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Contents

Partial cutting with a cable yarding system in coastal British Columbia

Abstract

The Forest Engineering Research Institute of Canada (FERIC) conducted a study of a partial-cutting skyline operation at Knight Inlet, British Columbia in 1998. Results include productivity and costs for engineering, falling, yarding, and loading; post-harvest basal area and volume; woody debris volume; damage to residuals; site disturbance; and visual impacts. Factors influencing feasibility and efficiency are discussed.

Keywords

Partial cutting, Cable logging systems, Skyline systems, Old-growth forests, Mountainous terrain, Steep slopes, Basal area, Woody debris, Tree damage, Site disturbance, Visual impacts, Productivity, Costs, Coastal British Columbia.

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Introduction

Until recent years, clearcutting was the accepted silvicultural system for forest operations in coastal British Columbia. Today, clearcutting is no longer an option on many coastal landscapes for environmental and social reasons. The forest industry has performed many operational trials aimed at developing safe and cost-effective partial cutting alternatives, but most partial cutting trials performed to date have occurred in favourable terrain and second-growth stands. The feasibility of partial cutting in decadent old-growth stands is therefore still not well understood. This is especially true of old-growth cedar/hemlock stands, which are widespread throughout coastal British Columbia. There is a need for well-planned operational trials in such stand types, especially on difficult terrain where cable harvesting methods are prescribed.

This report presents the results of a partial-cutting skyline harvesting operation in old-growth cedar/hemlock stands in coastal British Columbia. The harvesting trial described in this report took place in Knight Inlet in 1998, and was performed by Timfor Contractors Limited of Campbell River, B.C. FERIC monitored the operation to determine harvesting productivities and costs and to document site and stand impacts. FERIC's work was funded by Forest Renewal BC.

Objectives

The purpose of this study was to examine the costs and operational feasibility of partial-cutting cable harvesting in typical coastal old-growth stands and sites where Visual Quality Objectives (VQOs) precluded conventional clearcutting. The following specific objectives were established for this study:

- Determine overall productivities and costs for the engineering, falling, yarding and loading phases of the partial cutting operations.
- Document site and stand impacts resulting from the harvesting operation, including basal area removal; woody debris volumes; types, extents and causes of damage to residual trees; and changes to soil surface conditions.

- Identify and discuss key site, stand and operational factors that influence the feasibility and/or efficiency of partial cutting in these stand types.
- Discuss the effects of the harvesting treatments on visual quality.

Site and stand characteristics

The study area is located in the Port McNeill Forest District on the mainland coast at Knight Inlet, approximately 80 km northwest of Campbell River, B.C.

The 117-ha study site is in the Submontane variant of the Very Wet Maritime subzone, Coastal Western Hemlock biogeoclimatic zone (CWHvm1) (Green and Klinka 1994). Aspects are predominantly northerly (N-NE-NW) and elevations range from 180 to 600 m. Slopes range from 0 to 85% with rock bluffs in some areas. Tree species composition was 41% western red cedar (*Thuja plicata*), 22% yellow cedar (*Chamaecyparis nootkatensis*), 22% western hemlock (*Tsuga heterophylla*), 13% amabilis fir (*Abies amabilis*), and 2% Sitka spruce (*Picea sitchensis*). The net volume ranged from 255 to 920 m³/ha and averaged 590 m³/ha. The average decay, waste and breakage factor was 21%. The average tree to be cut was 1.6 m³ net volume, 34 m tall, and 50 cm diameter at breast height (dbh). Stand density was 426 trees/ha before harvesting.

Table 1. Removal prescription in the single tree selection area [a]

	Trees (no./ha)	Basal area (m²/ha)	Net volume (m³/ha)
Pre-harvest	426	67.5	555
Planned 1st cut	142	37.5	321
Post-harvest	284	30.0	234
Removal (%)	33	56	58

[a] ≥15 cm dbh class.

Silviculture prescription

A combination of patch cut and single tree selection (STS) systems was employed to achieve the VQO. The VQO for the area was Partial Retention, which is defined as “activities are visible but remain subordinate” (BCMOF and BC Environment 1995). The 11 patch cuts harvested ranged from 0.3 ha to 1.1 ha for a total area of 9.6 ha or 8% of the block area. Leave areas between the patches totalled 8.6 ha, approximately the same area as the patch cuts. The prescription called for 50–100 leave trees/ha in the harvested patches, with 5–20 cm dbh. Even-aged management will be used on the patch cut area on a rotation of 100 years, based on a mean annual increment (MAI) of 3 m³/ha. The leave areas will be harvested in 30 or 60 years with the second or third entry in the STS area. The area prescribed for patch cuts is on the flatter ground in the block where there is less visual concern.

STS for uneven-aged stand management was prescribed in the remaining steeper areas. Removal of skyline corridors with thinning between corridors was prescribed. This treatment comprised 89.2 ha or 77% of the block. The STS area included 11 special management areas, designated to protect riparian areas and areas of stability concern and to increase visual screening of logged areas. Roads, landings, quarries, and non-productive areas made up the final 8% of the total area.

The prescription in the STS area was to remove 56% of the basal area or 321 m³/ha (Table 1). The corridor centrelines and patch cuts were marked in the field and tree

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selection was determined by the fallers. Prism sweeps were made during harvesting to determine if the prescription was being met, and the fallers were instructed to adjust their cutting accordingly. The fallers also monitored the visual effect of their work and modified their falling to minimize their view of the inlet.

A second entry in the STS area could be scheduled in 30 years, calculated on an MAI of 9 m³/ha and 10% mortality of the immature trees. The silviculture prescription notes that care will have to be taken in the second entry in the STS area to minimize damage to the residual stand, especially the regeneration, and suggests options of changing corridor locations from the first cut or using an aerial harvesting system. The second entry calls for the same removal level as the first—56% of the basal area, calculated as 302 m³/ha.

The reforestation plan specifies planting the patch cuts after harvesting and surveying the STS area to determine stocking. The STS area will be fill-planted if minimum stocking standards are not met.

Harvesting system

Two Madill 044 swing yarders on rubber-tired carriers (Table 2) were used to harvest both the STS area (Figure 1) and the patches. Most of the time they were configured as standing skyline systems using Bowman Mark V-d motorized slack-pulling carriages with self-contained skidding drums. A grapple was used to yard a portion of the patch cut area. On one corridor with poor deflection, the Bowman carriage was used to yard the logs laterally to the skyline and then it was replaced with a lighter shotgun carriage for yarding the logs to the landing. See Appendix I for more information on the yarding equipment.

The crew size varied from three to seven workers, averaging five workers when using the carriages and dropping to three workers when using the grapple. One yarder operated two shifts per day during part of the study period.

Yarding in the STS area was conducted from a number of central landings with the corridors radiating from a central point (Figure 2). There was a total of 65 corridors ranging from 70 to 650 m in length and averaging 289 m. The radiating pattern resulted in wide distances of up to 175 m between corridors in some areas. A gravity return

Figure 1. Yarding in the STS area.

Table 2. Equipment specifications

	Yarder Madill 044 (rubber mounted)	Loader Madill 075 [a] (rubber mounted)	Carriage Bowman Mark V-d
Weight with lines (kg)	74 843	67 585	1 247
Engine power (kW)	354 [b]	237	58
Line pull @ mid-drum (kg)	30 844 [c]	45 836 [d]	10 886
Line speed @ mid-drum (m/s)	4.6 [c]	1.5 [d]	1.8

[a] Similar to the Northwest 60T used in the study. [b] One machine was turbocharged and had 392 kW. [c] Haulback drum, low gear, GM 12V71N engine. [d] Bare drum.

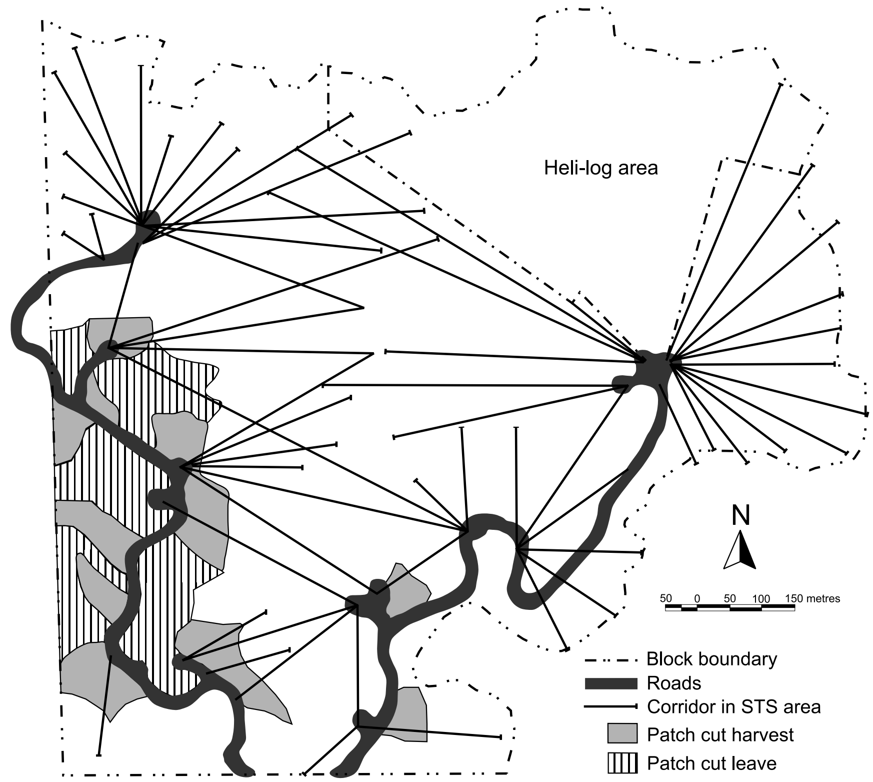

Figure 2. Block layout for harvesting.

(shotgun) system was used to yard 93% of the volume uphill, while a haulback return system was used to yard 7% of the volume downhill.

To operate the yarder as a skyline system, the mainline was threaded through the top or haulback fairlead on the boom and operated as the skyline. When yarding uphill with a shotgun system, the haulback was threaded through the second highest or mainline fairlead and operated as the skidding line. When yarding downhill, the tagline was used as the skidding line and the haulback line stayed as the haulback to achieve sufficient braking power.

Yarding long distances while using the small haulback fairlead for the skyline placed additional stress on the top part of the boom, compared to grapple yarding. During the study, one boom failed and the booms on both machines were replaced with ones with two mainline fairleads. The replacement booms were originally designed to accommodate a double-mainline yarding configuration. When the lines were reconfigured to use the extra mainline fairlead, the system operated successfully. Other modifications included the addition of a second guyline to the single guyline machine and the addition of three 300-m skyline extensions to extend the range of the yarders.

A Northwest 60T line loader cleared the landing and loaded the trucks. When production was low, the line loader and logging trucks only operated every second 10-day shift. A Hitachi EX400 hydraulic loader separated poles and yellow cedar from the other logs at the landing so they could be loaded and sold separately. This loader also cleared the landing when the line loader was not operating.

Study methods

Productivity and costs

Engineering productivity, i.e., the time required to lay out the roads, cutting boundaries and corridors, and to prepare the road and cutting permits, was determined from information supplied by the forestry consultant who did the work. Engineering labour with 40% wage benefit loading was included but engineering supplies were excluded in the costs.

Falling and yarding productivities were determined from time card information supplied by the falling contractor and licensee, and from log scale information provided by the licensee. The yarder operators recorded piece counts, turn counts, and treatment unit (i.e., patch cut or STS) each day. The piece count information was used to determine the production in cubic metres. The operators also recorded operating time, moving and rigging time, delays equal to or longer than 30 minutes, and creek cleaning time. This information was used to calculate machine time distributions. Each yarder operator also recorded the time the line loader worked on his side.

Hourly equipment ownership and operating costs for yarders and loaders were calculated according to FERIC's standard costing method (Appendix II).

Productivity model

Detailed timing of yarding was conducted in the STS area to determine average cycle times, cycle element times, and delays less than 30 minutes. Multiple-regression analysis was performed to develop a predictive equation for delay-free cycle time and a model to predict productivity. Parameters tested included slope distance, horizontal distance, height to the carriage at the hook point, lateral distance, total logs per cycle, logs per cycle between corridors, and yarding direction. Observations made during detailed timing and analysis of the data identified key site, stand and operational factors that influenced the feasibility and/or efficiency of the operation.

Post-harvest surveys

Post-harvest surveys on a 100 × 100 m grid were conducted to determine the basal area harvested, woody debris volumes, damage to residual trees, and site disturbance caused by harvesting.

To determine the basal area harvested, the number and species of each remaining tree were recorded at the licensee's cruise plots. Basal area per hectare was calculated by multiplying the tree count per plot by the basal area factor, excluding dead useless[1] and live useless[2] trees.

Site disturbance was sampled at points along random-bearing transects radiating from each grid point using the method described by Curran and Thompson (1991). All disturbances were tallied by type, depth, and cause.

Woody debris[3] >1 cm in diameter was sampled on the same transects as the site disturbance, using the line intersect method described by Sutherland (1986). Material >5 cm in diameter was classified into four groups based on the amount of decayed wood. As well, slash piles at the landings and roads were measured and their volumes were calculated, without allowance for air space.

Fixed-radius plots of 0.025 ha were established at each grid point to survey the damage to residual trees. The trees greater than 15 cm dbh in each plot were counted and each tree was classified by location (edge of corridor, between corridors, leave areas and special management areas). The extent, location and cause of damage, dbh, and species were recorded for each damaged tree. The damage was classified according to Canadian Forest Service (CFS) (Mitchell 1994) and British Columbia Forest Practices Code (FPC) criteria (BCMOF and BC Environment 1997).

Visual assessment

A subjective qualitative assessment of the visual effect of the operation was performed using pre- and post-harvest photographs, and from ground observations in the block. In addition to these observations, included in the results are remarks from a report by the University of British Columbia (UBC) (Sheppard and Picard 2000).

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1 Dead standing trees with less than 50% of original volume in sound wood.

2 Trees with only a few live branches and considered useless for lumber or chip recovery.

3 This included all material deposited or disturbed by logging, including logs, chunks, slabs, cut saplings, limbs, tops, uprooted stumps, cut snags, undercuts, old dead and downed trees, and fresh blowdown.

Results and discussion

Productivity and costs

Engineering

Results for engineering work in two blocks are reported (Table 3). Block 1 is the subject of the detailed assessment in this study while Block 2 was not logged during the study period. Results for Block 2 are provided for comparison purposes to show how experience has improved engineering productivity.

The engineering productivity was 4.7 mandays/ha for Block 1 and 3.4 mandays/ha for Block 2. Block 1 was the engineers' first experience with partial cutting so productivity may continue to improve.

Engineering labour costs for the first and second blocks were calculated at $3.77/m³ and $2.22/m³, respectively, based on planned harvest levels. The lower cost in Block 2 reflects both the higher productivity with crew experience and a higher planned harvest level.

The final harvest volume in Block 1 was lower than planned, therefore, the final cost was higher than reported in Table 3.

Table 3. Engineering productivity and costs [a]

	Block 1 (STS+Patch cuts)	Block 2 (STS)
Field work (mandays)		
Roads [b]	79	70
Block layout [c]	322	330
Subtotal	401	400
Office work (mandays)		
Road permit	68	48
Cutting permit	78	50
Subtotal	146	98
Total (mandays)	547	498
Volume (m^3) [d]	41 280	63 793
Total area (ha)	116.6	144.9
Productivity (mandays/ha)	4.7	3.4
Cost ($/$m^3$)	3.77	2.22

[a] A two-man crew of one Crewman IV and one Crewman II, at $23.46 and $21.71/h, respectively, was used to calculate engineering labour.
[b] Included reconnaissance, locating roads within block, and traversing.
[c] Included boundary location, stream classification, running deflection lines, locating corridors, and traversing the boundaries.
[d] Planned harvest, based on cruise including patch cut, STS, and right-of-way volume. Final harvest volume for Block 1 was only 33 622 m^3.

Falling

Falling productivity was 135 m³/manday in the STS area and 151 m³/manday in the patch cuts for costs of $3.46/m³ and $3.10/m³, respectively (Table 4).

Some of the fallers had recent experience with partial cutting in old-growth stands (Bennett 1997) and were highly productive. In Bennett's study, all trees to be cut were marked while in this study, only the corridor centrelines were identified. The fallers selected trees based on the cutting specifications and the visual effect. Bennett reported a 31% drop in faller productivity to 125 m³/manday in a 65% basal area retention treatment, compared to clearcutting.

At the start of this study, the licensee's assessment plots indicated the fallers were not taking enough basal area, so they modified their cutting pattern and increased the cutting intensity. To increase the removal level, keep the damage level low, and preserve visual quality, the fallers cut bulges in some corridors. This technique was applied on the steep ground where controlling damage between the corridors was more difficult. Corridors were 8 to 10 m wide but bulges reached up to 70 m wide.

Yarding

Yarding productivity when using the carriage was only 6% higher in the patch cuts at 114 m^3/8-h shift (scheduled machine hour [SMH]) compared to the STS area at 108 m^3/8-h shift (Table 5), even though the average yarding distance was much shorter. This was because a higher proportion of time was spent in mechanical downtime and other delays in the patch cuts (Figure 3). However, productivity per productive machine hour (PMH) was 25% higher in the patch cuts compared to the STS area.

Productivity was highest when grapple yarding in the patch cuts at 174 m^3/8-h shift.

Table 4. Falling productivity and cost

	Right-of-way	STS	Patch cuts	Total
Time (mandays)	30.5	207.0	19.5	257
Scaled volume (m^3)	2 729	23 567	2 944	29 240
Estimated heli-logged volume (m^3)		4382		4 382
Total volume cut (m^3)	2 729	27 949	2 944	33 622
Productivity (m^3/manday)	89 [a]	135	151	131
Cost ($/$m^3$) [b]	5.22	3.46	3.10	3.57 [c]

[a] Low productivity due to long walking distance.
[b] Based on June 15/98 coastal IWA rate of $293.04/day, 40% wage benefit loading, and $57/day for saw, gas, and oil.
[c] Average cost for corridors and patch cuts only was $3.43/$m^3$.

Table 5. Yarder productivity

	Single tree selection	Patch cuts: Carriage	Patch cuts: Grapple	All
Sample size				
SMH [a]	1 740.5	137.5	45.0	1 923.0
m^3 [b]	23 567	1 968	976	26 511
Average shift length (h)	8.9	8.6	9.0	8.9
Turn size				
pieces	2.1	2.5	2.1	2.1
m^3 [c]	3.19	3.78	3.32	3.23
Delay-free cycle time (min)	10.5	10.0	6.9	10.4
Productivity [a]				
m^3/SMH	13.5	14.3	21.7	13.8
m^3/PMH	14.8	18.3	24.4	15.3
m^3/YH	18.2	22.7	28.9	18.7
m^3/8-h shift	108	114	174	110

[a] SMH=scheduled machine hour. PMH=productive machine hour (excluded delays $\geqslant$30 min). YH=yarding hour (exludes delays $\geqslant$30 min and move/road change time).
[b] Total volume was weighted by yarder operator's piece count to calculate volume by treatment type.
[c] Based on 1.54 m^3/piece, calculated by dividing volume by yarder operator's piece count.

The average productivity for the block was 110 m^3/8-h shift for both the STS area and the patch cuts.

The yarders spent an average of 10% of SMH in delays equal to or longer than 30 minutes. Examples of the most significant delays were breaking and replacing the yarder boom (19 h), repairing the yarder engine (18 h), replacing lines (17 h), and breaking the skyline (7.5 h). Creek cleaning was only required in

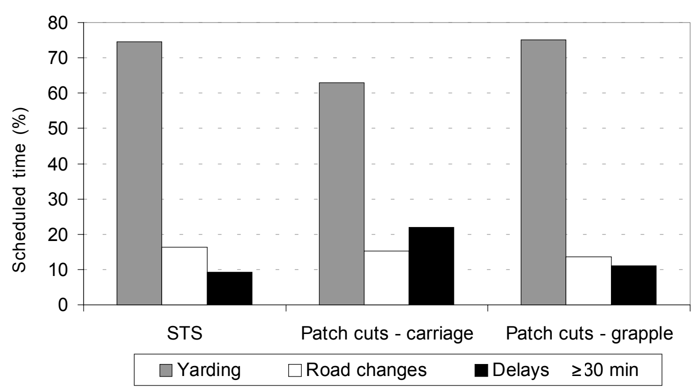

Figure 3. Time distribution for yarders.

Table 6. Road changes [a]

	STS	Patch cuts
Avg volume (m^3/sample)	399	268
Road change time		
h/sample	4.8	2.5
min/m^3	0.72	0.55

[a] Based on 59 corridors in the STS area and 11 patch cuts.

the STS area, and comprised 6% of delay time.

Yarding costs were \$30.42/m³ in the STS area, \$28.78/m³ in the patch cuts using the carriage, and \$14.42/m³ in the patch cuts when using the grapple (Table 8). The low cost when using the grapple reflects the higher productivity, lower labour cost with a smaller crew (three instead of five), and elimination of the carriage cost (Appendix II).

Road change time per corridor was almost twice as long as the time per patch cut (Table 6). However, the total number of road changes in the patch cuts is unknown and sometimes there was more than one road change per patch cut. Although the proportion of scheduled time spent changing roads was very similar for both systems at 14–16% (Figure 3), considerably more time per cubic metre was spent changing roads in the STS area than in the patch cuts.

Table 7 shows the results from the detailed-timing study of yarding in the STS area. Detailed timing for yarding was only done in the steepest and roughest terrain area. The licensee stated that productivity was much higher in other areas of the block. No detailed timing was done in the patch cut area.

Where the distance between radiating corridors was great (up to 175 m), few trees were removed between corridors. The maximum lateral distances were beyond the capacity of the carriages' droplines (91 m with 16-mm line) and lateral yarding would have been difficult without damage to the residuals. The widest lateral yarding distance observed during the detailed timing was 30 m and the average was only 4.3 m. Distances may have been greater elsewhere. Within one wide corridor with bulges, the crew rigged two skyline roads to reduce the lateral line pulling distance.

The average delay-free cycle time for an average horizontal yarding distance of 243 m was 7 min. Most of the logs were yarded from within the corridors with only 53 of 657 logs yarded from between the corridors. Damage to 37 residual trees was observed during 441 yarding cycles. Most of the damaged trees were removed when yarding of a corridor was completed.

The average piece size from the log scale data was 1.30 m^3 but the scaler's piece count was higher than that of the yarder operators'. This difference is attributed to bucking at the landing. The calculated piece size for the logs yarded was 1.54 m^3.

Table 7. Detailed-timing of yarding in the STS area [a]

	Time/cycle (min)	Time/cycle (%)
Average yarding cycle elements		
Outhaul	1.1	14
Hook	2.1	25
Breakout	0.8	10
Inhaul	1.8	22
Unhook	1.2	15
Total delay-free cycle time	7.0	86
Delays <30 minutes	1.1	14
Total cycle time including delays <30 minutes	8.1	100
Avg outhaul speed (m/min)	216	
Avg inhaul speed (m/min)	140	
Avg logs yarded/cycle (no.)	1.9	
Avg turn size (m^3) [b]	2.9	
Avg horizontal yarding distance (m)	243	
Avg lateral yarding distance (m)	4.3	
Avg height of carriage at hook point (m)	23.6	

[a] Based on 241 cycles. Sample size for height of carriage was 182 cycles.
[b] Based on 1.54 m^3/piece.

Table 8. Cost summary by harvesting phase

	Cost ($/m³)			
	STS	Patch cuts with carriage	Patch cuts with grapple	All
Engineering [a]	3.77	3.77	3.77	3.77
Falling	3.46	3.10	3.10	3.43
Yarding	30.42	28.78	14.42	29.71
Loading [a, b]	10.21	10.21	10.21	10.21
Total ($/m³)	47.86	45.86	31.50	47.12

[a] Engineering and loading costs were not separated by logging method. [b] Loading costs exclude the hydraulic loader.

Timfor has made many changes to the yarding operation since the study ended. These are discussed in Appendix III.

Regression analysis

Regression analysis was used to predict delay-free cycle time for the STS area (Appendix IV). Slope distance and lateral distance were found to be significant variables to explain the variability in cycle times.

The derived regression equation was used with the average volume per cycle to develop a model to predict productivity per delay-free yarding hour (YH). The model shows lateral distance has a greater effect on productivity at shorter slope distances (less than 300 m) than at longer slope distances.

Delays

During the detailed-timing study, FERIC observed that several of the longer yarding corridors had very poor deflection and many delays were experienced due to hang-ups.

Hang-ups and resetting the chokers were the most time-consuming delays, comprising 48% of delay time and averaging 0.5 min/cycle. Deflection was so poor in one corridor that two spotters were required to deal with hang-ups between the hooking location and the landing. Large cedar logs in this area were too heavy for the carriage and had to be split using a hydraulic jack before yarding (Figure 4). The other most time-consuming delays during yarding were road change preparation (11%) and carriage repairs (10%). Delays averaged 4.2 minutes per occurrence.

Figure 4. Splitting a large cedar with a hydraulic jack.

A 14-ha area could not be yarded from the existing landings because of very poor deflection. The licensee thought a delay for road building would result in lower value of the logs for export and decided to heli-log this area.

Loading

In the patch cuts, logs were decked at roadside and loaded after yarding was completed. In the STS area, the line loader serviced both yarders, but worked only half of the yarders' operating days.

The loading productivity and costs are estimates because the data obtained from the operators were incomplete. The licensee provided the total time the loaders worked but this time was not separated into loading right-of-way, patch cut, and STS volume.

The line loader worked a total of 1202 h while the hydraulic loader worked a total of 1007 h. Together they handled 29 240 m³, including 2 729 m³ of right-of-way wood. Using the total volume results, productivities of 24.3 m³/SMH were estimated for the line loader and 29.0 m³/SMH for the hydraulic loader. Using the hourly rates (Appendix II) results in costs of \$10.21/m³ for the line loader and \$5.55/m³ for the hydraulic loader. Only the line loader was used to load the logging truck and normally the hydraulic loader would not be required. An estimate using only the line loader hours is more indicative of future costs (Table 8).

Post-harvest surveys

Basal area and volume removed

An overall average basal area of 35 m^2/ha or 46% was removed from the block, including patch cuts, leave areas, STS area, roads and landings (Figure 5). In the STS area, 32 m^2/ha or 42% of the basal area was removed, lower than the target removal level of 56% (Table 1). The low removal level resulted primarily from the extensive unharvested areas between the corridors and partly due to falling and yarding logistics. Also, within the special management areas in the block, very few trees were removed and this wasn't accounted for in the prescription.

The cruise plots in the patch cut area showed that the basal area and volume were much lower in the area prescribed for removal than in the leave areas. However, the prescription was based on averages for the entire area, so actual volume removed was lower than planned.

The volume removed in the STS area was calculated to be 313 m³/ha based on scale information provided by the licensee. This was 56% of the original STS volume. The volume removed for the whole block including the STS area, patch cuts, and road right-of-ways was 288 m³/ha or 49% of the original block volume.

Woody debris

Post-harvest woody debris on the block totalled 233 m³/ha with an average height of 23 cm (Table 9 and Figure 6), including all material >1 cm in diameter deposited or disturbed by logging. The heaviest levels were in the patch cuts and the corridors. The patch cuts had a large amount of shattered cedar slabs. The leave areas, special management areas, and non-productive areas had some tops and logs deposited in this area. The corridor and patch cut areas had the highest amounts of sound wood (0 to 25% decay class) >5 cm in diameter.

In addition to the woody debris on the block, 7 334 m³ of slash (including air space) accumulated at the roads and landings. This slash was located in piles on or near the roads.

Damage to residuals

The post-harvest damage survey showed that 10% of residual trees sustained some damage (Appendix V). The survey was conducted after the most severely damaged trees were removed during harvest.

Along the edge of the corridors, 44% of the trees sampled were damaged. These trees received the largest wounds and second largest wound area per tree at 787 cm^2. In all locations, the amount of girdling per tree was similar, averaging 15% of the circumference. The tree quadrants that received the most damage were "towards

Note:
No current target levels exist for post-harvest woody debris for British Columbia. FERIC's goal in measuring the woody debris was to document the levels as part of the overall post-harvest site description. The results are not equivalent or comparable to the BCMOF residue and waste survey results.

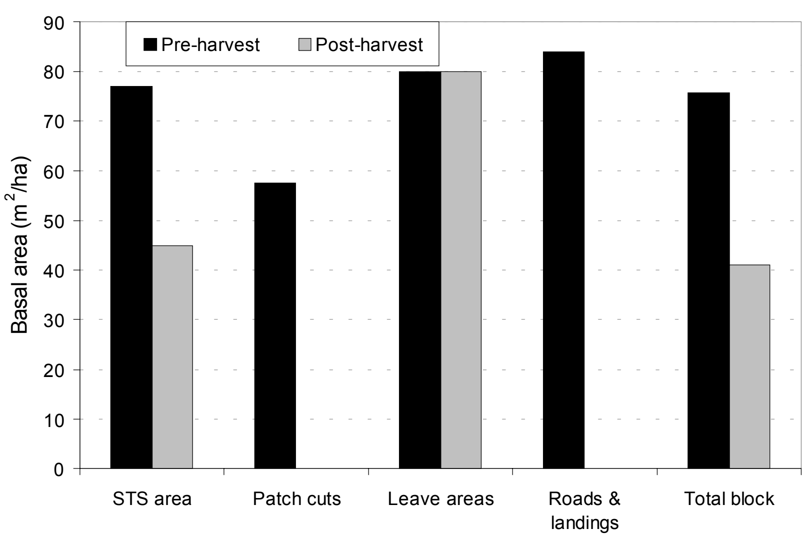

Figure 5. Basal area before and after harvesting.

Table 9. Woody debris levels by location, size, and decay class [a]

	Average height of debris (cm)	Material >5 cm diameter by % of decayed wood (m^3/ha)					1–5 cm diameter (m^3/ha)	Total (m^3/ha)
		0–25	26–50	51–75	76–100	Undet [b]		
Corridors	42	122	68	81	171	2	17	461
Timber between corridors	16	33	8	37	44	0	3	126
Patch cuts	36	49	127	323	15	31	24	569
Leave areas, SMA [c] & NP [d]	4	6	2	0	5	19	1	33
Overall	23	57	31	55	76	6	8	233

[a] Sample size of 1 259 2-m quadrats. [b] Undetermined decay class (material was buried). [c] Special Management Area. [d] Non-productive area.

the corridor" and "away from the landing"; this is understandable as most of the trees were harvested from within the corridors. For trees between the corridors, most of the damage occurred in the quadrant "away from the landing" during lateral yarding towards the corridor.

When tree damage severity was classified according to CFS criteria, the most damage was in Class B—"phloem exposed, wood not gouged." When classified according to FPC criteria, 6% of all residual trees were found to have sustained damage that rendered them unacceptable crop trees under Forest Management Regime B (long-term retention), Regime C (true uneven-age management) and Regime D (special management areas). Four percent of all trees were unacceptable under Regime A (short-term retention). The area adjacent to the corridors had the highest proportion of unacceptable trees at 23% for Regime C.

Expressed on an area basis, 27 trees/ha were damaged with 15 trees/ha deemed to be unacceptable crop trees for Regimes B, C, and D. Seventeen trees/ha in the STS area received damage that made them unacceptable crop trees according to FPC criteria.

Although the cause of damage could not be determined on 21% of the damaged trees, 49% of all damage was caused by falling, 23% by yarding and 7% by guylines or tailholds. Most of the tailspar trees were dead or dying due to girdling. This systematically located damage (one tree per corridor) was not accounted for by damage survey plots but would amount to about 0.7 trees/ha in the STS area if every tailspar tree was damaged. Each cruise plot had one severely damaged tree due to blazing for future plot reference. Because logging did not cause this damage, it was not included in the survey.

Figure 6. Measuring height of woody debris.

Site disturbance

Logging, excluding the roads and landings, disturbed a total of 2% of the soil in the block (Table 10). The corridors in the STS selection area had the highest proportion of disturbed soil.

Gouges due to logs dragging caused 49% of the soil disturbance and had an average depth of 8.3 cm. Fifteen percent of the disturbance was mounded soil with an average height of 21.3 cm.

The silviculture prescription reported that 5.3 ha or 4.6% of the block was taken up by permanent access for roads, landings, and quarries. FERIC did not survey the block after harvesting to determine if these numbers were correct.

	STS area				
	Between corridors (%)	In corridors (%)	Patch cuts (%)	Leave areas SMA & NP (%)	Total area (%)
Disturbed soil	1	5	2	2	2
Undisturbed soil	93	59	82	96	83
Woody debris [b]	5	27	15	1	11
Natural features [c]	1	8	1	1	3

Table 10. Proportion of site disturbed by logging [a]

[a] Excludes roads and landings. A total of 3 789 points was surveyed. [b] Branches, chunks, logs, slabs, or windfalls. [c] Creeks, rocks, trees, snags, or roots.

Visual assessment

The location and steep terrain within the block make it highly visible from Knight Inlet. A pre-harvest visual impact assessment utilizing computer simulation was conducted in conjunction with the layout to minimize the visual effect from the inlet.[4]

The large areas of standing trees remaining after harvest have produced an unobtrusive visual effect. When viewed from the roads on site, there is little evidence of logging in the STS area except when at the landings and looking directly down a yarding corridor. The corridors are only 8–10 m wide in most areas and radiate at various angles to the road from each landing, so the harvested area in view is quite narrow. Adjacent leave strips screen bare ground. Widenings or bulges cut in the corridors to harvest more trees are difficult to see from the road as they are hidden by the narrower parts of the corridors. Feathering[5] helped to soften the edges of the corridors. In the STS area, the visual effects of logging are most pronounced around the landings where several corridors converge.

Logging in the patch cuts is visible from the ground in the immediate vicinity but the patches are small with leave areas of equal or larger size separating them. While the patch cuts are more noticeable than the corridors, they represent only 8% of the 117-ha block. The silviculture prescription specified that 100 trees/ha from 5 to 20 cm dbh be left in the patch cuts to contribute to structural diversity, but few trees remained. The licensee stated that it was impractical to leave these trees during harvesting.

Aerial photographs of the block show the STS and patch cut areas after harvesting (Figure 7). The patch cuts can be seen more easily from the air and will be visible until they have revegetated.

While FERIC did not view the block from Knight Inlet after logging, the patch cuts were located on a bench and screened by topography and vegetation. The minimum viewing distance of 800 m to the patch cuts

[4] Pre-harvest computer simulations conducted by Ken B. Fairhurst of Resource Design Inc., Vancouver, B.C.

[5] Selective removal outside the corridors.

Figure 7. Aerial view after harvesting.

Photo credit: Ken Piercy, TFL Forest Ltd.

would make them difficult to see from the inlet. Many of the corridors are on steep ground but they would also be very difficult to see unless the viewer was in line with a corridor. The narrow corridors and the 500 m minimum viewing distance will make the viewing time brief for boaters travelling along the inlet.

UBC study

In June 2000 Dr. Stephen Sheppard, Associate Professor, Forest Resources Management and Landscape Architecture, and Paul Picard, graduate student, from UBC conducted a post-harvest assessment of the visual quality of the study area from the ground and from a boat on Knight Inlet. Their subsequent report (Sheppard and Picard 2000), based on their field observations and personal communications with the licensee and the BCMOF, as well as information obtained from Truck Logger's Magazine (Johnson 1998) and Jones et al. (1999), contained the following findings:

"The harvesting is recognized by BCMOF as having met a VQO of "Partial Retention" on the first 2 blocks (K1[6] and K2); however, our assessment (made during the field trip) of the third (latest) block (K3) indicates that it meets a "Retention"[7] VQO."

and

"It is Esmond's[8] and our opinion that the reality looks better than the simulations, i.e., the harvesting appears less obvious than in the simulations. However, the simulations do not appear to represent roads adequately; these have a noticeable visible impact. In fact, roads (displaced granite boulders and blasted rock bluffs) and old slash (which turned gray with the sun and time) were the two most prominent visual cues that logging occurred on the hillside. In this regard, visual quality could potentially be improved if special considerations are given to road construction, slash removal/disposal, and more careful retention of trees below roads."

and

"Overall, however, Timfor leaves only 40% of the basal area and yet has not received any negative comments regarding the visual appearance of their cuts. (Knight Inlet Lodge fly in several loads of tourists each day throughout the summer over this area.) Comments from both eco-tourism operators and senior BCMOF officials are very positive and encouraging; 'if only all logging was done like that …'. There is an overall positive public reaction, though Esmond is not satisfied with 40% retention.......Esmond seems to believe that Timfor could achieve higher quality with similar levels of removal and still more careful design."

Conclusions

Engineering productivity for field and office work was 4.7 mandays/ha at $3.77/m³. Falling productivity ranged from 135 m³/manday in the STS area at $3.46/m³ to 151 m³/manday in the patch cuts at $3.10/m³. Yarding productivity was 108 m³/8-h shift in the STS area at $30.42/m³ with the carriage, 114 m³/8-h shift in the patch cut area at $28.78/m³ with the carriage, and 174 m³/8-h shift in the patch cut area at $14.42/m³ with the grapple. Overall loading cost was $10.21/m³ for the line loader.

A basal area of 32 m² or 42% was removed from the STS area, lower than the target removal level of 56%. A volume of 313 m³/ha, or 56% of the stand volume, was removed from the STS area. Including the right-of-way and patch cut wood, 49% of the volume was removed from the entire block.

Post-harvest woody debris on the block totalled 233 m³/ha with the heaviest levels in the patch cuts (569 m³/ha) and the corridors (461 m³/ha). Ten percent of all residual trees sustained some damage with 17 trees/ha in the STS area receiving damage that made them unacceptable crop trees according to FPC criteria. Logging, excluding the roads and landings, disturbed only 2% of the soil in the block.

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6 Block K1 is the subject of this FERIC report.

7 "Activities are not visually evident," BCMOF and BC Environment 1995.

8 Esmond Preus, owner of Timfor Contractors Limited.

Large areas of standing trees left in the block have produced an unobtrusive visual effect. The corridor and patch locations were effective at preserving scenic viewscapes in Knight Inlet.

Implementation

Several factors were found to influence the feasibility and efficiency of the harvesting operation.

- **Safety.** Partial cutting in large timber on steep slopes has the potential to create safety hazards for the crew. Timfor used the Partial-Cutting Safety Handbook (BCMOF and Forest Renewal BC 1997) as a guide for its practices to minimize risks. The best fallers available were chosen to perform the work. Poor falling practices not only place a faller at risk but also may create hazards for the yarding crew.
- **Patch cuts compared to STS system.** Harvesting small patches was more efficient than working in corridors. Falling and yarding productivity were both higher. Yarding costs were lowest when a grapple was used in the patch cuts.
- **Removal level.** Removal level directly influences costs in several ways. Total costs for cruising, engineering, and road construction reflect the area harvested more than the volume logged. Therefore, if the planned removal level is low or targets are not reached, the cost per cubic metre for these phases will be high. When yarding long distances with a skyline system, the rigging time per corridor can be long and these costs are written off over the harvested volume. Again, if the removal level is low, the rigging and machine-move cost per cubic metre will be high.
- **Yarding distance.** Slope distance and lateral distance also influenced the feasibility and efficiency as seen in the productivity model (Appendix IV). Lateral distance had less influence as slope distance increased because lateral-out became a smaller proportion of the total yarding cycle. The Madill 044 yarders used for this operation are older machines (1976 and 1980 model years) with slow line speeds (e.g., maximum haulback speed is 905 m/min) compared to newer machines such as the Madill 124 (e.g., maximum haulback speed is 1814 m/min). Although line speed has a greater influence on productivity as slope distance increases, the licensee felt that increasing inhaul speed would result in more tree damage in the narrow corridors.
- **Deflection.** Deflection had a great influence on the operation. In the STS area, 48% of yarding delays less than 30 minutes were due to hang-ups caused by poor deflection. Large stumps and rock bluffs in areas with marginal deflection resulted in very low productivity. When yarding is confined to corridors, there is less opportunity to relocate lines to clear obstacles, compared to when clearcutting. Although the swing yarders could relocate the lines slightly within a corridor, the corridor trees could be damaged and safety hazards could be created.

  The combination of large trees and poor deflection on some corridors resulted in logs that could not be yarded. These logs had to be split along their length before yarding. The results of accurate payload analysis must be incorporated into the layout for skyline systems to operate effectively. Four corridors (12% of the block) could not be yarded to the existing road and were heli-logged. Sound engineering is essential to successfully cable yard STS systems.

  Poor deflection also contributed to site disturbance. Although site disturbance was quite low for the block overall, one corridor had heavy disturbance due to poor deflection.
- **Road access.** Road access near the end of some long corridors improved efficiency by reducing rigging time and the crew's walking time.

- **Corridor and patch locations.** The corridor and patch locations were effective at preserving scenic viewscapes in Knight Inlet. Locating the patch cuts in the flat area of the block with a large distance of standing timber between the patch cut and the inlet effectively screened the patch cuts. In the STS area, the wide areas of timber between the narrow corridors were also effective at reducing the visual impact of logging.
- **Market conditions.** Market conditions were poor for hemlock and balsam logs when this area was logged. The high component of higher-value cedar in the block and permission to export a portion of the hemlock and balsam logs helped make the operation feasible. The licensee is now certified by Forest Stewardship Council as a Resource Manager, which may increase the market value of the products produced from this site. This would help offset the lower productivity and higher costs of the operation.
- **Experience.** Most of the people involved in the operation, including the engineers, rigging crews, and some of the fallers, had no experience with this type of logging. As the workers gain more experience with this system, productivity is expected to improve. The licensee has finished logging the second block and reports that productivity and costs are much better than those experienced in this first block (Appendix III).

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Appendix I

Yarding equipment selection, costing, and performance

When planning how to harvest this block, the licensee's yarding equipment options were limited to its older model Madill 044 yarders. These non-interlock machines were originally designed for short-distance grapple yarding and may not appear to be the best choice for a long-distance skyline system. However, by rigging the yarders as standing skyline systems with gravity outhaul and adding motorized slack-pulling carriages with self-contained skidding drums, these yarders were adequate for this application. It is unlikely that someone would purchase a new swing yarder to use exclusively for this yarding system, as other equipment is available that would be less expensive and better suited to this application.

An advantage of the rigging configuration used is that it is possible to use a wide selection of yarders by just adding a motorized drum carriage. This allows companies that own older yarding equipment to employ this system without incurring the high capital cost of purchasing new yarders; however, they must acquire an expensive carriage. A tower yarder also has the capabilities to operate this yarding system, especially when radiating corridors are used and moves are infrequent.

The Madill 044 yarder is no longer manufactured.Therefore, a Madill 124 was used to determine an hourly rate for cost calculations. While the 124 could be considered an appropriate replacement for the 044, it has many differences. The 124 is a modern, versatile swing yarder with features that could result in different productivity and cost/m^3.

For example:

- **Interlock.** The 124 has regenerative-interlock while the 044 has no interlock. Interlock is not necessary to apply this yarding system which uses a standing skyline and a motorized drum carriage. However, interlock would make the machine more versatile, allowing it to operate more efficiently if used as a running skyline with a grapple or a less expensive mechanical slack-pulling carriage.
- **Drum capacity and configuration.** The greater drum capacities and configuration on the 124 allow more layout options compared to the 044, which has limited downhill yarding capabilities when used in this yarding system. The double mainline drum configuration on the 124 is better suited for downhill yarding than the 044's arrangement with a single mainline and tag line. The small tag line on the 044 had to be used as the skidding line when yarding downhill on this project.
- **Line pull and line speed.** Maximum line pulls for the mainline and haulbacks are similar for the two machines but the tag line pull on the 044 is only about 1/6 that of the other drums. Maximum haulback speed on the 044 is only one-half the haulback speed on the 124.

Overall the Madill 124 and Madill 044 are quite different machines. The effects of these differences will depend on how the machines are applied.

Appendix II

Machine costs [a]

	Swing yarder Madill 124 [b] 5 man crew	Swing yarder w/grapple [c] Madill 124 [b] 3-man crew	Carriage Bowman Mark V-d	Log loader Madill 075 [d]	Log loader Hitachi EX400
OWNERSHIP COSTS					
Total purchase price (P) $	1 150 000	1 165 000	98 600	1 450 000	510 000
Expected life (Y) y	12	12	5	12	5
Expected life (H) h	17 280	17 280	7 200	17 280	7 200
Scheduled hours per year (h)=(H/Y) h	1 440	1 440	1 440	1 440	1 400
Salvage value as % of P (s) %	30	30	10	30	30
Interest rate (Int) %	8.5	8.5	8.5	8.5	8.5
Insurance rate (Ins) %	2.0	2.0	3.0	2.0	2.5
Salvage value (S)=(s•P) $	345 000	349 500	9 860	435 000	153 000
Average investment (AVI)=((P+S)/2) $	747 500	757 250	54 230	942 500	331 500
Loss in resale value ((P-S)/H) $/h	46.59	47.19	12.33	58.74	49.58
Interest=((Int•AVI)/h) $/h	44.12	44.70	3.20	55.63	19.57
Insurance=((Ins•AVI)/h) $/h	10.38	10.52	1.13	13.09	5.76
Total ownership costs (OW) $/h	101.09	102.41	16.66	127.46	74.91
OPERATING COSTS					
Wire rope (wc) $	31 600	31 600	660	8 000	-
Wire rope life (wh) $	1 440	1 440	360	2 000	-
Rigging & radio (rc) $	12 500	12 500	-	-	-
Rigging & radio life (rh) h	5 760	5 760	-	-	-
Fuel consumption (F) L/h	36.0	36.0	1.5	64.0	25.0
Fuel (fc) $/L	0.40	0.40	0.40	0.40	0.40
Lube & oil as % of fuel (fp) %	10	10	10	10	10
Track & undercarriage replacement (Tc) $	63 000	63 000	-	-	-
Track & undercarriage life (Th) h	8 640	8 640	-	-	-
Annual operating supplied (Oc) $	10 000	10 000	-	-	-
Annual repair & maintenance (Rp) $	85 000	85 000	20 000	36 000	60 000
Shift length (sl) h	8.0	8.0	8.0	8.0	8.0
Wages $/h [e]					
Operator	24.60	25.26	-	23.93	23.93
Hooktender	26.64	24.60	-	-	-
Rigging slinger	24.60	-	-	-	-
Chaser/utility man/second loader	22.43	22.14	-	21.65	-
Chokersetter	21.83	-	-	-	-
Total wages (W)	120.10	72.00	-	45.58	23.93
Wage benefit loading (WBL) %	40	40	-	40	40
Wire rope (wc/wh) $/h	21.94	21.94	1.83	4.00	-
Rigging & radio (rc/rh) $/h	2.17	2.17	-	-	-
Fuel (F•fc) $/h	14.40	14.40	0.60	25.60	10.00
Lube & oil (fp•(F•fc)) $/h	1.44	1.44	0.06	2.56	1.00
Track & undercarriage (Tc/H) $/h [f]	3.65	3.65	-	-	-
Operating supplies (Oc/h) $/h	6.94	6.94	-	-	-
Repair & maintenance (Rp/h) $/h	59.03	59.03	13.89	25.00	41.67
Wages & benefits (W•(1+WBL)) $/h	168.14	100.80	-	63.81	33.50
Total operating costs (OP) $/h	277.71	210.37	16.38	120.97	86.17
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	378.80	312.78	33.04	248.43	161.07

[a] These costs are based on FERIC's standard costing method for determining machine ownership and operating costs. Costs exclude fire protection, supervision, crew transportation, room and board, additional equipment for machine moves, first aid coverage, overhead, taxes, and profit; and are not the actual costs for the contractor or company studied. Annual costs for repairs and maintenance were provided by the equipment suppliers and estimated by FERIC. [b] Similar to the Madill 044 used in the study which is no longer manufactured. Wire rope requirements for the 044 were used for costing. [c] An allowance of $15,000 was used for the grapple. [d] Similar to the Northwest T-60 used in the study which is no longer manufactured. The purchase price listed is an estimate by Madill. [e] IWA coastal rates for June 15, 1998. No premium was included for overtime hours worked. [f] Assumes the track and undercarriage will be replaced only once during the machine's expected life.

Appendix III

Changes and improvements since the study

Improvements in productivity and costs

FERIC's research was conducted during the licensee's first year operating this logging system. Timfor Contractors Limited's productivity and costs improved greatly in the second year as the company became more proficient. FERIC did not study the operation beyond the first year, so Timfor's figures for productivity and costs for Years 1 and 2 are reported here for comparison (Table III-1). Although these figures are not directly comparable to FERIC's, they provide a useful indication of the improvement that has taken place.

Table III-1 Yarding productivity

	FERIC Year 1	Timfor Year 1	Timfor Year 2
m^3/YH	19	20	26
m^3/PMH	15	16	20
m^3/SMH	14	15	18
m^3/8-h shift	110	121	146

Timfor's figures do not separate productivity by logging method (patch cut or STS) and include volume from road right-of-ways. Yarding productivity increased 21% from 121 m^3/8-h shift in Year 1 to 146 m^3 in Year 2. All logging in Year 2 was done using the STS method.

Timfor's yarding costs dropped from \$25.64/m^3 in Year 1 to \$14.42/m^3 in Year 2. These costs include depreciation, labour, travel, maintenance, and overtime. Timfor's loading costs dropped from \$10.83/m^3 to \$7.74/m^3. These costs include both the line loader used to load trucks, and the hydraulic loader which was used to separate poles and yellow cedar. The licensee estimates that loading costs would be about \$5/m^3 if only one loader was used. Timfor also stated that this method of logging reduced the yarders' fuel consumption by 55% compared to grapple yarding, because the engine spent more time idling or running at a low speed.

FERIC's calculated costs for Year 1 are considerably higher at \$29.71/m^3 for yarding and \$10.21/m^3 for loading (one loader) because they are based on using new equipment with high depreciation expenses. Timfor was able to use old equipment with lower depreciation, but possibly with higher repair and maintenance costs. FERIC's costs do not include travel time and overtime expenses.

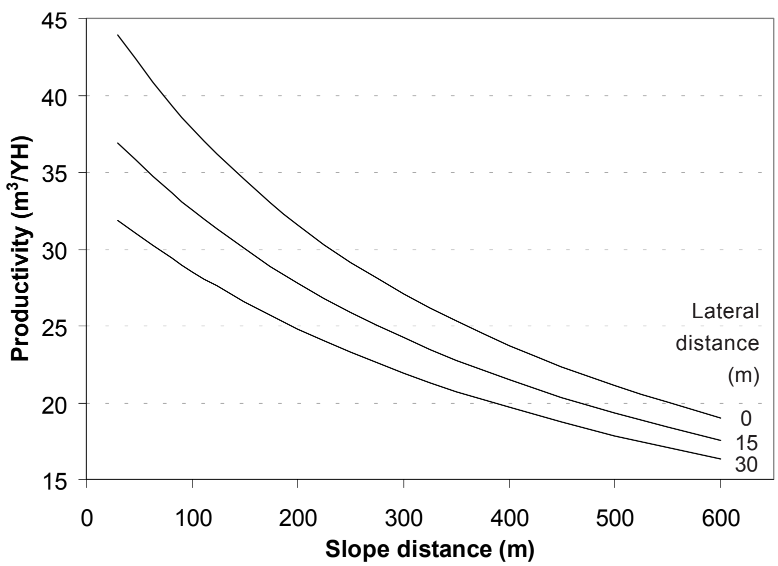
What Timfor has changed

- Maximum yarding distance was reduced from 650 to 518 m for uphill yarding and from 325 to 300 m for downhill yarding.
- Maximum distance between corridors was reduced from 175 to 75 m.
- Layout was changed from radial corridors to corridors perpendicular to the contours wherever possible. This change resulted in removal of more volume because the corridors were evenly spaced. It also reduced downhill sidehill yarding which resulted in logs crashing into the carriage and damaging it, especially in areas with large logs. Timfor is considering using a mechanical slack-pulling carriage in the future where downhill sidehill yarding is necessary.
- Large diameter logs are now bucked shorter to reduce their weight and make them easier to yard. The shortest log length has changed from 5 m to 3.2 m and the large diameter logs are not split.
- Timfor is now using a set of electronic chokers and plans to purchase another set (approx. \$13,000). A chaser is still part of the crew and Timfor feels the gains in productivity and safety outweigh the cost of the chokers.
- Layout has improved resulting in better deflection.

Appendix IV

Regression analysis to predict productivity per delay-free yarding hour

Model to predict productivity per delay-free yarding hour:



This model was developed from a regression equation, derived from detailed-timing data, that predicts delay-free cycle time:

Cycle time (min) = 3.7294 + 0.0092•(slope distance [m]) + 0.0504•(lateral distance [m])

R^2 (coefficient of determination)	= .41
S.E.E. (standard error of the estimate)	= 2.01
Number of observations	= 209

Appendix V

Damage to residual trees

	STS area: Trees between corridors	STS area: Trees lining corridors	Leave areas & SMA	Total area
Trees sampled (no.)	211	48	153	412
Total trees with damage [a]				
no.	20	21	2	43
% of sample	9	44	1	10
Avg dbh of damaged trees (cm)	44	45	63	45
Avg area/wound (cm^2)	373	385	79	353
Avg wound area/tree (cm^2)	806	787	345	775
Avg wounds/tree (no.)	2.2	2.0	4.5	2.2
Girdling of tree by all wounds (% of circumference)	16	14	13	15
Avg wound height above the ground (m)	1.5	0.9	0.5	1.2
Quadrant of tree where damage occurred				
Towards corridor (%)	18	34	0	26
Away from corridor (%)	5	13	100	10
Towards landing (%)	21	16	0	18
Away from landing (%)	56	21	0	38
All quadrants were damanged (%)	0	16	0	8
Distribution of damage by CFS damage classification (%)				
Class A (bark scuffed or bruised, phloem not exposed) (%)				
Class B (phloem exposed, wood not gouged) (%)	4	29	0.7	6
Class C (phloem exposed, wood gouged <1 cm deep) (%)	2	6		2
Class D (phloem exposed, wood gouged >1 cm deep) (%)		4	0.7	1
Class E-g (tree damaged at ground) (%)	2			1
Class E-m (main root system damaged) (%)		4		1
Total (%)	8	43	1	11
Distribution of damage by B.C. FPC classification				
Trees with unacceptable damage based on Forest Management Objective [b]				
Regime A (short term retention) (%)	4	13	1	4
Regime B (long term retention) (%)	1	10		2
Regime C (true uneven-age management) (%)				
Regime D (special management areas)				
Total (%)	5	23	1	6
Distribution of damaged trees by cause				
Falling (%)	60	37	50	49
Yarding (%)	25	24	0	23
Guyline or tailhold (%)	0	10	50	7
Unknown (logging) (%)	15	29	0	21
Damaged trees/ha				
All damage	32		7	27
FPC Regime A [c]	11		3	10
FPC Regime B [c]	6		0	5

[a] This table only includes trees damaged directly by logging. Excluded are trees damaged by wind, road construction, and cruising.

[b] The figures shown are not cumulative. To determine the total for a Regime, add the figures from all the Regimes above, e.g., the total proportion for Regime C is 4% (Regime A) + 2% (Regime B) + 0% (Regime C) = 6%.

[c] Not cumulative, e.g., trees that are not suitable for Regime A are also not suitable for Regimes B, C and D.