
	C2	6	1400	25.36	145.2	15.19	6.5	100.0					
C	C2	17	1200	18.61	85.2	14.05	5.0	72.1	14.3	6.1		7.5	
	C2	18	1440	18.50	81.0	12.79	5.2	72.1	11.3	7.6	-	8.8	
D	C2	13	1420	22.31	113.2	14.14	5.9	81.0	18.9		-		
	C2	14	1280	21.80	143.5	14.73	5.7	25.1	65.4	9.5			
B	S	7	1940	29.66	144.9	13.95	7.9	100.0					
	S	8	1680	25.91	145.8	14.01	6.9	84.6	15.4				
C	S	23	1700	30.30	213.2	15.06	7.8	74.2	23.6	0.3	-	1.9	
	S	24	1420	25.40	152.0	15.09	6.5	75.7	24.3			-	
D	S	9	2400	28.44	171.1	12.28	8.1	77.3	22.7		-		
	S	10	1920	27.03	143.1	13.39	7.4	86.9	13.1		-	-	
B	U	3	9780	45.71	206.1	7.71	16.5	99.0	1.0				
	U	4	7960	42.35	186.2	8.23	14.8	96.6	3.4				
C	U	19	5440	36.60	152.7	9.26	12.0	95.6		2.7		1.7	
	U	20	5180	35.30	152.5	9.31	11.6	80.1	9.1		4.4	6.4	
D	U	15	5400	37.49	196.8	9.40	12.2	68.2	11.8	4.0	3.1	12.9	
	U	16	4000	35.23	213.6	10.59	10.8	31.9		59.0	2.9	6.2	

The seven-year period ending with the 2003 growing season saw some significant mortality in lodgepole pine due to mountain pine beetle attack in some of the plots (Tables 5 and 6). Since lodgepole pine was not distributed evenly among the plots and treatments, and because the attack, to date, varied in severity among plots, the growth response to the various treatments was confounded by this mortality. There also was a considerable range of growth among plots within a treatment. For example, the seven-year periodic volume growth based on the six plots within treatment C2 varied from a loss of almost 36 m^3/ha to a gain of almost 58 m^3/ha.

The lodgepole pine mortality which had occurred by the beginning of the 2004 growing season is given by plot and treatment in Table 7. Although only one or two trees died in some of the plots, they were among the larger trees in those plots and hence their death did impact on the volume and basal area for those plots. Plot 5 (Treatment C2) and Plots 23 and 24 (Treatment S) lost between 5 and 8 large trees per plot; this had major impacts on the volume and basal area for those plots. Treatment S had the highest lodgepole pine mortality, followed by Treatment C2. Only one lodgepole pine tree died in the Treatment C1 plots and only one died in the control plots. This is more likely a matter of chance and the fact that the plots in these treatments had the lowest amount of pine at the beginning of this growth period (Table 4), than to any impact the treatments themselves might have had.

Table 4. Four-year growth (1993 to 1996 growing seasons).

Block	Treatment	Plot	Periodic Change						Change in Composition (%)					
			Ingrowth (St./Ha)	Mort. (St./Ha)	BA/ha (m^2/ha)	Volume[a] (m^3/ha)	QMD (cm)	RD	Fd	Pl	Sx	At	Ep	W
B	C1	1	0	0	4.90	27.5	1.28	1.1	0.0					
	C1	2	0	0	3.14	22.7	0.75	0.6	0.0					
C	C1	21	80	140	3.27	23.9	0.88	0.7	-0.6	1.6	0.2	-0.1	-1.2	
	C1	22	160	240	3.21	26.9	0.85	0.7	0.6	1.6	0.2		-2.4	
D	C1	11	0	60	2.92	30.0	0.61	0.6	0.6	-0.1	-0.1	-0.4		
	C1	12	0	20	3.66	30.3	0.85	0.8	0.9		-0.9			0.0
Avg.	**Period**		**40**	**77**	**3.52**	**26.9**	**0.87**	**0.75**						
Avg.	**Year**		**10**	**19**	**0.88**	**6.7**	**0.22**	**0.19**						
B	C2	5	0	20	3.36	20.4	0.87	0.7	2.0	-2.0				
	C2	6	0	0	2.99	19.0	0.93	0.6	0.0					
C	C2	17	80	40	3.13	18.0	1.01	0.7	3.4	0.3	0.8		-4.5	
	C2	18	160	0	3.75	19.7	0.68	0.9	1.6	-1.3	-0.2	0.0	-0.2	
D	C2	13	0	80	3.36	22.7	1.46	0.6	0.5	-0.5				
	C2	14	40	0	3.40	26.5	0.99	0.7	1.3	-1.6	0.3			
Avg.	**Period**		**47**	**23**	**3.33**	**21.0**	**0.99**	**0.70**						
Avg.	**Year**		**12**	**6**	**0.83**	**5.2**	**0.25**	**0.18**						
B	S	7	0	0	3.37	24.0	0.81	0.7	0.0					
	S	8	0	40	3.33	21.9	0.99	0.6	1.0	-1.0				
C	S	23	120	160	2.22	18.3	0.73	0.4	0.0	0.0	0.1	0.0	0.0	
	S	24	40	60	4.16	30.3	1.39	0.8	-0.1	0.1			0.0	
D	S	9	200	100	5.23	21.7	0.94	1.2	-7.9	7.9				
	S	10	60	0	3.33	22.8	0.65	0.8	-2.1	2.1				
Avg.	**Period**		**50**	**60**	**3.61**	**23.2**	**0.92**	**0.75**						
Avg.	**Year**		**12**	**15**	**0.90**	**5.8**	**0.23**	**0.19**						
B	U	3	0	680	1.97	18.3	0.41	0.3	1.2	0.0		-1.2		
	U	4	0	280	2.68	19.8	0.39	0.6	0.2	-0.2				-0.1
C	U	19	40	100	4.02	26.5	0.64	0.9	0.2		0.0		-0.2	
	U	20	20	320	2.85	22.1	0.63	0.6	2.1	-0.1		-1.9	-0.1	
D	U	15	60	160	1.34	16.8	0.24	0.3	3.4	0.4	0.3	-2.7	-1.3	
	U	16	0	340	1.24	18.3	0.60	0.1	0.6		-0.2	0.0	-0.3	
Avg.	**Period**		**20**	**313**	**2.35**	**20.3**	**0.48**	**0.47**						
Avg.	**Year**		**5**	**78**	**0.59**	**5.1**	**0.12**	**0.12**						

To undo the confounding effects caused by the lodgepole pine mortality, the stems per ha, basal area per ha and volume per ha determined for the dead lodgepole pine given in Table 7 were added to the appropriate columns in Table 5 and the quadratic mean diameter and relative density were recalculated to give values as if no lodgepole pine mortality had occurred[5]. The plot values prior to the 1997 growing season (Table 3) were subtracted from these recalculated values to give Table 8, the growth rates for the 1997 to 2003 growth period, adjusted to offset the lodgepole pine mortality.

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[5] Since the basal area and volume of the dead lodgepole pine trees were based on the 1997 measurements for those trees, no growth was assumed to occur on those trees. Hence, the basal area and volume values for the plots with dead lodgepole pine trees probably underestimate the values that would have been present had no mortality occurred.

Table 5. Summary of plot conditions prior to the 2004 growing season.

Block	Treatment	Plot	Stems/ha	BA (m^2/ha)	Volume[a] (m^3/ha)	QMD (cm)	RD	% Comp. Fd	Pl	Sx	At	Ep	W
B	C1	1	2260	28.7	142.1	12.7	8.0	100.0					
	C1	2	1920	34.1	192.9	15.0	8.8	100.0					
C	C1	21	2160	31.5	222.3	13.6	8.5	63.1	15.1	5.3	0.1	16.4	
	C1	22	2660	31.3	203.6	12.2	8.9	68.3	15.0	4.0		12.7	
D	C1	11	2920	44.4	319.9	13.9	11.9	45.0	3.8	42.7	8.6		
	C1	12	2240	36.3	227.4	14.4	9.6	63.3		36.7			
B	C2	5	1800	25.1	138.0	13.3	6.9	100.0					
	C2	6	1400	29.3	185.6	16.3	7.3	100.0					
C	C2	17	1280	23.7	134.6	15.3	6.0	72.8	13.6	7.1		6.5	
	C2	18	1500	23.1	127.7	14.0	6.2	77.5	6.5	7.4		8.6	
D	C2	13	1400	27.6	162.4	15.9	6.9	82.0	18.0				
	C2	14	1240	26.4	201.1	16.6	6.5	27.7	62.3	10.0			
B	S	7	1880	34.4	185.1	14.0	8.8	100.0					
	S	8	1580	27.8	158.6	14.7	7.2	94.3	5.7				
C	S	23	1720	27.9	191.0	14.4	7.4	98.8	0.7	0.5			
	S	24	1300	25.6	155.6	15.8	6.4	95.5	4.5				
D	S	9	2020	29.2	176.9	13.6	8.0	86.0	14.0				
	S	10	1860	32.2	188.9	14.9	8.4	87.9	12.1				
B	U	3	8380	49.4	242.6	8.7	16.8	100.0					
	U	4	7120	47.1	228.0	9.2	15.5	96.8	3.2				
C	U	19	4960	41.3	207.2	10.3	12.9	96.7		2.8		0.5	
	U	20	4600	40.1	214.6	10.5	12.3	82.2	9.1		2.5	6.1	
D	U	15	4960	41.3	251.3	10.3	12.9	70.5	11.3	4.2	3.1	11.0	
	U	16	3220	36.3	250.7	12.0	10.5	33.6		57.8	2.9	5.8	

The growth values given in Table 8 better reflect the response to the thinning treatments over the 1997 to 2003 growth period than those in Table 6. From Table 8 it can be seen that the net basal area growth was higher on the thinned plots than on the control plots, as was the average increase in quadratic mean dbh and relative density. This is an indication that some of the extra growing space/resources created by the precommercial thinning treatments were still accessible to the residual trees. Not surprisingly, ingrowth was higher on the thinned plots than on the control plots, and mortality was considerably lower. A less clear trend was evident for net volume growth, where the average growth on the control plots exceeded that of Treatments C2 and S.

Average net yearly basal area per ha growth, average yearly ingrowth, and the yearly change in relative density were lower in the 1997 to 2003 period than in the 1993 to 1996 period for all treatments (Table 9). Yearly average quadratic mean dbh growth also decreased in the 1997 to 2003 period for the thinning treatments; however, it increased for the control. The yearly average growth in volume per ha was higher in the most recent period for all treatments, as was mortality.

Table 6. Seven-year growth (1997 to 2003 growing seasons)

Block	Treatment	Plot	Periodic Change						Change in Composition (%)					
			Ingrowth (St./Ha)	Mort. (St./Ha)	BA/ha (m^2/ha)	Volume[a] (m^3/ha)	QMD (cm)	RD	Fd	Pl	Sx	At	Ep	W
B	C1	1	0	0	5.78	43.8	1.3	1.2	0.0					
	C1	2	0	40	4.21	34.4	1.1	0.8	0.0					
C	C1	21	60	280	3.57	68.7	1.4	0.5	3.0	0.5	0.6	-0.2	-3.9	
	C1	22	300	360	5.41	71.1	1.2	1.1	0.9	0.3	-0.1		-1.1	
D	C1	11	0	120	4.68	60.1	1.0	0.8	1.0	-0.4	-0.4	-0.2		
	C1	12	0	40	5.46	58.5	1.3	1.1	1.1		1.1			
Avg.	**Period**		**60**	**140**	**4.84**	**56.1**	**1.21**	**0.92**						
Avg.	**Year**		**9**	**20**	**0.69**	**8.0**	**0.17**	**0.13**						
B	C2	5	0	240	-3.46	-35.7	-0.1	-0.9	22.8	-22.7		-0.1		
	C2	6	0	0	3.94	40.4	1.1	0.8	0.0					
C	C2	17	100	20	5.09	49.4	1.2	1.0	0.7	-0.7	1.0		-1.0	
	C2	18	140	80	4.60	46.7	1.2	1.0	5.4	-4.8	-0.2		-0.2	
D	C2	13	40	60	5.29	49.2	1.8	1.0	1.0	-0.9				
	C2	14	40	80	4.60	57.6	1.8	0.8	2.6	-3.1	0.5			
Avg.	**Period**		**53**	**80**	**3.34**	**34.6**	**1.18**	**0.62**						
Avg.	**Year**		**8**	**11**	**0.48**	**4.9**	**0.17**	**0.09**						
B	S	7	0	60	4.74	40.2	0.1	0.9	0.0					
	S	8	0	100	1.89	12.8	0.7	0.3	9.7	-9.7				
C	S	23	200	200	-2.40	-22.2	-0.6	-0.4	24.6	-22.9	0.2		-1.9	
	S	24	0	120	0.20	3.6	0.7	-0.1	19.8	-19.8				
D	S	9	40	420	0.76	5.8	1.3	-0.1	8.7	-8.7				
	S	10	20	80	5.17	45.8	1.5	1.0	1.0	-1.0				
Avg.	**Period**		**43**	**163**	**1.73**	**14.3**	**0.62**	**0.24**						
Avg.	**Year**		**6**	**23**	**0.25**	**2.0**	**0.09**	**0.03**						
B	U	3	20	1420	3.69	36.5	1.0	0.3	1.0	-1.0				
	U	4	0	840	4.75	41.8	1.0	0.7	0.2	-0.2				
C	U	19	20	500	4.70	54.5	1.0	0.9	1.1		0.1		-1.2	
	U	20	0	580	4.80	62.1	1.2	0.7	2.1	0.0		-1.9	-0.3	
D	U	15	0	440	3.81	54.5	0.9	0.7	2.3	-0.5	0.2	0.0	-1.9	
	U	16	60	840	1.07	37.1	1.4	-0.3	1.7		-1.2	0.0	-0.4	
Avg.	**Period**		**17**	**770**	**3.80**	**47.8**	**1.08**	**0.50**						
Avg.	**Year**		**2**	**110**	**0.54**	**6.8**	**0.15**	**0.07**						

Expressing the changes in the various stand level variables as a proportion of their changes in the control plots allows common changes (e.g., climatic influences, stand development progression) to be controlled between the two periods (Figure 1). Yearly ingrowth rates and relative density increased in the thinned stands relative to those on the control plots, and were higher in the second growth period than in the first period. Growth rates for basal area per ha, volume per ha, and QMD increased in the thinned stands, relative to those on the control plots, and were lower in the second period than in the first period. These trends are reflective of a slowing plot-level response to the precommercial thinning treatments with time.

Table 7. Lodgepole pine mortality in the 1997-2003 growth period.

Block	Treatment	Plot	Measurements Prior to the 2004 Growing Season			Lodgepole Pine Mortality		
			Stems/Ha	BA (m^2/ha)	Volume[a] (m^3/ha)	Stems/Ha	BA (m^2/ha)	Volume[a] (m^3/ha)
B	C1	1	2260	28.7	142.1	0	0	0
	C1	2	1920	34.1	192.9	0	0	0
C	C1	21	2160	31.5	222.3	0	0	0
	C1	22	2660	31.3	203.6	0	0	0
D	C1	11	2920	44.4	319.9	20	0.15	1.18
	C1	12	2240	36.3	227.4	0	0	0
Average						**3.3**	**0.025**	**0.20**
B	C2	5	1800	25.1	138.0	160	7.29	61.89
	C2	6	1400	29.3	185.6	0	0	0
C	C2	17	1280	23.7	134.6	0	0	0
	C2	18	1500	23.1	127.7	20	0.83	5.42
D	C2	13	1400	27.6	162.4	0	0	0
	C2	14	1240	26.4	201.1	0	0	0
Average						**30.0**	**1.353**	**11.21**
B	S	7	1880	34.4	185.1	0	0	0
	S	8	1580	27.8	158.6	40	2.53	24.68
C	S	23	1720	27.9	191.0	120	6.80	71.98
	S	24	1300	25.6	155.6	100	4.87	44.40
D	S	9	2020	29.2	176.9	40	2.98	33.13
	S	10	1860	32.2	188.9	0	0	0
Average						**50.0**	**2.863**	**29.03**
B	U	3	8380	49.4	242.6	0	0	0
	U	4	7120	47.1	228.0	0	0	0
C	U	19	4960	41.3	207.2	0	0	0
	U	20	4600	40.1	214.6	0	0	0
D	U	15	4960	41.3	251.3	20	0.29	1.96
	U	16	3220	36.3	250.7	0	0	0
Average						**3.30**	**0.048**	**0.33**

Summary of the Impacts of the Precommercial Thinning Treatments

A number of general trends can be identified from the plot-level responses to the three different precommercial thinning treatments in this experiment. The direction of many of these responses are consistent with prior expectations, but the potential magnitude of the responses were unknown.

- The plots that received the precommerical thinning treatments averaged higher levels of ingrowth, considerably less mortality, greater basal area per ha growth, larger changes in QMD and higher increases in relative density than did the control plots.
- Average volume per ha growth was similar between the control plots and treatments C2 and S. However, a much larger proportion of the volume growth in the control plots has accumulated on trees that will not become merchantable. If volume growth per ha was expressed in terms of net merchantable volume, the volume growth rates would be considerably higher in the thinning plots than in the control plots.
- Volume per ha growth was consistently the highest (by more than 1 m^3/ha/year) in plots that received treatment C1.

Table 8. Seven-year growth (1997 to 2003 growing seasons) adjusted to offset the impact of lodgepole pine mortality.

			Periodic Change					
Block	Treatment	Plot	Ingrowth (St./Ha)	Mort. (St./Ha)	BA/ha (m^2/ha)	Volume[a] (m^3/ha)	QMD (cm)	RD
B	C1	1	0	0	5.78	43.8	1.3	1.2
	C1	2	0	40	4.21	34.4	1.1	0.8
C	C1	21	60	280	3.57	68.7	1.4	0.5
	C1	22	300	360	5.41	71.1	1.2	1.1
D	C1	11	0	100	4.83	61.3	1.0	0.9
	C1	12	0	40	5.46	58.5	1.3	1.1
Avg.	**Period**		**60**	**137**	**4.88**	**56.3**	**1.22**	**0.95**
Avg.	**Year**		**9**	**20**	**0.70**	**8.0**	**0.17**	**0.14**
B	C2	5	0	80	3.83	26.2	1.2	0.7
	C2	6	0	0	3.94	40.4	1.1	0.7
C	C2	17	100	20	5.09	49.4	1.3	1.1
	C2	18	140	60	5.43	52.1	1.4	1.2
D	C2	13	40	60	5.29	49.2	1.7	1.0
	C2	14	40	80	4.60	57.6	1.7	0.8
Avg.	**Period**		**53**	**50**	**4.70**	**45.8**	**1.40**	**0.92**
Avg.	**Year**		**8**	**7**	**0.67**	**6.5**	**0.20**	**0.13**
B	S	7	0	60	4.74	40.2	1.3	0.9
	S	8	0	60	4.42	37.5	1.4	0.8
C	S	23	200	80	4.40	49.8	0.5	1.0
	S	24	0	20	5.07	48.0	1.6	0.9
D	S	9	40	380	3.74	38.9	1.8	0.4
	S	10	20	80	5.17	45.8	1.5	1.0
Avg.	**Period**		**43**	**113**	**4.59**	**43.4**	**1.35**	**0.83**
Avg.	**Year**		**6**	**16**	**0.66**	**6.2**	**0.19**	**0.12**
B	U	3	20	1420	3.69	36.5	1.0	0.3
	U	4	0	840	4.75	41.8	1.0	0.7
C	U	19	20	500	4.70	54.5	1.0	0.9
	U	20	0	580	4.80	62.1	1.2	0.7
D	U	15	0	420	4.10	56.5	0.9	0.7
	U	16	60	840	1.07	37.1	1.4	-0.3
Avg.	**Period**		**17**	**750**	**3.85**	**48.1**	**1.08**	**0.52**
Avg.	**Year**		**2**	**107**	**0.55**	**6.9**	**0.15**	**0.07**

Table 9. Comparison of the average yearly net growth rates by treatment and growth period (after adjusting for lodgepole pine mortality).

		Average Yearly Change					
Growth Period	Treatment	Ingrowth (St./Ha)	Mort. (St./Ha)	BA/ha (m^2/ha)	Volume[b] (m^3/ha)	QMD (cm)	RD
1993-1996	C1	10.0	19.2	0.88	6.72	0.22	0.19
1997-2003		8.6	19.6	0.70	8.04	0.17	0.14
Average[a]		**9.1**	**19.5**	**0.77**	**7.56**	**0.19**	**0.16**
1993-1996	C2	11.8	5.8	0.83	5.25	0.25	0.18
1997-2003		7.6	7.1	0.67	6.54	0.20	0.13
Average		**9.1**	**6.6**	**0.73**	**6.07**	**0.22**	**0.15**
1993-1996	S	12.5	15.0	0.90	5.80	0.23	0.19
1997-2003		6.1	16.1	0.66	6.20	0.19	0.12
Average		**8.4**	**15.7**	**0.75**	**6.05**	**0.20**	**0.15**
1993-1996	U	5.0	78.2	0.59	5.08	0.12	0.12
1997-2003		2.4	107.1	0.55	6.87	0.15	0.07
Average		**3.3**	**96.6**	**0.56**	**6.22**	**0.14**	**0.09**

[a] The average is weighted by the number of years in each of the growth periods.

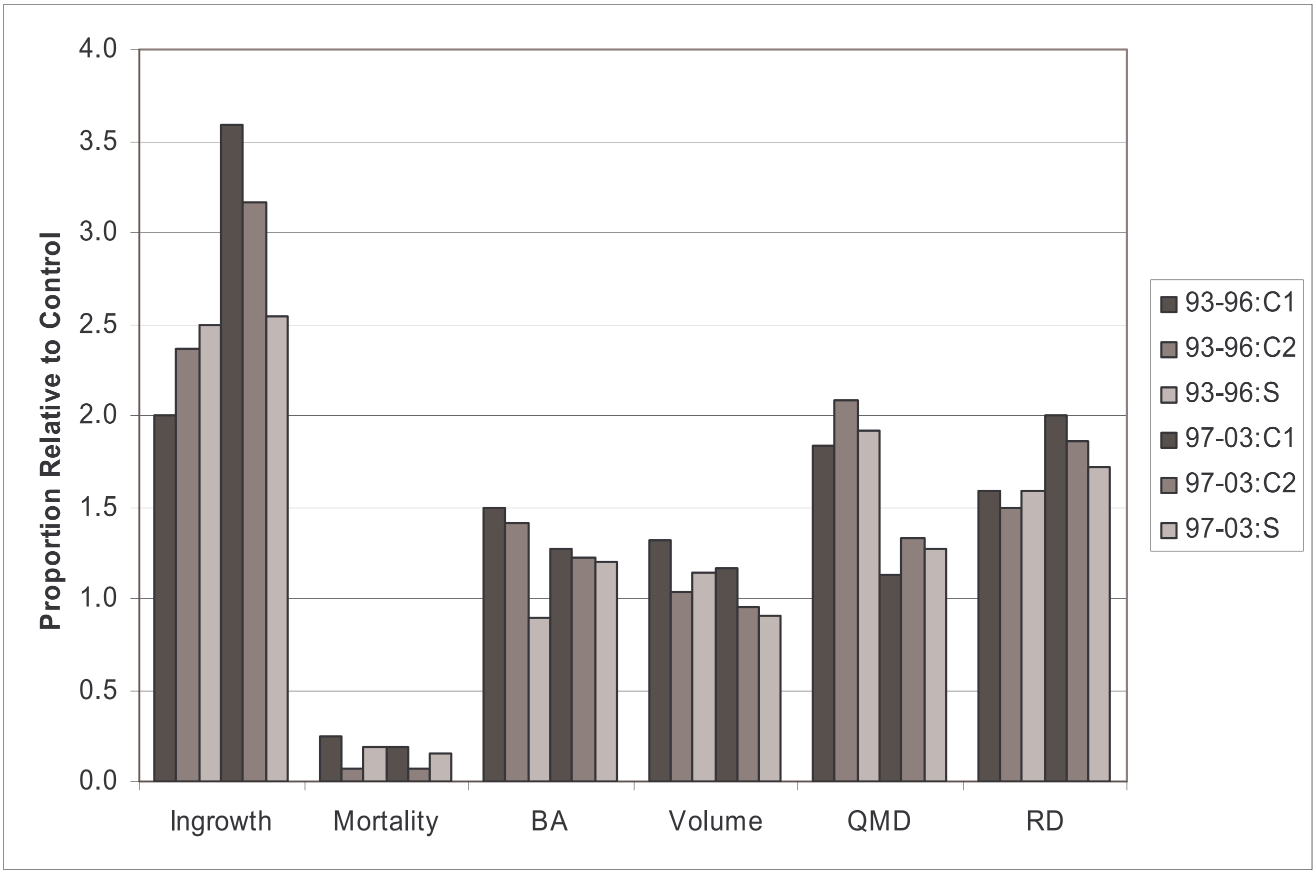

Figure 1. Yearly changes in stand-level variables expressed as a proportion of their yearly changes in the control plots.

- The growth responses to the three precommercial thinning designs tested were similar to one another, with the exception of volume per ha growth. However, as expected the heaviest thinning (Treatment C2) had the least mortality, the largest increase in QMD, and slightly lower basal area per ha growth than the other two thinning treatments.
- Ingrowth is much higher for the thinning treatments than the control, but the rank order of the thinning treatments with respect to ingrowth changed between periods. We suspect this is a result of established regeneration that was less than 1.3 m after thinning responding at different rates according to the differing environments resulting from the thinning treatments.

Implications to Forest Management

Stands of interior Douglas-fir that have been diameter-limit logged in the past are common throughout the lower elevations in the central and southern interior of BC. Many of these stands today are comprised of dense patches of sapling-sized trees and are apparently developing relatively slowly. The results of this experiment demonstrate that any of the precommercial thinning treatments applied will increase the dbh growth of the residual trees in these types of stands, without apparent sacrifice in total volume growth. The "clumpy" treatments, which were novel at the outset of this experiment, performed at least as well as the standard treatment of the day. The 3 m clumped treatment in particular shows promise since it produced the highest volume and basal area growth response of the treatments examined. Increased dbh growth rates will be of benefit to producing both higher quality mule deer winter range and higher value timber in a shorter period of time than relying on the natural dynamics of these types of stands.

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