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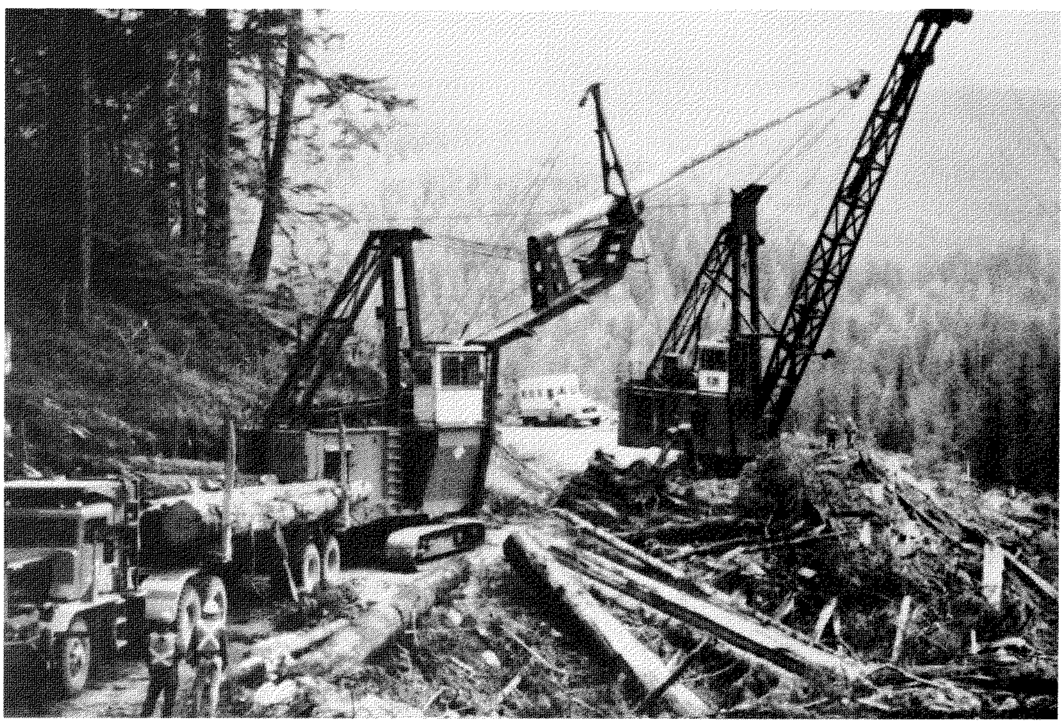
Patrick D. Forrester

March 1995



Technical Report

TR-112

EVALUATION OF THREE CABLE-YARDING SYSTEMS WORKING IN A COASTAL OLD-GROWTH FOREST

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Abstract

During 1992 and 1993 the Forest Engineering Research Institute of Canada (FERIC) observed three cable-yarding systems harvesting old-growth forest in the Walbran Valley on the west coast of Vancouver Island, British Columbia. FERIC compared the performances of the cable-harvesting techniques, and evaluated them in terms of productivity and cost, quality of merchantable logs recovered, site disturbance, and amount and quality of fibre left on the site after harvesting.

Acknowledgements

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Author

Patrick D. Forrester received a Forest Technologist diploma from the British Columbia Institute of Technology and is an Applied Science Technologist. He joined FERIC's Western Division in 1978 and is now a Researcher in the Harvesting Operations Group.

Disclaimer

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Summary

The Walbran Valley, a 13 000-ha watershed in the Coastal Western Hemlock biogeoclimatic zone, is located on the west coast of Vancouver Island, British Columbia. In 1990, the Walbran Local Resource Advisory Group was established to assist the Caycuse Division[1] of Fletcher Challenge Canada Limited with the harvest planning of the Walbran Valley. The group recommended a full review of the appropriateness of the yarding systems used to harvest the high-value old-growth forests of the valley. In 1991 the Forest Engineering Research Institute of Canada (FERIC) was asked to compare the performances of the following three Coastal cable-harvesting techniques in the Walbran Valley:

- Choker yarding using a swing yarder with a fixed backspar (i.e. topped and rigged tree).
- Grapple yarding using a swing yarder with a mobile backspar.
- Choker yarding using a mobile steel tower rigged in a highlead-scabline (running skyline) configuration with a mobile backspar.

Field evaluations of harvesting activities were conducted intermittently from April 1992 to March 1993. The objectives of this study were to determine the advantages and disadvantages associated with these three systems pertaining to:

- Productivity and cost.
- Quality of merchantable logs recovered (yarding breakage).
- Site disturbance.
- Amount and quality of fibre left on the site after harvesting (residue and waste).

FERIC's program for studying fibre recovery and utilization is supported in part by the Forestry Practices Component of the Canadian Forest Service's Green Plan.

The study site contained 328 trees/ha; had a net cruise volume of 828 m³/ha; and consisted of 65% Western red cedar, 27% Western hemlock, and 8% Amabilis fir. The terrain is mostly uniform with concave slopes ranging from 10 to 60%. Non-fish-bearing streams occur throughout the area and feed into Walbran Creek.

The study determined that the swing yarder with grapple system had the highest productivity and machine utilization, and the lowest production costs and value loss due to damage. However the two choker systems had less waste, residue, and site disturbance than the grapple system. The use of a mobile backspar with two of the systems did not noticeably increase site disturbance. Road and landing occupancy was average for grapple yarder areas on the Coast and did not include any constructed backspar trails.

Large, partially buried cedar windfalls were often left by the choker systems for subsequent recovery by shake cutters because the chokers could not be passed under the logs. When attempts were made to move these stems by attaching chokers across their end faces, slabbing frequently resulted. With the grapple system, however, the legs of the grapple could be positioned carefully to lift and move these buried cedar windfalls with minimal damage. The grapple yarder had a higher volume/ha, larger average piece size, and considerably faster turn times which resulted in a cost advantage of 40% for the wood loaded on a truck.

With the current trend towards harvesting smaller openings in old-growth forests the relative economics of grapple yarding will become more attractive. However, choker systems will still be more appropriate on areas with poor visibility or long yarding (>250 m).

Future studies of harvesting systems working in old-growth timber should be directed towards reducing yarding breakage, waste, and site occupancy of roads and landings.

Sommaire

La vallée de la Walbran, un bassin hydrographique de 13 000 hectares dans la zone biogéoclimatique côtière de la pruche de l'Ouest, est située sur la côte ouest de l'île de Vancouver, en Colombie-Britannique. En 1990, un groupe de consultation sur l'utilisation des ressources de la région (Walbran Local Resource Advisory Group) fut formé pour aider la Division Caycuse[2] de Fletcher Challenge Canada Limited à planifier les opérations de récolte dans la vallée. Le groupe recommanda de revoir en profondeur l'acceptabilité des systèmes de téléphérage utilisés pour récolter les vieilles forêts primitives de la vallée, dont les arbres avaient une grande valeur. En 1991, l'Institut canadien de recherches en génie forestier (FERIC) fut invité à comparer les performances, dans la vallée de la Walbran, des trois techniques de téléphérage suivantes utilisées sur la côte:

- Téléphérage par élingues au moyen d'un câble-grue à mât orientable avec pylône arrière fixe (i.e. un arbre écimé et équipé de câbles).

[1] Formerly a part of Fletcher Challenge Canada Limited, this division is now part of TimberWest Forest Limited.

[2] Anciennement associée à Fletcher Challenge Canada Limited, cette division fait maintenant partie de TimberWest Forest Limited.

- Téléphérage par grappin au moyen d'un câble-grue à mât orientable avec pylône arrière mobile.

- Téléphérage par élingues au moyen d'une tour mobile en acier équipée à la façon d'un câble-grue à chariot autoleveur, avec pylône arrière mobile.

Des évaluations sur le terrain des activités de récolte furent effectuées de façon intermittente d'avril 1992 à mars 1993. Les objectifs de cette étude visaient à déterminer les avantages et les inconvénients de ces trois systèmes au point de vue:
- productivité et coût;
- qualité des billes marchandes récupérées (bris des tiges dû au téléphérage);
- perturbation du site;
- quantité et qualité de la fibre laissée sur le site après la récolte (résidus et déchets).

Le programme de FERIC qui étudie le rendement en fibre et son utilisation est financé en partie par le volet Pratiques forestières du Plan vert du Service canadien des forêts.

L'aire d'étude contenait 328 arbres/ha; le volume net indiqué par l'inventaire était de 828 m^3/ha; et la composition en essences était la suivante: 65 % de cèdre de l'Ouest, 27 % de pruche de l'Ouest et 8 % de sapin gracieux. Le terrain est en grande partie uniforme avec des pentes concaves allant de 10 à 60 %. Des cours d'eau non poissonneux traversent la région et se jettent dans la rivière Walbran.

Les résultats de l'étude indiquent que le câble-grue à mât orientable avec grappin donnait la productivité et le taux d'utilisation des machines les plus élevés, ainsi que les plus faibles coûts de production et pertes de valeur dues à des dommages. Cependant, les deux systèmes avec élingues produisaient moins de déchets, de résidus et de perturbation du site que le système à grappin. L'usage d'un pylône arrière mobile avec deux des systèmes n'augmenta pas la perturbation du site de façon perceptible. L'occupation du terrain par les routes et les jetées correspondait à la moyenne pour les aires récoltées par câble-grue à grappin sur la Côte et ne comprenait aucun sentier construit pour permettre l'accès au pylône arrière.

Les gros cèdres renversés par le vent et partiellement enfouis dans le sol étaient souvent laissés sur place par les systèmes à élingues, pour être récupérés plus tard par des ouvriers qui les transformeraient en bardeaux, parce qu'il était impossible de glisser les élingues sous les billes. Quand on essayait de déplacer une tige en attachant une élingue en travers de la partie visible de sa face transversale, il arrivait souvent que la tige fende sur toute sa longueur. Avec le système à grappin, cependant, les griffes du grappin pouvaient être placées avec précaution de façon à soulever et à déplacer les cèdres enfouis dans le sol avec un minimum de dommages. Avec le câble-grue à grappin, le volume par hectare était plus élevé, les dimensions des pièces étaient plus fortes, et la durée d'un cycle était beaucoup plus courte, ce qui conférait un avantage de coût de 40 % au bois chargé sur un camion.

Avec la tendance actuelle vers la création d'ouvertures plus petites dans les vieilles forêts primitives, la rentabilité relative du téléphérage par grappin deviendra plus intéressante. Cependant, les systèmes à élingues demeureront plus appropriés dans les aires qui présentent une mauvaise visibilité ou une longue distance de téléphérage (>250 m).

Les études futures sur les systèmes de récolte dans les vieux peuplements primitifs devraient chercher des moyens de réduire le bris des tiges dû au téléphérage, les déchets et l'occupation du terrain par les routes et les jetées.

INTRODUCTION

The Walbran Valley is a 13 000-ha watershed located on the west coast of British Columbia's Vancouver Island in the Coastal Western Hemlock biogeoclimatic zone (Figure 1). Fletcher Challenge Canada Limited (FCCL) and MacMillan Bloedel Limited both have harvesting licenses in this drainage. Over the past decade, the old-growth forests of the Walbran have been targeted by preservationists who have staged demonstrations and road blockades to draw public attention to perceived bad logging methods. The licensees have responded to these public concerns by modifying their forest practices to reduce both the size of openings and the rates of cut; they have also increased public involvement in harvest planning.

In 1990, the Walbran Local Resource Advisory Group was established to assist the Caycuse Division[1] of FCCL with the harvest planning of the Walbran Valley. The Group recommended that FCCL review the appropriateness of the yarding systems used to harvest the high-value old-growth forests of the valley. In 1991 FERIC was asked to compare the performance of three cable-harvesting techniques commonly used on Coastal sites:

- Swing yarder with chokers working from a fixed backspar (i.e. topped and rigged tree).
- Swing yarder with a grapple and a mobile backspar.
- Mobile steel tower rigged in a highlead-scabline (running skyline) configuration, with chokers and mobile backspar.

Field evaluations of harvesting activities were conducted intermittently from April 1992 to March 1993. The objectives of this study were to determine the advantages and disadvantages associated with these three systems pertaining to:

- Productivity and cost.
- Quality of merchantable logs recovered (yarding breakage).
- Site disturbance.
- Amount and quality of fibre left on the site after harvesting (residue and waste).

The "quality of fibre recovered" portion of the study was undertaken by a graduate student from the Faculty of Forestry at the University of British Columbia (UBC), with funding from the Science Council of British Columbia.

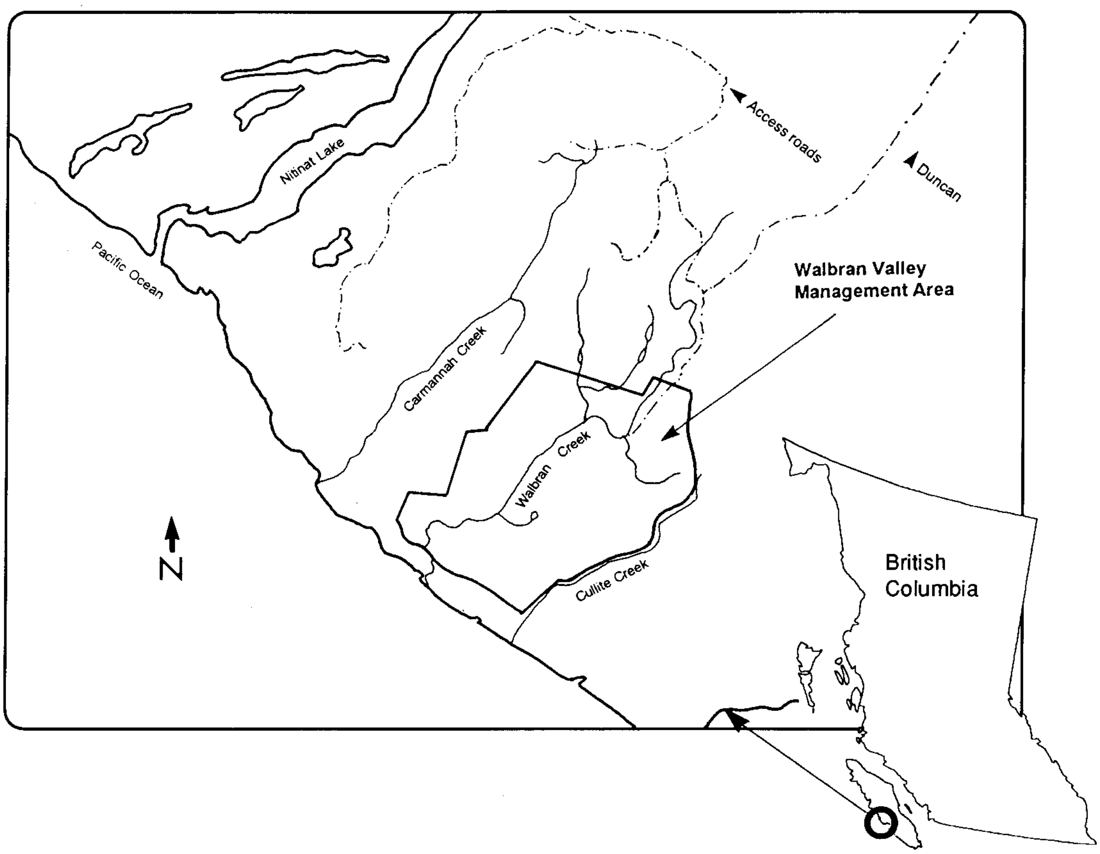

Figure 1. Walbran Valley study area.

[1] Formerly a part of Fletcher Challenge Canada Limited, this division is now part of TimberWest Forest Limited.

FERIC's program of fibre recovery and utilization is supported in part by the Forestry Practices Component of the Canadian Forest Service's Green Plan.

SITE AND SYSTEM DESCRIPTIONS

The site, adjacent to and south of Walbran Creek, is southwest of Lake Cowichan, British Columbia. The Preharvest Silviculture Plan for the entire harvest block reported that the old-growth stand contained 328 trees/ha; had a net cruise volume of 828 m^3/ha; and consisted of 65% Western red cedar, 27% Western hemlock, and 8% Amabilis fir. The study area, at an elevation of 150-200 m, has mostly uniform terrain with concave slopes ranging from 10 to 60%. Non-fish-bearing streams occur throughout the area and feed into Walbran Creek.

The 18-ha study area was divided into three blocks (Figure 2). The first system to be evaluated (A) comprised a Cypress 7280C swing yarder (with a boom height of 21.3 m) rigged as a running skyline with a scab block (scab skyline); two chokers were attached to the butt rigging (Figure 3). The yarder was secured by two guylines. The tailblock was hung 26 m above ground on a delimbed and topped backspar tree. The backspar was secured with five guylines. The yarded logs were windrowed along the road for processing, loading, and hauling after yarding was completed. All wood decked by this system was yarded downhill. The five-person crew consisted of one hooktender, one yarder operator, two choker setters, and one chaser.

The second system studied (B) used the same Cypress 7280C swing yarder as in the first study, but it was equipped with a grapple rather than chokers (Figure 4). Again, the yarder was anchored with two guylines and the yarded stems were windrowed along the roads for future processing, loading, and hauling. Both uphill and downhill grapple-yarding directions were monitored during the study. A Hitachi UH-14 excavator was used as a mobile backspar (Figure 5). The three-man crew consisted of a hooktender (who also ran the mobile backspar), a yarder operator, and a utility person. Processing and loading occurred after yarding was completed, except during a four-day period when the grapple yarder worked along an active main haulroad at which time the loader was required to keep the road open for passing traffic.

An American 7220 cable log loader aligned logs for manual processing and loaded log trucks for both systems.

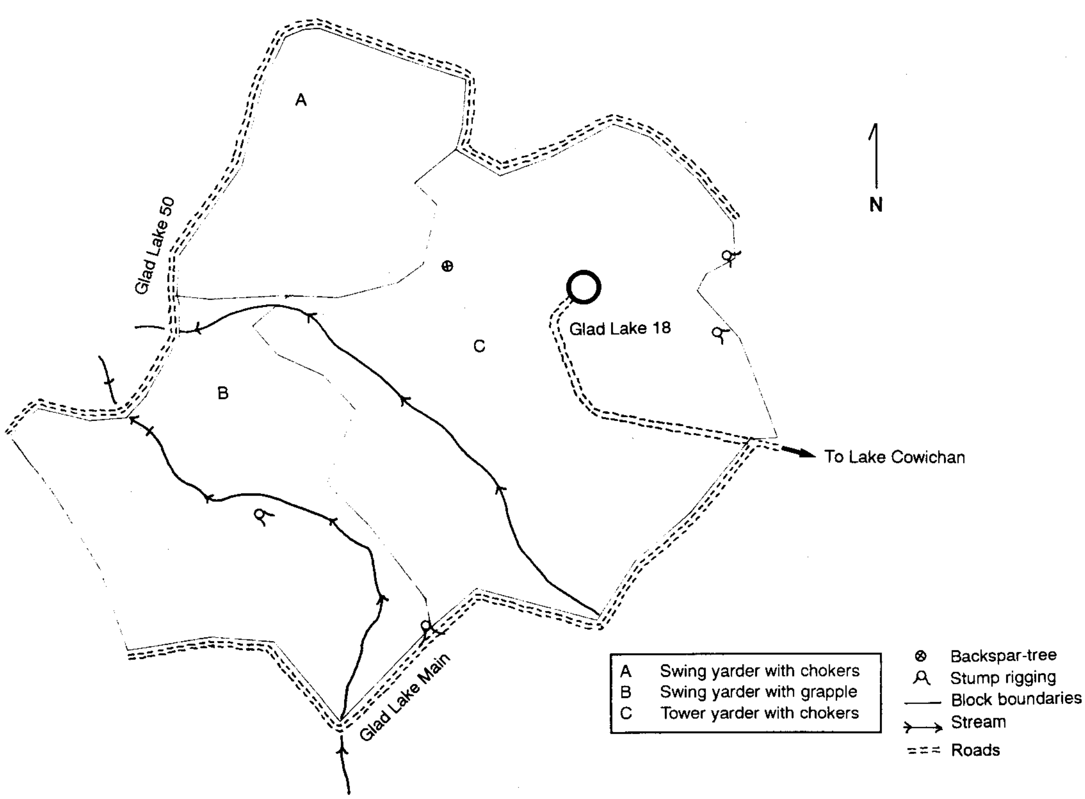

Figure 2. Map of block layout.

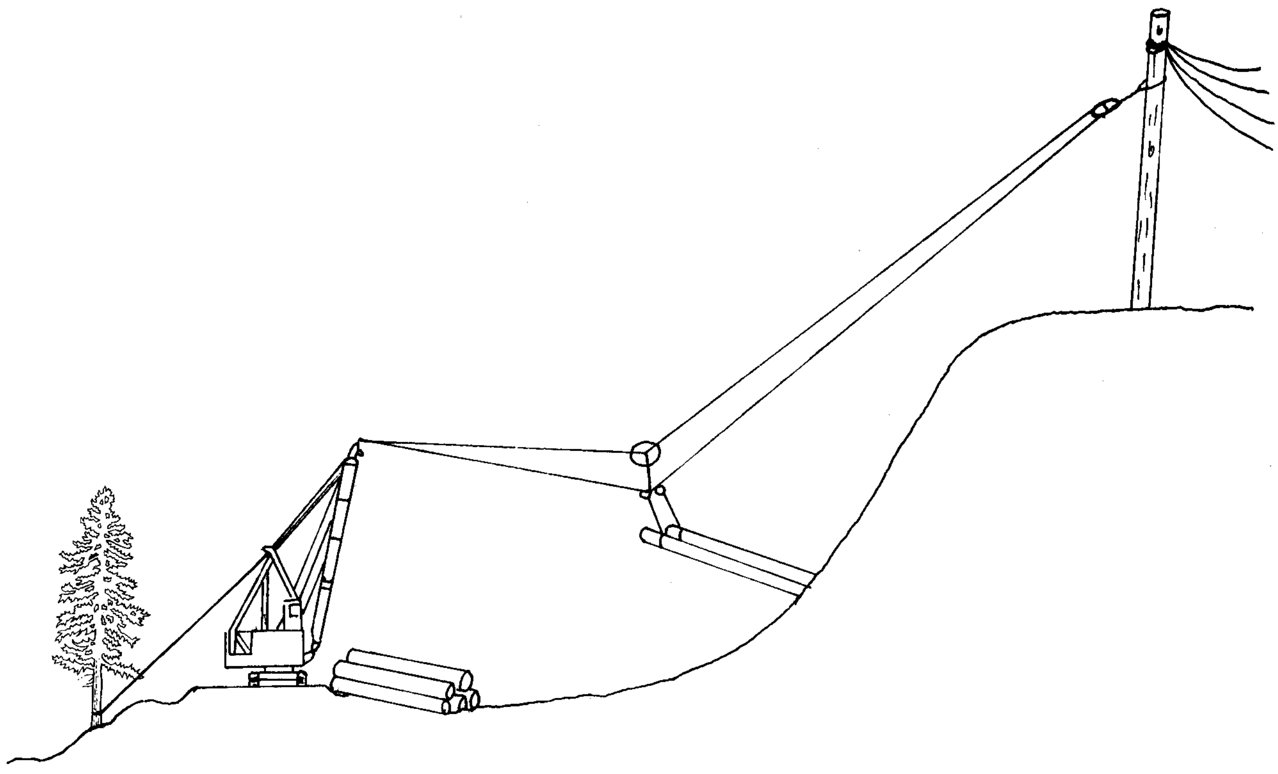

Figure 3. Cypress 7280C swing yarder rigged as a running/scab skyline with chokers.

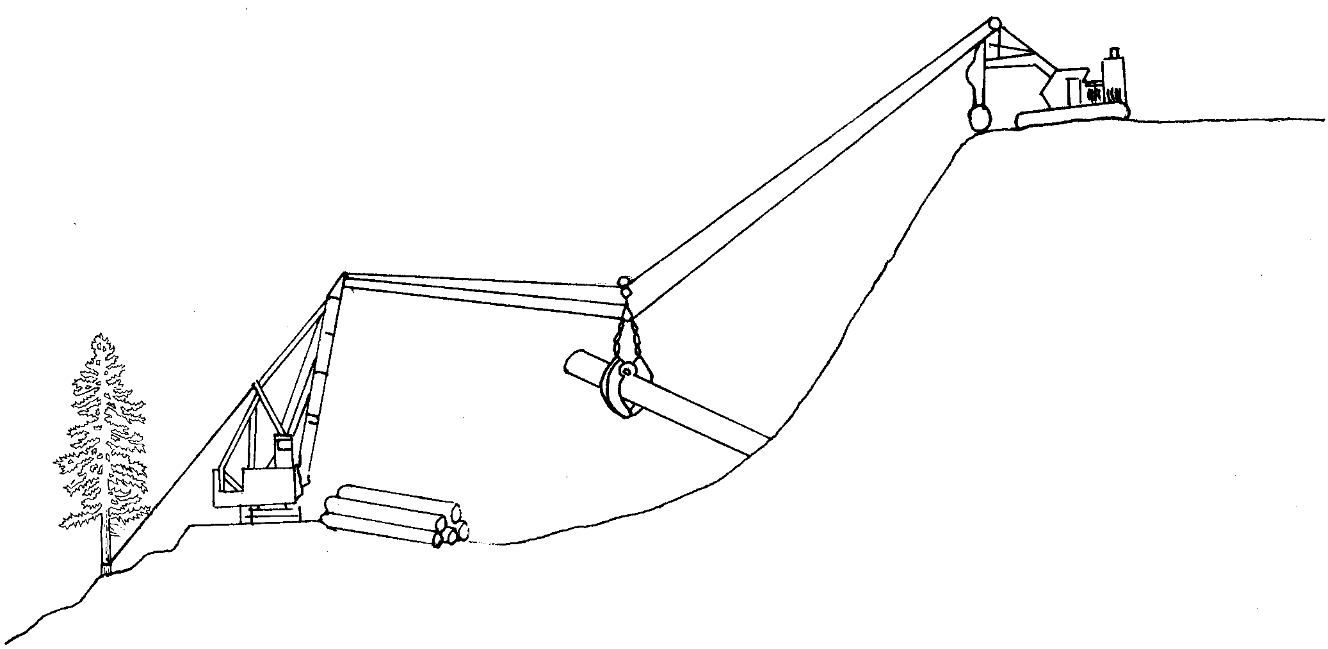

Figure 4. Cypress 7280C swing yarder with grapple.

The third system studied (C) was a Madill 009 highlead yarder with a 27.4-m tower. This machine was also rigged as a running/scab skyline with three chokers hung from the butt rigging (Figure 6). The tower was anchored to stumps by six guylines. All yarded stems were processed and loaded out concurrent with yarding. All wood was yarded uphill by this system. A Hitachi UH-14 excavator functioned as a mobile backspar for most of the area, and on the remainder, standing trees or stumps were used to anchor the running lines. The five-man crew consisted of a hooktender (who also operated the mobile backspar), a yarder operator, two choker setters, and a chaser. A Chapman 1800 hydraulic loader worked continuously with the highlead tower to keep the landing area clear and to load log trucks.

Figure 5. Hitachi UH-14 excavator used as a mobile backspar.

STUDY METHODS

Shift-level data were collected on site by FERIC researchers and from crew reports. These data included yarding time, yarder move and set-up time, backspar moves, loading and delay time ≥10 min. Delays <10 min are included in productive time. System productivity was calculated using log scale volumes provided by FCCL.

Detailed timing, using stop watches and a hand-held data logger, was conducted by FERIC researchers at random intervals during the study period. All delays ≥10 min were removed before data analysis. Time included for yarding road changes or mobile backspar moves ≥10 min was apportioned to the respective systems (i.e. if the total amount of detailed time recorded represented 30% of the total shift level time, then 30% of the road change and backspar moves was included in the detailed time summaries).

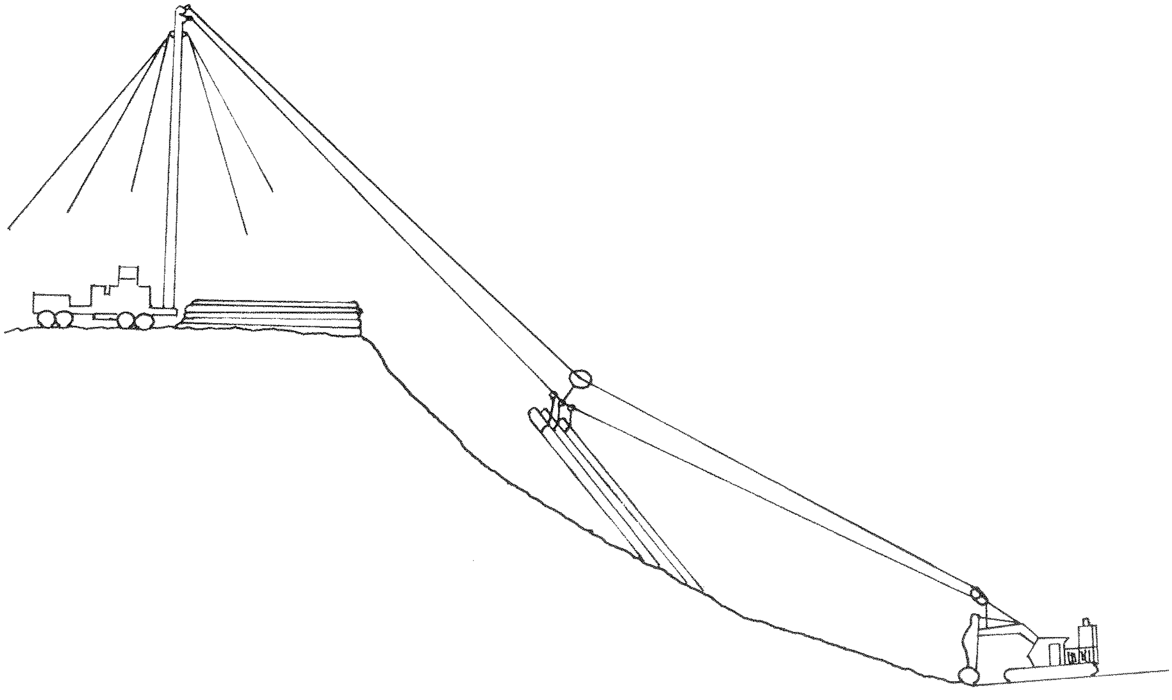

Figure 6. Madill 009 with chokers rigged as a running/scab skyline.

System costs were derived using FERIC's standard machine costing methodology (Appendix I). These costs do not include supervision, profit, or overhead, nor costs related to lost productivity of one or more shifts; the derived costs are not the actual costs of the company.

The site disturbance surveys (BCMOF 1993) were conducted by FERIC personnel after all yarding and loading activities were completed. To determine area occupied by roads and landings, as defined by Krag et al (1993), 29 cross sections at a 59-m spacing were measured on the three roads: Glad Lake Main, Glad Lake 18, and Glad Lake 50. The measurements of road cross sections include: cutbank, ditch, running surface, berm, turnout, and sidecast (Figure 7). No trails were constructed by the mobile backspar. In addition, the landing on Glad Lake 18 was traversed. The site disturbance survey collected data using the grid point intercept system and random bearing (BCMOF 1993). Four 30-m transects were located from each plot centre. Ground disturbance observations were recorded at every metre along the transect (Figure 8). Each yarding study area was treated as a separate unit.

Residue and waste surveys (BCMOF 1991b) were carried out, sampling each block separately. Plots were established to sample roadside slash accumulations, spot slash accumulations (100% scale), and dispersed slash.

FCCL assisted FERIC with the data collection for this survey and the data were compiled by For-Sight Consulting and Training (a division of Holmboe Enterprises Ltd.) of Nanaimo, British Columbia.

To assess fibre quality and yarding damage a sample of randomly selected undamaged logs was marked, then scaled and graded (by a licensed scaler) before yarding and again prior to loading in each of the three study areas.

Figure 8. Sampling along a site disturbance transect.

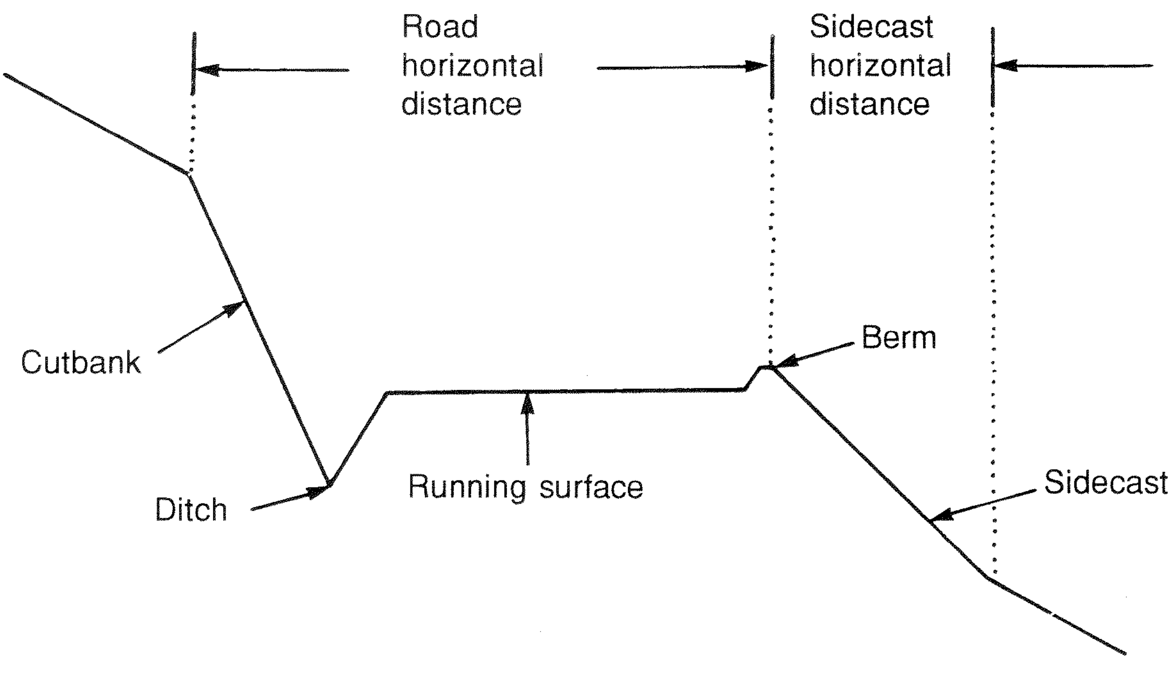

Figure 7. Road profile.

RESULTS

Shift-Level Studies

The percentage of shifts with production, as a portion of total potential shifts (not including weekends, holidays, or closures for fire and snow) ranged from 100% for the swing yarder with grapple to 72% for the swing yarder with chokers (Table 1). The swing yarder using chokers lost two days of production when the roto-coupling was replaced, and three days to repair damage caused by vandals. The tower was shut down for a day to repair the engine torque converter. Machine utilization ranged from 79 to 86%, and mechanical availability from 89 to 92% (Table 2).

The swing yarder with grapple system had the highest productivity at 480 m^3/shift (or 57 m^3/scheduled machine hour (SMH)). The highlead tower system produced 29 m^3/SMH, and the swing yarder with chokers system produced 28 m^3/SMH (Table 2). Some of the higher grapple-yarder productivity is attributable to the operator working through crew breaks (lunch). This is illustrated in Table 3 where the 'Personal' category of delays in the non-mechanical section shows the grapple at 10% of all delay time as compared to 42% and 47% for the other systems.

The proportionately larger amount of time spent by the grapple yarder for mechanical delays was caused by repair to the grapple closing line, which did not exist on either of the choker systems.

Detailed-Timing Studies

The detailed timing of the yarding operations revealed several interesting differences in productivity and operation. The swing yarder with grapple system produced 37.2 pieces/productive machine hour (PMH) (Table 4) which was more than double that of both the tower system (18.2 pieces/PMH) and the swing yarder with choker system (15.9 pieces/PMH). The grapple system appeared to use considerably more time for road changes (19% of total PMH) than either the swing yarder with chokers (11% of total PMH) or the tower with chokers (7% of total PMH) (Table 4). Part of this difference occurred because road changes for the grapple system involved moving both the yarder and the backspar, whereas the two choker systems were stationary at one end during road changes. However, most of the variance was due to the higher yarding productivity of the grapple yarder, which necessitated more frequent road changes. The road change frequency is a function of the log volume associated with the yarding road, which depends upon the volume per hectare and the length and width of the yarding road. When the road change time per cubic metre yarded is calculated (Table 4), the tower yarder is the lowest (0.13 min/m^3) and the swing yarder with chokers is the highest (0.20 min/m^3), while the swing yarder with grapple is intermediate (0.15 min/m^3).

Table 5 shows the average time per turn for each productive cycle for each system. The grapple system had an average cycle time of 1.71 min and the fastest times for all cycle elements. The tower had a slightly faster average cycle time than the swing yarder with chokers (6.39 versus 6.58 min/turn respectively). This difference is mostly attributable to shorter road change and hook-up times for the tower.

Although the grapple system's cycle times were about one quarter those of the choker systems, the actual grap-

Table 1. Potential Shifts: Summary, All Systems

Shifts	Swing yarder with chokers		Swing yarder with grapple		Tower yarder with chokers	
	(no.)	(%)	(no.)	(%)	(no.)	(%)
Shifts with production	13	72	14	100	33	94
Shifts without production [a]						
Mechanical						
Repair coupling	2	11				
Repair vandalism	3	17				
Repair torque converter					1	3
Non-mechanical						
Turn tower 180°					1	3
Total	18	100	14	100	35	100

[a] Does not include weekends.

Table 2. Shift-Level Timing: Summary, All Systems [a]

Description	Swing yarder with chokers		Swing yarder with grapple		Tower yarder with chokers	
	(h)	(%)	(h)	(%)	(h)	(%)
Productive machine hours (PMH)						
Yarding	71.2	69	81.3	69	186.3	74
Move and rig yarder	12.4	12	15.8	13	9.7	4
Move and rig backspar	0.0	0	4.4	4	3.2	1
Subtotal	83.6	81	101.5	86	199.2	79
Mechanical delay hours (MDH) [b]						
Repairs	4.1	4	8.7	7	9.54	
Wait (parts, mechanic)	3.4	3	0.0	0	1.5	1
Service	0.4	0	4.1	4	8.5	3
Subtotal	7.9	7	12.8	11	19.5	8
Non-mechanical delay hours (NDH)						
Operational	11.9	12	3.4	3	32.3	13
Organizational	0.0	0	0.4	0	0.0	0
Subtotal	11.9	12	3.8	3	32.3	13
Scheduled machine hours (SMH)	103.4	100	118.1	100	251.1	100
Utilization (PMH/SMH) (%)	81		86		79	
Mechanical availability (SMH-MDH)/SMH) (%)	92		89		92	
Volume produced (m^3) [c]	2898		6718		7377	
Shifts with production (no.)	13		14		33	
Productivity						
m^3/PMH	34.7		66.2		37.0	
m^3/SMH	28.0		56.9		29.4	
m^3/shift	222.9		479.9		223.5	

[a] Differences due to rounding. [b] Only delays ≥ 10 min included. [c] Net volume delivered to the sort yard.

ple productivity in stems/PMH was only twice that of the choker systems. This is due to the grapple system's tendency to yard single log turns (average of 1.1 stems/turn) compared with the multi-log turns of 1.7 and 1.9 stems/turn averaged by the swing yarder with chokers and the tower with chokers respectively (Table 4).

The detailed analysis of delay times in Table 6 shows that rigging delays (i.e. changing broken chokers, up-ending kinked chokers, and untangling chokers) represented a substantial part of total delay time for the choker machines (37% and 24% respectively for the swing and tower systems). The grapple system and the tower also had numerous delays relating to "yarder and landing", and "other equipment". This time included waiting for the bucker to walk clear of the deck area, and moving the yarder to let trucks pass on the mainline (grapple phase only). Landing delays can be expected when yarding and loading on a mainline, regardless of the system, because those activities must be interrupted to let traffic pass. These delays did not occur with the swing yarder with choker system, which was windrowing on an untravelled spur road.

Loading Productivity

Loading productivity varied considerably between the yarding systems. The cable loader had its highest productivity (72 m^3/SMH) on the block yarded by the swing

Table 3. Shift-Level Delays: Summary, All Systems

Description	Swing yarder with chokers (no.)	(h)	(%)	Swing yarder with grapple (no.)	(h)	(%)	Tower yarder with chokers (no.)	(h)	(%)
Mechanical delays									
Repairs to carrier	2	0.8	4	3	3.4	21	3	5.4	10
Repairs to prime attachment									
Rigging	1	3.2	16	10	5.3	32	4	4.2	8
Wait (parts, mechanic)	2	3.4	17	0	0	0	1	1.5	3
General service	2	0.4	2	7	4.1	25	5	8.5	16
Subtotal	7	7.8	40	20	12.8	78	13	19.6	38
Non-mechanical delays									
Operational									
Personal	13	8.3	42	3	1.7	10	30	24.2	47
Visitors	1	1.6	8	0	0	0	1	0.9	2
Weather	0	0	0	0	0	0	1	0.6	1
Planning	2	0.6	3	1	0.4	2	1	5.3	10
Auxiliary equipment	4	1.4	7	3	1.2	8	1	1.3	3
Organizational									
Wait for other phase	0	0	0	2	0.4	2	0	0	0
Subtotal	20	11.9	60	9	3.7	22	34	32.3	62
Total	27	19.7	100	29	16.5	100	47	51.9	100

Table 4. Detailed Timing: Summary, All Systems

Description	Swing yarder with chokers (min)	(%)	Swing yarder with grapple (min)	(%)	Tower yarder with chokers (min)	(%)
Total yarding time	3015	85	1823	77	7506	87
Total road change time	381	11	454	19	586	7
Total sumtime [a]	15	<1	-	-	-	-
Total delay time (<10 min each)	137	4	94	4	501	6
Total productive time	3548	100	2371	100	8593	100
Total productive machine hours (PMH)	59.1		39.5		143.2	
Total cycles (no.)	540		1381		1346	
Total stems yarded (no.)	938		1470		2609	
Total stems yarded/turn (no.)	1.7		1.1		1.9	
Total stems/PMH (no.)	15.9		37.2		18.2	
Average piece size (m^3) [b]	2.0		2.1		1.7	
Road change (min/m^3)	0.20		0.15		0.13	
Production during detailed timing (m^3)	1867		3043		4409	

[a] Sumtime is the total cycle time when individual elements are missed. [b] From dryland sort scale records.

Table 5. Detailed Timing: Summary of Elements, All Yarding Cycles

Activity	Swing yarder with chokers [a] (min)	(%)	Swing yarder with grapple [b] (min)	(%)	Tower yarder with chokers [c] (min)	(%)
Outhaul	0.26	4	0.25	15	0.33	5
Hookup	3.63	55	0.55	32	3.32	52
Inhaul	0.47	7	0.30	18	0.66	10
Deck	0.30	5	0.22	13	0.29	5
Unhook	0.94	14	-	-	0.98	15
Road change	0.71	11	0.33	19	0.44	7
Delay	0.27	4	0.06	3 [d]	0.37	6
Total cycle time	6.58	100	1.71	100	6.39	100

[a] Average yarding distance 65 m, range 5-195 m. [b] Average yarding distance 79 m, range 5-185 m. [c] Average yarding distance 81 m, range 5-210 m. [d] Differences due to rounding.

Table 6. Detailed Timing: Delay Summary, All Systems

Delays	Swing yarder with chokers (no.)	(min)	(%)	Swing yarder with grapple (no.)	(min)	(%)	Tower yarder with chokers (no.)	(min)	(%)
Mechanical delays									
Rigging	24	51	37	-	-	-	75	122	24
Service	3	25	18	1	10	11	1	2	<1
Non-mechanical delays									
Wait for crew	4	7	5	-	-	-	5	10	2
Plan	4	12	9	2	4	4	8	25	5
Yarder and landing	16	12	9	15	32	34	131	174	35
Other equipment	4	11	8	9	28	30	37	97	20
Miscellaneous	5	19	14	2	20	21	22	71	14
Total	60	137	100	29	94	100	279	501	100

yarder with chokers. In this system, the loader operated independently of the yarder and logs were always available for loading. Cable loader productivity on the swing-yarder-with-grapple block was 56 m³/SMH. Loader productivity with this system was reduced during four of the fifteen shifts, when the loader worked with the yarder to keep the haul road clear (Figure 9). At the highlead tower block, the hydraulic log loader averaged only 28 m³/SMH, again because of an intermittent log supply.

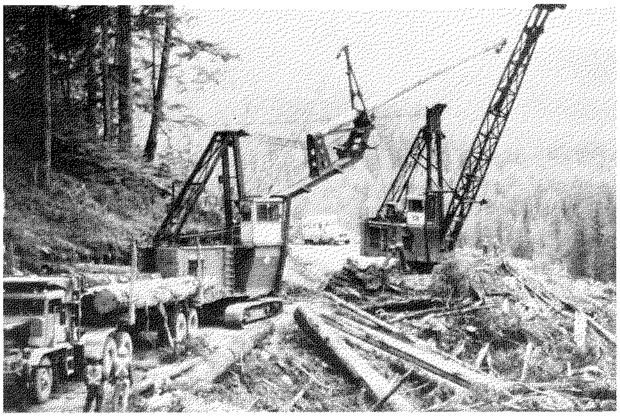

Figure 9. American 7220 cable loader on Glad Lake Main. Cypress 7280C with grapple is shown yarding in background.

System Costs

Production costs were derived using a standard FERIC format (Appendix I). Purchase prices for the yarders and loaders were based on new equipment values; however, the mobile backspar was assessed at its used market value (as supplied by Fletcher Challenge Canada's Surplus Equipment Department). The standing backspar cost included only the rig-up wages for a hooktender and a rigging slinger for one day. As the tree itself was recoverable and the rigging was available as surplus materials, no extra hardware costs were assigned.

The grapple-yarding system cost from stump to truck was \$8.85/m³ (Table 7). The grapple system had the lowest cost due to its much higher productivity, as examined earlier. This cost would have been somewhat lower had the log loader not been required to work four concurrent shifts to keep the road clear. The production costs of the swing yarder/choker system and the tower/choker system were \$14.77 and \$14.92/m³ respectively.

When compared to the swing yarder/choker system, the direct yarding cost was lower for the tower system. However, the extra cost associated with having a loader in attendance full-time resulted in a higher combined cost for yarding and loading for the latter.

Site Disturbance Survey

The results of the site disturbance survey are presented in two parts. Road and landing occupancy reflects development for the whole area, while disturbance on the harvested portions can be used to compare disturbance between specific yarding systems.

Total occupancy of the site by roads and landings was 11.7% by area (Table 8). Only 50% of the area occupied by Glad Lake Main and Glad Lake 50 was used in this calculation because only the timber on one side of these roads was harvested. This site occupancy is simi-

Table 7. Production Costs: Summary, All Systems

	Swing yarder with chokers				Swing yarder with grapple				Tower yarder with chokers			
Phases	SMH (h)	Cost (\$/h) [a]	Total cost (\$)	Cost (\$/m³)	SMH (h)	Cost (\$/h) [a]	Total cost (\$)	Cost (\$/m³)	SMH (h)	Cost (\$/h) [a]	Total cost (\$)	Cost (\$/m³)
Yarding	103.4	334.91	34 630	11.95	118.1	295.21	34 864	5.19	251.1	260.30	65 361	8.86
Backspar rigging	8.0	54.15	433	0.15			0	0.00			0	0.00
Mobile backspar					118.1	11.37	1 343	0.20	251.1	11.37	2 855	0.39
Yarding subtotal			35 063	12.10			36 207	5.39			68 216	9.25
Loading & bucking	40.0	193.45	7 738	2.67	120.0	193.45	23 214	3.46	264.0	158.48	41 839	5.67
Total production costs			42 801	14.77			59 421	8.85			110 055	14.92
Volume harvested (m³) [b]			2 898				6 718			7 377		

[a] Costs are based on FERIC's costing methodology (Appendix I). [b] From shift-level study (Table 2).

Table 8. Site-Disturbance Survey: Summary of Site Occupancy by Roads and Landings

Location	Occupancy (m²)	Factor (%)	Adjusted occupancy (m²)
Glad Lake 18 (including landing)	4 765	100	4 765
Glad Lake Main	16 709	50	8 355
Glad Lake 50	21 008	50	10 504
Total area occupied by roads and landings			23 624
Block area (ha)		17.8	
Total area (ha)		20.2	
Occupancy ratio (roads and landings) (%)		11.7	

lar to the 11.8% reported by Krag et al (1993) for grapple-yarded areas. The authors in that report stress that *total site occupancy is not equivalent to loss of growing site,* as currently defined by the British Columbia Ministry of Forests (BCMOF). Readers should refer to Vancouver Forest Region's Guidelines for preparing Preharvest Silviculture Prescriptions (BCMOF 1991a, 1992), and to the Regional Soil Conservation Committee for current definitions of loss of growing site.

The summary of disturbance on the harvested areas is shown in Table 9. The "undisturbed" observations ranged from 70 to 83% for the three systems and there was little difference in soil surface condition after yarding. Total off-road soil disturbance ranged from 17% for the swing yarder with chokers to 23% for the swing yarder with grapple. In all cases, most of the disturbance was confined to the litter and duff layers. Exposed mineral soil amounted to 5% or less in all cases, and gouges extending deeper than 15 cm into mineral soil made up only 1-2% of the observations for all three systems.

Residue and Waste Survey

A residue and waste survey was conducted on each block following harvesting to determine the volume and characteristics of the unrecovered fibre remaining on the treatment areas. The British Columbia Ministry of Forests' definitions of residue and waste are quoted in Appendix II. Both of these classifications are further subdivided into 'avoidable' and 'unavoidable' categories (also quoted in Appendix II). 'Billable waste' is avoidable and is subject to monetary as well as cut control charges.

Table 10 summarizes the results of the residue and waste surveys conducted on the study areas following harvest. Total residue and waste for the two choker systems was 78 m^3/ha, and 111 m^3/ha for the grapple system. The billable waste portion represents 4, 6, and 7% of the total volume harvested by the swing yarder with chokers, grapple yarder, and the tower respectively. The volume of cedar 'X'-grade logs tallied (19-36 m^3/ha) was billable for stumpage effective July 1, 1993; however, because harvesting finished on March 3, 1993, this volume is not included in the billable waste volumes reported here.

Quality of Fibre Recovered[2]

A sample of 694 sound logs (bucked both ends) was scaled and graded before and after yarding in the three study areas. Only 16 logs (2%) incurred yarding damage that resulted in a volume loss and/or a grade reduction. Broken ends, splits, and partial slabbing were the most common sources of damage. Crushing or penetration damage from either chokers or the grapple was not observed as a problem. Table 11 illustrates the volume and value losses as a percentage of the volume and values for the entire sample, and relates these to yarding system. The grapple-yarding system caused a loss of 0.8% in value, followed by the swing yarder with chokers with 1.1%, and the tower with 1.6%. Comparing the volume and value losses for the two choker systems identified less volume loss for the tower, but higher value loss. This is the result of a degrade of one damaged high-value cedar log. The tower presents a greater potential for causing log damage because it cannot swing a turn around stumps and other obstructions during inhaul.

Table 9. Site-Disturbance Survey: Summary of Disturbance on Harvested Area, All Systems

Type of disturbance	Swing yarder with chokers Observations (no.)	(%)	Swing yarder with grapple Observations (no.)	(%)	Tower yarder with chokers Observations (no.)	(%)
Undisturbed	591	83	786	70	1511	80
Disturbed organic, <15 cm	91	13	201	18	310	16
Disturbed organic, >15 cm	16	2	3	<1	18	1
Disturbed mineral, <15 cm	9	1	37	3	41	2
Disturbed mineral, >15 cm	4	1	17	2	10	1
Other (stream bed)	-	-	72	7	-	-
Total	711	100	1116	100	1890	100

[2] Robert D. Copithorne, BSF, 1993, "Effect of Yarding Operations on Log Recovery Value", unpublished thesis submitted in partial fulfilment of the requirements for the Degree of Master of Forestry to the Department of Forestry at the University of British Columbia.

Table 10. Residue and Waste Survey: Summary, All Systems

Description	Swing yarder with chokers	Swing yarder with grapple	Tower yarder with chokers
Residue and waste categories			
Sawlog component (m^3/ha)	13.6	35.9	24.3
Grade 'X' logs (cedar) (m^3/ha)	35.8	35.2	19.0
Grade 'X' logs (other) (m^3/ha)	8.2	9.3	12.2
Other [a] (m^3/ha)	19.8	30.4	22.4
Total (m^3/ha)	77.4	110.8	77.9
Billable waste (m^3/ha)	38.2	72.7	51.3
Total volume harvested (m^3)	2898	6718	7377
System area (ha)	3.2	5.4	9.4
Overall treatment net volume (m^3/ha) [b]	944	1317	836
Billable waste as a proportion of total volume harvested (%)	4	6	7

[a] Bucking waste and high stumps. [b] Derived through combining scale volume with residue survey billable waste volume.

Table 11. Fibre Quality Assessment

System	Volume lost (%)	Value lost (%)
Swing yarder with chokers	1.1	1.1
Swing yarder with grapple	0.9	0.8
Tower yarder with chokers	0.4	1.6

When these damage levels are converted to dollar values based on the sample volumes and open market log values (December 1992), a \$1.94/m^3 loss results for the tower. The grapple yarder had the lowest value loss at \$1.05/m^3. As this loss is a "Cost of Doing Business" that adds up to a total cost (yarding and loading plus value loss) of \$15.68/m^3 for the tower (Table 12). The swing yarder using chokers comes in at \$14.91/m^3, and the grapple yarder at \$8.96/m^3. From another perspective, this increased cost due to breakage represents an average of 11% of total yarding and loading costs for the three systems.

OBSERVATIONS AND DISCUSSION

This section presents observations made by research personnel on site during the study, and further comments on the results of data analysis:

- It was impossible to place a choker around some large cedar windfalls or stems that had sunk into the ground after felling. In some cases the windfalls were left for shake and shingle cutters, or the rigging crew attempted to turn the log around and raise it off the ground. During the process of trying to swing a log, it was partially choked around the butt, and some slabbing resulted when the choker bit into the log end. In general, the grapple handled the large pieces that were partially buried in the ground (windfall) more easily than did the choker systems.

- Hangups during inhaul could be avoided with the swing yarders because the yarder could swing the boom to redirect log inhaul. However, the tower was stationary and chokers were broken on a number of occasions when inhaul hangups occurred. Sometimes the mobile backspar had to be moved to free a hangup by pulling from a different direction.

- Slab recovery from larger cedar that had shattered on impact after felling seemed to be more successful with the grapple yarder. The yarder was able to suspend these pieces when bringing them to the deck.

- The net volumes per hectare available for each harvesting system, as shown in Table 10, are substantially different. The area harvested by the grapple yarder had 1317m^3/ha compared to 944 m^3/ha and 836 m^3/ha for the swing yarder/choker and tower/choker systems respectively. This, in combination with a slightly higher average piece size of 2.1 m^3

Table 12. Log Damage Costs: Summary, All Systems

Description	Swing yarder with chokers	Swing yarder with grapple	Tower yarder with chokers
Total volume scaled (m^3)	816.3	1284.1	1119.4
Total volume lost to damage (m^3)	8.9	12.0	4.8
Value loss from damage ($)	1 253.00	1 351.02	2 176.00
Value loss from total scale [a] ($/m^3$)	1.53	1.05	1.94
Production cost ($/m^3$)	14.77	8.85	14.92
Total production cost ($/m^3$)	16.30	9.90	16.86

[a] This 'total scale' represents only those logs scaled for studying the quality of fibre recovered.

(compared to 1.7 m^3 and 2.0 m^3) and the system's ability to yard 3.7 to 3.8 turns to the others' one turn, result in a considerable production advantage for the grapple system. These factors also contribute to the cost advantage (approximately 40%, loaded on a truck) determined for the grapple yarding system in comparison to the others.

- With the current trend toward using smaller cutblocks in old-growth timber it should be remembered that the economies of scale will be lost (i.e. it is generally less expensive to harvest a large area than a small one). Thus, the swing yarder/grapple system with its high productivity, mobility, and windrowing capability (reduced landing occupancy) will be the system of choice where topography permits. Choker systems will be more appropriate on areas with poor visibility or long yarding (>250 m).

- The use of self-releasing chokers may reduce turn time for the choker systems as well as improve safety when windrowing. There was a considerable component of productive time used to deck and align logs for the chaser to release the chokers safely. Much of this time could be reduced with self-releasing chokers. A chaser/utility person would still be required to assist with road changes and to repair/replace broken chokers.

CONCLUSIONS

Beginning in 1991, FERIC monitored three common Coastal cable-yarding systems operating on an 18-ha study area of old-growth forest in the Walbran Valley on Vancouver Island, British Columbia. The study objective was to compare the performance of the three systems with respect to productivities and costs, quality of logs recovered, levels of site disturbance, and amount and quality of post-harvest residue. Field observations were concluded in March of 1993.

Table 13 summarizes the performance of the three systems studied. The swing yarder with grapple system had the highest productivity and machine utilization, and the lowest production costs and value loss due to log damage. However the two choker systems had less waste, residue, and site disturbance than the grapple system. The use of a mobile backspar with two of the systems did not noticeably increase site disturbance. Road and landing occupancy was average for grapple-yarded areas on the Coast and did not include any constructed backspar trails.

Large, partially buried cedar windfalls were often left by the choker systems for subsequent recovery by shake cutters because the chokers could not be passed under the logs. When attempts were made to move these logs by attaching chokers across their end faces, slabbing frequently resulted. With the grapple system, however, the legs of the grapple could be positioned carefully to lift and move these buried cedar windfalls with minimal damage.

The grapple yarder recorded a higher volume/ha, larger average piece size, and considerably faster turn times, which resulted in a cost advantage of 40% for the wood loaded on a truck.

With the current trend towards smaller harvest openings in old-growth forests, the relative economics of grapple yarding will become more attractive.

RECOMMENDATIONS

Future studies of harvesting systems working in old growth timber should be directed towards identifying causes of yarding breakage and methods of reducing it, as well as methods of reducing residue and waste, and site occupancy of roads and landings.

Table 13. Performance and Costs: Summary, All Systems

	Swing yarder with chokers	Swing yarder with grapple	Tower yarder with chokers
Yarding			
Performance (m^3/SMH)	28.0	56.9	29.4
Cost ($/$m^3$)	12.10	5.39	9.25
Loading			
Performance (m^3/SMH)	72.4	56.0	27.9
Cost ($/$m^3$)	2.67	3.46	5.67
Value loss from damage ($/$m^3$)	1.53	1.05	1.94
Total production cost ($/$m^3$)	16.30	9.90	16.86
Utilization (%)	81	86	79
Site disturbance [a] (%)	1	2	1
Residue and waste (m^3/ha)	78	111	78

[a] Disturbed mineral soil to depths >15 cm.

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APPENDIX I

Machine Costs

	Cypress 7280C swing yarder, chokers	Cypress 7280C swing yarder, grapple	Madill 009 highlead tower	Hitachi excavator backspar (used)	Cypress 7230 cable loader [a]	Cypress 1825C hydraulic loader [b]
OWNERSHIP COSTS						
Total purchase price (P) [c] $	1 228 462	1 235 896	706 899	25 000	883 000	650 000
Expected life (Y) y	12	12	12	5	12	12
Expected life (H) h	17 280	17 280	17 280	7 200	17 280	17 280
Scheduled hours per year (h)=(H/Y) h	1 440	1 440	1 440	1 440	1 440	1 440
Salvage value as % of P (s) %	30	30	30	30	30	30
Interest rate (Int) %	5.5	5.5	5.5	5.5	5.5	5.5
Insurance rate (Ins) %	2.0	2.0	2.0	2.0	2.0	2.0
Salvage value (S)=((P•s/100) $	368 539	370 769	212 070	7 500	264 900	195 000
Average investment (AVI)=((P+S)/2) $	798 500	803 332	459 484	16 250	573 950	422 500
Loss in resale value ((P-S)/H) $/h	49.76	50.07	28.64	2.43	35.77	26.33
Interest ((Int•AVI)/h) $/h	30.50	30.68	17.55	0.62	21.92	16.14
Insurance ((Ins•AVI)/h) $/h	11.09	11.16	6.38	0.23	7.97	5.87
Total ownership costs (OW) $/h	91.35	91.91	52.57	3.28	65.66	48.34
OPERATING COSTS						
Wire rope (wc) $	23 169	23 169	24 581		6 000	
Wire rope life (wh) h	1 800	950	1 800		1 440	
Rigging and radio (rc) $	5 096	12 727	10 318			
Rigging and radio life (rh) h	5 700	5 700	5 700			
Fuel consumption (F) L/h	46.0	55.0	36.0	10.0	37.0	37.0
Fuel (fc) $/L	0.42	0.42	0.42	0.42	0.42	0.42
Lube and oil as % of fuel (fp) %	10	10	10	10	10	10
Annual operating supplies [d] (Oc) $	14 256		14 256			
Annual repair and maintenance [e] (Rp) $	100 000	100 000	56 000	5 000	73 583	54 167
Shift length (sl) h	8.0	8.0	8.0	8.0	8.0	8.0
Wages [f] $/h						
Operator	21.12	21.12	19.38		19.94	19.94
Hooktender	21.12	21.12	21.12			
Choker setters (2)	35.52		35.52			
Utility person		18.37				
Chaser	17.94		17.94			
Bucker					21.12	21.12
Total wages (W) $/h	95.70	60.61	93.96		41.06	41.06
Wage benefit loading (WBL) %	35	35	35		35	35

...continued

	Cypress 7280C swing yarder chokers	Cypress 7280C swing yarder grapple	Madill 009 highlead tower	Hitachi excavator backspar (used)	Cypress 7230 cable loader [a]	Cypress 1825C hydraulic loader [b]
Wire rope (wc/wh) $/h	12.87	24.39	13.66		4.17	
Rigging and radio (rc/rh) $/h	0.89	2.23	1.81			
Fuel (F•fc) $/h	19.32	23.10	15.12	4.20	15.54	15.54
Lube and oil ((fp/100)•(F•fc)) $/h	1.93	2.31	1.51	0.42	1.55	1.55
Operating supplies (Oc/h) $/h	9.90		9.90			
Repair and maintenance (Rp/h) $/h	69.44	69.44	38.89	3.47	51.10	37.62
Wages amd benefits (W•(1+WBL/100)) $/h	129.20	81.82	126.85		55.43	55.43
Total operating costs (OP) $/h	243.56	203.30	207.73	8.09	127.79	110.14
TOTAL OWNERSHIP AND OPERATING COSTS [g] (OW+OP) $/h	334.91	295.20	260.30	11.37	193.45	158.48

[a] The machine in the study was a model 7220, but it has been superceded by the model 7230.

[b] The Chapman 1800 is no longer manufactured, therefore a Cypress 1825C is used in costing.

[c] Purchase price of backspar based on used market value. Purchase price of other equipment based on new units.

[d] Operating supplies for choker-yarding systems include the cost of chokers.

[e] Annual costs for repairs and maintenance were provided by the contractor, equipment suppliers, or company. Or, annual costs for repairs and maintenance were established.

[f] IWA, Coastal Wage Scale, effective June 15, 1992.

[g] 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 company.

APPENDIX II

Definition of Terms for Residue and Waste Survey (BCMOF 1991b)

Timber Utilization Policy

Waste is the volume of timber left on the cutting authority area that should have been utilized in accordance with the timber utilization standards specified in the cutting authority. Waste volumes that are 'avoidable' or 'unavoidable' are subject to cut control charges.

Residue is the volume of timber left on the cutting authority area that meets the size (or dimension) requirements but does not meet the quality (or log grade) requirements of the timber that must be utilized in accordance with the timber utilization standards specified in the cutting authority. Residue volumes that are 'avoidable, or 'unavoidable' are subject to cut control charges.

Avoidable and Unavoidable

Both Residue and Waste are classified as either *avoidable* or *unavoidable.*

- Unavoidable volumes are those which cannot be removed because of physical impediments, for safety considerations, for environmental reasons, or for other reasons beyond the control of the licensee.
- By definition, all other volumes are avoidable.
- Avoidable waste volumes are billed monetarily as well as for cut control.
- Unavoidable waste and both avoidable and unavoidable residue volumes are charged for cut control purposes only.

These definitions are quoted from the *Provincial Logging and Waste Measurement Procedures* manual (1991b).