WOOD HARVESTING

Technical Note TN-293 August 1999

FERIC

TN293

REDUCTION OF TRAIL DENSITY IN A PARTIAL CUT WITH A CUT-TO-LENGTH SYSTEM

S.M. Sambo

Abstract

During 1997/98, the Forest Engineering Research Institute of Canada (FERIC), in cooperation with Millar Western Forest Products Ltd. and Double B Logging of Whitecourt, Alberta studied a partial cutting operation near Swan Hills, Alberta. Two treatments were applied: forwarding trails spaced at 20-m and forwarding trails spaced at 27 m with ghost trails. Machine productivity and cost, soil disturbance and residual tree damage were determined.

Introduction

During the period from November 1997 to January 1998, the Forest Engineering Research Institute of Canada (FERIC), in cooperation with Millar Western Forest Products Ltd. and Double B Logging of Whitecourt, Alberta monitored a partial cutting operation near Swan Hills, Alberta. Millar Western uses the term salvage thinning for partial cuts in mature stands (older than 80 and 90 years for pine and spruce stands, respectively) (Jamieson 1998). During salvage thinning, trees are harvested that would otherwise be lost to natural mortality by the time adjacency requirements are met for the final clearcut harvest. Salvage thinning extends the life of the stand by providing additional growing space and resources to the remaining trees. Any biological response, however, is a bonus not factored directly into the treatment decision (Krygier 1996). The commonly used harvester-forwarder system is appropriate in partial cuts because it is believed to cause minimal site and stand impacts when compared to other ground-based systems.

During the thinning operation, a harvester fells a tree, delimbs it, then cuts logs to a specified length and piles them at the side of the trail. A forwarder then loads the logs and transports them to roadside. The spacing between trails is usually dependent on the reach of the harvester's boom. However, a method developed in Scandinavia and used in eastern Canada increases the spacing between forwarder trails by having the harvester make one or two passes, called ghost trails, between them. When a harvester is on a ghost trail, it uses natural openings to maneuver in the stand and harvests trees to meet the prescription. It piles logs close to the forwarder trail so that the forwarder can reach them.

The objectives of this study were to determine the productivities and costs using both regularly-spaced forwarder trails (control) and more widely-spaced forwarder trails with ghost trails. Soil disturbance and residual tree damage associated with these treatments were also studied.

Site and Stand Descriptions

The study site is located 20 km north of Swan Hills in the Upper Foothills of central Alberta. The slope ranges from level to a 19% grade. Soil textures include clay, sandy clay and clay loam. Soils are moderately well drained except in depressions and lower lying parts of the block. Eight treatment units were distributed throughout the stand (Figure 1).

The average age of the lodgepole pine and black spruce is 107 years, based on Millar Western's cruise, and blowdown had occurred throughout the stand. The

Keywords: Partial cut, Cut-to-length systems, Trail density, Productivity, Costs, Alberta, Timberjack 1270 single-grip harvester, Rottne Rapid EGS harvester, Timberjack 1010 forwarder.

Author: At the time of the study, Stephanie Sambo was a Researcher in the Silvicultural Operations Group at FERIC's Western Division.

INSTITUT CANADIEN DE RECHERCHES EN GÉNIE FORESTIER
FOREST ENGINEERING RESEARCH INSTITUTE OF CANADA
580 boul. Saint-Jean
Pointe-Claire, Québec
Canada H9R 3J9
(514) 694-1140
2601 East Mall
Vancouver, B.C.
Canada V6T 1Z4
(604) 228-1555

PRINTED IN CANADA
 ISSN 0381-7741

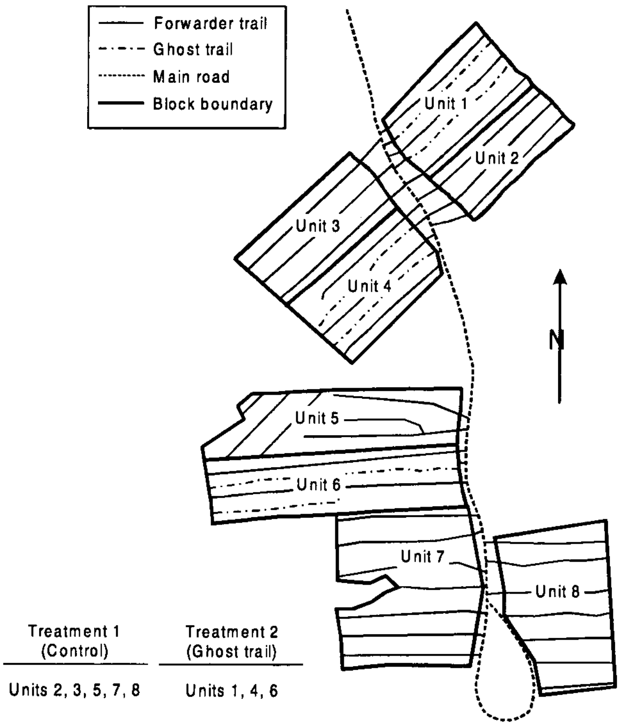

Figure 1. Distribution of trails.

stand had a mean annual increment of 3.4 m³/ha/y. The pre-harvest densities of the treatment units at the north end of the stand (Units 1, 2, 3, 4, and 5) were higher than at the south end (Units 6, 7 and 8) (Table 1). Units 1 through 5 had pre-harvest densities ranging from 1800 to 2333 trees/ha while for Units 6 to 8 densities ranged from 992 to 1367 trees/ha. The pre-harvest gross volume, total volume of the stand minus volume of dead trees, ranged from 278 to 534 m³/ha.

The stand prescription called for removal of approximately 50% of the trees, particularly trees with small diameter, poor form, or damage to the stem. Advanced regeneration was not to be removed.

Machine Descriptions

FERIC monitored two six-wheel-drive single-grip harvesters, a Timberjack 1270 with a Koehring Waterous head and a Rottne Rapid EGS with an EGS-85 head, in addition to a Timberjack 1010 forwarder (Table 2).

Harvesting System and Operating Procedures

Millar Western pre-marked trees at the northern end of the stand (Units 1–4) to train the harvester operators to achieve the required post-harvest density. The operators selected crop trees for the remainder of the study and Millar Western field supervisors checked their selection.

The harvesters began operation in November 1997 and finished in mid-December 1997. To keep the volume cut by each harvester separate for the study purposes, the Timberjack 1270 operated to the east of the main road running through the block (Figure 1), but it also worked in Unit 6, the side designated for the Rottne Rapid. The harvesters cut logs into 3.73 – 5.03 m lengths (with a minimum top diameter of 7 cm) and piled them along the trails. They placed tops and unmerchantable stems on the trail in front of their machines and traveled on the debris mat. Occasionally, the harvesters traveled back to the main road when they reached the end of the trails; otherwise they cut curved trails to join the next one.

In the control treatment, the harvesters cut 4-m wide forwarder trails, marked at 20-m intervals—Millar Western's conventional spacing. In the second treatment, the harvesters cut trails spaced at 27 m and also made one ghost trail between them (Units 1, 4, and 6, Figure 1). The harvesters piled logs from the ghost trails as close to the forwarder trails as possible. However, in areas of dense stocking the machines could not maneuver the logs between the residual trees so some logs were left beside the ghost trails (Figure 2); the forwarder therefore had to travel five of the six designated ghost trails.

Forwarding began in mid-December 1997, when the harvesters had almost completed felling the area. The temperature rose shortly after the forwarder began operating and it stopped work for a few weeks until the ground froze again. During forwarding operations, snow covered the log piles, and the operators searched for logs by dragging the grapple through the snow. Forwarding was completed at the end of January 1998 (Figure 3).

Figure 2. Rottne Rapid harvester.

Table 1. Pre- and Post-Harvest Stand Descriptions

Unit Treatment	Species (by volume) Lodgepole pine (%)	Black spruce (%)	Gross live volume [a] (m³/ha)	Density (% of pre-harvest)	Merchantable trees (no./ha)	Average volume (m³/tree)	Average dbh (cm)	Basal area (m²/ha)
Unit 1/Treatment 2								
Pre-harvest	84	16	422	100	1800	0.23	19	53.5
Harvest [b]	72	28	121	47	850	0.14	-	18.7
Residual Stand	89	11	301	53	950	0.32	22	34.8
Unit 2/Treatment 1								
Pre-harvest	58	42	278	100	2333	0.12	16	46.6
Harvest [b]	55	45	128	54	1267	0.10	-	23.2
Residual Stand	60	40	150	46	1066	0.14	17	23.4
Unit 3/Treatment 1								
Pre-harvest	35	65	287	100	2100	0.14	17	47.0
Harvest [b]	39	61	66	35	733	0.09	-	12.9
Residual Stand	33	67	221	65	1367	0.16	18	34.1
Unit 4/Treatment 2								
Pre-harvest	18	82	382	100	2300	0.17	18	57.6
Harvest [b]	25	75	200	59	1350	0.15	-	31.0
Residual Stand	12	88	182	41	950	0.19	19	26.6
Unit 5/Treatment 1								
Pre-harvest	64	36	314	100	1900	0.17	17	44.5
Harvest [b]	63	37	87	35	673	0.13	-	13.6
Residual Stand	65	35	227	65	1227	0.19	18	30.9
Unit 6/Treatment 2								
Pre-harvest	79	21	500	100	1367	0.37	23	54.2
Harvest [b]	62	38	71	24	325	0.22	-	9.3
Residual Stand	82	18	429	76	1042	0.41	23	44.9
Unit 7/Treatment 1								
Pre-harvest	73	27	435	100	1109	0.39	23	45.7
Harvest [b]	64	36	90	28	309	0.29	-	10.4
Residual Stand	76	24	345	72	800	0.43	24	35.3
Unit 8/Treatment 1								
Pre-harvest	93	7	534	100	992	0.54	25	49.8
Harvest [b]	93	7	113	29	283	0.40	-	11.2
Residual Stand	93	7	421	71	709	0.59	26	38.6

[a] Total gross volume - volume of dead trees. [b] Difference between pre- and post-harvest cruise information.

Table 2. Machine Specifications

	Timberjack 1270 harvester	Rottne Rapid EGS [a]	Timberjack 1010 forwarder
Engine power (kW)	128	125	82
Power transmision	6-wheel-drive, hydrostatic	6-wheel-drive, hydrostatic	6-wheel-drive, power-shift
Head capacity (cm)	60	50	-
Carrying capacity (t)	-	-	12
Approximate weight (kg)	16 410	15 000	13 330
Width (m)	2.7	2.5	2.8
Crane reach (m)	8.8	8.1	6.8
Ground clearance (m)	0.6	0.6	0.7

[a] The Rottne SMV Rapid EGS has replaced the Rottne Rapid EGS.

Figure 3. Timberjack 1010 forwarder loading logs.

Study Methods

Eight treatment units were laid out in the stand. Pre- and post-harvest measurements were taken in 0.1 ha sample plots (eight plots/treatment unit) to determine the density, basal area, species proportion and volume of trees in each treatment unit. Soil disturbance and residual stand damage were also measured in the sample plots.

Productivities and costs for the machines were calculated from shift level and detailed timing data. Shift level timing data were collected from Servis recorders mounted on the Rottne harvester and Timberjack 1010 forwarder. The Servis recorder could not be mounted in the cab of the Timberjack 1270 harvester, so the operator manually recorded his operational and delay times. FERIC researchers conducted detailed timing of machine operations by sampling cycle time using hand-held data loggers. The distances the forwarder traveled were also measured. The harvested volume was calculated from the number of stems harvested in each treatment unit compiled by the harvester's onboard computer, and the difference of the average volume per tree between the pre- and post-harvest cruise. A sample of 50 logs from each unit was measured and the volume of logs forwarded per forwarder load was calculated.

The data collected on the forwarder were incomplete as the shift-level notes did not always indicate when the forwarder was working in the treatment units. When data were missing, an estimate was made based on Servis recorder charts and detailed-timing data. When the forwarder worked the night shift, detailed timing was not done for safety reasons.

A soil disturbance survey, based on Curran and Thompson (1991), was conducted post-harvest to determine the amount of soil disturbed in trails. Two soil disturbance transects radiated from each plot centre at right angles to each other. A tree damage survey designed by the Canadian Forest Service was also conducted post-harvest (Mitchell 1994). Tree damage was divided into four classes: Class A had bruised or scuffed bark; Class B had exposed but not gouged phloem; Class C had phloem gouged less than 1 cm; and Class D had phloem gouged greater than 1 cm. Root damage was classified as either Class E, exposed, or Class T, torn, crushed or broken. The average width and length of the damage were measured as well as the height to the base of the damage. The possible causes of damage were recorded based on location.

Cost estimates were developed using FERIC's costing procedure, which is based on IWA rates and current purchase prices of machinery (Appendix I).

Results

The proportion of trees removed ranged from 24 to 59% (Table 1) while the volume of trees and basal area harvested were between 66 and 200 m^3/ha, and from 9.3 to 31.0 m^2/ha, respectively (Table 1).

Time Distribution and Delays

Harvester. The Timberjack 1270 and Rottne harvesters had mechanical availabilities of 82% and 83%, respectively, with utilization rates of 70% and 79%, respectively. Operator illness and repair were the primary causes of downtime for the Timberjack 1270, while repair and waiting for parts were the primary causes for the Rottne.

The harvesters were timed for 1720 cycles (Table 3) in treatment 1 and 1087 cycles in treatment 2. The total productive time to fall and process a tree in treatment 1 averaged 0.58 min and 0.86 min for high and low stand densities, respectively. In treatment 2, the total productive time to fall and process a tree averaged 0.76 min and 0.69 min at high and low stand densities, respectively. The harvesters' productive times in high density units were less in treatment 1 than treatment 2 (ghost trails) because at higher densities the harvesters had difficulty working on the ghost trails due to the large size of the boom. In low density units, the harvesters' productive times were greater in treatment 1 than treatment 2 (ghost trails) because the harvesters had sufficient room to maneuver between the trees. In treatment 2, the ghost trails didn't have to be straight or wide enough for the forwarders to travel.

Table 3. Productive Time Element Distribution: Harvesters (Treatment 1 (1720 cycles) and Treatment 2 (1087 cycles))

	Treatment 1 Forwarder trails @ 20 m spacing				Treatment 2 Forwarder trials @ 27 m + ghost trials			
	High density		Low density		High density		Low density	
Activity	Average time/ cycle (min)	Observed time (%)	Average time/ cycle (min)	Observed time (%)	Average time/ cycle (min)	Observed time (%)	Average time/ cycle (min)	Observed time (%)
Swing empty	0.15	26	0.19	22	0.19	25	0.17	25
Fell	0.08	14	0.11	13	0.10	13	0.08	12
Process first log	0.08	14	0.11	13	0.11	15	0.09	13
Process other logs	0.07	12	0.17	20	0.07	9	0.09	13
Deck	<0.01	<1	0.01	1	0.00	0	0.00	0
Move	0.06	11	0.12	14	0.11	15	0.10	14
Travel	0.01	2	0.04	5	0.02	2	0.05	7
Clean	0.08	14	0.06	7	0.12	16	0.05	7
Other	0.01	2	0.02	2	0.01	1	0.0	0
Delays <10 min	0.03	5	0.03	3	0.03	4	0.06	9
Total productive time	0.58	100	0.86	100	0.76	100	0.69	100

The harvesters' most time-consuming cycle element was swinging empty (22–26%). The harvesters spent a greater amount of time removing unmerchantable stems in the high-density units than the low-density units.

For both the Timberjack and Rottne harvesters, repairs to the harvesting head's saw chain was the most frequent delay. The most time-consuming delay for the Timberjack harvester was repairing the saw catch and replacing a bolt; for the Rottne harvester, it was talking with the field supervisor to plan operations. Although both operators were experienced with harvesters , they had limited experience in partial cutting.

Forwarder. Mechanical availability and utilization for the Timberjack 1010 forwarder were 77% and 72%, respectively. A temporary cylinder replacement on the forwarder's boom did not have the right hose fittings, so it required frequent repairs. Repairs were also made to the rack extension on the forwarder. Miscellaneous activities included traveling over the trails and packing down the snow as well as cleaning and looking for logs buried beneath the snow.

Detailed timing results for the forwarder are presented in Table 4, based on a total of 27 cycles. Total productive time did not differ greatly between treatments and averaged 32.79 min/turn. The forwarder's average productivity was lower in treatment 1 (control) at 16.9 m^3/PMH than in treatment 2 with ghost trails, at 20.5 and 21.5 m^3/PMH.

The forwarder spent more time loading and moving in the control block than in the treatment with ghost trails. Loading and unloading of logs were the most time-consuming activities in both treatments.

There were more delays in the ghost trail treatments than in the control. Talking with the field supervisors to plan work procedures was the most frequent delay for the forwarder, while the most time-consuming delay was looking for logs buried in the snow.

Productivity and Costs

Harvesters. Productivities for the Timberjack 1270 and the Rottne Rapid EGS harvesters over the study period are presented in Table 5. The productivity in treatment 1 (control) and treatment 2 (ghost trails) were very similar at 12.7 m^3/PMH and 12.6 m^3/PMH, respectively. A study in eastern Canada also reported that wider extraction trail spacing with ghost trails had little impact on the productivity of the single-grip harvesters (Meek 1999).

The harvesters' productivity in the high-density units was less than in low density units. For example, productivity in treatment 1 (control) at high stand densities was 8.1 m^3/PMH while at low stand densities it was 20.4 m^3/PMH. This was due in part to the smaller average tree size in units with high densities. The average tree size was 0.1–0.2 m^3/tree in high density units, half the 0.4–0.5 m^3/tree in the low density units (Table 1), while average dbh was 16–19 cm and 23–25 cm, respectively.

Table 4. Productive Time Element Distribtion: Forwarder

Activity	Treatment 1 Forwarder trails @ 20 m High density	Treatment 2 Forwarder trails @ 27 m + ghost trails High density	Low density	Both treatments overall
Travel empty (min/turn)	2.33	2.00	3.02	2.24
Load (min/turn)	20.18	17.12	13.57	16.91
Move (min/turn)	2.62	1.87	2.05	2.01
Travel loaded (min/turn)	1.12	1.36	3.14	1.66
Unload (min/turn)	7.71	8.53	8.78	8.45
Delays <10 min (min/turn)	0.30	1.50	2.58	1.52
Total productive time (min/turn)	34.26	32.38	33.14	32.79
Cycles sampled (no.)	4	18	5	27
Average pieces/cycle (no.)	141	136	101	130
Average volume/cycle (m^3)	9.7	11.1	11.9	11.0
Average productivity (m^3/PMH)	16.9	20.5	21.5	20.1
Average distance traveled empty (m)	80	74	142	87
Average distance moved during loading (m)	79	17	30	29
Average distance traveled loaded (m)	32	54	112	61

Table 5. Productivity Summary of Shift-Level Study: Harvester and Forwarder

	Productive time (PMH)	Scheduled time (SMH)	Volume (m^3)	Productivity (m^3/PMH)	Productivity (m^3/SMH)
Harvesters					
Treatment 1 Forwarder trails @ 20 m spacing					
High density	36.5	50.0	295.7	8.1	5.9
Low density	21.5	32.5	437.7	20.4	13.5
Overall	58.0	82.5	733.4	12.6	8.9
Treatment 2 Forwarder trails @ 27 m spacing + ghost trails					
High density	28.5	34.5	310.6	10.9	9.0
Low density	7.5	8.3	146.6	19.5	17.7
Overall	36.0	42.8	457.2	12.7	10.7
Forwarder					
Treatment 1 Forwarder trails @ 20m spacing					
High density	23.2	34.5	328.8	14.2	9.5
Low density	29.5	42.8	462.3	15.7	10.8
Overall	52.7	77.3	791.1	15.0	10.2
Treatment 2 Forwarder trails @ 27 m spacing + ghost trials					
High density	15.8	19.8	271.2	17.2	13.7
Low density	13.0	15.6	201.6	15.5	12.9
Overall	28.8	35.4	472.8	16.4	13.4

The harvesters' productivities fall within the range reported in other studies with single-grip harvesters. Harvesters doing commercial thinning near Whitecourt had a reported productivity in commercial thinning averaging 12.1 m^3/PMH (Bulley 1999).

Another study in the same area included seven Rottne harvesters in clearcutting operations and reported productivities ranging from 9.1 to 24.6 m^3/PMH (Andersson 1994). Riverside Forest Products Limited, of Kelowna, B.C. estimates that its Timberjack 1270 harvester has a productivity of 17 m³/h with a piece size of 0.3 m³/tree in a partial cut (Ferguson 1997).

Harvesting costs (Table 6) were derived from the hourly machine rates listed in Appendix I and the shift-level productivities based on scheduled machine hours. The calculated cost of salvage thinning with harvesters in treatment 1 (control) was $16.36/m³, greater than in treatment 2, at $13.61/m³. The cost at high densities was more than double that at low densities, for example in treatment 1, $24.68/m³ compared to $10.79/m³ respectively. With ghost trails, the cost was $16.18/m³ and $8.23/m³ for high and low densities, respectively.

Forwarder. The calculated productivity for the forwarder was less in treatment 1 (control), at 15.0 m³/PMH, than in treatment 2, at 16.4 m³/PMH (Table 5). Costs were $10.20/m³ and $7.76/m³, respectively (Table 6).

A regression equation was developed to determine the relationship between forwarder productivity and two independent variables, number of pieces per load and forwarding distance. A correlation (r^2) value of 0.77 was determined between forwarder productivity and the independent variables. The regression equation and range of values used are presented in Appendix II.

The combined cost of harvesting and forwarding in treatment 1 was $26.56/m³ compared to $21.37/m³ in treatment 2.

Table 6. Cost Summary

	Harvesters [a] ($/m³)	Forwarder ($/m³)	Total ($/m³)
Treatment 1 [b]			
High density	24.68	10.95	35.63
Low density	10.79	9.63	20.42
Overall	16.36	10.20	26.56
Treatment 2 [c]			
High density	16.18	7.59	23.77
Low denstiy	8.23	8.06	16.29
Overall	13.61	7.76	21.37

[a] Using the average of the costs for the two harvesters.
[b] Forwarder trials @ 20 m spacing.
[c] Forwarder trails @ 27 m spacing with ghost trails.

Soil Disturbance

Soil disturbance was less in treatment 1 (control), at 11.2 and 10.3%, than in treatment 2, at 17.2 and 15.0%, for high and low densities, respectively (Table 7). In some areas, the ground was not frozen so ruts developed. The amount of travel may have been higher in treatment 2, since more logs were collected from the trails. Wet soils with a risk of soil compaction may be harvested with less disturbance when frozen.

The results of the trail traverses are shown in Table 8 and Figure 1. In treatment 1 (control) the average forwarder trail width was between 3.2 and 3.5 m and the average trail spacing ranged between 18 and 23 m. In treatment 2 the average forwarder trail width was between 3.3 and 3.4 m and the average forwarder trail spacing ranged between 27 and 28 m. In treatment 1 (control) the area occupied by forwarder trails ranged from 15 to 20% while in treatment 2 it ranged between 12 and 14%, with an additional 9% in ghost trails. In a commercial thinning study with a Timberjack 1270 on Vancouver Island, the area in trails was from 18 to 24% with forwarder trails spaced at 17 m (Hunt 1995).

Residual Tree Damage

Tree injuries can provide entry points for fungal decay organisms, increase susceptibility to insects and diseases, decrease vigor, reduce growth and yield, and seriously degrade wood quality (Allen and White 1997). The stand damage survey results indicate the highest proportion of trees, 41.7%, were damaged in treatment units with ghost trails and high-density

Table 7. Results of Soil Disturbance Survey

Surface type	Treatment 1 Forwarder trails @ 20 m spacing		Treatment 2 Forwarder trails @ 27 m spacing + ghost trails	
	High density (%)	Low density (%)	High density (%)	Low density (%)
Harvester (ghost) trail, <5 cm depth	-	-	0.3	-
Forwarder trail, <5 cm depth	3.0	1.8	4.9	3.1
Forwarder trail, 5-10 cm depth	4.9	2.6	5.2	4.5
Forwarder trail, >10 cm depth	3.2	5.8	6.8	7.4
Gouge	0.1	0.1	-	-
Total disturbed	11.2	10.3	17.2	15.0

Table 8. Trail Traverse Results

Treatment	Unit (no.)	Area (ha)	Average forwarder trail spacing (m)	Average trail width (m)	Area occupied by forwarder trails (%)	Area occupied by ghost trails (%)
1: Forwarder trails @ 20 m spacing						
	2	0.66	18.2	3.5	20.0	-
	3	0.91	21.2	3.4	15.6	-
	5	1.18	18.0	3.4	15.6	-
	7	1.69	22.7	3.2	15.2	-
	8	1.29	21.6	3.4	15.4	-
2: Forwarder trails @ 27 m spacing + ghost trails						
	1	0.93	26.6	3.4	14.2	9.2
	4	0.97	27.6	3.3	12.2	8.6
	6	1.29	26.8	3.4	12.4	9.2

stands (Table 9). During harvesting, the harvesters' long boom hit the residuals when trying to move logs from the ghost trails to the forwarder trails. For an individual damage, the average area was highest in units with ghost trails and low density, at 91.0 cm^2. Across the treatment units, the harvesters caused between 61 and 94% of the damage, while the forwarder caused between 6 and 39%. Up to 6% had unknown cause.

Most of the damage was classified as Class B, phloem exposed. In a study by Allen and White (1997),

Table 9. Residual Tree Damage

	Treatment 1 Forwarder trails @ 20 m spacing		Treatment 2 Forwarder trails @ 27 m spacing + ghost trails	
	High density	Low density	High density	Low density
Total trees with damage (no.)	81	66	53	44
Trees with damage (%)	25.7	33.7	41.7	28.9
Trees with >1 scar (%)	14.3	12.2	22.0	12.5
Harvester caused damage (%)	75	94	61	88
Forwarder caused damage (%)	19	6	39	11
Unknown cause of damage (%)	6	-	-	1
Average damage occurrances (no.tree)	2.1	2.3	2.4	2.1
Average width of damage (cm)	3.6	4.0	4.4	4.3
Average length of damage (cm)	6.1	9.6	7.7	13.4
Average area of damage (cm^2)	24.9	49.5	37.5	91.0
Height from base of tree (cm)	178	193	226	179
Distribution of total damage				
Damage Class A (%) [a]	8	6	3	8
Damage Class B (%) [b]	82	83	77	86
Damage Class C (%) [c]	10	11	19	5
Damage Class D (%) [d]	-	-	1	-
Damage Class E (%) [e]	-	-	-	1

[a] Surface bruised, phloem not exposed.
[b] Phloem exposed
[c] Phloem gouged, <1 cm deep.
[d] Phloem gouged, > 1 cm deep.
[e] Exposed root.

wounds that affected the phloem but did not penetrate the wood had a lower incidence of decay than those in which the wood was gouged. The study also found that injuries to lodgepole pine are unlikely to cause significant levels of decay.

Discussion

Full-sized single-grip harvesters are larger (i.e., tires and harvester heads) and cost more than mini-harvesters. Full-sized cut-to-length machines like the Timberjack 1270B, Valmet 901C or 911, Rocan single-grips, Pikas, Ponsees, and Skogsjans cost $500 000 to $600 000 while smaller harvesters such as the Rottne 2004 and Rocan T cost $280 000 to $350 000 (Jamieson 1997). It is not recommended to use full-sized single-grip harvesters on ghost trails in dense stands due to the high degree of maneuverability required. Small harvesters are able to work on ghost trails because they can meander between the forwarder trails, favouring natural gaps in the stand. Another option suggested by Jamieson (1998) is to use full-sized harvesters to widen the trail width to 4 or 5 m and to increase trail spacing to 25 m. If the harvesters can reach 10 m on either side of the trail, then approximately 5 m would be left untouched in the area between the trails. For operations where more than one entry is expected before final harvest, this method could pose a problem with the middle area going unthinned for two or more entries.

In this study the harvesters spent between 7 and 16% of productive time brushing unmerchantable stems. If the stand had been pre-cleaned motormanually or mechanically, then the cleaning element would be eliminated. This could potentially reduce costs by $150/ha.

Conclusion

FERIC, in cooperation with Millar Western Forest Products Ltd. and Double B Logging, conducted a study near Swan Hills, Alberta to examine the effect of increased forwarder trail spacing and the use of ghost trails in a partial cut using a harvester-forwarder system. FERIC monitored the equipment and assessed the residual trees and soil condition.

Harvester productivity was similar in treatment 1 (control), with 20-m forwarder trail spacing and treatment 2 (ghost trails), with 27-m spacing. The forwarder had a lower productivity in treatment 1 (control) than treatment 2 (ghost trails). The cost of harvesting and forwarding was greater in treatment 1 than treatment 2, at $26.56/m^3$ and $21.37/m^3$, respectively. The cost of thinning at high densities was greater than at low densities, e.g., in treatment 1 $24.68/m^3$ and $10.79/m^3$, respectively. In treatment 2 the cost of harvesting at high densities was $16.18/m^3$ and $8.23/m^3$ at low densities.

Results of the trail traverse show that the average forwarder trail width was between 3.2 and 3.5 m. The percentage of area in forwarder trails ranged from 15 to 20% in treatment 1 and from 12 to 14% in treatment 2 (ghost trails), with an additional 9% in ghost trails.

Soil disturbance in treatment 1 ranged from 10 to 11%, less than in treatment 2, at 15 to 17%. The soil disturbance may have been linked to the wet soil which developed deep ruts due to extra travel to collect logs from the ghost trails. If there is a risk of soil compaction on wet soils, then the soil should be allowed to freeze before harvesting operations begin.

The stand damage survey results indicate the highest proportion of trees, 42%, were damaged in treatment units with ghost trails and high pre-harvest density. The damage was caused when booms and logs hit the residual trees as the harvesters cut the ghost trails and tried to move the logs close to the forwarder trails.

Matching the machine to the site, ensuring trail spacing is appropriate for the reach of the machine, the height of the trees and the length of log cut, are important considerations when ghost trails are used.

References

Allen, E; White, T. 1997. Decay associated with logging injuries in western larch, *Larix occidentalis*, and in lodgepole pine, *Pinus contorta*. Pacific Forestry Centre, Victoria, B.C. Technology Transfer Notes No. 7. 4 pp.

Andersson, B. 1994. Cut-to-length and tree-length harvesting systems in central Alberta: A comparison. FERIC, Vancouver, B.C. Technical Report TR-108. 32 pp.

Bulley, B.D. 1999. Effect of tree size and stand density on harvester and forwarder productivity in commercial thinning. FERIC, Vancouver, B.C. Technical Note TN-XX. 8 pp.

Curran, M.; Thompson, S. 1991. Measuring soil disturbance following timber harvesting. British Columbia Ministry of Forests, Victoria, B.C. Land Management Handbook, Field Guide Insert 5. 25 pp.

Ferguson, R. 1997. Cut-to-Length Experiences. *In*: Using harvest systems to achieve productivity, cost and site impact objectives on steep slopes. Proceedings of FERIC's steep slope harvesting seminar held at Kamloops, BC, October 22-23, 1997. Compiled by Brian Boswell. FERIC, Vancouver, B.C. Special Report SR-126. pp. 52-55.

Hunt, J.A. 1995. Commercial thinning a coastal second-growth forest with a Timberjack cut-to-length system. FERIC, Vancouver, B.C. Technical Note TN-235. 14 pp.

Krygier, R. 1996. Commercial thinning at Millar Western-a new direction, a new philosophy. *In*: Proceedings of a commercial thinning workshop held at Whitecourt, Alberta, Oct. 17-18, 1996. FERIC, Vancouver, Special Report SR-122. pp. 72-75.

Jamieson, S. 1997. It's not the size of your harvester that counts – it's how you use it. Can. For. Ind. Oct. 1997. pp. 22, 24.

Jamieson, S. 1998. Bush combers: salvage logging in Alberta. Can. For. Ind. Jan./Feb. 1998. pp. 14-19, 54.

Meek, P. 1999. Factors affecting equipment productivity in commercial thinning. FERIC, Pointe Claire, Que. Technical Note TN-285. 10 pp.

Mitchell, J. L. 1994. Commercial thinning of mature lodgepole pine to reduce susceptibility to mountain pine beetle. FERIC, Vancouver, B.C. Special Report SR-94. BC Ministry of Forests, Victoria, B.C. FRDA Report 224. 20 pp.

Acknowledgements

The author thanks Steven MacPhail of Millar Western Forest Products Ltd., Lonney Rask, John Briand and Jason Forseille of Double B Logging Ltd. and Grant Nobie formerly of Double B Logging, and Allan Matycio who subcontracted to Double B Logging Ltd. and Brent MacLeod of Rocan Forestry BC Ltd. for their help and cooperation in the study; Craig Evans of FERIC for assistance with data collection; Brian Boswell, Eric Phillips, Brian Bulley and Ernst Stjernberg of FERIC for assistance with data analysis.

Disclaimer

This report is published solely to disseminate information to FERIC members and partners. It is not intended as an endorsement or approval by FERIC of any product or service to the exclusion of others that may be suitable.

Appendix I

Machine Costing[a]

	Timberjack 1270 single-grip harvester	Rottne[b] Rapid EGS single-grip harvester	Timberjack 1010 Forwarder
OWNERSHIP COSTS			
Total purchase price (P) $	611 000	490 000	365 000
Expected life (Y) y	5	5	5
Expected life (H) h	10 000	10 000	10 000
Scheduled hours per year (h) h	2 000	2 000	2 000
Salvage value as % of P (s) %	30	30	30
Interest rate (Int) %	7.0	7.0	7.0
Insurance rate (Ins) %	2	2	2
Salvage value (S) = (P•s/100) $	183 300	147 000	109 500
Average investment (AVI) = ((P+S)/2) $	397 150	318 500	237 250
Loss in resale value ((P-S)/H) $/h	42.77	34.30	25.55
Interest = ((Int•AVI)/h) $/h	13.90	11.15	8.30
Insurance = ((Ins•AVI)/h) $/h	3.97	3.19	2.37
Total ownership costs (OW) $/h	60.64	48.64	36.22
OPERATING COSTS			
Fuel consumption (F) L/h	16.0	30	12.0
Fuel (fc) $/L	0.39	0.39	0.39
Lube and oil cost as % fuel (fp) %	24	18	15
Annual tire consumption (t) no.	0.5	1.0	0.5
Tire replacement (Ti) $	3 190	4 000	3 190
Track & undercarriage replacement(Tc) $	16 000	-	16 000
Track & undercarriage life (Th) h	20 000	-	20 000
Annual repair & maintenance (Rp)=(P/y•0.8) $	94 698	74 560	55 338
Shift length (sl) h	10	10	10
Operator wages (W) $/h	24.29	24.29	22.33
Wage benefit loading (WBL) %	35	35	35
Fuel (F•fc) $/h	6.24	11.70	4.68
Lube & oil ((fp/100)•(F•fc)) $/h	1.50	2.11	0.70
Tires ((t•tc)/h) $/h	0.80	2.00	0.80
Track & undercarriage (Tc/Th) $/h	0.80	-	0.80
Repair & maintenance (Rp/h) $/h	47.35	37.28	27.67
Wages & benefits (W•(1+WBL/100)) $/h	32.79	32.79	30.15
Prorated overtime (((1.5•W-W)•(sl-8)•(1+WBL/100))/sl) $/h	3.28	3.28	3.01
Total operating costs (OP) $/h	92.76	89.16	67.81
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	153.40	137.80	104.03

[a] These costs are based on FERIC's costing methology for determining machine ownership and operating costs. These costs do not include supervision, profit, or overhead, and are not the actual costs incurredby the contractor or company involved in the study.
[b] The Rottne Rapid EGS harvester has been replaced by the Rottne SMV Rapid EGS.

Appendix II

Forwarding Productivity Regression Equation

The following regresion equation (0.05 level of significance) was developed in this study to predict forwarding productivity using pieces per turn and forwarding distance as independent variables:

Time/turn (min)=10.70+[0.14 × (no. pieces per turn))] + [0.01 × (forwarding distance in m)]

$n = 27$ n is the number of observations used in this analysis.

$r^2 = 0.77$ A coefficient of determination (r^2) of 0.77 indicates a good relationship between pieces per turn, forwarding distance and time per turn. A high r^2 value indicates that a large proportion of the variation in y, time per turn, is accounted for by this regression.

S.E.E. = 3.78 The standard error of the estimate (S.E.E.) gives an indication of the spread of the observations around the regression line. Approximately 68% of the observations in the study are within 3.78 min above or below the regression line.

The range of values used in this study to develop the equation were:

	Minimum	Maximum	Average
Time/turn (min)	8.91	44.83	31.27
Pieces/turn (no.)	32	223	130
Forwarding distance (m)	40	450	191