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Contents

Harvesting mountain pine beetle-killed pine while protecting the secondary structure: a comparison of partial harvesting and clearcutting methods

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Abstract

FPInnovations studied a series of four partial harvesting trials and one combined partial harvesting–clearcut trial over three years in the Prince George (B.C.) Forest District. The partial harvesting trials harvested pine trees killed by the mountain pine beetle while protecting the non-pine secondary structure. The purpose of protecting the secondary structure is to provide a viable stand that will enhance the mid-term timber supply in 15 to 50 years. This report provides the costs, productivity, and harvesting damage results of the partial harvesting and clearcutting treatments used in the fifth and final trial. The pre-harvest stand was stocked with non-pine trees before harvesting, but was not stocked following the partial harvesting treatment. Slightly more than one-third of the net block area was clearcut for roads, trails, and landings. The trial results suggest up to 23% of the harvested non-pine overstory could potentially have been protected.

Keywords:

Partial cutting, Mountain pine beetle, *Dendroctonus ponderosae*, Advance regeneration, Understory protection, Harvesting, Partial cutting systems, Harvesting methods, Harvesting cost, Productivity, Residual stand damage, Interior British Columbia.

Introduction

Effective management of the current mountain pine beetle (*Dendroctonus ponderosae*) outbreak in the interior of British Columbia requires creative and innovative strategies to address the concerns of the projected mid-term timber supply shortage in 15 to 50 years. This type of partial harvesting requires finding blocks with sufficient pine for an economically viable harvest, and with adequate levels of secondary structure to leave a stocked post-harvest stand. Blocks with sufficient pine but insufficient secondary structure may be best suited for clearcutting. Blocks with insufficient levels of pine but abundant secondary structure may be better suited to be left unharvested until the mid-term time period (Hodges 2008).

Appropriate partial harvesting methods in suitable mixed stands that protect non-pine overstory and understory can potentially leave a residual stand that will mitigate projected reductions in mid-term timber supply and provide the possibility of a harvest opportunity several years earlier than a clearcut and plant strategy. However, when using this type of partial harvesting method, there are many challenges to achieving a viable residual stand. The main issues are related to harvesting costs, adequate protection of secondary structure (BCMOFR 2008), stand survival (post-harvest windthrow, sun-exposure, etc.), and proper identification of the stand's suitability for a partial harvesting treatment.

The goal of the overall FPInnovations study was to measure the costs and operational feasibility of harvesting pine trees from pine-dominated stands attacked by the mountain pine beetle while protecting the non-pine secondary structure. This report covers the final trial in a series of five trials from 2006 to 2009. Background information and results from the four earlier trials were reported in Nishio (2009).

Site description

This trial was conducted in the winter of 2008/09, 46 km north of Prince George, B.C. The trial site included one partial harvesting block and two smaller clearcut blocks (Table 1).

Harvesting system and equipment

The same equipment and operators were used in the partial harvesting and clearcutting blocks. The equipment included:

- one Madill 3200B feller-buncher;
- one Caterpillar 535 B rubber-tired (with chains) grapple skidder;
- one Caterpillar 320CLL processor with a Waratah HTH 622 B processor head;
- one Hyundai 210LC7 processor with an HTH 622 B processor head; and
- two John Deere 2054 loaders.

The partial harvesting treatment used a combination of extraction trails spaced apart at 20, 25, 30, and 35 m, and at random spacing distances selected by the feller-buncher operator. In both the partial

Table 1. Site description

	Block 1	Block 2	Block 3
Study area (ha)	7.0	4.2	39.7
Harvesting system	clearcutting	clearcutting	partial harvesting
Average gross harvested tree size (m^3)	0.4	0.3	0.6
Harvested volume not including right-of-way (m^3)	1041	474	6022
Harvested volume of right-of-way conifer (m^3)	226	70	552
Harvested volume of right-of-way aspen (m^3)	152	92	97
Soils	SiCL,[a] SiC [b]	SiCL[a]	SiCL[a]
Slope (%)	0–2	0–3	0–3
BEC sub-zone [c]	SBSmk1[d]	SBSmk1[d]	SBSmk1[d]

[a] SiCL: Silty Clay Loam (BCMOFR 2003).
[b] SiC: Silty Clay (BCMOFR 2003).
[c] The Biogeoclimatic Ecosystem Classification (BEC) system (http://www.for.gov.bc.ca/hre/becweb/index.html).
[d] SBSmk1: Sub-Boreal Spruce zone, moist, cool subzone.

harvesting and the clearcutting blocks, trees were felled with the feller-buncher and skidded to roadside landings. One loader loaded the logging trucks and another loader worked at the roadside landings to deck trees, assist the skidder and, whenever possible, "loader forward" trees that had been felled near the landings.

All trees were processed at roadside landings. In the partial harvesting block, landing areas were cleared to be approximately two tree lengths wide to accommodate the manufacturing of both short and long logs. The processing and hauling of logs in the partial harvesting block were planned such that the logs were hauled away quickly. This was done primarily to reduce standby time for trucks, but also to "reuse" the landing areas for processing trees, thereby keeping the total required landing area to a minimum. However, this meant the skidder and processors had to move to another landing area while logging trucks were loaded. After the landing areas were cleared, the skidder and processors then moved back to the landing to process the remaining trees from that area of the block.

Study methods

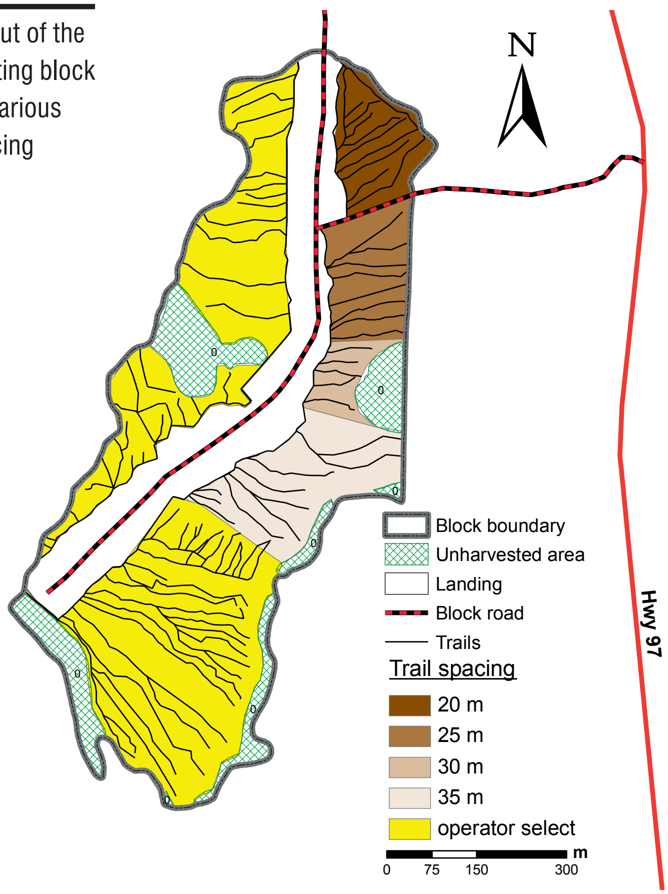
Stocking was estimated using the "deviation from potential" (DFP) method developed by Martin et al. (2005) for partially cut stands in British Columbia. The pre- and post-harvest stand values for overstory basal area, well-spaced understory stems, and DFP were measured. Pre-harvest DFP values were calculated from non-pine overstory basal area and understory density data. Post-harvest DFP values incorporated the residual basal area and understory density after the partial harvest. A slightly modified DFP value was used in this study that only included trees taller than 1.3 m in height to provide a mid-term DFP (MTDFP) stocking value which would estimate the potential of the stand to contribute to the mid-term timber supply (Nishio 2009).

Forty-eight permanent sample plots were located, prior to harvesting, in a systematic 100-m grid pattern. Tree variables included species, size, stems per hectare (density), basal area, and number of "well-spaced" understory trees (BCMOFR 2008). The permanent sample plots included variable-radius (wedge prism) plots to measure overstory trees ≥12.5 cm in diameter at breast height (dbh), and 3.99-m-radius fixed-area circular plots using the same plot centres to measure understory trees <12.5 cm dbh.

Similar to the earlier FPInnovations trials (Nishio 2009), this trial included three separate measuring phases. Phase 1 measurements included overstory and understory data from the permanent sample plots and was used to calculate pre-harvest non-pine stocking. In Phase 2, FPInnovations monitored the harvesting operation using MultiDATs to record the total productive machine hours (PMH) in each treatment, and conducted short-term detailed timing studies to record machine cycle times. In Phase 3, the same plots used in the pre-harvest stand were re-measured to estimate the change in non-pine stocking and harvesting damage to residual trees and understory. Also in Phase 3, the extraction trails were mapped and the total area of trails, landings, and roads was calculated.

Different inter-trail spacing intervals were initially flagged and used to determine the widest possible spacing distances that the feller buncher could effectively access all the pine from the main trail. It was considered acceptable to cut a limited number of short spur trails off the main trail to access the pine, but if the operator felt he required an excessive number of spur trails to access the pine trees, the inter-trail spacing was considered to be too wide. To avoid this, the feller-buncher operator used his discretion to reduce the spacing between trails as required to minimize the number of spur trails.

Figure 1. Layout of the partial harvesting block showing the various inter-trail spacing intervals.



Results and discussion

Trails and landings

The total areas of trails, landings, and roads and their proportions to the net block area for the partial harvesting block are listed in Table 2. Trail layout was also intended to avoid areas where there was no pine to harvest, but since pine was fairly evenly distributed, trails generally covered most of the net block area. Roads, trails, and landings in the partial harvesting block are illustrated in Figure 1. After felling some of the 35-m-spaced trails, the feller-buncher operator decided the spacing was too far apart to effectively access the pine trees and changed the remaining 35 m trails to operator-selected locations (Figure 1). Smaller landing areas could have accommodated the same number of trees if higher log decks were used, but decks were limited to a height (approximately 5 m) that allowed the dangle-head processors to work effectively.

Stand stocking and post harvest damage

The pre-harvest MTDFP stocking value for the non-pine species in the partial harvesting block was 0.21 (Table 3). This value indicates that the pre-harvest stand had the potential to provide a timber volume of 21% below that of a fully stocked clearcut plantation (Martin et al. 2005). The MTDFP value recorded after harvesting was 0.61. The removal (or severe damage) of secondary structure (overstory and/or understory trees) from trail building and general harvesting damage resulted in an increase in the MTDFP value of 0.40 (Table 3), indicating a drop of 40% in the stand's stocking potential. This means the block was initially "stocked" with secondary structure, but partial harvesting activities reduced much of the secondary structure and the block became not stocked or "open". Martin et al. (2005) generally suggests DFP values of 0.20 or lower are "stocked", values between 0.21 and 0.40 are "partially stocked", and values above 0.40 are "open" (not stocked). However, the adjacent Vanderhoof Forest District has accepted a maximum post-harvest DFP

Table 2. Trail, road, and landing areas in the partial harvesting block

	Trail area	Landing area	Road area	Total road, landing, and trail area	Net block area
Area (ha)	6.3	7.4	1.2	14.9	39.7
Proportion of block area (%)	15.9	18.6	3.0	37.5	100.0

value of 0.28 and the Prince George Forest District accepted a maximum DFP value of 0.28 in a previous FPInnovations trial (Nishio 2009). For the mean DFP rule, the minimum stocking standard of 700 well-spaced trees per hectare that is common in the BC interior roughly translates to a mean DFP of 0.28 (Martin et al. 2005).

Harvesting damage was considered as damaged or missing stems (Table 4). Parameters for moderate and severe damage to the overstory trees were taken from the "acceptable" and "not acceptable" tree damage classifications, respectively, for stands with a scheduled re-entry within 20 years as defined in BCMOFR (1997).

Post-harvest damage and secondary structure loss were only recorded for the partial harvesting block, as clearcut blocks are not expected to have any remaining secondary structure. Post-harvest stand results for the partial harvesting block were calculated as the lost, damaged, and harvested (missing) secondary structure stems proportional to what was present in the pre-harvest stand.

The total area of roads, landings, and trails was 37% of the block area (Table 2), but fully 60% of the non-pine overstory stems were harvested (Table 4). Since the non-pine trees were relatively evenly distributed throughout the block, it is estimated that approximately 23% of the non-pine overstory trees were unnecessarily harvested in this study. In the four previous FPInnovations trials, the percentage of non-pine overstory stems harvested was roughly equal (within 3%) to the percentage of developed block area (Nishio 2009).

The deep snow conditions in this trial protected most of the understory in the non-developed area. The result was that the amount of understory stems being harvested (40%) was approximately the same as the area developed for trails, roads, and landings (37%). In the four previous FPInnovations trials, the lost or damaged understory stems were 13–30% higher than the developed areas (Nishio 2009) because these blocks were harvested in the summer without the protection of deep snow.

Machine shift-level costs and productivity

The trial was harvested in February during cold winter conditions with temperatures of -30 C° and snow reaching depths of 2 m. The partial harvesting block contained a volume per hectare of 152 m^3/ha and an average piece size of 0.6 m^3. The clearcut block contained a volume per hectare of 135 m^3/ha and an average piece size of 0.4 m^3. Since the same harvesting equipment and operators were used for the two treatments, the partial harvesting treatment was expected to have lower productivity and higher costs than the clearcut treatment. However, all machine costs for the partial harvesting block were lower than the clearcut blocks (Table 5). This is likely because the harvested volume per hectare and average piece size were

Table 3. Pre- and post-harvest results for the partial harvesting block

	Pre-harvest	Post-harvest	Post-harvest change
Overstory basal area (m^2/ha)	14.9	7.6	7.3
WS USS[a] (no./0.02-ha plots)	3.5	1.2	2.3
DFP value	0.16	0.53	0.37
MTDFP value	0.21	0.61	0.40

[a] WS USS = Well Spaced Understory Stems (<12.5 cm dbh).

Table 4. Post-harvest secondary structure damage as a percentage of the pre-harvest stand in the partial harvesting block

	(%)
Lost or damaged understory stems	40
Undamaged or moderately damaged non-pine overstory stems	38
Severely damaged non-pine overstory stems	2
Harvested (missing) non-pine overstory stems	60

higher for the partial harvesting block than the clearcut block and resulted in a higher volume productivity in the partial harvesting block for the feller-buncher and processor. In a separate B.C. interior mountain pine beetle harvesting study, Dyson and McMorland (2008) found a 35% increase in clearcutting productivity for both feller-buncher and processor when piece size increased from 0.4 m^3 to 0.6 m^3, indicating a similar trend.

The gross merchantable cruise volume for the partial harvesting block was 9406 m^3 and the volume hauled away in trucks was

Table 5. Costs and productivity for block and right-of-way harvesting

Block	Machine	Owner/ operator cost ($/SMH)	PMH (h)	SMH [a] (h)	Harvested volume (m^3)	Cruise volume (m^3)	Productivity (m^3/PMH)	Cost [b] ($/$m^3$)
Partial	Feller-buncher	196.11	243.4	280.3	6022.4 [c]	9406	24.7	9.13
Partial	Loader	177.53	85.3	104.7	6022.4 [c]	9406	70.6	3.09
Partial	Processor	157.86 [d]	218.1	250.4	6022.4 [c]	9406	27.6	6.56
Partial	Skidder	133.65	157.6	188.5	6022.4 [c]	9406	38.2	4.18
Clearcut	Feller-buncher	196.11	74.3	82.0	1515.6 [c]	2261	20.4	10.61
Clearcut	Loader	177.53	31.7	36.3	1515.6 [c]	2261	47.8	4.25
Clearcut	Processor	157.86 [d]	63.9	70.6	1515.6 [c]	2261	23.7	7.35
Clearcut	Skidder	133.65	49.4	52.0	1515.6 [c, e]	2261	30.7	4.59
Partial R/W	Feller-buncher	196.11	na	20.8	694.1 [f]	na	na	5.88
Partial R/W	Loader	177.53	9.2	11.3	694.1 [f]	na	75.5	2.89
Partial R/W	Processor	157.86 [d]	23.5	26.9	694.1 [f]	na	29.5	6.12
Clearcut R/W	Feller-buncher	196.11	na	20.2	713.2 [g]	na	na	5.55
Clearcut R/W	Loader [h]	177.53	11.3	12.9	713.2 [g]	na	63.1	3.21
Clearcut R/W	Processor	157.86 [d]	22.8	25.2	713.2 [g]	na	31.3	5.58

[a] SMH is calculated from the start of the work day as it begins with the initial machine ignition power on and ends with the work day end as indicated from the final machine ignition power off.
[b] Cost = (owner/operator cost x SMH) / harvested volume.
[c] Harvested volume does not include right-of-way (R/W) volume.
[d] Processor owner/operator cost is the average cost of the two processors (see Appendix 1).
[e] Some estimated skidder volume was actually loader-forwarded and not skidded.
[f] Partial harvest right-of-way volume includes 96 m^3 of aspen.
[g] Clearcut right-of-way volume includes 244 m^3 of aspen.
[h] Loader calculations for the right-of-way harvesting include time loading logs onto logging trucks.

6022 m^3. The cruise volume for the clearcut blocks was 2261 m^3 and the volume hauled away in trucks was 1516 m^3 (Table 5). Presumably, due to the dry brittle conditions of the dead pine, the difference between the cruise volume and the hauled volume indicates that the volume that was left on site was waste and breakage. This means the harvesting machines, particularly the feller-buncher, handled about one-third more volume than the harvested volume used in the calculation of shift-level productivity (Table 5).

Sometimes the snow conditions were more of an adverse factor on skidder productivity than skid distances because the travel speed in deep snow was very slow and only became faster after the snow was packed from the skidder travelling several times over the same trails. Thus, the travel speed on the longer, more frequently travelled trails was generally faster than the travel speed on the less frequently travelled shorter trails. In general, the trails in the clearcut blocks were often less travelled than the longer, more frequently travelled trails in the partial harvesting block.

Feller-buncher productivity was dramatically affected with snow levels often pushed up to the cab window. Also, during very cold days (i.e., below -20oC), a granular or "sugary snow" was created that made it more difficult for the rubber-tired skidder to get traction than during warmer days when the snow could be packed down. The skidder operator believed a tracked machine would have been better suited for these cold, deep snow conditions. Also, the skidder volumes and loader-forwarded volumes could not be separated so some of the volume recorded as skidder harvested volume was actually loader-forwarded, which means the indicated skidder productivity is slightly higher than it should be (Table 5). Much more loader-forwarding occurred in the clearcut block than in the partial harvesting block. FPInnovations calculations for hourly machine costs are in Appendix 1.

Detailed machine cycle time results did not indicate any obvious differences in productivity between the different trail spacing intervals (Appendix 2). This suggests trails can be spaced as far apart as is operationally feasible (e.g., 30 m) for the feller-buncher without compromising productivity.

Conclusions

- Secondary structure damage can be reduced by keeping trails, roads, and landing areas to a minimum. Additional care must be taken to successfully protect a sufficient amount of secondary structure to leave a stocked stand. The fact that the deep snow conditions generally protected the understory off of the trails indicates the understory loss was directly related to the total area of trails, roads, and landings. Furthermore, since the proportion of harvested non-pine overstory was much higher than the combined trail, road, and landing area, this indicates non-pine removal was likely higher than necessary.
- The costing analysis in this case study indicated harvesting costs were higher for the clearcut compared to the partial harvesting treatments, demonstrating harvesting costs are affected by many factors including piece size, volume per hectare, machine travelling times, and snow conditions.
- Some removal of non-pine trees is unavoidable to build trails, roads, and landings. Therefore, these expected losses must be accounted for in the pre-harvest planning to ensure the pre-harvest stand has adequate non-pine trees to provide a stocked post-harvest stand.
- Excessive harvesting and/or tree damage can be avoided by clarifying protection objectives to operators and monitoring harvesting activities. Furthermore, it is essential that the operators are qualified and motivated to meet protection standards objectives.

Implementation

There are several things to consider when designing a cost-effective harvesting plan to selectively harvest pine while protecting secondary structure:

- Make every effort to keep the total area of trails, roads, and landings to a minimum.
- Make every effort to locate roads and landings in areas of higher concentration of pine.
- Locate trails as far apart as operationally possible, but adjust spacing as necessary to maximize efficiency. Trail spacing below 35 m may be required in stands with a well-distributed component of pine.
- Where possible, incorporate the open area of the road as processing space to reduce total landing area.
- Build log decks as high as operationally feasible to reduce total landing area.
- Harvest in winter to reduce tree damage, but consider the potential for snow conditions to reduce productivity.
- Manage for efficient use of harvesting machines so delays are kept to a minimum. If possible, plan the log hauling sequence to coincide with processing to allow smaller multiple-use landings to replace larger single-use landings.
- Clearly explain the harvesting objectives to the operators and monitor progress during harvesting. A high level of operator motivation is essential to achieving good secondary structure protection.
- Select candidate blocks that have sufficient pine to be an economically viable harvest, but also have an adequate level of secondary structure to accommodate harvesting damage losses and still leave a stocked residual stand. Most of the harvesting losses can be estimated before harvesting by calculating the total area of trails, roads, and landings. Calculating the proportion of harvesting damage will be challenging, but can be estimated by looking at various factors including stand density, snow conditions, pine distribution, equipment size, and operator experience and motivation. Also, pre-harvest DFP values will indicate the potential margin of loss available for post-harvest stocking.

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Appendix 1. Machine ownership and operating costs[a]

Ownership costs	Feller-buncher	Loader	Processor 1	Processor 2	Skidder
Total purchase price (P) [b] $ NEW	630 000	575 000	500 000	420 000	355 000
Expected life (Y) y	6	6	6	6	6
Expected life (H) h	10 000	10 000	10 000	10 000	10 000
Scheduled hours/year (h)=(H/Y) [c] h	1 620	1 620	1 620	1 620	1 620
Salvage value as % of P (s) %	25	25	25	25	25
Interest rate (Int) %	3.0	3.0	3.0	3.0	3.0
Insurance rate (Ins) %	3.0	3.0	3.0	3.0	3.0
Salvage value (S)=((P*s/100) $	157 500	143 750	125 000	105 000	88 750
Average investment (AVI)=((P+S)/2) $	39 3750	359 375	312 500	262 500	221 875
Loss in resale value ((P-S)/H) $/h	47.25	43.13	37.50	31.50	26.63
Interest ((Int*AVI)/h) $/h	7.29	6.66	5.79	4.86	4.11
Insurance ((Ins*AVI)/h) $/h	7.29	6.66	5.79	4.86	4.11
Total ownership costs (OW) $/h	**61.83**	**56.44**	**49.07**	**41.22**	**34.84**
Operating costs					
Fuel consumption (F) L/h	30.0	25.0	28.0	28.0	25.0
Fuel (fc) $/L	1.1	1.1	1.1	1.1	1.1
Lube & oil as % of fuel (fp) %	15	15	15	15	15
Annual tire consumption (t) no.	0	0	0	0	1
Tire replacement (tc) $	0	0	0	0	3 200
Track & undercarriage replacement (Tc) $	30 000	30 000	20 000	20 000	0
Track & undercarriage life (Th)	5 000	4 500	4 000	4 000	0
Lifetime repair & maint cost as % of purchase price	80	80	80	80	80
Lifetime repair & maintenance (Rp) $ [0.8 * P)]	504 000	460 000	400 000	336 000	284 000
Shift length (sl) h	9	9	9	9	9
Operator wages ($/h)	28.02	25.83	24.91	24.91	25.83
Total wages (W) $/h	28.02	25.83	24.91	24.91	25.83
Wage benefit loading (WBL) %	35	35	35	35	35
Fuel (F*fc) $/h	33.00	27.50	30.80	30.80	27.50
Lube & oil ((fp/100)*(F*fc)) $/h	4.95	4.13	4.62	4.62	4.13
Tires ((t*tc)/h) $/h	0.00	0.00	0.00	0.00	1.98
Track & undercarriage (Tc/Th) $/h	6.00	6.67	5.00	5.00	0.00
Repair & maintenance (Rp/H) $/h	50.40	46.00	40.00	33.60	28.40
Wages & benefits (W*(1+WBL/100)) $/h	37.83	34.87	33.63	33.63	34.87
Prorated overtime (((1.5*W-W)*(sl-8)*(1+WBL/100))/sl)	2.10	1.94	1.87	1.87	1.94
Total operating costs (OP) $/h	**134.28**	**121.10**	**115.92**	**109.52**	**98.81**
Total ownership and operating costs (OW+OP) $/h	**196.11**	**177.53**	**164.99**[d]	**150.74**[d]	**133.65**

[a] The costs in this study are not the actual costs incurred by the company and do not include supervision, profit, overhead, or transportation of equipment or logs. Actual machine costs may also differ due to differences in life expectancy, repair and maintenance costs, etc.

[b] New purchase prices were estimated; new replacement costs were provided by the contractor and operators.

[c] Scheduled hours per year (1620 h) was estimated as 9 hours per day for 5 days per week, 4 weeks per month, and 9 months per year.

[d] Average cost (OW+OP) of the two processors used in the trial is $157.86 [(164.99+150.74) / 2 = 157.86].

Appendix 2. Machine cycle times

Machine cycle times, recorded in minutes, are listed in Tables A–D. There were no obvious meaningful trends indicated between the mean machine cycle times at different trail spacings for the feller-buncher (Table A). Even with a larger average tree size, the mean processor time per tree was lower in the partial harvesting treatment (Table B). The mean cycle time for the skidder was higher in the partial harvesting block (Table C), likely the result of longer skid distances and the time the skidder spent building trails during the cycle timing.

Table A. Machine cycle times for feller-buncher

	Swing empty (%)[a]	Position & cut (%)[a]	Swing loaded (%)[a]	Deck (%)[a]	Brush (%)[a]	Travel (%)[a]	Delay (%)[a]	Move (%)[a]	Total cycle time (min)	No. of cycles	No. of trees	Mean cycle time (min)	Mean time/ tree (min)
Trail spacing													
20 m	23.6	20.1	11.3	3.0	0.9	4.9	34.5	1.6	43.2	64	122	0.67	0.35
25 m	9.1	28.6	15.9	9.4	2.3	0.0	0.4	34.3	169.3	155	406	1.09	0.42
30 m	7.5	30.5	14.9	12.4	2.2	0.0	0.9	31.5	161.3	147	429	1.10	0.38
35 m	4.6	29.0	13.2	11.8	2.5	0.0	3.3	35.6	107.5	78	237	1.38	0.45
Operator select	6.8	23.5	13.0	14.1	2.8	2.6	4.1	33.0	152.0	183	378	0.83	0.40
All trails	8.4	27.4	14.2	11.3	2.3	1.0	4.2	31.3	633.3	627	1572	1.01	0.40
Clearcut	10.2	32.0	16.4	9.7	9.1	0.6	3.4	18.7	210.5	207	579	1.0	0.36

[a] Values are the percent of total (cycle) time.

Table B. Processor cycle times

	Process (%)[a]	Sort (%)[a]	Move (%)[a]	Even deck (%)[a]	Debris (%)[a]	Process to waste (%)[a]	Other delay (%)[a]	Total time (min)	No. of trees	Mean time/ tree (min)
Partial harvesting	85.6	2.9	1.2	1.6	3.9	2.3	2.5	51.4	241	0.21
Clearcut	77.9	0.6	2.4	2.5	4.3	2.2	10.0	62.9	134	0.47

[a] Values are the percent of total (cycle) time.

Table C. Skidder cycle times

	Travel empty (%)[a]	Maneuver (%)[a]	Hook up (%)[a]	Travel loaded (%)[a]	Landing activity (%)[a]	Delay (%)[a]	Build trail (%)[a]	Total time (min)	No. of cycles	Mean skid distance	Mean cycle time (min)
Trail spacing											
20 m	25.73	14.89	13.48	31.20	9.95	4.75	0.00	813.1	25	105	32.5
25 m	26.80	11.66	15.14	28.04	7.44	10.67	0.00	40.3	10	143	4.0
30 m	15.63	2.78	21.41	19.63	15.35	25.14	0.00	179.8	18	na[b]	10.0
Operator select	20.11	6.29	8.73	21.30	15.69	18.92	8.95	176.5	32	83	5.5
Partial harvesting (all trails)	18.86	9.44	11.28	22.47	9.26	8.08	1.05	1503.7	85	110	13.0
Clearcut	29.97	8.71	9.41	26.83	16.03	9.76	0.00	28.7	5	76	5.7

[a] Values are the percent of total (cycle) time.
[b] Skid distance for 30 m trail spacing was not available.

The mean cycle time and mean time per tree for the loader that assisted the skidder were higher in the partial harvesting block (Table D). In the partial harvesting block, fewer trees felled close to the landings coupled with restrictions of trail access to landings resulted in a higher mean cycle time and mean time per tree (Table D). In the clearcut block, the loader was able to forward a higher number of trees adjacent to the landings. The lower proportional "wait for skidder" times and higher proportional "loader forward" times resulted in a lower mean cycle time and mean time per tree in the clearcut treatment. A relatively small amount of cycle timing data was collected from the clearcut blocks so the clearcut results may not be an accurate reflection of true cycle times. Also, machine cycle times are recorded over relatively short time periods and do not account for the longer delays such as travel between blocks or extended service/repair times that are included in the shift-level timing study.

The estimated productivities indicated in the detailed timing study for all machines were generally higher than the productivities indicated in the shift-level study. Several contributing factors could account for these discrepancies. The deep snow conditions required several modifications to the detailed timing procedures that created a bias for indicating an artificially higher productivity. Restricted researcher walking distance (and speed) reduced the amount of detailed timing recorded for unproductive long "travel empty" distances. The risk of working near dead trees increased the safe distance required for viewing machine operation. The increased safe distance requirement generally meant machines were timed on ground where snow had been previously worked on rather than on undisturbed snow cover resulting in higher productivities. Also, detailed timing was only done during daylight hours when productivity was presumably higher than night-shift work hours.

Table D. Cycle times for loader used to support skidder

	Wait for skidder (%)[a]	Deck (%)[a]	Move (%)[a]	Pile debris (%)[a]	Loader forward (%)[a]	Other delays (%)[a]	Total time (min)	No. of cycles	Mean cycle time(min)	No. of trees	Mean time/ tree (min)
Partial harvesting	27.5	34.7	2.8	3.4	9.2	22.4	540.8	106	5.10	1 255	0.43
Clearcut	21.6	17.9	11.0	0.0	15.6	33.9	21.8	11	1.98	72	0.30

[a] Values are the percent of total (cycle) time.

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