Advantage

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Contents

Commercial thinning in white spruce stands

Abstract

A multi-agency trial was established to determine the impacts of commercial thinning on the growth, yield, and development of white spruce stands. The commercial thinning operation was completed using a Timberjack 1270 harvester and a Timberjack 1210B forwarder. The Forest Engineering Research Institute of Canada (FERIC) monitored the harvesting phase, determined the operational cost and productivity of the harvester and forwarder, determined the residual tree damage, and evaluated the effectiveness of a brushing crew in increasing the productivity of the harvester in areas with high densities of non-merchantable trees.

Keywords

Commercial thinning, White spruce, Growth, Yield, Regeneration, Tree damage, Costs, Productivity, Alberta.

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Introduction

Thinning is an important long-term investment strategy both at the stand level and at the Forest Management Unit level. There is a lack of information in Alberta on the impacts of commercial thinning on the growth, yield, and development of white spruce stands. Multi-entry stand prescriptions need to maximize conifer growth in the residual stand without jeopardizing the harvesting productivity from the first entry through to final stand harvesting.

Vanderwell Contractors (1971) Ltd., the Northern Forestry Centre of the Canadian Forest Service (CFS), and FERIC were co-operators in a commercial thinning study during the summer of 2002 in white spruce stands near Calling Lake, Alta. The CFS and Vanderwell developed three stand-level prescriptions: 30, 50, and 70% removal of basal area and an uncut control. Vanderwell would like to increase the yield of the stand over the rotation and establish natural regeneration prior to final removal.

Although conifer regeneration will be measured as part of the research study and is expected to reach between 60 and 80% stocking by the time of the second entry, depending on the removal level, the treatment is not a shelterwood. The primary objective of the treatment was to harvest spruce by thinning in a cost-effective method and to increase the volume and value of the residual spruce by the second entry. Therefore, the treatment is more appropriately classified as a commercial thin.

FERIC monitored the costs and productivity of the commercial thinning operation and determined the residual tree damage. The CFS will determine the effects of the treatment on the development of the stand, the susceptibility of the residual trees to post-harvest wind damage, and the establishment of conifer regeneration on the treated sites. The CFS will also complete an in-depth financial analysis of the overall commercial thinning operation, tracking the costs from the planning stage through to the marketing of the final products.

Objectives

The overall study objectives were to assess the effects of commercial thinning on the growth, yield, and development of white spruce stands (Keddy and Sidders 2002b). The specific objectives to be met by the co-operators were to:

- Develop and test commercial thinning prescriptions using three harvesting patterns and removal intensities.
- Develop multi-entry stand prescriptions from the first entry through to final original stand harvest.
- Determine the cost and productivity of the harvesting phase.
- Determine the cost effectiveness of the commercial thinning treatments from the planning stage through to the marketing of the products.
- Determine the effect that non-merchantable trees have on the productivity of the harvester.
- Determine the residual tree damage after the commercial thinning operation.
- Evaluate the effectiveness of the harvesting operation to meet the prescription targets.

FERIC's objectives were to determine the operational cost and productivity of the harvester and forwarder, to determine the level of damage to the residual trees, and to evaluate the effectiveness of a brushing crew in removing the non-merchantable trees with chainsaws to keep the productivity of the harvester at maximum levels in areas with high densities of non-merchantable trees. Vanderwell and the CFS will be responsible for the remainder of the objectives.

Site description

Twelve cutblocks near Calling Lake were studied. The cutblocks were located between 22 and 34 km from the Alberta-Pacific Forest Industries Inc. (Al-Pac) pulp mill along the Al-Pac C-road, near Athabasca. Table 1 summarizes the species composition and stand characteristics of the cutblocks. The stands consisted of approximately 90% white spruce (*Picea glauca* [Moench] Voss), 6%

Table 1. Pre-harvest stand conditions

	Treatment unit[a]									
	130	150	170	230	250	270	330	350	370	Overall
Species composition (%)										
White spruce	92.8	91.3	82.4	85.8	88.0	95.5	93.6	90.0	78.2	89.6
Balsam poplar	5.6	8.7	2.9	3.6	11.0	3.9	3.2	4.1	5.2	5.6
Trembling aspen	1.6	-	14.7	2.6	1.0	0.6	3.2	5.3	16.6	4.0
Balsam fir	-	-	-	8.0	-	-	-	0.6	-	0.8
Average dbh (cm) [b]	20.7	18.2	20.0	20.7	18.7	19.9	20.3	18.0	22.9	19.8
Average height (m) [b]	23.0	19.5	21.6	21.0	20.0	20.5	21.2	19.9	24.0	21.2
Average stand density (trees/ha)										
White spruce	1 291	1 800	1 041	1 325	1 465	1 417	1 226	1 511	775	1 283
All species	1 391	1 971	1 264	1 545	1 665	1 483	1 311	1 679	965	1 432
Average merchantable volume (m^3/ha)										
White spruce	482	478	346	515	405	478	425	387	370	427
All species	554	659	536	615	452	520	496	494	574	534

[a] Does not include the uncut controls.
[b] For white spruce only.

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balsam poplar (*Populus balsamifera* L.), 4% trembling aspen (*Populus tremuloides* Michx.), and a few balsam fir (*Abies balsamea* (L.) Mill.) (Keddy and Sidders 2002a). There was some variation between the twelve stands, but the average diameter at breast height (dbh) for the white spruce was 19.8 cm, and the average height for the white spruce was 21.2 m (Figure 1). The average stand density for all species was 1432 trees/ha, and the average pre-harvest merchantable stand volume for all species was 534 m^3/ha (Keddy and Sidders 2002c).

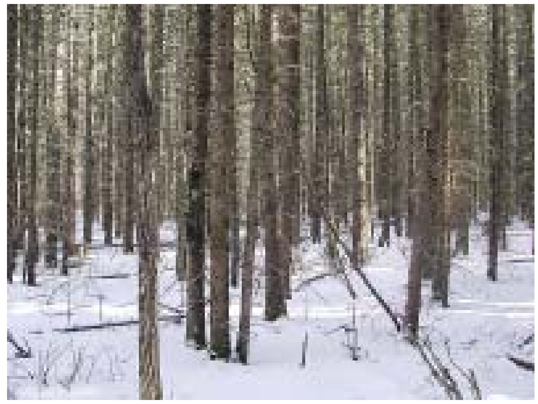

Figure 1. Pre-treatment.

Figure 2. An example of the "cut-no-cut" gauge for the operator.

Treatments

Three removal levels and an uncut control were tested with three replications of each treatment for a total of twelve treatment units (TUs): an uncut control, 30% merchantable basal area removed, 50% basal area removed, and 70% basal area removed. The treatment units ranged in size from 5.2 to 8.1 ha and had an average of 6.5 ha. The centrelines for the extraction trails were located and marked on the ground approximately 20 m apart. The trails were aligned perpendicular to the prevailing winds to minimize losses to windthrow after harvesting.

The harvester cut all the trees on the trails and some of the trees between the trails, in a systematic pattern, to remove the target basal areas. The completed trails were approximately 4 m wide. For all removal levels, approximately 20% of the block basal area removed came from the trails with the remainder from between the trails. The trees to be removed were distributed between the dominant, suppressed, and intermediate classes, leaving the co-dominant trees which are believed to have the best potential for release. The trees were not marked, but for each treatment the minimum and maximum diameters at breast height to cut were determined by the CFS. The CFS provided the operator with a "cut-no-cut" gauge (Figure 2). These minimum and maximum diameters were different for each of the nine harvested units because they depended on the pre-existing diameter distribution prior to harvesting and the removal level specified in the prescription (Table 2). The forwarder travelled along the same trails as the harvester, loading the processed logs and forwarding them to the decking areas.

Table 2. Minimum and maximum diameters to cut for each treatment unit

	Treatment unit								
	130	150	170	230	250	270	330	350	370
Minimum diameter (cm) [a]	16.1	22.1	22.1	14.1	18.1	24.1	16.1	20.1	20.1
Maximum diameter (cm) [b]	34.0	38.0	30.0	40.0	30.0	32.0	34.0	34.0	30.0

[a] All spruce less than this diameter (dbh) to be cut.
[b] All spruce greater than this diameter (dbh) to be cut.

A second entry is planned in the 30 and 50% removal treatment units when the residual stand has recovered at least 80% of the removed basal area and white spruce regeneration has established at 80% stocking level at 30 cm height (Keddy and Sidders 2002a). CFS researchers estimated that it will take between 10 and 15 years for these conditions to be met in the 30% removal treatment units and between 12 and 20 years for the 50% removal treatment units. A second entry in the 70% removal treatment units is planned when the residual trees have recovered at least 60% of the removed basal area and the regeneration has established an 80% stocking level at 1.3 m height, in 15 to 20 years.

Study methods

Both shift-level monitoring and detailed timing were used to document harvesting logistics and productivity. The scheduled and productive hours were documented by treatment unit for each machine by mounting a Servis recorder on the equipment. The Servis recorder charts were supplemented by daily records completed by the equipment operators. Operating time was determined from the daily records and Servis recorder charts, and was summarized by machine and treatment unit to determine productive machine hours (PMH) and scheduled machine hours (SMH).

The harvester had an on-board computer to record the harvested volume. A daily printout was provided that listed the volume and the number of trees cut by species. FERIC supplemented the volume information by detailed timing using a hand-held datalogger to record cycle time elements, and sample scales to measure piece size to determine the productivity of the harvester. Detailed timing was used to determine the effect of the brushing crew on the productivity of the harvester.

The forwarder operator kept track of number of loads per day and number of days with production on each treatment unit, while FERIC did some detailed timing to determine loading cycle time, cycle time elements, average pieces per load, and average piece size. This information was used to determine the productivity of the forwarder.

Harvested volumes were kept separate by treatment unit to track the volume. The conifer volume was obtained from Vanderwell's weigh scale receipts after the wood had been hauled, while the deciduous volume came from Al-Pac's weigh scale receipts.

Damage to the bark or crown of residual trees was assessed in a post-harvest survey using the method developed by the Pacific Forestry Centre of the CFS (Mitchell 1994). Damage was categorized by severity, area of damage, cause, and height from the base of the tree. The four classes of severity were: Class A, bark scuffed or bruised, but phloem not exposed; Class B, phloem exposed, but wood not gouged; Class C, phloem exposed, and wood gouged less than 1 cm deep; and Class D, phloem exposed, and wood gouged more than 1 cm deep.

Costs for the harvesting and forwarding phases were calculated using FERIC's standard costing methodology and assumptions for determining machine ownership and operating costs for new machines (Appendix I). The costs do not include supervision, profit, and overhead, and are not the actual costs for the contractor or the company. Because this was a research trial and the operator was asked to do things that would not be done in a regular operation, the contractor was paid an hourly rate.

Harvesting systems

Harvesting occurred from June to September 2002. The harvesting was completed with a Timberjack 1270—a 6-wheel drive cut-to-length processor with a directional felling head (Figure 3). First, the extraction trails were located and marked on the ground by researchers from the CFS. The harvester then cut all the trees on the trails and some of the trees between the trails to achieve the target basal area. Stems were processed at the stump with the tops and branches left on the trail to provide a debris mat to reduce ground disturbance and to minimize the amount of debris at the roadside. The processed logs were stacked at the side of the trail until they were forwarded to the decking locations by a Timberjack 1210B forwarder (Figure 4).

The forwarder travelled along the same extraction trails as the harvester and the logs were decked in the right-of-way of the main haul road or along existing seismic lines near the main haul road, using a separate location for each treatment unit. Both conifer and deciduous logs were forwarded at the same time, unless the deciduous volume warranted a separate trip. However, at roadside the deciduous and conifer logs were decked separately. Hauling was postponed until the winter of 2002 when the frozen road conditions would result in less damage to the travelling surface. The conifer component was hauled to Vanderwell's mill at Slave Lake and the deciduous logs were hauled to the Al-Pac pulp mill near Athabasca.

In some of the treatment units with the heaviest underbrush, a brushing crew with chainsaws was used to cut non-merchantable trees and brush to keep the productivity of the harvester at maximum levels. The contractor had found on previous commercial thinning operations that it was worthwhile having a brushing crew work ahead of the harvester to keep the harvester production levels high and the frustration level of the operator low. Harvester productivity is negatively affected by poor visibility and when the operator has to cut non-merchantable trees to access the merchantable trees. FERIC evaluated the effectiveness of the brushing crew in maintaining the harvester productivity by detail timing the harvester in both brushed and unbrushed areas.

Results

Productivity in this report is based on productive machine hours and not scheduled machine hours. Utilization rates are calculated as PMH/SMH. They ranged from 63 to 85% for both machines, and averaged 71% for the harvester overall and 81% for the forwarder overall.

Harvester productivity increased as the removal levels increased (Table 3). The harvester

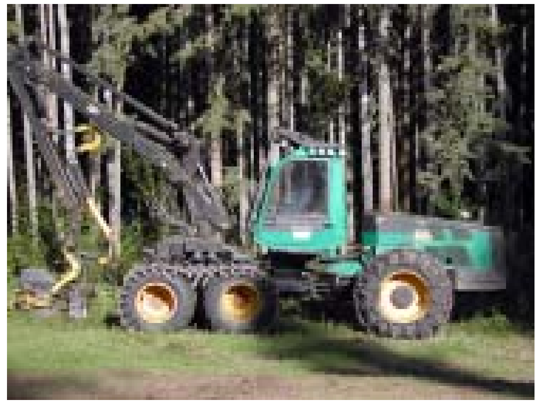

Figure 3. Timberjack 1270 harvester.

Figure 4. Timberjack 1210B forwarder.

Table 3. Harvester productivity by treatment (shift-level)

	Removal level		
	30%	50%	70%
Harvesting (PMH)	125.5	172.8	209.2
Non-mechanical delays (h)			
Move	2.7	1.6	1.8
Coffee	7.8	11.2	12.6
Talk	3.8	4.2	3.7
Total non-mechanical delays	14.3	17.0	18.1
Mechanical delays (h)			
Clean/cool down	6.3	7.0	11.6
Service	14.4	25.9	31.4
Repair	3.5	28.9	28.8
Total mechanical delays	24.2	61.8	71.8
Scheduled machine hours (SMH)	164.0	251.6	299.1
Area harvested (ha)	19.5	18.3	22.0
Volume (m^3)	2 230.7	3 243.4	4 893.0
Productivity			
(m^3/PMH)	17.8	18.8	23.4
(m^3/SMH)	13.6	12.9	16.4
Utilization (PMH/SMH) %	77	69	70
Cost ($/$m^3$)	11.48	12.12	9.55

Table 4. Harvester productivity by treatment unit (shift-level)

	Treatment unit								
	130	150	170	230	250	270	330	350	370
Harvesting (PMH)	40.9	68.7	54.5	55.4	56.7	98.1	29.2	47.5	56.6
Non-mechanical delays (h)									
Move	0.5	0.0	0.0	2.2	1.0	1.3	0.0	0.6	0.5
Coffee	3.1	4.3	3.1	3.2	4.0	5.9	1.6	2.9	3.6
Talk	0.8	2.3	0.7	2.0	1.2	1.5	0.9	0.8	1.5
Total non-mechanical delays	4.4	6.5	3.8	7.3	6.2	8.8	2.5	4.3	5.6
Mechanical delays (h)									
Clean/cool down	0.9	2.1	3.5	4.4	0.8	5.8	1.0	4.1	2.4
Service	5.9	11.5	11.1	5.1	9.2	13.3	3.4	5.3	7.1
Repair	3.3	19.5	7.6	0.0	8.7	16.5	0.3	0.8	4.7
Total mechanical delays	10.1	33.1	22.2	9.5	18.7	35.6	4.7	10.1	14.2
Scheduled machine hours (SMH) [a]	55.4	108.3	80.4	72.2	81.5	142.4	36.3	61.8	76.3
Area harvested (ha)	7.2	7.0	7.2	6.2	5.2	8.1	6.1	6.1	6.7
Volume (m^3)	774	1408	1249	953	970	1940	505	866	1704
Productivity (m^3/PMH)	18.9	20.5	22.9	17.2	17.1	19.8	17.3	18.2	30.1
Utilization (PMH/SMH) %	74	63	68	77	70	69	80	77	74

[a] Differences due to rounding.

Table 5. Harvester productivity in brushed and unbrushed areas (detailed timing)

	Treatment	
	Unbrushed	Brushed
Productive time (min)	329.1	229.1
Non-productive time (min) [a]	57.1	25.6
Total time (min)	386.2	254.7
Delay time >10 min (min)	26.8	41.5
Utilization (productive/total time) (%)	85	90
Pieces produced (no.)	1268	1118
Trees cut (no.)	579	492
Productivity		
(pieces/h)	231	300
(trees/h)	105	128
(m^3/h) [b]	24.2	29.4

[a] Most of the non-productive time was spent cutting non-merchantable stems.
[b] Assuming an average piece size of 0.23 m^3/tree.

produced 18 m^3/PMH in the 30% removal treatment, 19 m^3/PMH in the 50% removal treatment, and 23 m^3/PMH in the 70% removal treatment. This trend was consistent across the treatment units except in TU 250 where portions of the area had not been brushed because it was used to study the effect of brush on the harvester's productivity. In this treatment unit, the productivity was the same as TUs 230 and 330 (Table 4). The harvester productivity was highest in TU 370 at 30.1 m^3/PMH.

During the brushing study, the harvester's productivity increased 21% in the brushed area compared to the unbrushed area (29.4 m^3/h and 24.2 m^3/h, respectively) (Table 5). The chainsaw crew removed nonmerchantable trees and shrub species, which provided better visibility for the harvester operator and fewer trees to cut to waste. The productivity of the chainsaw crew is affected by the amount and size of the brush to cut. Based on studies by De Franceschi and Bell (1990) and Ellingston (1987), the chainsaw crew, at the cost of \$30.76/h,[1] would need a productivity greater than 0.09 ha/h to break even with the cost of the harvester.

Based on the shift-level study, the productivity of the forwarder ranged from 22 to 30 m^3/PMH for all treatment units (Table 6). The overall productivity of the forwarder ranged from 22 m^3/PMH for the 30% removal to 28 m^3/PMH for the 70% removal (Table 7). The detailed-timing study confirms the trend that productivity increased with removal level—the results indicated 46 m^3/PMH for the 30% removal, 61 m^3/PMH for the 50% removal, and 64 m^3/PMH for the 70% removal (Table 8).

[1] Lorne Carson, Vanderwell, personal communication, January 2004.

Table 6. Forwarder productivity by treatment unit (shift-level)

	Treatment unit								
	130	150	170	230	250	270	330	350	370
Forwarding (PMH)	34.8	52.6	46.7	43.4	32.6	65.9	22.0	35.2	63.9
Non-mechanical delays (h)									
Move	-	-	-	0.8	2.4	1.9	-	-	-
Other	1.6	-	-	0.6	2.4	0.6	-	-	1.0
Coffee	3.6	5.9	4.2	4.5	3.2	6.8	2.6	3.3	5.4
Talk	-	0.3	-	-	-	-	0.3	0.4	0.3
Total non-mechanical delays	5.2	6.3	4.2	5.9	8.0	9.3	2.9	3.7	6.7
Mechanical delays (h)									
Warm up machine	-	0.2	0.2	0.3	0.6	0.8	0.3	0.6	0.3
Clean	0.2	-	0.3	0.3	0.5	1.3	0.8	0.6	0.9
Service	2.3	2.0	1.8	1.3	2.2	3.3	0.8	1.7	3.5
Repair	2.3	2.5	3.3	1.1	2.2	0.3	-	0.3	-
Total mechanical delays [a]	4.8	4.7	5.5	3.0	5.4	5.6	1.8	3.1	4.7
Scheduled machine hours (SMH)	44.8	63.5	56.3	52.3	46.0	80.8	26.8	41.9	75.3
Area (ha)	7.2	7.0	7.2	6.2	5.2	8.1	6.1	6.1	6.7
Volume (m^3)	774	1408	1249	953	970	1940	505	866	1704
Productivity (m^3/PMH)	22.2	26.8	26.7	22.0	29.8	29.4	23.0	24.6	26.7
Utilization (PMH/SMH) %	78	83	83	83	71	82	82	84	85

[a] Differences due to rounding.

Table 7. Forwarder productivity by treatment (shift-level)

	Removal level		
	30%	50%	70%
Forwarding (PMH)	100.3	120.3	176.5
Non-mechanical delays (h)			
Move	0.8	2.4	1.9
Other	2.2	2.4	1.6
Coffee	10.7	12.3	16.3
Talk	0.3	0.8	0.3
Total non-mechanical delays	14.0	17.9	20.1
Mechanical delays (h)			
Warm up machine	0.5	1.3	1.2
Clean	1.3	1.1	2.4
Service	4.4	5.8	8.6
Repair	3.3	4.9	3.6
Total mechanical delays	9.6	13.2	15.8
Scheduled machine hours (SMH) [a]	123.8	151.4	212.3
Area (ha)	19.5	18.3	22.0
Volume (m^3)	2 230.7	3 243.4	4 893.0
Productivity			
(m^3/PMH)	22.2	27.0	27.7
(m^3/SMH)	18.0	21.3	23.0
Utilization (PMH/SMH) %	81	79	83
Cost (\$/m^3)	6.82	5.74	5.33

[a] Differences due to rounding.

Table 8. Forwarder productivity by treatment (detailed timing)

	Removal level		
	30%	50%	70%
Loads (no.)	41	65	35
Pieces (no.)	120	132	122
Loading distance (m)	80	58	36
Total distance (m)	223	130	132
Cycle time (min)	26.5	22.1	19.5
Productivity (m^3/PMH)	46.2	60.8	63.8

The costs of the harvesting phase for the three treatments ranged from \$9.55 to \$12.12/m^3, with the highest cost in the 50% removal level (Table 9). The costs of the forwarding phase ranged from \$5.33 to \$6.82/m^3, with the 30% removal having the highest cost and the 70% removal having the lowest cost. Overall the cost of harvesting and forwarding together ranged from \$14.88 to \$18.30/m^3 (processed logs at the roadside).

There was minimal damage to the residual trees during the harvesting and forwarding phases. Damage in Classes A and B are not expected to affect the vigour or survival of the residual trees. Damage in Classes C or D is more severe and was 3, 6, and 4% for the 30, 50, and 70% removal levels, respectively (Table 10). The size of the damage is important when determining how it will affect the tree. When only large damage (i.e., more than 400 cm^2 in surface area) was counted, the severe damage levels dropped to 1, 3, and 1% for the 30, 50, and 70% removal levels, respectively. Most of the damage that

Table 9. Harvesting costs by treatment

	Removal level		
	30%	50%	70%
Harvesting (\$/m^3) [a]	11.48	12.12	9.55
Forwarding (\$/m^3) [b]	6.82	5.74	5.33
Total (\$/m^3)	18.30	17.86	14.88

[a] Based on \$156.18/SMH for the Timberjack 1270 harvester (Appendix I).
[b] Based on \$122.89/SMH for the Timberjack 1210B forwarder (Appendix I).

Table 10. Damage survey results [a]

	All damage		Damage >400 cm^2	
	No. of trees	% of trees [b]	No. of trees	% of trees [b]
30% removal level				
A	8	3	3	1
B	34	13	1	<1
C [c]	7	3	2	1
D [c]	-	-	-	-
Root	10	4	1	<1
Bark	4	2	1	<1
Branches	2	1	-	-
No damage	197	75	-	-
Total trees assessed	262	-	262	-
50% removal level				
A	7	3	1	1
B	28	14	3	2
C [c]	13	6	6	3
D [c]	-	-	-	-
Root	4	2	-	-
Bark	-	-	-	-
Branches	-	-	-	-
No damage	152	75	-	-
Total trees assessed	204	-	204	-
70% removal level				
A	15	10	7	5
B	22	15	-	-
C [c]	6	4	2	1
D [c]	-	-	-	-
Root	6	4	-	-
Bark	1	1	-	-
Branches	4	3	-	-
No damage	90	63	-	-
Total trees assessed	144	-	144	-

[a] Based on 90 plots (5.64-m diameter), 30 plots per treatment.
[b] Differences due to rounding.
[c] Only damage in Classes C and D are considered serious.

occurred was caused by the harvester contacting the trees with its felling head.

Discussion

Harvesting productivity is affected by the number of trees to cut (both merchantable and non-merchantable), the size of trees, and the distance between trees. The number of trees to cut and the distance between trees are determined by the density of the original stand and the target removal level (Figure 5). The size of trees to cut is determined by the removal specifications as set in the minimum and maximum diameters to cut (Table 2), the original stand characteristics, and the tree species. Some of the treatment units had more aspen which tended to be larger than the spruce (Figure 6). Aspen stems were only harvested if they were on the extraction trail. Aspen between trails were left on site.

Ground conditions and operating technique can also affect the productivity of the harvester, but all the treatment areas had similar ground conditions and were harvested by the same operator and the same equipment, so these factors were not an issue in this study.

Harvester productivity clearly increased as the removal level increased, due to more volume and larger trees being removed and less time travelling between trees. The difference between the 30 and 50% removal levels was not as great as the difference between the 50 and 70% removal levels. The 50% removal level included the area that was not brushed, and this may explain some of the reduced productivity. There were more repairs to the harvester while working in TU 150 than in the other treatment units (Table 4).

Harvesting productivity was highest in TU 370. This unit also had the highest percentage of aspen trees at 17%, followed closely by TU 170 at 15% (Table 1). The spruce in TU 370 was also larger than the spruce in the other treatment units. The productivity results for TU 370 should therefore be viewed with caution as they are much higher than the rest of the units. TU 170 had the second highest productivity (Table 4).

Figure 5. TU 260, post-harvest.

Figure 6. Aspen trees with wide crowns.

On average the aspen had a piece size[2] of 0.47 m^3 while the spruce had a piece size of 0.23 m^3. The large aspen stems with their wide crowns were more difficult to handle than the spruce but produced more volume when processed (Figure 6).

In TU 250, where the non-merchantable brush had been removed by the chainsaws, the harvester had an increase in productivity of 21% over the non-brushed areas (Table 5). The harvester operator had better visibility and therefore could work more easily than in the brushed area. There was less non-productive time in this treatment unit.

The forwarding productivity is affected by the time to produce a load and the time to travel between the loading and decking areas. The loading time depends on the size of the piles of processed logs, the size of the logs within the piles, and the distance between piles. The travel time between the

[2] Piece size was calculated as total volume harvested divided by the total pieces cut for each species, based on the printouts from the on-board computer in the harvester.

loading and decking areas depends on the travel distance and trail conditions.

The productivity was expected to increase as the removal level increased because the forwarder would spend less time loading, as there would be more processed logs in each pile and less time moving between piles to fill its load. The productivity did increase as the removal level increased, but the difference between the 30 and 50% removal levels was greater than the difference between the 50 and 70% removal levels. Loading time, moving time, and loading distance decreased as the removal level increased. The piles were bigger and fewer piles were needed to complete a load. The total distance (i.e., loading distance plus distance to decking area) was greatest in the 70% treatment units, because of the shape of the block and the position in relation to the haul road where the logs were being decked. The extraction trails were perpendicular to the prevailing winds, and this sometimes meant longer forwarding distances to the decking location. When the extraction distance was standardized at 100 m, the cycle time for the forwarder was lowest in the 70% removal treatment units and highest in the 30% removal treatment units.

Damage to residual trees can become entry points for disease and weaken the trees, making them more susceptible to damage from wind. Caution is required in partial cutting operations to minimize damage to the residual trees. The incidence of damage is affected by tree size, distance between trees, harvesting equipment used, operator experience and attitude, trail width, harvesting season, and ground conditions. Damage levels are expected to be higher in stands with a high density of residual trees, when the distance between the trees is small, and when the extraction trails are narrow. In this study, there was minimal damage to the residual trees in all treatment units, largely because the equipment was well suited to the prescription and the operators were experienced.

The warm weather (greater than 30°C by mid-morning) during the first half of the study added extra delays to the operating time. The machines overheated after an hour of operation and had to be cooled before work could resume. The contractor provided living quarters for the machine operators and the supervisor/mechanic on site. This enabled them to begin work early in the day to avoid the heat later in the afternoon. The supervisor/mechanic was on site to solve mechanical and logistical problems promptly, and helped the operators with repairs and servicing. As many parts were kept on site, repairs could be made quickly. These factors all led to high productivities and minimal downtime due to waiting.

Conclusions

The productivity of the harvester and forwarder increased as the removal levels increased. The increase in harvesting productivity was due to more volume and larger trees being removed, and less time travelling between trees or cutting non-merchantable shrubs. Aspen stems were more difficult to handle than spruce because of their wide crowns, but they produced more volume when processed. Harvesting productivity was affected by the non-merchantable brush and was higher when the brush was removed before felling by a chainsaw crew. Visibility for the harvester operator increased and the number of non-merchantable stems to be cut decreased. An increase in cost of the chainsaw crew may be countered by an increase in harvester productivity. The forwarder's productivity increased as the removal levels increased because the piles were bigger and the operator required fewer piles to complete a load. The forwarding productivity was affected by the forwarding distance.

Residual tree damage was low overall and was not influenced by the removal level. The equipment was appropriate to the stands and prescription, and the crew was experienced in thinning. At the lowest removal level (30%), where the residual stand density was the highest, the harvester operator felled the trees, and processed and decked them at the side of the extraction trail without contacting the residual trees. The extraction trails were the same width for all treatment units, and the forwarder was able to load and forward the processed logs to the decking area without damaging the residual trees.

The warm weather at the beginning of the study affected the productivity of both the machines as they had to be cooled throughout the day. By living on site, the operators were able to begin early to avoid the heat later in the day. The on site supervisor/ mechanic was able to solve problems promptly and help the operators maintain productivity.

Implementation

- Minimize the number of different prescriptions for the harvester operator to avoid confusion and minimize the learning curve while adjusting to the new standards.
- Favour higher removal levels if they can meet the management objectives.
- Use an operator with experience in thinning to achieve high productivity and low residual tree damage.
- Use a crew with chainsaws to remove non-merchantable trees and brush in areas where they reduce the visibility of the harvester operator. This will maintain the productivity of the harvester.
- Minimize the travel distance of the forwarder by locating the decking areas as close as possible to the loading areas. This will maximize forwarding productivity.
- Have a mechanic and spare parts on site to minimize down time during repairs.
- Provide on-site living quarters for the crew when travel distances are long to allow flexibility in work hours. Operators can begin work earlier in the day to avoid the heat later in the afternoon.

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Appendix I

Machine costs ($/SMH) [a]

	Timberjack 1270 harvester	Timberjack 1210B forwarder
OWNERSHIP COSTS		
Total purchase price (P) $	611 000	450 000
Expected life (Y) y	5	5
Expected life (H) h	10 000	10 000
Scheduled hours/year (h)=(H/Y) h	2 000	2 000
Salvage value as % of P (s) %	30	30
Interest rate (Int) %	7.0	7.0
Insurance rate (Ins) %	2.0	2.0
Salvage value (S)=((P•s)/100) $	183 300	135 000
Average investment (AVI)=((P+S)/2) $	397 150	292 500
Loss in resale value ((P-S)/H) $/h	42.77	31.50
Interest ((Int•AVI)/h) $/h	13.90	10.24
Insurance ((Ins•AVI)/h) $/h	3.97	2.92
Total ownership costs (OW) $/h	60.64	44.66
OPERATING COSTS		
Fuel consumption (F) L/h	16.0	15.0
Fuel (fc) $/L	0.55	0.55
Lube & oil as % of fuel (fp) %	24	15
Annual tire consumption (t) no.	0.5	0.5
Tire replacement (tc) $	3 150	3 150
Track & undercarriage replacement (Tc) $	16 000	9 500
Track & undercarriage life (Th) h	20 000	5 000
Annual repair & maintenance (Rp)=0.8•P/Y $	97 760	72 000
Shift length (sl) h	11.0	8.0
Operator	21.78	21.78
Total wages (W) $/h	21.78	21.78
Wage benefit loading (WBL) %	38	38
Fuel (F•fc) $/h	8.80	8.25
Lube & oil ((fp/100)•(F•fc)) $/h	2.11	1.24
Tires ((t•tc)/h) $/h	0.79	0.79
Track & undercarriage (Tc/Th) $/h	0.80	1.90
Repair & maintenance (Rp/h) $/h	48.88	36.00
Wages & benefits (W•(1+WBL/100)) $/h	30.06	30.06
Prorated overtime (((1.5•W-W)•(sl-8)•(1+WBL/100))/sl) $/h	4.10	0.00
Total operating costs (OP) $/SMH	95.53	78.23
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/SMH	156.18	122.89

[a] These costs are estimated using FERIC's standard costing methodology for determining machine ownership and operating costs for new machines. The costs shown here do not include supervision, profit and overhead, and are not the actual costs for the contractor or the company studied.