Advantage

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Contents

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Using mechanized systems to harvest second-growth forests in coastal British Columbia: evaluation of Madill T2200 and Tigercat 860 feller-bunchers

Abstract

In the spring of 2002, the Forest Engineering Research Institute of Canada (FERIC) monitored the operational and economic feasibility of using mechanized systems for clearcut harvesting of second-growth on steep slopes in coastal British Columbia. This report presents the results of the mechanical felling study, and provides productivity and cost information. The other operational phases will be presented in subsequent reports.

Keywords

Coastal British Columbia, Second-growth, Mechanized felling, Madill T2200 feller-buncher, Tigercat 860 feller-buncher, Costs, Productivity.

Introduction

Mechanical timber harvesting systems comprised of feller-bunchers, processors, loader-forwarders, and skidders—if used appropriately—offer opportunities to reduce harvesting costs without exceeding the limits of acceptable site impacts. At the request of its members, FERIC has been investigating the use of this equipment in second-growth stands in coastal British Columbia.

In the spring of 2002, TimberWest Forest Corp.'s Cowichan Woodlands Operation and Honeymoon Bay Operation undertook a series of trials to investigate the feasibility of using mechanized systems for clearcut harvesting on steep slopes. FERIC monitored the trials to determine the operational and economic feasibility of these systems. Because of the scope of this study, the results will be presented in several "Advantage" reports. This report presents the results of the mechanized felling operations.

Objectives

The primary goal of this study was to assess the economic and operational feasibility of using mechanized equipment for clearcut harvesting on steep slopes. The overall objectives of the study were to:

- Determine productivities and costs for the mechanical felling, grapple yarding, loader-forwarding, and processing operations.
- Identify operational factors that influence performance of feller-bunchers, loader-forwarders, grapple yarders, and processors.
- Evaluate the grapple yarders, loader-forwarders, and processors as components of the roadside harvesting systems.
- Develop productivity and cost functions for harvesting operations.
- Determine and compare the optimum extraction distances for loader-forwarding and grapple yarding.

This report addresses the productivities and costs of the felling operation, and identifies operational factors that influence the performance of the feller-bunchers.

Harvesting systems

An overview of harvesting systems and equipment used in this project is shown in Table 1. Only Blocks A and B are discussed in this report. Both manual and mechanical felling with feller-bunchers were used. Depending on block layout and terrain conditions, stems were extracted with loader-forwarders and/or grapple yarders. At the roadside, the stems were decked for processing by mechanical dangle-head processors.

Description of sites and stands for felling study

Mechanical felling operations were observed in two study blocks. Block A was located approximately 65 km west of Duncan in the Honeymoon Bay Operation area and Block B was located approximately 15 km south of Mesachie Lake in the Cowichan Woodlands Operation area. The harvesting prescription for both blocks specified clearcutting with reserves. On Block A, the temporary deferred areas and wildlife tree patches constituted about 22% of the total block area. Variable retention groups covered about 9% of the total area of Block B. Table 2 summarizes the site and stand descriptions.

The sites in Block A were classified as the submontane variant of the Coastal Western Hemlock very wet maritime biogeoclimatic subzone (CWHvm1), and those in Block B as the western variant of the Coastal Western Hemlock very dry maritime biogeoclimatic subzone (CWHxm2) (Green and Klinka 1994). The terrain in both blocks ranged from almost level (slope class 0–10%) to very steep (slope classes 51–60 and 61–70%).

Forest cover in both blocks consisted of second-growth Douglas-fir *(Pseudotsuga menziesii)*, western hemlock *(Tsuga*

Table 1. Harvesting systems and equipment

Cutblock	A	B	C	D
Harvesting system	Clearcut, cold deck	Clearcut, cold deck	Clearcut, hot deck	Clearcut, cold and hot deck
Felling equipment	Madill T2200 feller-buncher with intermittent low-speed circular saw [a]	Tigercat 860 feller-buncher with high-speed circular saw [a]	Feller-buncher	Manual
Extraction equipment	Snorkel, loader-forwarders, grapple yarder	Madill 144 yarder, uphill and downhill yarding [a] Madill 3800 loader-forwarder [a]	Cypress 7280 yarder, uphill yarding [a] Loader-forwarders	Cypress 7280 yarder, downhill yarding [a]
Processing equipment	Madill 3800 carrier with Waratah processing head	Madill 3800 carrier with Waratah processing head [a]	Madill 3800 carrier with Waratah processing head [a]	Madill 3800 carrier with Waratah processing head [a]

[a] Monitored by FERIC in shift-level and detailed-timing studies.

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heterophylla), Sitka spruce *(Picea sitchensis),* western redcedar *(Thuja plicata),* red alder *(Alnus rubra),* and bigleaf maple *(Acer macrophyllum)* in varying proportions.

Felling operation and equipment

The study area in Block A was located above a single haul road, and loader-forwarding with an average distance of 100 m in a downhill direction was prescribed (Figure 1). Slope classes ranged from 0–10% to 61–70%. Block B was accessible to harvesting equipment from in-block spur roads with a total length of 1725 m (Figure 2). Loader-forwarding in a downhill direction, and grapple yarding in both uphill and downhill directions, were prescribed.

The study area in Block A was harvested with a Madill T2200 feller-buncher equipped with a 71-cm Quadco 2800 intermittent low-speed disc saw head (Figure 3), and in Block B with a Tigercat 860 feller-buncher with a 56-cm Quadco 22 high-speed disc saw head (Figure 4). Both heads have 360-degree lateral tilt abilities. This full tilt allows the feller-buncher operator to maintain control of the felled stems such that the bunches can be released closer to the ground than with standard 40-degree felling heads. This delayed release mitigates the impact of the stems on the ground and reduces stem breakage.

The technical specifications (Table 3) show that the Madill T2200 and the Tigercat 860 are comparable in terms of power rating, mass, basic dimensions, boom reach, and lift capacity. Both

Table 2. Site and stand descriptions

	Block A	Block B
Total area (ha)	43.0	29.9
Study area (ha)	17.4	29.9
Site characteristics		
Ecological classification [a]	CWHvm1	CWHxm2
Elevation range (m)	150–300	300–400
Terrain	Gentle to steep	Gentle to steep
Slope		
Range (%)	10–70	10–70
Average (%)	45	35
Soils		
Mineral soil texture	Till	Sandy loam
Coarse fragment content (%)	n.a.	40
Compaction hazard	High	Moderate
CPPA terrain classification [b]	2.3.4	1.2.4
Stand characteristics		
Species composition (%)		
Douglas-fir	81	89
Western hemlock	18	10
Spruce, redcedar, alder, maple	1	1
Net merchantable volume		
m^3/ha	500	513
m^3/tree	1.12	0.95

[a] Green and Klinka 1994.
[b] Mellgren 1980.

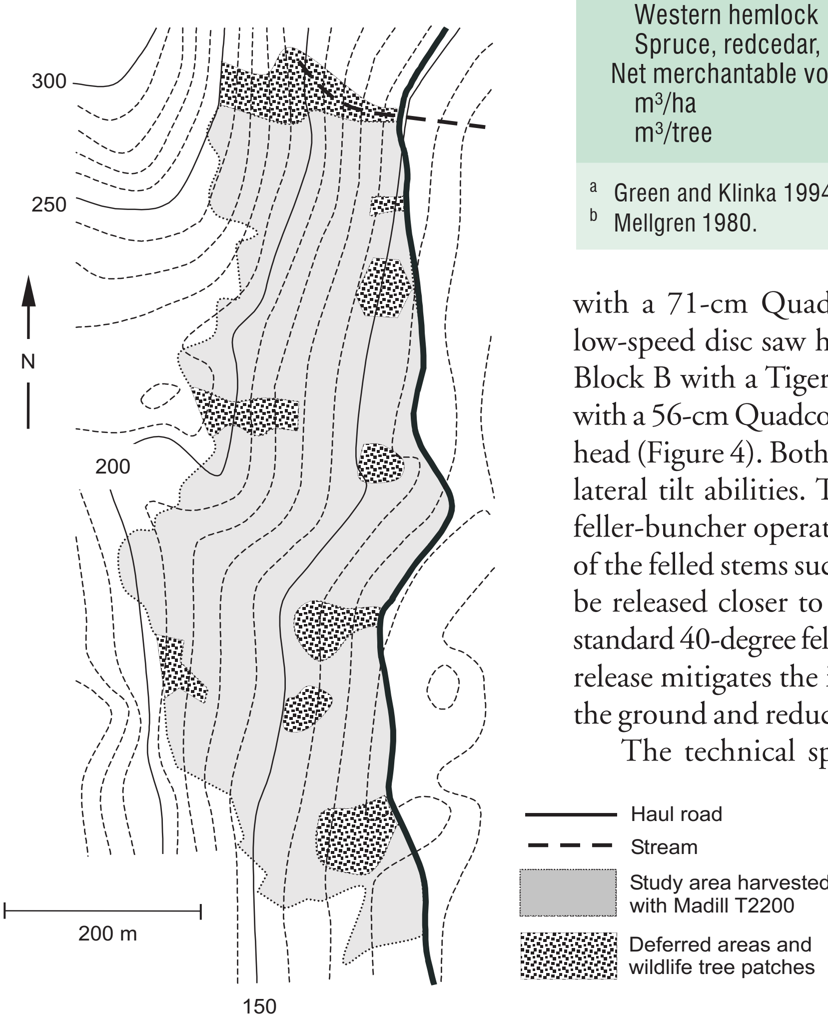

Figure 1. Layout of Block A.

Figure 2. Layout of Block B.

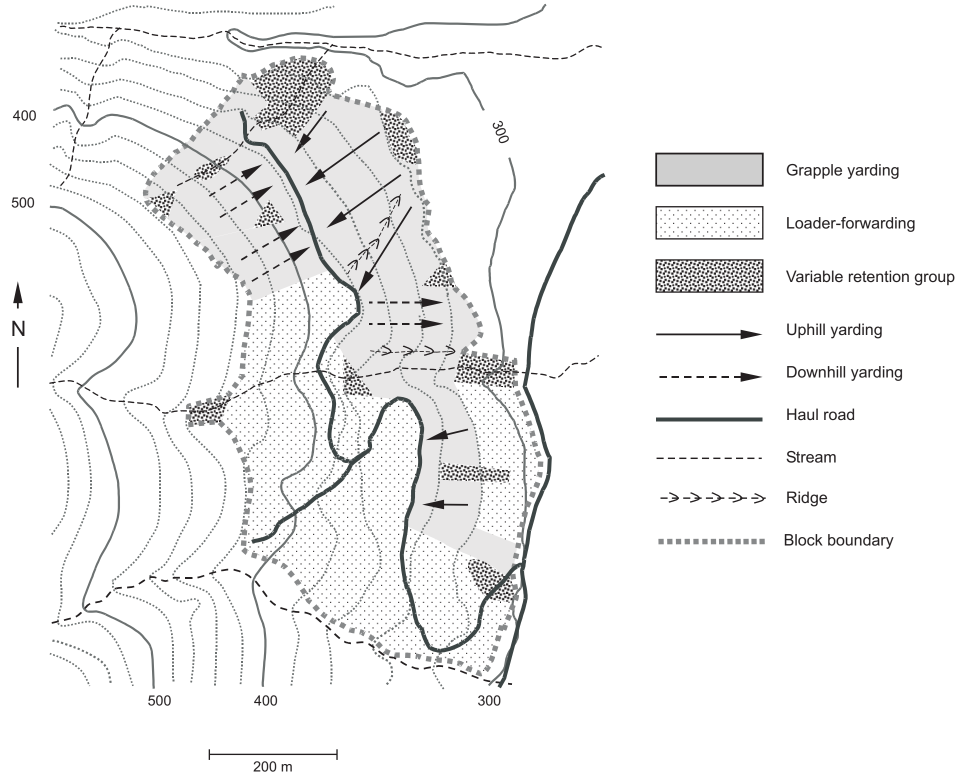

Figure 3. Madill T2200 feller-buncher equipped with a Quadco 2800 intermittent low-speed saw head.

Figure 4. Tigercat 860 feller-buncher equipped with a Quadco 22 high-speed saw head.

feller-bunchers can also tilt (level) their machinery decks (i.e., operator cabs and engine compartments) to maintain the machine's stability. This improves the operator's comfort and safety while working on steep slopes.

The main differences between the two machines were the felling heads. The saw blade in the Quadco 22 felling head spins continuously at 1100 rpm. During the cutting cycle, the head advances quickly and smoothly into the tree, and the cutting time is usually less than one second. The low-speed blade in the Quadco 2800 felling head rotates only when cutting a tree. The blade is mounted on a swinging arm that allows the felling head to fully grasp the tree when the blade is in the retracted position. Once the grapple arms close, the saw blade advances, usually taking 4–5 seconds to cut through the tree. Because motor power, not kinetic energy, is used to cut the tree, low-speed saws can be used on larger-diameter trees. According to the distributor, when cutting trees with butt diameters of 56 to 60 cm, the 71-cm intermittent saw is reported to be more efficient than 56-cm high-speed saws (no matter the brand) because the feller-buncher does not have to travel around the tree to complete the double or triple cut.[1]

1 Alain Perron, Quadco Equipment Inc., St. Eustache, Que.; personal communication, July 2003.

Both feller-bunchers were scheduled to work five days per week. The Madill T2200 worked on a double-shift basis, and the Tigercat 860 worked in a single-shift system. The three operators were familiar with all phases of harvesting on steep slopes and very experienced in operating their machines in difficult terrain.

The feller-buncher operators were provided with maps showing the boundaries of the block, road network, deferred areas, variable retention groups, wildlife tree patches, and areas prescribed for loader-forwarding and grapple-yarding.

Table 3. Technical specifications for the Madill T2200 and Tigercat 860 feller-bunchers

	Madill T2200	Tigercat 860
Engine	Cummins 6 CTA 8.3	John Deere
Power (kW)	172 @ 2000 rpm	186 @ 2 200 rpm
Mass (kg)	30 400	30 720
Width (m)	3.2	3.15
Length (m)	11	11.5
Undercarriage clearance (m)	0.66	0.78
Boom system		
Cut radius		
Maximum (m)	8.2	8.6
Minimum (m)	4.0	4.6
Lift capacity at full reach (kg)	2 860	2 720
Tilt angle (degrees)	Forward 30, each side 10, rearward 0	Forward 17, each side 10, rearward 5
Fuel tank capacity (L)	833	1 305
Felling head	Quadco 2800 intermittent low-speed saw head	Quadco 22 high-speed saw head
Cutting capacity (cm)	71	56
Blade speed (rpm)	600	1 100

Study methods

FERIC observed the harvesting operation and collected shift-level and detailed-timing data. Sources of shift-level data for the felling phase consisted of datalogger charts, operators' reports about daily production and major delays (>15 min/occurrence), and TimberWest's scale records containing net harvest volumes.

Felling cycles were detail-timed at frequent intervals throughout the study period. Each timed cycle was divided into four elements: grab, cut, and bunch; move feller-buncher; brush and move debris; and in-cycle delays. Slope, number of stems per cycle, and reasons for observed delays were also recorded. A one-way analysis of variance (ANOVA) was used to test whether the felling cycle times were affected by the slope class. The results of the analysis were then combined with the utilization coefficients to derive productivity and cost functions. Hourly feller-buncher costs were calculated using FERIC's standard costing methods (Appendix I). Scheduled hours per year for the Madill T2200 and the Tigercat 860 were estimated at 15 000 and 10 000, respectively.

Results and discussion

Overview of felling operations

Felling in Blocks A and B was performed during an extended rainless period from late April to early June 2002. Overall, the study block harvested by the Madill T2200 was slightly steeper than the block harvested by the Tigercat 860. Maximum slope classes accessible by the Tigercat 860 and Madill T2200 in this study were 51–60 and 61–70%, respectively.

Terrain gradient, extraction method (loader-forwarding or grapple yarding), and extraction direction dictated the feller-buncher's direction of travel and stem placement. Travel direction was either up-slope, down-slope, or across-slope, and stem placement was either in front of the machine, to the rear of the machine, or to the side of the machine. On the level-to-moderately-steep slopes (0–30%) prescribed for loader-forwarding, all travel directions and all drop locations were used. To maintain the stability of the machine on slopes ranging from 31 to 50%, the operator preferred up-slope travelling with bunching to the front or side of the machine. For the steepest terrain, up-slope travelling and bunching to the front were used almost exclusively.

Because of the topography and size of the stems, the feller-bunchers rarely handled more than one stem per cycle. However, to facilitate extraction operation, multi-stem bunches were built on the ground. Their size and orientation depended on the extraction mode (Figure 5).

Shift-level study

The Madill T2200 and the Tigercat 860 harvested 7300 and 16 110 m³, respectively. Table 4 summarizes shift structures, productivity in m³/productive machine hour (PMH) and m³/scheduled machine hour (SMH), and costs in $/m³ in Blocks A and B.

Figure 5. Bunches built by the Tigercat 860 feller-buncher for loader-forwarding in Block B.

Table 4. Shift-level summary and productivity for the Madill T2200 and Tigercat 860 feller bunchers

Description	Madill T2200	Tigercat 860
Productive shifts (no.)	15	24
Productive machine hours (PMH)	103.5	209.3
Mechanical delays (MD) (h)	13.8	39.5
Non-mechanical delays (h)	0	5.2
Total all delays (h)	13.8	44.7
Scheduled machine hours (SMH) (h)	117.3	254
Average shift time (h)	7.8	10.6
Utilization (PMH/SMH) (%)	88	82
Availability [(SMH-MD)/SMH] (%)	88	84
Total volume (m³)	7 300	16 110
Volume (m³/stem)	1.12	0.95
Stems (no.)	6 518	16 958
Productivity		
m³/productive shift	487	671
m³/PMH	70.5	77.0
m³/SMH	62.2	63.4
m³/8.5-h shift	529	539
Cost ($/m³)	2.46	2.41

The Madill T2200 feller-buncher worked a total of 15 shifts, or 117 h, on a double-shift basis. Shift length ranged from 7 to 10 h and averaged 7.8 h. For the monitoring period, utilization was 88%, and almost all delays were caused by mechanical problems related to hydraulic components.

Overall, the Madill T2200's productivity was 70.5 m³/PMH. At a utilization of 88%, productivity translated into 62.2 m³/SMH. At an estimated hourly cost of $153.24/SMH (Appendix I), the felling cost for the Madill T2200 feller-buncher was calculated to be $2.46/m³.

The Tigercat worked 24 shifts, or 254 h, in a single-shift system. Shift length ranged from 4.5 to 14 h and averaged 10.6 h. Utilization was 82%, and the delay times were caused primarily by mechanical problems.

The Tigercat 860's productivity was slightly higher than that of the Madill T2200 and averaged 77 m³/PMH. At a utilization of 82%, productivity was 63 m³/SMH. For an estimated hourly cost of $151.64/SMH (Appendix I), the felling cost for the Tigercat 860 feller-buncher was $2.41/m³.

Detailed-timing study

The Madill T2200 and the Tigercat 860 feller-bunchers were detail-timed for 19.5 and 18.5 h, respectively, and the study results are summarized in Table 5. Figure 6 shows the frequency of slope classes in 10-percent intervals for both study blocks.

The average cycle times for the Madill T2200 and Tigercat 860 were 0.97 and 0.77 min, respectively. The difference occurred mainly in the combined time of "Grab, cut, and bunch" elements. This time averaged 0.47 min/cycle for the Madill T2200 and 0.36 min/cycle for the Tigercat 860. The difference in these combined cycle time elements can be attributed to the different types of felling heads (intermittent low-speed saw on the Madill, and high-speed saw on the Tigercat) and differences in steepness of the blocks. The "brush and move debris" element was shorter for the Tigercat 860 because the stand harvested with this machine had been thinned, and therefore had a more uniform structure, fewer undersized stems, and less debris.

The gradient on the study block harvested by the Madill T2200 varied from 0 to 70%, and Figure 7 shows cycle times by slope classes. For classes from 0–10% to 51–60%, the differences in cycle times were not significant, and the average time was 0.95 min/cycle. For the steepest slopes in this study (class 61–70%), the cycle time of 1.92 min was more than twice the cycle time for the less steep portions of the study block. This class is probably the maximum operational limit for the Madill T2200. Lanford and Stokes (1984) found a similar effect of the slope classes up to 60% on the Timbco Hydro-Buncher's performance.[2]

The gradient of areas harvested by the Tigercat 860 varied from 0 to 60%. For all

Table 5. Summary of detailed timing for the Madill T2200 and the Tigercat 860 feller-bunchers

Description	Madill T2200	Tigercat 860
Productive time (min)	1167	1107
Productive machine hours (PMH)	19.5	18.5
Total cycles (no.)	1205	1446
Stems (no.)	1231	1498
Distribution of cycle time		
Grab, cut, and bunch (min)	0.47	0.36
Move feller-buncher (min)	0.26	0.25
Brush and move debris (min)	0.19	0.14
Delays (min)	0.05	0.01
Average cycle time (min)	0.97	0.77
Productivity (stems/PMH)	63	81

2 Because of the small average stem volumes harvested by the Timbco (0.12 m³), its productivity and cost cannot be compared with the results of the current study.

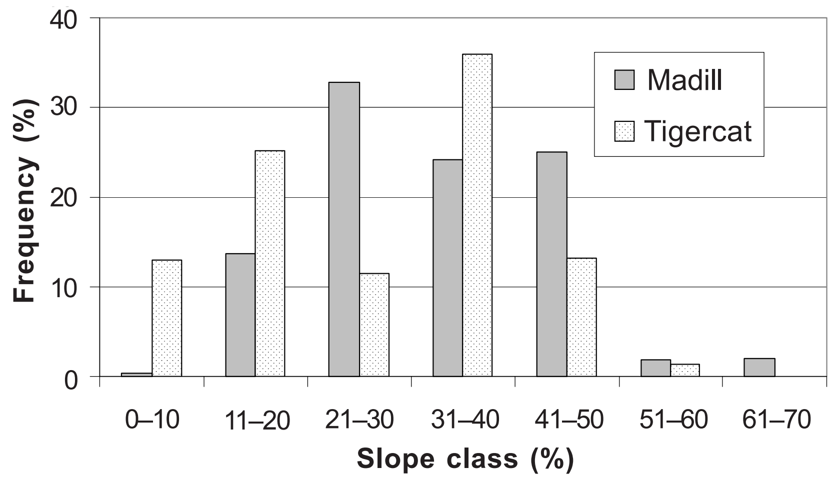

Figure 6. Frequency of slope classes for the Madill T2200 and Tigercat 860 feller-bunchers.

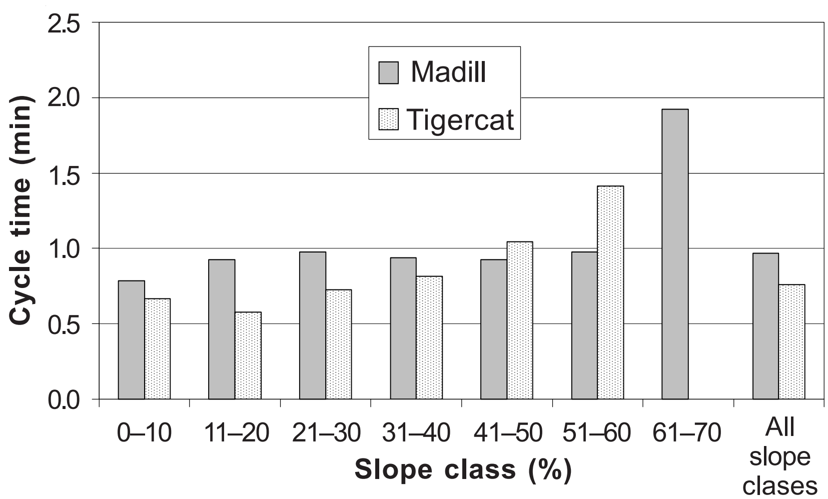

Figure 7. Average cycle times for the Madill T2200 and Tigercat 860 feller-buncher, by slope class.

slope classes, the differences between the Tigercat's cycle times are significant, and the cycle times increased as the slope class increased (Figure 7). Portions of the block with gradients above 60% were too steep for the feller-buncher and were left for hand falling.

Because the feller-bunchers rarely handled more than one stem per cycle and average stem volumes were similar (1.12 and 0.95 m^3/stem for the Madill T2200 and the Tigercat 860, respectively), an assumption may be made that cycle times for these machines were not affected by average piece volume.

For the first four slope classes, the Tigercat's cycle times were about 23% shorter than the cycle times for the Madill T2200. However for the slope classes 41–50% and 51–60%, the Madill's cycle times were shorter than that of the Tigercat 860. Because the steepest ground constituted only a small portion of the block areas, the average cycle time on all slope classes for the Tigercat 860 was 22% less than for the Madill T2200, which is similar to the difference in the lower slope classes.

Predicted productivities and costs

The shift-level and detailed-timing results for the two feller-bunchers were combined to estimate productivity during scheduled felling time (Equation 1, Appendix II) and to estimate unit cost (Equation 2, Appendix II). To facilitate comparison of productivities and costs for both machines, a *uniform* volume of 1.0 m^3/felling cycle and an assumed long-term utilization of 85% were used. Overall, the estimated productivities and costs of the Madill T2200 and the Tigercat 860 are about 53 and 68 m^3/SMH at costs of \$2.86 and \$2.25/m^3, respectively

Estimated productivities for both feller-bunchers by slope class are shown in Figure 8. For slope classes ranging from 0–10% to 51–60%, the differences in the Madill T2200's productivities are relatively small. For these classes, the productivity averages 55.6 m^3/SMH. Productivity decreases to 26.5 m^3/SMH for the slope class 61–70%. For the Tigercat 860, the productivity visibly decreases as the slope class increases. For the first four slope classes (0–10 to 31–40%), the Tigercat's productivities are, on average, about 30% greater than those for the Madill. For steeper terrain (slope classes 41–50% and 51–60%), the Tigercat's productivities were, on average, about 20% less than the Madill's productivities.

Estimated felling costs for the two feller-bunchers are presented in Figure 9. For slope classes 0–10% to 51–60%, the Madill T2200's felling costs are similar and average about \$2.80/m^3. For slope class 61–70%, the average cost is higher, at \$4.20/m^3.

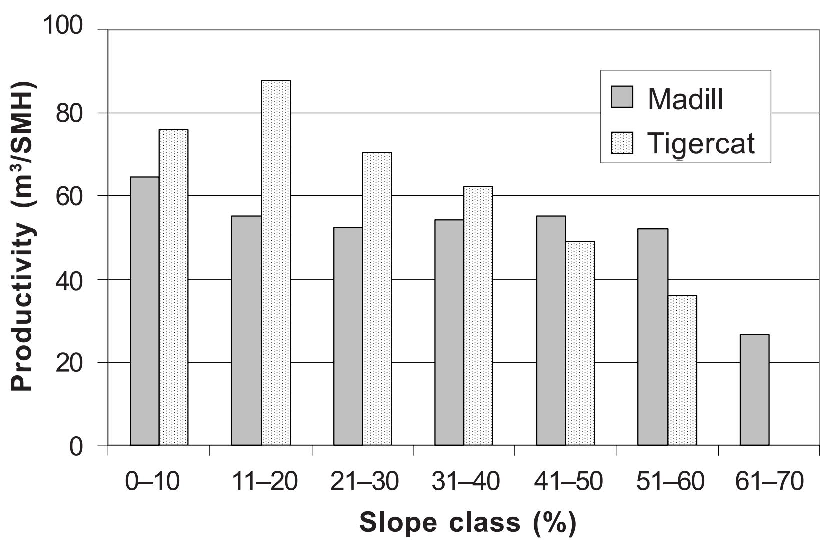

Figure 8. Estimated productivities for the Madill T2200 and Tigercat 860 feller-bunchers, by slope class.

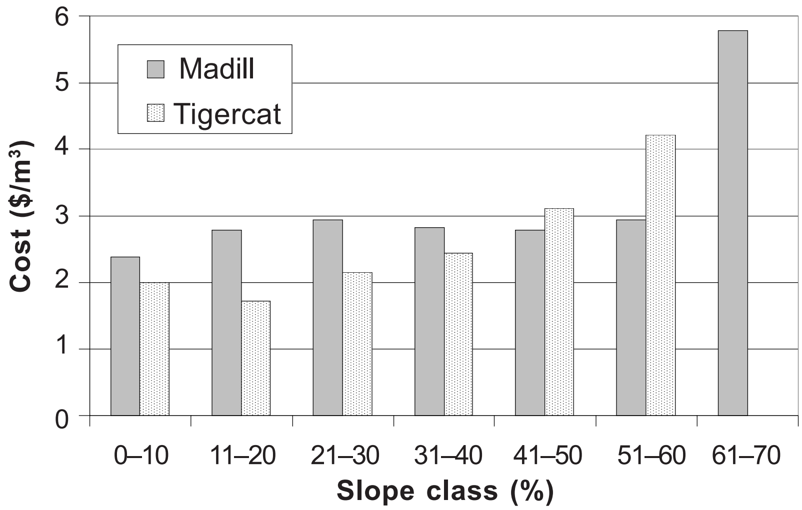

Figure 9. Estimated costs for the Madill T2200 and Tigercat 860 feller-bunchers, by slope class.

For the Tigercat 860, the estimated costs depend on slope class. For the first four classes, costs average \$2.10/m³ and are about 25% less than those for the Madill T2200. For the next two classes, however, the Madill T2200 is more cost-efficient.

Conclusions

In the spring of 2002, FERIC monitored the operational and economic feasibility of using mechanized systems for clearcut harvesting of second-growth on steep slopes in coastal British Columbia.

The study demonstrated that the Madill T2200 feller-buncher equipped with a 71-cm Quadco 2800 intermittent low-speed disc saw head and the Tigercat 860 feller-buncher equipped with a 56-cm Quadco 22 high-speed disc saw head were capable of operating on steep terrain in second-growth coastal British Columbia forests. Both feller-bunchers can tilt (level) their machinery decks to maintain the machine's stability on slopes. Maximum slope classes accessible for the Tigercat 860 and the Madill T2200 in this study were 51–60% and 61–70%, respectively. The Madill 860 was double-shifted due to its higher capital cost, bringing the hourly rates for the two machines to a similar value.

Because of the topography and size of the stems (1.12 and 0.95 m³/stem for the Madill and the Tigercat, respectively), no attempts were made to accumulate stems before bunching. However, to facilitate extraction operations, multi-stem bunches were built on the ground.

For a uniform volume of 1.0 m³/felling cycle and an assumed long-term utilization of 85%, the estimated productivities and costs of the Madill T2200 and the Tigercat 860 are about 53 and 68 m³/SMH at costs of \$2.86 and \$2.25/m³, respectively.

Implementation

During the observed harvesting operation, FERIC identified conditions for successful and effective use of the Madill T2200 and the Tigercat 860 feller-bunchers on steep slopes:

- The Madill T2200 and the Tigercat 860 feller-bunchers can be employed on steep terrain but they should be operated exclusively by experienced operators.
- An early field reconnaissance of the cutblock by the machine operators is recommended to allow them to gain familiarity with the stand, topography, areas prescribed for different extraction modes, and potentially difficult locations. They should pay special attention to the areas with gradients close to the feller-buncher's maximum slope abilities and these areas should be identified on the setting map.

- To ensure good visibility, the felling operation on the steeper sections of the block should be limited to the daylight hours.
- On level-to-moderately-steep slopes, all travel and bunching directions can be used. To maintain stability on steeper terrain, the feller-buncher should travel up-slope and bunch to the front. Extended reaches of the boom should be avoided, especially while cutting large trees.
- Even if the stem sizes allow only single-stem bunching during felling, multi-stem bunches can still be created on the ground.
- In stands with substantial numbers of trees with butt diameters exceeding 56 cm, the Quadco intermittent low-speed disc saw is a better choice than a Quadco high-speed disc saw. The latter is more suitable for diameters less than 56 cm.
- To be competitive with the Tigercat 860, the Madill T2200 has to be employed in a multi-shift system due to its higher capital cost.

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Appendix I

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

	Feller-bunchers	
	Madill T2200	Tigercat 860
OWNERSHIP COSTS		
Total purchase price (P) $	700 000	475 000
Expected life (Y) y	5	5
Expected life (H) h	15 000	10 000
Scheduled hours/year (h)=(H/Y) h	3 000	2 000
Salvage value as % of (P) (s) %	30	30
Interest rate (Int) %	5	5
Insurance rate (Ins) %	3	3
Salvage value (S)=((P · s)/100) $	210 000	142 500
Average investment (AVI)=((P+S)/2) $	455 000	308 750
Loss in resale value ((P-S)/H) $/h	32.67	33.25
Interest ((Int · AVI)/h) $/h	7.58	7.72
Insurance ((Ins · AVI)/h) $/h	4.55	4.63
Total ownership costs (OW) $/h	44.80	45.60
OPERATING COSTS		
Fuel consumption (F) L/h	30	30
Fuel (fc) $/L	0.75	0.75
Lube & oil as % of fuel (fp) %	15	15
Track & undercarriage replacement (Tc) $	37 000	25 000
Track & undercarriage life (Th) h	5 000	5 000
Annual repair & maintenance cost (Rp) $	108 000	72 000
Shift length (sl) h	8	8
Operator wages $/h	29.01	29.01
Wage benefit loading (WBL) %	35	35
Fuel (F · fc) $/h	22.50	22.50
Lube & oil ((fp/100) · (F · fc)) $/h	3.38	3.38
Track & undercarriage (Tc/Th) $/h	7.40	5.00
Repair & maintenance (Rp/h) $/h	36.00	36.00
Wages & benefits (W · (1+WBL/100)) $/h	39.16	39.16
Total operating costs (OP) $/h	108.44	106.04
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/SMH	153.24	151.64

[a] The costs used in the study are not the actual costs incurred by the company or contractor, and do not include indirect costs such as crew and machine transportation, overhead, profit, and risk.

Appendix II

Productivity and cost equations

Equation 1

$$\text{Productivity} = \frac{60(CV)(U)}{CT}$$

Where:

Productivity	=	predicted productivity in m^3/SMH
CV	=	average volume per felling cycle (m^3)
U	=	utilization (%/100)
CT	=	felling cycle delay times included (min)

Equation 2

$$\text{Cost} = \frac{HC}{\text{Productivity}}$$

Where:

Cost	=	predicted felling cost in \$/m^3
HC	=	estimated felling cost in \$/SMH
Productivity	=	predicted felling productivity in m^3/SMH from Equation 1