An Operational Comparison of Partial Cut and Clearcut Harvesting Methods in Old Cedar-Hemlock Forests in Central British Columbia

Chad Renzie and Han-Sup Han,
Forestry Program,
University of Northern British Columbia,
3333 University Way,
Prince George, B.C.,
Canada, V2N 4Z9.

ACKNOWLEDGEMENTS

The authors wish to knowledge Forest Engineering Research Institute of Canada (FERIC) for providing technical assistance and a detailed timing program used in the study. Special thanks are also extended to the logging contractors and the staff of the Robson Valley Forest District for their cooperation. The authors would also like to thank Rob Bourcier for his assistance with the fieldwork. This project was funded by the Robson Valley Enhanced Forest Management Pilot Program (EFMPP) and Northern Land Use Institute (NLUI). Our sincere thanks go to Mike Jull for inviting us to participate in the silvicultural systems trial project.

ABSTRACT

Although clearcutting has been a historically dominant harvesting method in British Columbia (representing 95% of the total area harvested annually), forest managers are increasingly recommending the use of alternative silvicultural systems and harvest methods, including various types of partial cutting, to meet ecological and social objectives. In this study we compared harvesting productivity and harvesting costs between treatments in 300-350 year-old Interior Cedar-Hemlock stands. This was achieved through detailed and shift level time studies. Residual stand damage was also assessed and recommendations for improving operational planning/layout and the implementation of clearcut and partial cutting silvicultural systems were made. Ground-based clearcut harvesting was the most cost effective at $\$11.96/m^3$, followed by the cable clearcut using a running skyline system at $\$16.08/m^3$. The group selection treatment had the highest cost at $\$16.95/m^3$, an increase in cost of 42% compared to the ground-based clearcut treatment. The net merchantable volume in the harvested stand ranged from 32% to 49% of the total harvested volume, due to the high proportion of butt and pocket rot. The high amounts of decay and waste had a large effect on the final cost per cubic meter. Residual leave trees damaged by ground-based skidding in the group selection accounted for 9% of the residual stand.

Acknowledgements 1
Abstract 2
I. Methods 5
II. Results and discussion 6
  Planning and layout 6
  Harvesting operations 6
    Felling 6
    Primary transport 7
      Skidding 7
      Yarding 7
    Processing / Decking / Utilization of western redcedar 8
    Other harvesting costs 9
  Stand damage 10
III. Conclusion 10
IV. References 11
APPENDICIES 12
Appendix 1. Machine cost 13
Appendix 2 Detailed time of felling phase 14
Appendix 3 Detailed time of ground-based skidding phase 15
Appendix 4 Detailed time of Yarding phase 16

INTRODUCTION

Forest management in British Columbia (BC) is rapidly changing due to increasing emphasis on ecological and social goals that include the management of non-timber resources such as visual quality and wildlife habitat. The use of alternative silvicultural systems, including partial cutting, are being increasingly considered for achieving these management goals. Since clearcutting has been a dominant harvesting method in BC, knowledge and experience with partial cutting is limited for many of BC's forest ecosystems. Also, it has been traditionally widely viewed that the low market value of the Interior Cedar-Hemlock (ICH) stands make it more difficult to practice Partial cut silvicultural systems in these stands (Sinclair 1984). Partial cutting generally is considered to be more expensive than clearcutting (Daigle 1995).

For example, Thibodeau et al. (1996) compared logging productivity and costs of partial cut and clearcut treatments in a second growth ICH stand with an age of 130 years and moderately gentle terrain in northwestern BC, and found that the cost of a ground-based partial cut harvesting system was 1.98 times higher than that of a ground-based harvested clearcut. Layout costs for the partial cut were 1.9 to 2.3 times that of clearcut units due to more intensive timber cruising, layout and marking of internal patch cut boundaries, increased tree marking, and designated skid trail networks (Thibodeau et al. 1996; BCMOF 1996).

Tree marking in partial cuts allows fellers to be free from selecting trees to be felled, thus increasing their productivity (Bennett 1997). Tree marking must take into consideration the safety of the feller through individual tree characteristics (i.e. lean, and distribution of branches), and the characteristics of adjacent trees (Moore 1991). When hand felling, stumps should be close to ground level to minimize hang-ups (Pavel 1999). The primary consideration of the feller is safety (Moore 1991). In decadent western redcedar, felling is dangerous and difficult due to a lack of holding wood and a result of both branches and tops being prone to breakage during falling.

Skidding productivity is affected by weather, skidding distance and slope (Mitchell 2000). The skidding cost per cubic meter, when using a line skidder, a 60 % removal treatment is 1.85 times higher in cost than a conventional clearcut as a result of longer skid distances and less volume delivered to the landing per turn (Thibodeau et al. 1996).

Effective use of the loader is essential to ensure that the landing is clear and safe and that trucks are loaded with a minimum delay (Pavel 1999). The loading cost per cubic meter in partial cuts ranges from 1.31 to 1.46 times greater than in clearcut units as a result of increased non-productive time in the partial cut units (Bennett 1997).

The majority of residual stand damage is located along skid trails where the most harvesting activity occurs (Pavel 1999; Bennett 1997). In ground-based partial cuts, the orientation of harvest units and directional felling play an important role in reducing stand damage (Thibodeau et al. 1996).

The objectives of this study are to 1) compare harvesting productivity and costs between treatments, 2) assess residual stand damage in a partial cut block, and 3) document the current utilization of old western redcedar with high internal defects.

I. METHODS

The research was conducted on sites in the Interior Cedar- Hemlock biogeoclimatic zone (Ketcheson et al. 1991), 35 km west of McBride, BC. The sites were dominated by western redcedar (*Thuja plicata*) with minor components of Engelmann spruce (*Picea engelmanii*), western hemlock (*Tsuga heterophylla*), and subalpine fir (*Abies lasiocarpa*) (Table 1). The stands within the study area had an average age of 300-350 years and high incidence of defect; scaling data indicated combined decay, waste, and breakage total ranging from 51 to 68%. There were three treatments: a group selection and two clearcut blocks. In the group selection treatment the primary goal of the layout crew was to design a skid trail system that would allow for multiple entries while maintaining visual quality.

Two contractors participated in this study; Contractor A harvested the ground-based treatment units (70% retention and 0% retention) using a ground-based harvesting system consisting of hand felling, skidding with rubber-tired and tracked line skidders, manual delimbing/bucking, and loading with a front end wheel loader. Contractor B harvested the cable unit (100% removal) using an adapted running skyline system with a non-slackpulling carriage consisting of hand felling, yarding with a tower yarder, manual delimbing/bucking, and loading with a heel boom log loader. Manual felling was the only method used for all harvest units because of large

Table 1. Site and stand description.

Harvesting system	Ground skidding		Cable
Silvicultural treatment	Group selection	Clearcut	Clearcut
Treatment size (ha)	8.7	1.1	6.7
Harvested area (ha)	2.1	1.1	6.7
Slope range	0-50%	0-30%	30-130%
(avg.)	(20%)	(15%)	(55%)
Species (%)			
Western red cedar	87	79	90
Subalpine fir	3	10	3
Englemann spruce	10	5	2
Western hemlock	0	6	5
Stems/ha[a]	404.7	424.3	424.3
Avg. DBH (cm)[a]	56.2	53.2	53.2
Avg. ht (m)[a]	36.7	33.5	33.5
Gross vol. (m^3/ha) [a]	1074.6	908.0	908.0
Net merchantable vol. (m^3/ha)[b,c]	349.0	441.6	433.0

[a] Provided by the BC MOF Cruise data.
[b] The low net merchantable volume resulted from high decay, waste, and breakage.
[c] The net merchantable volume was calculated from the BCMOF Scale data.

tree size and steep slopes. Contractor A and B had separate fellers with similar amount of felling experience (20 years). During felling, snow was present (<20cm) on the site but shovelling was not required for the majority of trees.

There were three methods used to collect time study data on logging operations: shift level, detailed, and activity sampling. A Ranger 3100 data logger was used to time the components of each harvesting process. In activity sampling, sampling intervals were set at 20 seconds to ensure the accuracy of the data as recommended by Olsen and Kellogg (1983).

Harvesting costs were calculated using the Forest Engineering Research Institute of Canada's (FERIC) standard costing methods and were based on local standard contractor rates for workers (Appendix 1). A multiple regression analysis was completed for felling and primary transportation elements of the harvesting operation. Systematic transect sampling was used to estimate the damage to residual trees. To determine the utilization of the western redcedar, harvested from this site, three mills were asked to provide a list of their products.

II. RESULTS AND DISCUSSION

Planning and layout

The layout and planning costs were highest in the group selection ($2.62/$m^3$) because of the need to designate removal patches. The recommended skid trails were also marked in both ground-based treatments during the layout phase. The contractors were given the option to modify the location of these skid trails, if necessary. In all treatments pre-existing landings from the construction of the East Twin Forest Service Road were utilized instead of constructing new landings, because the locations of these landings were suitable and resulted in decreased landing construction costs. Layout of the cable-based clearcut incurred higher costs ($0.68/$m^3$), than the ground-based clearcut ($0.53/$m^3$), due to increased time requirements for layout of skyline roads to ensure sufficient deflection.

Harvesting operations

Felling

Pronounced butt flare in western redcedar in combination with the presence of butt rot, made directional felling difficult and potentially dangerous. In all treatments the cedar was generally felled in a downhill direction as the trees were leaning and weighted by branches to fall in that direction. Breakage occurred in less than 2.0% of the felled timber. In the partial cut, trees were felled towards skid trails unless tree conditions safety or felling constraints made this impossible.

Felling production in the cable clearcut was the highest as a result of the fastest cycle time of 1.97 min./tree (Appendix 2). This resulted in a volume production of 359.28m^3 per 8-hour shift. The group selection cycle time (3.13 min./tree) was faster than that of the ground-based clearcut (3.58 min./tree). However, the higher volume per tree, 1.54m^3/tree for the ground-based portion of the clearcut versus 1.22m^3/tree for the group selection treatment, resulted in a larger volume harvested in the ground-based clearcut per cycle. These results indicate that total cycle time, tree size, and decay percentage can have a significant effect on the production.

[1] Total productive time (min.) = 0.040 + 0.020 * Diameter

n = 212 R^2 = 0.513 S.E. of Estimate = 0.604

Primary transport

Skidding

The average skidding distance in the group selection was 284 m, which was 143 m longer than in the clear cut (Appendix 3). In the group selection, an additional 1.5 logs were delivered to the landing each turn, but resulted in a longer cycle time. The average total cycle time in the group selection was 2.83 min. greater than the clearcut. In the clearcut and group selection, 0.6% and 1.1% of the total cycle time was spent waiting for the track skidder to clear and develop skid trails. An additional 0.23-min. wait for the feller per cycle was also incurred in the group selection. These delays could have been avoided through better planning by the contractor.

[2] Total productive time (min.) = 8.582- 1.195 * Treatment + 0.025 * Distance+ 0.793 * No of logs

n = 136 R^2 = 0.521 S.E. of Estimate = 3.248

Where: Treatment: 0 = Clearcut, 1 = Group selection

Yarding

The yarding was downhill with distances ranging from 35 to 225 meters with an average distance of 125 meters. The unit cost for yarding was 72.5% more expensive than skidding in the group

Table 2. Summary of total costs. All costs are in \$/m^3.

Harvesting system	Ground-based		Cable
Silvicultural treatment	Group selection	Clearcut	Clearcut
Layout/planning cost	2.62	0.53	0.68
Felling cost	2.01	2.02	1.11
Skidding/yarding cost	4.48	4.14	7.73
Bucking cost	1.54	0.96	1.15
Loading cost	5.32	3.33	5.01
Moving cost	0.98	0.98	0.40
Total cost	16.95	11.96	16.08

selection and 86.7% higher than skidding in the clearcut. Productive yarding time constitutes 75% of the total cycle time (Appendix 4). This is higher than that found in ICH stands near Kitwanga, BC (Pavel 1999), which found that only 55% of the total cycle time was actually productive. Yarder setting change time accounts for 11% of the total cycle time. Approximately 19% of the non-productive time, or 2.52% of the total cycle time, was spent on repairing the haulback drum and general repairs, such as repairing a coolant leak or broken hydraulic line. Equation 3 shows that the number of logs has a greater effect on the total productive time than distance.

[3] Total productive time (min.) = 2.002 + 0.027 * Distance + 0.639 * No of logs

n = 285 $R^2 = 0.290$ S.E. of Estimate = 1.791

Processing / Decking / Utilization of western redcedar

Processing for all sites was manually completed using a chainsaw at the landing. The primary consideration of processing was to maximize commercially valuable wood recovery such as saw logs and post and rail wood. The saw logs were required to have a minimum of a 10 cm sound outer shell (distance between outer bark and inner rot) of timber in order to be merchantable. The minimum required length for saw logs was 5m, up to a maximum length of 19 m. The saw logs were processed into dimensional lumber such as 2.5cm x 10cm (1"x4"), 5cm x 7.5cm (2"x3"), and 5cm x 30cm (2"x12") of various lengths, radius edge decking, tongue & groove, channel siding, and rough facia board. The post and rail timber required a 7.5 cm shell. Post and rail timber required a minimum length of 2.5m and a maximum length of 19m. Timber for this product was processed into 7.5cm x 7.5 cm (3"x3") and 10cm x 10cm (4"x4") posts of 2.4 to 3.0m (8 to 10 feet) lengths and 10cm x 10cm (4"x4") and 7.5cm x 7.5cm (3"x3") rails of 2.4 to 4.9m (8 to 16 feet) lengths

The combined decay, waste, and breakage totals for the ground-based group selection, ground-based clearcut, and cable clearcut treatments were 68%, 51%, and 52%, respectively. These numbers are high as a result of butt and pocket rot being present in the western redcedar (Fig. 1). Butt and pocket rot not only destroy heartwood and sapwood, but also increases the possibility of breakage when felling and skidding/yarding. The bucker made multiple cuts with a chainsaw at 0.75m intervals to determine where the timber was commercially valuable. In the cable clearcut, the timber was first processed for saw logs and then post and rail wood.

The lowest cost of processing and decking wood ($/m^3) was the ground-based clearcut. This lower cost may be partially compounded by a lower defect rate per tree and the higher proportion of spruce and subalpine fir in this block. The hemlock, spruce, and subalpine fir generally did not have any decay, thus was faster to process for the bucker. These species were processed for saw logs only. Decking was necessary to sort the timber as it was being sent to mills throughout central and southern British Columbia. Additionally by decking the timber, the landings were kept clear and the safety of bucker was improved. Decking and processing costs were the highest in the group selection because workers and equipment on the landing were waiting for wood to process due to a longer cycle time for wood being skidded to the landing. The cable

Figure 1. Pocket and ring rot in the but of western redcedar

clearcut had higher costs than the ground-based clearcut largely due to higher equipment costs per hour, although a heel-boom loader showed a greater productivity (m^3/hr) than the front end wheel loader did in the group selection.

According to the activity sampling, primary transportation was not delayed by decking and processing on the landing. In the ground-based treatments, the loader was waiting for timber to sort 49% to 51% of the scheduled operating time. This was also similar for bucking where 39% to 41% of the scheduled operating time was spent waiting for skidded timber to process. To improve loading and bucking efficiency on the landing in the ground-based treatments, we recommend another skidder be employed to reduce the non-productive time. In the cable treatment, the operation was well balanced in its components.

Other harvesting costs

The cost of moving logging equipment by low-bed truck from McBride to the harvest site, a 35km distance, was calculated by dividing the cost of moving by the volume removed. The local rate for moving equipment was $600 per low-bed of equipment. As contractor A harvested both the group selection and ground-based clearcut, the moving cost was shared. Contractor B harvested the cable clearcut block with different equipment and thus new moving costs were incurred.

Skid trail and landing construction costs were calculated by timing the number of hours taken to construct the trail and landings, and the equipment and manpower used to complete the task for each treatment. The group selection treatment required 15 hours of landing and skid trail construction while the ground-based clearcut only required 7.5 hours of landing and skid trail construction. This resulted in a higher cost per cubic meter in the group selection ($2.97/m^3) compared to the clearcut ($2.24/m^3).

Stand damage

In the group selection treatment 9.25% of the residual stand was damaged during harvesting (Table 3). Stems along the skid trail had the highest incidence of stand damage, 73% of the total stand damage. This damage occurred within 5 meters from the centre of the skid trails. The average width of the skid trails was 5 meters. The remaining 27% of the total stand damage occurred adjacent to the harvest openings, within 5 meters.

Table 3. Summary of stand damage

	Skid trails	Openings	Both
Damage summary			
% of residual stand	6.8	2.5	9.3
No. injuries/ tree	1.4	1.1	1.3
Average size			
Width (cm)	14	9.5	13.1
Length (cm)	42.1	18.7	37.2
Area (cm^2)	659.4	578.3	564
Height [a] (cm)	66.2	12.6	68.3
Percent of total damage [b]			
Stem	84	91	86
Stem and Root	13	9	12
Root	3	0	2

[a] Measured from base of tree to middle of damage
[b] Damage classes: Stem - scarring or gouging stem
Root – scarring or cutting root system
Stem and root - multiple of stem and root damage

III. CONCLUSION

Tree volume, amount of internal decay, and efficiency of harvesting elements were the most important factors affecting final harvesting cost. Ground-based clearcut harvesting was the most cost effective at $11.96/m^3, followed by the cable clearcut at $16.08/m^3. The group selection treatment had the highest cost at $16.95/m^3, an increase in cost of 42% compared to the ground-based clearcut treatment. This low cost of the ground-based clearcut can be partially attributed to the lower decay waste and breakage of the harvested wood in comparison to the group selection (17% lower). In a group selection, harvest groups should be arranged in a manner that facilitates felling the trees into an open skid trail or other opening, as it is easier and more productive for the feller and skidder. The trees scheduled for removal should be examined for lean and branch orientation, as it will affect the direction and ease of felling. Loading and bucking productivity could be improved in the ground-based treatments by employing another line skidder. Economic feasibility in all three treatment units is dependent on market value. Therefore before harvesting the contractor should ensure that a buyer for the wood to be harvested exists and that the highest commercial volume is being extracted from the timber by processing the timber for use as multiple products.

Stand damage levels in the group selection is 9.25% of the residual stand. Of this damage 73% is located along skid trails and could be decreased if prevention or remediation techniques were utilized, such as straight skid trails and use of rub trees.

IV. REFERENCES

British Columbia Ministry of Forests 1996. Cruising Manual, Section 2.0, Cruise Design. April 1, 1996 Amendment. Crown Publications Inc., Victoria BC. Publication #106BC.

Bennett D.M. 1997. Partial cutting in mountainous old-growth forests in coastal British Columbia; harvesting productivity and cost, and residual stand impacts. FERIC, Vancouver, BC. Tech. Report. TR -119. 20 pp.

Daigle, P.W. 1995. Partcuts: a computerized annotated bibliography of partial-cutting methods in the Pacific Northwest (1995 update). Forestry Canada; British Columbia Ministry of Forests. 25 pp.

Ketcheson, M.V., Braumandl, T.F., Meidinger, D., Utzig, G., Demarchi, D.A., and Wikeem, B.M. 1991. Ecosystems of British Columbia, Chapter 11: Interior Cedar–Hemlock Zone. Crown Publications Inc., Victoria BC. ISSN 0843-6452 167-181 pp.

Mitchell, J. 2000. Productivities and costs of harvesting small openings in the Cariboo Forest Region. FERIC, Vancouver, BC. Advantage Vol. 1 No. 22. ISSN 1493-3381 8 pp.

Moore, K. 1991. Partial cutting and helicopter yarding on environmentally sensitive floodplains in old growth Hemlock/Spruce forests. FRDA, Vancouver, BC. ISSN 0835-0752 42 pp.

Olsen, E.D. and Kellogg L.D. 1983. Comparison of time-study techniques for evaluating logging production. Forest Research Lab. Oregon State University. Corvallis, Oregon. Research Paper 1701. 4p.

Sinclair, A.W.L. 1984. The Economics of utilizing decadent interior cedar hemlock. FERIC, Vancouver, BC. Tech. Report. TR-059. 36 pp.

Pavel, M. 1999. Analysis of a Skyline Partial Cutting in the Interior Cedar-Hemlock Biogeoclimatic Zone. FERIC, Vancouver, BC. Tech. Report. TR-125. 21 pp.

Thibodeau, E. D., Krag, R. K., and I.B. Hedin 1996. The Date Creek Study: Productivity of ground-based harvesting systems in the interior cedar hemlock zone of British Columbia. FERIC, Vancouver, BC. Special Report. SR-114. 38 pp.

APPENDICIES

APPENDIX 1. MACHINE COST

CONTRACTOR	A			B	
OWNERSHIP COSTS	John Deere 640G Line Skidder	Caterpillar D6R Line Skidder	John Deere 644H Front End Log Loader	Madill 172-5 Drum Tower Yarder	Barko 475B Heel Boom Loader
Total Purchase Price (P) $	246,200	395,000	316,000	900,000[a]	544,000
Expected Life (Y) y	5	5	5	10	5
Expected Life (H) h	10000	10000	10000	20000	10000
Scheduled hours/year (h)=(H/Y) h	2000	2000	2000	2000	2000
Salvage value as % of P (s) %	30	30	30	30	30
Interest rate (Int) %	10	10	10	10	10
Insurance rate (Ins) %	3	3	3	3	3
Salvage value (S)=(P*s)/100) $	73,860	118,500	94,800	270,000	163,200
Average investment (AVI)=((P+S)/2) $	160,030	138,250	110,600	315,000	190,400
Loss in resale value ((P-S)/H) $/h	17.23	27.65	22.12	31.50	38.08
Interest ((Int*AVI)/h) $/h	8.00	6.91	5.53	15.75	9.52
Insurance ((Ins*AVI)/h) $/h	2.40	2.07	1.66	4.73	2.86
Total ownership costs (OW) $/h	27.64	36.64	29.31	51.98	50.46
OPERATING COSTS					
Wire rope (wc) $				15100	
Wire rope life (wh) h				2000	
Rigging and radio (rc)				13800	
Rigging and radio life (rh) h				4000	
Fuel Consumption Diesel (F) L/h	22	23	22	40	20
Fuel Cost Diesel (fc) $/L	0.50	0.50	0.50	0.50	0.50
Lube and oil as % of fuel (fp) %	15	15	15	15	15
Track and undercarriage replacement (Tc) $	0.00	20000	0	10000	8,000
Track and undercarriage life (Th) h	0.00	10000	0	100000	10,000
Annual repair & maintenance (Rp) $	20,000	14000	12000	20,000	20,000
Annual operating supplies (Oc) $	1,500	1500	1000	1,500	1,000
Annual tire consumption (t) no.	2		2		
Tire replacement (tc) $	3,300		2300		
Operator wages $/h	25.00	25.00	25.00	25.00	25.00
Hook tender wages				20.00	
Number of hook tenders				2	
Wage benefit loading (WBL) %	35	35	35	35	35
Shift length (sl) h	8	8	8	8	8
Wire rope (wc/wh) $/h				7.55	
Rigging and radio (rc/rh) $/h				3.45	
Fuel (F*fc) $/h	11.00	11.50	11.00	20.00	10.00
Lube and oil ((fp/100*(F*fc)) $/h	3.30	3.45	3.30	6.00	3.00
Tires ((tc*t)/h) $/h	3.30		2.30		
Repair and maintenance (Rp/h) $/h	10.00	7.00	6.00	10.00	10.00
Track and Undercarriage (Tc/Th) $/h		2		0.10	0.80
Operating supplies (Oc/h) $/h	0.75	0.75	0.50	0.75	0.50
Wages and benefits (W*(1+WBL/100) $/h	33.75	33.75	33.75	87.75	33.75
Prorated overtime ((1.5*W-W)*(sl-8)*(1 +WBL/100))/sl) $/h	0.00	0.00	0.00	0.00	0.00
Total operating costs (OP) $/h	62.10	58.45	56.85	135.60	58.05
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	89.74	95.09	86.16	187.58	108.51

[a] Yarder cost includes the cost for a non-slackpulling carriage.

* Wage Costing: Feller is on a day rate of $400 based on an 8-hour workday and the bucker is on an hourly rate of $25 per hour

APPENDIX 2 DETAILED TIME OF FELLING PHASE

	Avg. time/element (min)	Time/Cycle (%)	Avg. time/element (min)	Time/Cycle (%)	Avg. time/element (min)	Time/Cycle (%)
Treatment	Group Selection (70% retention)		Clearcut Ground-based		Clearcut Cable	
Feller	A	A	A	A	B	B
Productive Elements:						
Moving from tree to tree	0.302	9.6	0.359	10.0	0.367	18.6
Brushing	0.065	2.1	0.096	2.7	0.076	3.8
Cutting	1.192	38.1	1.175	32.8	0.799	40.6
Wedging	0.086	2.7	0.112	3.1	0.012	0.6
Bucking	0.021	0.7	0.015	0.4	0.000	0.0
Shovelling	0.165	5.3	0.183	5.1	0.019	0.9
Reconnaissance	0.034	1.1	0.043	1.2	0.018	0.9
Total Productive Time	1.864	59.6	1.983	55.4	1.290	65.5
Non Productive Elements						
Resting	0.570	18.2	0.510	14.2	0.403	20.5
Fuelling saw	0.102	3.3	0.123	3.4	0.079	4.0
Filing saw	0.054	1.7	0.019	0.5	0.088	4.5
Fixing saw	0.021	0.7	0.148	4.1	0.099	5.0
Moving equipment and fuel	0.001	0.0	0.061	1.7	0.011	0.6
Hiking in block	0.067	2.1	0.056	1.6	0.000	0.0
Choking trees	0.043	1.4	0.302	8.4	0.000	0.0
Waiting for skidder	0.039	1.2	0.140	3.9	0.000	0.0
Lunch	0.368	11.8	0.238	6.6	0.000	0.0
Total Non-Productive Time	1.265	40.4	1.596	44.6	0.681	34.5
Total Cycle Time	3.130	100.0	3.579	100.0	1.970	100.0
Volume per hour (m^3/hr)	24.92		24.75		44.91	
Feller cost ($/hr)	50.00		50.00		50.00	
Felling cost ($/$m^3$)	2.01		2.02		1.11	

APPENDIX 3 DETAILED TIME OF GROUND-BASED SKIDDING PHASE

	Avg. time/element (min)	Time/Cycle (%)	Avg. time/element (min)	Time/Cycle (%)
Treatment	Group Selection (70% retention)		Clearcut Ground-based	
Productive Cycle Elements				
Travel empty	3.51	16.43	2.74	14.81
Winch line out	0.90	4.22	0.69	3.71
Winch line in	0.72	3.37	0.60	3.24
Repositioning	0.15	0.69	0.07	0.40
Choke #1	2.86	13.40	2.42	13.08
Choke #2	1.62	7.57	1.46	7.91
Choke #3	0.70	3.26	0.59	3.21
Choke #4	0.39	1.83	0.18	0.95
Choke #5	0.08	0.37	0.00	0.00
Total choking time	5.64	26.42	4.65	25.15
Travel Loaded	4.38	20.51	4.29	23.21
Unchoking	1.35	6.34	1.13	6.08
Delimbing	0.30	1.41	1.32	7.14
Turning on landing	1.53	7.16		
Total Productive Time	18.47	86.55	15.50	83.74
Total Non-productive	2.87	13.45	3.01	16.26
Total Cycle Time	21.34	100.00	18.50	16.26
Average distance (m)	238.70		140.80	
Number of chokers available	8		5	
Choking averages				
Trees in choke #1/cycle (no.)	2.90		2.40	
Trees in choke #2/cycle (no.)	1.70		1.10	
Trees in choke #3/cycle (no.)	0.90		0.50	
Trees in choke #4/cycle (no.)	0.30		0.30	
Trees in choke #5/cycle (no.)	0.10		0.00	
Average pieces/cycle (no.)	5.90		4.40	
Volume per hour (m3/hr)	20.05		21.69	
Skidder cost ($/hr)	89.74		89.74	
Skidding cost ($/m3)	4.48		4.14	

APPENDIX 4 DETAILED TIME OF YARDING PHASE

	Avg. time/element (min)	Time/Cycle (%)		Avg. time/element (min)	Time/Cycle (%)
Productive Cycle Elements			Non-productive Elements		
Outhaul	0.735	7.80	Warm and fuel up	3.25	3.36
Hookup	3.131	33.22	Replacing choker	1.92	1.98
Hookup #2	0.128	1.35	Repairing mainline	1.73	1.78
Inhaul	2.246	23.83	General repairs	1.19	1.23
Unhook	0.838	8.89	Adjusting guylines	0.84	0.87
			Wait for loader	0.83	0.86
Total productive time	7.076	75.10	Repairing haulback drum	0.79	0.82
			Broken strawline	0.72	0.74
Yarder setting change time	1.006	10.68	Adjusting haulback brake	0.53	0.55
			Tangled lines	0.52	0.53
			Rechoking log	0.49	0.50
			Untangling logs	0.33	0.34
			Wait for chokerman	0.31	0.32
			Communication	0.26	0.26
			Repairing carriage	0.21	0.22
			Personal delay	0.20	0.21
			Crossed lines	0.05	0.05
			Wait for bucker	0.04	0.04
			Wait for chaser	0.01	0.01
			Total non-productive time	1.34	14.22
Total cycle time (min)	9.42	100.00			
Cycles per hour (no.)	6.37				
Average pieces/cycle (no.)	2.59				
Average yarding distance (m)	155.98				
No. of timed cycles		297			
Total harvested volume (m^3)		2987.9			
Total trees (no.)		2031			
Volume per tree (m^3)		1.47			
Volume per hour (m^3/hr)		24.27			
Yarder cost ($/hr)	187.58				
Yarding cost ($/$m^3$)	7.73				