Operational Analysis of Partial Cut and Clearcut Harvesting Methods in North-central Interior ICH Mountain Forests – Part 2

Final Report to the Robson Valley Enhanced Forest Management Pilot Project (EFMPP)

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EXECUTIVE SUMMARY

For interior cedar hemlock (ICH) stands along the Rocky Mountains, partial harvesting methods have been increasingly considered to maintain visual quality and wildlife habitat while allowing for timber production. The implications of increasing the use of partial cutting approaches on harvest productivity, logging costs, and an impact on residual trees is not yet fully understood.

The objectives of this study were to assess planning and harvesting productivities and costs; assess stand damage levels; and identify ways to improve operational planning and implementation of partial cutting silvicultural systems in ICH ecosystems.

This study is the second of two being conducted by the University of Northern BC with the cooperation of the Small Business Forest Enterprise Program (SBFEP) of the Robson Valley Forest District and includes results from the Minnow Creek site where a contractor harvested the site with a semi-mechanized ground-based harvesting system between January and February 2001. The ground-based system consisted of mechanized and manual felling, a grapple skidder, manual processing, and front-end loader. UNBC researchers collected shift level and detailed timing data on all skidding and mechanical felling activities, shift level data for manual felling, processing, and loading, summarized layout and planning requirements and costs for each of the study treatments, and surveyed stand damage after harvesting for the three harvesting treatments (0%, 30% and 70% retention). The calculated harvesting costs do not include supervision, overhead, profit, and risk allowances.

The 30% and 70% retention treatments clearly required more intensive planning and fieldwork, requiring 2.5 and 3.8 times more planning and layout effort than the clearcut treatment. Costs of planning and layout were calculated at $\$1.73/m^3$ for the 70% treatment, $\$1.16/m^3$ for the 30% treatment, and $\$0.45/m^3$ for the ground based clearcut treatment.

Both mechanical and manual felling methods were used to harvest all three treatment units. Manual felling was utilized where slopes and tree characteristics (size, decay, and species) did not permit mechanized felling. The overall felling cost in the clearcut was only marginally higher than the group selection at $\$3.87/m^3$ versus $\$3.80/m^3$. Felling cost was lowest in the group retention, $\$3.28/m^3$, due to a higher merchantable volume per tree, gentle slopes and increased mechanized felling. These results indicate that tree and terrain characteristics had a greater impact on felling cost than silvicultural treatment.

Skidding was completed with a rubber tired skidder equipped with a grapple. In the group retention treatment a production rate of $32.95m^3/hr$ was achieved at a cost of $\$3.53/m^3$. The production rate was lower in the clearcut and 70% retention at $21.29m^3/hr$ and $23.25m^3/hr$ respectively with corresponding costs of $\$5.56/m^3$ and $\$5.00/m^3$. These higher costs may be the result of the average slope being greater and the average skidding distance being approximately twice that of the group retention treatment.

Hoe chucking was completed with an excavator using a standard bucket and thumb combination and was utilized where slopes were greater than those that could be safely traveled with the rubber-tired grapple skidder. In the case of this study only two of the three treatments (group selection and clearcut) required hoe chucking due to slope constraints. The costs were highest in the clearcut at $\$1.17/ m^3$ followed closely by the group selection at $\$1.02/m^3$.

Processing was done by manual means on the landings. The costs were highest in the clearcut at $\$1.21/m^3$, followed by the group selection treatment at $\$1.08/m^3$. The ground-based clearcut treatment had the lowest processing cost at $\$1.05/m^3$. Again these costs are highly dependent on log quality as lower quality timber requires greater processing on the landing. This was observed from the combined decay, waste, and breakage values for the group selection, group retention, and clearcut treatments which were 55%, 53%, and 68%, respectively.

Loading was completed by a front-end loader in all treatments. Loading costs were the highest in the group selection at $4.75/m^3. The group retention and clearcut treatments both had lower costs at $4.40/m^3 and $4.18/m^3, respectively. The costs were highest in the group selection due to a greater amount of unproductive time for the loader.

Overall planning, falling, skidding, hoe chucking, processing, and loading costs were calculated at $13.45/m^3 for the group retention, $16.33/m^3 for the clearcut, and $17.37/m^3 for the group selection treatment. If one is to set the piece size equal to 1m^3 and disregards the use of hoe chucking a different story becomes apparent the clearcut has the lowest cost at 13.81/m^3 followed by the group retention and group selection at $14.33/m^3 and $17.31/m^3, respectively. This illustrates that tree and terrain characteristics can have a larger impact on harvesting costs and productivity then that of treatment in the case of the group retention versus the clearcut treatments. It seems, however, that regardless of these characteristics the group selection treatment remains the most expensive.

In all three treatments the stand damage was assessed post harvest. It was found that all of the stand damage occurred within 7 meters of skid trails and harvest boundaries. In the majority of cases the boundary damage (openings, patch and block boundaries) could had been avoided through better placement of timber bunches by the feller buncher. Felled timber was commonly placed outside or on the edge of the harvest unit by the feller buncher. This resulted in the damage of boundary trees if not through the placement of felled trees, than by the removal of those bunches by the skidder. Stand damage on the skid trails occurred at the funnel points in the boundary or on the downhill side of a skid trail when the trail was not level. This could easily be avoided through either the creation of level skid trails or the use of artificial tree protection such as rub logs on the side of the skid trails or the use of rub trees which are removed after harvest.

During the course of the harvesting operations, UNBC researchers identified opportunities for potentially improving the operational efficiency and/or cost of harvesting in ICH stands. As at the previous research site, layout of harvest groups which facilitates felling and skidding could reduce stand damage while improving harvesting efficiency. When using mechanical felling, care must be taken to ensure log quality and reduce residual stand damage. Work plans should be developed at the beginning of each shift to ensure no unnecessary non-productive delays occur.

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TABLE OF CONTENTS

Executive Summary ii
Acknowledgements v
I. Introduction 1
II. Study methods 4
Site and harvesting systems 4
Data collection 6
III. Results and discussion 8
Planning and layout 8
Harvesting operations 9
Felling 9
Skidding 12
Hoe chucking 14
Processing / bucking 15
Loading 16
Other harvesting costs 17
Summary of harvesting costs 18
Landing activity 20
Stand damage 21
Utilization of cedar 22
IV. Conclusion 23
V. Recomendations 25
References 28
Appendix 1. Machine Cost 29
Appendix 2. Detailed Time of Mechanized Felling Phase 30
Appendix 3. Detailed Time of Skidding Phase 31

LIST OF TABLES

(Not including data tables in appendices)

Table 1. Site and stand description. 5
Table 2. Equipment and labour complement for contractors. 6
Table 3. Summary of layout and planning costs. 9
Table 4. Detailed time of mechanized felling phase. 11
Table 5. Summary of mechanized felling costs. 11
Table 6. Summary of hand felling costs. 11
Table 7. Detailed time of ground-based skidding phase. 12
Table 8. Summary of skidding production and costs. 12
Table 9. Shift level summary for hoe chucking. 15
Table 10. Shift level summary for bucking. 16
Table 11. Species volumes for each treatment. 16
Table 12. Shift level summary for loading. 17
Table 13. Summary of skid trail and landing construction costs. 18
Table 14. Summary of total costs. All costs are in $/m^3$. 18
Table 15. Summary of total costs given a standardized average piece size of 1m^3. All costs are in $/m^3$. 20
Table 16. Summary of landing activity sampling 21
Table 17. Stand damage summary 22

LIST OF FIGURES

Figure 1. Summary of non-productive timing elements for skidding. 13

I. INTRODUCTION

Forest management in British Columbia continues to rapidly change as the result of social goals that include the management of non-timber resources. Partial cutting is an alternative method for achieving these management goals, but knowledge and experience with partial cutting continues to be limited for many of BC's forest ecosystems. This is especially true for the interior cedar hemlock (ICH) stands. Many of the previous partial cut harvesting studies conducted in this zone state partial cutting as being operationally feasible, yet fail to state what the costs were of these systems (Walters 1996; Walters 1997; Walters 2001). Compound this with the low market value of the interior cedar hemlock (ICH) stands during the early 1980's and one begins to have a background of partial cut harvesting systems in the ICH (Sinclair 1984).

The cost of a mechanized harvesting system in a partial cut was 2.5 times higher than that of a clearcut in the ICHmc2 biogeoclimatic zone, however, in comparison a conventional harvesting system was also 1.64 times more expensive than that of a mechanized harvesting system (Thibodeau et al. 1996). This illustrates that through mechanization, partial cutting may become more efficient, as has clearcutting. Thibodeau et al. (1996) is currently the only study reporting the cost of mechanized harvesting in ICH stands, the study reported logging productivity and costs of partial cut treatments in stands in the northwest of BC, in a second growth stand with an age of 130-years and moderately gentle terrain. Thus it is not clear if the study can be extrapolated to wet-belt ICH forests in east-central BC where slopes are steeper and the forests are 300 years or older.

Layout costs in partial cuts are 1.4 to 4 times that of clearcut units (Walters 1996; Thibodeau et al. 1996; Walters 1997; Renzie and Han 2001; Walters 2001). The increased cost is the result of more intensive timber cruising, the creation of internal patch cut layout boundaries, increased tree marking, and the need for designed skid trail networks. Directional felling in cedar stands is often difficult and as such, laying out removal patches in a funnel pattern in the direction of skid trails may result in improved skidding and felling productivity (Walters 1996; Thibodeau et al. 1996; Renzie and Han 2001). As mentioned in Renzie and Han (2001), tree marking in partial cuts allows fellers to be free from selecting trees to be felled, and can result in increased productivity. However when marking trees, the layout crew 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). Through mechanized felling, better control can be achieved than with hand felling and as such directional felling of timber can be easily accomplished even when individual tree characteristics such as lean would not have permitted hand felling in the desired direction. Again when hand or mechanized felling, stumps should be close to the ground and on an angle to minimize hang-ups (Pavel 1999; Renzie and Han 2001). Mechanized felling costs, in 60% removal treatments in the ICH, range from being equal to that of clearcuts to 1.6 times more expensive depending on terrain and tree characteristics (Thibodeau et al. 1996). Hand felling costs also range from being the same as that of a clearcut to 1.2 times more expensive than those in clearcuts (Thibodeau et al. 1996; Renzie and Han 2001).

It has been thought in the ICH that tree size dictates felling method and as such may also dictate skidding equipment and methods (Thibodeau et al. 1996). With large diameter decedent cedar, the use of mechanical felling is possible as the large trees are often hollow and easily felled by multiple cuts. Through the use of mechanized felling, the use of grapple skidders becomes not only viable but is often the contractors' choice as faster turn times can be achieved. As with line skidding, grapple skidding productivity is also affected by weather, skidding distance and slope (Mitchell 2000). The skidding cost per cubic meter, when using a rubber-tired grapple skidder in a 60% removal treatment is 1.5 to 1.8 times higher in cost than a clearcut and 2.3 to 2.9 times more economically efficient than that of a line skidder in the same treatment (Thibodeau et al. 1996).

Effective utilization of the loader is essential to ensure that workers on the landing are safe, the landing is clear, and that trucks are loaded with a minimum delay (Pavel 1999). The loading cost per cubic meter in partial cuts ranges from 1.3 to 1.6 times greater than in clearcut units (Bennett 1997; Renzie and Han 2001). This is largely the result of a lack of timber for the loader to process. Renzie and Han (2001) found that in partial cut treatments the bucker and loader were idle 39% to 50% of the scheduled working time.

In the case of group selection type partial cuts, the majority of residual stand damage is located on the skid trails where the most harvesting activity occurs (Pavel 1999; Bennett 1997; Renzie and Han 2001). This damage is often grouped and is found generally within 5 meters of the skid trail in the group selection type treatments. In partial cuts, the orientation of harvest units, directional felling, and the use protective coverings on trees or rub trees play an important role in reducing stand damage (Thibodeau et al. 1996; Matzka 1998; Renzie and Han 2001).

In order to improve knowledge regarding partial cutting, the University of Northern British Columbia is examining partial cutting at various retention levels in the ICH at study areas located on the eastern rim of the central interior plateau of BC.

The primary goal of this study is to assess the operational and economic feasibility of partial cutting in ICH stands. The following objectives were established to achieve this goal:

- Determine the logging planning/layout cost and techniques required for various retention levels of partial harvesting operations;
- Determine logging costs ($/m^3) for three different retention treatments: (0%, 30%, and 70%) with ground-based, and cable harvesting systems;
- Investigate the amount of stand damage to residual stands from partial cutting; and
- Develop recommendations for partial cutting practices to improve logging efficiency and minimize impacts on residual stands, and
- Examine the utilization of cedar harvested.

This report includes the results of the second of two harvesting and stand damage studies based in the ICHwk3. The study was located at the Minnow Creek Site, near McBride, BC and was administered by the Small Business Forest Enterprise Program (SBFEP) of the Robson Valley Forest District. Three ground skidding treatments (0%, 30%, and 70% retention) were studied.

II. STUDY METHODS

Site and harvesting systems

The research was conducted on two sites, East Twin Creek and Minnow Creek, in the ICHwk3 biogeoclimatic zone of the Robson Valley Forest District in the Prince George Forest Region. East Twin Creek site was harvested in the winter of 2000 and contains treatments of 0% and 70% retention. The 0% retention treatment was harvested using both ground-based and cable harvesting systems. The Minnow Creek site contains three treatment units of 0%, 30% and 70% retention and was harvested during the winter of 2001 using ground-based skidding and will be the focus of this report.

The Minnow Creek site was located at 3 km on the Minnow Creek spur road branching from the Mountain View Forest Service Road, 35 km west of McBride, BC. The treatment units are located at 1050 to 1200 meters in elevation and have a northwest aspect. The primary species are western red cedar (*Thuja plicata*), with minor components of western hemlock (*Tsuga heterophylla*), hybrid white spruce (*Picea glauca x engelmannii*), and subalpine fir (*Abies lasiocarpa*). Table 1 summarizes terrain and stand characteristics for each of the three silvicultural treatments. While the treatment area for the group selection harvest unit is 11.2 hectares (ha) the actual harvest area is 3.6 ha in size, composed of eleven openings ranging in size between 0.2 and 0.35 ha. In the group retention treatment, 12 patches ranging in size between 0.2 and 0.35 ha were retained. 1.7 hectares of the treatment units had been previously harvested to provide access to a nearby cut block.

Table 1. Site and stand description.

Silvicultural treatment	Group selection	Group retention	Clearcut
Treatment size (ha)	11.2	10.7	7.4
Previously harvested area (ha)	0.2	1.5	0.0
Harvested area (ha)	3.6	6.1	7.4
Slope (avg.)	0-50% (30%)	0-30% (15%)	0-40 (30%)
Species (%)[a]			
Western red cedar	60.4	46.5	75.0
Subalpine fir	19.4	27.3	11.4
Engelmann spruce	18.3	24.6	13.0
Western hemlock	1.9	1.6	0.3
Stems/ha[b]	349	288	394
Average DBH (cm)[a]	44.7	47.1	48.2
Average height (m)[a]	25.4	26.0	25.9
Gross merchantable vol. (m^3/ha)[a]	819.8	659.4	1122.1
Net merchantable vol. (m^3/ha)[b,c]	367.6	308.8	359.2

[a] Calculated from data of Northern Wetbelt Silvicultural Systems Project Establishment Report (Jull et al., 2001)
[b] The low net merchantable volume resulted from high decay, waste, and breakage.
[c] The net merchantable volume was calculated from the BC MOF Scale data.

The site was put up for sale by the SBFEP in the fall of 2000 and was awarded in early winter. A single contractor harvested all treatments using a semi-mechanized system. The harvesting equipment profile is shown in Table 2. The equipment reflects a semi-mechanized ground-based harvesting system that is being used to harvest cedar in southern BC. The contractor utilized the same equipment to harvest both the clearcut and partial cut treatments.

During January and February 2001, the contractor harvested all three treatment units, the group selection (70% retention), group retention (30% retention), and clearcut (0% retention), using a ground-based harvesting system consisting of mechanized and manual felling, skidding with rubber-tired grapple skidders, manual delimbing / bucking, and loading with a front-end wheel loader. Hoe chucking was utilized when slopes did not permit the use of a grapple skidder. Hand felling was employed on steep slopes and when trees were unsuitable for mechanized felling.

Table 2. Equipment and labour complement for contractors.

Silvicultural treatment	Group selection	Group retention	Clearcut
Felling	Timberjack 618 Feller Buncher 1 hand feller	Timberjack 618 Feller Buncher 1 hand feller	Timberjack 618 Feller Buncher 1 hand feller
Skidding	John Deere 748E Grapple Skidder	John Deere 748E Grapple Skidder	John Deere 748E Grapple Skidder
Hoe chucking	N/A	Hitachi EX270LC Excavator	Hitachi EX270LC Excavator
Processing / bucking	1 bucker	1 bucker	1 bucker
Loader	Komatsu WA 320 Front-end Log Loader	Komatsu WA 320 Front-end Log Loader	Komatsu WA 320 Front-end Log Loader
Skid trail and landing construction	Caterpillar D7H tractor Hitachi EX270LC Excavator	Caterpillar D7H tractor Hitachi EX270LC Excavator	Caterpillar D7H tractor Hitachi EX270LC Excavator

Data collection

Under the direction of SBFEP staff, UNBC researchers and contractors completed all preliminary layout and cruising. As on the East Twin Site harvested in 2000, individual trees were marked for removal in groups based on topography and skid trail layout. Trees on skid trails contributed to the prescribed stand density reductions in both harvest units. Haul roads and openings for landings were pre-existing for all three treatments and for these treatments the skid trail location was suggested but the final decision of skid trail location was left with contractor. Harvesting operations took place from January to February 2000.

There were three methods used to collect time data on logging operations: shift level, detailed, and activity sampling. On a daily basis, machine operators filled out shift-level data forms. These forms described their daily activities, which include shift length, break time, delay time, and types of delay. To collect detailed timing information for mechanized felling and skidding UNBC researchers used handheld data loggers to time the components of each harvesting phase. During the detailed-timing phase, the skidding cycle was sub-divided into cycle elements (travel empty, repositioning, choking, travel loaded, etc.), and skidding distances, slope, bunch length, and pieces per cycle were also recorded. Mechanized felling of each treatment was also timed and subdivided into cycle elements. This provided the necessary information on productive and non-productive time for each machine during the study. Landing activity sampling measured any delays on the landing that were caused by unbalanced production activities. For each treatment, landing activities were randomly sampled twice: once before and after 12:00 pm. The equipment and personnel on the landing were then observed for an hour. In that hour, sampling intervals were set at 20 seconds to ensure the accuracy of the data as recommended by Olsen and Kellogg (1983). The equipment and personnel on the landing were classified as working, delayed, or not working on the landing.

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. Equipment purchase prices were based upon the costs for similar models being produced today, as all the equipment used in the study is no longer made (Appendix 1). The costs do not include supervision, overhead, profit, and risk allowances.

Harvested volumes used for unit cost calculations ($\$/m^3$) were obtained from BC Ministry of Forest (BCMOF) weigh scale records. The volume for each treatment was then determined from the BCMOF weigh scale data by hauling dates. Once the treatment volume was known, the average volume per tree was calculated by dividing the volume per treatment by the number of commercial trees (>17.5 cm in DBH) cut in that treatment. The number of trees per unit was calculated from shift level and detailed time data. The unit cost was then calculated using the volume per tree, number of trees per cycle, cycle time, and cost per hour for the equipment and/or labour.

A general linear model was developed for the primary transportation element of the harvesting operation. This process first identified the significant variables involved in primary transportation. Once the significant variables were identified, an equation to estimate productive cycle time for each component was developed. This equation allows for the estimation of productive time from on site factors such as slope or skidding distance.

Stand damage was quantified by the post harvest examination of residuals and boundary trees for all treatments. Damage was quantified in three main categories; root, stem, and crown damage. Root and stem damage was measured using a tape measure. The width, depth, and length of each scar or gouge was recorded as well as its orientation and location on the tree in comparison to the closest opening or skid trail. The scar area will be calculated from the width and length values measured. Crown damage was measured by the use of a clinometer to measure the proportion of live crown that had been impacted. Crown damage was recorded if greater than 50% of the crown had been impacted (Han and Kellogg, 2000). Harvest boundary feature sampling was chosen as it provides exact results and allows for patterns in stand damage to be recognized and recommendations to be made to reduce this negative harvesting impact.

To determine the utilization of cedar harvested from this site the mills the cedar was sold to were contacted and asked to provide a list of products they produced from this timber.

III. RESULTS AND DISCUSSION

Planning and layout

The cost for the layout of the harvest units was obtained from the contractor hired to complete the layout and from the UNBC researchers involved. The layout and planning costs were highest, $1.73/m^3, in the group selection because of the need to designate removal patches and a greater block perimeter (Table 3). The costs were also 1.6 times higher in the group retention due to the need to designate retention patches and a greater block perimeter. In all ground-based treatments, recommended skid trails were marked. The contractors were given the option to move these skid trails and to make them bladed skid trails. In the group selection unit the primary goal of the layout crew was to design a skid trail system that would allow for multiple entries while promoting visual quality. The primary goal of the layout in the group retention treatment was to ensure that all of the harvested area was within two tree lengths to a retention patch or and unharvested block boundary. As result of not having to designate removal or retention patches, the layout cost per cubic meter was lowest in the ground-based clearcut at $0.45/m^3.

Table 3. Summary of layout and planning costs.

Silvicultural treatment	Group selection	Group retention	Clearcut
Traverse and boundary cost ($)	1377.60	1281.77	1078.13
Mapping and office cost ($)	157.40	146.45	123.18
UNBC group selection layout cost ($)	750.00	750.00	0.00
Total cost ($)	2285.00	2178.22	1201.31
Final volume (m^3)[a]	1323.26	1883.62	2657.78
Layout / planning cost ($/m^3)	1.73	1.16	0.45

[a] The final volume is the same as the net merchantable volume was calculated from the BC MOF Scale data.

Pre-existing skid trails and a landing from previous harvest units were used when possible. This resulted in decreased landing and skid trail construction costs. The contractor constructed an additional two landings. During harvesting the closest landing was utilized, often resulting in the same landing being utilized for multiple treatments.

Harvesting operations

Felling

Mechanized and manual felling methods were utilized in all three units. Mechanized felling was utilized where slopes and tree characteristics permitted. This is often just considered to be tree size but in the case of this study, large cedar trees were able to be mechanically felled through multiple cuts and pushing by a feller buncher, as a result of being hollow or rotten in the center. This was not done with the spruce on the site as the spruce present was solid and these multiple cuts and pushing would have resulted in unnecessary stump pull and butt shatter. The feller buncher operator had 12 year hand falling experience and had been running the buncher for the past 6 years in both clearcut and partial cut conditions. The slope of the treatments ranged from 0 to 50%. During felling, snow was present on the site and often resulted in problems for the feller buncher as the snow was sugar like and repeatedly caused the buncher to slide downhill. In the case of hand felling, the snow had no observable effect on productivity.

Increased butt flare in cedar in combination with butt rot can make directional felling difficult and at times dangerous, however through the use of mechanized felling much greater control of the felling stem can be achieved and result in increased skidding productivity, decreased breakage, and increased safety. In all treatments, the mechanically felled timber was felled uphill to promote access for the grapple skidder. When hand felling, the timber was felled in a downhill direction as the trees were leaning and weighted by branches to fall in that direction. In the case of skidding it was preferred that the trees be felled uphill as the contractors stated it was easier to grapple the butts of the logs then the tops. Grappling the tops of the timber often resulted in breakage and the loss of logs when skidding. Hoe chucking was utilized in these cases to orient and group the logs in a manor favourable to grapple skidding

Even though mechanical felling in the clearcut had the fastest cycle time of 1.35 minutes per tree, production was highest in the group retention treatment due to the greatest merchantable volume per tree (Table 4 and 5). The second highest production occurred in the group selection, again due to a higher merchantable volume per tree. The clearcut cycle time was the lowest but due to the lowest average merchantable volume per tree the cost ended up being \$3.60/m^3. If the volume per tree was equal for all treatments, 1m^3 per tree, the cost would have been lowest in the clearcut, followed by the group retention, and lastly by the group selection at \$3.29/m^3, \$3.45/m^3, and \$3.60/m^3, respectively. This indicates that tree size, and decay percentage can have a significant effect on the production. Multiple cuts appeared to have no effect on the overall productivity of the buncher.

Table 4. Detailed time of mechanized felling phase.

	Avg. time/element (min)	Time/cycle (%)	Avg. time/element (min)	Time/cycle (%)	Avg. time/element (min)	Time/cycle (%)
Silvicultural treatment	**Group selection**		**Group retention**		**Clearcut**	
Total productive time	0.82	57.99	0.87	64.27	0.87	67.54
Total non-productive time	0.59	42.01	0.48	35.73	0.42	32.46
Total cycle time	1.41	100.00	1.35	100.00	1.29	100.00

Table 5. Summary of mechanized felling costs.

Silvicultural treatment	Group selection	Group retention	Clearcut
Average slope (%)	21.04	12.17	28.49
Percent of total trees multicut (%)	3.24	16.81	10.14
Net. volume per tree (m^3)[a]	1.05	1.07	0.91
Volume / hour (m^3/hr)	44.85	47.79	42.52
Equipment and labour rate ($/hr)	153.24	153.24	153.24
Felling cost ($/$m^3$)	3.42	3.21	3.60

[a] The net merchantable volume per tree was calculated from the BC MOF Scale data.

Manual felling was utilized where slopes and tree characteristics did not permit mechanized felling. A total of 507 trees were hand felled in the study with the majority being in the clearcut treatment (Table 6). The highest felling cost was observed in the group retention due to the spread-out locations of the trees to be felled. When this cost is spread over the total volume harvested, the overall hand felling cost is lowest in the group retention. The trees in the group retention were hand felled due to tree characteristics where in the group selection and clearcut treatments tree are being hand felled as a result both tree characteristics and steep slopes.

Table 6. Summary of hand felling costs.

Silvicultural treatment	Group selection	Group retention	Clearcut
Time (hrs)	10.25	2.50	14.00
Trees felled	168	34	305
Net. volume per tree (m^3)[a]	1.05	1.07	0.91
Feller cost ($/hr)	50.00	50.00	50.00
Observed hand felling cost ($/$m^3$)	2.90	3.43	2.52
Volume per treatment (m^3)	1323.26	1883.62	2657.78
Prorated hand felling cost ($/$m^3$)	0.39	0.07	0.26

Skidding

Conventional ground-based skidding techniques were used for all treatment units. Detailed timing data for the John Deere 748E grapple skidder is displayed in Table 7 for all three treatments. A more complete summary of the skidding cycle elements is located in Appendix 3. As mentioned to accommodate the grapple skidder both feller bunching and hoe chucking was utilized to ensure the timber was grouped in a manor which made the used of a grapple skidder efficient.

The highest productivity was observed in the group retention treatment due to gentle slopes and a shorter average skidding distance, half of that of the average skidding distances in the group selection and clearcut treatments (Table 8). While a greater number of logs per cycle were delivered to the landing in the clearcut, a lower average volume per log and greater cycle time still resulted in it having the lowest productivity and highest costs.

Table 7. Detailed time of ground-based skidding phase.

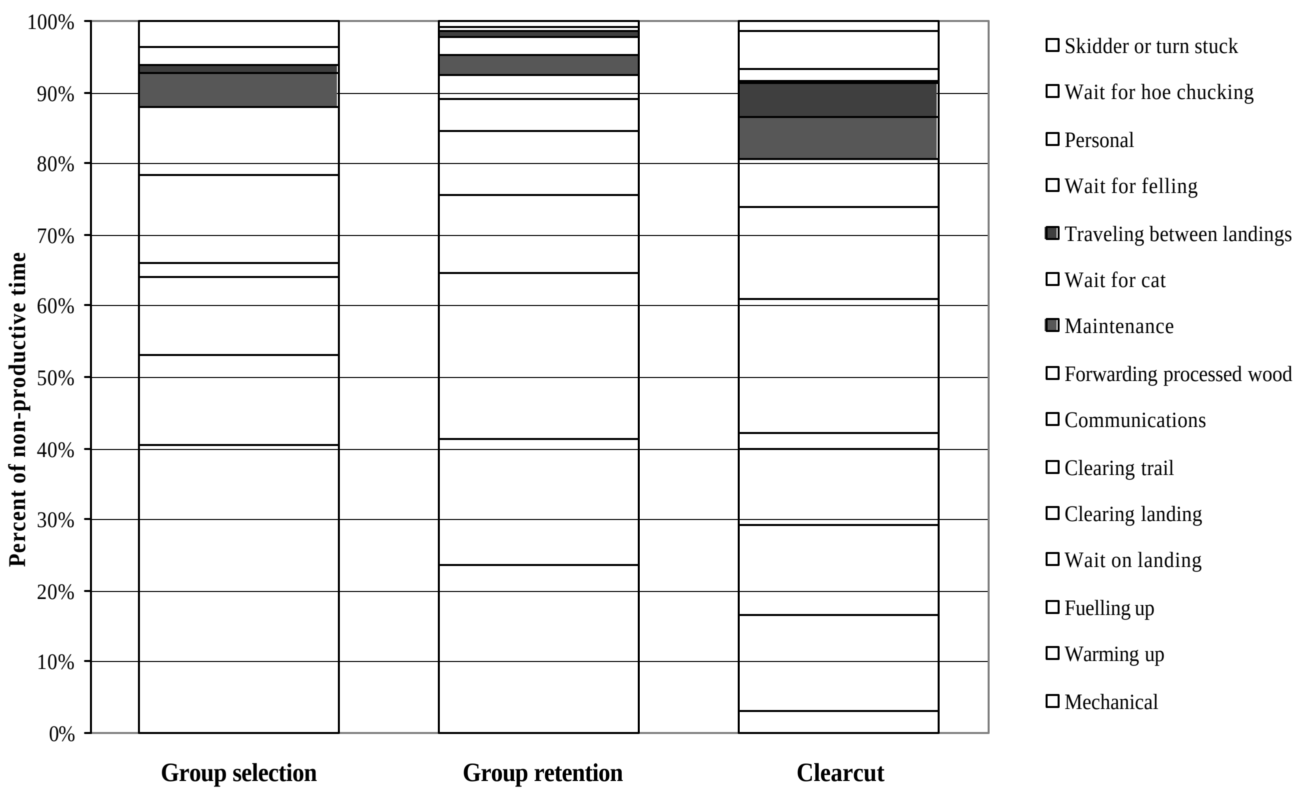
	Avg. time/element (min)	Time/cycle (%)	Avg. time/element (min)	Time/cycle (%)	Avg. time/element (min)	Time/cycle (%)
Silvicultural treatment	**Group selection**		**Group retention**		**Clearcut**	
Total productive time	8.63	65.67	7.27	80.89	11.07	76.56
Total non-productive	4.51	34.33	1.72	19.11	3.39	23.44
Total cycle time	13.14	100.00	8.99	100.00	14.47	100.00

Table 8. Summary of skidding production and costs.

Silvicultural treatment	Group selection	Group retention	Clearcut
Average pieces/cycle (no.)	4.83	4.60	5.63
Average slope (%)	15.5	13.4	27.2
Average turn length (m)	26.2	28.3	25.0
Average distance loaded (m)	246.8	133.9	273.7
Average distance empty (m)	246.8	133.9	289.3
Turns hoe chucked (%)	20.18	0	25.58
Volume / tree (m^3)	1.05	1.07	0.91
Volume / turn (m^3)	5.09	4.94	5.13
Volume / hour (m^3/hr)	23.25	32.95	21.29
Equipment and labour rate ($/hr)	116.26	116.26	116.26
Skidding cost ($/$m^3$)	5.00	3.53	5.46

Figure 1 illustrates the proportion each delay that constitutes the non-productive time. The group selection had the greatest amount of non-productive time per cycle at 4.51 min/turn followed by the clearcut and group retention at 3.39 min/turn and 1.72 min/turn respectively. The largest delay observed in all three treatments occurred in the group selection and was due to a blade pin on the skidder shearing. This delay accounted for 11.9% of the total cycle time, and if it had not occurred, skidding in the group selection would have had a cost of $\$4.41/m^3$, reducing the cost by $\$0.59/m^3$.

Figure 1. Summary of non-productive timing elements for skidding.



Equation 1 gives the total productive cycle time (delay free) for a grapple skidder, determined from a general linear model analysis. A significant linear relationship was found between total productive time, treatment, distance, slope, maximum length of logs in a turn, and number of logs per turn. The equation is applicable for stand with similar characteristics and slopes of 0-40%.

[1] Total productive time (min) = 0.278 + 0. 017d + 0.316lg + 0.103ln + 0.027s - 0.647gs - 0.086gr +0.00cc.

Where : d = Distance skidded (m)
lg = Number of logs
ln = Maximum length logs in a turn (m)
s = Slope (%)
gs = Group selection treatment (if yes = 1, no = 0)
gr = Group retention treatment (if yes = 1, no = 0)
cc= Clearcut treatment (if yes = 1, no = 0)

Sample number = 1066 R^2 = 62.9% Standard error of estimate = 2.60

According to this equation the group retention and selection treatments have a lower productive cycle time than the clearcut treatment when all factors are constant. Treatment had an effect on the total productive time as illustrated in the range of constant values for the different treatments being from 0 to -0.647. Even though treatment had an effect on the productivity, its effect is minor when compared to the other components of the model. For each log skidded, the cycle time is increased by 0.316 minutes. This is due to such factors as accumulating and organizing bunches. The maximum log length in a turn played a role in the cycle time but to a lesser degree as the lengths of the logs varied little. Slope and distance have the smallest constants, however, depending on the slope or distance values these factors can play the largest role, especially where terrain is steep and the skidding distance is great.

Hoe chucking

Hoe chucking was utilized only when slopes did not permit the use of the grapple skidder. The felled timber was then moved by the excavator, using its bucket and thumb, down slope one tree length and returned into bunches. This allowed the timber to then be accessed by the grapple skidder. Hoe chucking was only required in the group selection and clearcut treatments and had an observed cost of \$6.34/m^3 and \$4.67/m^3 respectively. When these costs are prorated to the entire volume removed per treatment these costs become \$1.02/m^3 for the group selection and \$1.17/m^3 for the clearcut treatment.

Table 9. Shift level summary for hoe chucking.

Silvicultural treatment	Group selection	Group retention	Clearcut
Time (hrs)	13	0	30
Equipment and labour rate ($/hr)	103.48	103.48	103.48
Cost ($)	1345.24	0.00	3104.40
Trees hoe chucked	202	0	730
Volume per tree (m^3)	1.05	1.07	0.91
Volume hoe chucked (m^3)	212.10	0.00	664.30
Observed cost ($/$m^3$)	6.34	0.00	4.67
Volume per treatment	1323.26	1883.62	2657.78
Prorated cost ($/$m^3$)	1.02	0.00	1.17

Processing / bucking

Processing for all treatments was completed manually. The primary consideration of processing was to maximize commercially valuable wood recovery such as peelers, saw logs, post and rail wood, and finally pulpwood. The minimum requirements of a peeler are as follows; over 75% sound wood of either spruce or subalpine fir, with the sound wood being greater than 20.3cm (8in) in diameter, a minimum length of 5.3m (17ft 4in) to 15.8m (51ft 9in) in length, In order to be suitable for a saw log, 50% of the wood has to be sound with the sound wood being a minimum of 10cm (4in) of sound wood. All species except hemlock on site were suitable for the production of saw logs. The minimum required length for saw logs was 3.7m (12ft) to a maximum length of 15.8m (51ft 9in). In the case of cedar, these logs will be processed into small dimension aesthetic lumber. Post and rail timber required a minimum 7.5cm (3in) shell of clear solid wood and length of 2.5m (8ft 3in) to 15.8m (51ft 9in).

The combined decay, waste, and breakage estimates for the group selection, group retention, and clearcut treatments were 55%, 53%, and 68%, respectively. These numbers are high as a result of butt and pocket rot being present in the cedar. Butt and pocket rot not only destroy heartwood and sapwood, but also increases the possibility of breakage when felling and skidding. The decay level required the bucker to make multiple cuts at 0.75m (2 ft) intervals to determine where the timber was commercially valuable. The timber was then processed such that the most commercial value was derived from each log.

The treatment with the lowest cost was the group retention followed by the group selection and clearcut. This may be the result of the group selection having the lowest decay waste and breakage rates and the higher proportion of spruce and subalpine fir (Table 10 and 11). The hemlock, spruce, and subalpine fir on site had less decay, thus was faster to process.

Table 10. Shift level summary for bucking.

Silvicultural treatment	Group selection	Group retention	Clearcut
Time (hrs)	57	79	128
Trees processed (no.)	1256	1756	2916
Gross volume per tree (m^3)	2.35	2.29	2.85
Net. volume per tree (m^3)	1.05	1.07	0.91
Cost ($/$m^3$)	1.08	1.05	1.21

Table 11. Species volumes for each treatment.

	Volume (m3)	% of total volume	Volume (m3)	% of total volume	Volume (m3)	% of total volume
Silvicultural treatment	**Group selection**		**Group retention**		**Clearcut**	
Cedar – saw logs	369.6	27.9	457.5	24.3	925.9	34.8
Cedar – post & rail	405.8	30.7	385.0	20.4	646.0	24.3
Spruce and subalpine fir – saw logs and peelers	515.8	39.0	1019.3	54.1	1073.4	40.4
Hemlock – pulp	32.0	2.4	21.8	1.2	12.4	0.5
Total	1323.3	100.0	1883.6	100.0	2657.8	100.0

Several improvements can be made in the felling of trees that can improve the efficiency of the bucker. These include hand felling larger trees to minimize butt shatter and stump pull and when using multiple cuts during mechanical felling, cuts should be matched to ensure a level flat cut on the bottom log.

Loading

Loading was during and immediately after harvesting. Upon conversations and observations, it became clear that the primary consideration of the loader operator was safety. Other primary duties of the loader included loading trucks, sorting timber on the landing, aid bucker by separating timber and moving processed timber lumber out of way, and clearing slash and waste from landing to promote bucker safety. The timber on this site was sorted into 6 categories: dry spruce, spruce and subalpine fir peelers, spruce and subalpine fir saw logs, cedar saw logs, cedar post and rail timber, and hemlock pulp. As a result of these multiple sorts landing space became an issue on landing 2 as it was the smallest of the three landings measuring 50 m by 50 m while landing 1, a pre-existing landing, measured 150 m by 50 m, and landing 3 measured 80 m by 40 m. This effect can be observed in the loading costs below as the group selection treatment primarily used landing 2 and had the highest loading cost at \$4.75/m^3 compared to the group retention and clearcut which had costs of \$4.44/m^3 and \$4.18/m^3 respectively (Table 12). In the group selection treatment, the loading cost was increased by a greater amount of unproductive time due to delays and lack of wood to process (Table 16).

Table 12. Shift level summary for loading.

Silvicultural treatment	Group selection	Group retention	Clearcut
Volume per tree (m^3)	1.07	1.05	0.91
Volume processed (m^3/hr)	19.36	20.7	22.03
Equipment and labour rate (\$/hr)	91.97	91.97	91.97
Cost (\$/m^3)	4.75	4.44	4.18

Other harvesting costs

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 volume of timber removed from that treatment was then divided into the corresponding costs (Table 13). The group retention treatment required only 24 hours of landing and skid trail construction, compared to 55 and 71 hours for the group retention and clearcut units as all of the required harvesting info structure was pre-existing and only required minimal work to bring it up to legislative standards. This was also true for over half of the skid trails required in the group selection, however a landing had to be constructed so that skidding costs would be reduced. The clearcut required both the construction of skid trails and a landing and as a result had the greatest amount of hours spent in constructing these features. As the costs are dependent on the volume of timber removed, the costs are lower in the clearcut versus the group selection as more volume was removed from the same amount of area. The group retention had the lowest costs as the features were already pre-existing. As skid trails and landings were pre-existing in some of the treatments, these results will not be included in the comparison of harvesting costs between treatments.

Table 13. Summary of skid trail and landing construction costs.

Silvicultural treatment	Group selection	Group retention	Clearcut
Time - excavator (hrs)	31.00	9.00	38.50
Excavator and labour cost ($/hr)	103.48	103.48	103.48
Time - bulldozer (hrs)	24.00	15.00	32.50
Bulldozer and labour cost ($/hr)	111.78	111.78	111.78
Total costs ($)	5890.51	2608.01	7616.73
Final volume (m^3)	1323.26	1883.62	2657.78
Cost ($/m^3$)	4.45	1.38	2.87

Summary of harvesting costs

The unit cost ($/m^3$) was lowest in the group retention treatment as a result of having the shortest average skidding distance, gentle slope, less hand felling being required, and a higher volume of merchantable timber extracted per tree. The increased volume is the result of more non-cedar species being present. These species have a lower low level of defect than the cedar on this site and this lower defect level allowed the bucker to process the logs without making multiple cuts, thus increasing productivity and efficiency. The clearcut had the second highest cost at $16.33/m^3$ due to a greater skidding distance, steeper slopes, and lower merchantable volume per extracted tree than in the group retention. This cannot only be observed in the differences in skidding and felling costs but also through added costs such as hoe chucking which did not occur in the group retention (Table 14).

Table 14. Summary of total costs. All costs are in $/m^3$.

Silvicultural treatment	Group selection	Group retention	Clearcut
Layout/planning	1.73	1.16	0.45
Mechanized felling	3.42	3.21	3.60
Hand felling	0.39	0.07	0.26
Skidding	5.00	3.53	5.46
Hoe chucking	1.02	0.00	1.17
Bucking	1.08	1.05	1.21
Loading	4.75	4.44	4.18
Total cost	17.37	13.45	16.33

The highest costs were observed in the group selection treatment as a result of having steep slope conditions and long skidding distances similar to that of the clearcut while having the added constraints to skidding and felling as a result of treatment. These constraints caused mechanical delay for the skidder and resulted in the feller buncher becoming stuck. In addition the layout and planning costs were highest, $1.73/m^3$, in the group selection because of the need to designate removal patches and skid trails in the block compared to the group retention, where retention patches and skid trails were easy to mark due to gentle terrain, and the clearcut, where only the boundary and main skid trail were laid out and marked.

The results and discussion presented here were based upon relatively small treatment units ranging in size from 3.6 ha to 7.4 ha. According to the final volume data, the merchantable volume per hectare is greater in the group retention treatment than in the other treatments due to a slightly lower defect percentage, 53% versus 55% in the group selection and 68% in the clearcut treatment. This defect variation results in a merchantable volume differences between the treatments and has a large effect on the harvesting costs. As a result of this higher volume, the group retention treatment has lower planning and layout, felling, skidding, processing, and loading costs than the group selection or clearcut.

If the merchantable volume per tree was identical (1 m^3/tree) in each treatment and the number of harvested trees in each treatment remained constant, the group retention harvesting system would cost $14.33/$m^3$ due to a decrease in merchantable volume per piece (Table 15). This is an increase of $0.88/$m^3$. The group selection costs would also increase by $0.99/$m^3$ to $18.38/$m^3$ as a result of a decrease in piece size. The cost of the clearcut unit would decrease by $1.45/$m^3$ due to an increase in average piece size of 0.09m^3. The group selection and clearcut costs would also decrease by $1.07/$m^3$ and $1.06/$m^3$ respectively if slopes had not required the use of an excavator for hoe chucking. It can also be estimated that skidding costs would decrease by 25% if the average skidding distances in the clearcut and group selection treatments was the same as that in the group retention.

Table 15. Summary of total costs given a standardized average piece size of 1m^3. All costs are in \$/m^3.

Silvicultural treatment	Group selection	Group retention	Clearcut
Layout/planning	1.82	1.24	0.41
Mechanized felling	3.60	3.44	3.28
Hand felling	0.41	0.07	0.24
Skidding	5.27	3.78	4.98
Hoe chucking	1.07	0.00	1.06
Bucking	1.13	1.13	1.10
Loading	5.08	4.67	3.80
Total cost	18.38	14.33	14.88

Landing activity

According to the activity sampling, primary transportation was delayed by loading and bucking on the landing 3.8% to 9.1% of the scheduled operating time (Table 15). These delays resulted in the skidding cost being increased not only for the skidder but also for the loader and bucker as less wood was available for processing, sorting, and loading over the same period of time, than if no delays were to occur. The skidding delay on the landing can easily be avoided through better communication and coordination of activities. In the different treatments, the bucker was waiting for timber to process 13% to 33% of the scheduled operating time. The loader was waiting less time for timber to process, 3% to 12% of the scheduled operating time, as other tasks such as loading trucks or clearing slash or debris could be completed after sorting and decking was completed. The implementation of another skidder on the sites would increase bucking and loading efficiency by a minimum of 3% but would cause a greater increase in the skidder delay time due to the harvesting components becoming largely unbalanced. Thus no improvements could be achieved through the use of a second skidder.

Table 16. Summary of landing activity sampling

	Element [a]	Time (min/hr)	% of time	Time (min/hr)	% of time	Time (min/hr)	% of time
		Group selection		**Group retention**		**Clearcut**	
Skidder	Delay	2.31	3.85	2.62	4.36	5.44	9.06
	Not on Landing	46.62	77.69	40.00	66.67	44.23	73.72
	Working	11.08	18.46	17.38	28.97	10.33	17.22
Loader	Delayed from working	16.15	26.92	4.92	8.21	12.33	20.54
	Waiting for timber	2.00	3.33	7.69	12.82	3.08	5.14
	Working	41.85	69.74	47.38	78.97	44.59	74.32
Bucker	Delayed from working	12.77	21.28	5.54	9.23	4.89	8.16
	Waiting for timber	12.31	20.51	7.85	13.08	19.94	33.23
	Refuelling and/or filing [b]	2.77	4.62	6.15	10.26	3.81	6.34
	Working	32.15	53.59	40.46	67.44	31.36	52.27

[a] Denotes if the equipment or personnel are delayed by another operation on the landing, working on the landing, not on the landing, and waiting for timber (no work available) on the landing.
[b] Saw refuelling and/or filing occurs off of the landing but limits buckers total productive time.

Stand damage

During the spring following harvest, all treatments were surveyed to determine the condition of residual trees. In the treatments, the residual stand damage was classified by the type of damage and location from harvesting infrastructure (Table 17). There is no significant difference in the amount of stand damage between the three treatments. Stand damage in all treatments was found within 7 meters of harvest features. The skid trails were dominated by skid trail creation and skidding origin stand damage, or stem and root type damage. Damage on patch, block and opening boundaries was a combination of both skidding and mechanical felling damage, or stem and crown type damage. In the majority of cases the boundary damage (openings, patch and block boundaries) could have been avoided through better placement of bunches by the feller buncher. It was common practice by the buncher operator to place bunches of timber outside or on the edge of the boundary resulting in timber outside of the harvest area being damaged if not by the felled trees placement then by the removal of those bunches by the skidder. Stem damage on the skid trails occurred at the funnel points in the boundary or on the downhill side of a skid trail when the trail was not level. This could easily be avoided through either the creation of level skid trails or the use of artificial tree protection such as rub logs on the side of the skid trails or the use of rub trees which are removed after harvest. Increased damage was also found on skid trail corners and thus these corners should be placed in harvest patches to provide extra area for the timber to swing.

Table 17. Stand damage summary

Silvicultural treatment	Group Retention			Group Selection			Clearcut
Feature	**Block Boundary**	**Patch Boundary**	**Both**	**Skid trails**	**Openings**	**Both**	**Block Boundary**
Damage summary							
No. of injured trees	26	17	43	55	40	95	26
No. of sampled trees	538	534	1072	2049	1331	3380	753
% of residual stand	4.8	3.1	4.0	1.5	1.6	3.1	3.5
No. injuries/tree	2.2	1.9	2.1	1.8	1.4	1.5	1.6
Average size							
Width (cm)	12.9	10.6	12.1	14.7	14.4	14.6	14.8
Length (cm)	41.7	22.2	35.1	37	40.2	37.7	42.8
Area (cm^2)	668.7	250.6	527.7	691.7	694.4	690.1	859.1
Height (cm) [a]	307.3	178.9	264	110.5	135.4	121.4	248.5
Percent of total damage [b]							
Stem	93.2	93.3	93.3	83.1	96.3	89.1	90.5
Stem and root	0	0	0	1.5	0	0.8	0
Root only	0	0	0	15.4	3.7	10.1	0
Crown only	6.8	6.7	6.7	0	0	0	9.5

[a] Measured from base of tree to middle of damage
[b] Damage classes: Stem – Stem damage only, Stem and root – Stem and root damage combined, Root – Root damage only, and Crown – All crown damage.

Utilization of cedar

Cedar removed from the three treatments was sold as saw logs and post and rail wood. The saw log timber was sent to a mill in southern BC where the logs were processed into dimensional lumber such as 2.5cm x 10cm (1in x 4in), 5cm x 7.5cm (2in x 3in), and 5cm x 30cm (2in x 12in) of various lengths, radius edge decking, tongue & groove, channel siding, and rough facia board. The mill also stated that they would cut other products depending on customer requests. The post and rail timber was sold locally and was manufactured into 7.5cm x 7.5 cm (3in x 3in) and 10cm x 10cm (4in x 4in) posts of 2.4 to 3.0m (8 to 10 ft) lengths and 10cm x 10cm (4in x 4in) and 7.5cm x 7.5cm (3in x 3in) rails of 2.4 to 4.9m (8 to 16 ft) lengths. The local cedar mill not only processes post and rail products from the wood but has recently began producing cedar mulch used in landscaping from the waste products such as bark. While these are not the only products that could be produced from the cedar, these were the logical and financially sound milling choices from the stand point of the contractor.

IV. CONCLUSION

In 1997, the UNBC and BCMOF Robson Valley District initiated the Northern Rockies Wet-belt ICH/ESSF Silvicultural Systems Project, to investigate the effects of partial cut/clearcut prescriptions on ecosystems dynamics in ESSF and ICH stands in the northern portion of the interior wet belt, in central British Columbia. This report covers the final results of harvesting cost study for the second ICH site, Minnow Creek. The Minnow Creek site contains three ground-based treatments, clearcut, group selection and group retention. UNBC objective was to assess planning, determine harvesting productivities and costs; and assess stand damage; and identify ways to improve operational planning and implementation of both partial and clearcut harvesting operations.

The group selection and retention prescriptions clearly required more intensive planning and layout, requiring 3.8 and 2.6 times more planning and layout investment than the clearcut treatment. Mechanical felling on the other hand was more cost efficient in the group retention treatment due to a larger merchantable volume per tree then the other treatments. Hand felling costs were also lower in the group retention treatment as only 34 trees had to be hand felled compared with 168 and 305 trees being felled in the group selection and clearcut treatments respectively. When this cost is prorated to the entire volume removed from each treatment the hand felling costs are highest in the group selection at \$0.39/m3 followed by the clearcut and group retention at \$0.26/m^3 and \$0.07/m^3 respectively.

As a result of both increased volume per tree, lower average slope, and the average skidding distance being half of that of the other treatments the skidding cost was lowest in the group retention treatment at \$3.53/m^3. Again the clearcut had the highest skidding costs due to the average piece size being between 0.14m^3 to 0.16m^3 less per piece than in the group selection and retention treatments. This resulted in the clearcut skidding costs being costs being \$5.46/m^3.

The greater merchantable volume per tree in the group retention compared to that in the group selection and clearcut also resulted in the lowest bucking costs. If volume per tree is standardized at 1m^3 the bucking cost then becomes quite similar for all three treatments only ranging by \$0.03/m^3. Loading cost was the highest in the group selection due to increased non-productive time and increased time spent waiting for timber, due to the long average skidding distance. The clearcut had the most efficient use of the loader's time as during non-productive time the loader was able to load trucks from the other treatments, reducing the total time spent working on the clearcut treatment.

Overall the cost per cubic meter was lowest in the group retention treatment at \$13.45/m^3. The clearcut harvesting cost was higher than expected at \$16.33/m^3, which was due to the lowest average merchantable piece size, the need for hoe chucking, increased hand felling as the result of steep slopes, and an average skidding distance which was twice that of the group retention treatment. The group selection treatment had the highest costs because of an average skidding distance that is close to that of the clearcut treatment and the need for proportionately higher hand to mechanized felling. Hoe chucking was also required nearly to the same extent as in the clearcut. This illustrates that tree and terrain characteristics can have a larger impact on harvesting costs and productivity then that of treatment.

The bucking and loading processes, according to landing activity sampling, did delay skidding activities in all three treatments. As skidding productivity is often the constraining harvesting activity that determines overall productivity, it is recommended that the skidder be given preference on the landing over that of the loader and bucker. As previously mentioned another skidder would not improve the loading and bucking efficiency as it would cause the harvesting system to become increasingly unbalanced.

Stand damage levels in the treatments was quite similar for all treatments only ranging from 3.1% to 3.5% of the residual stand being damaged in the treatments. Damage on patch, block and opening boundaries was a combination of both skidding and mechanical felling damage and could had been avoided through better placement of bunches by the feller buncher. Stand damage on the skid trails occurred at the funnel points in the boundary or on the downhill side of a skid trail when the trail was not level and could easily be avoided through either the creation of level skid trails or the use of artificial tree protection. Increased damage was also found on skid trail corners and thus these corners should be placed in harvest patches to provide extra area for the timber to swing.

Opportunity costs, non-timber values, and long-term costs, aspects not measured in this report, should be considered when comparing costs and productivities of partial and clearcuts. Economic feasibility in all three treatment units is dependent on market value. The result from this study are derived from western red cedar dominate stands in the ICHwk3 biogeoclimatic zone of the Robson Valley Forest District and should only be extrapolated to similar sites.

V. RECOMENDATIONS

As non-timber values and social values increase, both conventional and alternative harvesting practices will have to become more economically efficient and environmentally responsive. In old growth cedar in the McBride area where large diameter trees with high defect rates exist, the following are recommendations for improving the partial and clearcut logging operations in ICH stands, based on the Minnow Creek study:

1. Layout of harvest groups should be arranged in a manner that facilitates felling the trees into a single open skid trail or other opening in the group selection treatment, as it is easier and safer for the feller. Be sure to examine the trees to be removed for lean and branch orientation when marking timber for removal as it will affect the direction and ease of felling.

2. Ensure that layout colours used are suitable; often reds and greens are difficult for those with colour blindness to see. It is suggested that blues and yellows be used instead.

3. Straight skid trails should be used. Small radius curves in skid trails cause skidded wood to swing into residual trees, wounding trees next to the trails,. The placement of curves in harvest openings will also decrease possible stand damage.

4. Leave low stumps. High stumps on skid trials can force the skidded timber to one side, wounding tree next to the trial. High stumps can also cause skidding hang-ups.

5. When using a feller buncher to fell large diameter timber, multicuts should be kept at the same level as the original cut so that extra processing on the landing need not occur.

6. Care must be taken when mechanical felling large diameter timber such that multiple cuts fully severe all ties between the timber and stump. If the tie is not completely severed between stump and timber, stump pull may occur severely degrading the value of the butt log.

7. Ensure no unnecessary non-productive delays by developing work plans at the beginning of each shift. An example would be ensuring that the operators and labourers are not working so close to one another that they negatively impact each other’s production.

8. On the landing, preference should be given to the skidder over the loader, logging trucks and bucker as skidding productivity has the largest effect on the overall harvest system productivity.

9. Mitigate stand damage. As this site may be used for recreational purposes, damaged trees should be removed as they are more susceptible to decay and thus windthrow or wind snap. This will ensure public safety and minimize the loss of timber from wound origin decay. Trees on designated skid trails that are severely damaged should either be removed after the harvesting of openings or adequate prevention steps should be taken before hand. These include the use of artificial tree protection rigging such as rub pads.

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APPENDIX 1. MACHINE COST

	Timber Jack 618 Feller Buncher	John Deere 748E Grapple Skidder	Komatsu WA320 Front End Log	Hitachi EX270LC Excavator	Caterpillar D7H Tractor
OWNERSHIP COSTS					
Total Purchase Price (P) $	465,000	330,000.00	239,000.00	355,000.00	575,000.00
Expected Life (Y) y	5	5	5	5	5
Expected Life (H) h	10000	10000	10000	10000	10000
Scheduled hours/year (h)=(H/Y) h	2000	2000	2000	2000	2000
Salvage value as % of P (s) %	20.00	25.00	30.00	30.00	30.00
Interest rate (Int) %	10	10	10	10	10
Insurance rate (Ins) %	3	3	3	3	3
Salvage value (S)=(P*s)/100) $	93,000.00	82,500.00	71,700.00	106,500.00	172,500.00
Average investment (AVI)=((P+S)/2) $	186,000.00	206,250.00	83,650.00	124,250.00	201,250.00
Loss in resale value ((P-S)/H) $/h	37.20	24.75	16.73	24.85	40.25
Interest ((Int*AVI)/h) $/h	9.30	10.31	4.18	6.21	10.06
Insurance ((Ins*AVI)/h) $/h	2.79	3.09	1.25	1.86	3.02
Total ownership costs (OW) $/h	49.29	38.16	22.17	32.93	53.33
OPERATING COSTS					
Fuel Consumption Diesel (F) L/h	30.00	25.00	35	32	23
Fuel Cost Diesel (fc) $/L	0.50	0.50	0.50	0.50	0.50
Lube and oil as % of fuel (fp) %	20	15	15	15	15
Track and undercarriage replacement (Tc) $	30,000.00	0.00	0	8000	20000
Track and undercarriage life (Th) h	5,000.00	0.00	0	10000	10000
Annual repair & maintenance (Rp) $	86,400.00	49,600.00	22000	32000	14000
Annual operating supplies (Oc) $	0.00	0.00	0	0	1500
Annual tire consumption (t) no.	0.00	2.00	2	0	
Tire replacement (tc) $	0.00	3,300.00	2300	0	
Operator wages $/h	25.00	25.00	25	25	25
Wage benefit loading (WBL) %	35	35	35	35	35
Shift length (sl) h	8	8	8	8	8
Fuel (F*fc) $/h	15.00	12.50	17.50	16.00	11.50
Lube and oil ((fp/100*(F*fc)) $/h	6.00	3.75	5.25	4.80	3.45
Tires ((tc*t)/h) $/h	0.00	3.30	2.30	0.00	
Repair and maintenance (Rp/h) $/h	43.20	24.80	11.00	16.00	7.00
Track and Undercarriage (Tc/Th) $/h	6.00	0.00	0.00	0.00	2
Operating supplies (Oc/h) $/h	0.00	0.00	0.00	0.00	0.75
Wages and benefits (W*(1+WBL/100) $/h	33.75	33.75	33.75	33.75	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	103.95	78.10	69.8	70.55	58.45
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	153.24	116.26	91.97	103.48	111.78

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 MECHANIZED FELLING PHASE

	Avg. time/element (min)	Time/Cycle (%)	Avg. time/element (min)	Time/Cycle (%)	Avg. time/element (min)	Time/Cycle (%)
Silvicultural treatment	**Group selection**		**Group retention**		**Clearcut**	
Productive Elements:						
Moving from tree to tree	0.34	24.37	0.31	22.97	0.37	29.09
Brushing	0.12	8.43	0.10	7.48	0.07	5.70
Cutting	0.04	3.08	0.10	7.47	0.05	3.95
Pushing	0.01	0.90	0.02	1.28	0.03	2.03
Bunching	0.26	18.31	0.21	15.31	0.24	18.66
Repositioning	0.01	0.85	0.11	8.43	0.09	6.97
Reconnaissance	0.03	2.06	0.02	1.33	0.01	1.13
Total Productive Time	0.82	57.99	0.87	64.27	0.87	67.54
Non Productive Elements						
Walking	0.15	10.42	0.04	3.16	0.07	5.39
Resting	0.07	5.17	0.06	4.71	0.05	4.07
Personal	0.04	2.86	0.06	4.49	0.01	0.68
Wait for skidder	0.00	0.00	0.03	2.07	0.00	0.35
Communication	0.07	4.69	0.05	3.99	0.11	8.60
Clearing trail	0.00	0.14	0.00	0.00	0.00	0.04
Stuck	0.12	8.37	0.00	0.00	0.00	0.00
Repair	0.02	1.59	0.09	6.93	0.04	3.20
Lunch	0.06	4.17	0.06	4.19	0.05	4.16
Warming up	0.04	3.10	0.04	3.09	0.04	2.99
Fuelling up	0.04	3.10	0.04	3.09	0.04	2.99
Total Non-Productive Time	0.59	42.01	0.48	35.73	0.42	32.46
Total Cycle Time	1.41	100.00	1.35	100.00	1.29	100.00

Silvicultural treatment	**Group selection**	**Group retention**	**Clearcut**
Average slope (%)	21.04	12.17	28.49
Total trees multicut (%)	3.24	16.81	10.14
Volume / tree (m^3)	1.05	1.07	0.91
Volume / Productive Machine Hour (m^3/hr)	77.34	74.36	62.96
Volume / Scheduled Machine Hour (m^3/hr)	44.85	47.79	42.52
Felling cost ($/hr)	153.24	153.24	153.24
Felling cost / PMH ($/$m^3$)	1.98	2.06	2.43
Felling cost / SMH ($/$m^3$)	3.42	3.21	3.60

APPENDIX 3. DETAILED TIME OF SKIDDING PHASE

Silvicultural treatment	Group selection Avg. time/element (min)	Group selection Time/Cycle (%)	Group retention Avg. time/element (min)	Group retention Time/Cycle (%)	Clearcut Avg. time/element (min)	Clearcut Time/Cycle (%)
Productive Elements:						
Travel empty	3.18	24.20	2.30	25.59	4.64	32.10
Loading	0.19	1.43	0.34	3.74	0.21	1.48
Accumulating	0.98	7.49	0.70	7.77	1.14	7.88
Repositioning	0.00	0.00	0.00	0.04	0.00	0.01
Travel loaded	3.06	23.25	2.50	27.76	3.78	26.16
Unloading	0.05	0.36	0.10	1.11	0.04	0.30
Separating skidded trees	0.68	5.15	0.40	4.41	0.70	4.83
Delimbing	0.44	3.35	0.90	10.00	0.51	3.56
Reconnaissance	0.06	0.45	0.04	0.46	0.03	0.23
Total Productive Time	8.63	65.67	7.27	80.89	11.07	76.56
Non Productive Elements						
Clearing trail	0.00	0.00	0.15	1.68	0.63	4.36
Traveling between landings	0.04	0.30	0.01	0.16	0.16	1.11
Communications	0.47	3.61	0.08	0.91	0.45	3.08
Personal	0.10	0.76	0.01	0.14	0.05	0.35
Wait on landing	0.00	0.00	0.40	4.49	0.36	2.48
Wait for felling	0.00	0.00	0.01	0.14	0.01	0.09
Wait for hoe chucking	0.14	1.04	0.00	0.00	0.19	1.29
Wait for cat	0.00	0.00	0.04	0.44	0.00	0.00
Maintenance	0.19	1.45	0.05	0.56	0.20	1.35
Mechanical	1.56	11.85	0.00	0.00	0.11	0.75
Forwarding processed wood	0.36	2.77	0.06	0.61	0.23	1.58
Clearing landing	0.08	0.62	0.19	2.09	0.08	0.59
Skidder or turn stuck	0.00	0.00	0.00	0.00	0.05	0.32
Warming up	0.48	3.67	0.41	4.52	0.46	3.16
Fuelling up	0.42	3.18	0.30	3.35	0.42	2.92
Total Non-Productive Time	4.51	34.33	1.72	19.11	3.39	23.44
Total Cycle Time	13.14	100.00	8.99	100.00	14.47	100.00

Silvicultural treatment	Group selection	Group retention	Clearcut
Average pieces/cycle (no.)	4.83	4.60	5.63
Average slope (%)	15.49	13.35	27.18
Average turn length (m)	26.17	28.33	25.00
Average distance loaded (m)	246.75	133.89	273.70
Average distance empty (m)	246.75	133.89	289.16
Turns hoe chucked (%)	20.18	0	25.58
Volume / tree (m^3)	1.05	1.07	0.91
Volume / turn (m^3)	5.09	4.9376218	5.13
Volume / Productive Machine Hour (m^3/hr)	35.40	40.73	27.81
Volume / Scheduled Machine Hour (m^3/hr)	23.25	32.95	21.29
Skidder cost ($/hr)	116.26	116.26	116.26
Skidding cost / PMH ($/$m^3$)	3.28	2.85	4.18
Skidding cost / SMH ($/$m^3$)	5.00	3.53	5.46