Advantage

NOT Restricted to FERIC Members and Partners

Vol. 2 No. 21 April 2001

Contents

Partial cutting with a Timberjack harvester and forwarder in southern British Columbia

Abstract

Cut-to-length harvesting with a Timberjack harvester and forwarder was studied in patch cut, partial cut, and clearcut harvesting blocks in southern B.C. from 1996 to 1999. The harvesting treatments were prescribed to salvage tree mortality from insect attack and windthrow. This study documented operational logistics, cost and productivity of harvesting, residual tree damage, slash loading, and change in soil surface condition.

Keywords

Harvesting, Cut-to-length, Partial cutting, Patch cutting, Clearcutting, Site disturbance, Soil compaction, Tree damage, Costs, Productivity, Interior British Columbia.

Author

Eric Phillips,
Western Division

Introduction

Since 1993, Riverside Forest Products Limited has been using Timberjack harvester/forwarder mechanical cut-to-length systems in the Okanagan region of southern B.C., particularly in areas with restricted clearcutting. This area has an arid climate, and water quantity and quality are often a concern, requiring cut and leave patterns to meet hydrologic considerations. Generally, the forest is harvested in two or more passes, with cutblocks designed to meet size and green-up requirements. Lodgepole pine stands remaining for second-pass harvest are often overmature, and the timber volume available for the second entry is reduced as insect and disease attack accelerate mortality. Removing portions of the stand in an earlier entry salvages potential mortality and improves stand health.

By protecting the operator within the machine, harvesters eliminate most of the safety concerns associated with conventional handfalling (i.e., motor-manual chainsaw falling) in partial cutting. Also, by limbing and topping at the stump, they avoid accumulations of debris at roadsides and landings and may reduce site impact. However, the equipment is more complex than conventional harvesting systems. Thus, it is costly to operate and may not be viable in all stand conditions. Riverside's operations in the Okanagan presented a good opportunity to examine the application of mechanized cut-to-length systems under several stand conditions and harvesting prescriptions.

FERIC monitored a variety of patch cut and partial cut harvesting treatments and two clearcut blocks for comparison near Kelowna (Figure 1) from 1996 to 1999. The results could be applicable to similar sites and stands throughout the interior of B.C.

Objectives

The objectives of the study were to:

- Determine the overall productivity of the harvesting/forwarding system on a variety of sites and prescriptions, and calculate phase costs.
- Report on the operational factors associated with the harvesting, including post-harvest soil surface condition, residual tree damage, and slash loading.

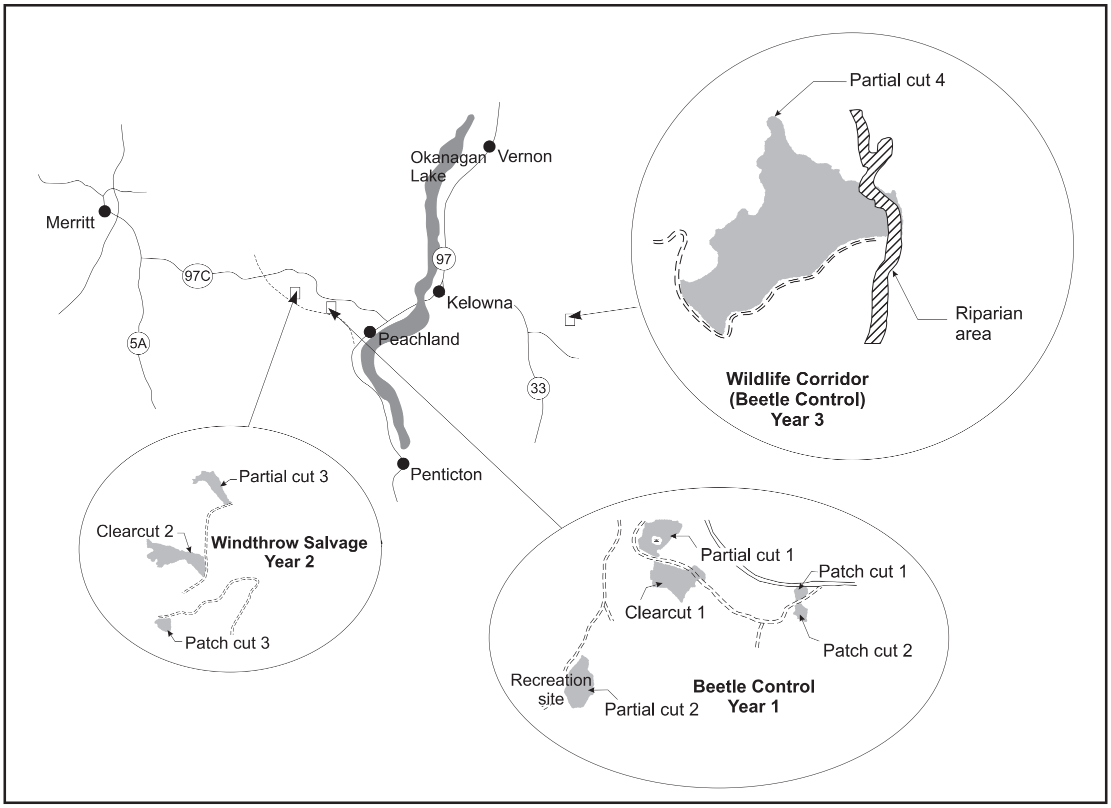


Figure 1. Map of study sites.

Figure 2. Timberjack 1270 harvester.

Figure 3. Timberjack 1010 forwarder.

- Establish plots to describe development of vegetation following harvest.

Machine description

A Timberjack 1270 harvester (Figure 2) and 1010 forwarder (Figure 3) were used to harvest all sites. The machine specifications are given in Appendix I.

Site and stand description

During the first year of the study, the cut-to-length system was partial cutting and clearcutting lodgepole pine stands attacked by mountain pine beetle. Two patch cuts, two partial cuts and one clearcut were selected for study (Patch cuts 1 and 2, Partial cuts 1 and 2, and Clearcut 1, respectively). The two patch cuts were 0.4 ha each, in an immature

Forest Engineering Research Institute of Canada (FERIC)

Find us Online! www.feric.ca

Eastern Division and Head Office
580 boul. St-Jean
Pointe-Claire, QC, H9R 3J9
(514) 694-1140
(514) 694-4351
admin@mtl.feric.ca

Western Division
2601 East Mall
Vancouver, BC, V6T 1Z4
(604) 228-1555
(604) 228-0999
admin@vcr.feric.ca

ISSN 1493-3381

forest stand on relatively gentle terrain. The remaining three blocks were each about 3 ha of mature forest. Partial cut 1 was on gentle terrain, bounded and indented by swampy areas. In contrast, Partial cut 2 was on steeper terrain with benches, and was bounded on two sides by a recreation site. Clearcut 1, studied for comparison, was on gentle terrain.

In the second year of the study, the salvage of windthrown timber to recover fibre, reduce spruce beetle populations, and stabilize standing timber margins was monitored. Three blocks were selected for the study: Partial cut 3 on moderate slopes, Clearcut 2 on steep ground, and Patch cut 3 on gentle terrain.

During the third and final year of monitoring, harvesting was prescribed to control mountain pine beetle outbreaks while retaining the integrity of a wildlife corridor (Partial cut 4).

Appendix II contains a comparison of the harvesting objectives for the study blocks. The stand descriptions for years 1 and 3, based on FERIC's pre-harvest cruises of non-windthrow salvage study blocks, are in Table 1.

Study methods

Pre-harvest surveys

FERIC completed a detailed pre-harvest cruise using circular fixed-radius plots for all blocks, except for windthrown areas where safety and logistics precluded plots. Plots 100–200 m^2 in size were systematically located using a 60-m × 60-m grid. The diameter at breast height (dbh) of all plot trees and a sample of their heights were used to calculate the pre-harvest stand volumes.

Shift-level monitoring

A Servis recorder was used in the first two study blocks to determine scheduled and productive machine hours. However, its use was discontinued after a comparison with the operator's log book showed similar results. FERIC's sample scale of roadside processed logs was used to determine the merchantable harvested volume by treatment unit. This volume, the scheduled machine time, and a calculated hourly machine cost (Appendix III) were then used to produce a comparative

Table 1. Pre-harvest stand description [a]

	Bark beetle control (year 1)					Wildlife corridor (year 3)
	Patch cut 1	Patch cut 2	Partial cut 1	Partial cut 2	Clear-cut 1	Partial cut 4
Area (ha)	0.4	0.4	2.7	3.0	2.8	29.2
Merchantable basal area (m^2/ha)	36	37	32	33	40	45
Live trees (no./ha)	650	600	411	631	534	724
Dead trees (no./ha)	133	117	63	152	141	126
Total trees (no./ha)	783	717	474	783	675	850
Live volume (m^3/ha)	194	158	225	194	264	266
Dead volume (m^3/ha)	44	116	40	48	66	28
Total volume (m^3/ha)	238	274	265	242	330	294
Avg dbh (cm)	23.3	23.9	28.3	22.3	26.7	34.0
Avg tree height (m)	18.9	20.4	23.6	21.5	23.2	24.3
Avg tree volume (m^3)	0.30	0.38	0.56	0.31	0.49	0.35
Non-merchantable snags (no./ha)	0	0	26	9	67	5

[a] Pre- and post-harvest stand and stock tables are available on request.

productivity and cost (Boyd and Novak 1977). These calculated costs are not the actual contractor costs or the costs to the company, but are based on FERIC's standard costing assumptions and operating days per year.

Detailed monitoring

Information about the harvesting phase was obtained with the detailed-timing elements described in Appendix IV. The detailed-timing data were also used to analyze the operational effects of tree size, layout and site conditions on the productivity of the harvesting equipment. Regression analysis was used in some comparisons and to standardize forwarding distance.

Post-harvest monitoring

Post-harvest tree density was measured in all partial cutting treatments. The pre-harvest plot centres were re-established and the number of residual trees recorded. In windthrow blocks, new plots were established. All trees within the post-harvest plots were assessed for logging damage using a Canadian Forest Service (CFS) methodology (Mitchell 1994). Each tree was also assigned a damage code as specified in the Forest Practices Code (FPC) of B.C. (BCMOF and BC Environment 1997) and assessed for acceptability under various management regimes.

The line intersect method of slash sampling was used to determine the amount of slash greater than 1 cm in diameter by decay class (Sutherland 1986; Hopwood 1991). The slash transects originated from the same plot centres used for density, damage and disturbance sampling. In the patch cut blocks, four transects per grid point were used to obtain an adequate sample size.

The site disturbance surveys, based on the methodology described by Curran and Thompson (1991), used point-sampling to determine the soil surface condition every metre along two or four 30-m transects. The soil surface was classified as "disturbed" only if there was evidence that a machine had travelled over the point. Disturbed points were further described according to three criteria: evidence of machine traffic, presence or absence of mineral soil, and depth of disturbance.

Changes in soil density on the most significant disturbance type—multi-pass forwarder trails—were assessed by measuring whole-soil bulk density of paired disturbed and undisturbed samples using a single-probe nuclear moisture/density gauge. Regression analysis was used to look for trends and relationships between the net increase in bulk density and slash depth, distance from landing (representing different number of forwarder passes), and rut depth.

Post-harvest vegetation was catalogued within each sample plot in each partial cut block, by layer and by family. The percentage of cover by layer (moss, herb and grass, and shrub) was estimated. The height, diameter, and any logging damage of advanced regeneration were also measured within each sample plot.

Results and discussion

Shift-level monitoring

To maximize productivity while keeping maintenance costs low and mechanical availability high, the harvester worked two shifts per day with maintenance occurring during an overlap period. The forwarder worked one longer shift per day to keep up with the harvester production. Most repairs were performed by the operators at the harvesting site, with the assistance of an on-site shop trailer.

Figures 4 and 5 illustrate the productivities and costs, respectively, of the nine blocks monitored. Clearcut 1 was used as a baseline against which other treatments could be compared. Although it was a salvage of dead and beetle-attacked trees, the conditions were similar to a clearcut of healthy trees. The terrain was even and gentle, the access was good, and the soil was well-drained. This cutblock gave the lowest overall cost per m^3 at roadside. Patch cut 2 was the costliest because mechanical problems slowed the harvesting, the slope was adverse instead of favourable, and the block was irregularly shaped. Table 2 summarizes the cost and site limitations.

Detailed monitoring

The detailed-timing data for the harvester and forwarder, based on 88 and 164 hours, respectively, are summarized in Figures 6 and 7.[1] Detailed-timing data were not collected for the forwarder in the patch cuts.

The most time-consuming activity for the harvester was processing. This was true for all blocks except for the windthrow Clearcut 2 where "falling" (bucking of the windthrown stem) and processing were about equal. However, there was considerable variation between treatments in processing time. Regression analysis found that over 80% of the variance in combined falling and processing time can be explained by the differences in average tree size (Figure 8). Bulley (1999) and American Pulpwood Association (1999) also found tree size to be the principal variable which affected productivity. The windthrow salvage treatments generally had longer falling times

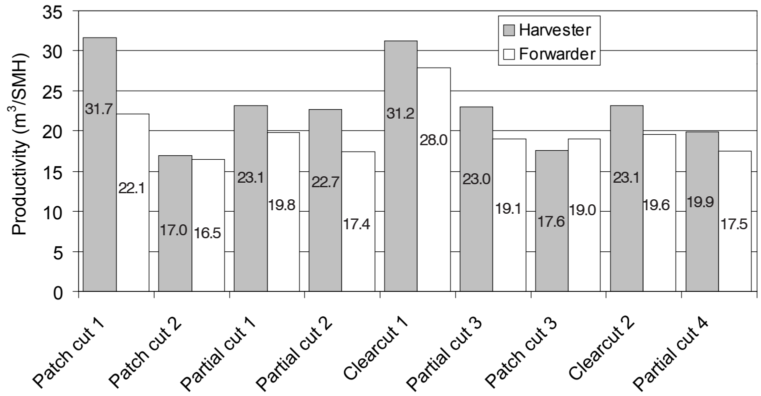


Figure 4. Productivity comparison based on shift-level data.

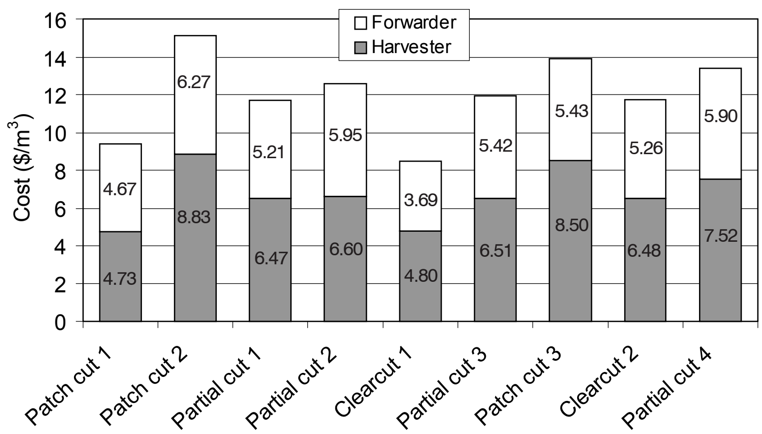


Figure 5. Cost comparison based on shift-level data.

[1] Detailed-timing data summaries and forwarder travel speeds, which were used to derive these figures, are available on request.

Table 2. Cost and site limitations comparison

Treatment	Cost at roadside ($/m³)	Increase from base (%)	Site limitations	CPPA terrain classifications [a]
Clearcut 1	8.49	0	gentle terrain; good access; well drained soil	2.1.1
Patch cut 1	9.39	11	gentle terrain with small wet area	2.1.2
Partial cut 1	11.68	38	gentle terrain, irregularly shaped block fragmented by swamp	3.3.1
Clearcut 2	11.74	38	steep favourable slopes, some adverse; some wet areas; small non-merchantable material; windthrow salvage	3.3.4
Partial cut 3	11.93	41	moderate/steep favourable slopes, wet patches; windthrow salvage	3.3.3
Partial cut 2	12.55	48	steep favourable slope with benches	1.3.3
Partial cut 4	13.42	58	gentle slopes; deep snow	2 [b].2.2
Patch cut 3	13.94	64	gentle slope but steep drop on margin; feathered edge; large non-merchantable material; windthrow salvage	2.2.2
Patch cut 2	15.10	78	gentle adverse slope; mechanical problems slowed harvesting; irregular block boundary	1.3.3

[a] From Mellgren (1980).
[b] The classification does not account for snow.

Figure 6. Harvester productivity comparison based on detailed timing.

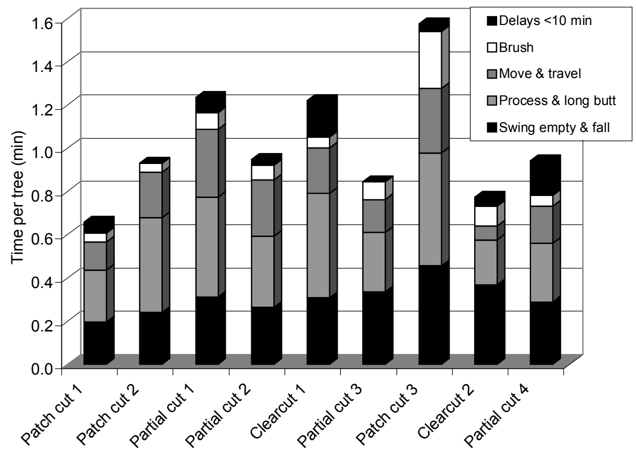


Figure 7. Forwarding time at 150 m standardized distance.

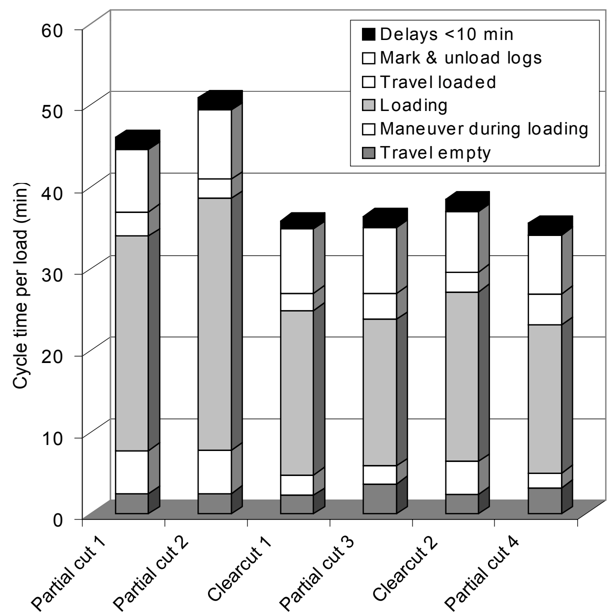
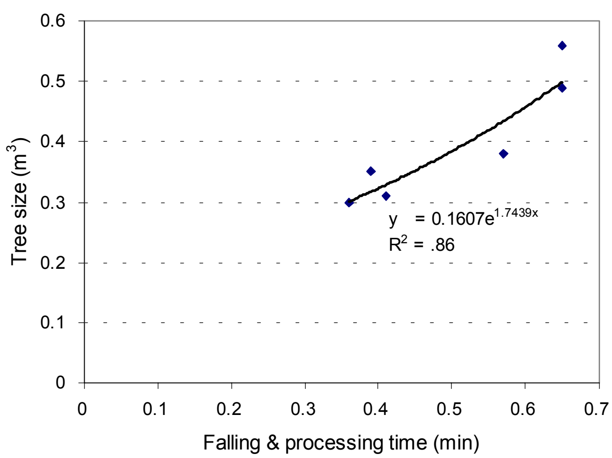


Figure 8. Effect of tree size on combined falling and processing time.



because the crossed stems were difficult to extract from the fallen material.

The largest portion of the forwarder cycle was spent in loading logs. To avoid building new access roads, some blocks had average forwarding distances of almost 300 m. To develop comparable cycle times, travel speed was used to calculate travel times for a prorated distance of 150 m. The longest cycle times were for Partial cuts 1 and 2. Forwarding in Partial cut 1 was probably affected by the swampy terrain, while in Partial cut 2, it was affected by the steep benched terrain and the longer loading time due to small piece size and largest average number of pieces per load.

Tree density

Pre-harvest and post-harvest stand conditions are summarized in Tables 1 and 3.[2] The principal focus of the bark beetle control was to remove all dead or heavily attacked trees and trees which were heavily damaged during harvest, and to leave a well-spaced, windfirm, fully-stocked stand after harvest. The harvesting objectives were accomplished while retaining a stand profile similar to pre-harvest distribution. The post-harvest stand tables will be used to monitor changes in the stand structure over time.

Tree damage

Damage to leave trees is summarized in Table 4 for the four partial cutting treatments. Partial cuts 2 and 4 had similar levels of harvest damage when assessed using both the CFS and FPC assessments. While Partial cut 1 was comparable in terms of both leave trees damaged and scars per tree, it had twice the average area per scar. This resulted in two to three times as many trees not meeting the FPC short-term, long-term and uneven-aged stand management objectives. The principal difference between Partial cut 1 and Partial cuts 2 and 4 was the season of harvest. Scheduling delays for weather and me-

[2] Detailed pre- and post-harvest stand volume and density information are available on request.

Table 3. Post-harvest stand description [a]

	Beetle control (year 1)		Windthrow salvage (year 2)	Wildlife corridor (year 3)
	Partial cut 1	Partial cut 2	Partial cut 3	Partial cut 4
Area (ha)	2.7	3.0	2.8	29.2
Merchantable basal area (m^2/ha)	18	18	23	18
Live trees (no./ha)	264	388	420	145
Dead trees (no./ha)	3	0	15	0
Total trees (no./ha)	267	388	435	415
Live volume (m^3/ha)	149	138	185	127
Dead volume (m^3/ha)	2	0	2	0
Total volume (m^3/ha)	151	138	187	127
Avg dbh (cm)	28.4	23.5	25.3	22.2
Avg tree height (m)	23.4	21.8	23.1	20.8
Avg tree volume (m^3)	0.57	0.36	0.43	0.31
Retention				
Merchantable trees (%)	61	50	n.a.	49
Basal area (%)	56	56	n.a.	39

[a] Summary of trees greater than or equal to 12.5 cm dbh.

chanical repairs meant the harvest of Partial cut 1 did not occur until spring "sap running" conditions, at which time the bark was more susceptible to damage.

Partial cut 3 had the highest number of trees damaged, the greatest number of scars per tree, the largest area per scar, and the greatest number of trees not meeting the FPC leave tree requirements. Damage from falling/processing, forwarding and windthrow could not be individually identified in most blocks. In Partial cut 2, about twice as much damage (23% compared to 13%) was attributed to the harvester than to the forwarder. Tree damage in Partial cut 3 was caused primarily by the original windthrow event and from moving windthrow trees in contact with or adjacent to leave trees (Figure 9) during the salvage operation. However, in the post-harvest surveys, only a small amount of damage (9%) could be attributed with certainty to windthrow. The tree damage survey does not address the potential for long-term snag recruitment for wildlife use.

Slash loading

Slash loading by diameter class and block is summarized in Table 5.[3] Post-harvest slash was not measured in Clearcut 2 or Partial cut 4 because of logistical and scheduling constraints.

There was twice as much small slash (1–5 cm diameter) in the patch cuts and clearcut than in the partial cuts. However, the amount of material greater than 5 cm in diameter was 4 times greater in the

Figure 9. Windthrow salvage block before harvest.

[3] Slash loading, summarized by decay class, is available by request.

Table 4. Leave tree damage incidence

	Beetle control (year 1)		Windthrow salvage (year 2)	Wildlife corridor (year 3)
	Partial cut 1	Partial cut 2	Partial cut 3	Partial cut 4
Trees sampled (no.)	120	139	99	95
CFS damage classifications:				
Total trees with damage (all depths) (%)	42	42	79	44
Trees with phloem exposed or gouged (damage ≥ Class B) (%)	21	35	77	43
Avg scar area (cm^2)	108	59	136	57
Avg scars/damaged tree (no.)	2.4	2.3	3.9	1.9
Avg scar height above ground (m)	1.2	1.3	1.5	1.8
Distribution of damages by depth class				
Class A (surface bruised-phloem not exposed) (%)	20	7	9	28
Class B (phloem exposed) (%)	74	90	78	70
Class C (wood gouged, <1cm deep) (%)	6	2	10	2
Class D (wood gouged, ≥1cm deep) (%)	0	0	2	0
Class E-g (tree stem damaged at ground) (%)	0	0	0	0
Class E-m (main root system) (%)	1	1	0	0
broken top	-	-	-	1
Forest practices code FPC damage criteria by management regime				
Short-term retention (leave trees not meeting “Regime A”) (%)	15	6	34	5
Long-term retention (leave trees not meeting “Regime B”) (%)	13	6	29	3
Uneven-aged management (leave trees not meeting “Regime C”) (%)	12	6	27	3
Special management areas (leave trees not meeting “Regime D”) (%)	3	3	9	2
Season of harvest	spring	early spring	summer	winter

Table 5. Summary of post-harvest slash volume

	Beetle control (year 1)					Windthrow salvage (year 2)	
	Patch cut 1	Patch cut 2	Partial cut 1	Partial cut 2	Clear-cut 1	Partial cut 3	Patch cut 3
1–5 cm diameter (m^3/ha)	28.3	27.1	11.2	13.8	25.9	17.5	24.7
>5 cm diameter (m^3/ha)	48.1	69.1	128.7	135.8	66.0	268.3	430.7
Total (m^3/ha)	76.4	96.2	139.9	149.6	91.9	285.8	455.4
Avg depth (cm)	15.3	21.9	8.5	9.5	14.3	18.1	30.4

windthrow blocks than in the beetle control treatment areas. In Partial cut 3, much of the windthrow material had been dead for a long time, which resulted in high levels of non-merchantable material left in the block. The average diameter of coarse woody debris increased with increasing decay class. The average diameters of fresh sound coarse woody material (Class 1) were consistent between treatment blocks.

The slash in the clearcut and patch cut treatments was piled and the piles were burned the year following harvest, as specified in the Silviculture Prescription, to improve the ease of replanting these areas and to reduce fire hazard. The slash volumes in the beetle control areas were not great enough to impede planting except on some of the trails. The forwarding trail in Patch cut 1, in particular, had a compacted slash depth up to 45 cm after harvest. The windthrow blocks had very high levels of slash loading and probably required treatment, at least on parts of each block (Figure 10). However, this treatment was not completed within the data collection period.

The two blocks with pre-harvest measurements show large volumes (77–121 m^3/ha) of old coarse woody debris prior to harvest. Partial cut 1 and Clearcut 1 were probably both excluded from frequent fires because of terrain—the partial cut by swamps and the clearcut by a large gully. Partial cuts 1 and 3 had some very large (>80 cm diameter) heavily decayed material which represented a large portion of the post-harvest volume.

Site disturbance

Dispersed site disturbance is summarized in Appendix V. Partial cut 4 was not surveyed because the heavy winter snowpack persisted until after the data collection period had ended. Clearcut 2 was also not surveyed because of scheduling conflicts, very high slash loading, and extensive disturbance from windthrow uprooting.

The surface condition of 11–20% of all sites was disturbed in Patch cuts 1 and 2, and Partial cuts 1 and 2 (beetle control blocks). Clearcut 1 and the windthrow salvage blocks (Partial cut 3 and Patch cut 3), had disturbance of 24–28%. Most of the observed surface disturbance was compacted material on the forwarder trails. The humus layers were still intact despite multiple passes by the forwarder. Non-compacted disturbance, primarily from gouges by logs and stumping, is not considered detrimental to tree growth, and may, in fact, increase the regeneration success of some species such as pine. To minimize impact, the harvester processed stems into logs and left slash on the trails, then the forwarder travelled over these slash-covered paths. Bundles of logs were used to prevent ditch-bank and water-bar erosion by the forwarder. The same strategy was used to prevent rutting while crossing dry and damp seepage areas. In two cases, rubber mats were used on top of these bundles. All bundles were removed on the last forwarder crossing. Chains and bogie tracks were used year-round on both the harvester and forwarder to maintain traction. The single-pass harvester trails were seldom visible, but defined harvester trails accounted for 0.6% of the whole area or 3.8% of the compacted disturbance.

Whole-soil bulk density was sampled in seven of the treatment blocks. The paired disturbed/undisturbed samples (Figure 11) were taken at regular intervals on the main forwarding trails. Clearcut 2 had sufficient lengths of two trail classes to allow comparison. The main, heavy use trail ran from the landing to the back corner of this long, narrow block ("forwarder: heavy use" category in Appendix V), while the secondary multi-pass trails were short, steep trails at right angles to the main trail.

Figure 10. Slash loading on windthrow Clearcut 2.

Figure 11. Paired disturbed and undisturbed sampling.

A summary of the average net increase in bulk density from undisturbed to disturbed is shown in Table 6. Patch cut 2, Clearcut 1 and Partial cut 3 all had increases of 20% or more in the 0–20 cm soil layer, with the greatest increase in Clearcut 1. The remaining blocks had increases of less than 15%. However, when the 0–15 cm bulk densities are compared with error bars of +/- 1 standard deviation (Figure 12), some of these increases in average density do not fall outside of the natural variability of the undisturbed soil (Partial cut 2 and Patch cut 3). The high coarse fragment proportion of 45% in Partial cut 2 resulted in high undisturbed soil bulk-density variability and minimal rutting, even on the steeper, heavy-use trail sections. It is not known why the greatest increase in bulk density was in Clearcut 1. This block was harvested in dry weather, had a high coarse fragment content, relatively short parallel trails and gentle, favourable slopes. However, the lack of impact in Clearcut 2 on either the main or secondary trails may have been related to the high slash loading up to 32 cm on the main trail (Figure 10), and slash loading and soil coarse fraction on the secondary trails.

In other studies on soil density, Meek (1996) found a relationship between soil density, number of skidder passes and rut depth, while McMahon and Evanson (1994) found the depth of the protective layer of slash on the trail reduced the soil impact proportional to its depth. To test these relationships, depth of slash, depth of rut, and distance from the landing were recorded for each sample-pair location, and regression

Table 6. Summary of change in bulk density

	Beetle control (year 1)				Windthrow salvage (year 2)			
							Clearcut 2	
	Patch cut 2	Partial cut 1	Partial cut 2	Clear-cut 1	Partial cut 3	Patch cut 3	main trail	secondary trail
0–5 cm (%)	14	9	6	15	25	11	10	14
0–10 cm (%)	15	13	10	21	29	12	8	15
0–15 cm (%)	18	15	10	25	23	14	13	16
0–20 cm (%)	20	13	14	28	20	13	12	13
Rut depth (cm)	7.1	4.3	6.4	4.5	7.9	4.1	9.6	5.8
Slash depth (cm)	10.3	4.4	1.5	6.0	12.3	12.2	10.4	4.7
Humus soil depth (L, F & H layers) (cm)	9.2	4.4	4.0	5.9	10.1	8.9	8.5	5.8
Paired samples (no.)	12	61	31	32	26	26	29	31

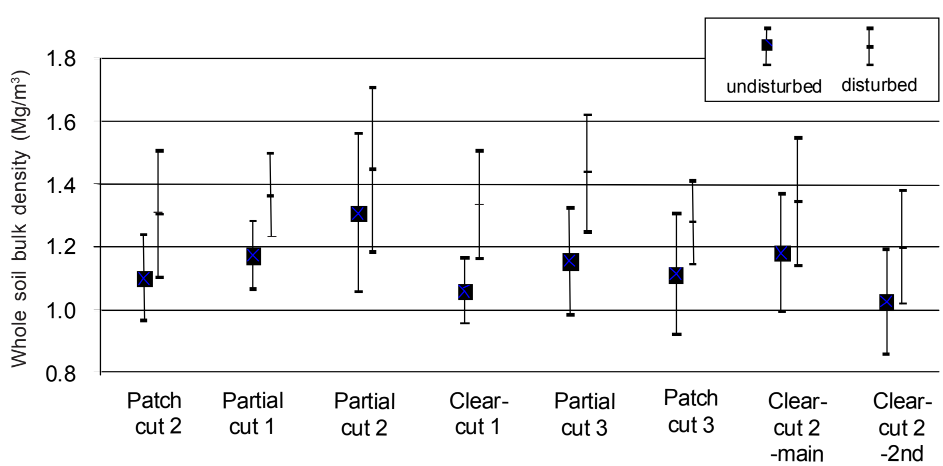


Figure 12. Comparison of disturbed and undisturbed bulk density.

analysis was used to compare the net soil density increase to these three factors. In each case, there was a poor relationship with the density increase, with less than 15% of the variance related to either slash depth, rut depth or distance from the landing. A confounding factor was that much of the original slash loading was displaced during the forwarding. Also, some of the rutting seemed to have resulted from compaction while other rutting was at least partly due to soil displacement, especially on the steeper hills.

Vegetation monitoring

Long-term vegetation monitoring plots were established to make it possible to monitor the response of advanced regeneration and vegetation succession.

Conclusions

This report identifies some of the cost, productivity and site impact implications of using the cut-to-length harvesting system as a tool to manage mature forests. This tool can provide harvest-scheduling flexibility by delaying mature forest disintegration.

The cut-to-length system studied successfully harvested portions of stands and windthrown trees to meet a variety of silvicultural objectives.

The nine harvesting blocks had a variety of terrain and operational limiting factors. The cut-to-length system adapted to each of these constraints but with greater cost to roadside, at 11–78% more than the base cost of clearcutting under favourable conditions.

Soil surface condition site impacts were confined primarily to forwarding trails and represent from 11 to 28% of the area sampled. The significance of these impacts varies depending on the sensitivity of the soils to compaction. The lowest levels of disturbance were recorded in the patch and partial cut blocks.

The greatest amount of leave tree damage was recorded in the windthrow partial cut block. Harvesting when the sap was running in the spring increased the area damaged per tree by two to three times. Slash loading varied between treatments but was highest in the windthrow salvage blocks. In all blocks, the cut-to-length harvesting system met the silvicultural objectives without compromising worker safety.

Implementation

- Although the cut-to-length system can operate in a variety of adverse conditions, consideration should be given to limiting factors such as steep slopes, layout, windthrow, partial cutting and deep snow, and the effect they have on harvester and forwarder productivity.
- Mechanical availability has to be maintained at as high a level as possible to keep costs low. A shift of less than 8 h allowed the harvester operator to avoid operating the machine while fatigued and allowed time for daily maintenance and inspection.
- The cut-to-length system is applicable for salvage and partial cutting where visual constraints or terrain limitations require winding trails with tight radius corners. It is also suitable for areas where roadside landings are either not possible or not desired.
- Where possible, do not schedule partial cut harvesting during spring sap flow.
- On sites sensitive to compaction, pay special attention to trail density and placement. Processing logs on the trails and leaving limbs and tops as a mat provide some soil protection. Use of log bundles and/or rubber mats when crossing wet areas is also a useful strategy. However, reduction of trail density through the use of techniques such as "ghost trails" may also be desirable for very sensitive sites.
- Year-round chain use on the harvester and forwarder was effective in maintaining traction on steep slopes and preventing rutting.

References

American Pulpwood Association. 1999. The effect of removal intensity and tree size on harvesting cost and profitability. APA Technical Release #99-R-3. 2 pp.

Boyd, J.H.; Novak, W.P. 1977. A method of comparing logging system and machine concepts. FERIC, Pointe Claire, Que. Special Report No. 2. 11 pp.

British Columbia Ministry of Forests (BCMOF); BC Environment. 1997. Forest practices code of British Columbia: Tree wounding and decay guidebook. 19 pp.

Bulley, B. 1999. Effect of tree size and stand density on harvester and forwarder productivity in commercial thinning. FERIC, Vancouver, B.C. Technical Note 292. 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.

Gingras, J.-F.; Godin, A. 1996. A comparison of feller-bunchers and harvesters for harvesting blowdown timber. FERIC, Point Claire, Que. 8 pp.

Hopwood, D. 1991. Principles and practices of new forestry. British Columbia Ministry of Forests, Research Branch, Victoria, B.C. BC Land Management Report 71. 95 pp.

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

McMahon, S.; Evanson, T. 1994. The effect of slash cover in reducing soil compaction resulting from vehicle passage. LIRO, Rotorua, NZ. Vol. 19, No. 1. 8 pp.

Meek. P. 1996. Effects of skidder traffic on two types of forest soil. FERIC, Pointe Claire, Que. Technical Report 117. 12 pp.

Mellgren, P.G. 1980. Terrain classification for Canadian forestry. Canadian Pulp and Paper Association, Montreal, Que. 13 pp.

Mitchell, J.L. 1994. Commercial thinning of mature lodgepole pine to reduce susceptibility to mountain pine beetle. Canadian Forest Service in association with British Columbia Ministry of Forests, Victoria, B.C. FRDA Report 224 and FERIC Report SR-94. 20 pp.

Sutherland, B.J. 1986. Standard assessment procedures for evaluating silvicultural equipment: a handbook. Canadian Forest Service, Sault Ste. Marie, Ont. 96 pp.

Acknowledgements

This project would not have been possible without the cooperation of Riverside Forest Products Limited (Kelowna) and Brookside Select Logging. FERIC employees Ingrid Hedin, Craig Evans, Brian Bulley, and students Eric Long, Nini Long, Chris Turner, Stefan Meining, Manuela Bacher and Tiffany Sinclair also provided valuable assistance during the project. The project received funding from Forest Renewal BC.

Appendix I

Machine specifications

Harvester

Model:	1270 single-grip Timberjack harvester
Power:	114 kW (153 hp) Perkins 1006-GT
Head:	FMG 762B felling/processing head 60-cm felling capacity 43-cm delimbing capacity
Power train:	6-wheel drive hydrostatic with optional wheel bogie tracks
Weight:	16 410 kg
Boom reach:	8.23 m

Forwarder

Model:	1010 Timberjack 11-t forwarder
Power:	82 kW (110 hp) Perkins 1004
Loader:	2 100 kg lift at 3 m (min. reach) 950 kg lift at 6.8 m (max. reach)
Power train:	6-wheel drive powershift with optional wheel bogie tracks
Weight:	11 690 kg

Appendix II

Harvesting objectives matrix

	Study block								
Objective	Patch cut 1	Patch cut 2	Patch cut 3	Clear-cut 1	Clear-cut 2	Partial cut 1	Partial cut 2	Partial cut 3	Partial cut 4
Fibre recovery from dead stems	X	X	X	X	X	X	X	X	X
Mountain pine beetle control	X	X		X		X	X		X
Spruce beetle control			X		X			X	
Windthrow control			X		X			X	
Minimize visual impact							X		
Maintain recreational use							X		
Maintain wildlife use									X
Harvest in area with wet soil						X		X	
Harvest on steep terrain					X		X	X	
Increase harvest schedule flexibility	X	X	X	X	X	X	X	X	X
Maintain worker safety	X	X	X	X	X	X	X	X	X

Appendix III

Cost analysis for Timberjack harvester and forwarder [a]

	Harvester 1270	Forwarder 1010
OWNERSHIP COSTS		
Total purchase price (P) $	611 000	365 000
Expected life (Y) y	5	5
Expected life (H) h	10 000	10 000
Scheduled hours per year (h)=(H/Y) h	2 000	2 000
Salvage value as % of P (s) %	30	30
Interest rate (Int) %	7	7
Insurance rate (Ins) %	2	2
Salvage value (S)=(s•P) $	183 300	109 500
Average investment (AVI)=((P+s)/2) $	397 150	237 250
Loss in resale value ((P-S)/H) $/h	42.77	25.55
Interest=((Int•AVI)/h) $/h	13.90	8.30
Insurance=((Ins•AVI)/h) $/h	3.97	2.37
Total ownership costs (OW) $/h	60.64	36.22
OPERATING COSTS		
Fuel consumption (F) L/h	16	12
Fuel cost (fc) $/L	0.39	0.39
Lube and oil as % of fuel cost (fp) %	24	15
Annual tire consumption (t) no.	0.5	0.5
Tire replacement (tc) $	3 150	3 150
Track replacement (Tc) $	16 000	16 000
Track life (Th) h	20 000	20 000
Annual repair & maintenance (Rp)=((P-(Tc•6))/y•0.8) $	94 736	55 376
Shift length (sl) h	10	10
Operator wages $/h	21.78	21.78
Wage benefit loading (WBL)%	35	35
Fuel (F•fc) $/h	6.24	4.68
Lube and oil cost ((fp/100)•(F•fc)) $/h	1.50	0.70
Tires ((t•tc)/h) $/h	0.79	0.79
Track (Tc/Th) $/h	0.80	0.80
Repair and maintenance cost (Rp/h) $/h	47.37	27.69
Wages and benefits (W•(1+WBL)) $/h	29.40	29.40
Prorated overtime (((1.5•W-W)•(sl-8)•(1+WBL))/sl) $/h	2.94	2.94
Total operating costs (OP) $/h	89.03	67.00
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	149.67	103.22
TOTAL OWNERSHIP AND OPERATING COSTS ((OW+OP)/machine utilization) $/PMH		
at 86% utilization [b]	174.04	120.03
at 75% utilization [c]	199.57	137.63

[a] Performed in 1997, and based on FERIC's methodology for determining machine ownership and operating costs. These costs do not include supervision, profit, or overhead, and are not the actual costs incurred by the contractor or company studied.

[b] Based on utilization observed in Partial cut 4.

[c] Based on Hunt (1995).

Appendix IV

Description of detailed timing elements

Harvester:	**Description**
Swing empty	Starts when the boom starts to swing and ends at the start of falling.
Fall	Starts at the end of swing empty and ends when the tree is horizontal.
Process	Starts at the end of fall and ends when the last log has been processed.
Long butt	Starts at the end of fall or process and is the time to remove a non-merchantable log end.
Deck	Starts at the end of process and is the time spent moving or re-piling log decks.
Move (during falling)	Starts at the end of any function and is the time the machine is maneuvering to another tree.
Travel	Starts at the end of process or deck and is the moving time to travel to the start of a new falling face.
Brush	Starts at the end of any function and is the time to clear underbrush.
Delays	Starts at the end of any productive function (delays>10 minutes are excluded).

Forwarder:	**Description**
Travel empty	Starts at the end of unload or delay and is the time to travel to the first loading site.
Maneuver during loading	Starts at the end of loading or travel empty and is the time to maneuver between loading piles.
Loading	Starts at the end of travel empty and continues until maneuver, travel loaded or a delay starts.
Travel loaded	Starts at the end of loading and is the time to travel fully loaded to the roadside unloading deck.
Mark	Starts at the end of travel loaded or unload and is the time to stamp the logs with the timber mark.
Unload	Starts at the end of travel loaded, mark or delay and ends when the load has been decked at roadside.
Delays	Starts at the end of any productive function (delays >10 minutes are excluded).

Appendix V

Post-harvest soil surface condition

	Bark beetle control (year 1)										Windthrow salvage (year 2)			
	Patch cut 1		Patch cut 2		Partial cut 1		Partial cut 2		Clearcut 1		Partial cut 3		Patch cut 3	
	Total area (%)	Average depth (cm)	Total area (%)	Average depth (cm)	Total area (%)	Average depth (cm)	Total area (%)	Average depth (cm)	Total area (%)	Average depth (cm)	Total area (%)	Average depth (cm)	Total area (%)	Average depth (cm)
Undisturbed	82.8		84.6		80.2		88.6		71.8		73.5		76.1	
Disturbance (by surface condition)														
Humus-compacted	15.0	6.9	14.3	6.5	14.1	3.9	8.0	3.3	26.2	4.0	19.1	6.7	21.6	3.5
Mineral-compacted	-	-	0.6	8.0	4.0	5.1	1.4	5.6	1.0	9.0	4.1	13.7	-	-
Other (non-conpacted)	2.2	-	0.5	-	1.7	-	2.0	-	1.0	-	3.3	-	2.3	-
Non-logging (windthrow) [a]	-	-	-	-	-	-	-	-	-	-	7.8	-	7.1	-
Disturbance (by cause)														
Harvester (all)	0.7	2.0	2.3	3.5	0.1	2.0	-	-	0.6	3.0	0.3	10.0	-	-
Forwarder														
Single pass	3.6	3.6	-	-	3.8	3.0	4.9	3.4	8.1	3.9	0.8	4.7	9.0	2.8
Two passes	-	-	-	-	1.3	3.4	-	-	-	-	22.2	6.6	-	-
Heavy use	12.2	8.1	12.5	7.1	13.5	4.1	4.5	3.9	18.7	4.5	2.4	10.3	14.6	4.1
Stumping	-	-	-	-	0.9	5.3	0.4	50.0	0.2	10.0	0.8	11.7	0.3	15.0
Log gouge	0.7	2.0	0.6	5.0	0.2	4.0	1.6	3.6	0.6	3.3	-	-	-	-
Windthrow [a]	-	-	-	-	-	-	-	-	-	-	7.8	2.3	7.1	26.2
Sample size	139	-	175	-	1 039	-	507	-	515	-	383	-	229	-

[a] Windthrow site disturbance is not included in the logging disturbance calculation.