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Commercial Thinning of Mature Lodgepole Pine to Reduce Susceptibility to Mountain Pine Beetle

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Commercial Thinning of Mature Lodgepole Pine to Reduce Susceptibility to Mountain Pine Beetle

by

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EXECUTIVE SUMMARY

In 1992, the Canadian Forest Service (CFS), the British Columbia Ministry of Forests (BCMOF), Galloway Lumber Company Ltd., Crestbrook Forest Industries Ltd. (CFI), and the Forest Engineering Research Institute of Canada (FERIC) co-operated in a project in the East Kootenay region of southeastern British Columbia to study the effect of commercial thinning and fertilizing of lodgepole pine on attack by mountain pine beetle. With assistance from the BCMOF and the forest companies, CFS located three study sites in the Cranbrook and Invermere Forest Districts.

FERIC monitored harvesting on two of the three study sites: in Galloway Lumber Company's operating area close to Cranbrook, and in CFI's operating area north of Elkford. Three harvesting treatments were compared to an uncut control: a commercial thin leaving trees at approximately 4-m spacing; a commercial thin leaving trees at approximately 5-m spacing; and a clearcut.

At Elkford, conventional hand-falling together with a John Deere 440 line-skidder, a Caterpillar D4H crawler-tractor, and an International Hough Dresser TD8 crawler-tractor were used in the thinning blocks, while conventional hand-falling, Timberjack 380A and 450B line-skidders, and a John Deere 644C loader were used in the clearcut block. At Cranbrook a mechanical system was tested, comprising a Morbark Wolverine three-wheeled chainsaw feller-buncher, a Caterpillar 518 grapple-skidder, and a Steyr processor mounted on a Link Belt 2207 C-series excavator. Both sites were treated in the winter.

The thinning operations were less productive than the clearcuts on both sites. On the Elkford site, harvesting productivity on the 4- and 5-m spacing treatments was similar; however, on the Cranbrook site, harvesting on the 4-m spacing unit was more productive than on the 5-m spacing unit. Piece size appears to be the reason for this difference.

Residual spacing was the primary concern, but leave-trees also had to be free from disease and obvious defects. The Elkford site was reduced from 990 stems/ha to 440 and 360 stems/ha for the 4- and 5-m units respectively. On the Cranbrook site the 4- and 5-m units were reduced from 1100 and 1400 stems/ha to 460 and 350 stems/ha respectively. Damage was low on all treatment units (19–28%), and was generally restricted to trees adjacent to the skid trails, with 70–93% caused during the skidding phase. Better planning of skid-trail location and orientation, increased supervision during falling and skidding, skidding in summer, and designating rub-trees along the skid trails would reduce damage to residual trees.

On the Elkford site the overall harvesting costs (using FERIC-calculated figures) for the 4- and 5-m thinning units were \$18/m^3 and \$16/m^3 respectively, while cost on the clearcut was \$12/m^3. On the Cranbrook site the overall harvesting costs for the 4- and 5-m thinning units were \$11/m^3 and \$12/m^3, while cost on the clearcut was \$8/m^3. These costs were comparable to other thinning operations, and to harvesting operations of low-volume pine stands.

Commercial thinning costs more than clearcutting, but if mountain pine beetle infestation is likely to occur before the block is scheduled for harvest, a thinning operation could decrease the risk of attack and ensure that the stand is available for harvest in the future. Preventing beetle attacks from reaching epidemic proportions, and thereby decreasing the volume of timber lost to beetle infestation, could justify the higher cost of thinning treatments as an investment in the future.

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DISCLAIMER

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TABLE OF CONTENTS

APPENDIX

TABLES

FIGURES

1 INTRODUCTION

Mountain pine beetle (*Dendroctonus ponderosa* Hopk.) causes more destruction in mature pine forests in British Columbia than any other insect (Moody 1992). All native pine are susceptible, but the most severe infestations occur in lodgepole pine (*Pinus contorta* Dougl.), western white pine (*Pinus monticola* Dougl.), and ponderosa pine (*Pinus ponderosa* Laws.). The female adult beetle begins the attack by boring through the outer bark on the main bole and laying eggs in the phloem (Safranyik *et al.* 1974). The release of chemical attractants (pheromones) concentrates many more attacks on the same tree. The attacking beetles also introduce other damaging agents such as blue stain fungi, which kill live cells and prevent the tree from producing pitch to kill and repel the beetles. The larvae feed on the phloem and cambium—physical maceration of the phloem/cambium region and action of the blue stain fungi eventually kill the tree. After passing through four stages of development the larvae pupate, developing into adult beetles in mid- to late summer and infesting more trees Outbreaks usually start in stands of less vigorous, overmature trees, but as more trees are affected the beetle population expands, spreading infestation to healthy trees (British Columbia Ministry of Forests and Lands 1987). In British Columbia, losses from mountain pine beetle infestations amounted to 2.7 million m^3 in 1993, representing about 18% of the annual lodgepole pine harvest (Wood and Van Sickle 1993).

Forest management for timber and other resources is greatly disrupted by beetle attack since management activities and resources must be diverted to the infested stands. Current short-term management techniques to reduce the loss of timber from mountain pine beetle attack include reactive approaches: sanitation logging, single-tree treatments, and the use of trap trees baited with pheromone. Sanitation logging usually involves clear-cutting stands with large infestations, thereby removing the insects. When only a few trees are affected, individual trees or small patches of trees are treated with an insecticide or felled and burned. This treatment is very labour-intensive and multiple treatments over several years may be required for effective control. Early detection and treatment are the keys to reducing loss of wood and maintaining the harvest planning schedule in an effective beetle-management program.

Long-term management strategies are also being developed to reduce the susceptibility of stands to mountain pine beetle (Safranyik *et al.* 1974). Bark beetles prefer older, larger, less vigorous trees. Thinning has been shown to increase the vigour of individual trees, which may increase their resistance to initial attack (Mitchell *et al.* 1983; Waring and Pitman 1985; Amman 1988). Thinning of a stand can also change microclimate on the tree boles, which may interfere with attack and with brood establishment (Amman 1988; Bartos and Amman 1989; Safranyik 1989). Changes in wind speed and in air turbulence within the stand may also disrupt the pheromone communication system of the mountain pine beetle and its flight path during dispersal, preventing mass attacks.

Little research data or information about operational experience with commercial thinning and fertilization in reducing the susceptibility of lodgepole pine to mountain pine beetle attack has been available. Consequently, in 1992 the Canadian Forest Service (CFS), the British Columbia Ministry of Forests (BCMOF), Galloway Lumber Company Ltd., Crestbrook Forest Industries Ltd. (CFI), and the Forest Engineering Research Institute of Canada (FERIC) co-operated in a study in the East Kootenay region in southeastern British Columbia. With assistance from the BCMOF and the forest companies, CFS located three study sites in the Cranbrook and Invermere Forest Districts.

This report documents the productivity and costs of the commercial thinning and the clear-cut harvesting operations on two of the sites. The productivity of the harvesting equipment and operating practices used during the harvesting phase on each treatment are compared, and the operational feasibility of commercial thinning is examined.

2 OBJECTIVES

The Canadian Forest Service established long-term objectives, while FERIC concentrated on short-term objectives aimed at evaluating the harvesting operations.

The objectives of the Canadian Forest Service were:

1. to measure the effectiveness of thinning and fertilization treatments in reducing the susceptibility of mature lodgepole pine stands to infestation by mountain pine beetles;
2. to measure the effects of thinning and fertilization treatments on stand climate, tree vigour, and the growth of residual trees;
3. to assess the performance of advanced, natural, and underplanted conifer regeneration; and
4. to monitor the effect of commercial thinning on species diversity and competition to crop trees in understory vegetation.

All four objectives are for long-term study and will be discussed in future reports of the Canadian Forest Service.

The objectives of FERIC were:

1. to document the productivity and costs of the commercial thinning operations and the clearcut control;
2. to describe and evaluate the equipment and operating practices used during the harvesting phase on each treatment, and to identify operating constraints;
3. to compare the productivity and costs of the different machines used in each harvesting system; and
4. to document the extent and severity of damage to the residual trees resulting from the commercial thinning treatment.

All of FERIC's objectives are addressed in this report.

3 SITE AND STAND DESCRIPTIONS

Stands at suitable sites had to be predominantly lodgepole pine, between 70 and 100 years old, with a density of approximately 1000 stems/ha, and with the trees having a diameter at breast height (dbh) greater than 15 cm. Site requirements were uniform terrain, an elevation lower than 1500 m, and proximity to stands currently infested with beetles but not under epidemic attack. One site was selected near Cranbrook, in Galloway Lumber Company's operating area, and one was selected in Crestbrook Forest Industries Ltd.'s operating area, north of Elkford and one west of Parson (Figure 1).

The Elkford site was at an elevation of 1450 m in the Montane Spruce dry cool biogeoclimatic zone (MSdk) (Braumandl and Curran 1992), with an average slope of 25% and an eastern aspect (Figure 2). The site near Cranbrook was at an elevation of 1320 m, also in the MSdk zone, but had a slope ranging from 0–55% (average of 20%) and a varied aspect.

The stands at Elkford consisted of lodgepole pine dominants with some spruce and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) codominants. The understory was composed of patches of subalpine fir, lodgepole pine and spruce, and several shrub species. Blowdown on the Elkford site had occurred in previous years and had created uneven ground conditions. The Cranbrook site consisted of lodgepole pine dominants, with some western larch and spruce codominants, but little or no understory vegetation and no blowdown (Figure 3).

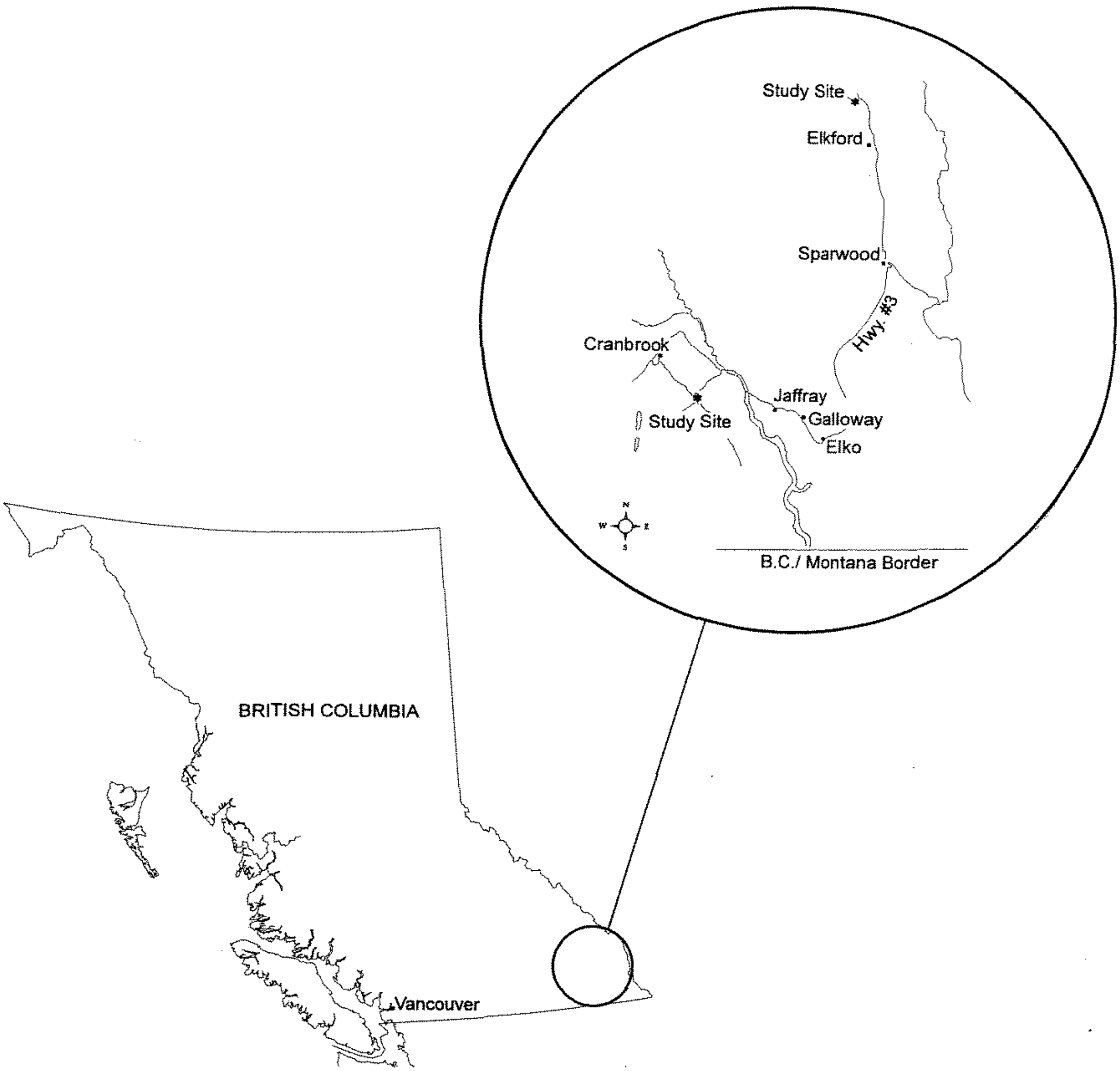

FIGURE 1. Location of the study sites.

FIGURE 2. Elkford site, pre-treatment.

FIGURE 3. Cranbrook site, pre-treatment.

The results from the pre-treatment basal area and density surveys are summarized in Table 1. The control unit was not sampled. The basal areas of the thinning units were higher than those of the clearcut blocks on both sites.

The pre-treatment densities of the merchantable stems at the Elkford site were 1000 stems/ha for the 4- and 5-m spacing units, and 900 stems/ha for the clearcut unit. At the Cranbrook site, the pre-treatment densities were 1100, 1400, and 700 stems/ha for the 4-m, 5-m, and clearcut units respectively. The distribution of trees was patchy on both sites.

The pre-treatment volumes at Elkford (as determined by the licensee's timber cruise) were 270 m^3/ha for the 4- and 5-m spacing units, and 230 m^3/ha for the clearcut unit. At Cranbrook, the pre-treatment volumes were 250 m^3/ha for the 4- and 5-m spacing units, and 290 m^3/ha for the clearcut unit.

TABLE 1. Pre-treatment stand conditions

				Density		
Site	Treatment	Net area treated(ha)	Basal area (m^2/ha)	Average (stems/ha)	Range (stems/ha)	Volume (m^3/ha)
Elkford	4-m	10.5	44.3	1000	500–1700	270
	5-m	22.3	42.0	1000	200–2100	270
	clearcut	27.7	36.2	900	100–1600	230
Cranbrook	4-m	18.7	39.7	1100	400–2800	250
	5-m	15.2	37.0	1400	300–3000	250
	clearcut	18.2	28.0	700	100–1600	290

4 STUDY METHODS

Each study site was divided into three treatment units—two thinning treatments and a conventional clearcut. CFS established two sample plots within each treatment unit for detailed measurements (Figures 4 and 5).

Operational cruises had been done on the study areas, but for all treatment units combined. In contrast, the CFS stand information was detailed, but only on CFS study plots. Therefore, FERIC surveyed the total area to be harvested on both sites to determine the basal area and density of each treatment unit. The control was not sampled. To determine basal area, FERIC made 25 prism sweeps in each treatment unit, with a prism of basal area factor (BAF) 3. To determine the density of the stand before harvest, twenty-five 100-m^2 fixed-radius plots were located in all treatment units, using the same prism cruise plot centres. Trees were classified by species and by merchantability, according to the criteria in the Pre-harvest Silviculture Prescription from the licensee.

Records were kept for crew members' activities for all contractors to obtain shift-level information. Servis recorders were mounted on all harvesting machines of the primary contractors. FERIC also conducted detailed timing (with stopwatches) on the skidding operation, observed tree counts for the fallers,

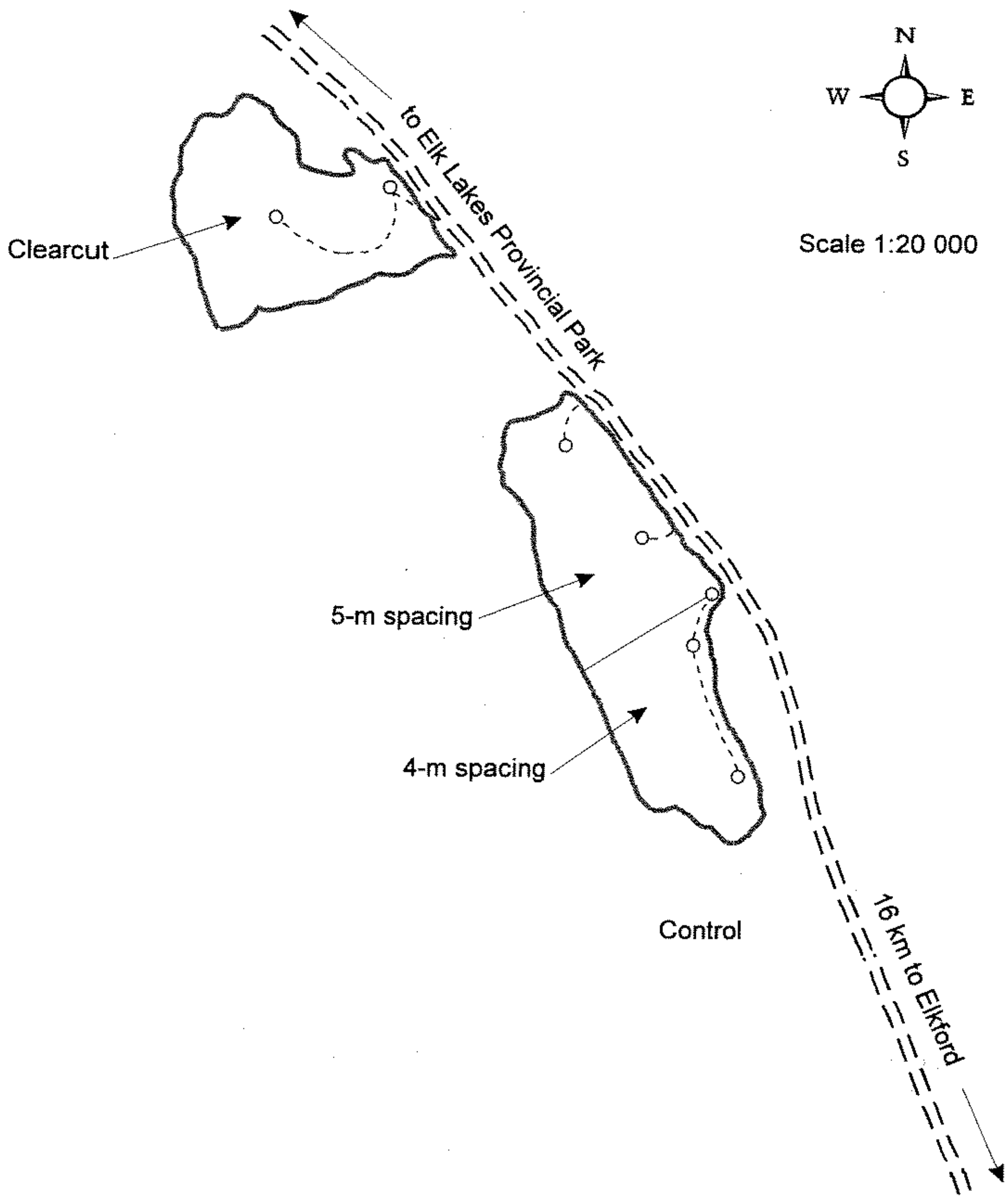

FIGURE 4. Elkford study site.

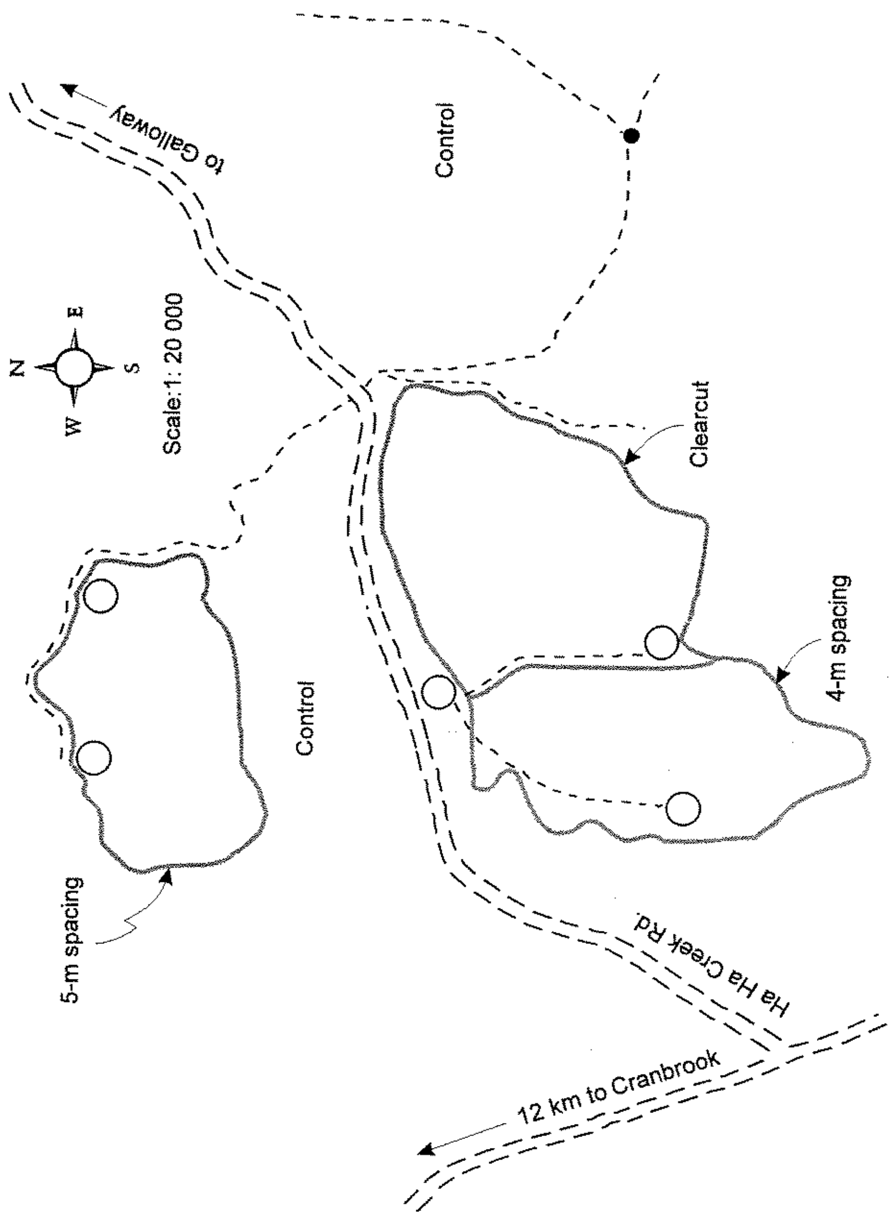

FIGURE 5. Cranbrook study site.

and scaled sample pieces to determine piece-size information. Volumes were obtained from the company weigh-scale receipts and compared to the sample scale done by FERIC.

Following treatment, FERIC re-surveyed the thinned units to determine residual density, basal area, inter-tree spacing, and tree damage. Approximately 25 prism sweeps were done with a BAF 4 prism in each treatment unit. Twenty-five 100-m^2 plots were measured in each thinning unit. Trees were classified by species and diameter class. The diameter of each tree in the plot was measured and stumps within the plots were counted. A procedure designed by CFS was used to categorize damage by severity, area of damage, cause, and height from the base of the tree. There were four classes of severity: Class A, bark scuffed or bruised, but phloem not exposed; Class B, phloem exposed, but wood not gouged; Class C, phloem exposed, and wood gouged less than 1 cm deep; and Class D, phloem exposed, and wood gouged more than 1 cm deep.

Production costs were derived using the standard FERIC costing method (Appendix 1), and were based on IWA rates for workers, and on current purchase price for equipment.

5 TREATMENTS

The Elkford and Cranbrook sites were each divided into three treatment units: a commercial thin, leaving trees at approximately 4-m inter-tree spacing (hereafter referred to as 4-m); a commercial thin, leaving trees at approximately 5-m inter-tree spacing (hereafter referred to as 5-m); and a conventional clearcut (Figures 2 and 3). The Elkford clearcut had no residual trees, but at Cranbrook western larch (*Larix occidentalis* Nutt.) with dbh less than 17.5 cm and greater than 35 cm were left as seed trees. To ensure that the study represented an operational size, the minimum treatment size was 10.5 ha, and the average size was 18.8 ha (Table 1). An uncut control area was designated at each site.

CFS established two 1-ha permanent sample plots within each treatment for detailed measurements and long-term monitoring of microclimate, understory vegetation, regeneration, and crop-tree response to thinning and fertilization. CFS marked the leave-trees within each 1-ha plot and a surrounding 75-m buffer for the fallers, but the trees outside the plots were left for faller selection. Fallers were instructed to remove any marked tree that could not be left for practical or safety reasons and leave another suitable tree in its place to maintain the desired spacing.

In the thinning operation, residual spacing was the primary concern, but leave-trees also had to be free from disease and obvious defects. Lodgepole pine was the preferred leave-species on both sites, but western larch, Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), and Engelmann spruce (*Picea engelmannii* Parry) were acceptable. Residual trees were selected from the dominant or co-dominant class, and damage during the thinning operation was not desirable. Advanced regeneration was to be retained at the Cranbrook site.

6 HARVESTING SYSTEMS AND ORGANIZATION

Developing and supervising the thinning units took twice as long as at the clearcut units at both sites. This included boundary and skid-trail layout, but did not include tree-marking. On all thinning blocks, licensee staff located skid trails at 30-m spacing. On the Elkford site, a CFI contractor constructed skid trails using a Yutani 14D excavator, but on the Cranbrook site the logging contractor cut the pre-marked trails with the feller-buncher.

6.1 Elkford

The contractor began harvesting the 4-m spacing unit at Elkford on December 1, 1992. Trees were manually felled and then skidded to a landing by either a John Deere 440 rubber-tired line-skidder or a Caterpillar D4H crawler-tractor. Bucking and limbing were done on the landing and the skidder and crawler-tractor decked the logs between turns. Self-loading logging trucks hauled the wood to CFI's sawmill at Elko, British Columbia, a distance of 125 km.

The break-in period at this operation was complicated by confusion in skid-trail layout, crew turnover, and harsh weather conditions. Initially, a three-person crew was used—a faller and two skidder operators—but a bucker/faller was added to increase production. Skid trails were originally built at 30-m spacing, but short trails branching off the main trails were added to decrease winching distance, and to increase skidding production while keeping the skidders on a trail. Heavy snowfall, high winds, and cold temperatures before and during the Christmas period made falling conditions difficult. As a result, the primary faller left for another job and a new faller began in January. Harvesting on the 4-m spacing unit was completed in mid-January.

The contractor then moved to the 5-m unit with the same equipment and crew (two skidders with operators, a faller, and a bucker). He added a small Komatsu crawler-tractor and an additional crew member, who felled, decked, and skidded as required. Harvesting on this unit began January 15, 1993, and was completed March 1.

To complete the 5-m unit by breakup, a second contractor was hired by CFI. One landing with its associated area was assigned to him. This contractor used a small International Hough Dresser TD8 crawler-tractor to line-skid and deck. A crew of three felled, skidded, and bucked on the landing, interchanging jobs as needed. This second contractor was active from January 18 to February 19, 1993.

A third contractor harvested the clearcut unit using conventional hand falling and rubber-tired skidders. Skid-trail construction began December 18, 1992, with a Komatsu D65E crawler tractor, and on December 23 a Yutani 14D excavator was brought in to complete the trails. Two fallers, three skidder operators (for two Timberjack 380A line skidders and one Timberjack 450B line skidder), two buckers, and a loader operator (for a John Deere 644C loader) made up the normal crew complement on this operation. The loader sorted the logs into decks of pulpwood and sawlogs, and loaded the trucks. These trucks also hauled to CFI's sawmill at Elko. This operation was completed March 10, 1993.

6.2 Cranbrook

The same contractor harvested all units on the Cranbrook site. This contractor used a Morbark Wolverine chainsaw feller-buncher, a Caterpillar 518 grapple skidder, and a Steyr processor mounted on a Link Belt 2207 C-series excavator. The crew consisted of two feller-buncher operators (because the Wolverine worked double shifts), one processor operator, and one skidder operator. Harvesting began in both the 5-m spacing and the clearcut units on January 26, 1993. The Wolverine felled on the 5-m spacing unit during the day shift and on the clearcut block during the night shift. In the thinning blocks, the feller-buncher cut a skid trail pre-marked at 30 m and bunched stems on the trail behind the machine. After this wood had been skidded, the feller-buncher felled the in-stand trees and bunched them on the trail, covering the area in two passes. In the clearcut the feller-buncher cut along a progressive face, leaving the bunches accessible to the skidder. During the day the skidder and processor worked on the thinned and clearcut blocks as wood became available. Self-loading logging trucks hauled the wood to the Galloway Lumber Co. Ltd. sawmill at Galloway, British Columbia, a distance of 40 km.

Two additional contractors were brought in to harvest portions of the blocks, but in all cases time and volume data were kept separate for each contractor and treatment unit. A second contractor, with a Morbark Wolverine shear feller-buncher and a Timberjack 240A grapple skidder, harvested the portions of the thinning blocks with high densities of small-diameter stems (average butt diameter of 15.4 cm, based on FERIC sample of removed stems). The skidder operator then bucked and decked the logs at the landing. Harvesting on the 4-m spacing unit began February 22, 1993, but a serious setback occurred when the Wolverine shear feller-buncher was destroyed by fire. The small wood in the 4-m unit was then hand felled by the second contractor. Self-loading logging trucks hauled the post-wood to a specialty mill near Jaffray, British Columbia, a distance of 35 km. Harvesting was completed on March 12, 1993 (Figure 6).

The third contractor hand-felled and line-skidded the portions of all three blocks where slopes were too steep for the Wolverine feller-bunchers. The crew consisted of two fallers, three skidder operators with older model Timberjack line skidders, and a bucker on the landing who helped unhook chokers, buck, and deck. Self-loading logging trucks hauled the logs to Galloway.

FIGURE 6. Cranbrook site, post-treatment.

7 RESULTS

7.1 Harvesting

Productivity was affected by the different thinning treatments because the residual trees affected the fallers' ability to fall the trees, maintain even spacing, and place the stems for easy skidding. At the Elkford site the fallers felled 32, 38, and 45 trees/h on the 4-m, 5-m, and clearcut units respectively (Table 2). In the 4-m spacing unit at the Cranbrook site, the feller-buncher operator was able to cut and bunch 101 trees/h, while in the 5-m spacing unit and clearcut unit, the operator felled and bunched 124 and 123 trees/h respectively. Tree placement was very important in both the 4- and 5-m spacing units, affecting falling time, safety, and skidding time.

According to the detailed timing study of the skidders on the Elkford blocks, the skidder operator spent 35–41% of the cycle time pulling line, hooking stems, and winching stems around residual trees (Table 3). Even with the branch trails, long winching distances were required to ensure that the skidders stayed on the trails. On the Elkford site, the average skidding distances for the 4- and 5-m units were 163 and 275 m respectively, while the average skidding distance for the clearcut block was 193 m. On the Cranbrook units, the skidder spent only 10% of the cycle time grappling pre-formed bunches of stems with the grapple-skidder. On the Cranbrook site, the average skidding distances were 125, 137, and 188 m for the 4-m, 5-m, and clearcut units respectively.

TABLE 2. Detailed timing of falling: summary

						Productivity		
Site	Treatment	Productive time (h)	Total delays <10 min (h)	Total delays >10 min (h)	Total time studied (h)	Time/cycle (min)	Trees/cycle (no.)	Trees/h (no.)
Elkford	4-m				0.5			32
	5-m				6.6			38
	clearcut				8.7			45
Cranbrook	4-m	10.9	1.9	1.0	13.8	0.9	1.9	101
	5-m	8.7	0.9	0.6	10.2	1.0	2.2	124
	clearcut	2.5	0.3	0.0	2.8	0.6	1.2	123

Productivity on the Elkford site was least for the 4-m spacing, and greatest for the clearcut (Table 4). More stems and a greater volume per hour were removed in this sequence. As well, the average stem sizes removed from the 4- and 5-m units were 0.41 and 0.49 m^3 respectively. The average size of the removed stems on the clearcut unit was 0.59 m^3. On the Cranbrook site, productivity was lower on the 4-m spacing unit than on the 5-m spacing unit, and highest on the clearcut block.

Productivity may have been lower at the Cranbrook 5-m unit because it was the first unit treated, and because the crew members were adjusting to the spacing. Although more stems were being removed on the 5-m spacing unit than on the 4-m spacing unit, the average stem size and overall harvested volume were smaller. The average volume (piece size) of the removed stems was 0.41 m^3 for the 4-m unit and 0.35 m^3 for the 5-m unit, a difference of 17%. At 0.47 m^3, the average piece size on the clearcut unit was larger than on both the thinning units. All trees on the clearcut units were removed, while on the spacing units the biggest trees were left. This contributed to the larger average piece size on the clearcuts.

The processor handled an average of 133 stems/h for all Cranbrook treatment units. Productivity was not affected by treatment, but by the supply of stems at the landings, which is a function of matching falling and skidding productivity to processor capacity. The processor moved between units at least once each day.

7.2 Post-harvest Assessment

Following harvesting, the thinned treatment units were re-surveyed to determine the basal area, density, and condition of the residual trees. The results from the basal area and density surveys are presented in Table 5. Table 6 illustrates the results from the damage survey.

The target densities of 625 and 400 stems/ha were not expected to be achieved because inter-tree spacing was of greater concern. The resulting inter-tree spacing was considered acceptable by both the BCMOF and the CFS on all treatment units.

In the thinning units, between 28 and 35% of the trees in the plots had at least one patch of damage (Table 6). If Class-A damage (bark scuffed or bruised, but the phloem not exposed) is deemed acceptable and discounted, then amount of damage decreases to 19–28%. If only damage classes B,C, and D are counted, then the Elkford 4- and 5-m units had damage to 23 and 28% of the sampled trees. The sampled trees had averages of 1.9 and 1.6 damage occurrences/tree on the 4- and 5-m units respectively. On the Cranbrook 4- and 5-m units, 19 and 25% of the sampled trees had damage. There were averages of 1.6 and 1.8 damage occurrences/tree for the sampled trees on the 4- and 5-m units respectively.

Class D damage (phloem exposed and wood gouged >1 cm), the most severe, occurred on only 4 and 7% of the sampled trees on the 4- and 5-m units at Elkford, and on 2 and 1% of the sampled trees on the 4- and 5-m units at Cranbrook. All occurrences of damage were measured, but the averages for size of damage for all the damage classes were 214 and 162 cm^2 for the 4- and 5-m spacing units respectively at Elkford, and 188 and 137 cm^2 for the 4- and 5-m spacing units respectively at Cranbrook.

On the Elkford sites, 82 and 93% of the damage was caused by skidding on the 4- and 5-m spacing units respectively (Table 6). Most of the damage occurred along the skid trails and was caused by the skidder or the skidded stems rubbing the residual trees On the Cranbrook site, 71 and 70% of the damage was caused by skidding in the 4- and 5-m spacing units respectively. On both sites the remainder of the damage was caused during the falling operation.

TABLE 3. Detailed timing of skidding: summary

			Time element													
Site	Treatment		Travel empty	Position	Hook/ grapple	Winch	Travel loaded	Unhook	Spread deck	Delays <10 min	Total cycle time	Delays >10 min	Total study duration (min)	Average skidding distance (min)	Average stems per cycle (no.)	Average volume per stem (m^3)
Elkford	4-m	portion of cycle (%)	16	7	37	4	16	8	6	6	100	0.0	280.9	163	11	0.4
		average time (min)	1.9	0.8	4.3	0.5	1.9	0.9	0.7	0.7	11.7					
	5-m	portion of cycle (%)	11	12	31	8	14	5	16	3	100	0.2	589.2	275	11	0.49
		average time (min)	4	4.3	10.9	2.7	4.9	1.9	5.9	1	35.6					
	clearcut	portion of cycle (%)	10	8	29	6	18	8	18	3	100	1.0	1857.0	193	7.3	0.6
		average time (min)	1.8	1.5	5.4	1.1	3.4	1.5	3.4	0.9	19					
Cranbrook	4-m	portion of cycle (%)	26	8	10		50		5	1	100	0.0	91.8	125	8	0.41
		average time (min)	1	0.3	0.4		1.9		0.2	0	3.8					
	5-m	portion of cycle (%)	26	10	11		40		5	8	100	0.5	482.4	137	12	0.35
		average time (min)	1.1	0.4	0.5		1.5		0.4	0.4	4.3					
	clearcut	portion of cycle (%)	24	9	13		44		7	3	100	1.6	512.4	188	8.4	0.47
		average time (min)	1.4	0.5	0.8		2.0		0.4	0.2	5.3					

TABLE 4. Harvesting productivity, by phase

Site	Treatment	Contractor	Phase: Fall (m^3/h)	Skid (m^3/h)	Process (m^3/h)	Buck (m^3/h)	Load (m^3/h)	Volume removed (m^3)	Piece size (m^3/stem)
Elkford	4-m	1	10.5	6.0		17.6		2358	0.41
	5-m	1	11.1	6.4		18.1		4072	0.49
		2	5.1	4.5		8.0		936	0.44
	clearcut	3	14.9	9.9		13.0	46.4	11079	0.59
Cranbrook	4-m	4	16.1	28.9	30.0			1806	0.41
		5	5.1	2.2				177	0.13
		6	12.1	15.1		27.1		907	0.41
	5-m	4	14.2	27.0	27.9			2478	0.35
		5	3.4	3.6				248	0.13
		6	4.7	7.5		15.0		75	0.35
	clearcut	4	25.0	38.3	36.6			4814	0.47

TABLE 5. Post-treatment stand conditions

Site	Treatment	Basal area(m^2/ha)	Density: Average (stems/ha)	Range (stems/ha)
Elkford	4-m	21.8	437	100–800
	5-m	17.8	362	100–700
Cranbrook	4-m	20.0	459	200–800
	5-m	12.6	351	100–800

TABLE 6. Damage incidence[a]

				Portion of damage, by cause (%)			Size				Breakdown of total damage, by damage class			
Site	Treatment	Portion of trees with damage (%)	Portion of trees with B,C, or D damage(%)	Falling	Skidding	Average damage occurrences (no./tree)	Average width (cm)	Average length (cm)	Average area (cm^2)	Height from base of tree (cm)	A (%)	B (%)	C (%)	D (%)
Elkford	4-m	29.8	22.9	18	82	1.9	7.3	25.1	214	85	11	54	31	4
	5-m	33.3	28.4	7	93	1.6	8.1	17.2	162	56	9	49	34	7
Cranbrook	4-m	28.2	19.0	29	71	1.6	7.4	19.5	188	102	21	57	20	2
	5-m	35.4	25.4	30	70	1.8	5.8	15.3	137	105	15	52	32	1

[a] Damage classes

A Surface bruised, phloem not exposed
B Phloem exposed
C Wood gouged, < 1 cm deep
D Wood gouged, > 1 cm deep

8 HARVESTING COSTS

Appendix 1 presents a cost analysis of the equipment of the primary contractors in this study, using the standard FERIC costing formula. These costs are only meant to illustrate the relative cost differences between treatments. They are not the actual costs incurred by the contractor, and they do not include taxes, profit and risk, or supervision.

The equipment chosen for each thinning treatment determined the overall harvesting cost for that treatment. On the Elkford site, the overall harvesting cost was highest for the 4-m treatment unit at $18/m^3$ (Table 7). Next was the 5-m treatment at $16/m^3$, followed by the clearcut at $12/m^3$. On the Cranbrook site, the highest overall harvesting cost was for the 5-m spacing at $12/m^3$. The 4-m spacing unit was $11/m^3$ and the clearcut was $8/m^3$. The lower costs on the Cranbrook site reflect the higher skidding productivity that resulted from the pre-bunching of turns by the feller-buncher.

TABLE 7. Harvesting costs, by phase

Site	Treatment	Felling ($/m^3$)	Skidding ($/m^3$)	Processing ($/m^3$)	Bucking ($/m^3$)	Total System ($/m^3$)
Elkford	4-m	4.41	11.77		1.73	17.91
	5-m	4.15	10.60		1.70	16.45
	clearcut	3.10	6.94		2.32	12.36
Cranbrook	4-m	4.40	2.86	3.77		11.03
	5-m	5.00	3.07	4.05		12.12
	clearcut	2.83	2.16	3.10		8.09

9 DISCUSSION

Inherent differences between the two study sites determined the choice of machines, the productivity and operational costs, and the condition and spacing of the residual trees at each. The weather, physical features of the sites, and harvesting method resulted in lower overall productivities and higher overall costs at the Elkford site.

Development of a block for thinning requires more planning time than a conventional clearcut operation. All portions of the block must be accessible by the trail system, and the trail pattern must allow for skidding without damage to residual trees. Marking all trees would not be practical or necessary on an operational basis. Once a faller had been trained to fall at a desired spacing, the crop trees could be selected rather than pre-marked. Supervision would be required to ensure that the target spacing was met.

Because this was a study, there were some constraints in skid-trail location and spacing at both sites that would not apply in an operational situation. Previous blowdown on the Elkford site created uneven ground conditions, making skidding more difficult. Skidding costs were higher on the thinning units because the skidder operators had to winch and manoeuvre the stems to minimize damage to the residual trees.

The steep slope at Elkford influenced the choice of machines. The blocks here were hand-felled and line-skidded. The stands were composed of pine, spruce, and subalpine fir, all with heavy crowns. Snow accumulations in the crowns reduced the productivity of falling by affecting tree placement. The results show fewer differences between the thinning and clearcut treatments at Cranbrook, because mechanical falling was used, which is less affected by snow and crown densities. The differences in average piece size between the two thinning blocks and the total volume removed explain some of the cost variation between sites.

The terrain at the Cranbrook site was gentle and rolling, except for a gully running through the block where the third contractor was working. The blocks were treated with a feller-buncher and grapple skidder, followed by a processor. The stand was composed primarily of pine, with small crowns, minimal understory, and no pre-treatment blowdown. Because the contract started in January, after a cold spell in December, the working conditions were better than at the Elkford operation.

On the Cranbrook site, the feller-buncher brought the stems to the trails, so the spacing between trails did not affect the skidding operation. The grapple-skidder then skidded bunches of trees to the landing. The Caterpillar 518 grapple-skidder is a very efficient machine when working with a feller-buncher, but the feller-buncher was limited to slopes of less than 30%.

The contractor on the Cranbrook site harvested the clearcut concurrently with the thinning blocks, which increased the utilization and efficiency of the equipment. In an operational context, the grapple skidder would need at least two feller-bunchers to maintain the productivity of the skidder, unless the feller-buncher double-shifted.

Initial stand density was patchy on both sites, but spacing and the condition of the residual trees were judged acceptable by the BCMOF and the licensee foresters at both sites. Damage to residual trees was low at both sites, occurring mostly along skid trails, and caused by the skidder or by trees rubbing during skidding. Damage could be reduced by skidding in the summer, eliminating the need for chains, or by designating rub trees. The feller-buncher felled and transported stems to the trail with minimal damage to residual trees, but on occasion the rear of the machine would rub a tree while manoeuvring. Good operator visibility is necessary when using a feller-buncher in a thinning operation. The operator needs to be able to see the top of the trees and the residual trees around the machine to ensure that damage to residuals is limited and to obtain the desired spacing. The Wolverine feller-buncher in this study had good operator visibility.

Total volume removed, harvesting productivity, and overall costs were strongly influenced by the average size of the stems removed. On average, the Elkford units had larger piece sizes than those at Cranbrook, and both clearcut blocks had larger piece sizes than the thinning blocks. On the clearcuts all trees were harvested, while on the thinning blocks the largest trees were retained.

Total harvesting costs and productivities are comparable to those found by Andersson (1992) for clearcutting low-volume pine stands in the Cariboo Region. The Cariboo study reported mechanical falling productivity of 116–225 stems per productive machine hour (PMH) (25 m^3/PMH), grapple skidding productivity of 44–66 m^3 /PMH, and mechanical processing productivity of 136–227 stems/PMH (26–38 m^3/PMH). Total harvesting costs averaged \$10.48 to \$15.05/m^3.

Holmsen (1990) reported productivities of 15–33 m^3/productive man-hour for falling, and 10–23 m^3/PMH for line-skidding for a commercial thinning operation of lodgepole pine near Kelowna; however, the proportion of residual trees damaged was high (38%).

In a lodgepole pine clearcut south of Fraser Lake, British Columbia, productivities of 203 stems/PMH (76.1 m^3/PMH) for the feller-buncher, 216 stems/PMH (72 m^3/PMH) for the grapple skidder, and 111 stems/PMH (46 m^3/PMH) for the processor at the roadside were reported at an overall cost of \$6.13/m^3 (Mitchell and von der Gönna 1994).

10 CONCLUSIONS

In 1992, CFS, BCMOF, Galloway Lumber Company Ltd., CFI, and FERIC cooperated in a study in the East Kootenay region of southeastern British Columbia to study the effect of commercial thinning and fertilizing lodgepole pine on mountain pine beetle attack. Three sites were located, and FERIC monitored harvesting activities and assessed the residual trees on two of the sites.

The commercial thinning operations were less productive than the clearcutting operations on both sites. Harvesting costs followed the same pattern, with lower costs for the clearcut units than for the thinned units.

On the Elkford site, the overall harvesting costs for the 4- and 5-m thinning units were $\$18/m^3$ and $\$16/m^3$ respectively, while the clearcut was $\$12/m^3$. On the Cranbrook site, the overall harvesting costs for the 4- and 5-m thinning units were $\$11/m^3$ and $\$12/m^3$ respectively, while the clearcut was $\$8/m^3$. These costs were comparable to other thinning operations and to harvesting operations of low-volume pine stands (Andersson 1992).

Residual spacing was acceptable to the BCMOF and licensees, with allowances for uneven stocking in the initial stands. The Elkford site was reduced from 1000 stems/ha to 440 and 360 stems/ha for the 4- and 5-m units respectively. On the Cranbrook site, the 4- and 5-m units were reduced from 1100 and 1400 stems/ha to 460 and 350 stems/ha respectively. Residual basal area was also at acceptable levels: Elkford was reduced from 44 and 42 m^2/ha to 22 and 18 m^2/ha for the 4- and 5-m units respectively, and the Cranbrook site was reduced from 40 and 37 m^2/ha to 20 and 13 m^2/ha for the 4- and 5-m units respectively. Damage incidence was low on all treatment units (19–28%), and was restricted to trees adjacent to the skid trails; moreover, 70–93% was caused during the skidding phase. This could be reduced by better planning of skid-trail location, increased supervision during falling and skidding, skidding in the summer, and by designating rub-trees along the skid trails.

Commercial thinning costs more than clearcutting, but could decrease the risk of attack and ensure that the stand is available for future harvest, if mountain pine beetle infestation is likely. Decreasing the volume of timber lost to beetle infestation by preventing attacks from reaching epidemic proportions could justify the higher cost of thinning treatments as an investment in the future.

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Appendix 1. Machine costs: harvesting equipment[a]

OWNERSHIP COSTS	Wolverine chainsaw, feller-buncher	Caterpillar 518RT grapple skidder	Link Belt excavator, Steyr processor	Timberjack 240A RTLS[c]	John Deere 440 RTLS[c]	Caterpillar D4H line skidder	Komatsu crawler line skidder	Dresser TD8E crawler	John Deere 644E RT loader	Timberjack 380A RTLS[c]	Timberjack 480A RTLS[c]
Total purchase price	172 000	200 000	350 000	130 000	140 000	200 000	100 000	100 000	200 000	120 000	140 000
Expected life (Y) yr	5	5	5	5	5	5	5	5	7	5	5
Expected life (H) h	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000
Scheduled hours per year (h)=(H/Y) h	2 000	2 000	2 000	2 000	2 000	2 000	2 000	2 000	1 429	2 000	2 000
Salvage value as % of P (s) %	20	25	20	25	25	25	25	25	20	25	25
Interest rate (Int) %	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Insurance rate (Ins) %	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Salvage value (S)=((P•s/100) $	34 400	50 000	70 000	32 500	35 000	50 000	25 000	25 000	40 000	30 000	35 000
Average investment (AVI)=((P+S)/2) $	103 200	125 000	210 000	81 250	87 500	125 000	62 500	62 500	120 000	75 000	87 500
Loss in resale value ((P-S)/H) $/h	13.76	15.00	28.00	9.75	10.50	15.00	7.5	7.5	16.00	9.00	10.50
Interest (Int•AVI)/h) $/h	6.19	7.50	12.60	4.88	5.25	7.50	3.75	3.75	10.08	4.50	5.25
Insurance ((Ins•AVI)/h) $/h	1.55	1.88	3.15	1.22	1.31	1.88	0.94	0.94	2.52	1.13	1.31
Total ownership costs (OW) $/h	21.50	24.38	43.75	15.84	17.06	24.38	12.19	12.19	28.60	14.63	17.06
OPERATING COSTS											
Wire rope (wc) $				2 295	2 295	2 295	2 295	2 295		2 295	2 295
Wire rope life (wh) h	0	0	0	1 600	1 600	1 600	1 600	1 600	0	1 600	1 600
Fuel consumption (F) L/h	15.0	16.0	20.0	15.0	15.0	16.0	15.0	15.0	20.0	20.0	20.0
Fuel (fc) $/L	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Lube and oil as % of fuel (fp) %	15	15	15	15	15	15	15	15	15	15	15
Annual tire consumption (t) no.		4.0		4.0	2.0					2.0	2.0
Tire replacement (tc) $		3 500		2 500	2 500					2 500	2 500
Track and undercarriage replacement (Tc) $			30 000			20 000	20 000	20 000			
Track and undercarriage life (Th) h	0	0	10 000	0	0	10 000	10 000	10 000	0	0	0
Annual operating supplies (Oc) $											
Annual repair and maintenance (Rp)[b] $	27 250	32 000	56 000	20 800	22 400	32 000	16 000	16 000	22 857	19 200	22 400
Shift length (sl) h	8.0	9.0	9.0	8.5	8.5	8.5	8.5	8.4	9.9	8.0	8.0
Wages $/h											
Wages, operator $/h	21.61	19.91	20.87	19.91	19.91	19.91	19.91	19.91	20.87	19.91	19.91
Wage benefit loading (WBL) %	35	35	35	35	35	35	35	35	35	35	35
Wire rope (wc/wh) $/h	0.00	0.00	0.00	1.43	1.43	1.43	1.43	1.43	0.00	1.43	1.43
Fuel (F•fc) $/h	5.70	6.08	7.60	5.70	5.70	6.08	5.70	5.70	7.60	7.60	7.60
Lube and oil ((fp/100)•(F•fc)) $/h	0.86	0.91	1.14	0.86	0.86	0.91	0.86	0.86	1.14	1.14	1.14
Tires ((t•tc)/h) $/h	0.00	7.00	0.00	5.00	2.50	0.00	0.00	0.00	0.00	2.50	2.50
Track and undercarriage (Tc/Th) $/h	0.00	0.00	3.00	0.00	0.00	2.00	2.00	2.00	0.00	0.00	0.00
Repair and maintenance (Rp/h) $/h	13.76	16.00	28.00	10.40	11.20	16.00	8.00	8.00	16.00	9.60	11.20
Wages and benefits (W•(1+WBL/100)) $/h	29.17	26.88	28.17	26.88	26.88	26.88	26.88	26.88	28.17	26.88	26.88
Prorated overtime (((1.5•W-W)•(sl-8)•1+WBL/100))/sl)$/h	0.00	1.49	1.57	0.79	0.79	0.79	0.79	0.64	2.70	0.00	0.00
Total operating costs (OP) $/h	49.49	58.36	69.48	51.06	49.36	54.10	45.66	45.51	55.62	49.15	50.75
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	70.99	82.74	113.23	66.90	66.42	78.47	57.85	57.70	84.22	63.78	67.82
Excluding interest $/h	64.80	75.24	100.63	62.03	61.17	70.97	54.10	53.95	74.14	59.28	62.57

[a] These costs are based on FERIC's standard costing methodology for determining machine ownership and operating costs. These costs do not include supervision and overhead, and are not actual costs for the contractor or company studied.

[b] Annual costs for repairs and maintenance were estimated by 80% of purchase price divided by expected life.

[c] RTLS: rubber tired line-skidder.