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AN ANALYSIS OF HARVESTING COSTS IN MIXEDWOOD FOREST

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Abstract

FERIC studied three harvesting systems in *clearcut* operations to define their specific productivities and costs under the harvesting conditions typical of mixedwood forest; the systems comprised mechanized full-tree and cut-to-length systems, as well as a manual system. FERIC compared their productivities with those typically observed in softwood stands and found that all three systems had lower productivities in mixedwood forest than in softwood forest at comparable stem volumes. The total harvesting cost, including the cost of loading, was higher than in softwood forest, and the manual system showed the greatest cost increase. Felling, delimbing, processing, and loading costs all increased for comparable volumes per stem and numbers of stems per hectare; however, since the average volume per stem is often greater in mixedwood forest than in softwood forest, the actual overall harvesting costs become comparable.

Introduction

Mixedwood forests include a broad variety of stand types. For the purposes of this report, FERIC defined mixedwoods as forests that contain between 25 and 75% of their volume in hardwood species. In these stands, the species diversity often contributes to increasing the overall stand yield. Thus, the forest industry finds such stands interesting because of the variety of products they offer.

However, this diversity can also lower the productivity of harvesting systems, particularly if only certain species have commercial potential (Figure 1). Therefore, FERIC began studying various clearcutting systems in 1998 with the goal of identifying the factors capable of affecting the cost of harvesting softwoods in mixedwood stands. The study included mechanized full-tree and cut-to-length systems, as well as a manual full-tree system. The results presented in this report will be integrated in version 2.0 of FERIC's *Interface* software to improve its effectiveness and accuracy.

Figure 1. Quality hardwood stems are often left standing in mixedwood forest.

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Study Methods

With the assistance of the companies that participated in the project, FERIC selected cut blocks that were representative of the typical working conditions in mixedwood forest. Wherever possible, nearby blocks of softwood forest were also chosen to permit a comparison of the relative productivities of *clearcutting* in mixedwood forest.

FERIC performed time studies for all the machines that made up the systems studied, including those used to load the trucks, and several observations were collected for each machine to provide a more realistic portrait. Each productivity observation involved a time study of about one hour to measure the work cycle elements capable of creating a productivity difference between the two types of forest. These observations were combined with an intensive measurement of all wood harvested during the time study. A pre-harvest stand inventory was performed to document the visibility, terrain conditions, stand density, and species distribution.

The productivity of certain machines was compared in the two types of forest by constructing productivity curves (m^3/PMH) as a function of the average volume per harvested stem (Appendix 1). For others, the comparison focused on the mean times required for harvesting or processing the softwood and hardwood stems. A third type of comparison consisted of analyzing the durations of the elements of the work cycle that could create productivity differences between the two types of forest.

Harvesting Systems

Manual Harvesting

In January and July 1998, FERIC studied a manual full-tree harvesting operation in the Mastigouche (Quebec) wildlife reserve in collaboration with Gérard Crête & Fils Inc. The volume harvested comprised 57% softwoods, 15% sugar maple and yellow birch, 12% aspen, 8% cedar, and 8% red pine and white pine. A feller and a cable skidder operator worked together as a team. The separation of softwoods, hardwoods, and aspen was performed in the forest during the extraction phase. Delimbing of hardwoods occurred in the forest, whereas mechanized delimbing of softwoods occurred at roadside. Even though the objective was to clearcut the stands, the pulpwood-quality hardwood stems were not harvested because of poor local markets for this product. Thus, a significant merchantable volume remained standing after harvesting. In the two studies, the cutover presented firm soils with some obstacles, and a slope of around 15% (CPPA class 1.2.2). In January, the snow depth was 1 m. Other studies in softwood forest were performed with Richard Pelletier et fils.

Mechanized full-tree harvesting

A mechanized full-tree system was studied in January 1998 near Ste-Anne-du-Lac (Quebec) in collaboration with the Coopérative Forestière des Hautes-Laurentides. The harvest block was composed of 60% black spruce and 40% white birch. A feller-buncher clearcut the stand and separated the birch from the spruce. For extraction, a grapple skidder and a cable skidder worked in tandem, with the cable skidder extracting those mixedwood loads where the product separation had not been completed by the feller-buncher. A delimber worked in a hot-logging operation with the skidders to handle the spruce, whereas the birch was manually delimbed and slashed at roadside. The cutover had firm soils, with no obstacles, but the slope reached 15% in some places (CPPA class 1.1.2).

A second full-tree harvesting system was observed in July 1998 with Manifor, south of La Vérendrye Park (Quebec). The mixedwood stands harvested during the study were composed of spruce (16%), balsam fir (22%), maple (11%), aspen (16%), and birch (35%). A feller-buncher and grapple skidders harvested the softwoods and the aspen without separating them, and left the other merchantable hardwoods standing. Harvesting of sawlog-quality hardwoods was done manually once the mechanized harvesting was complete, and pulpwood-quality hardwoods with a DBH of less than 28 or 34 cm (depending on the species) were left standing because of poor local markets for hardwood pulp. A delimber separated the softwoods and aspen at roadside. The cutover had firm soils with some obstacles and a slope of around 15% (CPPA class 1.2(1).2).

FERIC studied a third full-tree system in August 1998 northeast of Témiscaming (Quebec) with Tembec Inc.; only the felling and delimbing operations were observed. The harvested stand was composed of 56% softwoods and 44% hardwoods (primarily white birch, with a little aspen). The red pine and white pine were left standing for subsequent manual harvesting if their DBH was greater than 34 cm. A feller-buncher harvested all the merchantable volume without performing sorting. Grapple skidders extracted the stems to roadside, where a delimber delimbed them and separated the products. The cutover was firm, flat, and obstacle-free (CPPA class 1.1.1).

Mechanized cut-to-length harvesting

FERIC studied cut-to-length harvesting in February and September 1998 near Cabano (Quebec), with Alliance Forest Products Inc.–Guérette Inc. The stands had a variable softwood volume, with balsam fir, sugar maple, red maple, yellow birch, white birch, and cedar present. The hardwood volume represented more than 50% of the volume harvested. A feller-buncher separated the softwood and hardwood stems, and was followed by a Target processor that produced 5-m softwood sawlogs, 3.1-m softwood sawlogs and pulpwood, and 2.5-m hardwood sawlogs and pulpwood. A worker removed the largest hardwood branches to facilitate the processor's work. A shortwood forwarder extracted the products separately to roadside. The cutover had a firm soil, generally free of obstacles, with a slope that ranged from 0 to 15% (CPPA class 1.1(2).2(1)).

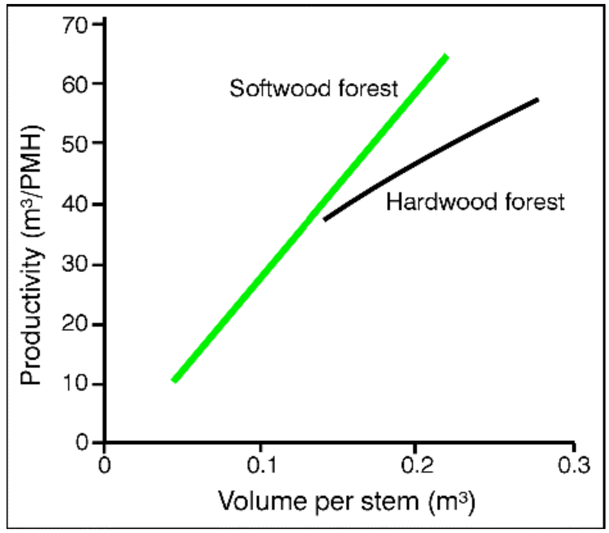

Figure 2. Comparison of the productivities of mechanized felling in mixedwood forest (hardwoods and softwoods) and softwood forest.

Results

Mechanized Felling

Figure 2 presents the productivities of the mechanized felling operations in mixedwood and softwood forest, with comparable harvested volumes per hectare, as a function of the average volume per stem. At a volume per stem greater than 0.12 m³, the felling productivity in softwood forest increased beyond that in mixedwood forest, and the difference increased with increasing stem volume, reaching 20% at 0.20 m³/stem. The large tops of the hardwoods and (sometimes) the interference from residual stems decreased productivity in mixedwood forest. These factors were more important than the proportion of hardwood stems in explaining the harvester's productivity. Some observations of harvesters performing sorting was used to construct the curve for mixedwood forest, but statistical analysis revealed no productivity loss as a result of the sorting.

Despite this, the mixedwood forest actually had a larger average stem volume than the softwood forest, and this increased the overall felling productivity. In the studies used to create the curves in Figure 2, the average volume per harvested stem was 0.12 m³ in softwood forest versus 0.20 m³ in mixedwood forest, whereas the number of stems per hectare was 45% higher in softwood forest. Based on these average volumes, felling was less productive overall in softwood forest than in mixedwood forest.

At-the-stump processing

Figure 3 presents the processor's productivity with softwood and hardwood stems that had been pre-separated by the feller-buncher. The processor was able to produce logs from large, highly branchy birch and maple stems with forks and curves. It was, however, necessary to manually delimb certain stems that were too difficult for the processor to handle. Processing hardwoods was about 28% less productive than processing softwoods for comparable average volumes per stem. This difference was relatively insensitive to the average stem volume.

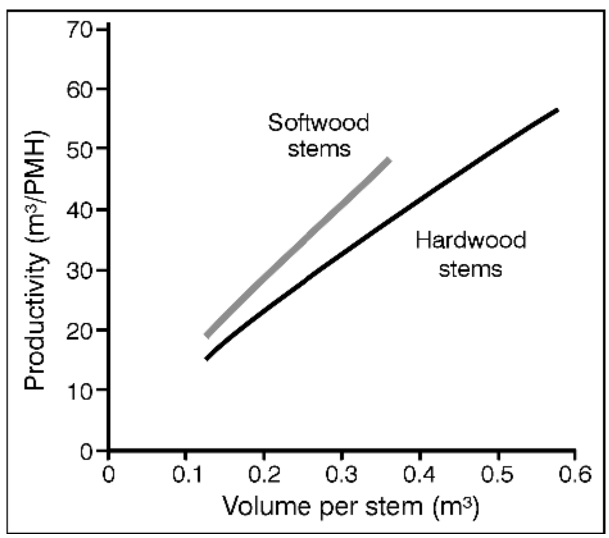

Figure 3. Comparison of the productivities of at-the-stump processing in mixedwood forest for softwood and hardwood stems already separated by the feller-buncher.

Extraction (mechanized system)

Table 1 presents FERIC's observations of the various extraction methods used by the mechanized harvesting systems in mixedwood forest. No productivity decrease was associated with mixedwood harvesting for extraction by cable skidder, grapple skidder, or shortwood forwarder. A detailed analysis of loading and unloading times, as well as of the load per trip, also provided no evidence of any difference. Despite slightly slower than normal travel speeds, FERIC observed shorter loading and unloading times in the mixedwood forest. The extraction payload per trip in mixedwood forest was not different from that measured in softwood forest.

Mechanized delimbing

Mechanized delimbing in mixedwood forest is used primarily for softwood stems, even though various studies have shown delimbers working with hardwood stems (Figure 4). Aspen was the easiest species to delimb, but it was also possible to delimb white birch if the delimber was equipped with a topping saw. Typically, the delimber separated the softwoods and hardwoods, working from mixed piles.

Figure 5 presents the productivity of the delimbers in mixedwood and softwood forests as a function of average stem volume. The two productivity curves differed by more than 20% in favor of delimbing in softwood forest. This difference increased slightly with increasing stem volume. The greater branchiness of the hardwoods and their longer trunks increased the delimbing time per stem. In addition, *for a comparable volume per stem*, the number of stems per delimbing cycle averaged 1.3 in softwood forest versus 1.2 in mixedwood forest; in effect, the presence of hardwoods in the piles and the greater number of products for the operator to separate reduced the number of opportunities to delimb more than one stem at a time. The time required to pick up stems, manipulate them, and perform the additional movements required for product separation also decreased productivity. However, the increased amount of travel between the more numerous piles in the mixedwood forest did not significantly affect productivity.

Figure 4. Delimbing and processing were less productive in mixedwood forest than in softwood forest.

The studies that provided the data for the curves in Figure 5 indicated that the volume per harvested stem averaged 0.14 m³ in the softwood forest, versus 0.20 m³ in mixedwood forest. Based on this volume difference, delimbing in the softwood forest was no more productive overall than delimbing in mixedwood forest.

Table 1. Productivity of the various extraction methods for the mechanized systems in mixedwood forest

	Average distance (m)	Average volume per piece (m³)	Productivity		
			m³/trip	m³/PMH	m³/PMH @ 150 m
Cable skidder					
Coop. des Hautes-Laurentides	370	0.21	3.0	9.4	11.6
Grapple skidder					
Coop. des Hautes-Laurentides	330	0.19	2.0	11.0	13.9
Manifor	400	0.23	2.9	13.4	17.9
Shortwood forwarder					
Alliance Forest Products	150	0.06	12.2	25.1	25.1

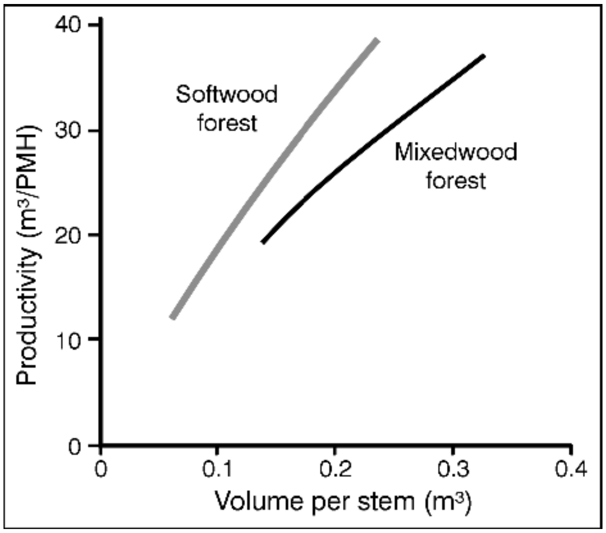

Figure 5. Comparison of mechanized delimbing productivities in mixedwood and softwood forests.

Figure 5 does not explain the influence of the proportion of hardwood stems on the delimber's productivity when working from mixed piles. Figure 6 provides more details on the productivity of the delimber in mixedwood forest by presenting separate curves for delimbing the softwoods and hardwoods (mostly aspen and white birch). For comparable stem volumes, the productivity difference was around 16% in favor of the softwoods.

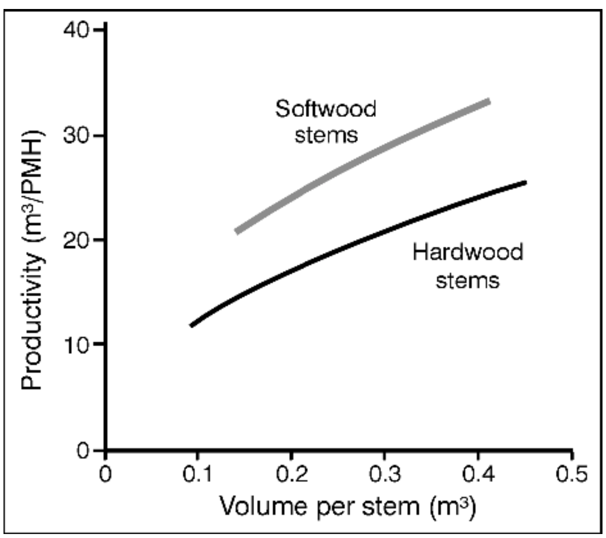

Figure 6. Comparison of mechanized delimbing productivities for softwood and hardwood stems in mixedwood forest.

Manual Harvesting

Table 2 presents the productivities observed for the manual felling teams in mixedwood forest in which the feller's work was synchronized with the skidding cycle. In this context, the felling productivity always corresponded to the extraction productivity. Softwood stems had to be felled before the hardwood stems, which were delimbed in the forest to facilitate extraction. Felling the hardwoods was also easier after extraction of the softwoods was complete. Hardwoods smaller than 24 cm in DBH were left standing, and this interfered with the work and the rhythm of the felling–extraction combination. By working in this manner, the feller had to help choke the felled stems, select the best felling sequence for delimbing the hardwoods, and pass twice over the cutover in a forest with fewer stems to harvest per hectare. The load of wood per skidder trip was also smaller and the loading time was longer than in softwood forest.

Manual full-tree harvesting in softwood forest does not impose these constraints and lets the feller maintain a rate of production different from that of the skidder. The decreases in productivity for softwoods in mixedwood forest were 58% during the felling phase and 39% during extraction. Harvesting hardwood stems in the mixedwood forest required the feller to perform delimbing and resulted in an average productivity of around 75% of that for harvesting softwoods in mixedwood forest.

Table 2. Productivity of manual felling in mixedwood and softwood forests[a]

	Productivity (m^3/PMH)		
	Softwood forest	Mixedwood forest	
		Softwoods	Hardwoods
Felling	16.3	6.9	5.2
Extraction	11.3	6.9	5.2

[a] Extraction distance of 130 m; a volume per stem of 0.27 m^3.

Loading wood for road transportation

FERIC also performed time studies of the loading phase to verify whether the larger number of piles created in the mixedwood forest and the distance between these piles affected the time required to load a truck. The results in Table 3 indicate a 24% productivity decrease for loading tree-length stems and logs compared with softwood-only sites. The distance between the piles and the number of piles required to load a truck increased the total loading time. The total time of around 32 minutes per truck was comparable for tree-length stems and logs.

Table 3. Studies of loading wood for transport in the mixedwood forest

	Number of piles to load a trailer	Total distance between piles (m)	Total loading time (min)
Loading tree-length stems			
Manifor	2.9	200	38.0
Coop. des Hautes-Laurentides	3.5	385	32.0
Gérard Crête & Fils Inc.	3.1	335	30.5
Loading logs			
Alliance Forest Products	3.7	340	32.4
Performance in mixedwood forest (weighted average)[a]	3.3	320	32.5
Expected performance in softwood forest[b]	1.0	0	24.8
Productivity decrease in mixedwood forest (%)	—	—	–24.0

[a] Performance was calculated by weighting the data from this Table using the number of observations from each study.
[b] The expected time in softwood forest was calculated by subtracting the time associated with travel between piles that was observed in mixedwood forest.

Analysis of the cost of each system

Based on the aforementioned results, Figure 7 presents the total theoretical harvesting cost for each system for a softwood forest and for a mixedwood forest with a 50% hardwood component under ideal harvesting conditions (CPPA class 1.1.1). The productivities were calculated with an average volume of 0.2 m³/stem (hardwood and softwood) in both types of forest and for an average extraction distance of 150 m. Product separation was performed entirely during delimbing in the mechanized full-tree system. In the manual full-tree system, sorting occurred during extraction. With the cut-to-length system, the feller-buncher separated the hardwoods and softwoods to facilitate the work of the at-the-stump processor. The detailed cost calculations are presented in Appendix 2.

The mechanized full-tree system was the least expensive of the three harvesting systems in all cases, but all three systems were more expensive in mixedwood forest than in softwood forest. The cost of the mechanized full-tree system was 22% higher in the mixedwood forest than in the softwood forest ($10.97/m³ versus $9.02/m³). The mechanized cut-to-length system cost $13.85/m³ in mixedwood forest, which amounts to 19% more than the $11.67/m³ cost in softwood forest. Lastly, the manual system cost $22.42/m³, which was 73% higher than the $12.94/m³ cost in softwood forest.

The production costs for the softwood component were also higher in mixedwood forests than in softwood forests, with a difference that ranged from 8% for the mechanized cut-to-length system up to 66% for the manual system. In addition, the harvesting cost for the hardwoods was 8 to 19% higher than that for softwoods of comparable volume in mixedwood forests. The increased cost for the hardwoods is due primarily to the difficulty of delimbing these species.

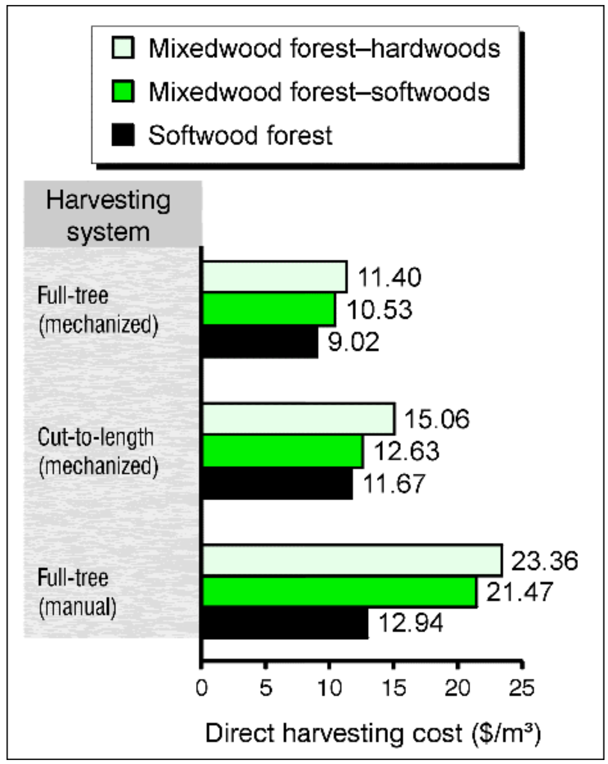

Figure 7. Theoretical total harvesting cost for the three systems in softwood and mixedwood forests (with 50% hardwoods in the mixedwood).

The delimber was mainly affected by two factors in the mixedwood forest: reduced opportunities to delimb more than one stem at a time, and increased delimbing times for the hardwoods. However, on the sites that FERIC studied, a processor worked with the hardwoods that were most difficult to delimb. A preliminary partial manual delimbing and the machine's superior ability to delimb the large hardwoods let the processor attain the good productivity reported in Appendix 2.

Conclusions

The total harvesting cost in mixedwood forests was 19 to 73% higher than in softwood forests because of the diversity of species present in mixedwood forests. For harvesting the softwood volume alone, the cost difference was lower (from 8 to 65%). The mechanized systems were less affected than the manual system FERIC studied by the working conditions in mixedwood forest. However, these results are based on comparable volumes per stem and numbers of stems per hectare. *In reality, the average volume per stem in mixedwood forest is often greater than that in softwood forest. The average harvesting cost thus becomes comparable to that obtained in softwood forest.*

The productivity of the manual system was most strongly affected by working in mixedwood forest, with a total cost 73% greater than in softwood forest. The feller had to first fell the softwoods to facilitate subsequent felling and delimbing of the hardwoods. This required two trips through the cutover. In addition, the load per skidder trip was lower than that normally extracted by a cable skidder working in softwood forest.

The two mechanized systems produced costs around 20% higher in mixedwood forest than in softwood forest. The site in which the cut-to-length harvesting was performed contained more hardwoods that were difficult to delimb than were encountered by the full-tree system. This affected the processor’s performance, but even so, the machine demonstrated a good ability to process large hardwood stems.

Delimbing is another production activity affected by the rigors of working in mixedwood forest. Product separation often occurs during this phase, and the high branchiness of the hardwoods noticeably affected the productivities of the delimber and the processor. Opportunities to delimb more than one stem at a time were reduced in piles with multiple products, which are common in mixedwood forests. In the context of this study, it was not possible to determine whether it would be preferable to separate the hardwoods during felling or delimbing. The proportion and distribution of species in the stand strongly influence this decision.

In addition to the parameters discussed in this report, other factors affect the harvesting costs in mixedwood forest. The rough topography, type of surface deposits, and low softwood volumes per hectare can lead forestry companies to reduce the density of the road network in mixedwood forests. In this case, the average extraction distance would increase. In addition, it is sometimes necessary to leave pulpwood-quality stems standing because of a lack of markets for hardwood pulp. The harvesting techniques must thus be modified, and this often leads to higher costs. It is also more difficult to fully mechanize mixedwood harvesting. Labor costs can thus increase rapidly, particularly given the costs associated with injuries while performing jobs that must be done manually. An analysis of the total harvesting cost in mixedwood forests must thus address all the operational parameters, including road construction and maintenance costs.

Acknowledgments

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Disclaimer

This report is published solely to disseminate information to FERIC's members.

Appendix 1
Productivity equations for Figures 2, 3, 5 and 6

Figure 2 : Softwood forest: Productivity (m³/PMH) = $312.36\times(\text{m}^3/\text{stem})^{1.04}$
Mixedwood forest: Productivity (m³/PMH) = $125.23\times(\text{m}^3/\text{stem})^{0.62}$

Figure 3 : Softwood stems: Productivity (m³/PMH) = $49.44\times(\text{m}^3/\text{stem})^{0.44}$
Hardwood stems: Productivity (m³/PMH) = $36.29\times(\text{m}^3/\text{stem})^{0.45}$

Figure 5 : Softwood forest: Productivity (m³/PMH) = $105.26\times(\text{m}^3/\text{stem})^{0.80}\times(1.3\ \text{stems/cycle})^{0.49}$
Mixedwood forest: Productivity (m³/PMH) = $68.17\times(\text{m}^3/\text{stem})^{0.74}\times(1.2\ \text{stems/cycle})^{1.1}$

Figure 6 : Softwood stems: Productivity (m³/PMH) = $100.11\times(\text{m}^3/\text{stem})^{0.85}\times(1.2\ \text{stems/cycle})^{0.73}$
Hardwood stems: Productivity (m³/PMH) = $82.3\times(\text{m}^3/\text{stem})^{0.83}\times(1.2\ \text{stems/cycle})^{0.48}$

Appendix 2
Details of the analysis of system costs

Table A1. Cost of the mechanized full-tree system in mixedwood and softwood forests

	Direct cost ($/PMH)	Softwood forest		Mixedwood forest			
				Softwoods		Hardwoods	
		Productivity (m³/PMH)	Cost ($/m³)	Correction (%)[a]	Cost ($/m³)	Correction (%)[a]	Cost ($/m³)
Felling	130	58	2.24	20	2.80	20	2.80
Extraction by grapple skidder	75	30	2.50	0	2.50	0	2.50
Mechanized delimbing	100[b]	33	3.03	13	3.59	30	4.46
Loading	100	80	1.25	24	1.64	24	1.64
Total cost	–	–	9.02	–	10.53	–	11.40
Weighted cost	–	–	n.a.	10.97			

[a] The correction is applied to productivity.
[b] The delimber costs $103/PMH in mixedwood forest because it is equipped with a topping saw.

Table A2. Cost of the mechanized cut-to-length system in mixedwood and softwood forests

	Direct cost ($/PMH)	Softwood forest		Mixedwood forest			
				Softwoods		Hardwoods	
		Productivity (m³/PMH)	Cost ($/m³)	Correction (%)[a]	Cost ($/m³)	Correction (%)[a]	Cost ($/m³)
Felling	130	58	2.24	20	2.80	20	2.80
Manual delimbing	33	n.a.	n.a.	n.a.	n.a.	n.a.	0.66[c]
Processing[b]	110	24	4.58	0	4.58	28	6.36
Forwarding	90	25	3.60	0	3.60	0	3.60
Loading	100	80	1.25	24	1.64	24	1.64
Total cost	–	–	11.67	–	12.63	–	15.06
Weighted cost	–	–	n.a.	13.85			

[a] The correction is applied to productivity.
[b] The processing productivity in mixedwood forest required preliminary manual delimbing for the larger hardwoods.
[c] Manual delimbing has a productivity of around 50 m³/PMH.

Table A3. Cost of the manual full-tree system in mixedwood and softwood forests

	Direct cost ($/PMH)	Softwood forest		Mixedwood forest			
				Softwoods		Hardwoods	
		Productivity (m³/PMH)	Cost ($/m³)	Correction (%)[a]	Cost ($/m³)	Correction (%)[a]	Cost ($/m³)
Manual felling[b]	33	12	2.75	58	6.55	69[c]	8.87
Extraction by cable skidder	65	11	5.91	39	9.69	54[c]	12.85
Mechanized delimbing	100[d]	33	3.03	13	3.59	n.a.	n.a.
Loading	100	80	1.25	24	1.64	24	1.64
Total cost	–	–	12.94	–	21.47	–	23.36
Weighted cost	–	–	n.a.	22.42			

[a] The correction is applied to productivity.
[b] Manual delimbing is included for the hardwood stems.
[c] The productivity with hardwoods in mixedwood forest is estimated at 75% of the productivity with softwoods in mixedwood forest.
[d] The delimber costs $103/PMH in mixedwood forest because it is equipped with a topping saw.