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A COMPARISON OF FULL-TREE VERSUS CUT-TO-LENGTH SYSTEMS IN THE MANITOBA MODEL FOREST

J.-F. Gingras

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Abstract

During the Fall of 1993, FERIC conducted a comparative study of two wood harvesting systems in the Manitoba Model Forest. The two systems were (1) full-tree to roadside using a feller-buncher, grapple skidders, a stroke delimber and a one-man slasher, and (2) a cut-to-length system using a single-grip harvester and a forwarder. The report presents information on productivity, costs and short-term environmental impacts (ground disturbance, damage to advance regeneration, residual fiber, nutrient losses).

Acknowledgments

The author would like to thank the woodlands staff of Abitibi-Price Inc. in Pine Falls for their cooperation during the trial, and in particular the role played by Harold Peacock in ensuring that everything ran smoothly and efficiently during our presence on site. The author also wishes to thank two FERIC colleagues, Jean Favreau and Philippe Meek, for their tremendous help in carrying out the data collection in the field. The author would like to thank the machine operators, in particular Ben Gagnon and Benoit Dubé, for their patience and cooperation during the studies. Finally, the excellent cooperation from the University of Manitoba's botany department personnel, especially Isabel Waters, should be underlined.

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MANITOBA

MODEL FOREST NETWORK

RÉSEAU DE FORÊTS MODÈLES

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Introduction

In 1992, the Pine Falls division of Abitibi-Price Inc. was awarded one of Canada's ten Model Forests. One of the projects approved for the Manitoba Model Forest is entitled "Alternative Harvesting Equipment (project number 93-301)". Its objectives are to:

- find a more environmentally "friendly" harvesting system,
- determine the feasibility of implementing a cut-to-length harvesting system using an FMG single-grip harvester, and
- determine the environmental impacts of the new system, including site degradation, protection of advance regeneration, post-harvest regeneration, wildlife habitat changes, and road and landing requirements.

In recent years, the dominant harvesting system used at Pine Falls has been a mechanized full-tree to roadside system using feller-bunchers, wide-tired grapple skidders, stroke delimbers and one-man slashers at roadside. For this project, the company arranged to use a demonstration cut-to-length system to harvest about 6000 m^3 during the fall of 1993.

FERIC's mandate within the scope of this project was to assess the suitability of this system in the operating context of the Pine Falls Model Forest, measured in terms of:

- cost and productivity,
- operating logistics,
- short-term environmental impact.

Another cooperator on the project was the University of Manitoba's Botany Department, whose responsibility was to measure the vegetational succession after harvesting. University personnel also determined the study block layout and carried out pre-harvest surveys in the area to characterize pre-harvest vegetation.

Study Methods

During the summer of 1993, six study blocks were located in the Beaver Creek Road - Saxton Lake operating district, approximately 100 km northeast of Pine Falls, Manitoba (Figure 1). There were two blocks located in each of the major forest ecosystems common around the area:

- Jack pine stands over bedrock (JP1 and JP2), mixed softwood,
- Mixed softwood stands (pine and spruce) over medium-drainage tills (MW1 and MW2), and
- Black spruce stands in slow-drainage lowlands (BS1 and BS2).

Each block was identical in dimensions, measuring 100 m by 270 m, and was further subdivided into nine equal strips, each measuring 30 m by 100 m deep. Three replications of the three treatments, (1) full-tree harvesting, (2) cut-to-length harvesting, and (3) an uncut control, were randomly allocated to the strips in each block. Figure 2 illustrates the treatment layout for the first jack pine block (JP1) and first mixedwood block (MW1).

Unfortunately, because of very wet conditions in Pine Falls during 1993, it was not possible to access the two lowland black spruce blocks and data were only gathered on four of the six study blocks. The black spruce swamp areas were logged after freeze-up, but no productivity data were collected by FERIC.

Abitibi-Price conducted an operational forest inventory and a forest ecological classification of the area during the summer. In addition, University of Manitoba personnel conducted vegetation surveys throughout the test area to measure total vegetational cover, including the moss and herbaceous strata.

The productivity studies were conducted by FERIC a few days after the arrival of the cut-to-length system in September 1993. Most of the time study efforts were directed at the cut-to-length system since the full-tree equipment was considered typical of eastern Canadian setups, from which average productivity information

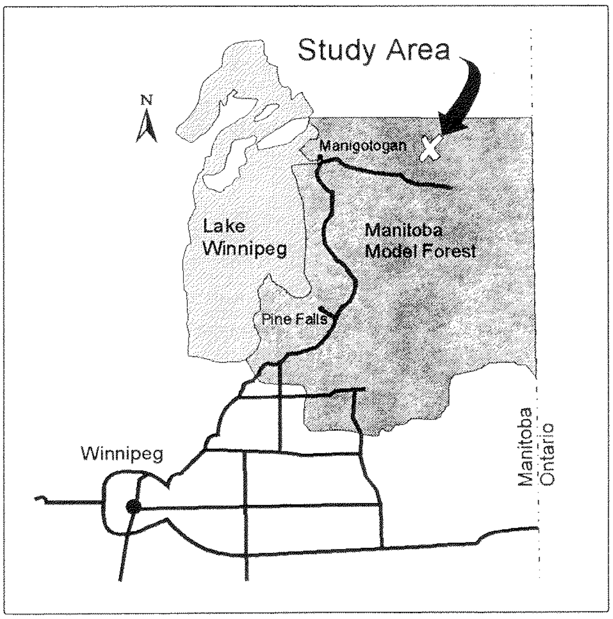

Figure 1. Study area.

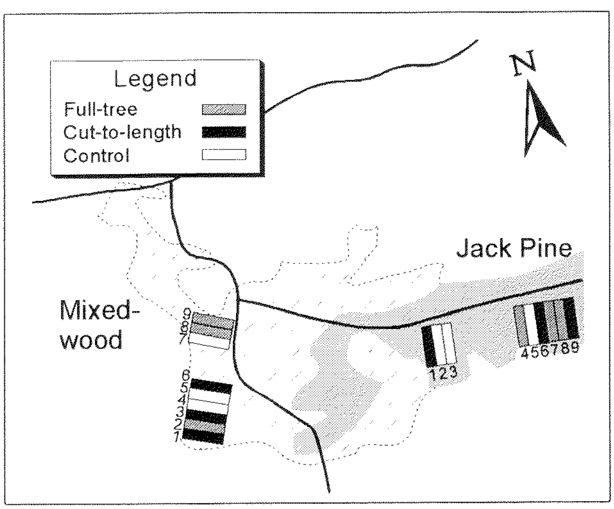

Figure 2. Treatment layout in jack pine block JP1 and mixedwood block MW1.

could be used for comparative purposes. Nevertheless, some data was collected on the full-tree machines to enable an assessment of the overall efficiency of the operations.

Detailed time studies were conducted with the use of the TS-1000 time study program developed by FERIC staff for their DAP PC-1000 handheld field computers. A sample of bucked logs was scaled to provide an average log volume for use in productivity calculations. In the case of full-tree machines, butt scaling of a sample of trees combined with volumetric tables for the area provided an average volume per tree for the productivity calculations. Machine costing calculations were done using the standardized FERIC technique and based on the assumptions presented in Appendix I.

Machine utilization, total production and mechanical repair data were collected by company representatives on the single-grip FMG harvester for the whole duration of the trials.

Post-harvest assessments were conducted by FERIC using continuous survey lines in all harvested strips. In every block, about 130 sample plots (4 m^2) were established for each treatment. In each plot, the following information was collected:

- presence/absence of possible microsites for natural or artificial regeneration,
- absence/presence of softwood regeneration,
- volume of merchantable debris,
- proportion of soil area subject to machine passage,
- relative ground disturbance coverage, using the classes described in Appendix II.

For the ground disturbance analysis, three groups were formed based on the perceived severity of the disturbance:

- ***low severity***: includes undisturbed humus, slight humus disturbance (i.e., no exposure of mineral soil) and non-disturbable areas (stumps, boulders). These disturbances have virtually no impact on the forest ecosystem.
- ***moderate severity***: includes disturbances that involve mineral-soil exposure to a depth of less than 10 cm. These areas are thus potentially subject to erosion, but are still able to provide an appropriate seedbed or plantable microsite. Classes include an organic/mineral mix, shallow mineral-soil exposure and mineral soil deposits over organic matter.

- ***high severity***: includes all classes in which mineral soil is exposed to a depth of greater than 10 cm. This also includes disturbances in which stagnant surface water will collect as a result of changes in the soil structure. The classes include deep mineral-soil exposure, muck and erosion features (ruts, gullies, sedimentation), and generally do not provide a suitable microsite for regeneration. In the shallow-soil areas (e.g., bedrock), removal of the loose surface layer to expose the bedrock was considered to be a high-severity disturbance.

Site Description

The test area is located in the fringe zone between the Nelson River and the Northern Coniferous forest regions, as described in the Environmental Impact Assessment Report of the Abitibi-Price Forest Resource Management Plan (1991-1998).

The Nelson River area consists of vast stands of black spruce growing in extensive swamps that run back from the rivers. Where drainage is improved, stands of white spruce can be found in association with trembling aspen and balsam poplar, and to a lesser extent, with white birch and balsam fir. In the Model Forest section of the Northern Coniferous area, jack pine is the predominant species primarily because frequent fires have favored its spread on many upland sites. In river valleys and around lakes, more favorable conditions permit growth of mixed stands of white spruce, balsam fir, trembling aspen and balsam poplar.

In general, the geomorphology illustrates the glacial history of the area, with extensive erosion and accumulation of glacial Precambrian till (granitic, gneiss, metavolcanic, etc.) with a wide range of particle sizes. The area was also inundated by Lake Agassiz after the ice receded some 10 000 years ago. The soils are now mainly luvisolic in nature, and most sites have a mix of well- and imperfectly drained soils, with sandy loam to clay (base saturated) parent material.

Table 1 provides some of the major parameters obtained by the forest ecosystem classification (FEC) for a sample of strips in the four blocks in which the trial was held. The survey procedure and terminology follows that developed by the Ontario Ministry of Natural Resources (Sims et al. 1989).

Table 1. Forest ecosystem classification (Sims et al. 1989) of sample plots in the four study blocks[a]

Parameter	JP1 cut-to-length	JP1 cut-to-length	JP2 cut-to-length	JP2 control	MW1 full-tree	MW1 control	MW2 cut-to-length
Vegetation type	V28	V9	V28	V29	V9	V10	V15
Stand height (m)	18	24	19	20	14	22-24	24
Stand age (year)	98	98	98	98	98	98	150+
Slope (%)	45	0	3	3	1	4	1
Soil classification	SS5	S10	S10	SS5	S6	S6	S10
Site position	upper	level	upper	crest	level	-	crest
Microtopography	severe	severe	smooth	severe	smooth	-	smooth
Site surface shape	CVE	STR	CVE	-	STR	CVE	-
Soil moisture class	5	5	4	0	3	3	5
Soil drainage class	L	L	P	VR	W	W	L
Seepage	none	slight	none	none	none	none	none
LFH thickness (cm)	2	2	5	0	4	2	3
Depth of A horizon (cm)	0	9	4	0	5	5	6
Depth of B/O horizon (cm)	30	91	146	28	50	65	47
Depth to bedrock (cm)	30	100	150	28	55	70+	53
Depth of water table (cm)	-	64	-	-	-	-	-
Particle size class	S	-	C	S	C	-	C

[a] Abbreviations follow those in Sims et al. (1989).

Table 2 describes the pre-harvest stand and advance regeneration condition in the four study blocks.

Table 2. Pre-harvest and advance regeneration data

Parameter	JP1	JP2	MW1	MW2
Density (stems/ha)				
- Softwood	900	700	350	400
- Hardwood	100	25	150	100
Volume (m^3/ha)				
- Softwood	165	185	120	85
- Hardwood	45	10	85	50
Volume per tree (m^3)				
- Softwood	0.18	0.26	0.34	0.21
- Hardwood	0.45	0.40	0.57	0.50
Regeneration density (stems/ha)				
- Softwood	10	225	1 325	19 650
- Hardwood	0	100	275	250
Regeneration stocking (%)				
- Softwood	2	4	24	93
- Hardwood	0	9	37	24

Description of the Harvest Systems

The full-tree system observed consisted of the following machines:

- A **Koehring model 618 feller-buncher** equipped with a 50-cm Koehring side-cut circular saw. This machine represents a common feller-buncher configuration in eastern Canada, although the side-cut head is fairly rare and a bit more difficult to operate than front-cut saws.
- **Clark 665 grapple skidders**, some equipped with narrow tires and others with 125-cm-wide tires, and some with Hydra-wrap 138 grapple attachments. These machines had tire chains on only the front wheels and typically had fairly worn lugs on the tires.
- A **Denis telescopic stroke delimber** mounted on a Komatsu 200L-3 carrier. This machine is typical of roadside processing machines used in the east.
- A **Hood tow-behind slasher.** This configuration is not very common compared with wheeled one-man slashers such as the Tanguay CC-100 or other Hood models. This machine featured a skid-mounted saw and no holding baskets for the top portion of the trees. The unit was producing only 2.54-m bolts.

All full-tree equipment had been in use for a number of years. The feller-buncher had been used for 15 000 hours, the skidders for between 7500 and 10 000 hours, and the delimber for 20 000 hours.

The cut-to-length system consisted of the following machines:

- A **Timberjack 1270 single-grip harvester** equipped with the 762B Koehring/FMG harvester head. This six-wheeled machine featured a parallel-action boom and a series of automated process controls. Again, only 2.54-m bolts were produced during the trial.
- A **Timberjack 1010 shortwood forwarder** featuring six-wheel drive and 11-tonne load capacity. The forwarder shares many common components with the harvester.

Both machines were less than 6 months old.

Productivity Results

Full-tree to Roadside System

Since full-tree to roadside was the usual harvesting system at Pine Falls, little new productivity data was collected on the full-tree machines. In addition, the very wet summer and fall in 1993 in Manitoba made ground conditions very soft, which made ground skidding, even with wide tires, extremely difficult. In fact, if it had not been for the cut-to-length trial already scheduled, normal harvesting operations would not have taken place.

Table 3. Productivity estimates for the full-tree machines

	Koehring 618 feller-buncher	Clark grapple skidders	Denis delimber	Hood slasher
Study block	MW2	JP1, MW1	Outside area	JP1
Studied productive machine hours (PMH)	3.2	5.2	1.7	0.9
Total trees	448	148	226	100
Trees/PMH	140	28	133	112
Average m³/tree[a]	0.20	0.31	0.17	0.31
Average m³/PMH	28.0	8.7[b]	22.6	34.6
Expected m³/PMH[c]	25-35	20-30	25-35	30-40

[a] from the sample scaling
[b] combined estimate from the two blocks
[c] based on earlier FERIC studies under similar conditions

Table 3 presents the productivity results for the full-tree machines, complemented by the expected productivity range of similar machines based on earlier FERIC studies.

The feller-buncher produced around 28 m³/PMH in the one block in which it was studied. This productivity appeared normal for the stand conditions encountered and no major flaws in operating techniques were apparent.

The skidding phase did not go well, partly because the skidder operators were not very experienced, but also because of the very wet ground in the two mixedwood study blocks. However, the trial results indicated that the use of grapple skidders may present problems under some of the Pine Falls conditions.

Both the delimber and slasher productivity appeared normal for the conditions that they were operating under. Both machines had experienced operators and by working at roadside, were less affected by the wet ground conditions.

Cut-to-length System

Most of the time study efforts were directed at the cut-to-length machines, and in particular at the harvester, since this represented the key machine in the trial. Table 4 summarizes the productivity information gathered by FERIC during the study.

Table 4. Productivity results for the cut-to-length machines

	Timberjack 1270 harvester	Timberjack 1010 forwarder
Jack pine (JP1)		(average distance: 300 m)
Total PMH studied	5.6	2.7
Total trees	409	---
Total bolts	2046	542
Average load size (m³)	---	11.3
Trees/PMH	73	---
Average m³/tree	0.36	---
Average m³/PMH	26.7	14.9
Mixedwood (MW1, MW2)		(average distance: 95 m)
Total PMH studied	6.8	10.9
Total trees	356	---
Total bolts	1707	2299
Average load size (m³)	---	5.6
Trees/PMH	52	---
Average m³/tree	0.32	---
Average m³/PMH	16.9	14.3

Both the harvester and forwarder worked well during the study period, and neither was seriously affected by the wet ground conditions. Average tree volumes during the FERIC time studies were higher than the average volume measured during the cruise. The productivity of the harvester was higher in the jack pine blocks mainly because of easier delimbing and a longer length of merchantable stem. In the mixedwood blocks, reduced visibility and more difficult delimbing conditions resulted in lower productivity.

Forwarder productivity was fairly constant between both study areas, since the longer skid distance in the jack pine blocks was offset by much softer ground conditions in the mixedwood blocks. The long forwarding distance in the jack pine block was a result of a lack of landing space near the actual study block. Because of its superior flotation, the forwarder was able to work in the mixedwood areas, which proved to be inaccessible to the grapple skidders, even with the wide tires. The forwarder operator did have to reduce his loads by about half during some trips, but he never got stuck during the study.

By recording the number of bolts produced per tree and per processing cycle, it was possible to generate an approximate relationship between average tree size and harvester productivity (Figure 3). The relationship shows a directly proportional increase between productivity and volume per tree until an inflection point at about 0.40 m³/tree. It was observed that beyond this volume, the size of the limbs created serious problems for the harvester. The boom had enough power to move these large trees, but the rollers did not provide enough traction on the stems to remove the largest branches. Considerable back and forth motion was thus required during delimbing.

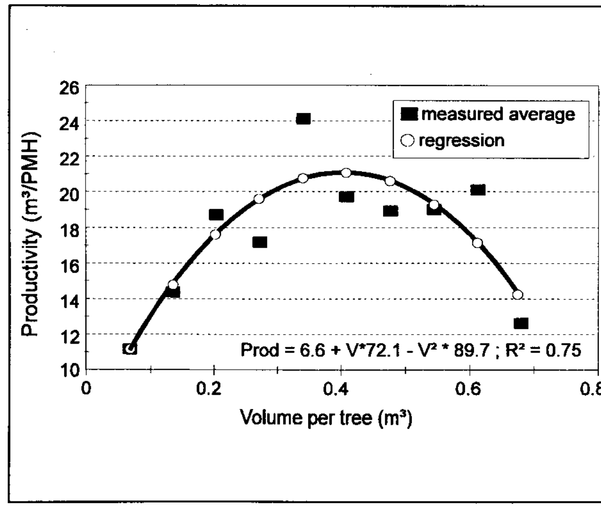

Figure 3. Effect of tree volume on harvester productivity in the cut-to-length system.

For the duration of the trial, company personnel recorded shift-level availability and production data for the cut-to-length machines. These data are presented in Table 5.

Table 5. Availability, utilization and total production for the Timberjack 1270 harvester and 1010 forwarder from September 17 to November 8, 1993

Parameter	Timberjack 1270 harvester	Timberjack 1010 forwarder
Total recorded shifts	38	38
Total scheduled (meter) hours (SMH)	519.5	498.5
Total service and repair hours	29.25	21.5
Total warm-up/move/dinner/misc.	70.50	59.5
Total PMH	419.75	417.5
Average SMH/shift	13.7	13.1
Average PMH/shift	11.1	11.0
Mechanical availability (%)	94.4	95.7
Machine utilization (%)	80.8	83.8
Total trees harvested	25 904	25 904
Total volume produced (m³)	6 245	6 245
Trees/PMH	61.7	62.0
Volume/PMH (m³)	14.9	15.0

Short-term Environmental Impacts

Ground Disturbance

Table 6 presents the post-harvest ground disturbance data. Unfortunately, some surveyed strips had to be eliminated from the analysis since there was evidence that some interference between systems had occurred, likely as a result of the very narrow experimental strips. For each retained strip, the ground disturbance had been caused by harvesting equipment operating exclusively within its own strip.

The higher levels of soil disturbance in the full-tree system clearly show that machines traveled over a greater proportion of the cutover area than in the cut-to-length system, regardless of the ecosystem considered. It follows that the percentage of undisturbed soil is higher in the cut-to-length strips. The areas in the *humus disturbed* class were twice as great in the full-tree system. A single passage of a wheel or a single scrape from skidded trees can produce this disturbance.

Other disturbance classes are encountered mainly in trails that sustained multiple passages by machinery (rutting, compaction, wheel slip and spin, etc.). Deep mineral-soil exposure in the jack pine ecosystem was mainly the result of bedrock exposure. In the mixedwood blocks, deep mineral-soil exposure was generally a result of rutting in soft soils, and machine travel also led to some mineral-soil deposition over organic layers.

Table 6. Ground disturbance data

	JP1/JP2		MW1/MW2	
System	Full-tree	Cut-to-length	Full-tree	Cut-to-length
Number of strips retained	3	3	3	3
Area sampled (% of treatment)	5.4	6.6	5.9	5.2
Ground disturbance (% of sampled area)				
Undisturbed soil	24	58	37	63
Humus disturbed	43	19	29	16
Mineral soil deposits	2	1	8	0
Shallow mineral soil exposure	6	1	10	1
Mix of mineral soil and organic matter	1	0	1	0
Deep mineral soil exposure	7	2	7	2
Muck	5	2	0	0
Erosion features	0	0	0	0
Non-disturbable	5	5	1	0
Non-assessable[a]	7	12	7	18
By severity class (% of assessable area only)[b]				
Low	77 *x*	91 *y*	70 *x*	95 *y*
Medium	9 *x*	4 *x*	22 *y*	3 *x*
High	14 *y*	5 *x*	8 *x*	2 *x*
Area with machine trails (%)	69	34	55	32

[a] Typically, areas covered by slash.

[b] Numbers in a row followed by the same letters are not significantly different ($\alpha = 0.05$).

Analysis of variance was conducted on the data for each group of severity and a least significant difference (LSD) procedure was used to recognize similar means. Disturbance levels in the cut-to-length strips in both ecosystems were very similar, and were consistently lower than in the full-tree strips. Full-tree harvesting in the mixedwood stands showed a higher level of medium-severity disturbance because of the presence of high levels of shallow mineral-soil exposure. In the high-severity disturbance class, the full-tree system created a greater quantity of muck in the trails, especially in the jack pine blocks.

A second statistical analysis was performed on the data using a factorial analysis of variance with ecosystem as one factor and harvesting method as the second factor. For the low-severity disturbance class, the harvesting system had a significant influence on the disturbance level but the ecosystem had no statistically significant effect. With the medium- and high-severity classes, the influence of both the ecosystem and the harvesting method were confirmed. In addition, disturbance levels in the medium-severity class showed that there was an interaction of the two factors when mixedwood blocks were harvested with the full-tree system.

Regeneration

Table 7 summarizes the results of the regeneration and residual fiber surveys conducted about one month after the harvest took place.

Debris in the full-tree strips was scattered and randomly distributed. The non-assessable category in Table 6 shows that in the cut-to-length strips, debris covered about twice the area as in full-tree strips and was concentrated on the machine trails. This resulted in a higher regeneration microsite loss in the cut-to-length strips (Table 7). In the mixedwood blocks, the loss was greater since the trees had a larger proportion of branches than in the jack pine. The accumulation of slash and debris appeared to protect the soil more in the cut-to-length trails (Table 6).

The post-harvest survey did not show any clear evidence of the relative abilities of either harvesting system to protect advance regeneration, except possibly in the mixedwood cut-to-length strips, where the post-harvest stocking and density were higher than elsewhere. However, in general, levels of advance regeneration were low except in the second mixedwood block and regeneration was not uniformly distributed no matter what system was used.

Residual Fiber

There was no evidence from the survey that either harvesting system caused poor fiber utilization, since only a small amount of merchantable debris remained on the cutover (Table 7). The measured amounts can be considered acceptable according to most provincial forest legislations. An earlier FERIC study had found a greater fiber yield per hectare with a cut-to-length system than with traditional full-tree roundwood systems (Gingras 1992).

Table 7. Post-harvest softwood regeneration and residual fiber results

	JP1/JP2		MW1/MW2	
System	Full-tree	Cut-to-length	Full-tree	Cut-to-length
Microsite loss because of debris (% of sample plots)[a]	2	3	2	5
Softwood stocking (%)				
- Initial	3[b]	3[b]	58[b]	58[b]
- Residual	0	1	16	38
Softwood regeneration density (stems/ha)				
- Initial	115[b]	115[b]	10 550[b]	10 550[b]
- Residual	0	50	1 000	4 300
Merchantable debris (m^3/ha)	2.2	0	0	0

[a] Plots that were fully covered with slash, so that there was not a single available microsite over the 4-m^2 area.
[b] Average stocking or density of the two blocks.

Nutrient Pool

It was beyond FERIC's abilities and expertise to conduct full-scale nutrient-loss studies in full-tree and shortwood harvesting. However, some noteworthy studies have been published recently and these may provide some insight into this topic as it relates to the Pine Falls operating conditions.

Pierce et al. (1993) published an excellent summary report summarizing ten years of work on nutrient cycling in New England watersheds. The report not only presents some study results, but also a very understandable explanation of some of the basic mechanisms by which nutrient status evolves in soils subjected to different modifications. Foster and Morrison (1987, 1989) compared losses of nitrogen and base cations with full-tree harvesting and tree-length harvesting in black spruce ecosystems. Similar studies were published for the Maritimes provinces (Freedman 1981, 1991; Freedman et al. 1981). Mahandrappa (1990) reported changes in nutrient cycling behavior in forest ecosystems for various harvesting systems.

From these studies, it appears that nutrient losses resulting from the export of full trees from the harvest site may represent a long-term problem on sites that have an inherently low fertility, such as shallow soils over granitic bedrock, or coarse material with a low cation-exchange potential, such as sands. In the absence of any firm conclusions from these studies, we can only assume that a cut-to-length system should have a positive impact, from a nutrient pool perspective, since the nutrient-rich components of the tree (foliage, small branches) remain on the harvest site. However, the nutrient-rich slash tends to be concentrated in windrows unless special operating techniques are used.

Discussion

Productivity

Full-tree to roadside machines are normally more productive than cut-to-length equipment under boreal forest conditions because they can handle several stems at a time, except for the delimber. In addition, feller-bunchers are not affected greatly by adverse stand conditions such as poor visibility or a dense understory of unmerchantable stems.

In the Pine Falls context, however, these advantages may be somewhat offset by problems incurred by the full-tree system. The trial clearly showed the problems that grapple skidders run into on soft ground, as both the grapple skidders and the feller-buncher became stuck in some of the research blocks during the trial. The six-wheeled forwarder was able to operate under the wettest conditions encountered, albeit with a slightly reduced productivity.

Average tree sizes in the area (0.15 to 0.25 m^3/tree), and especially during the time studies, were a bit larger than what is normally found under most eastern boreal conditions. This tree size represents the optimal operating range for most single-grip harvesters. Since these harvesters can only handle one tree at a time, productivity goes down fairly rapidly when average tree volume falls below 0.15 m^3.

When a large number of unmerchantable (non-crop) trees such as trembling aspen are present, the harvester appeared to be better than a feller-buncher because it could reach between and around them to harvest the merchantable stems. This led to lesser damage to non-crop trees, which the feller-buncher often had to remove from its path. With both machines, productivity decreased as the number of non-merchantable stems increased.

With the exception of the grapple skidders, the full-tree machines observed operated at an average or slightly below average rate, which could be expected under the conditions encountered. It is difficult to predict whether it will be possible to attain the productivity levels measured with the cut-to-length units during the trials over the long-term. Both demonstration operators were quite proficient and motivated, often working toward daily production objectives rather than shift lengths.

Harvesting Costs

Table 8 presents a comparison of calculated direct harvesting costs based on the productivity data obtained in the mixedwood trial blocks (little production data was gathered on full-tree machines in the jack pine blocks). Costs under different operating conditions and long-term costs may vary, and it should be remembered that operating conditions were particularly difficult in the two mixedwood blocks. The hourly machine costs are based on the assumptions presented in Appendix I. The utilization rates of the full-tree tracked machines were reduced by 10% over the normal assumptions to take into account the large amount of travel between blocks that was required at Pine Falls.

Table 8. Comparison of direct harvesting costs between the two systems in the mixedwood blocks

	Hourly cost ($/PMH)	Study productivity (m^3/PMH)	Direct cost ($/$m^3$)
Full-tree system			
Feller-buncher	115	28.0	4.11
Grapple skidder	61	20.0[a]	3.05
Delimber	85	22.6	3.76
Slasher	74	34.6	2.14
Total			13.06
Cut-to-length system			
Harvester	119	16.9	7.04
Forwarder	76	14.3	5.31
Total			12.35

[a] Because the observed productivity of the grapple skidders was not typical, the expected productivity for such machines was used in the costing calculations.

Based on the hourly cost calculated in Appendix 1, the productivity levels measured during the study, and an assumed productivity for the grapple skidders, the cut-to-length system was cheaper than the full-tree system by about $0.71/$m^3$ *during the trial.*

Logistics

The two harvesting systems require different logistical support and planning. Obviously, less supervision and support are needed with integrated teams of two machines than with non-integrated systems of four machines.

As well, the operating blocks at Pine Falls tended to be scattered because of the varied topography of the sites, where lowland spruce swamps are intermixed with bedrock outcrops. The integrated two-machine system is much easier to move around than the four-machine system, which needs cold deck inventories between each phase. Although it was not possible to measure differences in utilization rates during this short trial, it can be safely assumed that up to 10% of the full-tree machines' scheduled time involves delays induced by moving machines from one cut block to another. These delays would be drastically reduced with the two-machine system. The wheeled machines also have significant mobility advantages compared with the tracked machines.

Because of their small payload, grapple skidders are typically restricted to skidding distances of 300 m, and less on wet ground. Because forwarders carry a payload three to four times greater, the proportion of cycle time spent in traveling to and from the landing can be increased with a lesser impact on productivity. This means that block depth can be increased to about 1000 m, which reduces supervision requirements (e.g., more time spent in blocks, less landing to deal with, etc.) and permits wider spacing between roads.

Forwarders need very little room to unload. This means that they can pile wood almost anywhere, without having to prepare landings. This is very important if landing space is limited.

Environmental Impact

Generally, the cut-to-length machines produced less disturbance of the forest ecosystem than did the full-tree machines. Levels of moderate and severe ground disturbance were lower, and there are indications that destruction of advance regeneration would be reduced, since less of the block area showed signs of machine passage. The proportion of the area in the undisturbed soil class is a good indication of the capabilities of harvesting systems to preserve advance regeneration.

It should be remembered, however, that the summer and fall of 1993 had above-average amounts of rainfall, so that the harvesting sites were particularly wet. The problems encountered by the full-tree machines, and their associated impacts, cannot be generalized to all sites and all seasons at Pine Falls. Nonetheless, wet conditions are common for this area, and the cut-to-length machines seemed better adapted to those conditions than the full-tree machines. Under wet conditions, the full-tree machines observed showed less flotation and maneuverability, and thus created more soil disturbance.

The suitability of either system will vary with the planned silvicultural prescription. For example, in a silvicultural context of natural regeneration with after-harvest seeding, such as in the jack pine ecosystem, some levels of mineral-soil exposure are possibly beneficial. Because of the low level of soil disturbance observed with cut-to-length machines, some form of site preparation will likely be needed to prepare seedbeds under this regime. The large amount of concentrated slash piles produced by the cut-to-length system may also represent a handicap to producing suitable microsites in this context if special operating techniques are not adopted to spread the slash more evenly.

Advantages and Disadvantages of Cut-to-length Systems at Pine Falls

Advantages with respect to the full-tree system

- Comparable or lower costs from harvesting to roadside
- Reduced supervision and support requirements
- Increased machine mobility between cut blocks
- Better fiber recovery resulting from harvesting marginal quality trees (since cull can be removed in the bush), less re-handling of logs and reduced slasher losses from shorts and tops
- Cleaner logs, because wood is carried to roadside and not dragged in the dirt during skidding and slashing phases
- Comparable or greater log length accuracy for merchandising of sawlogs
- Reduced levels of moderate and severe ground disturbance
- Greater potential for protection of advance regeneration
- No roadside slash piles to dispose of
- Reduced probability of nutrient losses as a result of harvesting practices
- Easy to pile wood anywhere; no preparation of a landing needed
- Greater potential for sorting shortwood by species or length
- Potential for automated scaling and the generation of instant production reports
- A better system for harvesting wet sites because of greater flotation of machinery

Disadvantages with respect to the full-tree system

- The harvester is sensitive to adverse stand conditions (e.g., small trees, dense undergrowth, high branchiness, poor tree form, etc.)
- Machines are more complex to repair and maintain
- Machine productivity is more sensitive to poor operating practices
- The learning curve for machine operators is longer than with traditional machines
- Uncertainty as to microsite availability for post-harvest natural seeding of jack pine
- Greater obstruction by slash for seeding-in, site preparation and planting

Recommendations

Cut-to-length Systems

The operating methods used with the demonstration machines were good and FERIC had no major recommendations for improvement. Some points for the company to remember for optimal operation of their own cut-to-length machines are:

Harvester

- Stock a large number of bars and chains, both in the field garage and in the harvesters. These parts are the most frequently abused during the initial stages of learning to operate this type of machine.
- Keep log piles tight and compact. This greatly facilitates loading by the forwarder.

Forwarder

- On the forwarder, adjust load size to suit the bearing capacity of the ground. When stuck, the only alternative for a forwarder is to unload, then reload once out of the hole.

- Do not worry about pile neatness in the forwarder's bunk. It is easier to rearrange the piles at the roadside than in the bush.
- When there are large amounts of both spruce and pine to extract, it is preferable to make separate trips with a single species than mixing species in the same load. However, if there is only a small proportion of one species, then mixed loads are appropriate.
- Work from the back of the block toward the road. Backing up during travel to the rear of the block is easy with forwarders because the seat can swivel.

Full-tree to Roadside Systems

At this point, it appears that Abitibi-Price intends to shift some or all of their harvesting to cut-to-length systems. However, should the transition take longer than planned, or if a decision is taken to keep some full-tree operations, there are some improvements that will maximize efficiency and reduce costs. These points concern mainly the skidding and the slashing phases, as no major potential improvements were noted for the feller-buncher or the stroke delimber operations.

Grapple Skidders

- Consider converting one or some of the grapple skidders to a cable skidder configuration to handle the wet ground areas. Grapple skidders could then be restricted to firm ground and road right-of-ways, where they are most effective.
- Many of the tires now in use are badly worn. Consider replacing them with 81-cm (32-inch) tires, a size that is now commonly used in operations in eastern Canada. Alternatively, 112-cm (44-inch) tires have been used successfully elsewhere and seem to offer a good compromise between flotation and traction. Chains are available for these tires as well.
- Equip skidders with recuperator grapples on the side of the blade. These are very useful for retrieving lost stems during skidding and can be used to lift a variety of objects. They are readily available from skidder distributors, and are cheap, robust, almost maintenance-free and common in Quebec and northeastern Ontario.

Slasher

- Consider equipping the slasher deck with some sort of support structure for the trees. Currently, the stems drag on the ground during processing and become covered with dirt. This decreases the quality of the roundwood and is very abrasive for the slasher's saw.
- The operator should not let go of the trees during advance of the saw. This leads to delays due to letting go then grabbing the stems again after the cut. It also increases friction on the saw by the wood, which in turn leads to frequent rotational stalls of the saw.

Conclusions

The objective of this equipment trial was to assess the relative merits and overall suitability of the cut-to-length system compared with a traditional full-tree to roadside system in the context of the Manitoba Model Forest.

The study results indicate that the cut-to-length system represents an attractive and viable alternative to the current system because of similar or lower direct harvesting costs, logistical advantages and reduced immediate ecosystem disturbance. The main advantages demonstrated were:

- good productivity
- high product quality
- reduced soil disturbance
- high equipment mobility

Part of the success of the trial stemmed from the high skill level of the two operators in the demonstration. Successful implementation of a cut-to-length system at Pine Falls will require a comprehensive training program to ensure that the local operators achieve the same level of proficiency demonstrated during the trials. It will also be necessary to establish a long-term follow-up of the system to assess its future impact on stand re-establishment and growth.

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Appendix I - Machine Costing Assumptions

A. Full-tree machines

	Koehring 618 harvester	Clark grapple skidder	Denis/Komatsu delimber	Hood slasher
INPUTS				
Expected machine life (years)	5	5	5	5
SMH/year	3 600	3 600	3 600	3 600
Purchase price ($)	370 000	130 000	300 000	230 000
Salvage value ($)	37 000	13 000	30 000	23 000
License cost ($/year)	0	0	0	0
Insurance ($/year)	18 500	6 500	15 000	11 500
Interest rate (%)	10	10	10	10
Utilization (%)	75	75	80	80
Lifetime repair cost ($)	462 500	130 000	300 000	230 000
Fuel consumption (L/PMH)	20	18	15	18
Fuel price ($/L)	0.35	0.35	0.35	0.35
Oil and lube ($/PMH)	3.50	0.95	0.79	0.95
Operator wages ($/SMH)	22	22	22	22
FIXED COSTS				
Annual capital cost ($)	91 544	32 164	74 225	56 906
Yearly other costs ($)	18 500	6 500	15 000	11 500
Yearly total cost ($)	110 044	38 664	89 225	68 406
Cost per PMH ($)	40.76	14.32	30.98	23.75
Cost per SMH ($)	30.57	10.74	24.78	19.00
VARIABLE COSTS				
Yearly cost ($)	120 850	45 561	77 388	66 865
Cost per PMH ($)	44.76	16.87	26.87	23.22
Cost per SMH ($)	33.57	12.66	21.50	18.57
LABOR COSTS				
Yearly cost ($)	79 200	79 200	79 200	79 200
Cost per PMH ($)	29.33	29.33	27.50	27.50
Cost per SMH ($)	22.00	22.00	22.00	22.00
TOTAL COST				
Grand total per year ($)	310 094	163 425	245 813	214 471
Grand total per PMH ($)	114.85	60.53	85.35	74.47
Grand total per SMH ($)	86.14	45.40	68.28	59.58

B. Cut-to-length machines

	Timberjack 1270 harvester	Timberjack 1010 forwarder
INPUTS		
Expected machine life (year)	5	5
SMH/year	3 600	3 600
Purchase price ($)	430 000	250 000
Salvage value ($)	43 000	25 000
License cost ($/year)	0	0
Insurance ($/year)	21 500	12 500
Interest rate (%)	10	10
Utilization (%)	80	80
Lifetime repair cost ($)	537 500	250 000
Fuel consumption (L/PMH)	18	12
Fuel price ($/L)	0.35	0.35
Oil and lube ($/PMH)	3.15	0.63
Operator wages ($/SMH)	22	22
FIXED COSTS		
Annual capital cost ($)	106 389	61 854
Yearly other cost ($)	21 500	12 500
Yearly total cost ($)	127 889	74 354
Cost per PMH ($)	44.41	25.82
Cost per SMH ($)	35.52	20.65
VARIABLE COSTS		
Yearly cost ($)	134 716	63 910
Cost per PMH ($)	46.78	22.19
Cost per SMH ($)	37.42	17.75
LABOR COSTS		
Yearly cost ($)	79 200	79 200
Cost per PMH ($)	27.50	27.50
Cost per SMH ($)	22.00	22.00
TOTAL COST		
Grand total per year ($)	341 805	217 464
Grand total per PMH ($)	118.68	75.51
Grand total per SMH ($)	94.95	60.41

Appendix II - Ground Disturbance Classes

Undisturbed soil

The soil does not show physical alterations caused by harvesting operations. Lower vegetation may have been swept away but the humus layer is intact.

Humus disturbed

Disturbance of the humus (LFH) layers exclusively. This includes torn up humus or exposed fibric or humic sub-layers.

Mineral-soil deposits

Displaced mineral soil covering slash or undisturbed soil.

Shallow mineral-soil exposure

Exposure of mineral soil within the zone that encompasses 90% of the roots (approx. 10 cm).

Mix of mineral soil and organic matter

An intimate mix of mineral soil with litter, vegetation and other organic matter.

Deep mineral-soil exposure

Mineral-soil exposure below the rooting zone (generally deeper than 10 cm).

Muck

Mineral or organic muck caused by the passage of a machine over wet soils.

Erosion features

Occurrence of erosion features such as rills, gullies and sediment zones. The soil is unstable and still subject to runoff erosion.