TRIAL OF A DOUBLE-DRUM FLAIL DELIMBER/DEBARKER PROCESSING SMALL-DIAMETER FROZEN TIMBER: PHASE I

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DISCLAIMER

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ABSTRACT

This report discusses the results of a four-week flail trial that was undertaken in 1989 to determine the production ability of a chain-flail delimber/debarker processing frozen small-diameter timber at a satellite location in central Alberta. An objective of the field trial was to maintain bark content at 1%, or less, on a green-weight basis. The delimbed and debarked logs were chipped with a portable chipper and samples of the chips produced were analyzed for bark content, size distribution, and moisture content. The trial also included assessing the production of a ring debarker processing small-diameter frozen sawlogs at a sawmill, and the chipping of these frozen logs in the portable chipper. Delimbed, small-diameter, lodgepole-pine, pulpwood logs; spruce-pine tops; western red cedar slabs and logs; and fire-killed, delimbed, spruce-pine timber were also processed through the system. The report gives bark content, productivity, and cost information determined by the field trial.

Keywords: Chain flail, delimber/debarker, multi-stem; satellite chipping; portable chipping; small diameter; black spruce; white spruce, lodgepole pine; aspen; bark content

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INTRODUCTION

The primary objective of the trial was:

- To establish the production volumes and costs of using a portable chain-flail delimber/debarker and chipper system to process frozen small-diameter trees while attempting to maintain a bark content of 1% or less on a green-weight basis.

Secondary objectives were to:

- Identify and discuss conditions involved in running satellite debarking and chipping operations.
- Determine if chips produced during the trial could be upgraded by the PAPRIFER process.
- Undertake pulping trials on chip samples.

Information relating to pulping and chip upgrading will be presented in a separate report. This report will be prepared by FERIC and PAPRICAN and published through Forestry Canada as a Canada/Alberta FRDA report; the PAPRICAN laboratory analysis is currently underway.

During the trial, a test was undertaken to compare logs debarked with a flail debarker to those debarked with a ring debarker. In addition, a series of tests were undertaken to determine the effectiveness of the chain flail in removing bark and rot from decadent western red cedar, and bark and charcoal from fire-killed spruce-pine timber. The results of these tests are presented in Appendix I.

Satellite whole-log debarking and chipping operations in Alberta could supplement pulp-mill chip supplies and, in some circumstances, replace woodroom installations at pulp mills. Both options are of interest to the Alberta forest industry, which is currently expanding and constructing new operations in the northern part of the province. Some of the timber in these new operating areas consists of small-diameter black spruce, lodgepole pine, black poplar, and aspen not suitable for sawlogs. These trees could be processed into chips at satellite whole-log chipping operations.

An economic feasibility study undertaken by MacIntosh and Sinclair in 1988 indicated that economical debarking and chipping of small-diameter logs could be achieved using a debarker that had multiple-stem processing capability. They estimated production rates and costs but cautioned that none of the multiple-stem debarkers had operated on small-diameter frozen logs. MacIntosh and Sinclair recommended that field trials be undertaken to prove or disprove their estimates for processing frozen small-diameter logs. Consequently, this four-week field trial was undertaken in February-March 1989 with the financial support of Forestry Canada and Alberta Forestry, Lands and Wildlife through a Canada/Alberta FRDA contract.

The use of a chain flail in satellite chipping operations offers several potential benefits. Logging costs are reduced by eliminating the need to delimb with single-stem delimbing equipment. Stagnant, low-volume, small-diameter stands that are uneconomic to harvest and process conventionally may become economic with flail "multi-stem" delimbing/debarking. These stands could then be replaced with more vigorous stands, thereby increasing AAC calculations.

STUDY METHODS

For the flail and chipper trials, a detailed diary was maintained and Servis recorders were mounted on the loader, flail, and chipper to provide shift-level information on a daily basis. Work sampling techniques were applied to debarking and chipping activities to monitor all machines simultaneously and thereby determine machine interactions.

A 4-kg sample of chips was collected from each chip van when the van was half full. The chip samples were sent to PAPRICAN in Pointe Claire, Quebec for detailed analysis. Weldwood also analyzed chip samples which were taken from each chip van prior to dumping. During the trial, Weldwood's bark-analysis results were used to monitor the effectiveness of the flail debarker and to make adjustments in operating procedures to ensure that the 1% bark content objective was being achieved.

During the trial, all weights of chips were recorded.

Debris from the flail and chipper was loaded into a dump truck for disposal. For the first two weeks, every load of debris was weighed to establish an average weight. Thereafter, sample loads were weighed as time permitted.

Logs within felled bunches were randomly sampled to note species and to measure butt and top diameters (inside bark) and length.

TRIAL DESCRIPTION

Flail Trial

The chain-flail trial was located in a logging landing 38 km northeast of Weldwood's pulp mill at Hinton, Alberta. Temperatures during the trial (Figure 1) varied between -37°C and +5°C. All the trees were frozen, although outer bark sometimes softened during periods when temperatures rose above freezing for several consecutive afternoons.

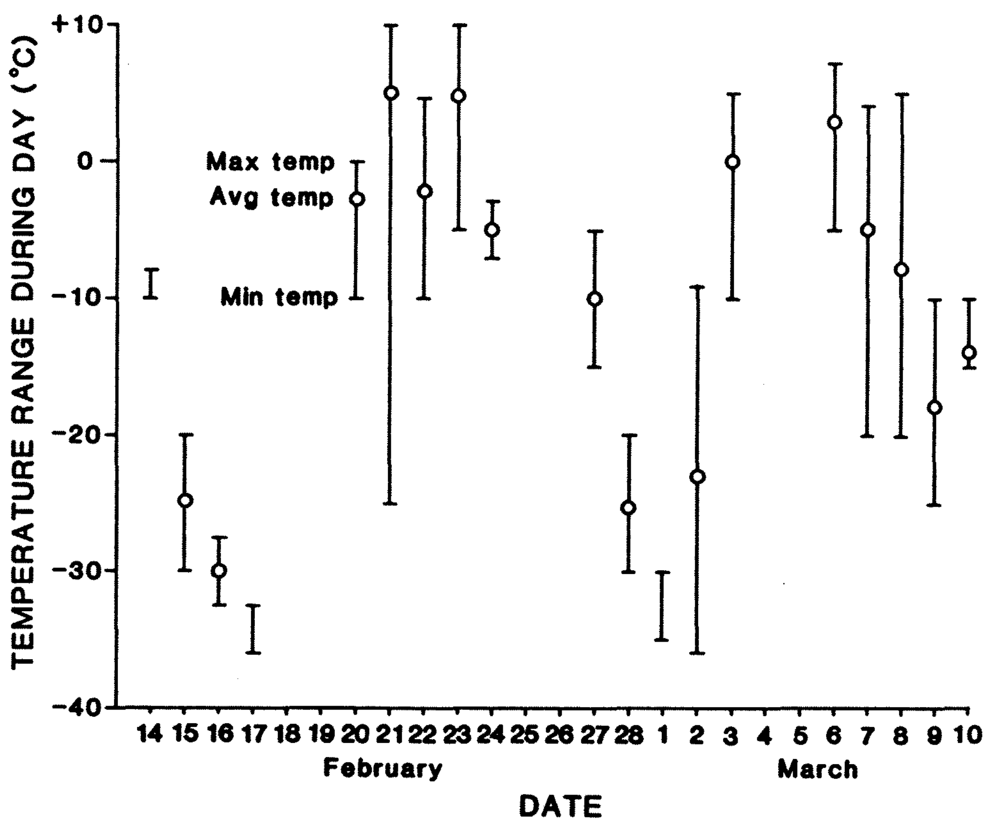

Figure 1. Temperatures recorded at chipping site during trial.

Figure 2 is a flow diagram of the system, and Figure 3 shows the arrangement of the equipment at the landing. The loader, backhoe, and gravel truck that worked with the flail and chipper were selected for reasons of availability rather than for their suitability for the job.

Logging was carried out by a company crew using a feller-buncher and grapple skidders. Bunches skidded to the landing were placed 4-6 m in front of the flail. Whenever the stockpile at the flail was full, the bunches were stockpiled around the landing perimeter. Logs were recovered from the perimeter stockpile when logging production fell behind the demand for logs for chipping.

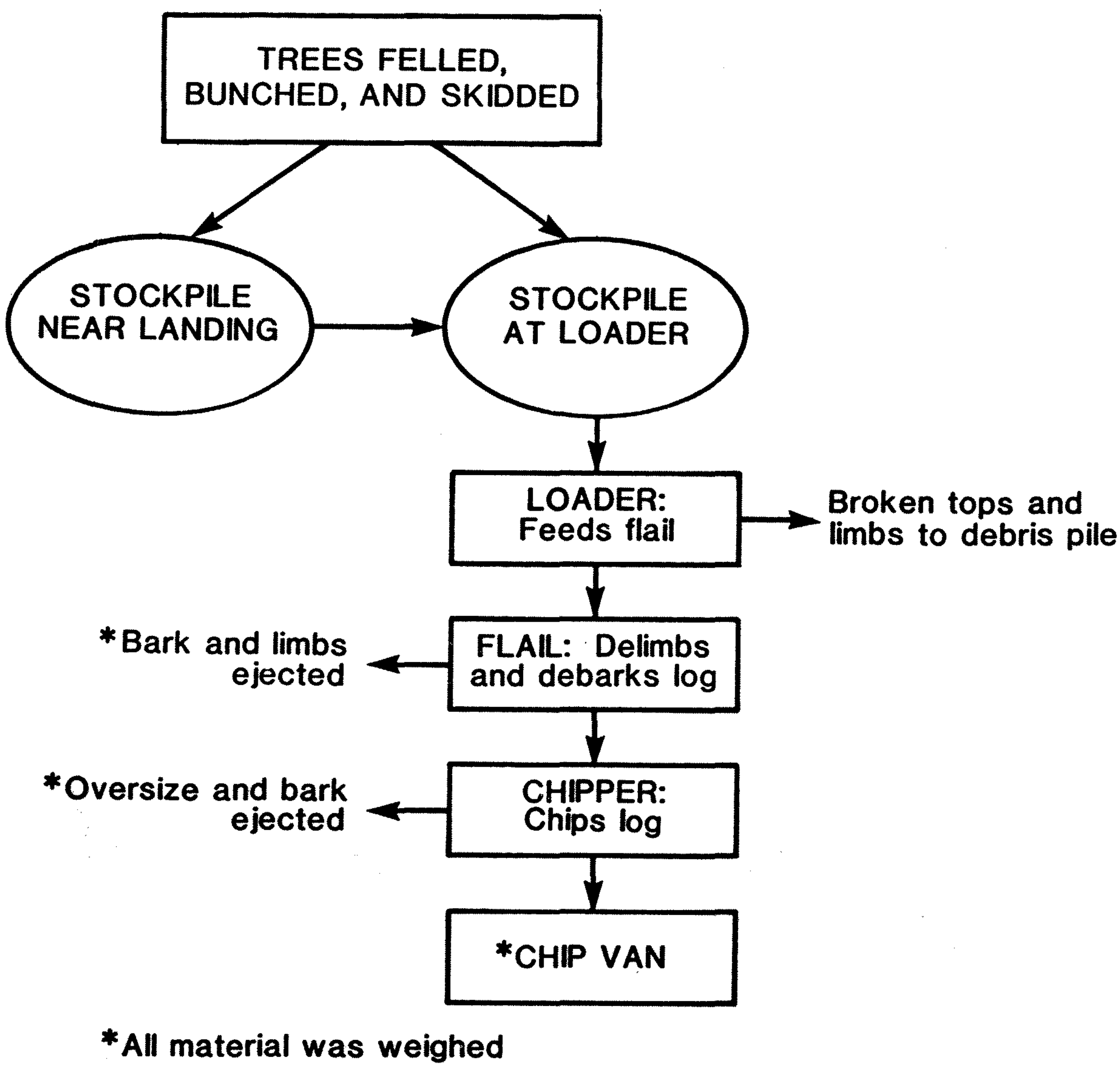

Figure 2. Flow diagram of system.

The logs were loaded into the flail with a hydraulic log loader equipped with a butt-and-top grapple. The loader was oversized for this application and the butt-and-top grapple was awkward to use around the flail. However, it was the only available loader in the area for the field trial.

Delimbing and debarking was done with a Peterson-Pacific Model 4800 chain flail (Figure 4). (See Appendix II for detailed specifications.)

Logs were fed directly from the Peterson chain flail into an older Morbark Model 22RXL four-knife Chiparvester equipped with a sliding-boom loader. The chipper was set up to process logs with diameters up to 56 cm (22 in.) into 22 mm (7/8 in.) long chips. Originally, a new 69-cm capacity Morbark Chiparvester was to be used, but it was unavailable when the field trials started.

Initially, the flail and chipper were set up so that flail outfeed was within 1 m of the chipper infeed chain. To have the height of the flail outfeed level with the height of chipper infeed, the flail height had to be reduced by 30 cm by digging holes for the wheels. Later, when the flail and chipper were separated by 3-5 m, it was not necessary to lower the flail height because the logs could be directed onto the chipper infeed with the chipper loader.

The flail drums are directly coupled to the engine by five vee-belts. The drums turned at 480-500 rpm at an engine speed of 2400 rpm. The infeed rate was determined by an air-driven motor and was infinitely variable between 1-46 m/min.

Initially, the pulp mill specified that all chips produced by the satellite chipping operation had to be screened to remove over- and undersized chips. To accommodate mill requirements, FERIC mounted a stationary Mortrans screen on a flatdeck truck. Chips were discharged directly from the chipper spout onto the Mortrans screen infeed deck and a blower unit transferred the chips from the screen discharge into the chip vans. Operation of the screen was discontinued because the screen was not working effectively and the blower fan repeatedly overloaded with chips. An analysis of the chips discharged through the screen indicated that the fraction of fines actually increased after screening. This was caused by frozen chips breaking as they were flung against the steel plates at the screen infeed. In addition, the screen deck became flooded with chips when chips froze to the steel screen and plugged the screen holes. Therefore, the screen was not used for the trial.

Chips were blown into 13.7-m (45-ft) enclosed vans that had been modified for chip hauling. Modifications included making two 929-cm^2 (1-ft^2) openings in the trailer front to allow the discharge of air and the installation of half-doors of steel mesh. These doors swung from the trailer roof at the rear of the van to contain the chips during loading. The van was backed up as close as possible to the discharge spout and parallel to the chipper.

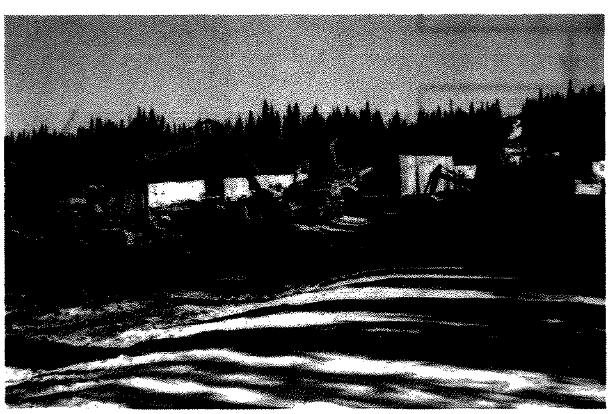

Figure 3. Equipment at the site.

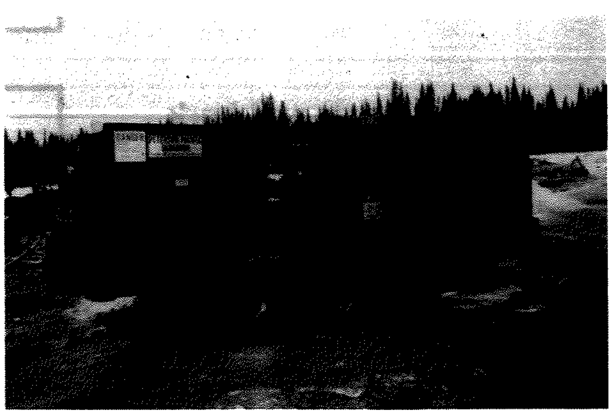

Figure 4. Peterson Model 4800 delimber/debarker.

Chips destined for hog fuel were delivered to the mill in a 16.2-m (53-ft) chip van with a live bottom to allow self-unloading at the hog-fuel dump.

RESULTS AND DISCUSSION

Stem Sizes

Table 1 summarizes the average sizes of stems processed by the flail during the trial. Appendix III provides a more detailed distribution of the logs processed.

Table 1. Summary of Stem Dimensions

Trial	No. logs sampled	Diameter		Avg length (m)	Avg volume (m^3)	Trees/m^3	Avg stem diameter [a] (cm)
		Avg top (cm)	Avg butt (cm)				
Spruce-Pine [b]	101	6	18	11.1	0.152	6.6	13
Black spruce	159	7	15	8.4	0.094	10.6	12
Pine pulpwood	176	7	13	6.6	0.054	18.5	10
Aspen	160	11	29	14.7	0.547	1.8	22

[a] Calculated as the diameter of a cylinder with stem length and stem volume indicated.
[b] White spruce, black spruce, and lodgepole pine.

Initially, logging concentrated in areas of larger trees (spruce and pine) but then progressed into areas of smaller trees (nearly pure black spruce).

Delimbed aspen logs were hauled from a log deck approximately 15 km away and were the largest logs processed during the field trial. For the purposes of this trial, it would have been preferable to process smaller logs.

The smallest diameter of stems processed were two truck-loads of lodgepole pine pulpwood harvested at Grande Cache, delimbed by a stroke delimber and then trucked to the chipping site.

Chip Production

Sixty-two van loads of conifer chips were produced during the trial, and two loads of aspen chips were delivered as hog fuel because the pulp mill could not utilize aspen chips (Table 2).

Debris Production

The trial generated 316 t of conifer debris (Table 2) while producing 1264 t of chips, and 12 t of aspen debris for 54 t of aspen chips. The debris produced by the flail consisted of pulverized tops, branches, bark, and stem wood. The debris from the chipper consisted of oversized chips, dirt, bark, and knots.

The resulting debris was not acceptable for hog fuel because the flail generated a number of oversized chunks which the pulp mill could not handle. Every effort should be made to utilize the debris as hog fuel as it represents 25% of the volume of chips produced and could be a source of energy.

Table 2. Summary of Production

	Chips			Debris		Tonnes of debris produced/ tonne chips
	No. loads	Green chips (kg)	Bark content [a] (%)	Flail (kg)	Chipper (kg)	
Spruce-Pine	30	616 980	1.18	94 550	16 610	0.18
Black spruce	30	609 280	1.12	168 820	27 780	0.32
Pine pulpwood	2	37 860	1.32	5 140	3 090	0.22
Total conifer	62	1 264 120		268 510	47 480	0.25
Aspen [b]	2	54 300	3.76	10 290	2 060	0.23

[a] Green-weight basis.
[b] Delivered as hog fuel.

The debris could be used for hog fuel at the mill if oversized pieces were screened out, or the debris was passed through a hammermill that would reduce the size of large chunks.

The debris from this trial was spread over the landing and an adjacent cutblock.

Bark Content

Pulp mills across Canada use bark content as an index of chip quality, but there is no standard method of obtaining a chip sample. Even if a standard sampling method was available to collect chip samples, spatial variability in a van-load of chips is often high, which would lead to wide ranges in measured bark contents. The standard deviation for bark content ranged between 0.20 and 0.30 for a series of chip samples taken during the loading of a single van (R. Berlyn, pers. comm., Feb. 1989).

The Weldwood mill collected a 2-kg random sample with a mechanical collector as each chip van was dumped. Bark particles were separated from a portion of this sample by hand, collected, and compared to the weight of chips sampled. The amount of bark found in the sample was directly related to the time spent sorting and the visibility of the bark fraction (small pieces and pieces of inner bark were difficult to distinguish from discoloured wood). All the chips were then returned to the sample pail and poured through a Williams Classifier for size distribution.

The bark contents obtained during this trial compared favourably with chip-production facilities in the area. For example, during the same time period, Weldwood's woodroom was processing frozen logs through drum debarkers and achieving bark contents of 2-3%. Observations of the drum debarking at the Hinton mill suggested that debarking frozen wood by this method was largely ineffective, with only small patches of bark being removed. However, because the average diameter of logs going through the drum debarker was larger than the log diameters processed during the flail trial, the drum debarker did not have to remove as much bark to achieve the same bark content.

The mill analysis (Table 2) indicated that bark content (% green-weight basis) averaged between 1.18 and 1.32% for the 62 vans of conifer stems debarked by the flail. Three-quarters of the loads were between 0.20 and 1.50 percent. The bark content of aspen chips averaged 3.76%.

Most flail-debarked stems had small patches or strips of outer bark left on the butt ends. Most of the loose bark was removed from the stem tops (5-cm diameter and less), however bark that was firmly attached to the wood remained in a "checkered" pattern.

During the trial, the quality of flail debarking appeared to be affected by the infeed speed of the flail, the flail drum speed, the number of stems being debarked simultaneously (Figure 5), the log's angle or position at infeed, the air temperature, the number of limbs on the stem, the tree species, and the diameter of the stems.

The flail infeed rate was continually adjusted between 18-20 m/min, and the flail drums were varied between 440-520 rpm (loaded engine speed of between 2200-2500 rpm) to maintain debarking quality. Provided the chains could wrap around the logs, debarking quality improved with decreasing feed rates and increased flailing. However, it was difficult to determine the specific effect of the adjustments because of variations in the number of logs processed per minute, temperature, and chip sampling. As an example, Table 3 presents the bark content results from a single day's trial with changes in infeed and flail speed noted.

The Model 22RXL Chiparvester engine speed determines the chipper knife rotation speed and the infeed chain speed. The distance from the flail outfeed to the chipper knives is about 4 m when the flail and chipper are "close-coupled." When the Model 22RXL is working at its governed rating of 2200 rpm, the infeed rate is 35 m/min, which is considerably faster than the flail feed rate. As a result, stems that are being debarked at 20 m/min are pulled through the flail at a faster rate than when the stems are picked up by the chipper infeed.

To minimize this interference, the flail and the chipper were separated by 3-4 m when processing the conifers and 6 m when processing aspen (Figure 8), and the engine speed on the chipper was reduced by 150 rpm. In addition, chipper feed-roller pressure was only applied to the logs when the stems cleared the flail. This allowed the flail to have a greater influence on both debarking and chipping rates. Throughout the trial, continuous attention was given to balancing production rate (i.e. higher flail-infeed speed) and bark content (i.e. lower flail-infeed speed). The test could have been undertaken at flail feed rates of 10-15 m/min, and bark content would probably have been less than 1%. However, the production output would have been insufficient for an economical operation.

Bark was removed consistently on spruce-pine and black spruce stems when they were processed three or four at a time (Figure 6). If more stems were in the flail, then the chains could not wrap completely around the stems and bark was left on the "sides" of the stems.

Table 3. Example of Daily Production Variation for Black Spruce

Load no.	Stems/ productive minute	Temperature		Infeed speed (m/min)	Loaded flail speed (rpm)	Bark content (%)
		1 h before (°C)	During (°C)			
1	5.0	-15	-12	20	470	0.92
2	4.1	-12	-10	18	470	1.10
3	4.3	-10	-9	20	450	1.08
4	4.7	-9	-5	20	450	0.90
5	4.2	-5	-11	20	510	0.26

Stems also had to be fed into the flail horizontally to ensure complete bark removal. The butts were not debarked adequately if they were raised because the lower chains could not reach the underside of the stem. This was especially noticeable when debarking aspen.

During cold weather, the bark seemed to chip off the stems as small particles, and the debarked stems had a gouged appearance. The bark particles fell off the stems as they exited the flail. The chip samples contained small fractions of bark that were sometimes ignored when determining bark content. When the temperatures warmed and the bark became softer, the bark tended to hang on the stems in larger pieces and the stems were gouged and "fuzzy." The larger particles were easier to see during bark-content analysis.

Limbs reduced the speed of stems travelling through the flail, especially for small-diameter stems. Consequently, bark removal was greater on trees with limbs than trees with limbs removed. The infeed rollers could not close tightly against the small-diameter stems and the limbs acted as infeed resistance as the stem was pulled through by the action of the chain flails. On delimbed stems (e.g. pine pulpwood) the partially debarked stems would shoot through the flail and land on the chipper infeed deck, cross-wise on the deck, or alongside the chipper.

Aspen was the most difficult species to debark because of its larger diameter and thicker bark, although several demonstration logs appeared to be debarked with excellent results (Figure 7). Aspen logs greater than 36 cm in diameter often had long strips of bark remaining along their sides. Mechanical breakdown of the chipper prevented the processing of more aspen during the trial, especially at slower infeed rates. Small-diameter aspen was not available for the short duration of the trial without logging a new stand. The stem sizes selcted were the smallest generally logged by Weldwood.

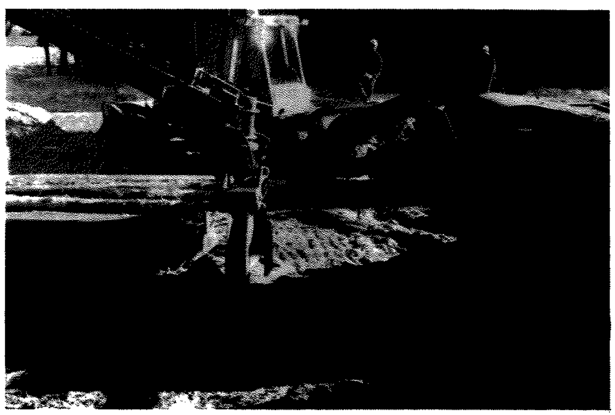

Figure 5. Debarking too many black spruce stems.

Figure 6. Debarking black spruce stems.

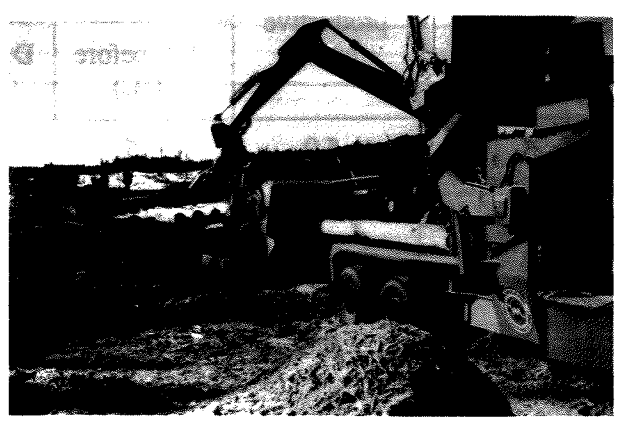

Figure 7. Debarking aspen stem.

Chip Quality

Table 4 summarizes the chip dimension distributions. The chipper was set up to cut 22-mm (7/8-in) chips. The high percentage of pins and fines and the small percentage of chips between 22 and 28.5 mm were the main concerns in terms of acceptability to the Hinton pulp mill.

The high percentage of fines may be directly attributable to the relatively small chip cut and the brittleness of the frozen chips. A chipper-knife configuration that cut a larger chip would probably reduce the fine content. In a study undertaken last February in Maine, a Peterson-Pacific Model 4800 coupled with a Trelan chipper processed small-diameter frozen wood and produced chips with less than 14% pins and fines (Bialozynski 1989). The fines were attributed mainly to impact fracture of frozen chips. Also, loose, fuzzy surfaces of flail-debarked logs generated fines when the stems were chipped. Log surfaces were deeply scarred by the chain and the chain may have pulverized and separated surface wood fibres. Discussions with other portable-chipper users indicate that worn counterknives on the rented Morbark chipper may have also contributed to the high proportion of fines.

To maintain chip quality, chipper knives were checked constantly, the chipper's anvil was adjusted so that it just cleared the chipper knives, and engine speed was reduced by 150 rpm to slow the chipper rotation and thereby cut a thicker chip. The result was a thicker chip, which held together better, and fewer broken chips and fines. Three chip samples obtained prior to adjustment averaged 25% pins and fines and averaged 15% or less for samples taken after the engine speed was reduced.

Most chips were not cleanly cut on one side and many chips were less than 22 mm long, but 2 cm or more wide. These features may have resulted when the forward ends of long logs reached the chipper knives while the rear ends were still being debarked. Vibrations caused by the flail and the mismatched feed rates may have prevented the stem from being fed at a constant feed rate to the chipper knives. To counteract feed-rate interference, the chipper and flail were separated as much as log length would permit.

Table 4. Summary of Chip-Quality Data

	Size of chips passing through screen (mm)										
	+28.6 (%)	+22 (%)	+16 (%)	+9.5 (%)	+4.8 [a] (%)	-4.8 [b] (%)	+28.6 and +22 (%)	+16 and +9.5 (%)	+4.8 and -4.8 (%)	+28.6 to +16 (%)	+9.5 to -4.8 (%)
Spruce-Pine: 17 samples											
Average	8.0	17.5	27.3	33.7	11.2	2.3	25.5	61.0	13.5	52.8	47.2
Standard deviation	4.6	5.8	3.3	4.5	5.8	1.7	-	-	-	-	-
Black spruce: 14 samples											
Average	11.1	16.6	27.6	32.5	10.2	2.0	27.8	60.1	12.2	55.4	44.6
Standard deviation	3.2	3.3	2.6	3.7	3.2	1.0	-	-	-	-	-
Pine pulpwood: 1 sample	13.1	16.3	29.3	30.9	8.7	1.7	29.4	60.2	10.4	58.7	41.3
Aspen: 2 samples											
Average	8.6	24.0	33.4	28.2	5.2	0.6	32.6	61.6	5.8	66.0	34.0
Standard deviation	2.0	0.1	1.0	1.5	0.2	0.1	-	-	-	-	-

[a] Pins

[b] Fines.

Production Results

Shift-Level Results. Table 5 summarizes the shift-level data collected during the entire study and Appendix IV summarizes the major delays. The tables summarize all the time the equipment worked or was available from February 11 to March 10, 1989, which was the total duration of the field trial.

As indicated in Table 5, the equipment was on site for 28 days and production occurred on 17 shifts. Three shifts were required to set up the equipment. There were six weekend shifts and two shifts were lost when work was cancelled because of extremely cold temperatures.

The chipper was an older model; it was not winterized, it was used only as a spare machine prior to the trial, and was the least mechanically reliable of all the equipment. Chipper repairs represented 80% of the total 33.2 h lost due to mechanical delays greater than 10 min, compared to only 4% for the flail. Chipper repairs were also undertaken during a portion of one weekend and one cancelled shift (4.5 h out-of-shift repairs).

The only mechanical delay of the flail occurred when the air controls froze because of moisture in the air system (1.4 h). Improved winterization of the flail controls, i.e. by ensuring moisture does not contaminate the air system, would reduce the flail's mechanical delays.

Three production shifts each had only one load of chips produced. The remainder of these three shifts were spent repairing the chipper or completing the setup of the equipment.

Overall equipment utilization was only 50%. Much of this was related to the nature of the study, the lack of winterizing, and the lack of spare parts for the chipper. Over 21 h of delay time were required to perform study-related tasks and 10 h were spent waiting for empty chip vans, i.e. these are delays which would not normally occur in a production mode.

Also, warm-up and wait-for-parts delays could be expected to be reduced in an operational setup. If the study-related and wait-for-empty-van delay times are removed from the shift-level summary, overall equipment utilization would increase to between 60-70%.

When all delays over 10 min were removed from the shift-level time, equipment utilization rose to 98%. More than half of the delays over 10 min exceeded 30 min in length, and 20% exceeded 60 minutes. Long delays were related to cold temperatures and a lack of spare parts and repair supplies for the chipper. This illustrates the loss in production that can occur when working in cold temperatures without proper equipment winterization (e.g. heaters or engines, shrouding, and insulated hydraulic lines) and without adequate spare parts and repair supplies for the chipper.

Flail-Debarker Production. Table 6 summarizes debarking production for the various flail trials. Production estimates are based on the time to load and change vans and excludes all delays less than 10 minutes.[1]

Aspen debarking, in terms of m/min, was the lowest rate of all species. However, because of its larger stem volume, the rate of production of chips was highest. Generally, only one aspen log could be processed at a time, while several softwood logs could be processed at once because of their smaller diameter. Other studies have noted that small (less than 13-cm DBH hardwood) is well suited to debarking in a flail operation (Bialozynski 1989; Turtle 1989; and Creelman 1989).

[1]When using detailed timing data to estimate long-term productivity, it is normal to eliminate delays greater than 10 minutes.

Flail production in the spruce-pine, black spruce, and pulpwood pine trials generally varied with timber size and the log infeed rate. However, production was also influenced by experiments to determine the time required to debark stems consistently to a known bark content (Table 7).

Table 5. Summary of Shift-Level Study

	No.	%
Shifts with no production		
Weekends [a]	6	21
Too cold [b]	2	7
Setup	3	11
Production shifts	17	61
Total	28	100

	Overall results		Results with delays >10 min removed	
	h	%	h	%
Production shifts				
Productive time (PMH) [c]	75.6	50	75.6	98
Delays				
Wait for vans	10.4	7	0.6	1
Organizational	21.3	14	0.1	0
Personal [d]	1.5	1	1.0	1
Repair and service				
Warm up	8.7	6	0	0
Repair	15.3	10	0	0
Go for parts	14.7	10	0	0
Wait mechanic	3.2	2	0	0
Total (SMH) [e]	150.7	100	77.3	100
Average shift length [f]	8.9		4.5	
PMH/shift (h) [f]	4.4		4.4	
Utilization (PMH/SMH x 100) (%)	50		98	

[a] Includes 0.2 shift undertaking repairs on the chipper.
[b] Includes 0.5 shift undertaking repairs and servicing chipper and flail.
[c] Productive machine hours.
[d] Excludes lunch delays and includes coffee breaks.
[e] Scheduled machine hours.
[f] Based on 17 production shifts.

Table 6. Summary of Production Rates (with all delays greater than 10 min deleted)

	Spruce-pine	Black spruce	Pine pulpwood	Aspen
Avg log length (m)	11.1	8.4	6.6	14.7
Avg log volume (m^3)	0.152	0.094	0.054	0.547
Oven dry (%)	57.4	58.6	59.2	50.8
No. of vans	30	30	2	2
Summary of production				
No. of logs processed	7 752	8 514	880	150
Volume solid wood (m^3) [a]	1 178	800	48	82
Weight of chips produced (kg)	616 980	609 280	37 860	54 300
BDU produced [b]	325	328	21	25
Bark content (% green weight)	1.18	1.12	1.32	4.00
Production/van load				
No. of logs	258	284	440	75
Volume solid wood (m^3)	39	27	24	41
Weight of chips (kg)	20 566	20 309	18 930	27 150
BDU	11	11	10	13
Total scheduled time to load van	67	70	74	61
No. logs/scheduled min	3.9	4.1	6.1	1.2
Net log feed speed (m/scheduled min) [c]	43	35	40	18
Volume solid wood (m^3/SMH)	35	23	20	41
BDU/SMH	9.9	9.6	8.7	12.6
Productive time to load van	57	59	67	53
No. logs/min	4.6	4.9	6.6	1.4
Net log feed speed (m/min)	51	41	43	21
Volume solid wood (m^3/h)	42	28	21	47
BDU/h	12	12	9	15

[a] Number of logs x average log volume.
[b] (Weight (kg) of chips + 1000) x (oven dry % + 100) x 0.919 BDU/t.
[c] Number of logs x average log length.

Table 7. Summary of Feed Rate, Bark Content, and Production

Stems/min [a]	Spruce-Pine		Black spruce		Pine pulpwood		Aspen	
	Bark content (%)	BDU/h [a]	Bark content (%)	BDU/h [a]	Bark content (%)	BDU/h [a]	Bark content (%)	BDU/h [a]
1-2	0.46	10.3	-	-	-	-	4.00	14.6
2-3	0.91	10.4	-	-	-	-	-	-
3-4	1.22	11.7	1.06	8.9	-	-	-	-
4-5	1.38	12.9	1.03	11.2	-	-	-	-
5-6	-	-	1.30	12.5	-	-	-	-
6-7	-	-	0.84 [b]	15.5	1.32	9.3	-	-

[a] Time period the equipment was actually working (productive time) excluding all delays.
[b] Could be caused by sample error.

Overall, when smaller stem sizes (black spruce and pine pulpwood) were being debarked, more stems/min were required to produce a BDU of chips than when larger stems (aspen and spruce-pine) were being debarked. Generally, bark content increased as the number of stems/min increased. The low bark content for 6-7 black spruce stems/min may be related more to chip-sample variation than to actual debarking quality.

Flail production was smoothest when a deck of stems was accumulated in front of the flail so that the loader could slide a bunch of stems to the infeed roller. The deck allowed the stems to travel horizontally through the flail and reduced the need for the loader to align the stems during debarking. The loader operator tried to keep three stems in the infeed of the flail at all times but this was not always possible with the butt-and-top loading grapple. The grapple was too large and cumbersome to be positioned easily near the infeed without disturbing the stems being debarked.

Stem length affected the transfer and alignment of logs from the flail to the chipper. Short stems tended to shoot out of the flail and onto the chipper infeed deck. Long stems were pushed out of alignment with the chipper infeed when the skidder drove over, or the loader grapple hit, the stems being fed into the flail. Misaligned stems had to be repositioned into the chipper infeed with the chipper's sliding boom loader (Figure 8), thus slowing production. Additional guarding and deflectors between the flail and the chipper would have corrected alignment problems.

Several grapple loads of 2- to 4-m-long conifer tops were inserted into the flail to determine if the flail had potential to debark logging residue. The tops jammed in the flail because they were not long enough to bridge the gap between the infeed and outfeed rollers, and the tops usually broke at 2-3 cm diameter. Also, the infeed rollers could not close tightly enough to hold the tops against the debarking action of the chains, so that tops were propelled through the flail at high speeds.

Chipping Costs

Equipment cost calculations are shown in detail in Appendix V. The machine costs are FERIC estimates based on results determined during the field trial. Interest costs and a ninth hour at overtime labour wage rates are included, but profit, company overhead, and supervision costs are excluded. Logging costs were not included. Operating costs for knife sharpenings, rod replacement, and chain replacement are determined separately because they are related to the volume of chips produced and not the number of hours the equipment works. Replacement chain cost $850/set and replacement rods $600/set. The chain was estimated to last 25 van loads (275 BDU) when processing conifer and 15 van loads (165 BDU) when processing aspen. Rods were expected to last ten times the life of the chain. Chipper-knife sharpening was estimated to cost $75/set of knives and would be required every 10 loads (110 BDU).

The equipment costs were prorated against both the production recorded during the trial (excluding delays greater than 10 min) and a revised rate that estimated production for an experienced, operational, satellite chipping facility (Table 8). The revised rate was based on a 17% increase in production that occurs when delays associated with the study (5%), waiting for access to logs at the log deck (6%), and waiting for an empty van to return to the chipping site to replace a full van (6%), are not incurred and the time is spent in production functions. Also, production was estimated to increase by 20% when the loader was able to feed a continuous supply of logs to the flail. Trial production was, therefore, revised upwards (17% + 20% = 37%) in total.

The equipment, as set up for this trial, was estimated to cost $231/h (including interest) to operate and require operating supplies that cost $4/BDU when processing conifer and $6.20/BDU when processing aspen. Equipment cost could be reduced to $220/h if a smaller, less expensive loader is used instead of the oversized one used during the trial.

Chips produced during the trial cost between $27.12 and $29.12/BDU for conifer and $23.99/BDU for aspen excluding cost of hauling ($15/BDU), logging costs, non-operational costs such as company overhead, supervision, or profit to enterprise. In a production operation, these costs were expected to decrease to between $20 and $23/BDU for conifer, and $19/BDU for aspen. A production operation could reduce costs by a further $0.80/BDU for conifer and $0.60/BDU for aspen chips if a smaller loader was used. The cost of production was directly related to the volume/piece and number of pieces processed/minute.

Figure 8. Aligning logs from debarker with chipper loader.

Table 8. Summary of Satellite Chipping Costs

	Operating cost/h ($)
Equipment costs:	
Komatsu 220 log loader	83.59
Peterson Model 4800 flail	42.35
Morbark 22RXL chipper	105.27
Total	231.21

Operating supply costs:	Total cost ($)	Production/set Conifer (BDU)	Production/set Aspen (BDU)	Operating cost Conifer ($/BDU)	Operating cost Aspen ($/BDU)
Chain	850	275	165	3.09	5.15
Rods	600	2 750	1 650	0.22	0.36
Knife sharpening	75	110	110	0.68	0.68
Total	1 525			3.99	6.19

	Spruce-Pine	Black spruce	Pine pulpwood	Aspen
Log sizes				
Average stem length (m)	11.1	8.4	6.6	14.7
Average stem diameter (cm)	13.2	12.0	10.3	21.9
Average stem volume (m^3)	0.152	0.094	0.054	0.547
No. logs/m^3	6.6	10.6	18.5	1.8
Production recorded				
Stems/minute	3.9	4.1	6.1	1.2
BDU/hour	9.9	9.6	8.7	12.6
Costs ($/BDU)				
Equipment (at $231.21/h)	$23.35	$24.08	$26.58	$18.35
Operating supplies	4.00	4.00	4.00	6.20
Total costs/BDU	$27.35	$28.08	$30.58	$24.55
Revised production [a]				
Stems/min	5.3	5.6	8.4	1.6
BDU/h	13.7	13.7	12.3	17.8
Costs ($/BDU)				
Equipment (at $231.21/h)	$16.88	$16.88	$18.80	$12.98
Operating supplies	4.00	4.00	4.00	6.20
Total costs/BDU	$20.88	$20.88	$22.80	$19.18

[a] Assumption based on reduced delays and more loader operator experience.

Operational Comments

Chain Replacement. The cost of replacing chain has been generally reported as a concern at chain-flail operations. During this trial, the chains were upended between the 12th and 15th loads and completely replaced after every 30 to 35 van loads of chips. Usually several lengths had 2 or 3 links missing by the 25th van load and debarking quality was noticeably reduced by the 30th van load. Chain wear appeared to be greatest when debarking the aspen, as several links were missing after debarking only 150 logs (Figure 9).

Chain replacement was a two-man job and took 30-45 min with additional time taken to check and service the flail. New chains had to have the inner surface of an end link ground out so the link would fit over the rod. The rods holding the chains were changed halfway through the trial, although they were only slightly worn. Peterson-Pacific claim rods will last ten times the life of chains.

The majority of links broke as a result of wear, however, link breakage at welds was also noted. Chain wear was expected to increase as the flail-drum speed increased. Therefore, infeed speed was varied more than the flail-drum speed, with the optimal production being the slowest flail speed and the fastest infeed rate that would result in acceptable chips.

Chipper-Knife Sharpening. Chipper knives remained sharp for between 11 and 16 van loads of chips. This was longer than expected, probably because the trees being chipped were free of dirt. Knives should probably be changed every ten loads. Changing knives took between 20 and 40 min (including minor servicing) and could be done by one man. Aspen chipping did not appear to change knife wear.

Logging Costs. Harvesting costs (Table 9) can be reduced when satellite chipping with a flail delimber/debarker because stems are not delimbed. This can reduce the higher costs associated with logging smaller-diameter timber.

Table 9. Summary of Harvesting Costs [a]

	Avg volume (m^3)	m^3/8-h shift	Harvesting cost [b]		Delimbing cost	
			$/$m^3$	$/BDU [c]	$/$m^3$	$/BDU [c]
Spruce-pine	0.152	221	6.21	17.59	4.60	13.03
Black spruce	0.094	150	9.15	25.92	5.40	15.30
Lodgepole pine	0.054	86	15.96	45.21	6.19	43.34

[a] O. Hanulla, pers. commun., Aug. 1989.
[b] Cost includes labour, fringe benefits, machine operating costs, depreciation, and interest; and excludes company profit, overhead, and supervision. Costs are for falling and skidding only.
[c] 2.83 m^3 of spruce-pine-fir = 1 BDU.

Equipment Interaction. During the flail/chipper trial, twenty-nine loads of chips produced from spruce-pine and black spruce samples were monitored in detail to study equipment interactions. The system processed 7991 stems and took an average of 73 min to load each van during this period. Figure 13 summarizes the equipment interaction and the effect of delays on the individual pieces of equipment and the system.

Overall, the system was mechanically available for work for 94% of this time period (Appendix VI).

The equipment was not able to work an additional 24% of the time because of overall delays as a result of study procedures (5%), waiting for empty vans to arrive at the site (5-6%), and exchanging empty chip vans for full vans (13-14%). The only operational delays expected to occur in a production setup would be those associated with changing full vans for empty vans.

The loader, flail, and chipper were working as a system for 70% of the scheduled time (Figure 10). However, each unit's productivity was influenced by its processing speed and the availability of stems to be processed.

The harvesting phase was able to maintain a continuous supply of stems to the loader and flail because stems were stockpiled during delays in the chipping phase, during repairs, and while waiting for chip vans. Without these delays in the debarking/chipping cycle, a single skidder and feller-buncher working only one shift per day would not keep up to chipping demand.

The loader was easily able to match the flail's production requirements. While waiting for the flail infeed to clear, the loader cleared debris that had accumulated around the flail infeed area. The loader's scheduled time was delayed 8% while the skidder dropped turns in the decking area, and 2% when stems being debarked prevented the loader from working. This directly affected the flail's production. If the time the loader spent waiting for the skidder could be reduced by skidding to two decks or having a "cold" deck available, flail production, and subsequently chipper production, could be increased. For each van load of chips produced, the loader averaged 6 min waiting for the skidder.

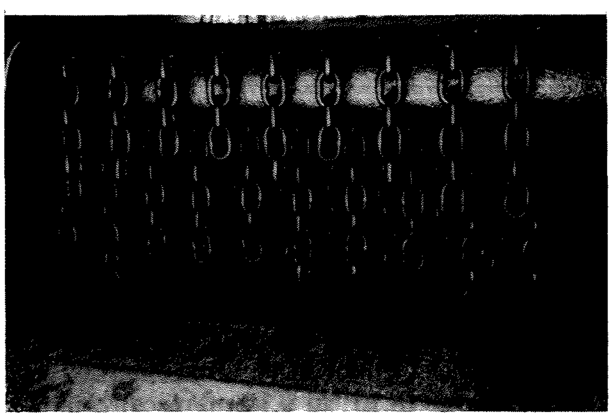

Figure 9. Chain wear prior to replacement.

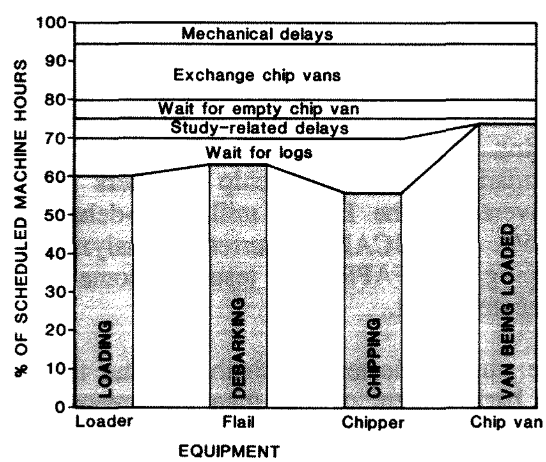

Figure 10. Equipment interaction.

Waiting for stems to arrive at the debarker totalled 7% of the flail's scheduled machine hours (SMH) and averaged 5 min for each van load of chips produced. This time could be reduced by exchanging the butt-and-top grapple attachment for a conventional loading grapple that could align logs into the flail infeed better than the butt-and-top grapple.

Chipper production was limited by the flail's production. The chipper had the lowest utilization of all machines in the system, and spent 14% of its scheduled time waiting for logs (10 min/van load). It is unlikely the chipper could ever be fully utilized, but increasing utilization of the flail and loader would minimize the chipper's idle time.

Waiting for full chip vans to be replaced with empty vans added 10 min/van load to the average cycle time. This did not include waiting for vans when an empty unit was not available on the landing. The time to change vans could be reduced if two vans had been positioned side by side at the chipper spout so that the chipper could continue working while vans were being re-positioned. This would require the chip spout to have greater side-to-side deflection than the spout on the chipper tested. The time required to turn the vans around at the chipping site varied, being fastest when the landing area was clear of vehicles and longest when auxiliary vehicles or other vans restricted turn-around space. Ensuring adequate landing area to turn the semi-trailers would reduce the time required to move and change vans, and reduce overall haul times.

Waiting for empty chip vans to arrive at the chipping site averaged 4 min/load because chip vans from the satellite operation were not granted priority for unloading at the pulp mill and operational delays at the chipping site made it difficult to schedule trucks. This delay could be reduced by parking empty vans at the chipping site rather than at the mill. A spare tractor unit could position the vans for loading.

Delays directly related to experimental activities accounted for 4 min/load.

Chip Hauling. The chip trucks had adequate traction on the chip-haul route, which was graded and sanded after all major snowfalls. The modified dry vans used as chip-hauling trailers were adequate for the trial period, but could not be fully loaded. The openings in the front for air escape were too small, and became plugged with chips and fines during loading. Once the openings became plugged, chips would begin to accumulate 3-5 m away from the van front. The void that was created was difficult to fill. In the future, converted vans must have air vents large enough to allow the discharge of the air that carries the chips into the van so that the vans can be filled to capacity.

CONCLUSION

Results of this trial indicate that the chain flail, when processing frozen small-diameter conifer stems, can consistently produce chips with a bark content of between 1.10 and 1.20% when limbs are left on the stem. This is acceptable to mills requiring a low bark content. While the goal of having a bark content of 1% or less (green-weight basis) was not achieved for all loads, a comparison with other chip suppliers indicates the chips were of the same quality were being delivered to the Hinton mill. Flail-debarked aspen logs resulted in chips with a bark content of 3.76%. PAPRICAN is currently analyzing the chips produced during the trials and will conduct pulping and PAPRIFER tests on some of the chip samples. The results will be presented in a separate report.

The study indicates the chain flail has the capability of processing up to 5 stems/min and maintaining bark content of less than 1% green weight. Based on the production recorded during the black spruce trial, a feed rate of 3-5 small-sized stems/min would result in a production of 11.2 BDU/operating hour. The data also suggest that larger logs (0.10 to 0.15 m^3/piece) could be processed at between 3 and 4 stems/min by ensuring an even flow of 3-4 logs/infeed unit. This would result in a production of 10.4 BDU/operating hour.

The production achieved during the trial was 50-54% of the production estimated by MacIntosh and Sinclair (1988). They based production on a continuous supply of three 12.7-cm diameter logs. However, the operating system could not maintain the continuous supply, and the stem diameter varied between 10-13 cm.

MacIntosh and Sinclair estimated that production rates for a portable flail-debarker and chipper system would be 20.7 BDU/h for SPF species and 19.9 BDU/h for aspen. Actual field-test results were 9.9 BDU/SMH for white spruce and pine; 9.6 BDU/SMH for black spruce; 8.7 BDU/SMH for pine pulpwood; and 12.6 BDU/SMH for aspen. Based on field observations, it was estimated that a fully operational system could produce 13.7 BDU/h for white spruce-pine and black spruce, 12.3 BDU/h for pine pulpwood, and 17.8 BDU/h for aspen.

Results of the Nicholson 22A5 ring debarker trial indicate a sawmill installation that processes frozen small-diameter pine and balsam sawlogs can achieve a production feed rate of 29.9 m/min. Debarked logs resulted in chips with an average bark content of 0.8% green-weight basis. Debarking production converts to an average production of 9.4 BDU/SMH.

The production achieved by the ring debarker was 50% of the production estimated by MacIntosh and Sinclair (1988). They based production on a continuous supply of 12.7-cm diameter logs. However, during the field trials, the log deck could not continuously "singulate" logs, the conveyor system could not maintain a continuous ribbon of logs to the debarker, and the average log diameter was greater than 14 cm.

MacIntosh and Sinclair proposed a portable flail-debarker and chipper system that had a cost of $360/h, and included, in addition to the flail and chipper, a front-end loader, a chip screen, a clean-up machine, and a conveyor system to remove debris. Based on this study, the front-end loader and chip screen would not be required. However, a clean-up machine and conveyor system is required to load flail and chipper debris onto a pile or trailer. The debris represents a considerable volume of potential hog fuel that should be utilized as fuel. MacIntosh and Sinclair did not recognize separately the cost of replacing chain rods and knives (they included these costs in repair and maintenance); this amounts to an estimated cost of between $34-55/h processing conifer and $78-110/h processing aspen. Total costs for the trial were estimated to be $231/h for equipment, plus operating supplies (chain, rods, and knives) of $4/BDU for conifer and $6.20/BDU for aspen.

MacIntosh and Sinclair (1988) estimated production costs of $17.38/BDU for SPF species and $18.08/BDU for aspen when processing with a portable flail debarker and chipper in a satellite yard. This study achieved a cost of $27.35/BDU for white spruce/pine, $28.08/BDU for black spruce, $30.58 for pine pulpwood, and $24.55 for aspen. Based on field-test results, the study estimates that a production cost of $20.88/BDU for spruce, pine, and black spruce, $22.80 for pine pulpwood, and $19.18/BDU for aspen could be achieved.

The chain flail has potential to remove bark and some rot from western red cedar, and bark and charcoal from fire-killed timber provided the chains are in good repair and the infeed rate is slow enough. Additional testing should be done to determine the best combination of infeed and drum rotation.

The satellite chipping operation that was tested seemed well suited to high production. However, the fast rate at which the flail and chipper equipment is capable of processing stems requires continuous skidding of logs to the infeed area and, if possible, a stockpile of logs. A feller-buncher and a skidder cannot adequately supply the system without working more hours than the chipping system.

The following operating factors should be considered to minimize bark content and to maximize chip production during sub-freezing temperatures:

- Do not try to screen chips in a portable operation in freezing weather.
- The loader and its grapple must be sized for the timber being debarked. The grapple should be able to pick up three to five logs at a time without disturbing other logs, as well as be able to pick through the log deck and pick up large grapples of debris to throw on the waste pile.
- Stems should be fed into the flail at a rate that is as constant as possible; stems should overlap and be well spaced across the infeed rollers.
- Air controls on the flail need insulating to protect them from cold temperatures, and the air system requires a system to remove all water vapour during the winter operating season.
- A deck of logs to be debarked should be built up in front of the flail so that stems can easily be fed horizontally through the flail, and assistance from the loader is not needed to keep the stems horizontal.
- The flail infeed and chipper outfeed speeds should be compatible. If the chipper infeed rate cannot match the flail outfeed, the chipper infeed should be separated as far as possible to minimize the time that the chipper is pulling logs through the flail at a rate that makes adequate debarking impossible.
- Chains should be replaced as soon as they are worn.
- With the present infeed roll system on the Peterson flail, lower bark contents can be achieved when the branches are left on the stems.
- Modify the flail so that infeed rollers can close tightly against the tops of the small-diameter stems. An infeed roller system that could put the same pressure on different diameters of logs would be useful.
- Modify the chip discharge spout so it can rotate through an arc large enough to allow the loading of two trucks at the front of the chipper.
- Install guarding and deflectors between the flail outfeed and the chipper infeed to ensure logs are aligned on the infeed and to minimize the need for the chipper loader to align logs.
- Mechanical delays that occurred to the chipper during the trial reinforced the need for the chipper to be in good operating condition and well maintained. There should be an adequate supply of spare hoses and fittings, the knives need to be changed regularly, the anvil must be properly adjusted, and the counterknives must be in good condition.
- All equipment needs to be fully winterized, particularly the chipper.
- An adequate supply of chip vans must always be at the outfeed of the chipper and they should be designed so that they can be filled to capacity. Landing size and configuration of chip vans with respect to the chipper outfeed must be such that system delay time is minimized when an empty van is exchanged for a full one.
- Uses must be found for the considerable volumes of potential hog fuel the system produces.

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APPENDIX I

Secondary Trials

Ring Debarker Trial

One sample log-truck load (559 logs) of frozen small-diameter sawlogs was processed through a new Nicholson 22A5 ring debarker at Grande Cache Forest Products Ltd. This trial was done to prove or disprove some of the estimates used in the MacIntosh and Sinclair (1988) economic feasibility study. The ring-debarked logs were then trucked to Hinton and chipped (while frozen) by the Morbark 22RXL Chiparvester. The chips were analyzed to determine bark content and chip quality.

The average log had a small-end diameter of 14 cm, a length of 4.8 m, an average volume of 0.11 m^3, and an average log diameter of 17.1 cm. Eighteen logs were required to produce 1 m^3 of solid wood. The total volume was scaled at 54 m^3. The logs processed by the ring debarker at Grande Cache sawmill were larger in overall diameter than the logs processed from standing timber at Hinton. However, they were shorter in length because they had to be bucked to fit through the mill.

Production Results. During the ring debarker trial, the Nicholson 22A5 ring debarker processed 559 sawlogs in 107 minutes (Table I-1). Debarking accounted for 54% of the total time, waiting for logs at the debarker 20%, and mechanical delays 6%. Delays directly related to experimental activities accounted for 16% of the total time.

Table I-1. Summary of Detailed Timing (All Delays Included) for Ring Debarker

	Min	%
Production time		
Debarking logs (productive min)	58	54
Waiting for log	21	20
Total productive time	79	74
Organizational delays		
Bucking long logs [a]	9	8
Wait for logs to arrive on deck [a]	8	7
Wait for logs to reach debarker [a]	1	1
Untangle logs on feed deck	3	3
Total organizational delays	21	19
Operational delays		
Clean debris at debarker	1	1
Mechanical delays		
Cut-off saw jammed	6	6
Total scheduled time	107	100

[a] Delays associated with study.

Delays associated with the study (16%) occurred because logs had to be bucked to length in the sawmill rather than on the log deck, and logs had to be forwarded from the log yard.

The Nicholson 22A5 ring debarker at Grande Cache Forest Products Ltd.'s sawmill was serviced and adjusted prior to the trial. The feed speed was set at 93.6 m/min (265 ft/min) which is significantly faster than the calculated debarking rate of 44.3 m/min when all delays and time associated with waiting for logs is eliminated.

The debarking rate was limited by the ability of the infeed deck to supply a continuous ribbon of logs to the ring debarker. Even with a full log deck, it was difficult to maintain a continuous feed of logs. With a proper infeed, Nicholson claims the feed rate should achieve 50 m/scheduled min. This would result in a feed rate of 4.5 logs (11.1-m long) per scheduled min.

Based on an average log length of 4.6 m, the measured feed rate of the 22A5 was 5.2 logs/scheduled min and 23.8 m/scheduled min.

Eliminating all delays associated with the study and excluding the time the 22A5 was waiting for logs to untangle along the infeed would increase the feed rate to 6.5 logs/schedule min and 29.9 m/scheduled min.

The debarked logs were processed through the chipper at a rate of 5.9 logs/scheduled min and 26.8 m/scheduled min. If the time to switch vans is excluded, 10.7 logs/scheduled min were chipped at a speed of 48.8 m/scheduled min.

A total of 34 420 kg of green chips were produced from the ring-debarked logs. Debarker debris totalled 3650 kg and represented 10.6% of the chips produced. A minor amount of chipper debris (weighing less than 300 kg) was collected.

Chip-Quality Results. Bark content averaged 0.84% green weight and had an oven-dry percentage (OD%) of 50.8%. Chips were generally larger in size with fewer fines than conifer chips derived from flailed stems (33.1% between +28.6 and 22 mm; 57.7% between 16 and 9.5 mm; and 9.2% between 9.5 and 4.8 mm or less). The larger chip size may have been due to the larger log diameter, and the reduced shattering around the outside of the log.

Logs from the ring debarker were relatively smooth in appearance, with spirals of inner and outer bark remaining.

Western Red Cedar Trial

One load of decadent western red cedar logs and slabs was trucked in from Prince George, B.C. The logs all had bark attached and were a variety of sizes and shapes. All pieces contained rot on their inner portions. The pieces were processed through the flail to determine the flail's effectiveness on species with stringy bark and to determine how effectively the flail can remove rot. The chipper broke down after processing only a few logs and bark-content samples could not be obtained. The remaining cedar was processed through the flail only.

Most of the cedar logs were between 35 and 50 cm in diameter and large patches of bark remained on the logs after processing in the flail. The chains appeared to spread out from the log and lose their impact during debarking. The areas where the bark had been removed were clean of inner bark.

Some of the rot from the inner surfaces of the slabs was removed. However, most of the firmly attached rotten fibres remained in place.

The ineffectiveness of the chain flail in removing bark and rot may have been caused by the bark being firmly frozen to the inner wood, and by the soft cedar wood absorbing the chain impacts, thereby reducing the ability of the chain to knock off bark or rot. Worn chain may also have been a factor; replacement chain was in short supply.

Debarking Fire-Killed Timber

Two truck loads of fire-killed timber, burned in a spring 1988 fire, were logged, debarked, and chipped to determine the potential of the chain flail to remove charcoal and bark from trees recovered from forest fires. Log sizes were similar to the spruce-pine logs processed during the study although there was insufficient time to obtain a sample scale. Analysis of chips by the Hinton mill indicated bark content was between 2-3% and would be acceptable to the mill. Charcoal was not entirely eliminated from the stems and the chips could not be used for pulp furnish at the Hinton mill. The frozen wood and the dryness of the bark made debarking difficult.

The fire-killed timber was processed (Figure I-1) at a rate of 4.5 logs/schedule min and 52 m/ scheduled min. However, this production rate could not be maintained operationally if bark content had to be less than 1% and all charcoal removed. The initial debarking was done at an estimated rate of 1.3 logs and 15.0 m/production minute (based on an average log length of 11.5 m).

Figure I-1. Debarked fire-killed timber.

APPENDIX II

Peterson 4800 Specifications

The Peterson 4800 is a field-proven unit used in conjunction with the portable chipper. The debarker feeding may be accomplished with the chipper's loader or a separate loading system. The Peterson 4800 will accept multiple stems from 5 cm up to 58 cm in diameter.

Specifications	
Weight	12 250 kg (27 000 lb)
Length	6.40 m (21' 0")
Height	2.44 m (8' 0")
Capacity	30-60 tonnes/h [a]
Feed rate	0.30 to 45 m/min
Flail speed	375-500 rpm [b]
Infeed opening	0.58 m x 1.22 m (23" x 48")
Hitch	Lunette Eye
Axles	Tandem
Multi stem	Yes
Loader	No
Top-feed system	Yes
Self-contained hydraulics	Yes
Engine	Cummins 6BTA 127 kW (177 hp)
Peterson Pacific Corp. 35573 Zephyr Way, Pleasant Hill, OR 97455 (503) 746-3177 Fax (503) 747-9123	

[a] Based on a 56.5-cm diameter log, unlimited length, being fed at 27.4 m/min.
[b] Based on engine speed.

APPENDIX III

Details of Tree Sizes Processed During Trial

Weldwood white spruce, black spruce, and pine (SPF)

Butt diameter distribution			Length distribution			Volume distribution			Average diameter distribution [a]		
Class (cm)	Freq.	%	Class (m)	Freq.	%	Class (m^3)	Freq.	%	Class (cm)	Freq.	%
12	3	3.0	8	7	6.9	0.06	2	2.0	10	3	3.0
14	18	17.8	9	9	8.9	0.08	12	11.9	12	33	32.7
16	23	22.8	10	15	14.9	0.10	11	10.9	14	28	27.7
18	19	18.8	11	18	17.8	0.12	11	10.9	16	25	24.8
20	19	18.8	12	21	20.8	0.14	8	7.9	18	7	6.9
22	7	6.9	13	16	15.8	0.16	12	11.9	20	3	3.0
24	7	6.9	14	8	7.9	0.18	10	9.9	22	1	1.0
26	2	2.0	15	3	3.0	0.20	7	6.9	28	1	1.0
28	2	2.0	16	2	2.0	0.22	7	6.9			
38	1	1.0	17	2	2.0	0.24	6	5.9		101	
	101			101		0.26	2	2.0	Avg = 13.2 cm		
Avg = 18 cm			Avg = 11.1 m			0.28	2	2.0	S.D. = 2.6 cm		
S.D. = 3.9 cm			S.D. = 2.0 m			0.30	2	2.0			
						0.32	3	3.0			
						0.36	2	2.0			
						0.48	1	1.0			
						0.88	1	1.0			
						0.96	1	1.0			
							101				
						Avg = 0.168 m^3					
						S.D. = 0.110 m^3					

Summary: Weldwood SPF - 101 logs

	Diameter		Length	Volume	Average diameter [a]	
	Top (cm)	Butt (cm)	(m)	(m^3)	(cm)	(in)
Average	6	18	11.1	0.152	13	5.2
Standard deviation	1	4	2.0	0.001	3	1.1
Maximum	10	37	16.9	0.951	27	10.5
Minimum	6	12	7.2	0.048	9	3.6

[a] Calculated as the diameter of a cylinder, with stem length and stem volume indicated.

Weldwood Black Spruce

Butt diameter distribution			Length distribution			Volume distribution			Average diameter distribution [a]		
Class (m)	Freq.	%	Class (m)	Freq.	%	Class (m^3)	Freq.	%	Class (cm)	Freq.	%
10	2	1.3	6	1	0.6	0.06	34	21.4	10	35	22.0
12	31	19.5	7	23	14.5	0.08	36	22.6	12	68	42.8
14	51	32.1	8	44	27.7	0.10	33	20.8	14	22	13.8
16	34	21.4	9	56	35.2	0.12	16	10.1	16	9	5.7
18	16	10.1	10	22	13.8	0.16	8	5.0	18	24	15.1
20	13	8.2	11	5	3.1	0.18	19	11.9	24	1	0.6
22	5	3.1	12	8	5.0	0.20	2	1.3	a	159	
24	6	3.8		159		0.22	4	2.5	Avg = 12 cm		
32	1	0.6				0.24	1	0.6	S.D. = 2.9 cm		
	159		Avg = 8.4 m			0.26	2	1.3			
Avg = 15.0 cm			S.D. = 1.1 m			0.28	3	1.9			
S.D. = 3.5 cm						0.52	1	0.6			
							159				
						Avg = 0.102 m^3					
						S.D. = 0.060 m^3					

Summary: Weldwood black spruce - 159 logs

	Diameter				Average diameter [a]	
	Top (cm)	Butt (cm)	Length (m)	Volume (m^3)	(cm)	(in.)
Average	7	15	8.4	0.094	12	4.7
Standard deviation	3	3	1.1	0.001	3	1.2
Maximum	14	31	11.3	0.513	24	9.5
Minimum	5	10	5.5	0.027	8	3.1

[a] Calculated as the diameter of a cylinder, with stem length and stem volume indicated.

Grand Cache Pulpwood

Butt diameter distribution			Length distribution			Volume distribution			Average diameter distribution [a]		
Class (m)	Freq.	%	Class (cm)	Freq.	%	Class (m^3)	Freq.	%	Class (m)	Freq.	%
10	30	17.0	3	2	1.1	0.04	51	29.0	8	27	15.3
12	55	31.3	4	1	0.6	0.06	62	35.2	10	57	32.4
14	47	26.7	5	12	6.8	0.08	6	3.4	12	51	29.0
16	39	22.2	6	71	40.3	0.10	40	22.7	14	41	23.3
18	5	2.8	7	27	15.3	0.12	9	5.1		176	
	176		8	25	14.2	0.14	8	4.5	Avg = 10 cm		
Avg = 176 cm			9	27	15.3		176		S.D. = 1.6 cm		
S.D. = 2.1 cm			10	10	5.7	Avg = 0.058 m^3					
			12	1	0.6	S.D. = 0.029 m^3					
				1							
				176							
			Avg = 6.6 m								
			S.D. = 1.4 m								

Summary: Grande Cache Pulpwood - 176 logs

	Diameter		Length	Volume	Average diameter [a]	
	Top (cm)	Butt (cm)	(m)	(m^3)	(cm)	(in)
Average	7	13	6.6	0.054	10	4.0
Standard deviation	1	2	1.4	0	2	0.7
Maximum	12	18	11.2	0.023	15	6.0
Minimum	4	9	2.6	0.005	7	2.7

[a] Calculated as the diameter of a cylinder, with stem length and stem volume indicated.

Weldwood Aspen

Butt diameter distribution			Length distribution			Volume distribution			Average diameter distribution [a]		
Class (cm)	Freq.	%	Class (m)	Freq.	%	Class (m^3)	Freq.	%	Class (cm)	Freq.	%
14	1	0.6	6	1	0.6	0.20	13	8.2	12	2	1.3
16	1	0.6	8	5	3.1	0.30	15	8.8	14	4	2.5
18	5	3.1	10	9	5.7	0.40	16	10.1	16	6	3.8
20	9	5.7	12	15	9.4	0.50	23	14.5	18	17	10.6
22	9	5.7	14	25	15.7	0.60	22	13.8	20	26	16.3
24	19	11.9	16	47	29.4	0.70	20	12.6	22	26	16.3
26	13	8.2	18	42	26.4	0.80	19	11.9	24	29	18.1
28	17	10.7	20	12	7.5	0.90	6	3.8	26	25	15.6
30	26	16.4	22	3	1.9	1.00	12	7.5	28	13	8.1
32	15	9.4	24	1	0.6	1.10	6	3.8	30	7	4.4
34	17	10.7		160		1.20	4	2.5	32	1	0.6
36	11	6.9	Avg = 14.7 m			1.30	2	1.3	34	3	1.9
38	6	3.8	S.D. = 3.1 m			1.40	1	0.6	40	1	0.6
40	7	4.4					160			160	
42	2	1.3				Avg = 0.590 m^3			Avg = 22 cm		
44	1	0.6				S.D. = 0.289 m^3			S.D. = 4.4 cm		
46	1	0.6									
	160										
Avg = 29 cm											
S.D. = 6.1 cm											

Summary: Weldwood Aspen - 160 logs

	Diameter		Length	Volume	Average diameter [a]	
	Top (cm)	Butt (cm)	(m)	(m^3)	(cm)	(in)
Average	11	29	14.7	0.547	22	8.6
Standard deviation	3	6	3.1	0.006	5	1.9
Maximum	36	45	23.1	3.007	41	16.0
Minimum	5	14	5.6	0.048	11	4.1

[a] Calculated as the diameter of a cylinder, with stem length and stem volume indicated.

APPENDIX IV

Summary of Delays Recorded During Shift-Level Monitoring

	No. of Occur.	Total (h)	Average (min)	Explanation
Organizational delays				
	1	8.0 [a]		Set up equipment and screen.
	1	2.2 [a]		CPPA demonstration field visit.
	1	1.7 [a]		Loader operator forgot keys.
	1	1.5 [a]		Timing interrupted to move screen.
	9	7.0 [a]	47 [a]	Cleaning debris and loading gravel truck.
	1	0.5 [a]		Try aspen debarking.
	1	0.3		Maintenance.
<10 min.	1	0.1	7	Try aspen debarking.
	16	21.3	78	Total organizational delays
Personal Delays				
	2	0.5	15	Planning and discussion.
<10 min.	11	1.0	5	Breaks.
	13	1.5	6	Total personal delays
Service and Repair Delays				
	4	8.7	130	Warm up and cold weather service.
	5	4.5	54	Replace flail chains or chipper knives.
	7	26.8	230	Mechanical repairs on chipper.[b]
	1	1.4	84	Mechanical repairs on flail.
	1	0.3	18	Skidder repairs.
	1	0.2	12	Maintenance.
	19	41.9	132	Total mechanical delays

[a] Would not occur in an operational setup.
[b] 4.5 h of repairs were also carried out during out-of-shift time.

Details of Mechanical Repairs Delays Greater then 10 Minutes Duration

Repair (h)	Get parts (h)	Wait mechanic (h)	Explanation
2.3	5.1	2.0	Idler pulley on radiator fan-came off.
2.7	3.8	1.2	Plate on chipper infeed chain broke.
0.5	3.3 [a]		Hose on chipper loader repaired.
0.6	2.0 [a]		Hose to chipper feed motor repaired.
2.0			Winterize chipper.
1.5			Change upper and lower flail chains after 15 loads.
1.4			Thaw frozen air lines on flail.
0.5	0.5		Repair chain to chipper feed roller.
0.8			Change upper flail chains after 14 loads and chipper knives after 16 loads.
0.8			Change lower chains on flail after 13 loads.
0.7			Change chipper knives after 19 loads.
0.7			Change chipper knives after 11 loads.
0.3			Change flat tire on chipper.
0.3			Repair broken skidder mainline.
0.2			Maintenance.
15.3 +	14.7 +	3.2 =	33.2

[a] Delay would not occur or not be as long in an operational set up where a supply of hoses and spare parts would be readily available.

APPENDIX V

Equipment Cost Calculation [a]

	Total [b]	Loader	Flail	Chipper	Alternate loader [c]
OWNERSHIP COSTS					
Purchase price (P) $	730 000	240 000	170 000	320 000	160 000
Expected life (y) yr		7.5	7.5	7.5	7.5
Hours per year (h) h	2 000	2 000	2 000	2 000	2 000
Interest rate (I) %	12.5	12.5	12.5	12.5	12.5
Insurance rate (Ins) %	3	3	3	3	3
Salvage value (S) = (0.2 x P)	146 000	48 000	34 000	64 000	32 000
Average investment (AVI) = (P + S)/2	438 000	144 000	102 000	192 000	96 000
Loss in resale value = (P - S)/(y x h)	38.93	12.80	9.07	17.07	8.53
Interest = (I x AVI)/h	27.38	9.00	6.38	12.00	6.00
Insurance = (Ins x AVI)/h	6.57	2.16	1.53	2.88	1.44
Total ownership costs	72.88	23.96	16.97	31.95	15.97
OPERATING AND REPAIR COSTS					
Fuel consumption (F) L/h	81	20	25	36	22
Fuel cost (f) $/L	0.50	0.50	0.50	0.50	0.50
Annual repair and maintenance (R) $	89 000	29 000	22 000	38 000	20 000
Wages (W) $/h	40	20		20	20
Wage benefit loading (WBL) %	35	35		35	35
Pickup reimbursement (PU) $/day	70	35		35	35
Hourly repair (R/h)	44.50	14.50	11.00	19.00	10.00
Fuel cost (FC) = (F x f)	40.50	10.00	12.50	18.00	11.00
Lube and oil cost = (0.15 x FC)	6.08	1.50	1.88	2.70	1.65
Pickup (PU/8-h shift)	8.75	4.38		4.37	4.38
Labour cost = [W x (1 + WBL/100)]	54.00	27.00		27.00	27.00
Overtime (W x 1.5WBL) x 0.5/9	4.50	2.25		2.25	2.25
Total operating costs ($)	158.33	59.63	25.38	73.32	56.28
OWNERSHIP AND OPERATING COSTS ($)	231.21	83.59	42.35	105.27	72.25
Excluding interest ($)	203.83	74.59	35.97	93.27	66.25
8-h shift cost ($)	1 630.64	596.72	287.76	746.16	530.00
ALTERNATE OWNERSHIP AND OPERATING COSTS [b] ($)					219.87
Excluding interest ($)					195.49
8-h shift cost ($)					1 563.92

[a] These costs do not include chain, rods, and knife replacement. These costs are calculated separately.
[b] Based on loader, flail, and chipper used during trial.
[c] Based on smaller loader, flail, and chipper.

APPENDIX VI

Flail-Debarker System: Summary of Detailed Timing (All Delays Included)

No. of vans loaded: 29
No. of logs processed: 7991
Logs per van: 276

	Loader			Flail			Chipper			Vans		
	Total (min)	Min/ van	%	Total (min)	Min/ van	%	Total (min)	Min/ van	%	Total (min)	Min/ van	%
Productive time												
Loading, debarking, chipping	1 232	42	59	1 327	46	63	1 183	41	56	1 559	54	74
Loader clearing debris	19	1	1									
Loader/flail/chipper wait for logs	10	0	0	140	5	7	291	10	14			
Loader waiting for skidder	161	6	8									
Loader waiting for flail	42	1	2									
Flail jammed	2	0	0	2	0	0	2	0	0			
Organizational delays												
Taking chip sample	75	3	4	75	3	4	74	3	4			
Shovel chips	10	0	0	10	0	0	10	0	0			
Clean debris with backhoe	27	1	1	27	1	1	27	1	1	27	1	1
Total productive time	1 578	54	75	1 581	55	75	1 587	55	75	1 586	55	75
Operational delays												
Wait for chip van	113	4	5	117	4	6	116	4	6	116	4	6
Exchange chip vans	292	10	14	285	10	13	281	10	13	282	10	13
Total operational delays	405	14	19	402	14	19	397	14	19	398	14	19
Mechanical delays												
Rep chipper hyd. fitting	22	<1	1	22	<1	1	22	<1	1	22	<1	1
Rep skidder mainline	15	<1	1	15	<1	1	15	<1	1	15	<1	1
Flail controls frozen	84	3	4	84	3	4	83	3	4	83	3	4
Total mechanical delays	121	4	6	121	4	6	120	4	6	120	4	6
TOTAL	2 104	73	100	2 104	73	100	2 104	73	100	2 104	73	100