WOOD HARVESTING

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FERIC

HARVESTING COASTAL SECOND-GROWTH FORESTS: TWO CASE STUDIES

TN232

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Abstract

In the winter and spring of 1993, the Forest Engineering Research Institute of Canada (FERIC) monitored two harvesting operations working in Coastal second-growth forests on Vancouver Island in British Columbia. The operations included mechanical and manual felling, and timber extraction with combinations of hydraulic log loaders (excavator-forwarders), long-boom loaders (super snorkels), and grapple yarders. FERIC measured machine productivities, identified factors that influenced machine performance, and conducted post-harvest site assessments.

Introduction

The change from harvesting old-growth to second-growth stands is presenting new operational challenges for the forest industry in Coastal British Columbia. The general consensus is that if old-growth harvesting methods are used in second-growth forests, harvesting costs will be higher than when the same methods are used in old growth. However, the smaller tree size of second-growth timber allows harvest planners to choose from a variety of mechanized harvesting systems, which could lead to reduced costs. Choosing appropriate systems for harvesting second-growth stands is presently difficult because little information exists concerning related costs and productivities. More information is also needed on grades and values of logs produced from second-growth stands.

In the fall of 1991, the Forest Engineering Research Institute of Canada (FERIC) and the Faculty of Forestry at the University of British Columbia initiated a four-year cooperative project to evaluate harvesting systems for clearcutting Coastal second-growth sites in British Columbia. Funding for the project was obtained through the Canadian Forest Service under the Canada/British Columbia Forest Resource Development Agreement (FRDA II). The overall objectives of the project are to develop productivity and cost prediction models for common harvesting systems operating in second-growth stands; and to develop a prediction model of harvested volumes by grade based on pre-harvest cruise data.

In the initial phase of the project, FERIC identified the characteristics of Coastal second-growth stands, surveyed current harvesting methods, summarized existing research of second-growth harvesting methods, and identified areas where additional data are required (Jukes 1992). The survey indicated that additional information should be obtained about harvesting systems utilizing mechanical felling, forwarding with hydraulic and long-boom loaders, mechanical processing at the stump or at roadside landings, and cable yarding. As a result, a two-year field study program was initiated to collect cost and productivity data on these harvesting systems operating in different types of second-growth stands.

This report, which is the first in a series, presents the results from the two case studies conducted in Year 1 of the field study program that took place near Union

Keywords: Harvesting, Old growth, Second growth, Felling, Manual method, Mechanical method, Processing, Excavator-forwarders, Loaders, Long-boom loaders, Grapple yarders, Productivity, Costs, Performance, Post-harvest site assessment, Coastal British Columbia, ACL 771B Feller-Buncher, John Deere 992D Loader, Hitachi EX400 Loader, Madill 075 Long-Boom Loader

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Bay and Holberg on Vancouver Island (Figure 1). The Union Bay study was done in cooperation with the Northwest Bay Division of MacMillan Bloedel Limited[1]; a feller-buncher and two hydraulic log loaders (excavator-forwarders [2]) were monitored. The Holberg study was done in cooperation with the Holberg Division of Western Forest Products Limited; manual falling and timber extraction with combinations of hydraulic log loaders and long-boom loaders (super snorkels), and grapple yarders were monitored.

The objectives of the case studies were to record machine operating procedures; determine machine productivity and operating cost; identify factors influencing machine performance; and conduct assessments of post-harvest slash[3], soil disturbance, and soil compaction.

Site Descriptions

The site at Union Bay consisted of two adjacent cutblocks (BB 302 and BB 305) (Table 1) of 80-year old timber that had regenerated naturally following clear-cut logging. A light sanitation thinning, in which suppressed and dead trees were removed, had been done about 20 years earlier. The predominant species was Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) with a minor component of western red cedar (*Thuja plicata* Donn) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). Gross merchantable volume of the two cutblocks averaged 614 and 583 m^3/ha, respectively. Both cutblocks had a park-like appearance with only small amounts of woody debris on the ground. Cutblock BB 302 had a gentle slope between 5 and 15%, while BB 305 was mostly flat, except for a small gully at one corner of the block.

The Holberg site (SS 611) (Table 1) was a mixed stand of western hemlock and amabilis fir (*Abies amabilis* (Dougl.) Forbes) that regenerated following a severe wind storm in 1908, but contained some large hemlock veterans from its pre-storm era. Gross stand volume averaged 1300 m^3/ha. The ground had a hump and hollow appearance, and contained a large amount of woody material. Slopes ranged from 0 to 30%.

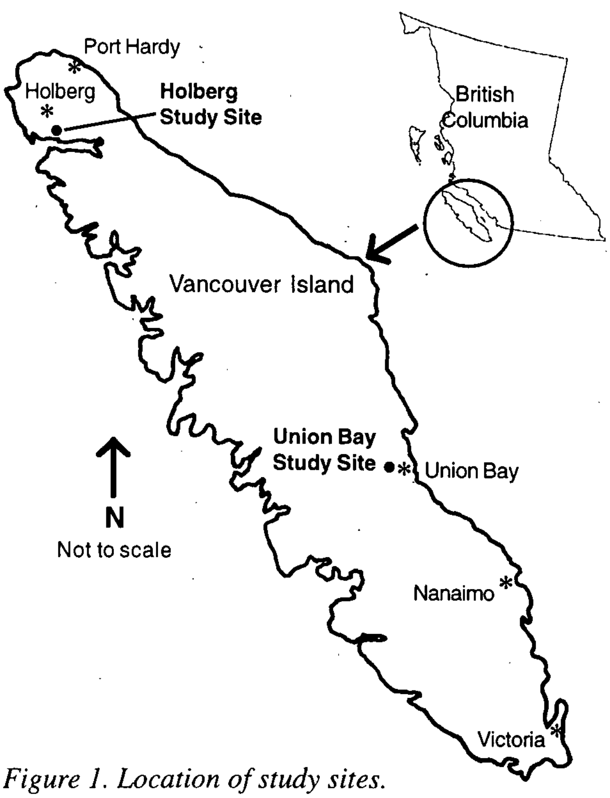

Figure 1. Location of study sites.

System Descriptions

Union Bay Operation. The harvesting operation at Union Bay consisted of three phases: mechanical felling with an ACL 771B feller-buncher[4] (Figure 2); extraction of full-tree stems with two hydraulic log loaders, a John Deere 992D and a Hitachi EX400; and combined roadside log manufacturing and loading using hydraulic log loaders and two buckers per loader.

Table 1. Average Stand Characteristics

	Union Bay		Holberg
	BB 302	BB 305	SS 611
Cutblock size (ha)	33.6	19.0	15.0
Merchantable trees [a]			
Species composition[b]	Df_9Cw_1	$Df_8Hw_1Cw_1$	Ba_5Hw_5
Tree dbh (cm)	38	32	41
Total height (m)	30	26	38
Trees/ha (no.)	418	525	500
Merchantable volume [c]			
m^3/tree	1.47	1.11	2.60
m^3/ha	614	583	1300

[a] Dbh at Union Bay: Df,Hw,Ba >13 cm; Cw >16 cm, Dbh at Holberg: all conifers >17 cm. [b] Species distribution based on total net volume; e.g. Df_9Cw_1=Douglas fir 90%, cedar 10%.
[c] Gross merchantable volume; no deduction for decay, breakage, or other fibre losses.

[1] Now South Island Woodlands Division.
[2] Excavator-forwarder and excavator-forwarding denote the use of hydraulic log loaders to extract stems from the felling site to the roadside. It is also sometimes referred to as "hoe-forwarding", or shovel logging.
[3] Fibre recovery and post-harvest wood waste analyses were conducted as a sub-project; results will appear in a separate report.

[4] The ACL 771B is a 'one-of-a-kind' feller-buncher, custom designed and built for Coastal conditions by Antler Creek Logging Company of Port Alberni, British Columbia.

The feller-buncher started felling along a cutblock boundary. Stems were bunched at right angles to the machine's felling pass, with butts aligned and facing the haul road. Along the boundary, the stems were bunched in standing timber, while in subsequent felling passes the stems were bunched between the bunches from previous felling passes.

The excavator-forwarders extracted the full-tree stems to roadside using the up-and-down working pattern (Figure 3). The machine first moved from roadside to the cutblock boundary (out-turn), relocating the stems from in front of the machine to alongside the path. At the end of the out-turn, the loader swung around and gradually forwarded the stems within boom reach towards the roadside decking area (in-turn). The favourable terrain conditions of the site allowed stems to be decked along the entire section of the haul road. In Cutblock BB 302 the stems were forwarded downhill.

Figure 2. ACL 771B feller-buncher operating at Union Bay.

The decked stems at roadside were manually delimbed, bucked into preferred log lengths (13.1 m), and roughly sorted before being loaded onto highway log trucks and delivered to the company sort yard. The mechanical felling phase was conducted on a double-shift basis, while other phases worked day shifts only. Scheduled shift time for all phases ranged between 8 and 8.5 h/shift, and included start-up time, personal breaks[5], and machine maintenance. Some machine maintenance was also done outside scheduled shift time. During the study, a new feller-buncher operator was being trained during the day shifts. FERIC estimated that the trainee operated the machine 5 and 20% of its working time in Cutblocks BB 302 and BB 305 respectively.

Holberg Operation. The trees at the Holberg site were manually felled along the contour of the site and generally not aligned to the forwarding direction. Stems with diameter at breast height (dbh) greater than 60 cm, (approximately 4% of the trees in the stand), were bucked into logs 13.1- or 20.1-m long at the stump area. Falling and timber extraction were done during

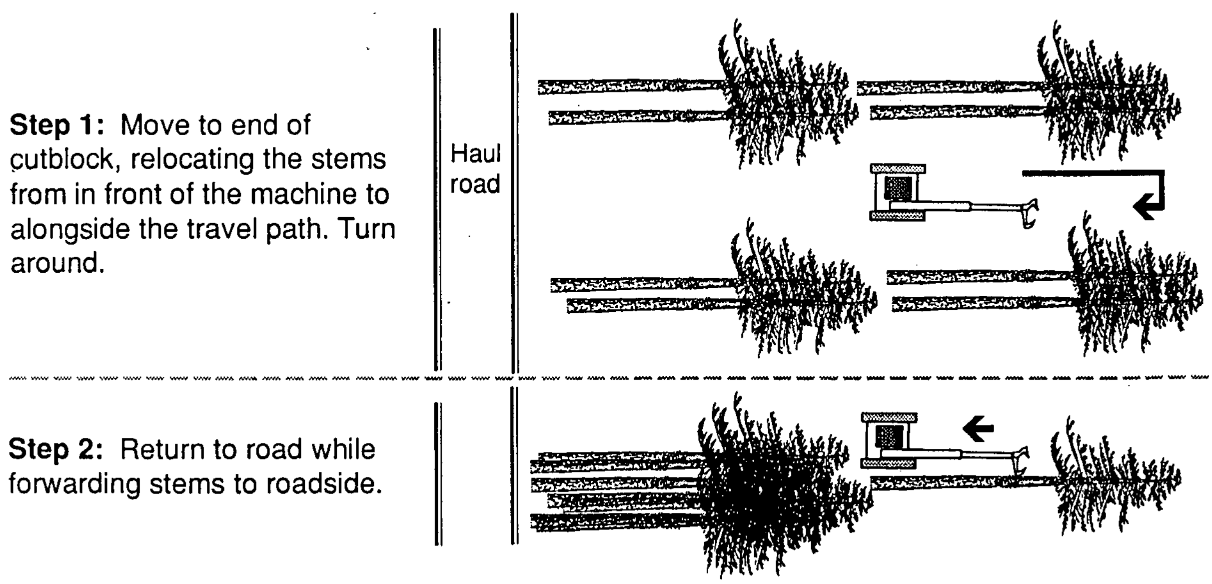

Figure 3. Up-and-down working pattern in excavator-forwarder operations.

[5] Includes meal breaks for machine operators, who normally took breaks <20 min, but excludes meal breaks of buckers, who took regular 30-min lunch breaks.

two periods. In the summer of 1992, a 50-m wide strip along the haul road was felled, and most of the stems were extracted with a Madill 075 super snorkel equipped with a 45-m long boom extension (Figure 4). The remaining timber was felled during the following fall/winter, and extracted during February/March 1993 using a Madill 075 super snorkel, a Madill 044 grapple yarding crane working with a Caterpillar 235 mobile back spar, and a John Deere 992D hydraulic log loader (Figure 5). The John Deere 992D loader was also used to semi-bunch and align the stems such that butts were facing the haul road (excavator-aligning) in part of the area prior to grapple yarding and super snorkelling.

The John Deere 992D loader used the serpentine working pattern during its forwarding and aligning operations (Figure 6). In the excavator-forwarding operation, the loader began forwarding along the back boundary, decking the stems in a continuous windrow with butts or tops facing the haul road. When it reached the side boundary, it moved one pass (about 50 m) towards the road, and began to forward the previous windrow towards the roadside decking area. The loader was not allowed to travel directly on the forest floor, therefore a corduroyed trail was constructed from woody debris and later removed. The loader was also the first machine to enter the cutover area, so its ini-

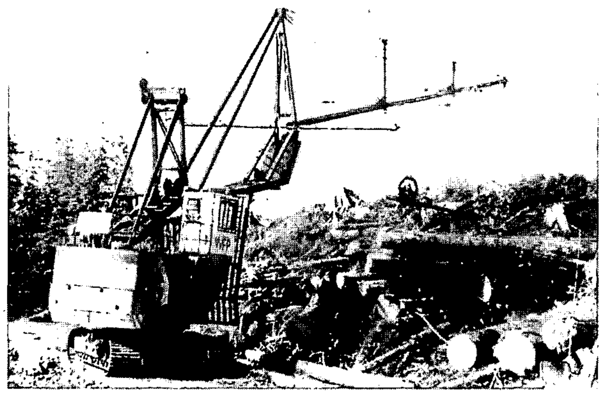

Figure 4. Madill 075 super snorkel at Holberg.

Figure 5. John Deere 992D loader being used as an excavator-forwarder at Holberg.

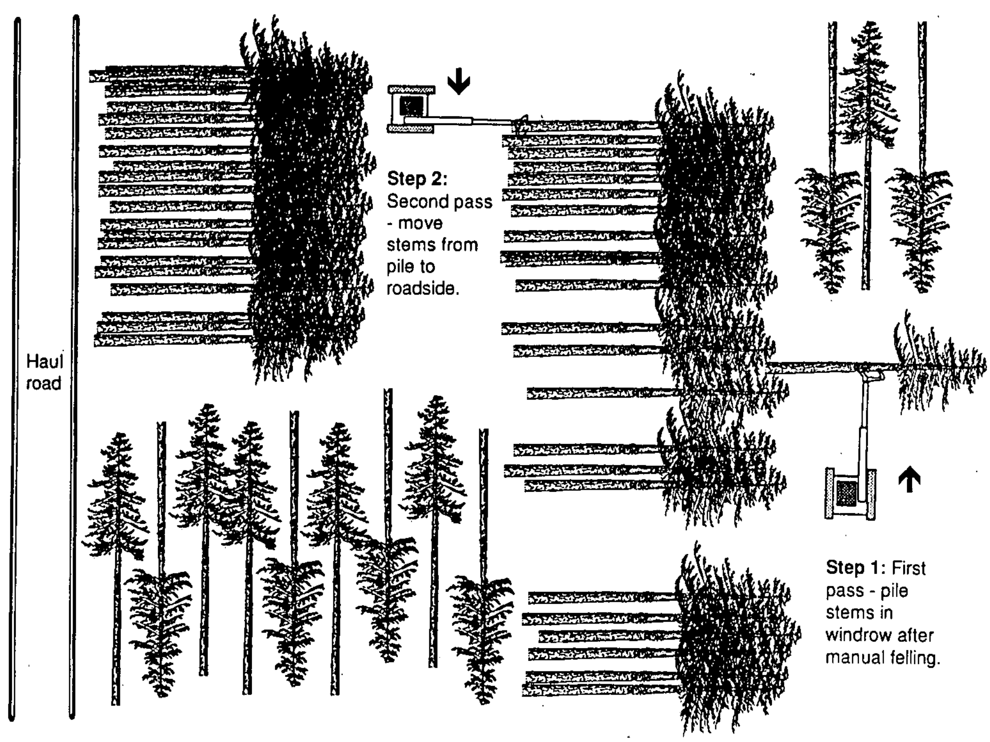

Figure 6. Serpentine working pattern in excavator-forwarder operation.

tial task was to make a corduroyed access trail into the cutblock that also served as the backspar trail in the grapple yarding operation. The access trail was reclaimed following completion of the extraction phase.

The stems at roadside were loaded onto off-highway trucks with either a John Deere 992D loader or a Washington TL6F line loader, and delivered to the company's log dump. Each loader was assisted by a bucker, who removed branches, and trimmed broken ends.

Study Methods

Prior to the falling operations, FERIC cruised each study block using 200-m^2 fixed area sample plots, located in a grid pattern 100-m apart. Species and dbh were recorded for all trees in the plots, and tree heights were recorded for a selected number of trees in each plot. The data were used to determine pre-harvest stand volumes and to develop local volume tables.

Data on machine performance were collected using shift-level and detailed-timing techniques. DSR Servis recorders were used to record shift-level data on the equipment in the feller-buncher, excavator-forwarder, and super snorkel operations, while daily time sheets provided information on the manual falling and grapple yarding operations. However, the duration of the shift-level studies on the machines at Holberg was too short to provide reliable data on work element distribution and machine utilization. Consequently, some of this information has been omitted in this report.

Detailed-timing studies were used to determine machine productivity of the feller-buncher, excavator-forwarders, super snorkel, and grapple yarder. Each detailed-timing study recorded operating conditions; distribution of work elements, and number of stems recovered, discarded, or broken; the type and size of stems recovered; and conditions created for subsequent phases.

Two different means were used to report machine productivity. Average net productivity in each study block was calculated using data on operating machine hours (OMH) that was recorded by the Servis recorders, and delivered production (loaded-out) volumes obtained from the cooperating companies. The net productivity is a measure of individual machine performance as well as overall efficiency and level of fibre recovery of the whole operation. Gross machine productivity was calculated from data on productive machine hours (PMH) and gross merchantable volume recorded in the detailed-timing studies. The two methods produce different numerical results, because gross merchantable volume does not account for fibre losses from stem defects or breakage occurring in subsequent operations, and in log conversion. OMH also differs from PMH in that OMH includes an unknown amount of machine travel (e.g. for maintenance, fuelling, and change of work sites) that cannot be separated from productive time with the Servis recorders used. In addition, OMH includes minor delays <15 min/occurrence, while, *in this study,* PMH does not include any delays.

Hourly machine costs were calculated using FERIC'S standard costing method (Appendix I), and do not necessarily reflect the actual operating costs incurred by the owners of the machines in the study.

Post-harvest site assessments of slash and soil disturbance were done using the line intercept method (Sutherland 1986). The plots were located in a grid pattern, 70-m apart. Soil disturbance was defined as occurrences of exposed mineral soil, and depressions or gouges in the organic layer >15 cm in depth., regardless of the area disturbed.[6] Soil compaction data were collected with a Campbell Pacific Nuclear Moisture/Density Gauge (densiometer). Four samples, two on undisturbed ground, and two on exposed mineral soil with clear indications of soil compaction and/or gouging, were taken near each plot. The soil compaction sample points were usually selected for their visual severity and therefore may not be representative of all soil disturbance occurrences recorded by the survey.

Results

Felling Operations. The net productivity of the fallers in the manual felling operation at Holberg was 36.7 m^3/productive hour[7], or 210 m^3/shift (6.5 h). Estimated falling cost[8] was $1.73/m^3.

The net productivity of the ACL 771B feller-buncher was 122.4 and 95.1 m^3/OMH in Cutblocks BB 302 and BB 305 respectively. The felling cost was calculated to be $1.69 and $2.17/m^3 (Table 2). The lower productivity on BB 305 is attributed to the lower volume/tree in this block compared to BB 302. The lower productivity of day-shift operations is attributed to operator training, and reserving the areas with better operating conditions for night shifts. The operator training also reduced the machine utilization; hence, the

[6] The soil disturbance data were collected prior to the enactment of the British Columbia Forest Practices Code, and do not reflect current Code standards.

[7] Productive hours for the fallers included time spent brushing, cutting, bucking, walking between trees, and fueling and filing chain saws. Nonproductive hours included time spent on saw maintenance, visitors, safety meetings, and lost time due to adverse weather conditions.

[8] Daily falling and bucking rate $254.08 (IWA), 35% fringe benefits, and $20/day chain saw allowance.

Table 2. Summary of Shift-Level Study: ACL 771B Feller-Buncher

	Cutblock BB 302		Cutblock BB 305	
	Day	Night	Day	Night
Shifts (no.)	15	13	10	9
Average time per shift				
Scheduled (h)	8.2	8.2	8.0	7.9
Operating (h)	6.8	5.6	6.5	4.8
Active repair (h)	0.2	1.4	0.4	0.6
Wait repair (h)	0.4	0.4	0.0	1.5
Service (h)	0.5	0.7	0.9	0.3
Non-mechanical delay (h)	0.3	0.1	0.2	0.7
Machine utilization (%)	83	68	81	61
Trainee's time (% of OMH)[a]	5	0	20	0
Net machine productivity				
Trees/OMH (no.)[b]	83	105	58	99
Volume/OMH (m^3)	122.4		95.1	
Felling cost ($/$m^3$)	1.69		2.17	

[a] Estimated time that trainee operated machine alone, but excludes other instruction time. [b] From operators' daily tree count.

machine performance portrayed by the shift-level data does not reflect the production capability of this machine.

Detailed-timing studies of the feller-buncher (with experienced operators) recorded gross machine productivities ranging from 98.6 to 185.8 m^3/PMH (Table 3). Most trees were felled and bunched individually, and the felling cycle time was found to be relatively independent of tree size. Consequently, differences in the average merchantable volume per tree was the primary reason for the variation in machine productivity.

The felled stems in the feller-buncher operation were well aligned in bunches, averaging 5 to 8 m^3/bunch, with all butts facing the haul road. In the detailed-timing studies, fewer than 1% of the merchantable stems were recorded as being broken in the feller-bunching operation. The low level of breakage is attributed to this feller-buncher's ability to control the falling speed and the placement of the stems during bunching.

Excavator-Aligning Operation. At Holberg, FERIC monitored an excavator-aligning operation in a 4-ha block. The John Deere 992D loader completed the operation in 21.2 OMH, during which time it travelled 800 m in a serpentine pattern. Average net productivity was 98.8 m^3/OMH, and estimated aligning cost was $1.98/$m^3$ (Table 4).

Gross productivity determined from detailed timing data was 67 pieces/PMH or 96.5 m^3 (Table 5). The data showed that 57% of the machine's productive time was spent on aligning stems (handle wood), and 29% on corduroying the travel path (prepare path).

Excavator-Forwarding Operations. Excavator-forwarding productivity determined from shift level data was considerably higher at the Union Bay site than that at Holberg; at Union Bay, the excavator-forwarders averaged 69.0 m^3/OMH at an estimated cost of $2.84/$m^3$, while at Holberg average productivity and cost were 42.1 m^3/OMH and $4.66/$m^3$, respectively (Table 4). This difference in productivity is attributed mainly to the bunching and stem aligning conditions created by the feller-buncher and the better ground conditions at Union Bay. However, variation in productivity within the two study locations show that other factors also affect productivity. The results from the detailed-timing studies gave some insight to the potential factors influencing excavator-forwarder productivity.

Piece size, length, orientation, and concentration of wood all appeared to have influenced the excavator-forwarder performance using the serpentine working pattern in manually felled wood at Holberg. Productivity increased initially with each additional pass due

Table 3. Summary of Detailed-Timing Studies: ACL 771B Feller-Buncher

	Study number					
	FB 1	FB 2	FB 3	FB 4	FB 5	FB 6
Observed time (h)	2.8	2.2	2.5	2.0	1.2	1.0
Merchantable trees						
Tree dbh (cm)	40	36	42	37	31	30
Tree volume (m^3/tree)	1.66	1.21	1.77	1.40	0.88	0.77
Trees/ha (no.)	400	590	310	550	550	510
Stand volume (m^3/ha)	664	714	549	770	484	393
Duration of work elements						
Fell & bunch (min/tree)	0.46	0.43	0.46	0.37	0.40	0.33
Move (min/tree)	0.13	0.08	0.10	0.07	0.07	0.07
Fell-to-waste (min/tree)	0.06	0.01	0.01	0.01	0.03	0.06
Other work (min/tree)	0.03	0.02	<0.01	<0.01	0.01	0.01
Total productive time (min/tree)[a]	0.68	0.54	0.57	0.45	0.51	0.47
Minor delay (min/tree)	0.01	0.02	0.01	<0.01	0.13	0.00
Total observed time (min/tree)	0.69	0.56	0.58	0.45	0.64	0.47
Gross machine productivity						
Trees/PMH (no.)	87	111	105	132	118	128
Volume/PMH (m^3)	144.4	134.3	185.8	184.8	103.8	98.6
Average trees/cycle (no.)	1.09	1.05	1.10	1.30	1.11	2.03

[a] Differences due to rounding.

Table 4. Summary of Shift-Level Studies: Excavator-Aligning and Excavator-Forwarding

	Union Bay			Holberg	
	Forwarding				
	BB 302	BB 305	Total [a]	Aligning	Forwarding
Shifts (no.)	43	18 [b]	61	3	10
Average time per shift					
Scheduled (h)	8.1	7.5	7.9	8.0	8.0
Operating (h)	6.7	6.2	6.5	7.1	7.2
Repair [c] (h)	0.7	0.6	0.7	0.4	0.2
Service (h)	0.3	0.3	0.3	0.3	0.3
Non-mechanical delay (h)	0.4	0.4	0.4	0.2	0.3
Machine utilization (%)	83	83	83	89	
Net machine productivity					
Pieces/OMH [d] (no.)	44	43	44	n.a.	n.a.
Volume/OMH (m^3)	74.6	54.5	69.0	98.8	42.1
Volume/shift (m^3)	500	338	448	701	303
Extraction/aligning cost (\$/m^3)	2.63	3.60	2.84	1.98	4.66

[a] Differences due to rounding. [b] Only about 60% of the wood extracted was monitored by FERIC. [c] Includes wait-for-repair time. [d] Based on operators' daily tree count. Union Bay operation only.

Table 5. Summary of Detailed-Timing Studies: Excavator-Aligning and Excavator-Forwarding Operations at Holberg

	Excavator-aligning	Excavator-forwarding				
		Pass 1[a]	Pass 2	Pass 3[b]	Pass 4	All passes
Observed time (h)	9.2	6.8	3.0	5.2	2.6	17.6
Average piece size (m^3/piece)	1.44	n.a.	n.a.	n.a.	n.a.	2.07
Duration of work elements						
Handle wood (min/piece)	0.51	0.57	0.46	0.56	0.62	1.38
Move (min/piece)	0.06	0.01	0.02	0.01	0.03	0.04
Prepare path (min/piece)	0.26	0.12	0.09	0.07	0.01	0.20
Other work (min/piece)	0.06	0.02	0.01	0.02	0.03	0.05
Total productive time (min/piece)[c]	0.89	0.73	0.58	0.65	0.68	1.67
Minor delay (min/piece)	0.04	0.05	0.05	0.05	0.05	0.13
Total observed time (min/piece)	0.93	0.79	0.63	0.71	0.73	1.80
Gross machine productivity						
Pieces/PMH (no.)	67	82[d]	104[d]	92[d]	88[d]	36
Volume/PMH (m^3)	96.5	n.a.	n.a.	n.a.	n.a.	74.4
Pieces handled/100-m distance						
Total pieces (no.)	171	444	707	951	915	n.a.
Full-length stems (%)	62	51	45	n.a.	35	n.a.
Manufactured logs (%)	12	19	15	n.a.	17	n.a.
Broken stems (%)	26	30	40	n.a.	48	n.a.

[a] Not a 'true' first pass; main and back trails already in place. [b] 2/3 of stems placed at roadside, 1/3 required a fourth pass. [c] Differences due to rounding. [d] Not true productivity, but a measure of the rate that stems were moved in each pass.

to the gradual increase in the concentration of windrowed stems (Table 5). However, in the final passes (i.e. when stems were placed at roadside) the productivity decreased because stems had to be decked at roadside with their butts facing the road. As a result, many stems had to be rotated 180° prior to decking, which increased the handling time per stem.

Data in Table 5 show that the number of broken stems increased with each pass, indicating that a certain amount of breakage occurred during the excavator-forwarding operation. However, most broken pieces were later recovered by the loader. The distribution of full-length stems, logs, and broken stems in Pass 1 and 'Excavator-aligning' is attributed to the manual falling operation.

Observations suggested that as the stem length increased, the distance between the passes in the serpentine pattern increased, and the number of passes required to forward the stems to roadside decreased. However, with a mixture of long and short pieces, typical of manual felling and bucking, the loader was not able to take advantage of the longer stems to maximize the distance between passes, because the short stems were out of reach of the grapple.

Gross productivity of the excavator-forwarders using the up-and-down pattern (Union Bay) ranged between 73.0 and 116.1 m^3/PMH (Table 6). While FERIC could not fully explain the wide range of the recorded machine productivities, productivity tended to increase with an increase in wood concentration (i.e. a combination of stem density and average stem size and boom reach). However, too much wood accumulated around the machine can reduce machine productivity because of insufficient space to deck the wood. This occurred in study EF 7 when the machine ran out of space for placing the stems along the trail at approximately 70 m from the roadside, and therefore had to forward the wood to roadside in two stages.

FERIC also examined the impact of forwarding distance on productivity for excavator-forwarders using the up and down working pattern. The results showed that the forwarding distance had little effect on productivity; an increase in the extraction distance from 50 to 200 m decreased productivity from 78 to 71 stems/PMH, or about 9% (Figure 7). The reason is that the amount of wood brought to roadside by the excavator-forwarders in each turn increases in direct proportion to the forwarding distance. Therefore, the increase in out-turn

Table 6. Summary of Detailed-Timing Studies: Excavator-Forwarding at Union Bay

	Study number						
	EF 1	EF 2	EF 3	EF 4	EF 5	EF 6	EF 7
Observed time (h)	2.1	5.0	3.9	2.8	2.8	2.9	5.1
Average operating conditions							
Merchantable stem dbh (cm)	42	40	38	42	46	40	35
Volume/stem (m^3)	1.71	1.66	1.44	2.32	2.19	1.50	1.13
Maximum forwarding distance (m)[a]	200	210	200	180	180	200	210
Duration of work elements							
Handle wood (min/stem)	0.83	1.13	0.92	1.32	0.96	0.97	0.74
Move (min/stem)	0.17	0.16	0.09	0.22	0.14	0.21	0.10
Prepare path (min/stem)	0.02	0.04	0.00	0.13	0.02	0.04	0.05
Other work (min/stem)	0.03	0.02	0.00	0.04	0.01	0.01	0.01
Total productive (min/stem)[b]	1.05	1.36	1.01	1.72	1.13	1.23	0.90
Minor delay (min/stem)	0.02	0.12	0.00	0.10	0.00	0.05	0.06
Total observed (min/stem)	1.07	1.47	1.01	1.82	1.13	1.28	0.96
Gross machine productivity							
Stems/PMH (no.)	57	44	60	35	53	49	67
Volume/PMH (m^3)	97.5	73.0	86.4	81.2	116.1	73.5	75.7

[a] Distance from roadside deck to end of out-turn. [b] Differences due to rounding.

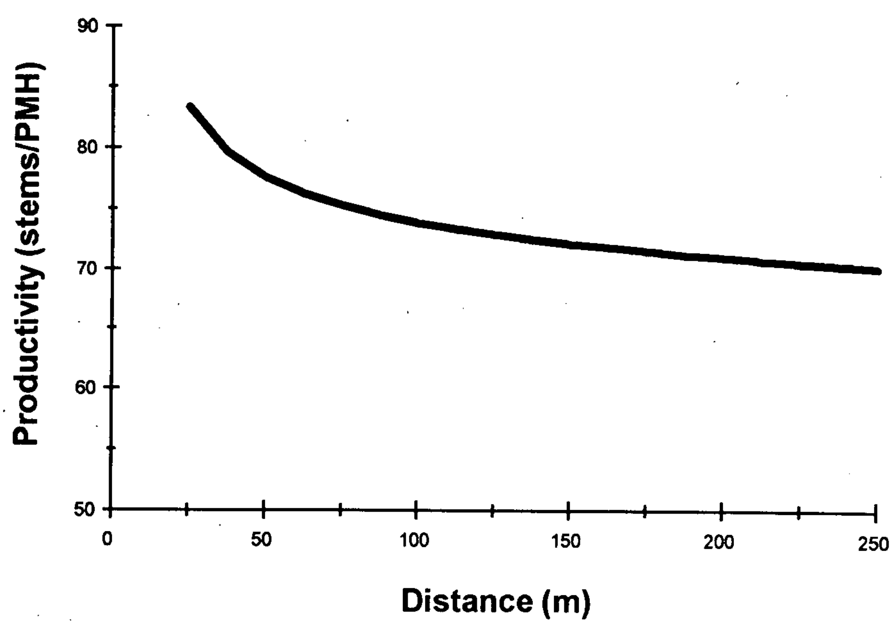

Figure 7. Excavator-forwarder productivity as a function of forwarding distance.

and in-turn times with increased forwarding distance is offset by the increase in the amount of wood brought to roadside in each turn.

Super Snorkel Operation. The Madill 075 super snorkel downhill yarded 4894 m^3 of aligned and as-felled wood in 32.2 OMH, resulting in an average net productivity of 152.0 m^3/OMH at an estimated yarding cost of $1.70/m^3. High road banks and wide ditches reduced the effective reach of the super snorkel to a strip about 25 m in width. Occasionally, the high road banks also obstructed visibility for the operator, making it more difficult to grapple the felled stems. In addition, the machine had to move frequently to minimize interfering with the log-hauling operation. Consequently, the productivity of the super snorkel on the study site was likely lower than its potential.

Detailed-timing studies (Table 7) showed that super snorkel productivity was 68% higher in aligned wood than in as-felled wood, primarily because the machine was able to yard more pieces per turn with the higher concentration of aligned wood.

Table 7. Summary of Detailed-Timing Studies: Super Snorkel

	As-felled	Aligned
	SS 1	SS 2
Observed time (h)	3.4	2.8
Operating conditions		
Average piece size (m^3)	1.90	1.88
Yarding distance [a]		
Average (m)	32	28
Range (m)	12-45	15-40
Duration of work elements		
Yard (min/piece)	0.48	0.29
Move (min/piece)	0.05	0.02
Other work (min/piece)	0.01	0.01
Total productive time [b] (min/piece)	0.55	0.33
Gross machine productivity		
Pieces/PMH (no.)	111	187
Volume/PMH (m^3)	210.9	351.6
Average pieces/turn (no.)	1.10	1.50

[a] Measured from centre of machine to point of grapple pick-up. [b] Differences due to rounding.

Grapple Yarder. The total net production of the grapple yarder was 4225 and 851 m^3 in aligned and as-felled wood, and the yarding operation was completed in 55 and 13 OMH respectively. Thus, the grapple yarder averaged 76.8 m^3/OMH in aligned wood at a calculated cost of $5.82/m^3, and averaged 65.5 m^3/OMH in as-felled wood at a cost of $6.82/m^3. The results may not fully reflect the benefits of aligning the stems prior to grapple yarding because of longer yarding distance and smaller piece sizes in the aligned block. In addition, the orientation of the stems in the as-felled block was better than average for the cutblock.

In the detailed-timing study of the grapple yarder working in excavator-aligned wood, the machine averaged 122.4 m^3/PMH at an average yarding distance of 70 m (Table 8).

Post-Harvest Site Assessment. All harvesting activities and soil distribution surveys were conducted on the study blocks prior to the British Columbia Forest Practices Code being enacted, and thus the results of these surveys should not be considered in the context of the new Code. However, Table 9 summarizes the soil disturbance results in approximation of the speci-

Table 8. Summary of Detailed-Timing Study: Grapple Yarding of Aligned Wood

Observed time (h)	6.1
Average operating conditions	
Piece size (m^3)	1.44
Yarding distance (m)	70
Yarding direction	downhill
Slope (%)	15
Duration of work elements	
Grapple out (min/piece)	0.17
Load (min/piece)	0.16
Grapple in (min/piece)	0.21
Deck (min/piece)	0.04
Aborted turns (min/piece)	<0.01
Move (min/piece)	0.11
Total productive time (min/piece) [a]	0.70
Minor delay (min/piece)	0.03
Total observed time (min/piece)	0.73
Gross machine productivity	
Pieces/PMH (no.)	85
Volume/PMH (m^3)	122.4
Average pieces/turn (no.)	1.58

[a] Differences due to rounding.

fications outlined under "Appendix 3 - Soil Disturbance Categories" in the *Forest Practices Code of British Columbia, Site Preparation Guidebook* (BCMOF 1995). Between 7% and 20% of the total harvested area showed some degree of disturbance. However, FERIC believes that the majority of the recorded disturbance would not constitute soil degradation; much of the disturbance at the feller-buncher site (Union Bay) resulted from single-pass machine travel, while dragging logs and path preparation/reclamation created most of the disturbance on the stem-aligned grapple yarder and excavator-forwarder sites at Holberg, respectively. Only the area with multiple-pass travel, such as the back spar trail at Holberg (also used by the excavator-forwarder to access the cutblock) and some frequently travelled areas near the haul road at Union Bay would be of concern for soil degradation.

Average soil density of the visually most disturbed areas near the base plots was higher than that of the undisturbed areas for all harvesting systems, but was not significantly different (at the 95% level of confidence) on the stem-aligned grapple yarder site (Table 10). However, not all soil disturbance showed evidence of increased soil density, nor could a statistical correlation be established between the depth of soil disturbance and the increase in soil density. Proportionally, the highest increase in soil density occurred in the excavator-forwarder block at Holberg, even though precautions had been taken by corduroying the machine path. Because the initial soil bulk density at Holberg was considerably lower than at Union Bay, and more susceptible to compaction, a direct comparison of the impact between feller-buncher/excavator-forwarder and manual fell/excavator-forwarder harvesting systems cannot be made. One explanation to the difference in bulk density increase between stem-aligned and excavator-forwarder areas at Holberg is that during excavator-forwarding the loader handles more wood from the same setup, thereby compacting the ground (through bouncing movements) more than during excavator-aligning, where relatively few stems are handled per machine location.

Discussion

Table 11 shows a cost summary by harvesting system based on shift-level data and loaded-out volumes. Because the costs are derived from machine productivities established under different stand conditions and yarding distances, a direct comparison of the costs cannot be made.

In addition, ground-based machines, such as the feller-bunchers and excavator-forwarders, are more limited in their application by stand and terrain conditions than are manual felling and cable-yarding systems (including super snorkel), and may therefore not be an option in stands with large trees or steep or wet terrain. Nevertheless, the results from these case studies do provide some indication of the relative cost difference between the systems.

Mechanical felling compares favourably to manual felling in terms of cost, when the smaller tree size on the Union Bay sites and the impact of operator training are taken into account. However, the main advantages of mechanical felling are the favourable conditions created for the subsequent extracting operation, and the reduction in wood breakage. This results in lower extraction costs and a better opportunity to

Table 9. Summary of Soil Disturbance Assessment, by Harvesting System

	Union Bay	Holberg	
Soil disturbance category	FB,EF [a] (% of block)	MF,EA,GY [a] (% of block)	MF,EF [a] (% of block)
Disturbance			
Organic layer >15-cm depth	1.7	10.1	10.5
Exposed mineral soil	5.6	9.6	8.9
Total	7.3	19.7	19.4
Undisturbed	89.5	65.2	59.4
Slash covered	1.2	11.5	16.0
Other (stump, rocks, etc.)	2.0	3.6	5.2
Total	100	100	100

[a] FB = feller-buncher, EF = excavator-forwarder, MF = manual felling, EA = excavator align with loader, GY = grapple yarder.

Table 10. Summary of Bulk Density Assessment on Disturbed and Undisturbed Sites

	0-10 cm depths		0-20 cm depths	
	Undisturbed	Disturbed	Undisturbed	Disturbed
Union Bay: Feller-buncher/excavator-forwarder operation				
Sample size (no.)	48	48	48	48
Average bulk density (g/cm³)	1.25	1.37 [a]	1.33	1.44 [a]
Standard deviation (g/cm³)	0.16	0.22	0.15	0.22
Holberg: Manual fell/excavator-align/grapple yarder operation				
Sample size (no.)	25	27	25	26
Average bulk density (g/cm³)	0.70	0.77	0.73	0.79
Standard deviation (g/cm³)	0.17	0.13	0.17	0.15
Holberg: Manual fell/excavator-forwarder operation				
Sample size (no.)	25	27	25	26
Average bulk density (g/cm³)	0.71	0.82 [a]	0.74	0.85 [a]
Standard deviation (g/cm³)	0.12	0.15	0.13	0.15

[a] Disturbed and undisturbed sites statistically different @ 95% level of confidence.

Table 11. Summary of Harvesting Costs to Roadside, by System

	Harvesting system				
Phases	FB,EF [a]	MF,EA,GY [a]	MF,GY [a]	MF,EF [a]	MF,SS [a] and MF,EA,SS [a]
Felling ($/m³)	1.84 [b]	1.73	1.73	1.73	1.73
Aligning ($/m³)	n.a.	1.98	n.a.	n.a.	0.99 [c]
Extraction ($/m³)	2.84	5.82	6.82	4.66	1.70
Total cost ($/m³)	4.68	9.53	8.55	6.39	4.42

[a] FB = feller-buncher, EA = excavator align with loader, EF = excavator-forwarder, MF = manual felling, GY = grapple yarder, SS = super snorkel. [b] Weighted average of cost in BB 302 and BB 305 (Table 2). [c] Assumes 50% of wood is excavator-aligned.

maximize log value during the bucking operation.

Mechanical felling was the primary reason that the excavator-forwarding cost at the Union Bay site was less than that at the Holberg site, even after considering the 10% additional cost for corduroyed trails at Holberg. Different working patterns (i.e. up-and-down versus serpentine) are not believed to have been a factor in the cost difference.

FERIC's data indicate that, compared to grapple yarding as-felled stems, excavator-aligning stems prior to grapple yarding does not reduce overall system costs. However, the shorter average yarding distance, as well as the relatively uniform orientation of stems in the as-felled area, make comparison of these operating practices difficult. Also, approximately $0.40/m³ of the pre-aligning cost was attributed to trail preparation, which may not be required on sites that have better ground conditions.

Excavator-forwarding and excavator-aligning costs can also be reduced by about 24% by double-shifting the machines (as derived in Appendix I). Western Forest Products Ltd. at Holberg has successfully double-shifted excavator-forwarding operations in the past when site conditions were favourable.[9]

Conclusions

As the amount of Coastal second-growth harvesting increases, forest planners will require accurate information about harvesting costs and machine productiv-

[9] Bernard Clarke, Woods Manager, Western Forests Products Ltd.; personal communication, February 1993.

ity in these stands. The case studies at Union Bay and Holberg are part of a 4-year FERIC and UBC project to develop cost and productivity models for harvesting systems working in second-growth stands.

The case studies show that mechanical felling with feller-bunchers is a more cost-effective alternative to manual felling in stands where feller-bunchers can operate, primarily because it reduces wood breakage and improves the alignment of stems to reduce subsequent extraction costs.

Excavator-forwarding with hydraulic loaders is an attractive alternative to grapple yarding and super snorkelling when terrain conditions are suitable. Excavator-forwarder productivity is influenced primarily by the concentration of wood, and to a lesser extent by forwarding distance. The reason for the latter is that the volume of wood decked at roadside by the excavator-forwarder increases in direct proportion to the length of the forwarding pass. However, too much wood accumulated around the machine will adversely affect machine productivity because of lack of decking space; this situation appears more likely to occur in the up-and-down working pattern than in the serpentine pattern.

The use of loaders to align wood prior to grapple yarding improved the productivity of the grapple yarder 65.5 to 76.8 m^3/OMH. However, the corresponding reduction in yarding cost (from \$6.82 to \$5.82/m^3) was not sufficient to offset the additional cost of excavator-aligning (\$1.98/m^3).

Between 7 and 20% of the harvested area showed some degree of soil disturbance. Machine tracks were the main cause of site disturbance on the feller-buncher site, while dragging logs and trail preparation/reclamation contributed to most of the disturbance on Holberg's stem-aligned grapple yarder and excavator-forwarder sites respectively.

The soil density of the disturbed areas was statistically higher than that of the undisturbed areas on the feller-buncher and excavator-forwarding blocks, but not on the stem-aligned grapple yarder block. However, the level of soil disturbance could not be correlated to the increase in soil density.

FERIC's case studies showed that factors such as tree size, stand density, and conditions created by the previous harvesting phase (i.e. bunching and aligning) influence the performance of the various machines studied. They also pointed out that more information and studies are needed before sufficient data are available to develop cost and productivity models for harvesting Coastal second-growth stands.

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Disclaimer

This report is published solely to disseminate information to FERIC members. It is not intended as an endorsement or approval by FERIC of any product or service to the exclusion of others that may be suitable. Results presented in this report are based on limited data for operating conditions in specific Coastal second-growth stands; caution must be exercised when comparing system performance.

Appendix I

Calculation of Machine Charge-Out Rates

	ACL 771B feller-buncher	Hitachi EX400 and John Deere 992D loaders Double-shift	Single-shift	Madill 075 super snorkel	Madill 044 grapple yarder	Caterpillar 235 (used) backspar
COST INPUT DATA						
Purchase price (P) ($)	750 000 [a]	510 000	510 000	950 000	1 200 000 [b]	125 000
Salvage value (S) (% of P)	20	20	20	20	20	20
Depreciation period (D) (y)	5	5	5	12	12	5
Machine utilization (MU) (%)	75	80	80	80	75	75
Operating days/year (no.)	180	180	180	180	180	180
Shifts/day (no.)	2	2	1	1	1	1
SMH/shift (h)	9	9	9	9	9	9
OMH/year (h)	2 430	2 592	1 296	1 296	1 215	1 215
Average investment ($/y)	450 000	306 000	306 000	570 000	720 000	75 000
Interest on investment (%)	10	10	10	10	10	10
Insurance (%)	3	3	3	3	3	3
Fuel consumption (F) (L/OMH)	30	25	25	35	55	5
Fuel cost (FC) ($/L)	0.45	0.45	0.45	0.45	0.45	0.45
Oil consumption (% of F)	6	4	4	4	4	4
Oil cost ($/L)	2.50	2.50	2.50	2.50	2.50	2.50
Repair cost (% of P/100 OMH) [c]	1	1	1	1	1	1
Operator's required (no.)	1	1	1	1	2 [d]	1 [d]
Operator wage ($/SMH) [e]	22.29	22.29	22.29	22.93	41.68	21.67
Fringe benefits (% of wage)	35	35	35	35	35	35
OPERATING COST						
Depreciation ($/OMH)	49.38	31.48	62.96	48.87	65.84	16.46
Interest on investment ($/OMH)	18.52	11.81	23.61	43.98	59.26	6.17
Insurance ($/OMH)	5.56	3.54	7.08	13.19	17.78	1.85
Repair/maintenance ($/OMH)	75.00	51.00	51.00	95.00	120.00	12.50
Fuel cost ($/OMH)	13.50	11.25	11.25	15.75	24.75	2.25
Lubrication cost ($/OMH)	4.50	2.50	2.50	3.50	5.50	0.50
Operator wages ($/OMH)	29.72	27.87	27.87	28.66	55.57	28.89
Fringe benefits ($/OMH)	10.40	9.75	9.75	10.03	19.45	10.11
Charge-out rate ($/OMH)	206.58	149.20	196.02	258.98	368.15	78.73
Charge-out rate ($/SMH)	154.94	119.36	156.82	207.18	276.11	59.05

[a] The 771B feller-buncher is not commercially available; purchase price is estimated by comparing size and features with commercially available feller-bunchers.
[b] The Madill 044 model is no longer manufactured by S. Madill; purchase price used in cost analysis is based on assumption that this model is available to purchase new.
[c] Repair cost estimated to be 1% of purchase price per 100 operating hours. Data obtained from Williams (1989).
[d] Grapple yarder crew consisted of three people. For purposes of cost calculation, two people are assigned to the yarder, and one person to the back spar.
[e] Based on IWA rates in January 1993. Regular rate for first 8-h day, and overtime premium of 1.5 • regular rate after 8 h.