WOOD HARVESTING

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TN 261

HARVESTING COASTAL SECOND-GROWTH FORESTS: LOADER-FORWARDING OF HAND- AND MACHINE-FELLED TIMBER

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Abstract

In the winter and spring of 1994, the Forest Engineering Research Institute of Canada (FERIC) monitored a loader-forwarding operation extracting hand- and machine-felled timber from second-growth stands on Vancouver Island in British Columbia. FERIC measured worker and machine productivities, identified factors that influenced harvesting performance, and conducted post-harvest site assessments.

Introduction

In 1991, the Forest Engineering Research Institute of Canada (FERIC) and the Faculty of Forestry at the University of British Columbia initiated a cooperative project to evaluate harvesting systems for clearcutting second-growth stands in coastal British Columbia. Funding for the project was obtained through the Canadian Forest Service under the Canada–British Columbia Forest Resource Development Agreement (FRDA II).

This report is the third in a series of FERIC publications on the performance of harvesting systems in coastal second-growth forests (Andersson and Jukes 1995; Andersson and Warren 1996). It presents the results of a study on hand and mechanical falling, loader-forwarding, and hand bucking at roadside. The study was done on Vancouver Island between January and April 1994, in cooperation with MacMillan Bloedel Limited, South Island Division.

The objectives of the study were to document falling and loader-forwarding[1] productivities; identify factors influencing harvesting performance; record volume by timber sort; and examine differences in post-harvest wood residue and soil surface conditions between harvesting systems.

Site Descriptions

The study was done at two locations (Figure 1). At the main study site at Buckley Bay, the stand consisted of 80-year-old Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) with minor components of western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) and western red cedar (*Thuja plicata* Donn). The stand had regenerated naturally following clearcut logging. A selective cut to recover logs suitable for log houses had been done on the site prior to the study.[2] The site was divided into three cutblocks (B1, B2 and B3), each harvested with a different system.

At the study site at Nanoose (N1), the stand consisted of 70-year-old Douglas-fir and western white pine (*Pinus monticola* Dougl.), with some western hemlock and western red cedar. As at Buckley Bay, the stand had regenerated naturally following clearcut logging. The Nanoose site was used only to conduct some detailed-timing studies on the loader-forwarder and to collect soil compaction data.

Based on the cruise information, the average stand volumes of the Buckley Bay and Nanoose sites were 480

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1 Loader-forwarding is the use of hydraulic log loaders to extract stems from the falling site to the roadside. Also referred to as excavator-forwarding, hoe-forwarding, hoe-chucking, or shovel logging.

2 Twenty-three percent of the total stand volume had been harvested using hand fallers and rubber-tired skidders.

Keywords: Harvesting, Second-growth forests, Forwarding, Loaders, Felling, Manual methods, Mechanical methods, Productivity, Costs, Site disturbance, Coastal British Columbia, ACL 771B feller-buncher.

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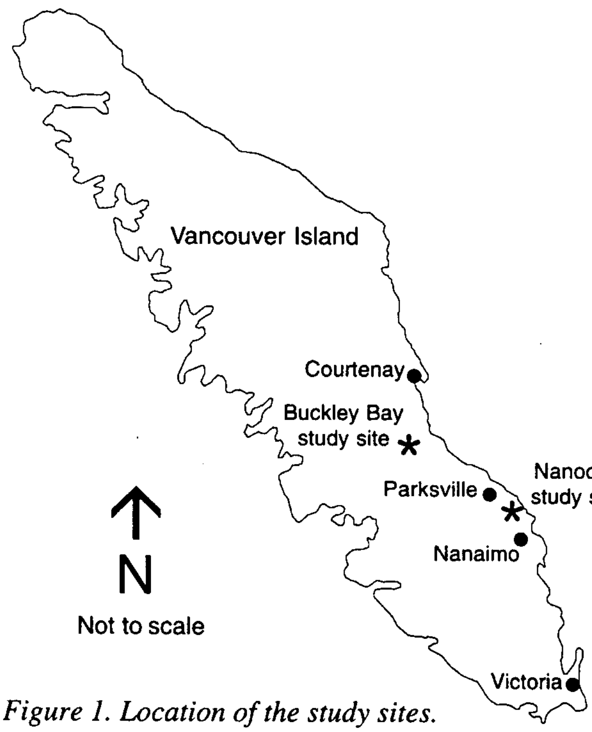

Figure 1. Location of the study sites.

Table 1. Average Stand Characteristics

	Buckley Bay (B1, B2, B3)	Nanoose (N1)
Cutblock size (ha)	20.8	11.2
Merchantable trees [a]		
Tree dbh (cm)	33	31
Total height (m)	26	27
Tree volume (m³/tree)	1.14	1.00
Stand density (trees/ha)	420	450
Stand volume (m³/ha) [b]	480	450

[a] Sound conifer with diameter at breast height (dbh) ≥13 cm.
[b] Differences due to rounding.

and 450 m³/ha, respectively (Table 1). All sites had good ground strength, few obstacles, and little woody material on the ground. Overall, the Buckley Bay site had a slight S-shaped profile, with slopes in Cutblocks B1 and B2 ranging from 0–5% and in B3 ranging from 0–10%. B3 also contained some irregular knolls with pitches of up to 40%. The terrain profile at the Nanoose site was convex, with slopes ranging from 0–35%.

System Descriptions

Cutblocks B1 and B2 were both hand felled. In B1, stems longer than 20 m were felled and bucked (fall–selective buck), while trees in B2 were felled only (fall only). Cutblocks B3 and N1 were felled with an ACL 771B feller-buncher (Figure 2). The stems and logs in all cutblocks were extracted to roadside with an Hitachi

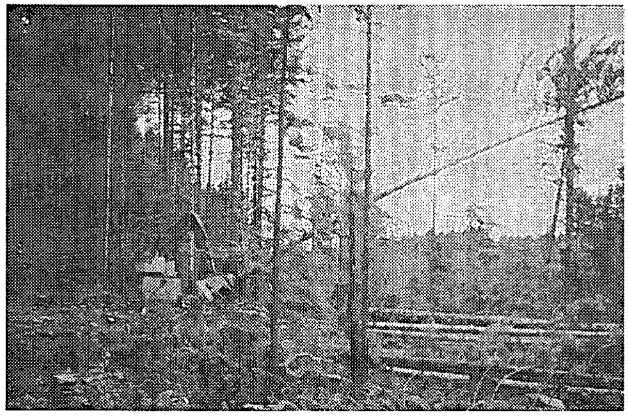

Figure 2. ACL 771B feller-buncher in Cutblock B3.

EX400 hydraulic log loader. At roadside, the stems in Cutblocks B2, B3 and N1 were manually bucked into preferred lengths by two buckers and loaded onto trucks. In Cutblock B1, some bucking and trimming were done by a landing bucker during the loading operation. All loading was done using a hydraulic log loader.

The scheduled workdays for the hand fallers, buckers, and machine operators were 6.5, 8, and 8.5 h, respectively. The feller-buncher operated two shifts per day. Two trainees, in addition to the regular operators, were assigned to the feller-buncher.

In Cutblocks N1 and B1, loader-forwarding occurred during day shifts. In Cutblocks B2 and B3, 40% and 100%, respectively, of the loader-forwarding operations were done during evening shifts.[3] During evening shifts, a bucker worked at roadside and was assisted by the loader-forwarder.

Study Methods

FERIC cruised the study sites at an intensity of two 200-m² plots/ha. The data were used to determine stand volumes, and to develop local dbh–gross volume stand tables.

Machine data were collected using shift-level and detailed-timing techniques. DSR Servis recorders were used to record feller-buncher and loader-forwarder shift-level data, while daily time sheets provided information on the hand falling and roadside bucking operations. Detailed-timing studies were done on the hand falling, mechanical falling, and loader-forwarding operations. Each study recorded the operating conditions, duration of various work elements, and number of stems produced.

Harvesting productivities were determined based on the shift-level data and recovered volume, as well as from

[3] About 2 h of the evening shift were under daylight conditions.

the detailed-timing data and local dbh–gross volume stand tables. The results from the two methods will often differ numerically because of the differences between cruise and recovered volumes, and between operating machine hours (OMH) and productive machine hours (PMH).[4]

Harvesting cost is based on FERIC's standard machine costing methodology, and IWA-Canada labour rates as of June 1994 (Appendix I).

Post-harvest site assessments of wood residue and soil disturbance were sampled using the line intercept method (Sutherland 1986) at an intensity of 2 plots/ha. The wood residue survey was done prior to any wood salvage operations. FERIC measured all sound pieces greater than 9.5 cm in diameter, regardless of length, and did not differentiate between avoidable and unavoidable logging waste. Each piece was graded using the industry-standard statutory grades (Watts 1983), and valued[5] based on the assumption that the piece would have been part of a merchantable log.

Site disturbance was defined as the occurrence of exposed mineral soil and depressions or gouges in the organic layer greater than 15 cm in depth, regardless of the area disturbed, or impact (positive or negative) on stand regeneration.[6] Soil compaction data were collected with a Campbell Pacific nuclear moisture/density gauge. Two samples, one on undisturbed ground and one on exposed soil with clear indications of machine travel, were taken near each plot. Thus, the compacted soil samples are more representative of the "worst case scenario" than of the average disturbance on the sites.

Results

Results presented in this report are based on limited data for operating conditions in a specific coastal second-growth stand. Therefore, caution must be exercised when interpreting the results of this study and when comparing them with those of other studies.

Harvesting Performance

Recovered volume and sorts. The recovered volumes[7] from Cutblocks B1, B2 and B3 at Buckley Bay were 2 768, 3 484 and 4 266 m^3, respectively. Based on a sample of 978 m^3 (1 176 pieces) of Douglas-fir, grades H and I sawlogs were 25% of the volume, and grade J sawlogs were 59% of the volume. Peeler, Utility and Chipper grades each accounted for approximately 4–6% of the sampled volume (Figure 3).

Hand falling. As expected, the faller productivity of the fall–selective bucking operation (Cutblock B1)

[4] OMH includes productive time, minor delays, and an unknown amount of non-productive activities that cannot be separated from productive time with the Servis recorders used. PMH includes only productive time and minor delays. In this study, minor delays are those delays <15 min/occurrence.

[5] Supplied by Information Services, Council of Forest Industries (COFI), pers. comm., August 1994.

[6] The soil disturbance data were collected prior to the enactment of the British Columbia Forest Practices Code, and do not reflect current Forest Practices Code standards. Both study sites were on private land, thus not subject to the site disturbance regulation under the Forest Practices Code.

[7] Converted to volume from weigh scale.

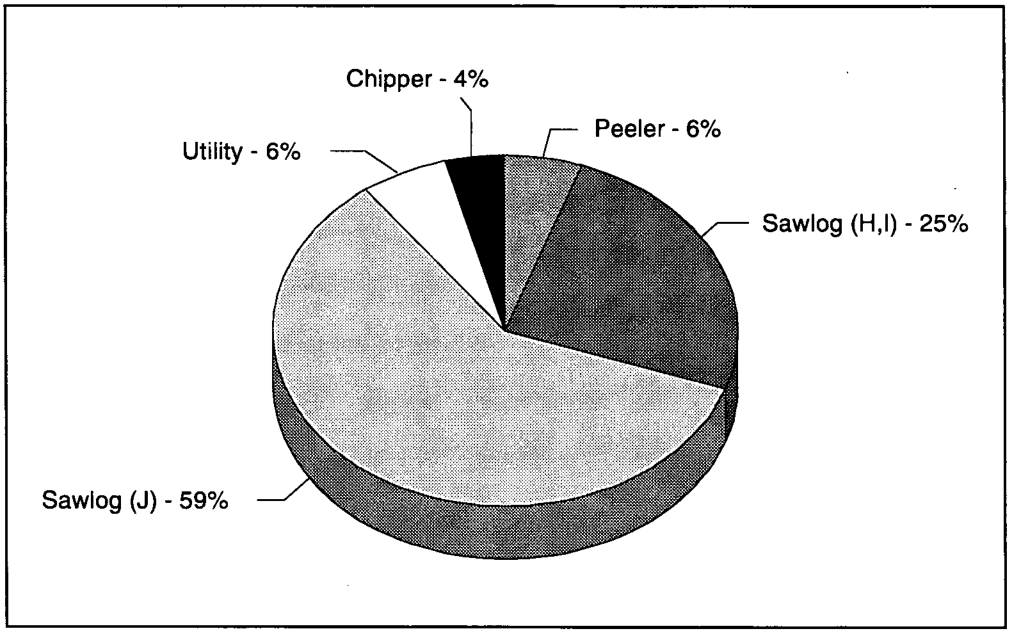

Figure 3. Proportion of timber grades in a sample of Douglas-fir logs.

Table 2. Summary of Shift-Level Data at Buckley Bay

	Cutblock B1			Cutblock B2			Cutblock B3		
	Fall	Extract	Buck	Fall	Extract	Buck	Fall	Extract	Buck
Labour (SMH) [a]	174.0	66.0	85.2	133.0	56.0	138.8	42.5	66.5	175.8
Machine (OMH) [b]	--	61.5	--	--	51.5	5.5	31.0	57.0	9.5
Production									
Pieces (no.) [c]	--	3 321	--	--	2 509	--	3 266	3 120	--
Volume (m^3)		2 768 [d]			3 484 [d]			4 266 [d]	
Productivity									
Pieces/OMH (no.) [c]	--	54	--	--	49	--	105	55	--
Volume/OMH (m^3)	--	45.0	--	--	67.7	--	137.6	74.8	--
Volume/worker-day (m^3) [e]	103	336	260	170	498	201	803	513	194

[a] SMH = scheduled machine hours.
[b] OMH = operating machine hours.
[c] From feller-buncher and loader-forwarder operators' tree and stem counts.
[d] Volume is for entire cutblock.
[e] 6.5 h/shift for hand falling operations, and 8 h/shift for all other operations. Hand falling and bucking operations may include an unspecified amount of lost work time, which may differ between the operations.

was considerably lower than that of the fall-only operation (Cutblock B2). Based on the shift-level data, the fallers in the fall-only operation averaged 170 m^3/worker-day compared to 103 m^3/worker-day in the fall–selective bucking operation (Table 2). However, an unspecified amount of lost work time (because of adverse weather, company meetings, etc.) is included and may be different for the two hand falling operations, as they were done during different time periods. The two sites were also felled by different fallers.

Results of detailed-timing studies of the fall–selective bucking operation show that the faller averaged 31 trees/PMH or 26.8 m^3/PMH (Table 3). Twenty-six percent of the faller's time was spent bucking 75% of the felled trees. Generally, only one bucking cut was made per tree, but occasionally two logs were manufactured.

The productivity recorded in the detailed-timing study was considerably higher than that determined from shift-level data (at 5.5 PMH/day, worker-day productivity would be 147 m^3), but is in line with hand falling productivities recorded by Peterson (1987) in second-growth timber of similar tree size. The shift-level data may therefore have included an abnormally high amount of lost work time.

No detailed-timing was done on the fall-only operation. However, if the faller in the fall–selective buck study had not done any bucking, FERIC estimates that productivity would have averaged 46 trees/PMH. This is in line with the 50 trees/h that the fallers in the fall-only operation thought they produced.

The time spent to fall and buck trees was found to increase with tree size, resulting in fewer felled trees per hour. However, the increase in tree volume with increased tree size more than offset the longer falling time per tree. Thus productivity, expressed in m^3/h, increased with tree size. Using least-square regression techniques, FERIC projected faller productivity as a function of tree volume for fall–selective bucking and fall-only operations (Figure 4). The results indicate that the difference in productivity between the two falling methods will increase with an increase in tree size. This is expected, as more bucking is required as tree size increases.

Table 3. Summary of Detailed-Timing Studies: Fall–Selective Buck Operations

	All studies
Observed time (h)	8.8
Average stand characteristics	
Merchantable tree dbh (cm)	32
Tree volume (m^3/tree)	0.87
Distribution of work elements	
Fall trees (min/tree)	0.66
Process (min/tree)	0.51
Walk in stand (min/tree)	0.22
Other work (min/tree)	0.25
Fuel/file saw (min/tree)	0.19
Minor delay (min/tree)	0.13
Productive time (min/tree) [a]	1.95
Productivity	
Trees/PMH (no.) [a]	31
Volume/PMH (m^3) [a]	26.8

[a] Differences due to rounding.

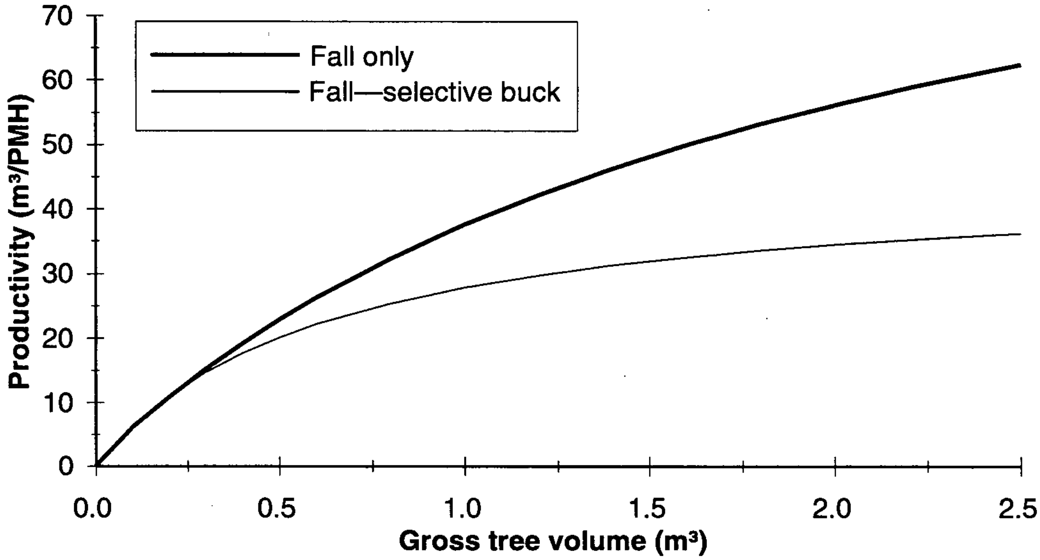

Figure 4. Projected productivity of hand falling operations, as a function of gross merchantable tree volume.

Mechanical falling. The average productivity of the ACL 771B feller-buncher in Cutblock B3 was 137.6 m³/OMH or 803 m³/8-h shift (Table 2). However, its overall productivity was hampered by the training of new operators. FERIC estimated that without training, the block would have been felled in 25 OMH, resulting in a machine productivity of 171 m³/OMH.

During the two-and-a-half day study, the machine was utilized 73% of its scheduled work time. While this study was too short to assess long-term machine utilization, the result was similar to the 74% utilization recorded by Andersson and Jukes (1995) during a 47-shift study.

The productivity of the feller-buncher recorded in five detailed-timing studies ranged between 102 and 130 trees/PMH, or 86.9 and 180.5 m³/PMH (Table 4). The difference between the high and low productivity values expressed in trees/PMH compared to those expressed in m³/PMH clearly demonstrates the impact of tree volume on feller-buncher productivity. The variation in trees/PMH performance appears to reflect differences in operator skill (e.g., efficient use of tree accumulator arms before bunching) and terrain conditions (e.g., moving and clearing debris).

Loader-forwarding. Overall, the productivity of the loader-forwarder was highest on the feller-bunched

Table 4. Summary of Detailed-Timing Studies: ACL 771B Feller-Buncher

	Study number				
	1	2	3	4	5
Observed time (h)	1.4	2.1	2.6	2.3	3.5
Average stand characteristics					
Tree dbh (cm)	38	33	28	28	35
Tree volume (m³/tree)	1.62	1.16	0.85	0.85	1.28
Merchantable trees/ha (no.)	500	420	310	310	390
Stand volume (m³/ha) [a]	816	486	255	255	503
Distribution of work elements					
Fell and bunch (min/tree)	0.40	0.44	0.40	0.32	0.35
Move (min/tree)	0.10	0.12	0.15	0.12	0.11
Other work (min/tree)	0.03	0.03	0.03	0.01	0.03
Minor delays (min/tree)	0.01	0.01	0.01	0.01	0.01
Total productive time (min/tree) [a]	0.54	0.59	0.59	0.46	0.49
Machine productivity [a]					
Trees/PMH (no.)	111	102	102	130	122
Volume/PMH (m³)	180.5	118.5	86.9	110.4	155.7
Average trees/cycle (no.)	1.16	1.03	1.20	1.55	1.25

[a] Differences due to rounding.

site (74.8 m^3/OMH), and lowest on the fall–selective bucking site (45.0 m^3/OMH) (Table 2). The external forwarding distance was similar (about 100 m) on all three sites. Therefore, the variation in machine productivity is attributed to differences in piece size, and the concentration and alignment of felled stems.

The machine utilization of the loader-forwarder during the 22-shift study was 90%. This is slightly higher than the machine utilization of 84% obtained in a prior, 74-shift study (Andersson and Jukes 1995).

The productivity of the loader-forwarder recorded in seven detailed-timing studies ranged between 48.4 and 113.0 m^3/PMH (Table 5). Analysis of the data showed that the variation in productivity of feller-bunched stems could be linked primarily to differences in forwarding distance, and secondarily to differences in stem size. More data are needed to quantify the impact of these and other factors on machine performance. However, observations and discussions with the machine operators provided FERIC with insight into some of the operating conditions influencing the machine performance.

Slope affects the productivity because it influences the distance the logs can be moved (forwarded) in each boom swing. Compared to level ground, adverse (uphill) slopes shorten the effective swing arc of the boom. On favourable (downhill) slopes, the operator can utilize slope and gravity to slide the logs a further distance with each swing.

Piece size affects the volume of wood that the machine can grapple in each boom swing. However, the relationship between piece size and productivity (or volume and swing) is not linear, because the amount of wood grappled in each swing also depends on the location and alignment of pieces within the boom reach.

Loader-forwarders will likely perform best when the stems are concentrated in bunches and aligned with butts facing the landing (Figure 5). This condition is likely more critical in operations extracting full-length stems than manufactured logs. Stems with tops facing the landing must initially be grabbed by their tops and turned around, increasing handling time and risk of stem breakage.

System harvesting costs. The harvesting cost of the feller-buncher operation compared favourably with that of the hand falling operations, with cost reductions in both the falling and forwarding phases (Table 6). In this study, the cost of the feller-buncher operation

Table 5. Summary of Detailed-Timing Studies: Loader-Forwarder

	Feller-bunched					Hand felled	
	Study number					Study number	
	1	2	3	4	5	6	7
Observed time (h)	4.2	2.9	4.0	2.4	4.5	7.2	3.4
Study site (block)	N1	N1	N1	B3	B3	B1 [a]	B2 [a]
Average operating condition							
Tree dbh (cm)	36	41	37	--	--	31	36
Volume/piece (m^3)	1.09	1.48	1.27	1.00	1.20	0.80	1.16
External distance (m) [b]	180	60	120	70	100	120	90
Slope (%) [c]	0	0	-20	-10	+10	+5	<+5
Distribution of work elements							
Handle wood (min/tree)	1.07	0.55	1.02	0.54	0.66	0.63	0.75
Move (min/tree)	0.17	0.16	0.18	0.15	0.22	0.09	0.15
Other work (min/tree)	0.04	0.03	0.15	0.11	0.16	0.05	0.04
Minor delay (min/tree)	0.07	0.04	0.07	0.04	0.06	0.04	0.05
Total productive time (min/tree) [d]	1.35	0.79	1.42	0.85	1.10	0.81	0.98
Machine productivity							
Stems/PMH (no.) [d]	44	76	42	71	54	74	61
Volume/PMH (m^3) [d]	48.4	113.0	53.6	70.8	65.4	59.5	70.7

[a] B1 was hand felled–selective bucked, B2 was hand felled only.
[b] Distance from roadside deck to end of out-turn.
[c] + indicates favourable (downhill) slope.
 - indicates adverse (uphill) forwarding.
[d] Differences due to rounding.

Figure 5. Hitachi EX400 loader forwarder extracting mechanically felled full-length stems.

was 12% and 33% lower than for the fall-only and fall–selective bucking operations, respectively. Had the feller-buncher been operated by experienced operators only, the difference in harvesting cost between this system and the hand falling systems would have been even greater. The difference in bucking cost between the feller-buncher and fall-only operation is believed to be purely coincidental.

The cost difference between the two hand falling operations reflects the difference in productivity between the fall-only and fall–selective bucking phases, and the higher loader-forwarding productivity of full-length stems compared to bucked logs. The cost difference was partly offset by the fall–selective bucking operation requiring less bucking at roadside.

Post-harvest Site Assessment

Waste assessment. The intent of FERIC's post-harvest waste survey was to examine possible differences in residual wood waste between harvesting systems. The survey recorded a higher volume of wood waste on the fall–selective buck harvesting site (B1) compared to the other sites (Figure 6). However, the wood waste volume varied considerably between individual sample plots on all three sites, and thus, the difference in wood waste volume between harvesting sites could not be determined to be statistically significant at the 95% level of confidence. Therefore, no conclusion could be made regarding differences in wood waste volumes between the three harvesting systems.

FERIC estimates that if all the pieces of wood waste had been recovered as part of merchantable logs (i.e., no breakage), the harvesting operation would have yielded approximately $1 400/ha in additional log revenue.

Site disturbance. The site disturbance, as defined in this study, ranged from 21 to 38% of the harvested area (Table 7). Both the highest and lowest site disturbances were found on the feller-bunched sites (Cutblocks B3 and N1, respectively), and the variation is attributed to the difference in ground conditions between the two sites. Cutblock B3 contained areas with short steep pitches while at Cutblock N1 the slope changed gradually. FERIC observed that tracks of the feller-buncher and loader-forwarder frequently exposed mineral soil when turning, or when climbing steep pitches. When the data were combined by harvesting system, i.e., mechanical (B3 and N1) versus hand falling (B1 and B2), there was no difference in the site disturbance.

Soil compaction. The bulk density of soil disturbed by machine travel was on average 8–19% higher than the bulk density of undisturbed soil (Table 8). However, the soil bulk density readings varied within a short distance, due to natural variation in the soil structure (rocks, organic matter, etc.). As a result, differences in bulk density readings between paired disturbed and undisturbed sites may not entirely be the result of compaction from machine travel.

The increase in bulk density did not statistically differ between blocks. Thus, in this study, the feller-buncher system was not found to cause a higher increase in soil bulk density than the hand faller systems. Observations suggest that the travel paths of the feller-buncher and loader-forwarder on the feller-bunched sites

Table 6. Projected Harvesting Costs

	Hand felled		Feller-
	B1	B2	bunched
Falling ($/m³)	3.81 [a]	2.31 [a]	1.58 (1.26) [b]
Loader-forwarding ($/m³)	3.85	2.56	2.31
Manual bucking ($/m³) [a]	0.92	1.67 [c]	1.84 [c]
Total ($/m³)	8.58	6.54	5.73 (5.41) [b]

[a] Includes labour rate (Appendix I), 35% fringe benefits, and $27/day chainsaw cost.
[b] Estimated cost in parentheses assumes the block had been felled by experienced operators only.
[c] Includes the machine cost of the loader (Appendix I) for time charged to the bucking operation (Table 2).

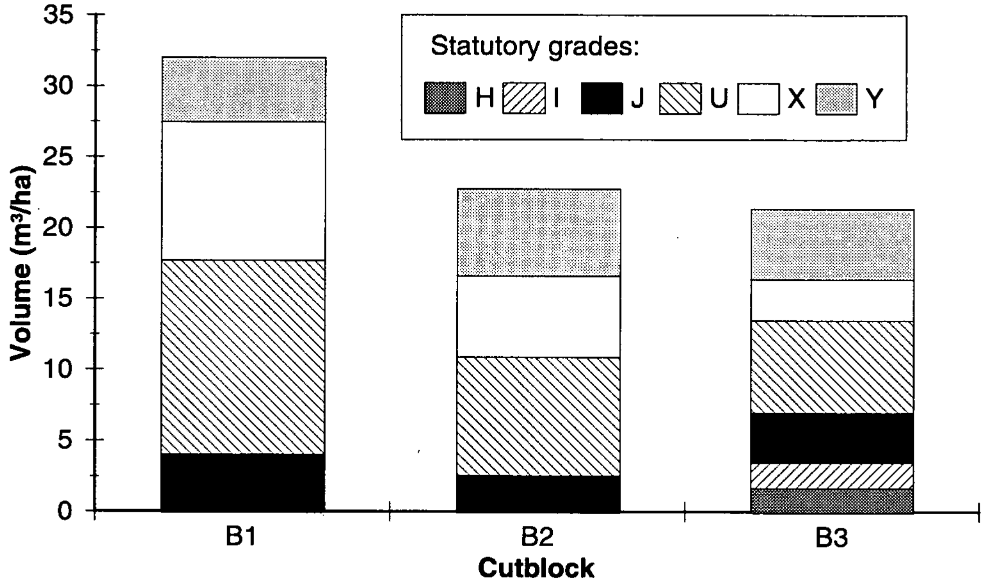

Figure 6. Results of post-harvest waste survey.

Table 7. Summary of Soil Disturbance Assessment

	Feller-bunched		Hand felled	
	N1 (%)	B3 (%)	B1 (%)	B2 (%)
Disturbance				
Organic layer >15-cm depth	1.7	4.2	9.8	8.9
Exposed mineral soil	19.5	33.8	16.5	17.8
Total	21.2	38.0	26.3	26.7
Undisturbed	76.3	60.2	71.6	70.9
Other (stumps, rocks, etc.)	2.5	1.8	2.1	2.4
Total [a]	100.0	100.0	100.0	100.0

[a] Excludes area covered by haul road and ditches.

Table 8. Summary of Bulk Density Assessment

	Feller-bunched		Hand felled	
	N1	B3	B1	B2
Average bulk density, 0–10 cm depth				
Undisturbed site (g/cm^3)	1.30	1.18	1.15	1.18
Disturbed site (g/cm^3)	1.52	1.28	1.33	1.28
Average bulk density, 0–20 cm depth				
Undisturbed site (g/cm^3)	1.44	1.26	1.19	1.20
Disturbed site (g/cm^3)	1.60	1.39	1.42	1.39
Average depth of disturbed plots (cm) [a]	18	25	18	20

[a] All disturbed site data were taken where the machine tracks had compressed the soil. The depth of depression was measured in relation to adjacent undisturbed area.

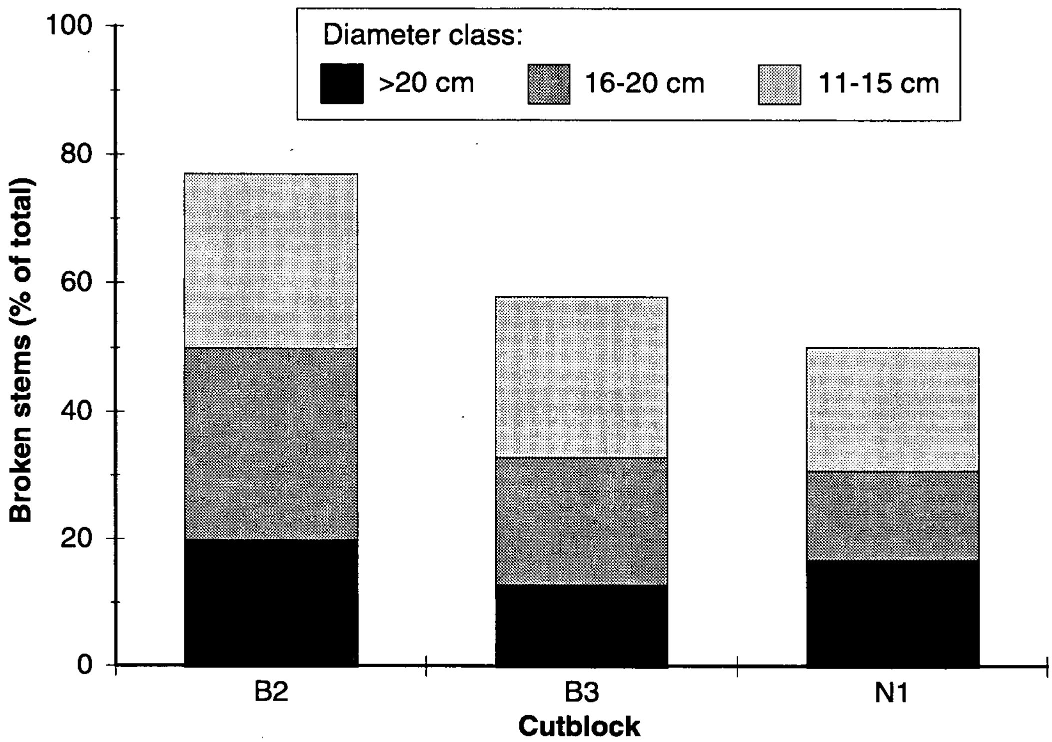

Figure 7. Distribution of stem breakage by diameter class where breakage occurred.

(Cutblocks B3 and N1) were perpendicular to each other, and thus only a small portion of the site would have been subjected to multi-pass machine travel.

Stem breakage. FERIC found that hand felled stems had a higher frequency of breakage and generally broke at a larger diameter compared to mechanically felled stems. Seventy-seven percent and 54% of stems sampled in the hand felled and feller-buncher felled cutblocks, respectively, had the stems broken at diameters greater than 10 cm (Figure 7). As a result, the potential fibre loss from stem breakage is higher in hand falling operations than in feller-buncher operations. In this study, FERIC recorded 6.7% fibre loss for hand felled stems compared to 4.0% for mechanically felled stems (before salvage operations).

Conclusions

In this study, using a large feller-buncher (the ACL 771B) to harvest second-growth timber compared favourably to using hand fallers in operations where the wood is extracted to roadside with loader-forwarders. The feller-buncher reduced harvesting costs and stem breakage, and did not appear to affect the harvested site any differently than the two hand falling operations.

The harvesting cost of the feller-buncher operation was 12% and 33% lower than in the fall-only and fall–selective buck hand falling operations, respectively. The feller-buncher had a lower falling cost than the hand fallers, and contributed to a lower forwarding cost as it created more favourable operating conditions for the loader-forwarder.

The fall-only operation was more cost effective than the fall–selective bucking operation, and reflects the higher productivity of both the falling and loader-forwarding phases. Recorded faller productivity in the fall-only operation was 170 m^3/worker-day, compared to 103 m^3/worker-day in the fall–selective bucking operation.

The productivities of the loader-forwarder, at 100 m average external forwarding distance, were 74.8 m^3/OMH in feller-bunched wood, 67.7 m^3/OMH in hand felled, full-length stems (fall-only), and 45.0 m^3/OMH in selectively bucked, hand felled stems.The higher loader-forwarder productivity is attributed to stems not being bucked into logs in the fall-only operation, thus allowing the machine to handle fewer but larger stems compared to the fall–selective bucking operation. The difference in productivity between feller-bunched and hand felled timber was attributed to whether or not stems were bunched. The difference in productivity between the hand falling operations was attributed to variations in average piece size.

No difference was found in the amount of site disturbance or degree of soil compaction between the harvesting systems. Both the highest and lowest site disturbances were found on the feller-bunched sites, and the variation was attributed to the difference in ground conditions between the two sites.

On sites where machine travel occurred, the increase in soil bulk density was on average 8–19%, compared to sites with no machine travel. However, this figure varied considerably between adjacent disturbed and undisturbed sample plots. Consequently, the increase in the soil bulk density on the feller-bunched sites was not found to be statistically different than on the hand felled sites. A possible explanation is that only a small portion of the ground had been subjected to multi-pass machine travel with the feller-buncher operations.

Fibre losses from broken stems (measured prior to any salvage operations) were estimated to be 4.0% in the feller-buncher operation and 6.7% in the fall-only operation. Fewer stems broke in the feller-buncher operation, and stem breakage generally occurred at a smaller diameter compared to the hand falling operations.

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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 suited. Results presented in this report are based on limited data for operating conditions in specific coastal second-growth stands; therefore, caution must be exercised when comparing system performance.

Appendix I

Costing

Calculation of Machine Charge-Out Rates

	ACL 771B feller-buncher	Hitachi EX400 loader-forwarder
COST INPUT DATA		
Purchase price (P) ($)	750 000 [a]	510 000
Salvage value (S) (% of P)	20	20
Depreciation period (D) (y)	5	5
Machine utilization (MU) (%)	75	85 [b]
Operating days/year (no.)	180	180
Shifts/day (no.)	2	1
SMH/shift (h)	9	9
OMH/year (h)	2 430	1 377
Average investment ($/y)	450 000	306 000
Interest on investment (%)	8	8
Insurance (%)	3	3
Fuel consumption (F) (L/OMH)	30	25
Fuel cost (FC) ($/L)	0.45	0.45
Oil consumption (% of F)	6	4
Oil cost ($/L)	2.50	2.50
Repair cost (% of P/1000 OMH) [c]	11.5	7.3
Operator wage ($/SMH) [d]	22.88	22.88
Fringe benefits (% of wage)	35	35
OPERATING COSTS		
Depreciation ($/OMH)	49.38	59.26
Interest on investment ($/OMH)	14.81	17.78
Insurance ($/OMH)	5.56	6.67
Repair/maintenance ($/OMH)	86.25	37.23
Fuel cost ($/OMH)	13.50	11.25
Lubrication cost ($/OMH)	4.50	2.50
Operator wages ($/OMH)	32.20	28.41
Fringe benefits ($/OMH)	11.27	9.94
Charge-out rate ($/OMH)	217.47	173.04
Charge-out rate ($/SMH)	163.10	147.09

[a] The ACL 771B feller-buncher is not commercially available; purchase price is estimated by comparing size and features with commercially available feller-bunchers.
[b] Average machine utilization of loader-forwarders recorded by FERIC (see page 5).
[c] Repair cost estimate based on data from Williams (1989).
[d] Based on IWA rates in June 1994. Regular rate for first 8 h/d, and overtime premium of 1.5 times the regular rate after 8 h.

Labour Rates (IWA-Canada) as of June 15, 1994

Position	Rate
Hand faller ($/day)	270.76
Bucker ($/h)	23.50
Landing bucker ($/h)	19.61