Advantage

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Contents



# Silviculture treatments for ecosystem management in the Sayward: cost and productivity of harvesting

**Abstract**

The Silviculture Treatments for Ecosystem Management in the Sayward (STEMS) research project was developed to test seven silvicultural systems and the concepts of ecosystem management as a means of creating diversity in forest structures. The Forest Engineering Research Institute of Canada (FERIC) reported on the harvesting phase of the first replicate of this project. This report summarizes the harvesting productivities, costs, tree damage, and soil disturbance for each of the treatments.

**Keywords**

Silvicultural systems, Ecosystem management, Visual impact, Retention, Commercial thinning, Clearcut, Patch cut, Group selection, Second-growth forests, Productivity, Costs, Coastal British Columbia.

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## Introduction

There has been an increasing emphasis on visual quality of forest land that is near urban and recreational areas. Many coastal forest companies have begun using non-clearcut harvesting methods to reduce visual impact. However, there is little long-term research information available to aid in the development of policy, regulation, and guidelines for harvesting in visually sensitive landscapes. The Silviculture Treatments for Ecosystem Management in the Sayward (STEMS) project was initiated by the Research Branch of the B.C. Ministry of Forests (BCMOF) to test silvicultural systems with different management strategies. These regimes are expected to enhance biodiversity and wildlife habitat, provide visually acceptable harvesting alternatives, and provide information on feasibility and costs.

The STEMS project will create three replicates of seven silvicultural systems to be used as a demonstration area by forest researchers and planners in ecosystem management. Harvesting of the first replication was completed in 2001 by contractors for the BCMOF Small Business Program.[1] FERIC observed the harvesting phase to report on productivity, costs, tree damage, and soil disturbance. Funding for the STEMS project is provided by the Forest Innovation Investment fund.

## Objectives

The overall objectives of the STEMS project are to:

- Create replicated examples of alternative harvest practices and silvicultural regimes that can be used as a demonstration area by foresters and planners in ecosystem management.
- Provide quantitative information for evaluation of feasibility and costs of alternative regimes, and of their long-term effects on production of timber volumes and other non-timber values.

[1] Now BC Timber Sales.

- Evaluate the effectiveness of a number of contrasting silvicultural systems in reducing environmental and visual impacts of forestry operations, while providing high timber outputs over time.

FERIC's study was directed towards the third objective for the first replication. Specifically, FERIC was to:

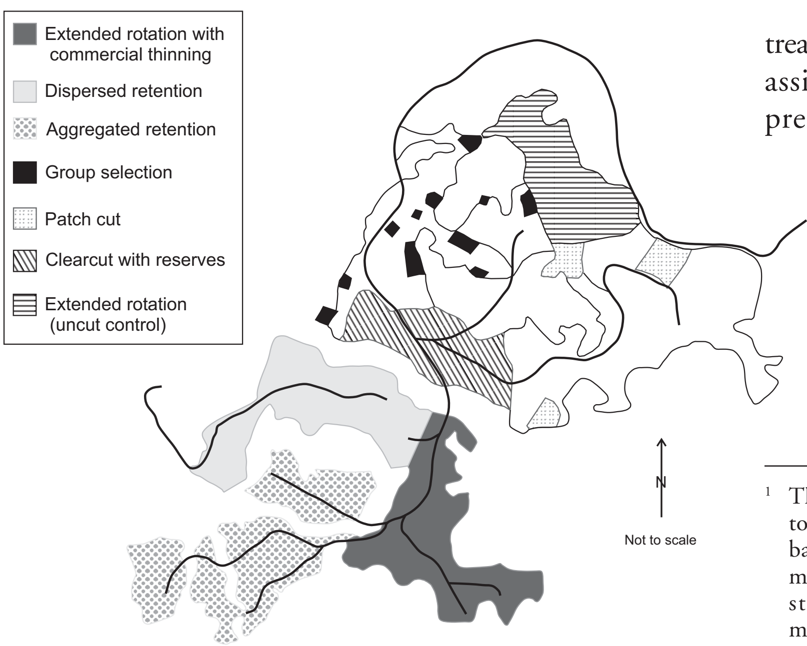
- Compare the costs and productivity of harvesting.
- Compare tree damage and level of soil disturbance in each of the treatments.
- Summarize site preparation costs and productivities.

## Site description

The STEMS study is located near Campbell River on the east side of Vancouver Island in the Sayward Forest. The Sayward Forest comprises 150 000 ha of uniform second-growth stands that are 40 to 60 years old. The first replicate was established in the Snowden Demonstration Forest, and covered 120 ha in the very dry maritime Coastal Western Hemlock (CWHxm) biogeoclimatic subzone. Recreational activities in this area include hiking, mountain biking, hunting, and the commercial harvest of chanterelle mushrooms. Of the six site series identified, the most common were 01—slightly dry to fresh/very poor to medium nutrient; and 05—slightly dry to fresh/rich to very rich. Laminated root rot (*Phellinus weirii)* was present with an infection level of 6.1% in a 250-ha survey area including the STEMS area (de Montigny 2002).

The pre-harvest stand was composed of Douglas-fir and western hemlock with a component of western red cedar, and had an average (weighted) total volume of 547 $m^3$/ha. The quadratic mean diameter at breast height for all species in all treatment units was 25–30 cm (de Montigny 2002).[1]

Figure 1.
Treatment areas.




## Silvicultural systems and harvesting methods

The study area was divided into seven treatment units and silvicultural systems were assigned to each (Figure 1). Treatments prescribed were:

- extended rotation with commercial thinning (even-aged)
- dispersed retention (two-aged)
- aggregated retention (two-aged)
- group selection (multi-aged)
- patch cut (multi-aged)
- clearcut with reserves (even-aged)
- extended rotation - uncut control

[1] The quadratic mean diameter has a stronger correlation to stand volume than does the arithmetic mean. The basal area of a tree with dbh equal to the quadratic mean diameter is equal to the mean basal area of the stand. See http://sres.anu.edu.au/associated/mensuration/s_diam.htm.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Details of the treatments are shown in Tables 1 and 2. Harvesting was coordinated by the B.C. Ministry of Forests, Small Business Program and was contracted through a public bid process with different blocks being awarded to different licensees. Some blocks were further sub-contracted and all harvesting was completed in the summer/ fall of 2001.

The next entry into this replicate is planned for 2011 (i.e., in the patch cut and group selection treatments). International Forest Products Limited is currently doing planning and layout work for the second replicate, to be done in 2004. The third replicate is planned for 2006.

Trees in all treatments were hand-felled. Loader forwarding was used as the primary method of extraction in the dispersed retention, aggregated retention, and clearcut treatments (Figure 2). Cable yarding was used in the extended rotation with commercial

**Table 1. Treatments and descriptions [a]**

| Silvicultural system (age structure) | Treatment unit (ha) | Opening size (ha) | Harvesting/ retention | Extraction method | Harvesting equipment |
|---|---|---|---|---|---|
| Extended rotation with commercial thinning (even-aged) | 18.6 | 18.6 | 350 overstorey trees/ha, 150 understorey trees/ha retained over 80 years with 5 ha of adjacent wildlife tree patches | cable yarding | rubber-tired skidder-mounted cable yarders |
| Dispersed retention (two-aged) | 18.2 | 18.2 | 40 dispersed trees/ha | loader forwarding | tracked log loaders with heel boom grapple |
| Aggregated retention (two-aged) | 25.5 | 3 openings: 4.4, 6.4 & 11.5 | 3.2 ha of treatment area temporarily deferred; 2.6 ha of internal reserves, 5.5 ha of riparian reserve | loader forwarding | tracked log loaders with heel boom grapple |
| Group selection (multi-aged) | 21.6 | 11 openings: 0.06 to 0.5 | 2.5 ha to be cut every 10 years over 80 years; retention of 12 adjacent wildlife tree patches | cable yarding & loader forwarding, forwarding to roadside | mini excavator with custom-built boom-mounted tower and winches for cable yarding; forwarding trailer pulled with agricultural tractor |
| Patch cut (multi-aged) | 35.7 | 3 openings: 0.7, 1.4 & 1.8 | 3.5 ha to be cut every 10 years in 0.5–2.0 ha openings over 80 years; retention of 10 ha of adjacent wildlife tree patches and individual trees | loader forwarding, cable yarding | rubber-tired skidder-mounted cable yarder |
| Clearcut with reserves (even-aged) | 10.9 | 10.9 | clearcut with 0.3 ha reserve | loader forwarding | tracked log loaders with heel boom grapple |
| Extended rotation uncut control (even-aged) | 12 | 0 | harvesting deferred for 80 years; 3 ha of adjacent wildlife tree patches | no extraction | n.a. |

[a] Provided by BCMOF.

## Table 2. STEMS treatment block stand description

| | Extended rotation with commercial thinning | Dispersed retention | Aggregated retention | Group selection | Patch cut | Clearcut | Extended rotation-uncut control |
|---|---|---|---|---|---|---|---|
| Density (stems/ha) | | | | | | | |
| Pre-treatment | 1325 | 1210 | 1208 | 725 | 763 | 747 | 607 |
| Post-treatment | 636 | 51 | 247 | 578 | 575 | 0 | 607 |
| % change | 52 | 96 | 80 | 20 | 25 | 100 | 0 |
| Pre-treatment density by species (%) | | | | | | | |
| Douglas-fir | 61 | 57 | 49 | 81 | 82 | 78 | 65 |
| Western hemlock | 22 | 24 | 18 | 15 | 14 | 18 | 32 |
| Western red cedar | 16 | 17 | 33 | 0 | 3 | 1 | 2 |
| Other | 0 | 2 | 0 | 4 | 1 | 3 | 2 |
| Post-treatment density by species (%) | | | | | | | |
| Douglas-fir | 61 | 84 | 34 | 81 | 80 | 0 | 65 |
| Western hemlock | 15 | 0 | 54 | 15 | 15 | 0 | 32 |
| Western red cedar | 23 | 16 | 12 | 0 | 3 | 0 | 2 |
| Other | 0 | 0 | 0 | 4 | 2 | 0 | 2 |
| Total volume ($m^3$/ha) | | | | | | | |
| Pre-treatment | 712 | 581 | 571 | 499 | 452 | 500 | 610 |
| Post-treatment | 388 | 57 | 96 | 405 | 372 | 0 | 610 |
| % change | 46 | 90 | 83 | 19 | 18 | 100 | 0 |
| Basal area ($m^2$/ha) | | | | | | | |
| Pre-treatment | 69 | 55 | 55 | 48 | 44 | 48 | 53 |
| Post-treatment | 37 | 6 | 10 | 41 | 36 | 0 | 53 |
| % change | 46 | 89 | 82 | 15 | 18 | 100 | 0 |
| Windthrow after 2 years (% of trees affected) | | | | | | | |
| Standing | 92 | 38 | 82 | 98 | 96 | 0 | 99.5 |
| Uprooted | 4 | 46 | 8 | 1 | 1 | 0 | 0.1 |
| Leaning | 3 | 15 | 10 | 1 | 0 | 0 | 0 |

Figure 2. Typical loader forwarding machine.

thinning treatment. A combination of loader forwarding and cable yarding was applied in each of the patch cut treatments.

In the group selection treatment, many of the openings were connected by designated forwarding trails. A modified mini-excavator/yarder and a tractor-trailer unit for forwarding were used as the primary methods of extraction. All forwarding trails were de-commissioned with water-bars and seeded with grass to prevent erosion until they will be used for the next harvesting entry. A description of the equipment, by treatment, is shown in Table 1.

All treatment areas were planted with Douglas-fir after harvest and areas identified with root rot had stumps removed (Figure 3).

## Study methods

To quantify harvesting costs for each treatment, shift-level information was collected using Servis recorders installed on all machines in the study. Daily activity log sheets were completed by each operator, collected by BCMOF personnel, and submitted to FERIC. For each treatment, charts were read and the data were summarized using the total harvested volumes provided by the

BCMOF. Hourly machine costs were calculated with primarily new machine purchase prices using the standard FERIC costing methodology (Appendix I). However, the cost for one hydraulic log loader used for loader forwarding was calculated as used equipment because the machine was larger than would be typically used for this application. Operators' hourly rates were calculated using coastal I.W.A. wage scales, current wage benefit loading, and prorated overtime for shifts longer than eight hours. The costs do not include supervision, profit, overhead, or crew transportation and do not reflect the actual costs incurred by each contractor.

After harvesting and site preparation, tree damage and soil disturbance data were collected. Damaged trees were classified by species and damage class, and areas with soil disturbance were stratified by site series, site preparation activity, and silviculture system. Trees were assessed for damage using a Canadian Forest Service methodology (Mitchell 1994). Raw tree damage data were submitted to FERIC for analysis together with a completed soil disturbance summary prepared by ECON Consulting (2003) of Merville, B.C. Soil disturbance data were collected in accordance with the Forest Practices Code Guidebook dated May 2001.[2]

## Results and discussion

### Productivities and costs of harvesting

System productivities for each treatment, expressed as a cost per cubic metre ($\$/m^3$), were derived based on shift-level data (Table 3). Costs were determined for the loader forwarding, cable yarding, and trailer forwarding phases only, as felling, loading and trucking costs were not part of this study. In the loader forwarding phase, a variety of hydraulic log loaders were used by the different contractors. This made direct comparisons of costs and productivities between treatment units difficult as not all machine models were used in all loader forwarding.

Figure 3. Group selection opening showing stump removal.

To make a fair comparison machine for the loader forwarding phase, costs were based on a used Hitachi EX300LC-3 log loader with heel boom grapple, the most common model used for forwarding on the study site. As shown in Table 3, all cable yarding phases, except in the group selection treatment, were yarded using two Skylead C40 model 16000 yarders (Figure 4) and a single hydraulic log loader which cleared the landing area of both yarders. Productivities of all machines in the study are reported in $m^3$/SMH (scheduled machine hours). Scheduled machine hours is the time that the machine was scheduled to work on any given day and includes all rest breaks, repairs, and daily maintenance.

### Extraction costs by treatment

#### Extended rotation with commercial thinning

Two Skylead C40 model 16000 yarders and a single log loader were used in this treatment unit. The loader worked with both yarders to clear and sort stems from each landing area. When one yarder crew moved to a new yarding corridor, rigged the next corridor, or repaired the machine, the loader worked with the other yarder. If both yarders were non-productive, i.e., broken down, the loader operator usually assisted with the repair. Productivity for each of the Skylead yarders averaged 9.4 $m^3$/SMH, which was slightly less than that found by Pavel (1999).

[2] Wolfram Wollenheit, ECON Consulting, personal communication November 2003.

## Table 3. Extraction productivity and cost per treatment unit

| Treatment unit & machines | Activity | Total volume yarded ($m^3$) | Total time (SMH) | Productivity ($m^3$/SMH) | Total cost ($/SMH) | Cost by machine ($/$m^3$) | Average cost by treatment unit ($/$m^3$) |
|---|---|---|---|---|---|---|---|
| Extended rotation with commercial thinning | | | | | | | |
| Yarder 1, Eaglet carriage | cable yarding | 2664 | 282.80 | 9.4 | 204.03 | 21.66 | 18.52 |
| Yarder 2, Maki 1 carriage | cable yarding | 1048 | 111.30 | 9.4 | 198.80 | 21.11 | |
| Log loader | clear turns at landing | - | 335.20 | - | 141.50 | 12.78 | |
| Dispersed retention | | | | | | | |
| Log loader 1 | loader forwarding | 4596 | 190.50 | 24.1 | 141.50 | 5.86 | 5.86 |
| Log loader 2 | loader forwarding | 4562 | 189.10 | 24.1 | 141.50 | 5.86 | |
| Aggregated retention | | | | | | | |
| Log loader 1 | loader forwarding | 5521 | 183.90 | 30.0 | 141.50 | 4.71 | 4.71 |
| Log loader 2 | loader forwarding | 5475 | 182.40 | 30.0 | 141.50 | 4.71 | |
| Group selection | | | | | | | |
| Mini-excavator with yarding winch | cable yarding, some loader forwarding to block edge | 1589 | 183.35 | 8.6 | 61.13 | 7.05 | 6.45 |
| Agricultural tractor & forwarding trailer | forward to roadside | 1589 | 161.63 | 9.8 | 57.53 | 5.85 | |
| Patch cut | | | | | | | |
| Yarder 1, Eaglet carriage | cable yarding | 700 | 39.00 | 18.0 | 204.03 | 11.36 | 10.26 |
| Yarder 2, Maki 1 carriage | cable yarding | 472 | 28.30 | 16.6 | 198.80 | 11.93 | |
| Log loader | clear turns at landing | 1172 | 70.00 | - | 141.50 | 8.45 | |
| Log loader | loader forwarding | 1455 | 95.70 | 15.2 | 141.50 | 9.31 | |
| Clearcut | | | | | | | |
| Log loader 1 | loader forwarding | 4867 | 131.80 | 37.0 | 141.50 | 3.83 | 3.83 |
| Log loader 2 | loader forwarding | 702 | 19.00 | 37.0 | 141.50 | 3.83 | |
| Log loader 3 | loader forwarding | 582 | 15.80 | 37.0 | 141.50 | 3.83 | |
| Extended rotation - uncut control | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. | n.a. |

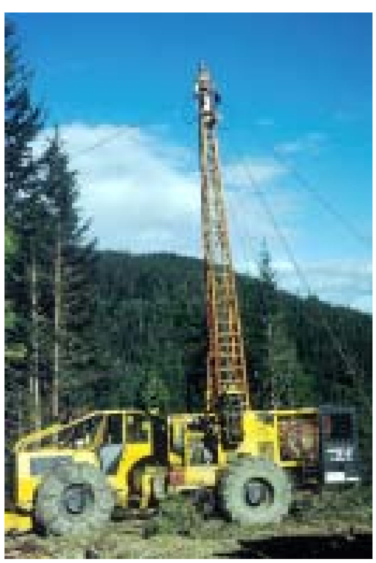

Figure 4. Skylead C40 model 16000.

The average yarding costs for each yarder were \$21.11 and \$21.66/$m^3$. In addition, the average cost for the loader was \$12.78/$m^3$, which resulted in a total average system cost of \$18.52/$m^3$.

### Dispersed retention

Each of the loader forwarders in this treatment unit had an average productivity of 24.1 $m^3$/SMH and an average cost of \$5.86/$m^3$. The slightly higher costs in this unit compared to the clearcut can be attributed to slightly steeper ground conditions as well as a residual stand of evenly dispersed trees.

### Aggregated retention

In this treatment unit, two loader forwarders each averaged 30 $m^3$/SMH. Logs were forwarded by the machines and decked along the roadside for a total unit cost of \$4.71/$m^3$.

### Group selection

Eleven small openings were spread throughout the group selection unit and were accessible from the main road through forwarding trails. A mini-excavator forwarded the small-diameter stems and yarded hard-to-reach portions of the area through forwarding trails. This machine was used almost exclusively for the entire treatment, and brought the stems to designated trails. Once on these trails, stems were forwarded to roadside with an agricultural tractor and forwarding trailer. This combination of equipment was able to negotiate the narrow forwarding trails while minimizing ground disturbance and residual tree damage. The average combined mini-excavator forwarding and cable yarding cost was \$7.05/$m^3$, while the average cost to forward to roadside using the trailer was \$5.85/$m^3$, resulting in an overall average cost of \$6.45/$m^3$ for the unit.

### Patch cut

The patch cut unit was divided into two separate sub-units and harvested by two different systems—cable and loader forwarding. Costs for the two yarders used in the cable yarding portion were \$11.36 and \$11.93/$m^3$, and their average productivities were 18 and 16.6 $m^3$/SMH, respectively. These costs are very similar to those found by Pavel (1999) and Forrester (1993). The log loader working in the landing area had an average cost of \$8.45/$m^3$, which is similar to that found in Pavel (1999). In the loader forwarding phase, the log loader had an average productivity and cost of 15 $m^3$/SMH and \$9.31/$m^3$, respectively. The overall average cost for the patch cut treatment was \$10.26/$m^3$.

### Clearcut with reserves

The clearcut with reserves treatment unit had the lowest harvesting cost of all the treatments in the study. Three loader forwarders extracted stems to the roadside at an average cost of \$3.83/$m^3$ and at an average productivity of 37 $m^3$/SMH, similar to results in studies by Andersson and Jukes (1995). One machine worked most of the area while two others helped as harvesting finished. The loader used for loading trucks usually forwarded logs to roadside near the end of the work day after the last truck had been loaded.

## Site preparation costs

Stump pulling was done to control laminated root rot. Infected areas within the STEMS site ranged in size from 1.0 to 7.8 ha (Table 4) and totalled 15.6 ha. A Hitachi EX200 excavator with bucket and thumb attachment was used to pull all stumps in the infected areas. Stumps were pulled and then placed upside down in the hole, with infected roots pulled from the soil where possible. The stump pulling cost was \$1757/ha (determined by SERVIS recorder data supplied by the operators) which is higher than reported by Dorion (1989) and DeLong (1994). This higher cost was probably due to the infected areas being scattered over a large region, as well as unnecesary additional stumping done by the operation.

## Tree damage

Overall, the level and type of tree damage (Table 5) was typical for the type of machines

**Table 4. Summary of site preparation activities**

| Treatment unit | Area stumped (ha) |
|---|---|
| Extended rotation with commercial thinning | 0.0 |
| Dispersed retention | 1.3 |
| Aggregated retention | 7.8 |
| Group selection | 1.1 |
| Patch cut | 1.0 |
| Clearcut | 4.4 |
| Extended rotation - uncut control | 0.0 |
| Total | 15.6 |

**Table 5. Incidence of tree damage**

| Treatment unit | Extended rotation with commercial thinning | Dispersed retention | Aggregated retention | Group selection | Patch cut |
|---|---|---|---|---|---|
| Trees sampled (no.) | 614 | 93 | 293 | 812 | 969 |
| CFS damage classification | | | | | |
| Trees with damage (all depths) (%) | 15 | 17 | 3 | 1 | 0 |
| Trees with phloem exposed or gouged (damage $\geq$B class) (%) | 12 | 16 | 3 | 1 | 0 |
| Avg. scar area ($cm^2$) | 885 | 801 | 1186 | 1557 | 3675 |
| Avg. scars/damaged tree (no.) | 1 | 1 | 1 | 1 | 1 |
| Avg. scar height above ground (m) | 0.71 | 1.24 | 1.19 | 1.53 | 0.03 |
| Distribution of damages by depth class | | | | | |
| Class A (surface bruised - phloem not exposed) (%) | 25 | 6 | 0 | 0 | 100 |
| Class B (phloem exposed) (%) | 73 | 88 | 40 | 29 | 0 |
| Class C (wood gouged <1 cm deep) (%) | 0 | 6 | 50 | 43 | 0 |
| Class D (wood gouged $\geq$1 cm deep) (%) | 2 | 0 | 10 | 14 | 0 |
| Class E-g (tree stem damaged at ground) (%) | 0 | 0 | 0 | 0 | 0 |
| Class E-m (main root system damaged) (%) | 0 | 0 | 0 | 14 | 0 |
| Distribution of damages by cause | | | | | |
| Falling (%) | 12 | 0 | 60 | 57 | 100 |
| Yarding (%) | 88 | 81 | 30 | 14 | 0 |
| Windfall (%) | 0 | 19 | 10 | 14 | 0 |

used in this study working among varying levels of residual trees. Damage was the highest in the dispersed retention unit with 17% of total retained trees showing damage, primarily caused by forwarding activities. The extended rotation with commercial thinning unit had the next highest damage at 15%. Damages in both treatments were primarily confined to near the base of standing trees, and occurred during yarding when stems rubbed against them. Treatments showing the lowest levels of residual tree damage were in the aggregated retention, group selection, and patch cut treatments with 3, 1, and 0% residual damage, respectively.

### Soil disturbance

A summary of disturbance levels is found in Appendix II. Levels of soil disturbance for each treatment were well below allowable maximums for all stratums which were not stumped. The lowest levels of soil disturbance in the non-stumped areas were 0.0, 0.4, and 0.5% of the area for the patch cut, group selection, and extended rotation with commercial thinning units, respectively. Slightly higher levels were found, as expected, in the treatments with loader forwarding with soil disturbance averaging 0.8, 2.1, and 3.2% of the area for the clearcut, aggregated retention, and dispersed retention units, respectively. These results were far below the 5% allowable maximums set in the prescription. For areas that were stumped, the level of disturbance ranged from 5.8 to 13.1% which is still very low considering this type of treatment.

## Conclusions and implementation

Extraction costs were highest for the extended rotation with commercial thinning treatment at $18.52/m$^3$, and lowest for the clearcut, aggregated retention, and dispersed retention treatments at $3.83/m$^3$, $4.71/m$^3$, and $5.86/m$^3$, respectively. The shift-level study showed that for loader forwarding, the costs did not change considerably with the level of retention. Unfavourable ground conditions in the patch cut treatment required the use of cable yarding and this increased costs.

Tree damage was highest in the dispersed retention block, with 17% of total trees showing some form of damage, followed by the extended rotation with commercial thinning treatment with 15% showing damage. The aggregated retention, group selection, and patch cut treatments had the lowest damage at 3, 1, and 0%, respectively.

In the dispersed retention treatment, 81% of the damage can be attributed to loader forwarding. This high level of tree damage is most likely attributed to the contractor not being careful enough rather than an inappropriate prescription as many of the leave trees had avoidable damage at the base. In the extended rotation with commercial thinning treatment, 88% of damaged trees were attributed to cable yarding activities. A commonly used method to avoid damage at the base of corridor trees is to use plastic barrels which can be removed once yarding is completed. Significant tree damage in this treatment could reduce tree health and growth, and affect tree form. The aggregated retention treatment had 60% of tree damage caused by falling and 30% from loader forwarding activities.

The levels of soil disturbance for each treatment were well below the allowable maximum set in the prescription for stratums that were not stumped. For areas that were stumped, the level of disturbance ranged from 5.8 to 13.1% which is still very low considering this type of treatment.

Generally, the extraction methods chosen for each treatment are not interchangeable. For example, in the commercial thinning unit, loader forwarding could not have been used because the corridors would have had to be much wider to accommodate the machine. Although cable yarding is expensive, it can operate on steeper slopes than other equipment. Overall, cable yarding productivity was slightly lower than the average for all the units, but it could be improved by using mechanized falling and bunching.

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## Appendix I

### Machine costs[a] ($/scheduled machine hour (SMH))

| | Skylead C40 yarder & Skidder - 16 000 series (yarding) | Skylead C40 - grey Eaglet sky carriage with one support jack (yarding) | Skylead C40 - orange Maki 1 Mini Mak carriage (yarding) | Hitachi EX300LC-3 log loader - used (loading forwarding, loading) |
|---|---|---|---|---|
| OWNERSHIP COSTS | | | | |
| Total purchase price (P) $ | 440 950 [b] | 56 200 | 25 700 | 190 000 |
| Expected life (Y) y | 10 | 10 | 10 | 3 |
| Expected life (H) h | 14 400 | 14 400 | 14 400 | 4 320 |
| Scheduled hours/year (h)=(H/Y) h | 1 440 | 1 440 | 1 440 | 1 440 |
| Salvage value as % of P (s) % | 20 | 20 | 20 | 20 |
| Interest rate (Int) % | 8.5 | 8.5 | 8.5 | 8.5 |
| Insurance rate (Ins) % | 3.0 | 3.0 | 3.0 | 3.0 |
| Salvage value (S)=((P•s)/100) $ | 88 190 | 11 240 | 5 140 | 38 000 |
| Average investment (AVI)=((P+S)/2) $ | 264 570 | 33 720 | 15 420 | 114 000 |
| Loss in resale value ((P-S)/H) $/h | 24.50 | 3.12 | 1.43 | 35.19 |
| Interest ((Int•AVI)/h) $/h | 15.62 | 1.99 | 0.91 | 6.73 |
| Insurance ((Ins•AVI)/h) $/h | 5.51 | 0.70 | 0.32 | 2.37 |
| Total ownership costs (OW) $/h | 45.63 | 5.82 | 2.66 | 44.29 |
| OPERATING COSTS | | | | |
| Wire rope (wc) $ | 17 000 | | | |
| Wire rope life (wh) h | 1 600 | 0 | 0 | 0 |
| Rigging & radio (rc) $ | 18 750 | | | |
| Rigging & radio life (rh) h | 2 400 | 0 | 0 | 0 |
| Fuel consumption (F) L/h | 4.0 | 1.0 | | 32.0 |
| Fuel (fc) $/L | 0.59 | 0.59 | | 0.59 |
| Lube & oil as % of fuel (fp) % | 12 | 12 | | 12 |
| Annual tire consumption (t) no. | 0.1 | | | |
| Tire replacement (tc) $ | 3 600 | | | |
| Track & undercarriage replacement (Tc) $ | | | | 18 000 |
| Track & undercarriage life (Th) h | 0 | 0 | 0 | 3 500 |
| Annual repair & maintenance (Rp) $ | 39 000 | 4 500 | 2 500 | 51 000 |
| Shift length (sl) h | 8.0 | 8.0 | 8.0 | 8.0 |
| Operator | 25.39 | | | 25.39 |
| Labourer No. 1 | 23.16 | | | |
| Labourer No. 2 | 23.16 | | | |
| Total wages (W) $/h | 71.71 | 0.00 | 0.00 | 25.39 |
| Wage benefit loading (WBL) % | 40 | | | 40 |
| Wire rope (wc/wh) $/h | 10.63 | 0.00 | 0.00 | 0.00 |
| Rigging & radio (rc/rh) $/h | 7.81 | 0.00 | 0.00 | 0.00 |
| Fuel (F•fc) $/h | 2.36 | 0.59 | 0.00 | 18.85 |
| Lube & oil ((fp/100)•(F•fc)) $/h | 0.28 | 0.07 | 0.00 | 2.26 |
| Tires ((t•tc)/h) $/h | 0.25 | 0.00 | 0.00 | 0.00 |
| Track & undercarriage (Tc/Th) $/h | 0.00 | 0.00 | 0.00 | 5.14 |
| Repair & maintenance (Rp/h) $/h | 27.08 | 3.12 | 1.74 | 35.42 |
| Wages & benefits (W•(1+WBL/100)) $/h | 100.39 | 0.00 | 0.00 | 35.55 |
| Total operating costs (OP) $/SMH | 148.80 | 3.79 | 1.74 | 97.22 |
| TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/SMH | 194.43 | 9.60 | 4.40 | 141.50 |

[a] These costs are based on FERIC's standard costing methodology for determining machine ownership and operating costs. These costs do not include supervision, profit, or overhead, and are not the actual costs incurred by the contractor or company.

[b] Consists of $342 000 for yarder, $35 000 for used skidder, $17 000 for line package, $18 750 for rigging package and radios, and $28 200 for recommended Eaton water-cooled haulback brake.

## Appendix I continued

| | Hitachi EX200 excavator (used) (site preparation) | Takeuchi TB53FR mini-excavator/yarder (loading forwarding, yarding) | Kubota 6340 agriculture tractor & homebuilt forwarding trailer (forwarding) |
|---|---|---|---|
| OWNERSHIP COSTS | | | |
| Total purchase price (P) $ | 119 000 | 109 500 [c] | 66400 [d] |
| Expected life (Y) y | 3 | 10 | 10 |
| Expected life (H) h | 4 320 | 14 400 | 14 400 |
| Scheduled hours/year (h)=(H/Y) h | 1 440 | 1 440 | 1 440 |
| Salvage value as % of P (s) % | 20 | 20 | 20 |
| Interest rate (Int) % | 8.5 | 8.5 | 8.5 |
| Insurance rate (Ins) % | 3.0 | 3.0 | 3.0 |
| Salvage value (S)=((P•s)/100) $ | 23 800 | 21 900 | 13 280 |
| Average investment (AVI)=((P+S)/2) $ | 71 400 | 65 700 | 39 840 |
| Loss in resale value ((P-S)/H) $/h | 22.04 | 6.08 | 3.69 |
| Interest ((Int•AVI)/h) $/h | 4.21 | 3.88 | 2.35 |
| Insurance ((Ins•AVI)/h) $/h | 1.49 | 1.37 | 0.83 |
| Total ownership costs (OW) $/h | 27.74 | 11.33 | 6.87 |
| OPERATING COSTS | | | |
| Wire rope (wc) $ | | 2 500 | |
| Wire rope life (wh) h | 0 | 1 600 | 0 |
| Rigging & radio (rc) $ | | | |
| Rigging & radio life (rh) h | 0 | 0 | 0 |
| Fuel consumption (F) L/h | 28.0 | 6.0 | 17.0 |
| Fuel (fc) $/L | 0.59 | 0.59 | 0.59 |
| Lube & oil as % of fuel (fp) % | 12 | 12 | 12 |
| Annual tire consumption (t) no. | | | 0.3 |
| Tire replacement (tc) $ | | | 460 |
| Track & undercarriage replacement (Tc) $ | 18 000 | 7 000 | |
| Track & undercarriage life (Th) h | 3 500 | 3 500 | 0 |
| Annual operating supplies (Oc) $ | | | |
| Annual repair & maintenance (Rp) $ | 32 000 | 9 700 | 5 500 |
| Shift length (sl) h | 8.0 | 8.0 | 8.0 |
| Wages $/h | | | |
| Operator | 25.39 | 25.39 | 25.39 |
| Total wages (W) $/h | 25.39 | 25.39 | 25.39 |
| Wage benefit loading (WBL) % | 40 | 40 | 40 |
| Wire rope (wc/wh) $/h | 0.00 | 1.56 | 0.00 |
| Fuel (F•fc) $/h | 16.49 | 3.53 | 10.01 |
| Lube & oil ((fp/100)•(F•fc)) $/h | 1.98 | 0.42 | 1.20 |
| Track & undercarriage (Tc/Th) $/h | 5.14 | 2.00 | 0.00 |
| Repair & maintenance (Rp/h) $/h | 22.22 | 6.74 | 3.82 |
| Wages & benefits (W•(1+WBL/100)) $/h | 35.55 | 35.55 | 35.55 |
| Total operating costs (OP) $/SMH | 81.38 | 49.80 | 50.68 |
| TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/SMH | 109.12 | 61.13 | 57.55 |

[c] Consists of $75 000 for mini excavator and $34 500 for two-drum winch, rigging, lines, two chokers, guarding, and tower.
[d] Consists of $41 400 for tractor and $25 000 for forwarding trailer with hydraulic grapple (custom).

# Appendix II

## Soil disturbance survey summary

| Treatment unit/stratum | Stratum area (ha) | Max. allowable disturbed area (%) | Stumped (yes/no) | Soil compaction hazard | Surface erosion hazard | Soil displacement hazard | Counted soil disturbance (mean %) | Disturbance categories |
|---|---|---|---|---|---|---|---|---|
| Extended rotation with commercial thinning | | | | | | | | |
| 1 | 18.6 | 2.5 | no | moderate | moderate | moderate | 0.5 | occasional scalps along roadside only |
| Dispersed retention | | | | | | | | |
| 1 | 1.3 | 10 | yes | moderate | moderate | moderate | 12.7 | deep gouge, wide gouges |
| 2 | 11.3 | 5 | no | moderate | moderate | moderate | 2.7 | track/rut >15 cm |
| 3 | 4.3 | 5 | no | high | moderate | low–moderate | 4.6 | track/rut >5 cm into mineral soil |
| Aggregated retention | | | | | | | | |
| 1 | 7.4 | 10 | yes | moderate | moderate | moderate | 7.3 | deep gouge, wide gouge, very wide scalp |
| 2 | 10.1 | 5 | no | moderate | moderate | moderate | 2.0 | track/rut >15 cm |
| 3 | 2.8 | 5 | no | high | moderate | moderate | 2.6 | track/rut >15 cm into mineral soil |
| 4 | 0.4 | 10 | yes | high | moderate | moderate | 13.1 | deep gouge, wide gouge, very wide scalp |
| Group selection | | | | | | | | |
| 1 | 1.1 | 10 | yes | moderate | moderate | moderate | 6.6 | very wide scalp |
| 2 | 1.6 | 5 | no | moderate | moderate | moderate | 0.4 | very wide scalp, repeated machine traffic |
| Patch cut | | | | | | | | |
| 1 | 1 | 10 | yes | moderate | moderate | low–moderate | 5.8 | deep gouge, wide gouges, less common very wide scalp |
| 2 | 2.8 | 5 | no | moderate | moderate | low–moderate | 0.0 | none counted |
| Clearcut with reserves | | | | | | | | |
| 1 | 4.4 | 10 | yes | moderate | moderate | low–moderate | 6.6 | very wide scalp, wide gouge, deep gouge |
| 2 | 5.5 | 5 | no | moderate | moderate | low–moderate | 0.8 | track/rut >15 cm |