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INSTITUT CANADIEN DE RECHERCHES EN GÉNIE FORESTIER

THE DATE CREEK STUDY: PRODUCTIVITY OF GROUND-BASED HARVESTING METHODS IN THE INTERIOR CEDAR–HEMLOCK ZONE OF BRITISH COLUMBIA

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Abstract

The Date Creek Silvicultural Systems Study compared clearcut, heavy removal, and light removal silvicultural systems in 135-year-old hemlock/cedar stands in northwestern British Columbia. The Forest Engineering Research Institute of Canada (FERIC) monitored productivities and costs of mechanized, conventional, and horse skidding harvesting systems on six study blocks (two clearcuts, three heavy removals, and one light removal). FERIC's objectives were to assess planning and harvesting productivities and costs; assess soil disturbance levels; and identify ways to improve operational planning and implementation of partial cutting silvicultural systems in Interior Cedar-Hemlock ecosystems.

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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.

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Table of Contents

Abstract	ii
Authors	ii
Disclaimer	ii
Acknowledgments	ii
Summary	v
INTRODUCTION	1
OBJECTIVES	2
STUDY SITE AND HARVESTING SYSTEMS	2
Biogeoclimatic Description	2
Silvicultural Prescriptions	4
Harvesting System Description	5
STUDY METHODS	5
RESULTS AND DISCUSSION	7
Overview	7
Productivities and Costs	7
Harvesting	10
Skidding	11
Summary of Harvesting Costs	23
Soil Disturbance	24
Slash Accumulation	26
SUMMARY AND CONCLUSIONS	26
RECOMMENDATIONS	28
Planning and Layout	28
Falling	28
Harvesting and Skidding Systems	28
REFERENCES	29
APPENDICES	30
Appendix I	30
Planning and Layout	30
Planning Time Estimates Based on Productivity Assumptions	31
Appendix II	34
Falling Productivities and Costs	34
Appendix III	35
Machine and Horse Costing	35
Costing Assumptions for the Horse Logging Operation	38

List of Tables

1 Descriptions of Sites and Stands 3
2 Equipment and Labour Complement for Contractors Involved in the Case Studies 6
3 Harvested Volume for Each Case Study 7
4 Planning Requirements by Case Study 9
5 Shift-Level Activities of Feller-Buncher—Clearcut and Heavy Removal Units 10
6 Falling Costs 12
7 Detailed Timing of Skidding Phase: Unit A-3—Clearcut 13
8 Detailed Timing of Skidding Phase: Unit B-4—Clearcut 13
9 Shift-Level Productivity and Skidding Cost: Unit A-3—Clearcut 14
10 Shift-Level Productivity and Skidding Cost : Unit B-4—Clearcut 15
11 Detailed Timing of Skidding Phase: Unit B-2—Heavy Removal 16
12 Detailed Timing of Skidding Phase: Unit B-3—Heavy Removal 17
13 Detailed Timing of Skidding Phase: Unit C-2—Heavy Removal 18
14 Shift-Level Productivity and Skidding Cost: Unit B-2—Heavy Removal 19
15 Shift-Level Productivity and Skidding Cost: Unit B-3—Heavy Removal 20
16 Shift-Level Productivity and Skidding Cost: Unit C-2—Heavy Removal 21
17 Detailed Timing of Skidding Phase: Unit C-3—Light Removal 22
18 Shift-Level Productivity and Cost of Skidding Phase for Horse System: Unit C-3—Light Removal 22
19 Overall Costs for Planning, Falling, and Skidding, by Case Study 23
20 Soil Disturbance by Case Study 25

List of Figures

1 Location of study area. 1
2 Clearcut treatment Unit B-4. 4
3 Heavy removal treatment Unit B-2. 4
4 Light removal treatment Unit C-3. 4

Summary

In 1992 the British Columbia Ministry of Forests (BCMOF) Prince Rupert Forest Region and Kispiox Forest District initiated the Date Creek Silvicultural Systems Study to investigate the biological effects of various partial cutting prescriptions on ecosystem dynamics in Interior Cedar-Hemlock (ICH) stands of northwestern British Columbia. The study compared clearcut, heavy removal, and light removal silvicultural systems in 135-year-old hemlock/cedar stands in Date Creek, north of Kispiox, B.C.

The overall objectives of the BCMOF study were to better understand ecosystem function in ICH forests, and to aid in the development of silvicultural systems for maintaining biological diversity, hydrological integrity of watersheds, wildlife habitat, and wood production. A replicated experiment was established with four levels of tree removal as treatments (in approximately 20-ha treatment units): (1) no removal; (2) light removal where 30% of the tree volume was removed in either single stems or small groups of stems (similar to a single-tree or group selection, or a light initial shelterwood); (3) heavy removal where 60% of the volume was removed using a combination of small patch cuts (1000–5000 m^2) and single-tree to small group selection in the forest matrix between the patch cuts (similar overall to an irregular shelterwood system); and (4) total removal or clearcut. Within this framework a multidisciplinary set of experiments was established to examine ecosystem processes and timber production.

FERIC's objectives were to assess planning and harvesting productivities and costs; assess soil disturbance levels; and identify ways to improve operational planning and implementation of partial cutting silvicultural systems in this ecosystem. FERIC monitored productivities and costs of mechanized, conventional, and horse skidding harvesting systems on six study blocks (two clearcuts, three heavy removals, and one light removal).

Between July and December 1992, four contractors harvested the six study blocks described in this report. FERIC collected shift-level and detailed-timing data on all skidding and mechanized falling activities, summarized planning requirements in terms of the type and scope of field work required for each of the study blocks, and surveyed soil disturbance after harvesting. Actual labour inputs for planning and hand falling could not be obtained and were estimated indirectly from other sources. All costs were calculated using standard FERIC procedures.

The partial cutting prescriptions defined for this study clearly required more intensive planning and field work than clearcut blocks of similar size. Based on the actual workloads by study block and assumed productivities, the heavy removal and light removal prescriptions required 2.3 and 1.9 times the planning effort (on a per-hectare basis), respectively, of the clearcuts. However, the heavy removal prescription recovered a substantially larger proportion of the developed timber volume and therefore used planning resources more efficiently than the light removal prescription. Costs of planning and layout were estimated at \$0.65/m^3 for clearcut harvests, \$2.66/m^3 for heavy removal harvests, and \$4.66/m^3 for light removal harvests.

The feller-buncher produced 413 m^3/8-h shift at a cost of \$2.84/m^3 when falling and bunching trees in the clearcut, and 262 and 404 m^3/8-h shift at costs of \$4.47/m^3 and \$2.91/m^3, respectively, when falling and bunching trees in the patch openings of the heavy removal cuts.

Indirect estimates indicated that in clearcuts, hand falling costs 40–50% more than mechanized falling (\$4.11/m^3 for hand falling compared to \$2.84/m^3 for mechanized falling). Relative to clearcuts, hand falling costs were estimated to be 24% higher in heavy removal patch cuts (\$5.08/m^3), 62% higher in individual tree selection when falling for line skidders (\$6.67/m^3), and 136% higher in light removal when falling for extraction by horses (\$9.71/m^3).

Skidding was done with a grapple skidder, several line skidders, and several teams of horses. The grapple skidder achieved average production rates and costs of 334 m^3/8-h shift and \$2.30/m^3, respectively, on the clearcut unit and 195–214 m^3/8-h shift and \$3.59–\$3.95/m^3, respectively, in patches on two heavy removal units. Line skidder production rates and costs averaged 119–141 m^3/8-h shift and \$4.88/m^3, respectively, on the clearcut unit and 57–71 m^3/8-h shift and \$9.07–\$10.41/m^3, respectively, in patches on the heavy removal units. Line skidder production rates and costs averaged 55–87 m^3/8-h shift and \$7.15–\$11.84/m^3, respectively, in the individual tree selection areas of the heavy removal units. The production rates and costs for the horse teams averaged 11.6–23.4 m^3/shift and \$10.74–\$17.87/m^3, respectively, on the light removal unit.

Overall planning, falling, and skidding costs were estimated at \$5.85/m^3 for mechanized clearcut operations, \$9.60/m^3 for conventional clearcut operations, \$14.46–\$14.51/m^3 for combined conventional/mechanized operations in heavy removals, \$19.00/m^3 for conventional operations in heavy removals, and \$28.95/m^3 for horse skidding in the light removal. Relative to the mechanized system, the conventional system had higher falling and skidding costs in the clearcut prescription, and higher skidding costs in the heavy removal prescription. The horse skidding operation in the light removal prescription had the highest costs in all phases as well as overall.

The mechanized system is clearly the most cost-effective option for clearcut prescriptions and can work effectively in partial cutting if patch cutting is employed, at least for the site and stand conditions observed in this trial. Finally, although expensive, horse skidding was well-suited for light removal in this trial in terms of ability to work in high-density stands. However, production rates and costs cannot be readily compared to the other mechanical and conventional operations.

Although only one of the six study blocks (the horse-logged light removal unit) satisfied study objectives for road, landing, and skidding soil disturbance levels, the disturbance objectives set for the study blocks were realistic and achievable. Landings were within acceptable limits on all sites, but poor construction practices on main access roads resulted in excessive haul road disturbance on two study blocks. The two conventional and three mechanized harvesting operations exceeded allowable skidding disturbance levels. Skidding in wet weather was suggested as the primary reason for higher-than-expected levels of dispersed skidding disturbance in the two clearcut units. The practice of using some small patches to store logs when landings were temporarily filled resulted in substantial disturbance to the patches, causing skidding disturbance to exceed specified limits in the three heavy removal blocks.

During the course of the harvesting operations, FERIC researchers identified opportunities for potentially improving the operational efficiency and/or cost of partial cutting in ICH stands. Suggestions are presented; these assume that the same light- and heavy-removal silvicultural prescriptions apply, ground-based harvesting systems are used, and stand and site conditions are similar to those observed in this study.

INTRODUCTION

Forest management objectives and practices in British Columbia are changing rapidly to place stronger emphasis on non-timber resources. In particular, partial cut prescriptions are not only encouraged, but in some cases are now required, to meet new management goals. Foresters recognize that partial cutting will affect harvesting economics, soil characteristics, residual stand growth and health, and the subsequent establishment, diversity and productivity of plant and animal species, in different ways and magnitudes than clearcutting. Because experience with partial cutting is still limited for many of British Columbia's forest ecosystems, research is needed to learn how to manage forests under these regimes.

The Date Creek Silvicultural Systems Study, located west of Smithers in northwestern British Columbia (Figure 1), was designed to develop a better understanding of the function of the forest and the short- and long-term effects of varying intensities of stand removal in Interior Cedar-Hemlock (ICH) stands. The British Columbia Ministry of Forests (BCMOF), Prince Rupert Forest Region, in cooperation with the Kispiox Forest District, initiated planning for the study in 1990. The overall objectives of the BCMOF study were to better understand ecosystem function in ICH forests, and to aid in the development of silvicultural systems for maintaining biological diversity, hydrological integrity of watersheds, wildlife habitat, and wood production. A replicated experiment was established with four levels of tree removal as treatments, in approximately 20-ha treatment

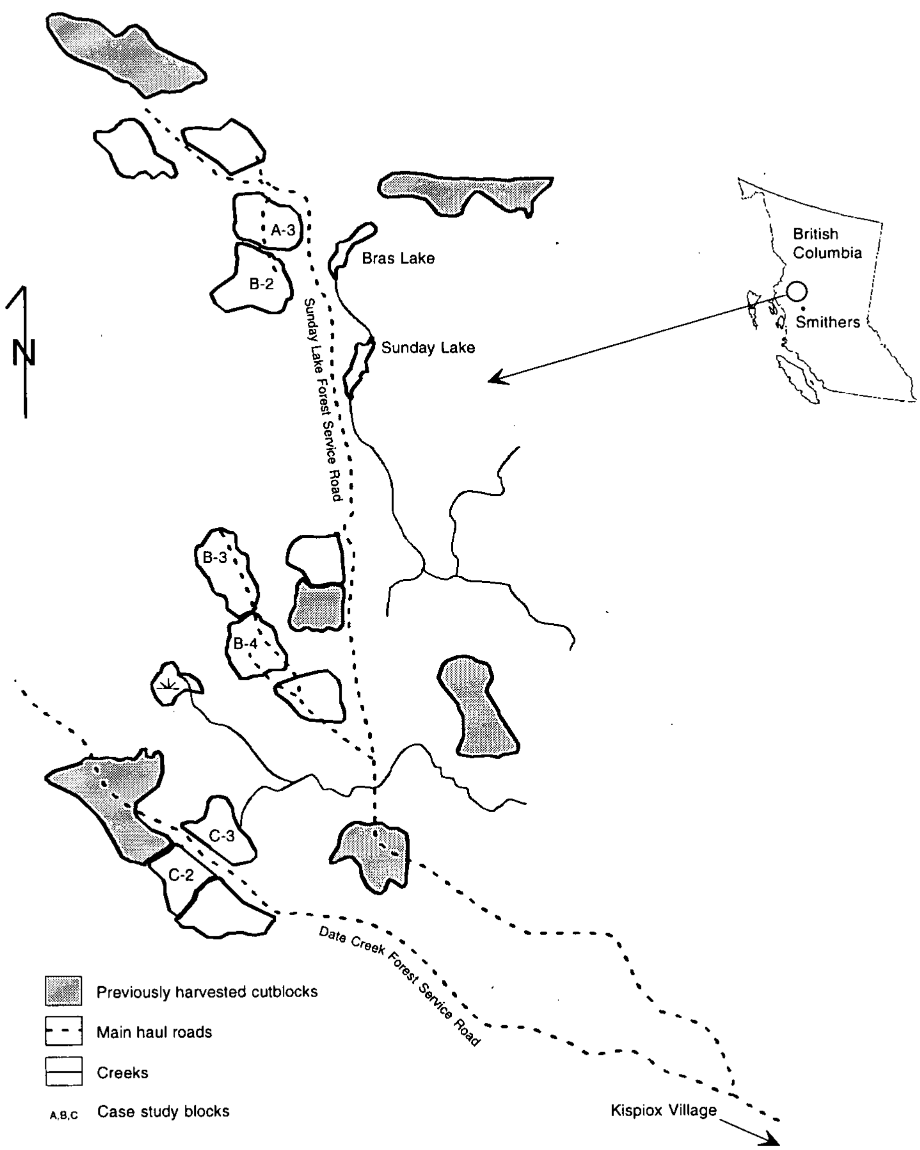

Figure 1. Location of study area.

units: (1) no removal; (2) light removal where 30% of the tree volume was removed in either single stems or small groups of stems (similar to a single-tree or group selection, or a light initial shelterwood); (3) heavy removal where 60% of the volume was removed using a combination of small patch cuts (1000–5000 m^2) and single-tree to small group selection in the forest matrix between the patch cuts (similar overall to an irregular shelterwood system); and (4) total removal or clearcut. Within this framework a multidisciplinary set of experiments was established to examine ecosystem processes and timber production (see Coates et al [1996] for a more detailed overview of the project).

While the focus of the Date Creek Silvicultural Systems Study was biological, the BCMOF also recognized that the harvesting operations would provide valuable insights about the adjustments needed to adapt harvesting systems and work forces from traditional clearcutting to partial cutting practices. Therefore, in late 1991 the BCMOF approached the Forest Engineering Research Institute of Canada (FERIC) to cooperate by monitoring the harvesting operations. The FERIC study was funded in part by the BCMOF through its Alternative Silvicultural Systems Research Program and by the Forestry Practices component of the Canadian Forest Service's Green Plan.

This report presents the case study results of two clearcut and four partial cut harvesting operations monitored by FERIC during the summer and fall of 1992. In the clearcut operations, both conventional line skidder and mechanized grapple skidder systems were used. In the partial cut operations, horses, line skidders, and both line and grapple skidders completed the skidding phase. As well as productivity, cost, and site disturbance results, the report identifies opportunities in the planning, layout, and harvesting phases to improve the operational effectiveness of partial cutting within this ecosystem.

OBJECTIVES

The objective of the FERIC study was to estimate, by means of case studies, the productivities and costs of ground-based harvesting operations in clearcut and partial cut silvicultural prescriptions in the ICH zone of the Prince Rupert Forest Region.

Specific FERIC objectives were to:

- Summarize and discuss the planning and layout requirements for each case study.
- Estimate, compare, and contrast the productivities and costs of conventional and mechanized systems in clearcut and partial cut harvesting operations, and the cost and productivity of horse logging in a partial cut operation.
- Estimate the sources and extent of potentially degrading soil disturbance associated with each case study.
- Identify opportunities in the planning, layout, and harvesting phases to increase productivity and reduce costs and soil disturbance in summer partial cutting operations.

This report presents and discusses the results of FERIC's study of the summer logging operations performed for the Date Creek Silvicultural Systems Study.

STUDY SITE AND HARVESTING SYSTEMS

The study blocks monitored by FERIC were located in the Kispiox Forest District, between 13 and 18 km northwest of the village of Kispiox, along the Date Creek and Sunday Lake Forest Service Roads (Figure 1). Kispiox is north of Highway 16, 94 km northwest of Smithers.

Site and Stand Description

All case studies were conducted in the ICH biogeoclimatic zone of the Prince Rupert Forest Region; specifically, the Hazelton variant of the Moist Cold Interior Cedar Hemlock ecosystem (ICHmc2) (Banner et al 1993). The mesic phase of the ICHmc2 subzone predominates in the treatment units, with submesic to mesic, and mesic to subhygric associations scattered within individual treatment units. Combined with slopes averaging less than 25%, coarsely textured soils, and well-defined drainage patterns, all case study sites were considered by the BCMOF to be suitable for summer ground skidding.

Forests in the ICH zone are dominated by a mixture of conifer and deciduous tree species. In mature forests, western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) dominates, but is mixed with western red cedar (*Thuja plicata* Dougl. ex D. Don), amabilis fir (*Abies amabilis* [Dougl.] Forbes), lodgepole pine (*Pinus contorta* var *latifolia* Engelm.), hybrid spruce (the complex of white spruce [*Picea glauca* (Moench) Voss], Sitka spruce [*P. sitchensis* (Bong.) Carr.] and occasionally Engelmann spruce [*P. engelmannii* Parry ex Engelm.]), paper birch (*Betula papyrifera* Marsh.), trembling aspen (*Populus tremuloides* Michx.), and black cottonwood (*Populus balsamifera* ssp. *trichocarpa* Torr. & Gray). Subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) occurs at higher elevations.

Table 1 summarizes the silvicultural prescriptions, ecosystem classifications, soil, slope, terrain, stand characteristics, and timber volumes for each case study.

Table 1. Descriptions of Sites and Stands

Case study	A-3	B-4	B-2	B-3	C-2	C-3
Prescription	Clearcut	Clearcut	Heavy removal, 60% volume removal	Heavy removal, 60% volume removal	Heavy removal, 60% volume removal	Light removal, 30% volume removal
	Conventional harvest with dispersed skid trails	Mechanical harvest, skid roads	Conventional harvest, small patch and ITS [a]	Combination conventional and mechanical harvest, small patch and ITS	Combination conventional and mechanical harvest, small patch and ITS	Horse, ITS
Gross area (ha)	25.3	18.5	25.2	22.0	20.6	22.9
Slope (%)						
Range	0-35	0-25	0-30	0-20	0-45	0-30
Average	10	5	10	5	20	10
Terrain	even	even	even to rolling	rolling	even	even
Ecosystem	ICHmc2	ICHmc2	ICHmc2	ICHmc2	ICHmc2	ICHmc2
Stand composition (% by volume)						
Western hemlock	51	64	66	58	50	61
Western red cedar	19	15	15	17	24	10
Spruce	15	3	7	4	18	21
Subalpine and amabilis fir	2	3	5	3	7	6
Lodgepole pine	5	10	5	4	0	0
Deciduous	8	5	2	14	1	2
Average parameters						
Net merchantable volume (m^3/ha) [b]	442/484	343/360	374/380	257/298	524/529	492/502
Tree density (no./ha) [b]	689/837	528/618	859/872	537/680	810/829	771/802
Conifer volume (m^3/tree) [c]	0.64	0.65	0.44	0.48	0.65	0.64
Conifer diameter (cm)	36	31	29	28	31	31
Conifer total height (m)	29	26	28	25	30	30
Nonmerchantable snags						
Density (no./ha)	80	87	45	91	92	72
Diameter (cm)	31	26	31	25	26	32

[a] Individual tree selection.
[b] Conifer only/total for all species.
[c] Net merchantable.

Silvicultural Prescriptions

Three silvicultural prescriptions were used on the study blocks: clearcut, heavy removal, and light removal treatments. The prescriptions were written in terms of volume removal, with targets of 60% for the heavy removal and 30% for the light removal. All of the study units were medium-sized cutblocks ranging from 18 to 25 ha, with average skidding distances of between 90 and 180 m (except for the horse-logged unit which was between 50 and 80 m).

Figure 2 depicts Unit B-4, an 18.5-ha clearcut block with two landings and an average skidding distance at about 110 m. The block was laid out for conventional harvesting (hand falling and line skidding) because it had even terrain and gentle slopes. Figure 3 illustrates one of the heavy removal sites, Unit B-2. The unit was 25.2 ha in size, had designated skid roads and two landings, and had an average skidding distance of about 180 m. To meet the prescription, 24 clearcut openings of less than 0.5 ha each were distributed more or less uniformly throughout the block. Approximately 30–40% of the harvested volume was removed from the clearcut openings. Skid roads were located to access the patches while avoiding the steep pitches within the block. The remainder of the unit was harvested with light removal, meeting the overall prescribed 60% volume reduction.

Figure 4, Unit C-3, is the horse-skidded light removal unit. This area had generally uniform terrain, but contained

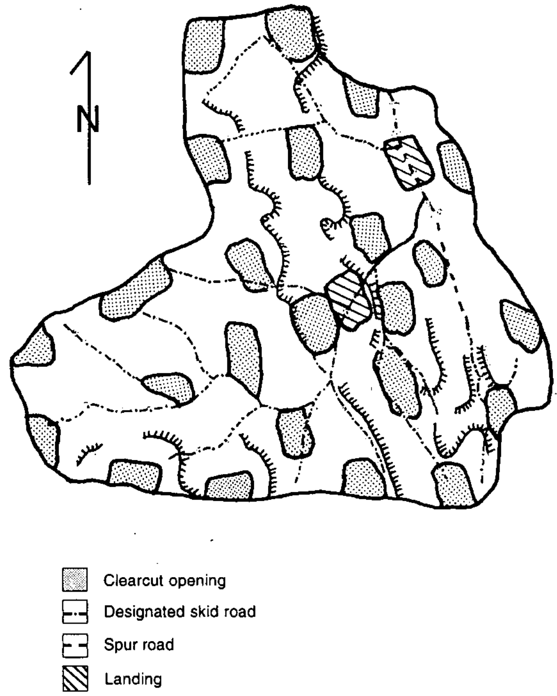

Figure 3. Heavy removal treatment Unit B-2.

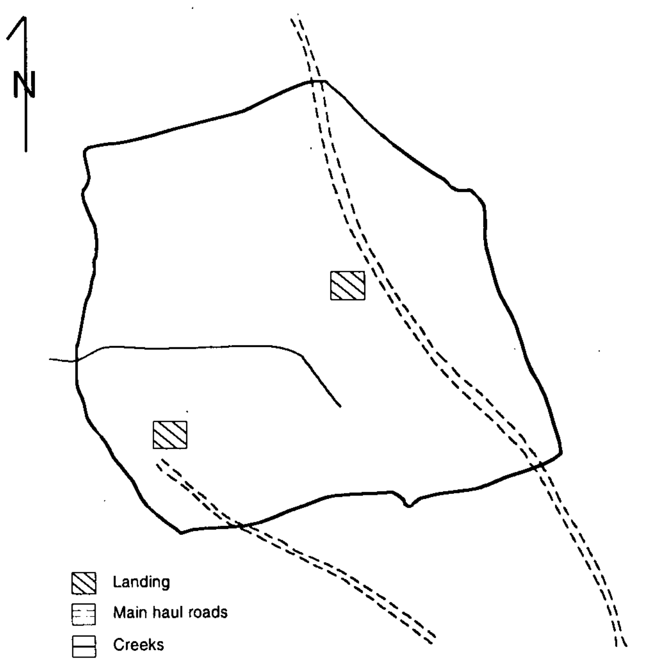

Figure 2. Clearcut treatment Unit B-4.

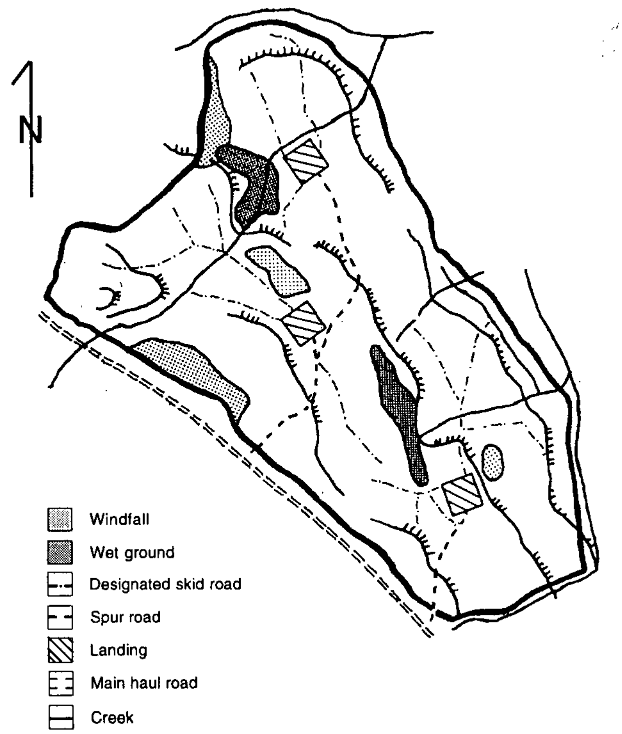

Figure 4. Light removal treatment Unit C-3.

some slopes to 30%. As well, wet areas and areas of windfall affected skidding patterns. Although unusual in horse logging operations, in this block adverse skidding was common.

Harvesting System Description

The harvesting equipment used in each case study was owned by the contractor participants in the Small Business Forest Enterprise Program (SBFEP). The contractors' harvesting equipment profiles, shown in Table 2, reflect the traditional use of the clearcut silvicultural system in the old-growth cedar/hemlock stands that characterize the Kispiox Timber Supply Area. At the time of this study, partial cutting was new to the Kispiox area and the Date Creek Silvicultural Systems Study was the contractors' first exposure to partial cutting. None of the contractors purchased new equipment for the trials, electing instead to adapt their existing equipment fleets and work forces to the new requirements of partial cutting.

Contractor A harvested three of the study units (B-3 and C-2, both heavy removals, and B-4, a clearcut) using a mechanized harvesting system consisting of a feller-buncher, a grapple skidder, one or two line skidders, and a processor. Contractors B and C harvested one study unit each (B-2, a heavy removal unit, and A-3, a clear-cut, respectively) using conventional ground skidding systems consisting of hand fallers and rubber-tired and tracked line skidders. Contractor D harvested one study unit (C-3, a light removal unit) using hand fallers and horses.

STUDY METHODS

Although the layout and cutting prescriptions were designed primarily to achieve research objectives, the treatment units were large enough to warrant administering as SBFEP sales.

All preliminary layout and cruising were done by contractors under the direction of BCMOF staff, and this information was supplied to FERIC. Operational cruises were conducted on all of the treatment units. Supplementary count plots were installed between main plots to collect additional tree-count data to aid tree marking. Based on cruise results, individual trees were marked for removal either singly or in groups, as required by the silvicultural prescription. Trees on proposed landings, skid roads and within-block spur roads contributed to the prescribed stand density reductions. Roads and landings were located prior to harvest in all units and, in partial cuts, primary and secondary skid trails were pre-located as well.

To obtain shift-level information for the conventional and mechanized skidding systems, FERIC installed a Servis recorder on each skidding machine and the feller-buncher, and maintained daily crew records. This provided the necessary information on productive and non-productive times for each machine during the study.

Over the course of the harvesting operations, each skidding machine in each treatment unit was timed in detail with stopwatches to provide specific information on the skidding cycles. The objective was to obtain 20 productive hours of detailed timing for each skidding machine, achieved in most but not in all cases. During the detailed-timing phase, the skidding cycle was sub-divided into cycle elements (travel empty, position, hookup, etc.), and skidding distances and pieces per cycle were also recorded. The horse skidding operation was monitored by intensive detailed timing and hand-scaling of skidding cycles, supplemented by shift-level reports from crew members.

Harvesting costs were calculated using FERIC's standard costing methods and were based on International Wood-worker of America (IWA) rates for workers and new equipment purchase prices (Appendix III). The costs used in the study were not those experienced by the contractors, and do not include supervision, overhead, profit, and risk allowances.

Costing the horse skidding operation was problematic because it was difficult to quantify the care requirements for the animals during non-working periods. Therefore the information in Appendix III illustrates the assumptions that FERIC used in its calculations and identifies the items excluded from the cost calculations. Estimates related to the purchase and care of horses and tack requirements were obtained from the horse logging contractors. IWA bucker rates were assigned to teamsters.

Harvested volumes were obtained from BCMOF weigh scale records and checked against tree marking reports and FERIC hand-scaling data. The wood harvested for contractor-built roads and landings was included in the scale summaries provided by the BCMOF. Right-of-way volumes therefore had to be estimated and removed from the gross volumes to determine the net treatment unit volumes. The harvest volumes for two of the blocks were combined, so the volume attributable to each block was estimated.

Post-harvest soil disturbance was assessed using BCMOF soil disturbance survey procedures in effect at the time of this study (Curran and Thompson 1991). A 70-m grid was established on each cutblock after harvest. At each intercept point, two 30-m transects were located, the first at a random bearing and the second perpendicular to the

Table 2. Equipment and Labour Complement for Contractors Involved in the Case Studies

Contractor	Contractor A			Contractor B	Contractor C	Contractor D
Case study—Prescription	B-4—Clearcut	B-3—Heavy removal	C-2—Heavy removal	B-2—Heavy removal	A-3—Clearcut	C-3—Light removal
Falling	Case 1187C with Lokomo cone saw feller-buncher head	2 hand fallers Case 1187C with Lokomo cone saw feller-buncher head	2 hand fallers Case 1187C with Lokomo cone saw feller-buncher head	2–3 hand fallers	1 hand faller	2 hand fallers
Processing/bucking	stroke delimber	stroke delimber, part of hand fallers' tasks as required	stroke delimber, part of hand fallers' tasks as required	part of hand fallers' tasks, 1 bucker	part of hand faller's tasks	part of hand fallers' tasks
Skidding	Clark 668F rubber-tired grapple skidder	Clark 667F rubber-tired line skidder Clark 668F rubber-tired grapple skidder	Clark 667F rubber-tired line skidder Clark 668F rubber-tired line skidder Clark 668F rubber-tired grapple skidder	2 Caterpillar 518 line skidders Caterpillar D6 crawler tractor line skidder	2 Clark 667F rubber-tired line skidders Clark 667D rubber-tired line skidder	9 horses 5 teamsters
Support and development machine	Caterpillar D6D crawler tractor line skidder	Caterpillar D6D crawler tractor line skidder	Caterpillar D6D crawler tractor line skidder		Caterpillar D7G crawler tractor line skidder	Caterpillar D4E crawler tractor with Hyster winch
Loader	Caterpillar 225B	Caterpillar 225B	Caterpillar 225B	Caterpillar 950B rubber-tired loader	Caterpillar 966C rubber-tired loader	
Skidding period	September 8 to October 15, 1992	September 25 to October 22, 1992	August 16 to September 24, 1992; December 2–11, 1992	July 24 to October 26, 1992	August 25 to October 9, 1992	July 22 to October 1992

first. Soil disturbance was sampled at 1-m intervals along each transect line. Each sample point was classified as either disturbed or undisturbed. If disturbed, the depth of impression into mineral soil, surface composition, and source of disturbance were recorded. The same criteria were applied to all operations, including the horse-logged unit. Roads and landings were surveyed separately, and the area occupied by these structures was removed from the associated cutblock. Compiled survey results were compared to Pre-harvest Silviculture Prescription (PHSP) objectives.

Reliable information on planning/layout and hand falling activities could not be obtained for the case study blocks, so assumed productivities for these phases were used in order to present complete cost profiles. Estimates for these phases were developed from a variety of sources, including FERIC researchers' experience and judgment, previous FERIC studies, and discussions with resource planning and falling contractors. Planning/layout and falling costs are used primarily to provide relative comparisons between treatments.

RESULTS AND DISCUSSION

Overview

Harvesting activities on the study sites were administered by the SBFEP. Contracts for the nine summer harvest blocks were awarded in June 1992 through the normal bidding system. Field layout began prior to FERIC's involvement in the research project and was completed by June 1992.

Harvesting operations took place from July to September 1992 as individual contractors finished previous commitments outside of the Date Creek study or, in the case of the contractor who was awarded three study sales, as harvesting was completed on other study units (see Table 2). Harvesting was completed by mid- to late October on most of the summer study blocks, and by mid-December at the latest.

One clearcut and two light removal units were dropped from the FERIC study. The clearcut was not completed in 1992. The contractors in the two light removal units were not considered to be efficient operators; thus, monitoring their activities would not provide useful data on harvesting operations in partial cuts. Therefore only six of the original nine cutblocks were monitored to completion.

Table 3 summarizes the volumes harvested from the six blocks described in this report. The adjusted scale volume excludes the estimated right-of-way volumes credited to each study unit, and therefore represents the volume of timber actually harvested from each site during this trial period.

Productivities and Costs

Planning and Layout. Planning and layout costs could not be determined directly for the six study blocks monitored by FERIC. Most of the field planning and layout

Table 3. Harvested Volume for Each Case Study

Case study	Net cruise (m^3)	Projected cut (m^3)	Scale returns (m^3)	Estimated right-of-way volume [a] (m^3)	Adjusted scale volume (m^3)	Percent removed [b] (%)
A-3	11 178	11 178	13 354	300	13 054	119
B-4	6 345	6 345	8 330	600	7 730	131
B-2	9 423	6 596	6 354	300	6 054	67
C-2	10 794	7 556	6 354	0	6 354	59
B-3	5 655	3 958	4 038 3 338	700 [c] 540	2 798	59
C-3	11 273	3 382	3 503	600	2 903	31

[a] Right-of-way and landing volumes excluded from the shift-level study.
[b] Based on total scale returns and net cruise.
[c] The contractor for Unit B-3 also harvested right-of-way volume outside of the unit. As this was included in the scale volume for B-3, it has been removed to determine the adjusted volume for productivity calculations.

was completed prior to FERIC's involvement in the Date Creek research project, and the layout contractor's records did not have the detail needed to reliably establish production rates by fieldwork task or to separate research from operational fieldwork requirements for each site. However, complete information about the type and scope of fieldwork performed to implement the silvicultural prescription was available for five of the six sites monitored. FERIC combined this task-related information with fieldwork productivity estimates, derived from a variety of sources, to estimate representative planning and layout costs for the five study blocks.

Table 4 presents the planning requirements and estimated crew-hours and costs for field layout, excluding preparation of the silvicultural prescription, for the five study sites (two clearcut units, two heavy removal units, and one light removal unit) on the basis of cost per cubic metre of timber harvested and cost per hectare of area developed. The type and amount of fieldwork actually performed on each study block (also shown in Table 4), in terms of lengths of external and internal boundaries, roads and skid roads to be located and traversed, and need for tree marking, is assumed to be representative of that particular silvicultural prescription. Timber cruising requirements are assumed to be one measure plot and one count plot per hectare for the clearcut units, and two measure plots per hectare for the partial cut units, as defined by the British Columbia Ministry of Forests Cruising Manual, Section 2.0, Cruise Design (April 1, 1996 amendment). The estimated fieldwork production rates and assumptions which FERIC used to generate planning and layout costs, and detailed summaries by study site, are shown in Appendix I. The estimates assume that all field work is done by a two-person field crew (one professional and one technical) at an all-inclusive cost of $600 per 8-h crew-day.

Comparing planning and layout effort on a per-hectare basis illustrates the relative differences in planning and layout workloads between the three prescriptions. The clearcut prescription's average workload was 4.1 crew-h/ha (based on 106.5 crew-h for Unit A-3 and 73.6 crew-h for Unit B-4), resulting in an average planning and layout cost of $308/ha. The average workloads for the light removal prescription (at 7.9 crew-h/ha or $590/ha) and the heavy removal prescription (at 9.6 crew-h/ha or $722/ha) were 1.9 and 2.3 times greater, respectively, than for clearcuts.

On a per-cubic-metre basis, the average (weighted) cost was $0.65/m^3 for clearcuts, $2.66/m^3 for heavy removal harvests, and $4.66/m^3 for light removal harvests. Therefore, planning and layout costs per cubic metre for the heavy removal prescription were 4.1 times the cost for clearcutting, and for the light removal prescription, 7.2 times that for clearcutting. The results are relatively consistent because the production rate for a given field task is assumed to be the same regardless of prescription. The observed minor cost variations within a given silvicultural prescription are explained by site-specific differences in the types and quantities of fieldwork required.

Per-cubic-metre planning and layout costs were lowest for the two clearcut units ($0.61/m^3 for Unit A-3 and $0.71/m^3 for Unit B-4) because internal boundary surveying and tree marking were not required and harvest volume was maximized. Relative to the clearcuts, costs were substantially higher for the two heavy removal units ($2.80/m^3 for Unit B-2 and $2.53/m^3 for Unit C-2). The heavy removal units required more intensive timber cruising than the clearcuts, as well as locating and surveying of internal patch cut boundaries and skidding networks, and tree marking throughout the residual stands. Also, the total planning and layout cost was written off against less volume because only 60% of the total merchantable volume developed by the field layout was actually harvested. The light removal unit, at $4.66/m^3, had the highest planning and layout cost of the three prescriptions. Like the heavy removal, light removal required more timber cruising, locating and surveying of skidding networks, and tree marking than did clearcuts. In contrast to the heavy removal, no internal patch cut boundaries were needed, but this was offset by more extensive tree marking. Finally, the total planning and layout cost for the light removal prescription was written off against only the volume harvested in the first pass, which was 30% of the total developed volume.

This analysis suggests that for the Date Creek study, the clearcut prescription was the most efficient in terms of planning effort per cubic metre of timber harvested, while the heavy removal prescription was intermediate and the light removal prescription was the least efficient. It should be stressed that the estimated workloads and costs discussed here are for fieldwork only and do not include associated administrative tasks (such as preparation of the silvicultural prescription, cutting permit application, mapping, and cruise compilation) which can add substantially to planning workload and costs.[1]

When transposed into labour-hours per cubic metre of timber harvested, the Date Creek results compare well with values presented by Thibodeau and Manning (1995). Their results were based on information supplied by two experienced resource planners who were asked

[1] Steven Webb, R.P.F., Silvicon Services Inc., Smithers, B.C., personal communication, July 1996.

Table 4. Planning Requirements by Case Study

Case study	A-3		B-4		B-2		C-2		C-3	
Prescription	Clearcut		Clearcut		Heavy removal, 60% volume removal		Heavy removal, 60% volume removal		Light removal, 30% volume removal	
		Estimated crew-hours required		Estimated crew-hours required		Estimated crew-hours required		Estimated crew-hours required		Estimated crew-hours required
Gross area (ha)	25.3		18.5		25.2		20.6		22.9	
Area reconnaissance		16.2		11.8		16.1		13.2		14.7
Cruising										
Cruise grid and mapping		12.7		9.3		12.6		10.3		11.5
Primary cruise plots (no.)	25	16.7	19	12.7	50	33.3	41	27.3	46	30.7
Secondary cruise plots (no.)	25	8.3	19	6.3	0		0		0	
Cutblock layout										
Cutblock boundaries										
External perimeter (m)	2 070	20.7	1 680	16.8	2 212	22.1	1 490	14.9	2 367	23.7
Internal perimeters (m)	0		0		3 970	33.1	3 462	28.9	0	
Roads, landings and skid roads										
Haul roads (m)	712	17.8	670	16.7	440	11.0	65	1.6	492	12.3
Landings pre-located (no.)	3		2		2		3		3	
Skid roads and trails (m)	1 696	14.1	0		2 194	19.9	2 008	17.9	1 817	15.8
Tree marking		0		0		78.0		100.3		71.5
Total time required for layout[a]		106.5		73.6		226.2		214.4		180.2
Total cost ($)	7 987		5 520		16 965		16 080		13 515	
Volume harvested (m^3)	13 054		7 730		6 054		6 354		2 903	
Cost ($\$/m^3$)	0.61		0.71		2.80		2.53		4.66	
Cost ($/ha)	316		299		673		781		590	

[a] Sums may differ due to rounding.

to estimate labour inputs required to plan and lay out two hypothetical cutting permits in Interior Plateau lodgepole pine stands. The Date Creek estimates of planning labour inputs were 0.016–0.019 labour-h/m^3 for clearcuts, 0.067–0.075 for heavy removal, and 0.124 for light removal. Thibodeau and Manning reported estimates of 0.013–0.018 labour-h/m^3 for clearcuts and 0.091–0.117 for light removal (with PHSP preparation excluded). Their report does not present data for heavy removal prescriptions, but the Date Creek results for heavy removal are in the middle of the ranges described by their shelterwood and group selection estimates. The similarities between the two studies suggest that the estimated planning inputs for the three Date Creek prescriptions, and the relative differences between them, are realistic.

Harvesting

Falling. Table 5 summarizes the feller-buncher's time distributions and productivities for Unit B-4 (clearcut) and Units B-3 and C-2 (heavy removal) from shift-level summaries. Production/8-h shift was highest in the clearcut unit (at 413 m^3), marginally lower in one of the heavy removal blocks (Unit C-2, at 404 m^3), and substantially lower in the other heavy removal blocks (Unit B-3, at 262 m^3). The low shift productivity for Unit B-3 reflects, in part, the repair time included in this unit. The observed difference in productivity between B-4 and C-2 appears to be due to slight differences in machine utilization and piece size rather than operating environment. For example, on a per-productive-machine-hour

Table 5. Shift-Level Activities of Feller-Buncher—Clearcut and Heavy Removal Units

	Case 1187C feller-buncher		
	Unit B-4 Clearcut	Unit B-3 Heavy removal Patch	Unit C-2 Heavy removal Patch
Falling (h)	131.7	33.0	42.1
Non-mechanical delays			
Coffee/lunch (h)	4.5	1.5	1.1
Work planning (h)	6.5	0.4	2.2
Total non-mechanical delays (h)	11.0	1.9	3.3
Mechanical delays			
General service and maintenance (h)	6.7	0.2	3.5
Repairs (h)	0	7.6	1.3
Total mechanical delays (h)	6.7	7.8	4.8
Total time (h)	149.4	42.7	50.2
Total volume harvested (m^3) [a]	7 730	1 401	2 532
Total pieces (no.)	11 124	2 645	3 895
Productivity			
m^3/PMH	58.7	42.5	60.1
pieces/PMH	84.5	80.2	92.5
Production/8-h shift (m^3)	413	262	404
Utilization (%)	88	77	84

[a] Piece sizes of 0.69, 0.53, and 0.65 m^3 were used for Units B-4, B-3, and C-2, respectively, to prorate the volume harvested by the feller-buncher.

(PMH) basis, which removes the influence of utilization level, Unit C-2 has the highest productivity (60.1 m^3) and Unit B-4 has the second highest (58.7 m^3). Unit B-3 continues to have the lowest productivity (42.5 m^3); it also has the smallest tree size of the three blocks.

Mitchell (1996) presented falling productivities for feller-bunchers working in 0.1-ha patches and 10.0-ha clearcuts in lower-volume overmature subalpine fir/spruce stands in southern B.C. Feller-buncher productivities ranged from 54.8 to 70.5 m^3/h in the 0.1-ha patches on three trial units, and from 66.2 to 112.8 m^3/h in 10.0-ha openings on three other units. Therefore, the feller-buncher's productivities in the heavy removal patches in this study agree closely with Mitchell's results, while the productivity in the Date Creek Unit B-4 (clearcut) is low (although still within the productivity ranges reported in other FERIC studies of feller-bunchers). Reasons for the low productivity in the clearcut were not evident.

Table 6 presents falling costs for the six case study blocks. (In this table, the mechanized falling costs are based on actual field data but the hand falling costs are derived from FERIC's productivity estimates [see below], and are not actual costs developed from data collected on the Date Creek study blocks.) In falling the patches in the heavy removal blocks, the feller-buncher had costs of \$2.91/m^3 in Unit C-2 and \$4.47/m^3 in Unit B-3; in the clearcut unit the feller-buncher's cost was \$2.84/m^3.

The results from the heavy removal blocks demonstrated that a feller-buncher can work efficiently in small patch openings, at least for the site and stand conditions experienced in this study. Within patches, compared to hand falling, the feller-buncher is more productive, has greater ability to control the falling process (which should reduce damage to residual trees), can orient the felled stems to enhance skidding productivity, and is safer for the workers. However, the feller-buncher's high production rate compared to hand falling also means that it requires a larger volume of wood in order to be cost-effective.

FERIC initially attempted to collect shift-level hand falling data for the study blocks. However, accurate and complete data could not be obtained for individual study blocks because falling subcontractors often worked irregular schedules and frequently moved from block to block. Detailed timing was not considered feasible for safety reasons. For the purpose of comparing costs in this report, therefore, FERIC derived estimated falling productivities from limited on-site observations of hand falling in individual tree selection (ITS) and patch cuts, hand falling data for similar terrain and tree sizes in other FERIC studies, and discussions with harvesting and falling contractors.

The following logic was applied to estimate hand falling production rates. First, hand falling in partial cutting prescriptions in general must be of higher quality than in clearcuts to ensure the safety of the faller, maximize the efficiency of the extraction phase, and minimize damage to the residual stand. In the particular circumstances of this study, therefore, productivity when hand falling in small patch openings was assumed to be reduced because the faller had to move between patches and develop new falling faces more frequently than in clearcuts. Productivity was further reduced in individual tree selection because the faller had to work steadily in standing timber. In the heavy removal treatment, the patches created openings into which trees from the surrounding stands could be directed. Finally, in the light removal treatment, the combination of falling in standing timber, lack of stand openings, more careful placement of felled trees, and significantly more delimbing and bucking to match log sizes to the horses' capabilities reduced hand falling productivity substantially. Estimated productivities based on these assumptions are given in Appendix II.

The assumptions used to develop the falling costs indicate that in clearcuts, hand falling costs 40–50% more than mechanized falling (\$4.11/m^3 for hand falling vs. \$2.84/m^3 for mechanized falling). Relative to clearcuts, hand falling costs were estimated to be 24% higher in heavy removal patch cuts (\$5.08/m^3), 62% higher in individual tree selection when falling for line skidders (\$6.67/m^3), and 136% higher in light removal when falling for extraction by horses (\$9.71/m^3) (Table 6). Actual hand falling productivities, and therefore costs, are highly faller-, site- and stand-specific and considerable variation around these estimates is possible. Nevertheless, the authors believe the assumptions used are appropriate and the resulting productivities and costs are valid for comparative purposes.

Skidding

Clearcut. Clearcutting was prescribed for two of the case study areas. Unit A-3 was harvested using conventional hand falling and line skidding techniques, while Unit B-4 was harvested with a feller-buncher and grapple skidder. Tables 7 to 10 summarize the detailed-timing and shift-level information for the skidding phases for these two blocks.

Skidding cycles for each of the Clark rubber-tired line skidders used in A-3 were timed in detail (Table 7). While there was variation between the skidders and operators, total cycle times were similar, ranging from

Table 6. Falling Costs

	Unit A-3	Unit B-4	Unit B-2 Heavy removal			Unit B-3 Heavy removal			Unit C-2 Heavy removal			Unit C-3
	Clearcut	Clearcut	Patch	ITS	Overall	Patch	ITS	Overall	Patch	ITS	Overall	Light removal
Total time (h)		149.4				42.7			50.2			
Hourly cost ($/h) [a]		146.81				146.81			146.81			
Total cost ($)		21 933	**14 651**	**21 144**	**35 795**	6 269	**18 663**	**24 932**	**7 370**	**42 381**	**49 751**	
Volume (m^3)		7 730	2 884	3 170	6 054	1 401	2 798	4 199	2 532	6 354	8 886	
Cost ($/m^3$) [b]	**4.11**	2.84	**5.08**	**6.67**	**5.91**	4.47	**6.67**	**5.94**	2.91	**6.67**	**5.60**	**9.71** [c]

[a] For the Case 1187C feller-buncher in the mechanical harvesting system.
[b] Bold numbers are estimates from Appendix II.
[c] Includes bucking and delimbing.

Table 7. Detailed Timing of Skidding Phase: Unit A-3—Clearcut

	Clark 667F line skidder #1		Clark 667F line skidder #2		Clark 667D line skidder	
	Average time/element (min)	Time/cycle (%)	Average time/element (min)	Time/cycle (%)	Average time/element (min)	Time/cycle (%)
Element						
Travel empty	1.36	6	1.71	10	1.10	6
Position	2.06	10	2.07	12	3.07	16
Hookup	7.45	35	7.03	39	6.68	35
Winch	2.08	10	0.66	4	1.00	5
Assemble	1.32	6	1.02	6	1.16	6
Travel loaded	1.67	8	1.56	9	1.40	8
Landing	2.91	14	1.42	8	2.53	13
Unhook	2.30	11	2.24	12	1.87	10
Delay	0.06	<1	0.09	<1	0.23	1
Total cycle time	21.21	100	17.80	100	19.04	100
Cycles timed (no.)	62		89		32	
Average slope (%)	-2		-13		-2	
Distance						
Travel empty (m)	140		179		95	
Travel loaded (m)	109		145		73	
Pieces/cycle (no.)	11		12		12	
Productivity/skidding hour (m^3/h)	18.0		23.9		22.1	

17.80 min to 21.21 min. Variability was due to factors such as skidding distance, slope, and operator technique. Long skidding distances in one corner of Unit A-3 reduced the skidding productivity in that unit. Although the second Clark 667F had the shortest cycle time, it also had the longest skids and the greatest adverse skid slope. Despite the travel times associated with these skids, winch and assemble times, as well as landing time, were less than for the other machines. The number of pieces skidded/cycle was similar for all three machines. Based on skidding time only (excluding other productive activities and delays), productivity ranged from 18.0 to 23.9 m^3/h.

As would be expected, the Clark 668F rubber-tired grapple skidder used in Unit B-4 clearly outperformed the line skidders. Its cycle time was about one-third that of the line skidders in Unit A-3 (Table 8). Every cycle element was shorter, and several cycle elements for the line skidders did not occur with the grapple skidder. Compared to Unit A-3, the skidding distance on B-4 was shorter and favourable, while the number of logs/cycle was less, and piece size was similar. The grapple skidder's shorter cycle time more than offset the fewer logs/cycle, so its productivity, based on skidding hours, was more than twice that of the line skidders.

Table 8. Detailed Timing of Skidding Phase: Unit B-4—Clearcut

	Clark 668F grapple skidder	
	Average time/element (min)	Time/cycle (%)
Element		
Travel empty	0.91	14
Position	0.87	14
Grapple	0.73	12
Assemble	0.85	13
Travel loaded	0.99	16
Landing	1.65	26
Delay	0.30	5
Total cycle time	6.30	100
Cycles timed (no.)	250	
Average slope (%)	2	
Distance		
Travel empty (m)	72	
Travel loaded (m)	73	
Pieces/cycle (no.)	8	
Productivity/skidding hour (m^3/h)	52.6	

Tables 9 and 10 summarize the shift-level activities and skidding costs for the two units. Utilization of all the skidders was good, with greater than 80% for all machines, and greater than 85% for three of the four. Consistent with the detailed-timing data, shift-level production was 135 to 180% greater for the grapple skidder compared to the line skidders. Productivity for the grapple skidder was 334 m³/shift compared to 119–141 m³/shift for the line skidders. With the conventional harvest, skidding cost is calculated as $4.88/m³, compared to $2.30/m³ for the mechanized system. Although a grapple skidder is more expensive to purchase than a line skidder, the higher capital cost is more than offset by the increased productivity associated with using a feller-buncher/grapple skidder system. This is supported in another recent FERIC study (Mitchell 1996).

Heavy removal. Three units were harvested using the heavy removal prescription; two of these (B-3 and C-2) were harvested with combined mechanical/conventional systems by one contractor, while the third (B-2) was harvested conventionally by another contractor.

The heavy removal prescription consisted of small patch cuts, 0.1–0.5 ha in size, with individual tree selection in the remaining area. Generally, the patches were skidded first, and the forest matrix areas were felled and skidded after the patches were harvested.

Table 9. Shift-Level Productivity and Skidding Cost: Unit A-3—Clearcut

	Clark 667F line skidder #1	Clark 667F line skidder #2	Clark 667D line skidder	Overall unit
Skidding (h)	234.7	243.5	215.2	
Non-mechanical delays				
Coffee/lunch (h)	20.8	22.0	18.4	
Work planning, minor delays (h)	4.2	2.3	1.5	
Total non-mechanical delays (h)	25.0	24.3	19.9	
Mechanical delays				
General service and maintenance (h)	9.2	3.8	2.6	
Repairs (h)	21.4	3.3	7.9	
Total mechanical delays (h)	30.6	7.1	10.5	
Total time (h)	290.3	274.9	245.6	
Total volume harvested (m³) [a]	4 582	4 832	3 640	13 054
Total cycles (no.)	696	792	561	
Total pieces (no.)	7 836	8 266	6 222	
Productivity				
m³/PMH	19.5	19.8	16.9	
cycles/PMH	3.0	3.3	2.6	
pieces/PMH	33.4	33.9	28.9	
m³/cycle	6.6	6.1	6.5	
pieces/cycle	11.3	10.4	11.1	
Production/8-h shift (m³)	127	141	119	
Utilization (%)	81	89	88	
Cost ($/h)	78.58	78.58	78.58	
Total cost ($)	22 812	21 602	19 299	63 713
Cost ($/m³)	4.98	4.47	5.30	4.88

[a] Piece size of 0.585 m³ was used to prorate the total adjusted scale volume between machines.

The conventional system, used by Contractor B on Unit B-2, consisted of hand falling and line skidding with two Caterpillar 518 rubber-tired skidders and a Caterpillar D6 crawler tractor. Table 11 shows the results of the detailed timing for the skidding in this unit. Cycle times for these machines averaged from 20.50 min for the crawler tractor with an average skidding distance of 102 m, to 22.56 min for one of the rubber-tired skidders with an average skidding distance of 180 m. The second rubber-tired skidder had an intermediate skidding cycle time, and the longest skidding distance at 203 m. All skids were adverse, with the second rubber-tired skidder averaging an 18% adverse slope. Productivity for the machines, based on skidding time only, ranged from 10.4 to 11.4 m^3/h.

Contractor A used the feller-buncher and grapple skidder within the patches, and hand falling with line skidders in the individual tree selection portion of the units. As expected, the grapple skidder had shorter cycle times than the line skidders (Tables 12 and 13), 36 to 59% that of the line skidders. This is reflected in a much higher productivity per skidding hour for the grapple skidder by a factor of two to three times. Between the line skidders, variability in productivity was evident due to differences in skidding distances, number of pieces/cycle, and slopes. In Unit C-2 skidding was primarily adverse, while in Unit B-3 it was favourable. There was some difference in piece size between the units, with C-2 having the largest of the three heavy removal units.

Table 10. Shift-Level Productivity and Skidding Cost : Unit B-4—Clearcut

	Clark 668F grapple skidder	Clark 667F line skidder	Overall unit
Skidding (h)	157.4	1.9	
Non-mechanical delays			
Coffee/lunch (h)	16.6		
Total non-mechanical delays (h)	16.6		
Mechanical delays			
General service and maintenance (h)	5.9		
Repairs (h)	4.5		
Total mechanical delays (h)	10.4		
Total time (h)	184.4	1.9	
Total volume harvested (m^3) [a]	7 695	35	7 730
Total cycles (no.)	1 633	7	
Total pieces (no.)	11 074	50	
Productivity			
m^3/PMH	48.9	18.4	
cycles/PMH	10.4	3.7	
pieces/PMH	70.4	26.3	
m^3/cycle	4.7	5.0	
pieces/cycle	6.8	7.1	
Production/8-h shift (m^3)	334		
Utilization (%)	85	n.a.	
Cost ($/h)	95.73	78.58	
Total cost ($)	17 653	149	17 802
Cost ($/$m^3$)	2.29	4.25	2.30

[a] Piece size of 0.695 m^3 was used to prorate the total adjusted scale volume between machines.

Table 11. Detailed Timing of Skidding Phase: Unit B-2—Heavy Removal

	Caterpillar 518 line skidder #1		Caterpillar 518 line skidder #2		Caterpillar D6 crawler tractor	
	Average time/element (min)	Time/cycle (%)	Average time/element (min)	Time/cycle (%)	Average time/element (min)	Time/cycle (%)
Element						
Travel empty	2.84	13	2.53	12	2.32	11
Position	2.69	12	2.95	14	1.73	8
Hookup	6.46	29	5.59	26	7.38	36
Winch	1.93	9	1.60	7	1.25	6
Assemble	1.09	5	0.94	4	1.33	7
Travel loaded	2.22	9	2.44	11	1.93	9
Landing	2.56	11	2.71	13	2.38	12
Unhook	1.86	8	1.59	8	1.59	8
Delay	0.91	4	1.04	5	0.59	3
Total cycle time	22.56	100	21.39	100	20.50	100
Cycles timed (no.)	89		84		39	
Average slope (%)	-5		-18		-11	
Distance						
Travel empty (m)	224		212		122	
Travel loaded (m)	180		203		102	
Pieces/cycle (no.)	8		8		7	
Productivity/skidding hour (m^3/h)	10.9		11.4		10.4	

The shift-level results for the conventional unit, B-2 (Table 14), afford comparisons of skidding production in patches and individual tree selection areas. With all three skidders, skidding productivity in the patches was moderately higher than in the individual tree selection (by 19 and 28% for the rubber-tired skidders, and 10% for the crawler tractor). Productivities in Unit B-2 ranged from 57–71 m^3/shift in the patches and 55–59 m^3/shift in the individual tree selection portions of the block. Utilization rates for these machines ranged from 74 to 83%, while productivities ranged from 8.4 to 11.3 m^3/PMH.

The productivities of the line skidders in heavy removal Unit B-2 were only about half those of the line skidders in clearcut Unit A-3, even though both contractors used hand falling methods and skidders of similar sizes. Average skidding distances and cycle times were only slightly longer on Unit B-2 than on A-3, so the primary reasons for the differences in skidding productivities were the numbers and average sizes of pieces skidded per cycle. On Unit B-2 the skidders averaged 7 to 8 pieces per cycle (combined average for patches and individual tree selection areas) with an average piece size of 0.44 m^3, while on Unit A-3 the skidders averaged 11 to 12 pieces per cycle with an average piece size of 0.64 m^3. The reduction in skidding productivity is largely due to the increased difficulty in accumulating and maneuvering a full load of logs in the more confined circumstances of the heavy removal prescription. Rather than struggle to maximize their load sizes, the skidder operators opted to maintain consistent production by skidding smaller, more manageable loads.

FERIC observed that the shape of the patch cuts and their orientation relative to the direction of skidding affected productivities of both the falling and skidding phases. In most cases the patches were roughly rectangular with the skid road forming one of the patch boundaries. This design forced hand fallers to fall some trees at right angles to the skidding direction in order to facilitate hookup. The feller-buncher was able to swing and place trees into better alignment for skidding, but the need to swing trees through large angles reduced the feller-buncher's productivity in the patch cuts. In hand felled patches the skidder operators also had to swing the trees

Table 12. Detailed Timing of Skidding Phase: Unit B-3—Heavy Removal

	Clark 668F grapple skidder Patch		Clark 667F line skidder ITS	
	Average time/element (min)	Time/cycle (%)	Average time/element (min)	Time/cycle (%)
Element				
Travel empty	1.58	20	1.19	8
Position	1.43	18	1.95	13
Hookup, grapple	1.01	12	5.48	35
Winch	0.00	0	0.71	5
Assemble	0.92	11	1.17	7
Travel loaded	1.74	22	1.48	10
Landing	1.35	17	1.90	12
Unhook	0.00	0	1.37	9
Delay	0.04	<1	0.22	1
Total cycle time	8.07	100	15.47	100
Cycles timed (no.)	125		125	
Average slope (%)	3		5	
Distance				
Travel empty (m)	150		102	
Travel loaded (m)	148		93	
Pieces/cycle (no.)	9		6	
Productivity/skidding hour (m^3/h)	35.5		12.4	

through large angles to bring the logs into lead, resulting in increased breakage and longer cycle times. Also, the skidders frequently had to travel off the skid roads in order to reposition logs to bring them into lead for skidding, causing additional soil disturbance within the patches. Where terrain and direction of tree lean are favourable, diamond or teardrop shapes with the narrow end pointing toward the landing may be more effective patch shapes for both falling and skidding operations, as they would minimize tight corners and facilitate falling the trees in the skidding direction.

Tables 15 and 16 present the shift-level results for Contractor A in Units B-3 and C-2, respectively. The grapple skidder skidding from the patch cuts produced 2.5 to 3 times more volume per productive machine hour than the line skidders skidding from the individual tree selection areas (195–214 m^3/shift compared to 74–87 m^3/shift). The higher productivity of the grapple skidder was attributed to its shorter cycle time, as well as to skidding efficiencies created by careful placement and prebunching of trees by the feller-buncher in the patch cuts, compared to hand falling and line skidding in the individual tree selection areas. Costs were \$2.03/m^3 in the clearcut and \$3.59–3.95/m^3 in patches for the grapple skidder. For the line skidders, costs ranged from \$9.07 to \$10.41/m^3 in the patches and \$7.15 to \$11.84/m^3 in the individual tree selection areas.

Line skidder productivities for the individual tree selection component were higher for Units B-3 and C-2 than for Unit B-2, even though all were hand felled. Average skidding distances were longer on Unit B-2, which accounted for some of the observed productivity differences, but lack of coordination between the falling and skidding phases was also a significant factor. On Units B-3 and C-2, falling in the individual tree selection areas was done concurrently with the skidding phase, and trees were felled carefully to ensure that they were in lead with the skidding direction. On Unit B-2, however, all of the marked trees in the individual tree selection areas were felled prior to skidding, and skidding direction was not always considered. This practice created a dense accumulation of felled and often crossed trees, which hampered the hookup and extraction phases of the skidding cycle.

Table 13. Detailed Timing of Skidding Phase: Unit C-2—Heavy Removal

	Clark 668F grapple skidder Patch		Clark 668F line skidder ITS		Clark 667F line skidder ITS	
	Average time/element (min)	Time/cycle (%)	Average time/element (min)	Time/cycle (%)	Average time/element (min)	Time/cycle (%)
Element						
Travel empty	2.18	24	1.61	10	3.38	13
Position	1.19	13	2.35	15	2.15	9
Hookup, grapple	0.94	10	5.04	33	8.24	33
Winch	0.00	0	0.71	5	1.33	5
Assemble	1.18	13	0.72	5	1.79	7
Travel loaded	2.09	23	1.37	9	3.14	12
Landing	1.52	17	2.13	14	2.79	11
Unhook	0.00	0	1.30	8	2.24	9
Delay	0.05	<1	0.20	1	0.32	1
Total cycle time	9.15	100	15.43	100	25.38	100
Cycles timed (no.)	78		27		71	
Average slope (%)	-17		-11		-18	
Distance						
Travel empty (m)	206		145		270	
Travel loaded (m)	187		156		226	
Pieces/cycle (no.)	8		6		7	
Productivity/skidding hour (m^3/h)	34.3		15.2		10.6	

Unit B-2 was harvested using a hand faller/line skidder system, and has the most expensive skidding cost of the three heavy removal units—\$10.29/m^3 compared to \$5.85 and \$6.38/m^3 for Units B-3 and C-2, respectively (Tables 14–16). Units B-3 and C-2 were harvested by the same contractor, and show some differences in cost due to operators, block conditions, and piece sizes.

Light removal. The light removal unit was harvested using hand falling and horse skidding techniques, with each teamster and team varying in experience and technique. Two of the teamsters felled their own wood (Teamsters 2 and 5), and two additional fallers supported the remaining three teamsters. Nine horses were used: four teams of two, and one horse working alone (Teamster 5). While the other operations in the Date Creek study were full tree, in this treatment, trees were felled, delimbed, and bucked at the stump in order to provide the horses with more appropriate log lengths and lower drag resistance. The horses were assisted by a Caterpillar D4 crawler tractor, operated primarily by Teamster 2, which skidded right-of-way and worked on the landing.

Detailed timing of the skidding operations (Table 17) illustrates the variation between teamsters and teams. Teamster 5 worked for only a short period on this site and is therefore not included in Table 17 nor in this particular analysis. Teamsters 2 and 3, and their teams, were experienced in skidding, and show a relatively short total time per cycle with short position and hook times. Teamster 3 also had very short delay times.

Teamster 4 was the most experienced of the group, although superficial examination of the cycle data suggests otherwise; the average skidding distance for this team was greater than for the other three teams, and during the loaded travel, the skid was on steep, adverse grades averaging 8%. When on a slope, additional care must be taken in hooking, maneuvering, and pulling the logs from the residual trees, resulting in increased position and hook time as well. The large component of minor delays with this team is attributable primarily to cleaning the trails, caring for the horses, and bucking logs prior to skidding.

Table 14. Shift-Level Productivity and Skidding Cost: Unit B-2—Heavy Removal

	Caterpillar 518 line skidder #1			Caterpillar 518 line skidder #2			Caterpillar D6 crawler tractor					
	Patch	ITS	Total	Patch	ITS	Total	Patch	ITS	Total	All patches	All ITS	Overall unit
Skidding (h)	92.8	148.9	241.7	115.6	158.4	274.0	67.3	59.9	127.2			
Non-mechanical delays												
Coffee/lunch (h)	16.0	24.7	40.7	19.9	24.4	44.3	13.5	9.7	23.2			
Operational delays (h)	0.2	0	0.2	3.3	1.6	4.9	2.2	1.9	4.1			
Total non-mechanical delays (h)	16.2	24.7	40.9	23.2	26.0	49.2	15.7	11.6	27.3			
Mechanical delays												
General service and maintenance (h)	5.7	7.7	13.4	5.9	4.4	10.3	4.0	2.5	6.5			
Repairs (h)	5.4	1.0	6.4	2.0	1.4	3.4	4.2	0	4.2			
Total mechanical delays (h)	11.1	8.7	19.8	7.9	5.8	13.7	8.2	2.5	10.7			
Total time (h)	120.1	182.3	302.4	146.7	190.2	336.9	91.2	74.0	165.2			
Total volume harvested (m^3) [a]	932	1 244	2 176	1 305	1 402	2 707	647	524	1 171	2 884	3 170	6 054
Total cycles (no.)	223	321	544	321	357	678	170	135	305			
Total pieces (no.)	1 830	2 441	4 271	2 560	2 750	5 310	1 270	1 028	2 298			
Productivity												
m^3/PMH	10.0	8.4	9.0	11.3	8.9	9.9	9.6	8.8	9.2			
cycles/PMH	2.4	2.2	2.3	2.8	2.3	2.5	2.5	2.3	2.4			
pieces/PMH	19.7	16.4	17.7	22.2	17.4	19.4	18.9	17.2	18.1			
m^3/cycle	4.2	3.9	4.0	4.1	3.9	4.0	3.8	3.9	3.8			
pieces/cycle	8.2	7.6	7.9	8.0	7.7	7.8	7.5	7.6	7.5			
Production/8-h shift (m^3)	62	55	58	71	59	64	57	57	57			
Utilization (%)	77	82	80	79	83	81	74	81	77			
Cost ($/h)	80.78	80.78		80.78	80.78		64.33	64.33				
Total cost ($)	9 702	14 726		11 850	15 364		5 867	4 760		27 419	34 850	62 269
Cost ($/$m^3$)	10.41	11.84		9.08	10.96		9.07	9.08		9.51	10.99	10.29

[a] Piece size of 0.51 m^3 was used to prorate the total adjusted scale volume between machines.

Table 15. Shift-Level Productivity and Skidding Cost: Unit B-3—Heavy Removal

	Clark 668F grapple skidder Patch	Clark 667F line skidder ITS	Overall unit
Skidding (h)	47.3	115.0	
Non-mechanical delays			
Coffee/lunch (h)	6.2	16.7	
Plan work, minor delays (h)	0.2	0	
Total non-mechanical delays (h)	6.4	16.7	
Mechanical delays			
General service and maintenance (h)	2.8	3.3	
Repairs (h)	0	4.5	
Total mechanical delays (h)	2.8	7.8	
Total time (h)	56.5	139.5	
Total volume harvested (m^3) [a]	1 371	1 427	2 798
Total cycles (no.)	366	419	
Total pieces (no.)	2 598	2 703	
Productivity			
m^3/PMH	29.0	12.4	
cycles/PMH	7.7	3.6	
pieces/PMH	54.9	23.5	
m^3/cycle	3.8	3.4	
pieces/cycle	7.1	6.4	
Production/8-h shift (m^3)	195	82	
Utilization (%)	84	81	
Cost ($/h)	95.73	78.58	
Total cost ($)	5 409	10 962	16 371
Cost ($/$m^3$)	3.95	7.68	5.85

[a] Piece size of 0.53 m^3 was used to prorate the total adjusted scale volume between machines.

The cycle times recorded for Teamster 1 reflect inexperience and poorer technique, as the position and hook time is clearly higher than those of the other teams; this greater time is also influenced by the greater number of pieces/cycle skidded by this team. Travel times are relatively high, given the short distances within the sample. These data, however, are limited to 29 cycles and therefore cannot be applied to the whole operation by this teamster.

Based on the detailed-timing data, Teamster 3 had the greatest production; his skidding distances were less than those of Teamsters 2 and 4, and the skidding was favourable, resulting in relatively short travel times. He also had the lowest number of pieces per cycle and the lowest position and hook time.

Table 18 illustrates the times, productivities, and costs for the teams on a shift-level basis. Teamster 5 worked only 12 of the 152 shifts and had the lowest production of all the teams. The teamster and horse were inexperienced and the information is provided only for comparative purposes.

Productivities ranged from 11.6 to 23.4 m^3/shift. Consistent with the cycle times, the highest production team was Teamster 3, although this team only worked 10 shifts. Teamster 4, the most experienced, was second in productivity and outperformed Teamsters 1 and 2 by an average of 5 pieces (2.3 m^3) per shift. Despite having more time available for skidding, Teamsters 1 and 3, who subcontracted their falling, did not appear

Table 16. Shift-Level Productivity and Skidding Cost: Unit C-2—Heavy Removal

	Clark 668F grapple skidder Patch	Clark 558F line skidder ITS	Clark 667F line skidder ITS	Total ITS	Overall unit
Skidding (h)	67.3	138.9	192.1		
Non-mechanical delays					
Coffee/lunch (h)	6.8	18.1	23.2		
Plan work, minor delays (h)	0.7	8.9	1.8		
Total non-mechanical delays (h)	7.5	27.0	25.0		
Mechanical delays					
General service and maintenance (h)	3.8	4.3	5.9		
Repairs (h)	6.8	2.7	1.7		
Total mechanical delays (h)	10.6	7.0	7.6		
Total time (h)	85.4	172.9	224.7		
Total volume harvested (m^3) [a]	2 279	1 605	2 470	4 075	6 354
Total cycles (no.)	476	446	587		
Total pieces (no.)	3 520	2 477	3 812		
Productivity					
m^3/PMH	33.9	11.6	12.9		
cycles/PMH	7.1	3.2	3.1		
pieces/PMH	52.3	17.8	19.8		
m^3/cycle	4.8	3.6	4.2		
pieces/cycle	7.4	5.6	6.5		
Production/8-h shift (m^3)	214	74	87		
Utilization (%)	79	80	85		
Cost ($/h)	95.73	84.89	78.58		
Total cost ($)	8 175	14 677	17 657	32 334	40 509
Cost ($/$m^3$)	3.59	9.14	7.15	7.93	6.38

[a] Piece size of 0.65 m^3 was used to prorate the total adjusted scale volume between machines.

to work their horses longer per shift than Teamster 2, who did his own falling. Teamster 4 subcontracted his falling and worked his horses significantly longer than the other teamsters, but he also had the longest skidding distances and his daily production was similar to the others. (Note that the skidding time per shift is an estimate only, and is calculated on the basis of the detailed-timing results.) If the daily skidding hours accurately reflect the amount of time that horses can be expected to work each day, then Teamster 2's practice of splitting his work day between skidding and falling would appear to be more efficient than subcontracting falling.

However, when choosing a work technique and deciding how long to work a team of horses, the teamster must also consider the well-being and care of the animals. Each teamster must make his own judgements about the capabilities and needs of his horses and make the choices he feels are appropriate. Horses require tending before, during, and after skidding tasks. While this is comparable to maintenance on equipment, the times involved may be greater, and neglecting a machine for a day or a week will have a much smaller impact than neglecting a team of horses for the same period. In this study, 45 min to 1 h was required to feed, water, groom, and harness the animals in the morning, before skidding began. After the day's

Table 17. Detailed Timing of Skidding Phase: Unit C-3—Light Removal

	Teamster 1		Teamster 2		Teamster 3		Teamster 4	
	Average time/ element (min)	Time/ cycle (%)	Average time/ element (min)	Time/ cycle (%)	Average time/ element (min)	Time/ cycle (%)	Average time/ element (min)	Time/ cycle (%)
Element								
Travel empty	1.55	19	1.31	25	1.13	31	1.27	14
Position and hook	3.04	37	0.93	18	0.77	21	1.90	21
Travel loaded	1.59	20	1.06	21	0.87	24	2.46	27
Unhook	1.61	20	0.82	16	0.57	15	0.98	11
Delay	0.30	4	1.02	20	0.32	9	2.41	27
Total cycle time	8.09	100	5.14	100	3.66	100	9.02	100
Cycles timed (no.)	29		133		131		99	
Average slope (%)	0		4		-3		8	
Distance								
Travel empty (m)	39		77		64		82	
Travel loaded (m)	45		76		65		83	
Pieces/cycle (no.)	1.7		1.2		1.1		1.4	
Time/piece (min)	4.8		4.3		3.3		6.4	
Productivity/skidding hour (m^3/h)	5.8		6.5		8.3		4.3	

Table 18. Shift-Level Productivity and Cost of Skidding Phase for Horse System: Unit C-3—Light Removal

	Teamster 1	Teamster 2	Teamster 3	Teamster 4	Teamster 5	Total
Horses (no.)	2	2	2	2	1	9
Shifts with production (no.)	43	40	10	47	12	152
Time on site (h)	351	317	83	391	102	1 244
Time (h/shift)	8.2	7.9	8.3	8.3	8.5	8.2
Total production (pieces)	1 519	1 418	509	1 886	302	5 634
Total production (m^3) [a]	699	652	234	868	139	2 592 [b]
Production/shift (m^3)	16.3	16.3	23.4	18.5	11.6	17.1
Production/shift (no. pieces)	35	35	51	40	25	37
Pieces (no./cycle) [c]	1.7	1.2	1.1	1.4	n.a.	
Cycles (no./shift)	21	29	46	29	n.a.	
Estimated skidding time/shift (h)	2.8	2.5	2.8	4.3	n.a.	
Cost ($/shift)	290.49	175.08	290.49	290.49	145.25	
Total cost ($)	12 491	7 003	2 905	13 653	1 743	37 795
Cost ($/$m^3$)	17.87	10.74	12.41	15.73	12.54	14.58

[a] Piece scale was done for the horse logged area and provided a piece size of 0.46 m^3, bucked.
[b] Total volume is for reported shifts only.
[c] From the detailed timing.

work was completed, another 20 to 30 minutes was needed to unharness and prepare the horses for the night. Rests during the day were also required, with the frequency and length depending upon the temperature, skidding conditions, and volumes skidded.

Horse skidding costs ranged from \$10.74 to \$17.87/m^3 for individual teamsters (Table 18), and the average skidding cost was \$14.58/m^3. Teamsters 1, 3, and 4 subcontracted their falling tasks, so their full workday was charged to skidding; Teamsters 1 and 4 had the highest skidding costs. Teamsters 2 and 5 felled their own trees and their total skidding cost per shift was reduced correspondingly. As well, Teamster 5 used only one horse.

Summary of Harvesting Costs

Table 19 summarizes estimated harvesting costs per cubic metre by phase (planning, falling, and skidding) and in total for the six study blocks. The table shows that costs for all phases are lower for clearcutting than for either heavy removal or light removal prescriptions. Total harvesting costs for clearcutting were \$5.85 to \$9.60/m^3, compared to \$14.46 to \$19.00/m^3 for heavy removals and \$28.95/m^3 for light removal. Planning costs increase relative to clearcuts because partial cutting prescriptions require more intensive field reconnaissance and layout, and the costs are written off against less volume. Falling costs increase because more falling must be done in standing timber and, in the case of horse skidding, more delimbing and bucking is required. Again, unlike the skidding costs which are based on the actual skidding productivities for the six study blocks, the planning and falling costs presented in this report are derived indirectly because the actual productivities could not be determined for these sites.

The mechanized feller-buncher/grapple skidder system was more cost-effective than the conventional hand faller/line skidder system in clearcuts, while the combined conventional/mechanized system was more cost-effective than the conventional system in the heavy removal harvests. The mechanized system had total costs of \$5.85/m^3 in clearcuts compared to \$9.60/m^3 (or 64% higher) for the conventional system, and \$14.46 to \$14.51/m^3 for heavy removals compared to \$19.00/m^3 (or 31% higher) for the conventional system. In the clearcuts, planning costs were comparable for the two units but falling and skidding costs on the conventional clearcut were noticeably higher. In the heavy removals, planning and falling costs for the conventional system were slightly higher than for the mechanized system; most of the cost increase was due to a substantial increase in skidding cost. The grapple skidders had much shorter cycle times and therefore higher skidding productivity compared to the line skidders.

Table 19. Overall Costs for Planning, Falling, and Skidding, by Case Study

Case study	A-3	B-4	B-2	B-3	C-2	C-3
Prescription	Clearcut	Clearcut	Heavy removal, 60% volume removal	Heavy removal, 60% volume removal	Heavy removal, 60% volume removal	Light removal, 30% volume removal
	Conventional harvest with dispersed skid trails	Mechanical harvest, skid roads	Conventional harvest, small patch and ITS	Combination conventional and mechanical harvest, small patch and ITS	Combination conventional and mechanical harvest, small patch and ITS	Horse, ITS
Planning and layout (\$/m^3)	0.61	0.71	2.80	2.67 [a]	2.53	4.66
Falling (\$/m^3)	4.11	2.84 [b]	5.91 [b]	5.94 [b]	5.60 [b]	9.71 [b,c]
Skidding (\$/m^3)	4.88	2.30	10.29	5.85	6.38	14.58
Total cost on the road or landing (\$/m^3)	9.60	5.85	19.00	14.46	14.51	28.95 [b]

[a] Prorated from B-2 and C-2.
[b] Estimates from Appendix II.
[c] Includes bucking and delimbing; log length at the landing.

The study demonstrated that it is operationally feasible to use mechanized systems to perform some harvesting tasks in partial cutting prescriptions. However, the results are specific to the sites and stands encountered here and caution must be exercised in extrapolating these results to other stand conditions in the ICH zone. In this study, the use of small patch openings allowed the combined conventional/mechanized system to outperform the conventional system in the heavy removal harvests. The feller-buncher and the grapple skidder were very effective for harvesting the patches in the heavy removal prescriptions. Other mechanized systems consisting of smaller machines might be able to work effectively in light removal prescriptions in the relatively dense, uniform stands that characterized this study, but it is not possible to say whether they would be more cost-effective than conventional hand faller/line skidder methods.

Horse logging was well-suited to the light removal prescription. Although Unit C-3 had a considerably higher total cost ($28.95/m^3) than the other systems, the increased cost was not due only to the harvest method. For example, the higher planning cost was a function of the prescription (the low level of removal) rather than the harvesting method, while the higher falling cost was a function of both the prescription and the harvesting method; on-site manufacturing of logs is required to match the horses' capabilities and in this treatment, falling included bucking and delimbing operations as well. Only the higher skidding cost was a function of the harvest method rather than the prescription. Because this was the only light removal unit in the study, direct comparisons with the other harvest systems are not possible.

Soil Disturbance

After the study blocks were harvested, FERIC conducted soil disturbance surveys using standard BCMOF procedures (Curran and Thompson 1991). Most of the sites were surveyed in late fall of 1992; however, some study sites were still being logged when early-winter snowfalls occurred, and these were surveyed in the early summer of 1993. Table 20 summarizes soil disturbance levels for the six case studies and compares these with the levels from each PHSP.

For the purposes of FERIC's survey, haul road disturbance, expressed as a percentage of total or gross cutblock area, was the sum of two components: "prebuilt" roads (new permanent all-weather roads into the study blocks, probably built in 1991) and "contract" roads (temporary seasonal roads built by the harvesting contractor immediately prior to or during harvesting). Units A-3, B-2, C-2, and C-3 were within acceptable limits and had total haul road disturbances ranging from 0.8 to 3.7%, compared to specified maximum limits of 3.4 to 7.5%. These study blocks were either adjacent to older pre-existing main roads or had only short lengths of prebuilt roads within their boundaries. Haul road disturbance exceeded specified limits on Units B-3 (9.5% actual vs. 2.0% allowable) and B-4 (9.6% actual vs. 8.6% allowable). Both sites contained significant lengths of prebuilt roads and no contract or pre-existing roads.

Poor construction practices associated with the prebuilt roads were responsible for the excessive road disturbance on these two sites. Prebuilt roads constituted the main access routes into most of the Date Creek study sites, including four of the units monitored by FERIC, and were built independent of the harvesting operations. Partly because of wet weather during the subgrade construction phase, the prebuilt roads were characterized by excessive soil excavation and stripping across almost the full width of the road rights-of-way. As a result, study blocks that contained or bordered long stretches of prebuilt roads exceeded allowable haul road disturbance limits, while sites with only short segments of prebuilt road or adjacent to existing roads were within acceptable limits. It must be stressed that the harvesting contractors for Units B-3 and B-4 were not responsible for the excessive levels of haul road disturbance on these sites.

Contract roads accounted for relatively low levels of disturbance on the four sites where they were required. These were usually short, narrow, within-block spurs built by the contractor to access predetermined landing sites. Landing disturbance was less than the maximum stipulated on the PHSP for the four units on which landings were used. (One clearcut and one heavy removal harvest used roadside logging systems which did not require landings.) On all sites, landings were built within stipulated boundaries. Landing dimensions were generally satisfactory for the low-volume harvesting operations (the horse and line skidding contractors), but landings occasionally became filled with the higher-producing mechanized (feller-buncher/grapple skidder) operations in the heavy removal harvests.

Disturbance due to skidding is represented in Table 20 as "skid trails" and "patch disturbance". Total skidding disturbance is the sum of these two components and is expressed as a percentage of each block's Net Area to be Reforested (NAR), which excludes haul roads, rather than gross cutblock area. Skid trail disturbance consists of permanent (bladed) skid roads and all machine impressions greater than 5 cm deep into mineral soil (usually unbladed skid trails). Patch disturbance is specific to the heavy removal units and consists of generalized disturbance greater than 5 cm deep within the patch cut areas only.

In contrast to roads and landings, total disturbance due to skidding exceeded the PHSP limits on all but one of

Table 20. Soil Disturbance by Case Study

Case study	A-3	B-4	B-2	B-3	C-2	C-3
Prescription	Conventional harvest, clearcut, dispersed skid trails	Mechanical harvest, clearcut, skid roads	Conventional harvest, small patch and ITS	Combination conventional and mechanical harvest, small patch and ITS	Combination conventional and mechanical harvest, small patch and ITS	Horse, ITS
Gross area (ha)	25.3	18.5	25.2	22.0	20.6	22.9
Net area (ha)	23.8	16.1	23.6	19.9	19.8	22.4
Prebuilt roads (%) [a]	2.7	9.6	3.3	9.5	0.0	0.0
Contract roads (%) [a]	0.4	0.0	0.4	0.0	0.8	2.2
Landings (%) [a]	2.9	0.0	2.6	0.0	1.9	0.1
Maximum allowable [b]						
Spur road (%)	7.5	8.6	6.0	2.0	3.4	3.5
Landings (%)	4.0	3.2	3.2	4.0	3.9	3.5
Skid trails (%) [c]	9.1	10.0	4.3	3.9	5.0	1.0
Patch disturbance (%) [c]	n.a.	n.a.	0.9	1.9	1.9	n.a.
Maximum allowable [b] dispersed skid trails and skid roads (%)	7.0	4.3	4.0	4.0	2.9	3.0

[a] Expressed as percentage of gross block area.
[b] Defined in the PHSP.
[c] Expressed as a percentage of Net Area to be Reforested (NAR).

the study sites. The only study block that achieved an acceptable level of skidding disturbance was Unit C-3, the horse logged light removal unit. Skidding activity on this unit was generally well dispersed with only a few main access trails meeting the criterion of 5-cm impressions into mineral soil. The other five sites were harvested with either conventional or mechanized systems consisting of various combinations of line or grapple skidders and crawler tractors. Units A-3 and B-4, the two clearcuts, had the highest levels of skidding disturbance, at 9.1 and 10.0%, respectively. Unit A-3 was harvested with rubber-tired line skidders and a crawler tractor with chokers; dispersed skidding (i.e., no bladed skid roads) was prescribed. Unit B-4 was harvested with a feller-buncher, a grapple skidder, and a crawler tractor; the grapple skidder travelled off the skid roads as required, and the crawler tractor line-skidded from a network of pre-located skid roads. Dispersed skidding during wet weather in the summer may have contributed to elevated levels of off–skid-road disturbance, resulting in substantially higher than expected skidding disturbance on these two units.

Units B-2, B-3, and C-2, the three heavy removals, had total skidding disturbances of 5.2, 5.8, and 6.9%, respectively, exceeding the maximums of 4.0, 4.0, and 2.9% stipulated in their respective PHSPs. While skidder traffic off the preconstructed skid road networks in wet weather was a contributing factor, the tendency of the contractors to temporarily store logs in previously harvested patch cuts was probably the main reason. When landings were filled or trucks were being loaded, the skidders often unhooked and piled logs in a convenient patch cut rather than stopped skidding temporarily. Once the landing was clear again, another skidder transferred the accumulated logs from the patch cut to the landing. Using patch cuts as production buffers concentrated more machine traffic on these patches and resulted in high levels of disturbance. As Table 20 illustrates, patch disturbance was 20 to 50% of total skidding disturbance. If patches had not been used in this fashion, total skidding disturbance may have been very close to acceptable levels on all three sites.

Slash Accumulation

The combinations of cutting prescriptions and harvesting systems had different levels and patterns of slash accumulation. Slash levels were low and the slash was evenly distributed throughout the harvest area on the horse-logged light removal unit, because of the low removal level and the need to delimb and buck felled trees carefully to meet the horses' skidding capabilities. Heavy amounts of slash accumulated at the landings or at roadside on the clearcut units; however, these accumulations could be easily treated by piling and burning where necessary. Heavy slash accumulations also occurred at landings in the heavy removal units, and burning of slash was more difficult because of the surrounding standing timber. The need for slash disposal should therefore be considered when planning future partial cutting operations. Alternatives for reducing slash concentrations, such as partial or complete delimbing and bucking at the stump, should be specified where required.

SUMMARY AND CONCLUSIONS

In 1992 the BCMOF Prince Rupert Forest Region and Kispiox Forest District initiated the Date Creek Silvicultural Systems Study to investigate the biological effects of various partial cutting prescriptions on ecosystem dynamics in ICH stands of northwestern British Columbia. The study compared clearcut, heavy removal, and light removal silvicultural systems in 135-year-old hemlock/cedar stands in Date Creek, north of Kispiox, B.C. FERIC monitored productivities and costs of mechanized, conventional, and horse skidding harvesting systems on six study blocks (two clearcuts, three heavy removals, and one light removal). FERIC's objectives were to assess planning and harvesting productivities and costs; assess soil disturbance levels; and identify ways to improve operational planning and implementation of partial cutting silvicultural systems in this ecosystem.

Field planning and layout was completed in June 1992. Four contractors harvested the six study blocks described in this report between July and December 1992. FERIC collected shift-level and detailed-timing data on all skidding and mechanized falling activities, summarized planning requirements in terms of the type and scope of fieldwork required for each of the study blocks, and surveyed soil disturbance after harvesting. Actual labour inputs for planning and hand falling could not be obtained and were estimated indirectly from other sources. All costs were calculated using standard FERIC procedures.

The partial cutting prescriptions defined for this study clearly required more intensive planning and field work than clearcut blocks of similar size. Based on the actual workloads by study block and assumed productivities, the heavy removal and light removal prescriptions required 2.3 and 1.9 times the planning effort (on a per-hectare basis), respectively, of the clearcuts. However, the heavy removal prescription recovered a substantially larger proportion of the developed timber volume and therefore used planning resources more efficiently than the light removal prescription. Costs of planning and layout were estimated at $0.65/m^3$ for clearcut harvests, $2.66/m^3$ for heavy removal harvests, and $4.66/m^3$ for light removal harvests.

The feller-buncher produced 413 m³/8-h shift at a cost of \$2.84/m³ when falling and bunching trees in the clearcut, and 262 and 404 m³/8-h shift at costs of \$4.47/m³ and \$2.91/m³, respectively, when falling and bunching trees in the patch openings of the heavy removal cuts. The falling and bunching production rates and costs for the heavy removals are consistent with results of another FERIC study in the southern interior of B.C., but the production rate for the clearcut is low and the cost high compared to the same study.

Indirect estimates indicated that in clearcuts, hand falling costs 40–50% more than mechanized falling (\$4.11/m³ for hand falling compared to \$2.84/m³ for mechanized falling). Relative to clearcuts, hand falling costs were estimated to be 24% higher in heavy removal patch cuts (\$5.08/m³), 62% higher in individual tree selection when falling for line skidders (\$6.67/m³), and 136% higher in light removal when falling for extraction by horses (\$9.71/m³).

Skidding was done with a grapple skidder, several line skidders, and several teams of horses. The grapple skidder achieved average production rates and costs of 334 m³/8-h shift and \$2.30/m³, respectively, on the clearcut unit and 195–214 m³/8-h shift and \$3.59–\$3.95/m³, respectively, in patches on two heavy removal units. Line skidder production rates and costs averaged 119–141 m³/8-h shift and \$4.88/m³, respectively, on the clearcut unit and 57–71 m³/8-h shift and \$9.07–\$10.41/m³, respectively, in patches on the heavy removal units. Line skidder production rates and costs averaged 55–87 m³/8-h shift and \$7.15–\$11.84/m³, respectively, in the individual tree selection areas of the heavy removal units. The production rates and costs for the horse teams averaged 11.6–23.4 m³/shift and \$10.74–\$17.87 m³, respectively, on the light removal unit.

Overall planning, falling, and skidding costs were estimated at \$5.85/m³ for mechanized clearcut operations, \$9.60/m³ for conventional clearcut operations, \$14.46–\$14.51/m³ for combined conventional/mechanized operations in heavy removals, \$19.00/m³ for conventional operations in heavy removals, and \$28.95/m³ for horse skidding in the light removal. Relative to the mechanized system, the conventional system had higher falling and skidding costs in the clearcut prescription, and higher skidding costs in the heavy removal prescription. The horse skidding operation in the light removal prescription had the highest costs in all phases as well as overall. The mechanized system is clearly the most cost-effective option for clearcut prescriptions and can work effectively in partial cutting if patch cutting is employed, at least for the site and stand conditions observed in this trial. Finally, although expensive, horse skidding was well suited to light removal in this trial in terms of ability to work in high-density stands. However, production rates and costs cannot be readily compared to the other mechanical and conventional operations.

Although only one of the six study blocks (the horse-logged light removal unit) satisfied study objectives for road, landing, and skidding soil disturbance levels, the disturbance objectives set for the study blocks were realistic and achievable. Landings were within acceptable limits on all sites, but poor construction practices on main access roads resulted in excessive haul road disturbance on two study blocks. The two conventional and three mechanized harvesting operations exceeded allowable skidding disturbance levels. Skidding in wet weather was suggested as the primary reason for higher-than-expected levels of dispersed skidding disturbance in the two clearcut units. The practice of using some small patches to store logs when landings were temporarily filled resulted in substantial disturbance to the patches, causing skidding disturbance to exceed specified limits in the three heavy removal blocks.

Patterns and levels of slash accumulation varied among the cutting prescription/harvesting system combinations, from light, well distributed levels in the light removal unit to heavy concentrations at landings and roadside in the heavy removal and clearcut units. Post-harvest slash disposal was straightforward for the clearcut and light removal units. However, significant concentrations of slash at the landings on the heavy removal units were difficult to treat by burning because of the surrounding standing timber.

RECOMMENDATIONS

During the course of the harvesting operations, FERIC researchers identified opportunities for potentially improving the operational efficiency and/or cost of partial cutting in ICH stands. The following suggestions assume that the same light- and heavy-removal silvicultural prescriptions apply, ground-based harvesting systems are used, and stand and site conditions are similar to those observed in this study.

Planning and Layout

This study demonstrated that light- and heavy-removal partial cutting treatments require more intensive and careful field planning and result in higher planning costs per cubic metre than clearcuts. However, high-quality field layout is widely regarded as essential to an efficient partial cutting operation and should therefore remain a high priority in future operations. In particular, thorough site reconnaissance and route location are needed to ensure that the extraction network (within-block haul roads, landings, and skid roads) is properly located and aligned to facilitate falling and skidding.

However, some layout efficiencies may be possible without sacrificing quality. For example, using patch-opening designs that "funnel" trees in the direction of skidding (such as teardrop or diamond shapes) may enhance falling and skidding productivities and thereby reduce overall harvesting costs. Also, minor time savings in the layout phase may be realized by increasing patch sizes slightly and reducing the number of patch openings within a given treatment block. This could potentially reduce the lengths of patch boundaries to be located, marked, and surveyed, and may improve the productivities of the falling and skidding phases. Finally, ways to streamline tree marking in light-removal treatments should be investigated. Possibilities include using handheld dataloggers to monitor marking progress on an on-going basis in the field, developing modified marking methods that reduce the proportion of trees to be marked on a given site, or experimenting with faller-selection techniques.

Falling

Planners should consider the possibility of using feller-bunchers for falling in some partial cutting prescriptions. This study showed that, for the stand types observed in this trial, mechanized falling was feasible and more cost-effective than hand falling in patch openings in the heavy-removal treatments. Added advantages of mechanized falling include better worker safety, better control and placement of stems to reduce damage to residual trees and improve skidding efficiency, and the ability to prepare bunches which in turn permits the use of faster, larger-capacity grapple skidders.

However, machine size is an important consideration. Feller-bunchers for partial cutting operations must be small enough to negotiate skid roads and work in small patches. Although none were used in this study, there are several small feller-bunchers on the market that are designed for working in small areas. Small feller-bunchers with short tail swings and long reaches may even be suitable for working in light-removal prescriptions.

Also, the cost of transporting a feller-buncher to and from the cutblock must be considered in relation to the volume of timber available for mechanized falling. In this study, the feller-buncher also worked on a nearby clearcut and another heavy-removal unit, so collectively the volume was large enough to warrant mechanized falling. For an individual heavy-removal cutblock of the size used in this study, the available volume would probably not have been sufficient to warrant the use of a feller-buncher. Increasing the total area of the cutblock, and thus the volume available for harvest in each pass, may make the use of mechanized systems more feasible, and may streamline planning and development.

Harvesting and Skidding Systems

The contractors involved in this study were able to successfully modify their work methods to harvest the heavy-removal treatments with both conventional and mechanized systems using medium-sized skidders. This demonstrates the ability of loggers who have traditionally worked in clearcut operations to adapt to new situations, and also shows that specialized harvesting equipment is not a prerequisite for all partial cutting operations. Good layout and close supervision were probably more important to the success of the heavy-removal treatments than was equipment complement.

However, ground-based systems that use medium sized or larger skidders are probably not appropriate for light-removal harvests as used in this study. Horse logging is expensive but can be effective for these treatments, as the study shows. Small crawler tractor and processor/forwarder systems are also alternatives.

From a harvesting perspective the heavy-removal prescription, with its combination of small patch openings and dispersed harvest in the surrounding residual stand, is in effect two distinct operations. As demonstrated in this study, the patches can be harvested with either conventional or mechanized systems, while the light-removal areas are best suited to conventional hand falling and line skidding methods. Therefore, the choice of harvesting system will mainly depend upon the contractor's equipment profile and preference. The harvesting sequence is likewise a matter of preference, but most logging contractors would probably opt to harvest the patches first and the surrounding stands second.

A two-stage approach may be operationally efficient but it may also tend to concentrate more machine traffic and result in significant soil disturbance within the patches. Logging contractors are likely to use the harvested patches as focal points for subsequent harvesting of the surrounding light-removal areas because the patches serve as openings into which trees can be directed and allow skidders to maneuver more freely while accumulating turns. Also, patch openings may be used as sites to temporarily store logs when landings are busy or to transfer logs between, for example, line and grapple skidders on long skidding distances. If soil disturbance within patches is a concern, the conditions affecting the use of patch openings for these purposes should be clearly stated.

REFERENCES

Banner, A.; MacKenzie, W.; Haeussler, S.; Thompson, S.; Pojar, J.; Trowbridge, R. 1993. A field guide to site identification and interpretation for the Prince Rupert Forest Region. Part I. Research Branch, British Columbia Ministry of Forests, Victoria. 280 pp.

Coates, K.D.; Banner, A.; Steventon, J.D.; LePage, P.; Bartemucci, P.; Clement, C.J.E.; Macadam, A.M. 1996. The Date Creek study: Silvicultural systems and biodiversity in north temperate forests of British Columbia. B.C. Ministry of Forests, Victoria. Research Report. In press.

Curran, M.; Thompson, S. 1991. Measuring soil disturbance following timber harvesting. British Columbia Ministry of Forests, Victoria. Land Management Handbook, Field Guide Insert 5. 25 pp.

Mitchell, J. 1996. Trial of alternative silvicultural systems in southern British Columbia: Summary of harvesting operations. FERIC, Vancouver. Technical Note TN-240. 11 pp.

Thibodeau, E.D.; Manning, G.H. 1995. An assessment of employment opportunities in partial cutting practices. Phases I and II: Results of literature survey and field interviews. FERIC, Vancouver. Unpublished contract report submitted to B.C. Ministry of Forests, Silvicultural Practices Branch, Victoria. 31 pp. + app.

Appendix I

Planning and Layout

Productivity Assumptions	High	Medium	Low
Area reconnaissance (ha/day)	15.0	12.5	10.0
Locate/survey external boundaries (lineal m/h)	150	100	75
Skidding/transportation network			
Roads and landings (lineal m/h)	50	40	30
Skid roads (lineal m/h)	120	90	60
Skid trails (lineal m/h)	150	120	90
Mapping and timber cruising			
Locate grid and cruise plots (ha/day)	20	16	12
Main (full) plots (plots/day)	8	6	4
Secondary (count) plots (plots/day)	16	12	8
Patch layout (lineal m/h)	150	120	90
Tree marking (m^3/day)	400	325	250

Assumptions:
All work done by a 2-person crew (one professional, one technical) @ $600/8-h day ($75/crew-h).

Note: Planning costs in this report are based on the "medium" productivity assumptions shown above.

Planning Time Estimates Based on Productivity Assumptions

Block A-3: Clearcut /25.3 ha/13 054 m³	High	Medium	Low
Area reconnaisance (crew-h)	13.49	16.19	20.24
Locate/survey external boundaries (crew-h)	13.80	20.70	27.60
Skidding/transportation network			
Haul roads and landings (crew-h)	14.24	17.80	23.73
Skid roads (crew-h)	-	-	-
Skid trails (crew-h)	11.31	14.13	18.84
Mapping and timber cruising			
Locate grid and cruise plots (crew-h)	10.12	12.65	16.87
Main (full) plots (crew-h)	13.33	16.67	22.22
Secondary (count) plots (crew-h)	6.67	8.33	11.11
Patch layout (crew-h)	-	-	-
Tree marking (crew-h)	-	-	-
Total time (crew-h)	82.96	106.47	140.61
Total cost ($)	6 222.00	7 985.25	10 545.76
Total volume harvested (m³)	13 054	13 054	13 054
Cost ($/m³)	0.48	0.61	0.81
Cost ($/ha)	245.93	315.62	416.82

Block B-4: Clearcut/18.5 ha/7 730 m³	High	Medium	Low
Area reconnaisance (crew-h)	9.87	11.84	14.80
Locate/survey external boundaries (crew-h)	11.20	16.80	22.40
Skidding/transportation network			
Haul roads and landings (crew-h)	13.40	16.75	22.33
Skid roads (crew-h)	-	-	-
Skid trails (crew-h)	-	-	-
Mapping and timber cruising			
Locate grid and cruise plots (crew-h)	7.40	9.25	12.33
Main (full) plots (crew-h)	10.13	12.67	16.89
Secondary (count) plots (crew-h)	5.07	6.33	8.44
Patch layout (crew-h)	-	-	-
Tree marking (crew-h)	-	-	-
Total time (crew-h)	57.07	73.64	97.16
Total cost ($)	4 280.25	5 523.00	7 289.25
Total volume harvested (m³)	7 730	7 730	7 730
Cost ($/m³)	0.55	0.71	0.94
Cost ($/ha)	231.36	298.54	394.01

Block B-2: Heavy removal /25.2 ha/6 054 m³	High	Medium	Low
Area reconnaisance (crew-h)	13.44	16.13	20.16
Locate/survey external boundaries (crew-h)	14.75	22.12	29.49
Skidding/transportation network			
Haul roads and landings (crew-h)	8.80	11.00	14.67
Skid roads (crew-h)	4.90	6.53	9.80
Skid trails (crew-h)	10.71	13.38	17.84
Mapping and timber cruising			
Locate grid and cruise plots (crew-h)	10.08	12.60	16.80
Main (full) plots (crew-h)	26.67	33.33	44.44
Secondary (count) plots (crew-h)	-	-	-
Patch layout (crew-h)	26.47	33.08	44.11
Tree marking (crew-h)	63.40	78.03	101.44
Total time (crew-h)	179.22	226.20	298.75
Total cost ($)	13 441.50	16 965.00	22 406.25
Total volume harvested (m³)	6 054	6 054	6 054
Cost ($/m³)	2.22	2.80	3.70
Cost ($/ha)	533.39	673.21	889.14

Block C-2: Heavy removal/20.6 ha/6 354 m³	High	Medium	Low
Area reconnaisance (crew-h)	10.99	13.18	20.60
Locate/survey external boundaries (crew-h)	9.93	14.90	19.87
Skidding/transportation network			
Haul roads and landings (crew-h)	1.30	1.63	2.17
Skid roads (crew-h)	3.57	4.76	7.13
Skid trails (crew-h)	10.53	13.17	17.56
Mapping and timber cruising			
Locate grid and cruise plots (crew-h)	8.24	10.30	13.73
Main (full) plots (crew-h)	21.87	27.33	36.44
Secondary (count) plots (crew-h)	-	-	-
Patch layout (crew-h)	23.08	28.85	38.47
Tree marking (crew-h)	81.50	100.31	130.40
Total time (crew-h)	171.01	214.43	286.37
Total cost ($)	12 825.75	16 082.25	21 477.75
Total volume harvested (m³)	6 354	6 354	6 354
Cost ($/m³)	2.02	2.53	3.38
Cost ($/ha)	622.61	780.69	1 042.61

Block C-3: Light removal /22.9 ha/2 903 m^3	High	Medium	Low
Area reconnaisance (crew-h)	12.21	14.66	18.32
Locate/survey external boundaries (crew-h)	15.78	23.67	31.56
Skidding/transportation network			
Haul roads and landings (crew-h)	9.84	12.30	16.40
Skid roads (crew-h)	2.13	2.83	4.25
Skid trails (crew-h)	10.40	13.02	17.33
Mapping and timber cruising			
Locate grid and cruise plots (crew-h)	9.16	11.45	15.27
Main (full) plots (crew-h)	24.53	30.67	40.89
Secondary (count) plots (crew-h)	-	-	-
Patch layout (crew-h)	-	-	-
Tree marking (crew-h)	58.06	71.46	92.90
Total time (crew-h)	142.11	180.06	236.92
Total cost ($)	10 658.25	13 504.50	17 769.00
Total volume harvested (m^3)	2 903	2 903	2 903
Cost ($/m^3)	3.67	4.66	6.12
Cost ($/ha)	465.43	589.72	775.94

Appendix II

Falling Productivities and Costs

Productivity Assumptions	High	Mid	Low
Clearcut—conventional harvest			
Productivity (trees/scheduled hour)	30	26	22
Productivity (m^3/day)[a]	98-127	85-110	72-93
Cost (\$/m^3)[b]	3.56	4.11	4.74
Patch cut—conventional harvest			
Productivity (trees/scheduled hour)	27	21	15
Productivity (m^3/day)	88-114	68-89	49-63
Cost (\$/m^3)	3.95	5.08	7.12
ITS—conventional harvest			
Productivity (trees/scheduled hour)	20	16	12
Productivity (m^3/day)	65-85	52-68	39-51
Cost (\$/m^3)	5.34	6.67	8.90
ITS—horse skidding			
Productivity (trees/scheduled hour)	14	11	8
Productivity (m^3/day)	46-59	36-46	26-34
Cost (\$/m^3)	7.63	9.71	13.35

[a] Ranges are for net merchantable volumes of 0.50–0.65 m^3/tree.
[b] Cost/m^3 is based on a falling cost of $402.49/day (using IWA faller rates, 35% fringe benefits, and $26 for a chain saw) and an average net merchantable volume of 0.58 m^3/tree.

Appendix III

Machine and Horse Costing

	Case 1187C with Lokomo cone saw head	Clark 667F rubber-tired line skidder
OWNERSHIP COSTS		
Total purchase price (P) $	420 000	185 000
Expected life (Y) y	5	5
Expected life (H) h	8 000	10 000
Scheduled hours/year (h)=(H/Y) h	1 600	2 000
Salvage value as % of P (s) %	30	30
Interest rate (Int) %	9.0	9.0
Insurance rate (Ins) %	3.0	3.0
Salvage value (S)=(P•s/100) $	126 000	55 500
Average investment (AVI)=((P+S)/2) $	273 000	120 250
Loss in resale value ((P-S)/H) $/h	36.75	12.95
Interest ((Int•AVI/h) $/h	15.36	5.41
Insurance ((Ins•AVI)/h) $/h	5.12	1.80
Total ownership costs (OW) $/h	57.23	20.17
OPERATING COSTS		
Fuel consumption (F) L/h	25.0	22.0
Fuel (fc) $/L	0.40	0.40
Lube & oil as % of fuel (fp) %	20	15
Annual tire consumption (t) no.	0.0	2.0
Tire replacement (tc) $	0	3 200
Track & undercarriage replacement (Tc) $	30 000	0
Track & undercarriage life (Th) h	4 000	0
Annual operating supplies (Oc) $	0	1 500
Annual repair & maintenance (Rp) $	57 000	26 000
Shift length (sl) h	10.0	10.0
Operator wages $/h	23.20	21.10
Wage benefit loading (WBL) %	35	35
Fuel (F•fc) $/h	10.00	8.80
Lube & oil ((fp/100)•(F•fc)) $/h	2.00	1.32
Tires ((t•tc)/h) $/h	0.00	3.20
Track & undercarriage (Tc/Th) $/h	7.50	0.00
Operating supplies (Oc/h) $/h	0.00	0.75
Repair & maintenance (Rp/h) $/h	35.63	13.00
Wages & benefits (W•(1+WBL/100)) $/h	31.32	28.49
Prorated overtime (((1.5•W-W)•(sl-8)•(1+WBL/100))/sl) $/h	3.13	2.85
Total operating costs (OP) $/h	89.58	58.41
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) [a] $/h	146.81	78.58

[a] These costs are based on FERIC's standard costing methodology for determining machine ownership and operating costs. These costs do not include supervision, profit and overhead, and are not the actual costs for the contractor or company studied.

Machine and Horse Costing

	Clark 668F rubber-tired grapple skidder	Clark 668F rubber-tired line skidder
OWNERSHIP COSTS		
Total purchase price (P) $	285 000	220 000
Expected life (Y) y	5	5
Expected life (H) h	10 000	10 000
Scheduled hours/year (h)=(H/Y) h	2 000	2 000
Salvage value as % of P (s) %	30	30
Interest rate (Int) %	9.0	9.0
Insurance rate (Ins) %	3.0	3.0
Salvage value (S)=(P•s/100) $	85 500	66 000
Average investment (AVI)=((P+S)/2) $	185 250	143 000
Loss in resale value ((P-S)/H) $/h	19.95	15.40
Interest ((Int•AVI/h) $/h	8.34	6.44
Insurance ((Ins•AVI)/h) $/h	2.78	2.15
Total ownership costs (OW) $/h	31.07	23.98
OPERATING COSTS		
Fuel consumption (F) L/h	22.0	22.0
Fuel (fc) $/L	0.40	0.40
Lube & oil as % of fuel (fp) %	15	15
Annual tire consumption (t) no.	2.0	2.0
Tire replacement (tc) $	3 200	3 200
Annual operating supplies (Oc) $	0	1 500
Annual repair & maintenance (Rp) $	40 000	31 000
Shift length (sl) h	10.0	10.0
Operator wages $/h	21.10	21.10
Wage benefit loading (WBL) %	35	35
Fuel (F•fc) $/h	8.80	8.80
Lube & oil ((fp/100)•(F•fc)) $/h	1.32	1.32
Tires ((t•tc)/h) $/h	3.20	3.20
Track & undercarriage (Tc/Th) $/h	0.00	0.00
Operating supplies (Oc/h) $/h	0.00	0.75
Repair & maintenance (Rp/h) $/h	20.00	15.50
Wages & benefits (W•(1+WBL/100)) $/h	28.49	28.49
Prorated overtime (((1.5•W-W)•(sl-8)•(1+WBL/100))/sl) $/h	2.85	2.85
Total operating costs (OP) $/h	64.66	60.91
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) [a] $/h	95.73	84.89

[a] These costs are based on FERIC's standard costing methodology for determining machine ownership and operating costs. These costs do not include supervision, profit and overhead, and are not the actual costs for the contractor or company studied.

Machine and Horse Costing

	Caterpillar 518 rubber-tired line skidder	Caterpillar D6D line skidder (used)
OWNERSHIP COSTS		
Total purchase price (P) $	155 000	80 000
Expected life (Y) y	5	4
Expected life (H) h	8 000	6 500
Scheduled hours/year (h)=(H/Y) h	1 600	1 625
Salvage value as % of P (s) %	30	30
Interest rate (Int) %	9.0	9.0
Insurance rate (Ins) %	3.0	3.0
Salvage value (S)=(P•s/100) $	46 500	24 000
Average investment (AVI)=((P+S)/2) $	100 750	52 000
Loss in resale value ((P-S)/H) $/h	13.56	8.62
Interest ((Int•AVI/h) $/h	5.67	2.88
Insurance ((Ins•AVI)/h) $/h	1.89	0.96
Total ownership costs (OW) $/h	21.12	12.46
OPERATING COSTS		
Fuel consumption (F) L/h	22.0	23.0
Fuel (fc) $/L	0.40	0.40
Lube & oil as % of fuel (fp) %	15	15
Annual tire consumption (t) no.	2.0	0.0
Tire replacement (tc) $	1 300	0
Annual operating supplies (Oc) $	1 500	1 500
Annual repair & maintenance (Rp) $	25 000	14 000
Shift length (sl) h	10.0	10.0
Operator wages $/h	21.10	21.38
Wage benefit loading (WBL) %	35	35
Fuel (F•fc) $/h	8.80	9.20
Lube & oil ((fp/100)•(F•fc)) $/h	1.32	1.38
Tires ((t•tc)/h) $/h	1.63	0.00
Operating supplies (Oc/h) $/h	0.94	0.92
Repair & maintenance (Rp/h) $/h	15.63	8.62
Wages & benefits (W•(1+WBL/100)) $/h	28.49	28.86
Prorated overtime (((1.5•W-W)•(sl-8)•(1+WBL/100))/sl) $/h	2.85	2.89
Total operating costs (OP) $/h	59.66	51.87
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) [a] $/h	80.78	64.33

[a] These costs are based on FERIC's standard costing methodology for determining machine ownership and operating costs. These costs do not include supervision, profit and overhead, and are not the actual costs for the contractor or company studied.

Costing Assumptions for the Horse Logging Operation [a]

Where only one horse was used, the cost will be estimated as 50% of the team cost.

	Assumption		Cost ($/shift)
OWNERSHIP COSTS			
Purchase price	For team of two 5-year-old horses, trained, Belgian or Percheron	$11 000	
Expected working life		10 years	
Scheduled shifts		120/year	
Salvage value		none	
Loss in resale value			9.17
Interest		8%	3.67
Total ownership cost [b]			12.84
OPERATING COSTS			
Insurance	per team per year	$200	1.67
Harness	will last for life time of the team	$1 000	0.83
Collar	one for each horse, lifetime	$500	0.42
Collar pads	2 per horse per year	$140	1.16
Harness repair	per year	$200	0.42
Fly protection	per year	$200	3.33
Shoes and hoof trimming	6 sets / year / horse at $100 each	$1 200	10.00
Feed, while working	$10/shift/team	$1 200	
Feed, while not working	$6/day, prorated over working shifts	$1 470	22.25
Veterinary	2 visits per horse, $200 each	$800	6.67
Teamster wages	8-h shifts		230.90 [c]
Total operating costs			277.65
TOTAL OWNERSHIP AND OPERATING COSTS			290.49

[a] This cost information was gathered during the study, and from J. Grant, Echo Horse Logging, Cumberland, B.C., personal communication, March 1996.

[b] Costing is based on a team of horses, unless otherwise indicated. Where only one horse was used, the cost is estimated at 50% of the team cost. Costs do not include transportation, housing and corralling, nor tending during non-working shifts.

[c] The IWA bucker rate plus 35% fringe benefits was applied as the teamster wages. Teamsters 2 and 5 felled their own wood and therefore only 0.5 shift labour is used in calculating the skidding cost for these teamsters.

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