FOREST ENGINEERING
RESEARCH INSTITUTE
OF CANADA

FERIC

INSTITUT CANADIEN
DE RECHERCHES
EN GÉNIE FORESTIER

A PRODUCTIVITY COMPARISON OF CLEARCUTTING AND ALTERNATIVE SILVICULTURE SYSTEMS IN COASTAL BRITISH COLUMBIA

M.T. Bowden-Dunham

June 1998

TR-122

A PRODUCTIVITY COMPARISON OF CLEARCUTTING AND ALTERNATIVE SILVICULTURE SYSTEMS IN COASTAL BRITISH COLUMBIA

M.T. Bowden-Dunham

FOREST ENGINEERING RESEARCH INSTITUTE OF CANADA
Western Division
2601 East Mall
Vancouver, British Columbia
V6T 1Z4
Tel: (604) 228-1555 Fax: (604) 228-0999

FERIC Technical Report No. TR-122

June 1998

KEYWORDS: Harvesting, Silvicultural systems, Clearcutting, Alternative methods, Partial cutting systems, Uniform shelterwood system, Productivity, Costs, Comparison, Coastal British Columbia.

 ISSN 0381-7733

Abstract

Between March 1996 and April 1997, harvesting occurred on an alternative silviculture systems research study site in a mature naturally regenerated stand in the Roberts Creek Study Forest on coastal British Columbia. Three treatments (extended rotation, clearcut and two-pass uniform shelterwood) plus an unlogged control were studied. The Forest Engineering Research Institute of Canada (FERIC) monitored the harvesting phase of the three treatments in order to estimate productivity and costs, and to identify factors influencing harvest system productivity.

Author

Michelle Bowden-Dunham is a research technician in the Harvest Engineering Group at FERIC's Western Division. She graduated from the British Columbia Institute of Technology in Renewable Resources, Forestry Option, and is currently working towards accreditation as a Registered Professional Forester. Since joining FERIC in 1995, Michelle has worked on several cable yarding and partial cutting studies throughout British Columbia.

Acknowledgements

The author gratefully acknowledges the cooperation of Ken Sneddon, John Phare and the rest of the crew from Sechelt Creek Contracting. Special thanks are also extended to Mike Whitehouse of British Columbia Ministry of Forests (BCMOF), Sechelt Field Office and Brian D'Anjou of the BCMOF, Forest Sciences Section for their valuable assistance during the project. The author would also like to thank FERIC employees Clayton Gillies, Craig Evans and Stephanie Sambo for their assistance with field work; Ingrid Hedin, Ray Krag and Marv Clark for project advice and draft report review; and Shelley Corradini, Yvonne Chu and Monique Kalmokoff for their assistance with report preparation.

Partial funding assistance for the harvesting study was provided by the BCMOF, Silviculture Systems Program.

Table of Contents

List of Tables

List of Figures

Summary

In the early 1990s the British Columbia Ministry of Forests (BCMOF), Forest Sciences section initiated the Roberts Creek Study Forest Alternative Silviculture Systems Project to study and compare the short- and long-term biological, social and economic issues associated with three harvesting treatments. The study compares extended rotation, two-pass uniform shelterwood, and clearcut with reserves silviculture systems. The study area is located approximately 40 km north of Vancouver on the Sunshine Coast of B.C. in the Roberts Creek Study Forest (RCSF). The RCSF lies within the Dry Maritime Coastal Western Hemlock (CWHdm) biogeoclimatic subzone (Green and Klinka 1994) with relatively gentle slope conditions and a species composition consisting of Douglas-fir (*Pseudotsuga menziesii* [Mirb] Franco) with an understorey of western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) and western red cedar (*Thuja plicata* Donn). The stand ranges from 65 to 85 years of age, with a few veteran Douglas-fir and western red cedar trees that survived a natural wildfire that occurred in the early 1900s.

Long-term BCMOF objectives are to investigate alternative harvesting systems with operational application for the future, and to compare ecosystem processes and characteristics over time in a mesic mature Douglas-fir forest under three harvesting methods encompassing a range of canopy retentions. An experiment was established with three different removal levels: (1) Extended rotation encompasses five entries over the next 65 years. Entry 1, conducted during the study, created corridors within the stand and removed 11% of the stand volume. (2) Two-pass uniform shelterwood with reserves includes a regeneration and removal cut. The regeneration cut carried out during the study reduced the stand to 75–95 trees/ha. (3) Clearcut with reserves involves clearcutting while retaining Douglas-fir and western red cedar veterans and one seed tree per hectare.

The Forest Engineering Research Institute of Canada's (FERIC) objectives were to determine the overall productivity of each harvesting treatment and to calculate phase costs for the operations; obtain detailed cycle time and cycle delay information on the yarding phase of the operations; and identify operational factors that influence the performance of the harvesting methods.

Between March 1996 and April 1997, FERIC monitored the harvesting phase of the three treatment units. The harvesting phase was publicly tendered under the Small Business Forest Enterprise Program and the contract was awarded to Sechelt Creek Contracting of Gibsons, B.C. The contract included the falling, yarding and loading phases of the operation.Both falling and yarding crews were experienced with cable commercial thinning. A Washington SLH 78 swing yarder, with a Berger mechanical slackpulling carriage configured as a running skyline system, performed all yarding operations.

Harvesting costs were derived using standard FERIC costing methodology. The extended rotation unit achieved the highest falling productivity at 139.5 m^3/6.5-h shift, while the clearcut and shelterwood units achieved 93.2 m^3/6.5-h shift and 83.5 m^3/6.5-h shift, respectively. The greatest influences on falling productivity appeared to be tree volume, falling pattern and falling/yarding conflicts. The uniform shelterwood unit had the highest yarding productivity/8.0-h shift at 200 m^3, followed by the extended rotation unit at 181 m^3, and the clearcut unit at 143 m^3. Conversely, the clearcut unit had the fastest yarding cycle time when standardized to 100 m slope distance, at 5.31 min, followed by the uniform shelterwood and extended rotation units at 5.97 min and 6.43 min, respectively. Number of chokers and piece size were the most significant factors affecting productivity and may explain the inconsistency between productivity and cycle time results. The extended rotation unit had the lowest overall cost from stump to truck at \$20.76/m^3, followed by the uniform shelterwood unit at \$21.84/m^3, and the clearcut unit at \$26.14/m^3.

Productivity and cost results were significantly influenced by tree size, piece size and number of chokers or pieces per cycle. However, during the course of the harvesting operations, other operational factors influencing productivities and costs were also identified and are presented in this report.

Sommaire

Au début des années 1990, la section des Sciences forestières du ministère des Forêts de Colombie-Britannique (BCMOF) a entrepris un projet d'étude sur divers régimes sylvicoles dans la Forêt expérimentale de Roberts Creek, afin d'examiner et de comparer les enjeux biologiques, sociaux et économiques à court et à long terme, associés à trois traitements de récolte. L'étude compare trois traitements différents: une coupe avec rotation prolongée, une coupe progressive uniforme en deux passages et une coupe rase avec réserves. L'aire d'étude se trouve approximativement à 40 km au nord de Vancouver sur la Sunshine Coast de C.-B., dans la Forêt expérimentale de Roberts Creek (RCSF). Cette forêt, située dans la sous-zone

biogéoclimatique maritime sèche de la pruche occidentale côtière (CWHdm) (Green et Klinka, 1994), présente des conditions de pente relativement douce et une composition en essences consistant en Douglas taxifolié (*Pseudotsuga menziesii* [Mirb] Franco) avec sous-étage de pruche occidentale (*Tsuga heterophylla* [Raf.] Sarg.) et de thuya géant (*Thuja plicata* Donn.). L'âge du peuplement varie de 65 à 85 ans; on y trouve aussi quelques vétérans, des Douglas taxifoliés et thuyas géants ayant survécu à un feu naturel survenu au début des années 1900.

Les objectifs du BCMOF à long terme sont d'étudier divers systèmes de récolte pouvant s'appliquer de façon opérationnelle dans l'avenir, et de comparer sur une longue période les processus et les caractéristiques des écosystèmes dans une forêt mésoïque de Douglas taxifolié à maturité, suivant trois méthodes de récolte donnant des conditions variées de maintien du couvert. Un dispositif expérimental a été établi avec trois niveaux de prélèvement différents: (1) La coupe à rotation prolongée prévoit cinq entrées au cours des 65 prochaines années. L'entrée 1, effectuée pendant l'étude, a créé des corridors à l'intérieur du peuplement en y prélevant 11% du volume. (2) La coupe progressive uniforme en deux passages avec réserves comprend une coupe de régénération et une coupe secondaire. La coupe de régénération effectuée pendant l'étude a réduit le peuplement à 75-95 arbres/ha. (3) La coupe rase avec réserves consiste à enlever le peuplement en une seule coupe tout en conservant les Douglas taxifoliés et thuyas géants vétérans, ainsi qu'un arbre semencier par hectare.

Les objectifs de l'Institut canadien de recherches en génie forestier (FERIC) étaient de déterminer la productivité globale de chaque traitement de récolte et de calculer les coûts pour chacune des phases des opérations; d'obtenir de l'information détaillée sur le temps du cycle et les temps morts pour la phase de téléphérage; et d'identifier les facteurs opérationnels qui influencent la performance des méthodes de récolte.

Entre mars 1996 et avril 1997, FERIC a assuré un suivi de l'étape de récolte dans les trois blocs de traitement. Un appel d'offres avait été lancé publiquement pour cette étape dans le cadre du programme des petites entreprises forestières (Small Business Forest Enterprise Program) et le contrat avait été accordé à Sechelt Creek Contracting de Gibsons, C. B. Le contrat portait sur les phases d'abattage, de téléphérage et de chargement. Les équipes d'abattage et de téléphérage étaient toutes deux expérimentées dans l'éclaircie commerciale par câble. Un câble-grue Washington SLH 78 à mât orientable, équipé d'un chariot Berger à dispositif de tensionnement mécanique et configuré comme un système de câble-grue à chariot autoleveur, effectuait toutes les opérations de téléphérage.

Les coûts de récolte ont été obtenus à l'aide de la méthode standard d'analyse des coûts de FERIC. Le bloc à rotation prolongée a montré la productivité la plus élevée pour l'abattage, soit 139,5 m³/poste de travail de 6,5 h, contre 93,2 et 83,5 m³/poste de 6,5 h, respectivement, pour les blocs de coupe rase et de coupe progressive. Les facteurs qui avaient le plus d'influence sur la productivité à l'abattage semblaient être le volume par arbre, le schéma d'abattage et les conflits abattage-téléphérage. Le bloc de coupe progressive uniforme a donné la productivité la plus élevée au téléphérage, soit 200 m³/poste de 8 h; il était suivi par le bloc à rotation prolongée avec 181 m³ et le bloc de coupe rase avec 143 m³. Inversement, le bloc de coupe rase a eu le cycle de téléphérage le plus rapide, une fois la distance en pente normalisée à 100 m, soit 5,31 min, et il était suivi par les blocs de coupe progressive uniforme et de rotation prolongée à 5,97 et 6,43 min, respectivement. Le nombre de colliers étrangleurs et les dimensions des pièces étaient les facteurs les plus significatifs qui affectaient la productivité et ils peuvent expliquer le manque de cohérence entre les résultats relatifs à la productivité et au temps du cycle. Le bloc à rotation prolongée a montré le coût global le plus bas depuis la souche jusqu'au camion, soit 20,76 $/m³, suivi du bloc de coupe progressive à 21,84 $/m³, et du bloc de coupe rase à 26,14 $/m³.

Les résultats de productivité et de coût ont été influencés de façon significative par les dimensions des arbres, les dimensions des pièces et le nombre de colliers étrangleurs ou de pièces par cycle. Cependant, dans le cours des opérations de récolte, d'autres facteurs opérationnels ayant des répercussions sur les productivités et les coûts ont aussi été identifiés et sont présentés dans le rapport.

INTRODUCTION

Public pressure, concerns about long-term site productivity, and multi-resource management objectives in British Columbia have motivated both private and public forest sectors to explore alternative silvicultural systems and harvesting methods. As part of the investigation into alternative harvesting methods, the British Columbia Ministry of Forests (BCMOF) established the Roberts Creek Study Forest (RCSF) located on the Sunshine Coast of British Columbia (Figure 1). The Roberts Creek area has high recreation, water and biodiversity values due to its proximity to urban areas, relatively easy access for harvesting, and mild climate. The BCMOF has implemented a program of multi-disciplinary research to study and compare biological, social and economic issues associated with the three harvesting treatments (extended rotation, clearcut and two-pass uniform shelterwood) plus an unlogged control.

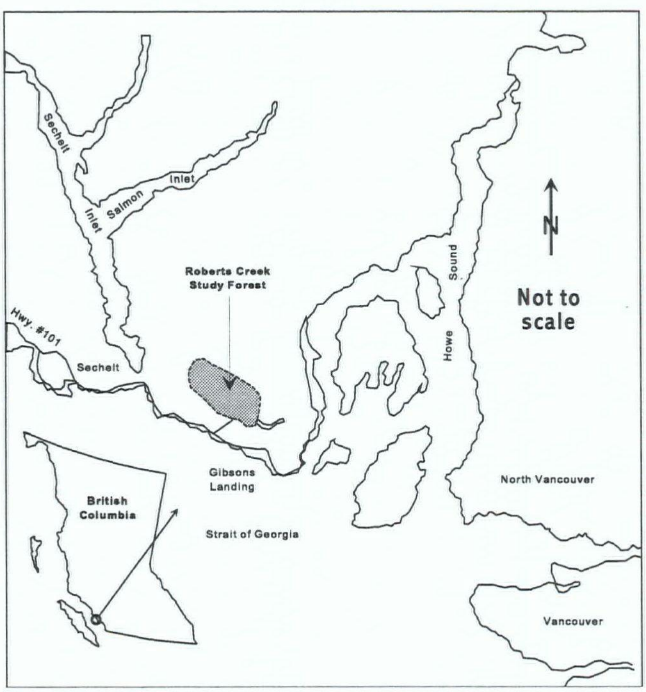


Figure 1. Location map.

In 1993, prior to initiating the larger research installation, the BCMOF conducted a pilot study of a uniform shelterwood harvest using a Cypress 6280B swing yarder, rigged in a running skyline configuration. The Forest Engineering Research Institute of Canada (FERIC) determined productivity and costs for the pilot study and identified factors influencing the harvesting operation (Hedin 1994). In 1996, the BCMOF implemented the initial treatment in a replicated experiment. FERIC monitored the harvesting operations between March1996 and April 1997. This report describes the harvesting operations, compares their productivities, and presents observations on the falling, yarding and loading phases for the three harvesting treatments.

OBJECTIVES

The Roberts Creek Alternative Silviculture Systems Project has both long- and short-term objectives. As coordinator of the research program, BCMOF Forest Sciences Section has set the following long-term objectives, to be addressed in future BCMOF publications:

- Undertake a study with a sound experimental design, investigating alternative harvesting systems with operational applications in the future.
- Describe and compare ecosystem processes and characteristics over time in mesic, mature Douglas-fir forests, under three harvesting methods encompassing a range of canopy retentions.

In consultation with the BCMOF, FERIC set the following short-term objectives, to be addressed in this report:

- Determine the overall productivity of each harvesting treatment and calculate phase costs for the operations.
- Obtain detailed cycle time and cycle delay information on the yarding phase of the operations.
- Identify operational factors that influence the performance of the harvesting methods.

STUDY METHODS

Block maps, cruises and layout of the treatment units were completed in 1994 by forestry consultants contracted by the BCMOF (Figure 2). The harvesting phase was publicly tendered under the Small Business Forest Enterprise Program, and the contract to harvest the three blocks was awarded to Sechelt Creek Contracting of Gibsons, B.C. The contractor began harvesting the treatment areas in March 1996.

FERIC monitored harvesting operations for each treatment unit by collecting shift-level data on the falling, yarding and loading crews and equipment, and detailed-timing data on the yarding phase of the operations. Shift-level data were collected by mounting a Servis Recorder on the harvesting equipment to record scheduled, productive, non-productive and delay times. The workers also

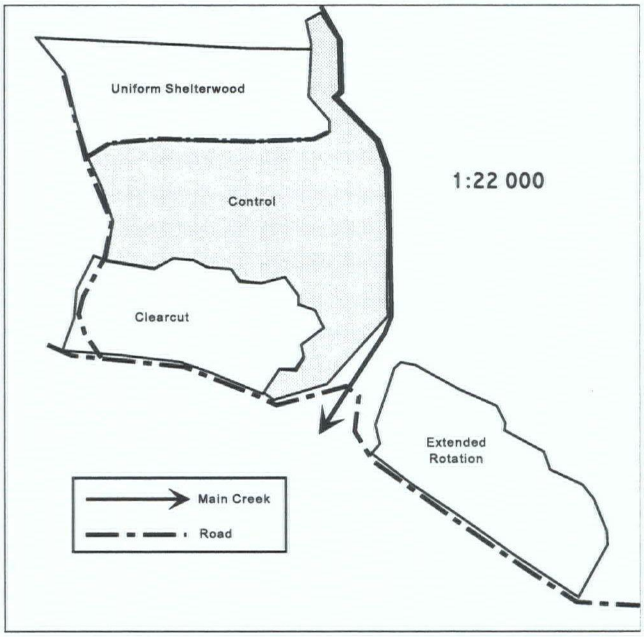


Figure 2. Roberts Creek treatment unit map.

kept records detailing daily events and production. Detailed timing was performed for a sample of yarding cycles using a hand-held computer, which recorded times for yarding cycle elements. Influential factors such as number of logs per cycle and slope distance were recorded for each timed turn. Scale data for each of the treatment units were obtained from log sort reports and used in productivity calculations.

Multiple regression analysis was performed on the detailed-timing data for each treatment unit, to relate total delay-free cycle time to slope distance, number of logs and number of chokersetters per cycle.

Production costs were derived using FERIC's standard costing methodology based on the IWA-Canada 1996 Standard Logging Wage Scale, with 35% fringe benefits and current purchase price for new equipment. These costs do not include supervision, profit and overhead, and are not representative of the contractor's costs.

SITE AND STAND DESCRIPTION

The Roberts Creek research project is located in the RCSF between the towns of Gibsons and Sechelt on the Sunshine Coast, approximately 40 km north of Vancouver, B.C. (Figure 1). The study forest occupies the lower slope of the Tetrahedron Mountains of the Pacific Ranges physiographic unit and lies within the Dry Maritime Coastal Western Hemlock (CWHdm) subzone (Green and Klinka 1994). The zonal conditions in this ecosystem were represented as mesic moisture and medium nutrient. Sites in the study area ranged in elevation from 350 to 500 m, categorizing it in the rain-on-snow transition zone which is characterized by occasional snowpack and frequent heavy rainfalls. Surficial material consisted primarily of compact basal till overlain by a blanket of looser sandy ablation till up to 3.0 m deep.

The treatment units within the study forest all have relatively gentle slope conditions with a similar species composition consisting of Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) with an understorey of western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) and western red cedar (*Thuja plicata* Donn) (Table 1). The stand ranges from 65 to 85 years of age, with a few veteran Douglas-fir and western red cedar trees that survived a natural wildfire that occurred in the early 1900s.

Table 1. Pre- and Post-Harvest Stand Description by Treatment Unit

	Extended rotation	Uniform shelterwood	Clearcut
Pre-harvest (actual)			
Cutblock size (ha)	11.0	12.1	10.1
Species composition [a]	F(HC)	F(HC)	F(CH)
Pre-harvest (trees/ha)	880	755	1 238
Pre-harvest (m^3/ha)	906	852	825
Post-harvest (prescribed)			
Stand removal (%)	11	87–90	100
Post-harvest (trees/ha)	783	75–95	1
Post-harvest (m^3/ha)	806	85–111	1

[a] F = Douglas-fir; H = western hemlock; C = western red cedar

SILVICULTURAL PRESCRIPTIONS

There are three prescriptions for the harvested area: extended rotation, two-pass uniform shelterwood with reserves, and clearcut with reserves. All treatment units will be planted with Douglas-fir and western red cedar during the first spring following the initial harvest. It is anticipated that the uniform shelterwood prescription will improve the establishment of natural regeneration, although some natural regeneration is also expected in the extended rotation unit.

Extended Rotation

The extended rotation prescription calls for three thinning passes followed by a shelterwood harvest with reserves, with 15-year intervals between each entry. Entry 1, conducted during the study, creates corridors within the stand and removes 11% of the stand volume. Entries 2 and 3, to occur 15 and 30 years, respectively, after the initial entry, removes trees between corridors from all diameter classes and species, while favoring removal of hemlock and retention of understorey cedar. The fourth harvesting phase will reduce overstorey density to 80–90 trees/ha of the tallest Douglas-fir and cedar. The final entry, scheduled for the year 2061, will reduce overstorey density to 15–20 trees/ha.

Two-Pass Uniform Shelterwood with Reserves

The prescription for uniform shelterwood with reserves requires two harvesting entries including a seed cut or regeneration cut, and a removal cut. The seed cut will retain dominant, healthy Douglas-fir and western red cedar with a stand density of 75–95 trees/ha. All western hemlock will be removed during this entry to reduce the potential for dense hemlock regeneration.

The removal cut will remove damaged, diseased or deformed trees, and reduce the stand to 20–30 trees/ha. The removal cut is scheduled for three to seven years after the first entry, depending upon understorey light requirements. The remaining stand will be left as reserve trees to continue through until the next rotation.

Clearcut with Reserves

This prescription involves clearcutting while retaining Douglas-fir and western red cedar veterans and one seed tree per hectare. Although not part of the prescription, a sparse 15-m-wide leave strip was left in order to buffer a small zero-order ephemeral creek. Leave strip trees were mainly co-dominant or suppressed and therefore less windfirm.

HARVESTING SYSTEMS AND EQUIPMENT

The contractor was responsible for falling, yarding and loading on all of the harvested treatment units. Both falling and yarding crews were experienced and highly skilled at coastal cable logging techniques. They also had previous experience with cable thinning operations, although not partial cutting prescriptions such as in this study.

Planning and Layout

Planning and layout activities and costs were not included in FERIC's study because of the research nature of the operations. Corridors and leave trees were marked by BCMOF researchers prior to harvesting in the extended rotation and shelterwood units. However, any leave tree deemed by fallers to be dangerous or hazardous was removed after discussion and approval by the BCMOF supervisor. The locations of two yarding corridors in the shelterwood unit were modified just prior to falling to decrease lateral yarding distance between corridors.

Falling

Falling began in the extended rotation unit, followed by the clearcut unit and then the shelterwood unit. The falling crew was comprised, on average, of two fallers. In the extended rotation and shelterwood units, falling was intermittent depending on the progression of yarding and on wind conditions. Falling in the clearcut was more continuous, with only periodic interruptions caused by snow conditions.

In both the extended rotation and shelterwood units, the trees were directionally felled towards the centre of the corridor and positioned perpendicular to the haul road. A herringbone pattern was used to fall a majority of trees between corridors in the shelterwood unit. However, most trees at the back ends of the yarding corridors were felled parallel to the haul road and left tree length to ensure they could be yarded. Delimbing and some bucking were done in conjunction with falling.

Falling and yarding in the extended rotation unit were carried out alternately. Two corridors were felled at one time with at least one inactive corridor separating the two active corridors. This was done to ensure the yarding crew was within a safe working distance of the falling crew. The extended rotation prescription also required falling and yarding of backspar trees once each corridor had been completely yarded. Initially, falling in the shelterwood unit was to be done in a similar manner as in the extended rotation unit. However, falling guidelines were amended to allow falling to proceed concurrently on and between corridors in an attempt to minimize falling/yarding schedule conflicts.

Yarding and Loading

A Washington SLH 78 mobile swing yarder (Figure 3) with a Berger mechanical slackpulling carriage, configured as a running skyline system, performed all the yarding operations (Tables 2 and 3). Log loading was done with either a Kobelco 912 or Chapman 172 hydraulic log loader.

Yarding crew size was fairly consistent throughout all treatment units, and typically consisted of a yarding engineer, a landing person (chaser/bucker), one chokersetter and a hook tender. Falling and yarding personnel often performed other tasks in addition to their primary roles and switched jobs as required.

Figure 3. Washington SLH 78 mobile swing yarder.

Table 2. Machine Specifications: Washington SLH 78 Mobile Swing Yarder

Maximum power (kW)	177 @ 2100 rpm
Tower height (m)	13
Tower weight (kg)	41 690
Winch drums (no.)	4
Guylines (no.)	3
Maximum line pull (kg)	14 060
Maximum line speed (m/min)	740

A running skyline cable system was used throughout the study. The running skyline configuration consisted of two haulback blocks hung approximately 15 m up the backspar tree, and one or two blocks positioned at the base of a tailhold tree (Figure 4). A mobile backspar was used for a 1-ha section of the clearcut unit between the main haul road and a short spur road.

All yarding road changes in the extended rotation unit were pre-rigged, while only 13 of 22 yarding roads in the shelterwood were pre-rigged. Pre-rigging was not necessary in the clearcut. Backspar tree rigging was placed using an extension ladder rather than using climbing gear (e.g., belt and spurs) for all of the treatment units. Road changes in the extended rotation and shelterwood units were generally more time consuming and complex than in the clearcut unit because each road change also entailed repositioning the yarder directly in front of each yarding road. All yarding was downhill; therefore, road changes were performed by stringing strawline extensions from the backspar currently in use over to the next backspar to be used, through the backspar blocks, and back towards the yarder positioned on the main haul road (Figure 5).

Layout problems in the shelterwood unit resulted in several wide sections between corridors, so the rigging was adapted to accommodate these irregular corridors. A modified Dutchman[1] was used in conjunction with the running skyline to increase lateral yarding capability (Figure 6). In addition, between Corridor 1 and the block boundary, yarding roads were stump-rigged near the tree line on Corridor 5, causing the yarding roads

[1] "Dutchman" refers to a block arrangement used to pull the bight of the line to alter its lateral placement (Tataryn 1993).

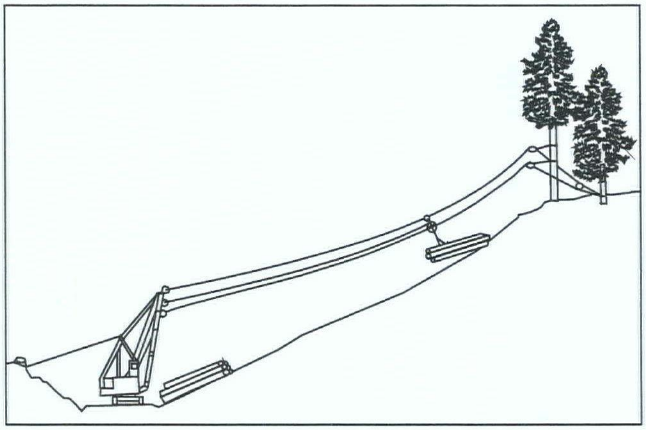


Figure 4. Running skyline configuration - one tail block.

Table 3. Harvesting System Description by Treatment Unit

	Extended rotation	Uniform shelterwood	Clearcut
Block layout			
Maximum yarding distance (m)	240	225	260
Yarding direction	downhill	downhill	downhill
Average slope (%)	19	10	24
Deflection (average % sag/road)	6.4	6.0	6.3
Corridors (no.)	11	11	-
Corridor width (m)	4–6	5–7	-
Yarding			
Average chokers used (no.)	2.0	3.0	2.4
Operator visibility	good	good	good
Extraction destination	roadside	roadside	roadside
Type of backspar	standing tree	standing tree	standing tree/ mobile backspar
Loading/hauling			
Average hauling distance (km) [a]	20	20	20
Average round-trip hauling time/load (h) [a]	2.0–2.5	2.0–2.5	2.0–2.5

[a] Hauling distance and time are contractor estimates.

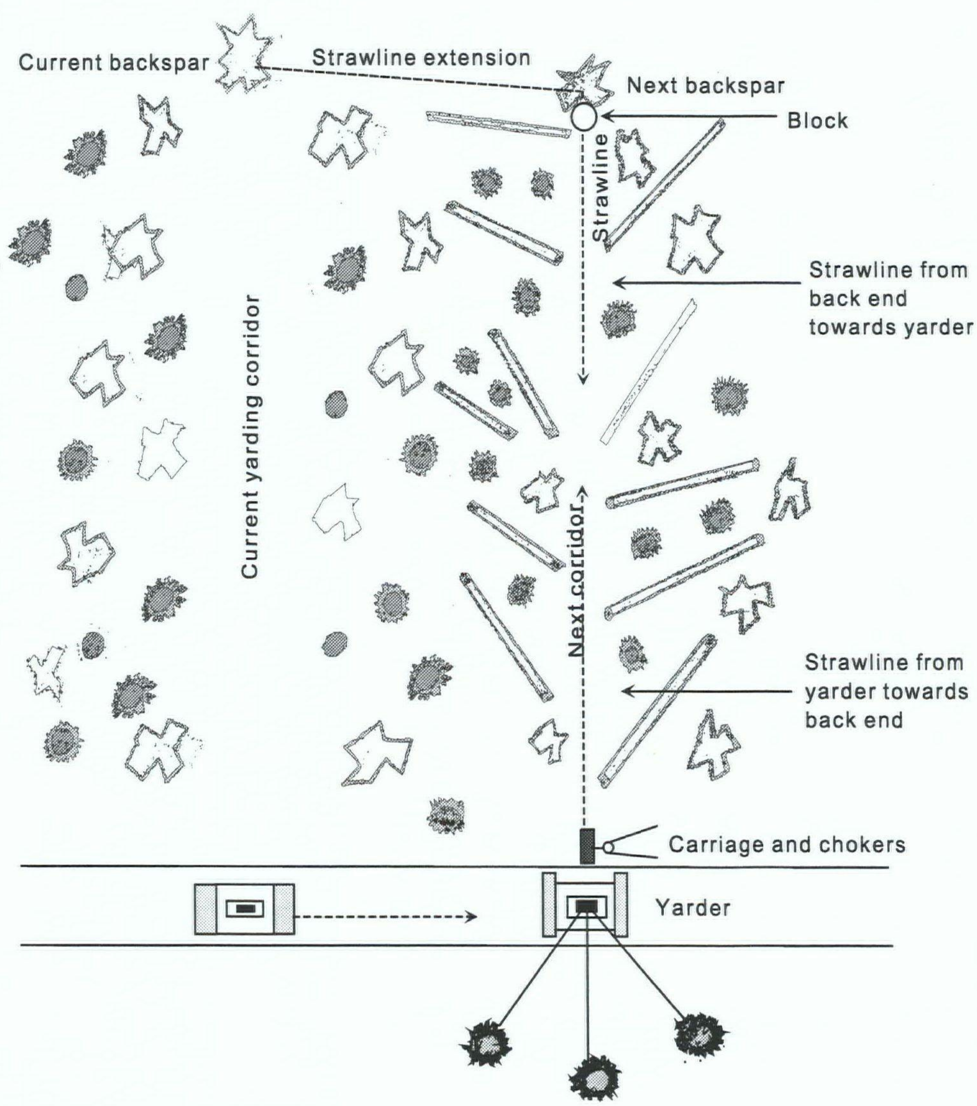


Figure 5. Road change procedure.

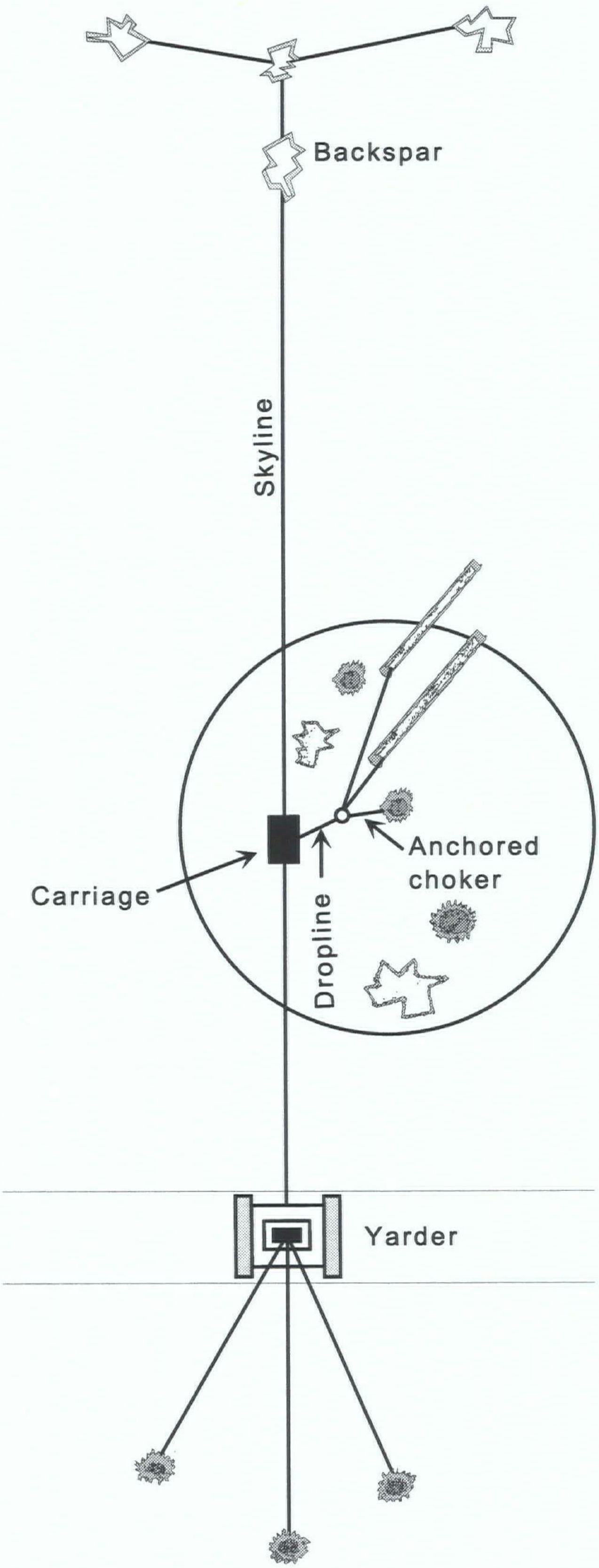


Figure 6. Modified Dutchman created by hooking one choker to a standing tree to deflect the lateral yarding direction of the turn.

to radiate about the landing. As a result, lateral yarding distances increased proportionally to inhaul distance (Figure 7). Rigging adaptations required BCMOF approval. Line rubbing was intensified when corridors were widely spaced because of the long lateral yarding distances. Therefore, additional measures were taken to reduce damage to residual trees. Protective rubber matting or wood chunks were often used to reduce residual damage in both the extended rotation and shelterwood treatment units. Cherry-picking[2] was performed on and between Corridors 7 through 11, one or two weeks before yarding.

RESULTS AND DISCUSSION

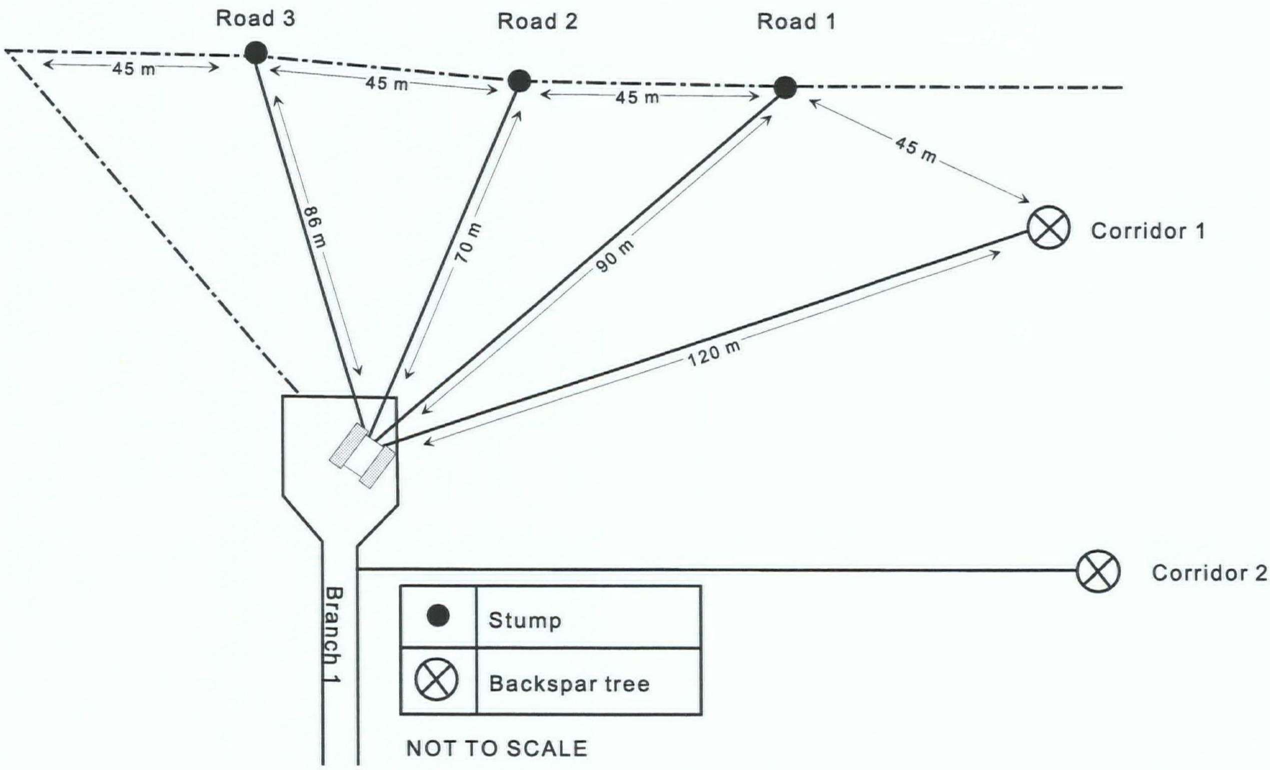
Harvesting, which began in early March 1996, was interrupted for three months during the summer of 1996 and concluded in mid-April 1997. Harvesting began in the extended rotation unit. Here the crews worked 13 faller shifts and 10 yarding shifts, and harvested a total volume of 1792 m^3. The clearcut unit was harvested from mid-July to early December. A total volume of 9311 m^3 was harvested during 100 faller shifts and 65 yarding shifts. In the shelterwood unit, which was harvested between early January and mid-April 1997, a total of 99 faller shifts and 41 yarding shifts were spent harvesting a volume of 8282 m^3.

Falling Operations

Table 4 summarizes falling production and costs for each treatment unit. A total time of 83.5 h was spent falling in the extended rotation unit, 649.0 h in the clearcut unit, and 645.0 h in the shelterwood unit. Downtime was mainly attributed to wind, with both the extended rotation and shelterwood units losing 5.2 h and 20.2 h, respectively, to wind. Windy conditions make directional falling more difficult and dangerous for falling crews.

Falling productivity was affected by tree size and volume/ha. The highest productivity was in the extended rotation unit at 139.5 m^3/6.5-h shift. The clearcut and shelterwood units had productivities of 93.2 m^3/6.5-h shift and 83.5 m^3/6.5-shift, respectively. Falling between corridors in the shelterwood unit appeared more rigorous and was more time consuming than corridor-only or clearcut falling. Between-corridor falling required the fallers to work in canopied conditions and could be compared to opening a right-of-way on a continuous basis. Hence, more time

2 "Cherry-picking" refers to the use of a log loader to pick up logs from the setting within reach of the loader's boom and bring them to roadside.



Note: Due to an oversight in the original layout, a large area of the block could not be accessed from Corridor 1. Additional yarding roads had to be established. As these yarding roads did not have backspars, the tail blocks were stump rigged.

Figure 7. Rigging adaptions on Corridor 1 (uniform shelterwood).

Table 4. Summary of Falling Productivity and Cost by Treatment Unit

	Extended rotation	Uniform shelterwood	Clearcut
Time with falling production (h)	83.5	645.0	649.0
Productivity			
Volume felled (m^3) [a]	1 792	8 282	9 311
Trees felled (no.)	1 740	7 329	13 897
Volume/tree (m^3) [b]	1.03	1.13	0.67
Average volume felled/6.5-h shift (m^3)	139.5	83.5	93.2
Average trees felled/6.5-h shift (no.)	135.4	73.9	139.2
Cost			
Falling labour cost ($/$m^3$)	2.24	3.74	3.35
Saw allowance cost ($/$m^3$)	0.19	0.32	0.29
Total falling cost ($/$m^3$)	2.43	4.06	3.64

[a] Volume felled is assumed to be equal to volume obtained from sort reports.
[b] Volume/tree is the average from the operational cruise summaries. Although these values are representative for both the extended rotation and clearcut units, the volume used for the uniform shelterwood unit may be overstated.

was needed to plan and execute falling in the shelterwood than in the clearcut and extended rotation units.

Marking of residual trees was done prior to falling; however, with fallers experienced in partial cutting this may not be necessary. Allowing fallers to select leave trees may increase residual stand quality because fallers are able to see crowns more clearly once the stand is partially opened up. If faller selection was practiced, clear selection criteria would be necessary.

The lowest falling cost was achieved in the extended rotation unit at $2.43/m^3. The falling costs for the clearcut and shelterwood units were $3.64/m^3 and $4.06/m^3, respectively (Table 4 and Appendix I).

Yarding and Loading Operations

Table 5 summarizes yarding and loading productivities and costs by treatment unit. A total of 521.6 scheduled machine hours (SMH) were spent yarding the clearcut unit, with 331.8 and 79.0 SMH yarding the shelterwood and extended rotation units, respectively. In the clearcut and shelterwood units, additional time was spent yarding blowdown which resulted from several major storms throughout the winter of 1997. Three backspar trees and 50–60% of leave strip trees completely or partially blew over in the clearcut unit. Wind damage was less severe in the shelterwood unit with only a few trees blown down. For purposes of productivity and cost comparisons, blowdown was excluded from calculations.

Table 5. Summary of Yarding and Loading Productivity and Cost by Treatment Unit [a]

	Extended rotation	Uniform shelterwood	Clearcut
Yarder			
Time with yarding production (h)	46.6	262.1	417.3
Time spent changing yarding roads (h)	15.0	19.9	26.1
Time without yarding production (h) [b]	17.4	49.8	78.2
Total time (h)	79.0	331.8	521.6
Loader			
Time with loader production (h)	79.0	410.4	466.4
Yarding productivity			
Volume yarded (m^3)	1 792	8 282	9 311
Cycles yarded (no.)	878	3 797	6 476
Pieces yarded (no.)	1 928	12 096	14 776
Average piece size (m^3)	0.93	0.69	0.63
Average pieces/cycle (no.)	2.2	3.2	2.3
Average cycles/8-h shift (no.)	89	92	99
Cycle volume (m^3)	2.04	2.18	1.45
Volume yarded/8-h shift (m^3)	182	201	143
Road changes			
Road changes (no.) [c]	10	21	40
Time/road change (h)	1.54	0.84	0.64
Volume yarded/road change (m^3) [d]	163	376	227
Pre-rigged road changes (no.)	10	12	-
Time pre-rigging/road change (h)	0.6	0.5	-
Costs			
Yarder ($/m^3)	7.42	6.73	9.40
Yarding labour ($/m^3)	5.36	4.86	6.79
Loader ($/m^3)	4.04	4.53	4.58
Loading labour ($/m^3)	1.36	1.52	1.54
Saw allowance ($/m^3)	0.15	0.14	0.19
Total yarding and loading cost ($/m^3)	18.33	17.78	22.50

[a] Differences due to rounding.

[b] Time without yarding production is any downtime occurring during the shift excluding lunch. Downtime consists of any mechanical, crew, tree damage prevention, or lines and rigging delays.

[c] Total number of road changes does not include the first road in each block because rigging, setup and machine move times were not separated.

[d] Volume yarded/road change calculation includes the first yarding road.

The loader spent a total of 79.0 SMH working in the extended rotation unit, 410.4 SMH in the shelterwood unit, and 466.4 SMH in the clearcut unit. In the shelterwood unit, the loader was used to cherry-pick the wood within reach of the road, and on and between Corridors 7 through 11. Cherry-picking in the shelterwood unit increased the ratio of loader hours to yarder hours, as compared to the extended rotation and clearcut units, and reduced the yarding time required. Hence, overall harvesting costs were reduced because the loader's hourly rate is considerably less and productivity is considerably more than the yarder's hourly rate and productivity.

The yarding time lost to wind and falling/yarding scheduling conflicts in the shelterwood and extended rotation units was considerable, compared with the clearcut unit which lost no time to these causes. The mandatory falling/yarding skipping pattern exercised in the extended rotation unit resulted in a loss of 39% of the potential yarding time. Similarly, in the uniform shelterwood unit, yarding crews often completed all available felled wood because of the two-pass harvesting method. A total of 14% of the yarding opportunity in the shelterwood unit was lost, caused by falling/yarding scheduling conflicts. The shelterwood unit lost 15.1 h of potential yarding time to unfavourable wind conditions, while the extended rotation unit lost 9.6 h.

During inactive periods, ownership costs are still incurred. Opportunity costs are not reflected in productivity and cost estimates, and these additional costs will make the extended rotation and shelterwood units less productive and less cost-effective than reported. However, if falling occurred continuously and before the harvesting equipment arrived on site, the reported calculations would be more representative. Researching seasonal weather patterns and correlating cutblock locations and harvesting season may reduce downtime caused by wind.

Mechanical problems prevented the yarder and yarding crew from working 75.9 h in the clearcut unit, 22.6 h in the shelterwood unit, and 2.2 h in the extended rotation unit (7%, 7% and 3% of scheduled yarding times, respectively). Similarities in harvesting systems, operating conditions and machine maintenance throughout the treatment units suggest mechanical downtime was not a function of silvicultural prescription.

Variability in piece size and number of chokers set per cycle significantly influenced productivity. The uniform shelterwood unit had the highest productivity per shift at 201 m^3 and 92 cycles, followed by the extended rotation unit at 182 m^3 and 89 cycles, then the clearcut unit at 143 m^3 and 99 cycles.

The faller's ability to place stems precisely influenced yarding production in all of the treatment units, particularly the extended rotation and shelterwood units. The yarding crew felt falling precision was greater in the shelterwood unit than in the clearcut and extended rotation units. If average yarding cycle time in the extended rotation and in the shelterwood (corridor only) are compared, the shelterwood cycle has a considerably faster time. This is believed to be mainly attributable to falling precision (Table 6).

Production losses in the extended rotation and shelterwood units were realized, in part because of problems with block planning and layout. Corridor layout and leave tree locations required re-examination by contractor crews and BCMOF, with amendments pending BCMOF approval. Approval was generally expedient because of close BCMOF/contractor interaction; however, numerous delays to falling and yarding still occurred. Some backspar trees in the shelterwood unit were located 10 to 15 m inside the backline with some harvested stems located behind the backspar (Figure 8). To yard this wood with minimal damage to the residuals, the crew yarded it to the skyline, unhooked and reset the chokers, and then yarded it to the landing. Ultimately, yarding production was reduced and damage to the backspar tree was increased. Backspar trees in the shelterwood unit must be made available for the next entry; therefore, if inappropriate backspars are selected the problem will recur. Harvesting crew involvement in the planning and layout stages may reduce operational problems during the harvesting stage and increase the success of the harvest, although this was not possible in this research-oriented operation. Previous partial cutting productivity studies have also stressed the importance of the planning phase to minimize overall problems and yarding downtime (Hedin 1994).

Productivity may have been increased by pre-setting turns, especially in the shelterwood unit where yarding roads were pre-determined and lateral yarding distance was up to 20 m on each side of the yarding road. Time was sufficient to allow chokersetters to pre-set turns during the inhaul and unhook components of the cycle.

In the extended rotation prescription, the backspar trees were felled and yarded to roadside upon completion of each yarding road. The long road change times were primarily a function of this requirement. System selection also influenced road change time. A system with two tail blocks was used in the shelterwood unit and sections of the clearcut unit, and this increased rigging time compared to the one tail block system used in the extended rotation and sections of the clearcut unit. However, the two tail block system eliminated full

Table 6. Distribution of Yarding Cycle Time by Treatment Unit [a]

	Extended rotation	Uniform shelterwood All samples	Uniform shelterwood Corridor	Uniform shelterwood Between corridors	Clearcut
Average time per element					
Outhaul					
min	0.93	0.78	0.81	0.75	0.80
%	14	13	16	12	14
Hook					
min	1.98	1.87	1.37	2.38	1.92
%	29	32	27	37	34
Inhaul					
min	1.99	1.60	1.57	1.63	1.28
%	30	28	30	25	23
Unhook					
min	0.73	0.76	0.74	0.77	0.84
%	11	13	14	12	15
Reposition					
min	0.05	0.04	0.03	0.06	0.26
%	1	1	1	1	5
Delay					
min	1.01	0.74	0.64	0.84	0.53
%	15	13	12	13	9
Total cycle					
min	6.69	5.79	5.16	6.43	5.63
%	100	100	100	100	100
min (at 100 m slope distance)	6.43	5.97	4.91	7.22	5.31
Average operating conditions					
Yarding distance (m)	104	97	105	89	106
Pieces/cycle (no.)	2.2	3.2	3.0	3.3	2.6
Crew size (no.)	4.2	5.0	5.0	5.0	4.0
Chokersetters (no.)	1.5	2.0	2.0	2.0	1.8
Chokers (no.)	2.0	3.0	3.0	3.0	2.3
Sample cycles (no.)	452	343	172	171	326

[a] Differences due to rounding.

block purchase on the tailhold and reduced the line wear caused by line wraps, making it the safer option. Road changes in the alternative silviculture system blocks also required the yarder to relocate with each road change. Yarder driving time was estimated by the yarding crew at 0.17 h per road change. Frequent road changes and yarder moves indicate that small cutblocks may not be as productive or cost-effective when partial cutting.

The shelterwood unit achieved the lowest overall yarding and loading cost at $\$17.78/m^3$. The extended rotation and clearcut units achieved $\$18.33/m^3$ and $\$22.50/m^3$, respectively (Table 5). Overall costs from stump to truck were calculated at $\$20.76/m^3$ for the extended rotation unit, followed by $\$21.84/m^3$ and $\$26.14/m^3$ for the shelterwood and clearcut units, respectively (Figure 9 and Appendix II). The Washington SLH 78 was costed at \$167.79/h (excluding operator). Since several hydraulic loaders were used, for simplicity the Chapman 172 hydraulic loader cost was applied to all three treatments at \$91.37/h (excluding operator) (Appendix I). Costs do not include mobilization and demobilization.

To demonstrate the effect of tree size, piece size, and number of chokers or pieces per cycle on harvesting productivity and costs, the variables were standardized to provide a more equitable comparison between treatment units (Appendix III). When comparing partial cuts with clearcuts, future and long-term costs must be also be considered. Partial-cutting systems generally have a higher overall harvesting cost than clearcutting systems because of the need for re-entry. For example, harvesting equipment in the extended rotation unit will be moved in and out of the unit five times before harvesting is complete, as compared to the clearcut unit with one entry.

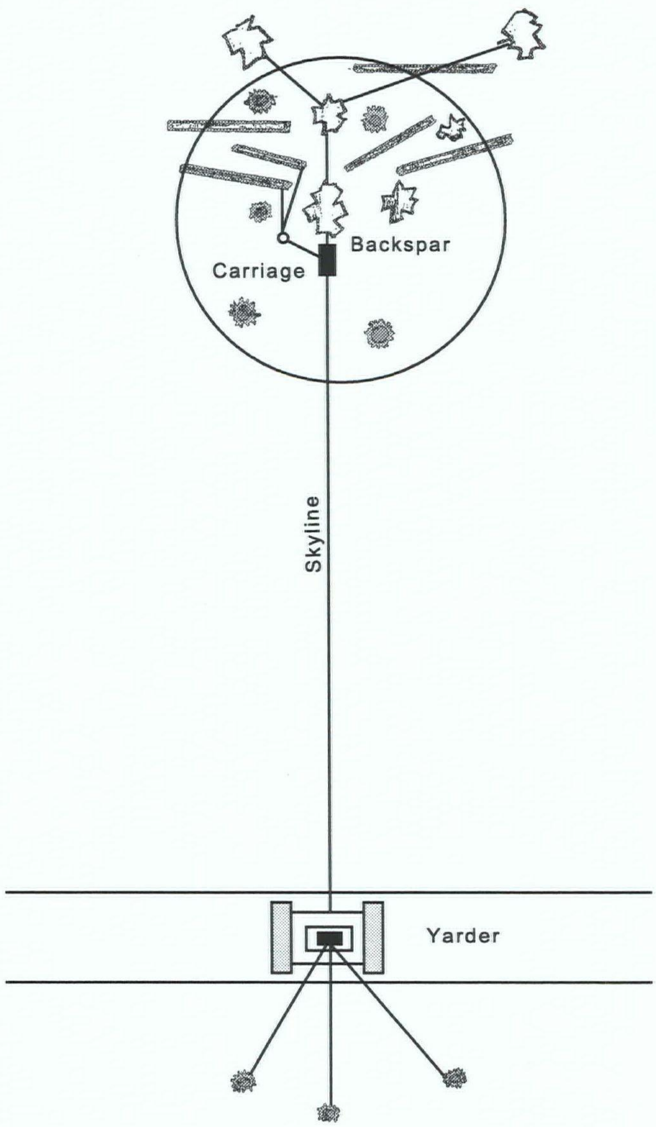


Figure 8. Behind backspar tree yarding.

Yarding Operations: Detailed Timing

Detailed timing was conducted on the yarding phase of all three treatment units. The clearcut unit had the lowest average cycle time when standardized to 100 m slope distance, at 5.31 min/cycle, while the uniform shelterwood unit was 5.97 min/cycle and the extended rotation unit was 6.43 min/cycle (Table 6). Cycles varied from 2.2 to 3.3 pieces/cycle throughout the study. On average, 1.5 to 2.0 chokersetters and 2.0 to 3.0 chokers were used.

Operating conditions throughout the treatment units were relatively similar and did not create any fundamental reasons for varying cycle times. However, delay and inhaul times can explain varying average cycle times between treatments. The 16% difference in cycle time between the fastest (clearcut) and the slowest (extended rotation) cycle times can be accounted for by the difference in delay time/cycle. Damage prevention, rigging and many crew delays are a function of treatment prescription. The extended rotation and shelterwood units require the yarding crew to be constantly aware of damaging leave trees, thereby causing slower inhaul time and increasing the incidence of and time attributed to related delays.

The absence of a loader also increased yarding cycle time. When log decks became large, the yarder spent additional time landing logs in order to maintain a safe log deck for the chaser. This was clearly demonstrated in the clearcut block where loading shifts often did not correspond with yarding shifts; decreased loader availability increased reposition time per cycle when compared with the other treatments. Self-releasing chokers could be used as an alternative to conventional chokers, and used with a self-loading truck in situations where average piece size and low production make a full-time loader inefficient.

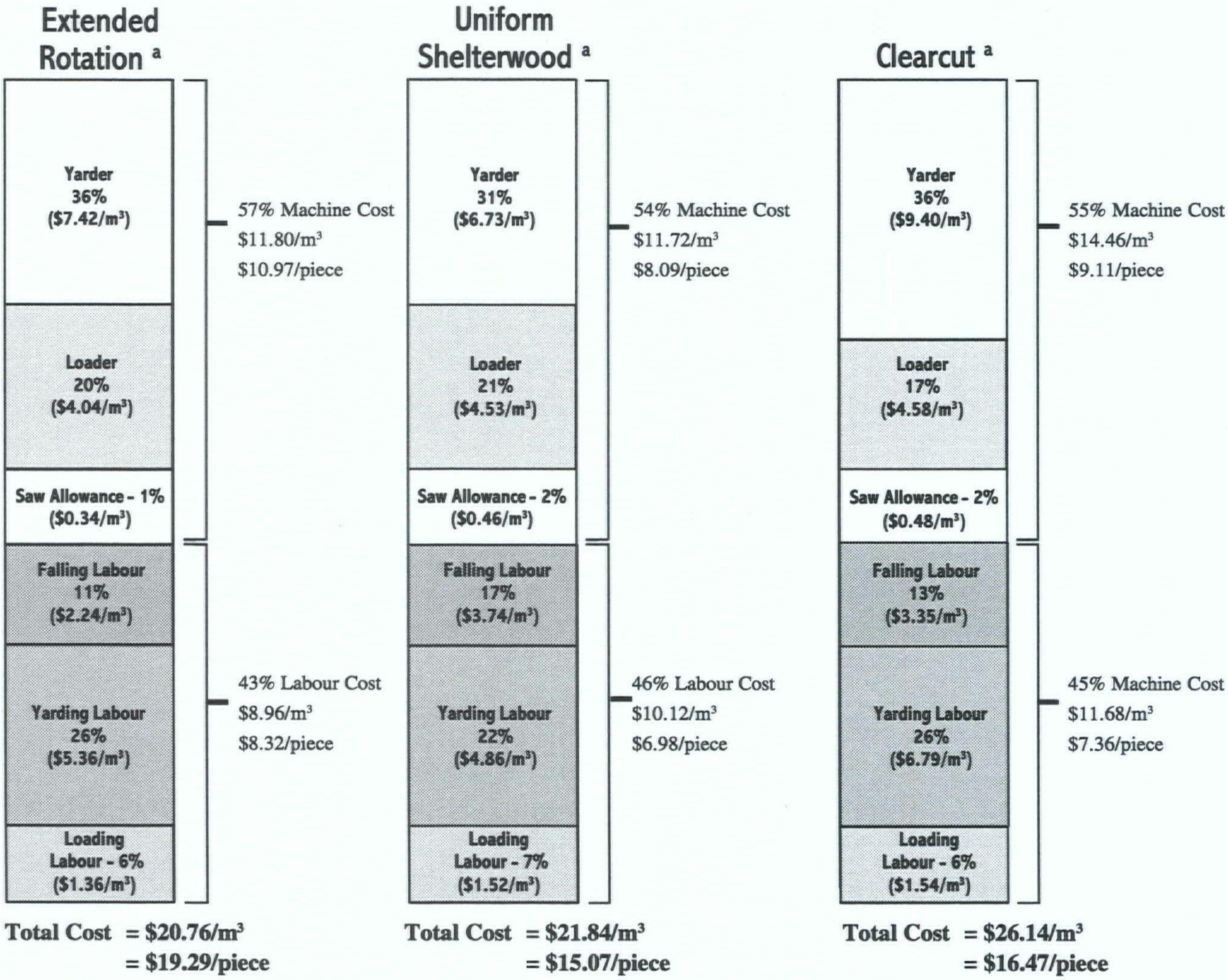
A statistical analysis was performed to derive productivity equations using a multiple regression analysis of the slope distance, number of logs and number of chokersetters per cycle. The resulting coefficient of correlation (r^2) values were .36, .46 and .09 for the extended rotation, shelterwood and clearcut units, respectively. This outcome suggests that cycle time variability is not explained very well using the independent variables that were analyzed.

CONCLUSION

The extended rotation unit achieved the highest falling productivity at 139.5 m^3/6.5-h shift, while the clearcut and shelterwood units achieved 93.2 m^3/6.5-h shift and 83.5 m^3/6.5-h shift, respectively. The greatest influences on falling productivity appeared to be tree volume, falling pattern and falling/yarding conflicts.

The shelterwood unit had the highest yarding productivity per shift at 201 m^3, followed by the extended rotation unit at 182 m^3 and the clearcut unit at 143 m^3. Conversely, the clearcut unit had the fastest yarding cycle time when standardized to 100 m slope distance, at 5.31 min, followed by the shelterwood and extended rotation units at 5.97 min and 6.43 min, respectively. Number of chokers and piece size were the most significant factors affecting yarding productivity and may explain the inconsistency between productivity and cycle time results.

The extended rotation unit had the lowest overall cost from stump to truck at $20.76/$m^3$, followed by the



[a] Differences due to rounding.

Figure 9. Summary of harvesting costs by treatment unit.

uniform shelterwood unit at $21.84/m³, and the clearcut unit at $26.14/m³. Productivity and cost results were significantly influenced by tree size, piece size, and number of chokers or pieces per cycle.

Opportunity costs and future or long-term costs, aspects not reflected in this report, should be considered when comparing costs and productivities between partial cuts and clearcuts. Economic feasibility in all treatment units is important and often largely dependent on market value. However, cost per m³ will be influenced with good prescription and block layout, experienced and skilled labour, correct system and equipment selection, payload maximization and favourable weather patterns.

REFERENCES

Green, R.N.; Klinka, K. 1994. A field guide to site identification and interpretation for the Vancouver Forest Region. Research Branch, Ministry of Forests, Victoria, B.C. Land Management Handbook Number 28. 285 pp.

Hedin, I.B. 1994. Shelterwood harvesting in coastal second-growth Douglas-fir. FERIC, Vancouver. B.C. Technical Note TN-216. 10 pp.

Tataryn, J., editor. 1993. Cable yarding systems handbook. Workers' Compensation Board of British Columbia. 175 pp.

Appendix I

Machine Costs [a,b]

	Washington SLH 78 swing yarder [c] (new)	Chapman 172 hydraulic loader [d] (new)
OWNERSHIP COSTS		
Total purchase price (P) $	790 000	350 000
Expected life (Y) y	12	8
Expected life (H) h	17 280	11 520
Schedule hours/year (h)=(H/Y) h	1 440	1 440
Salvage value as % of P (s) %	20	20
Interest rate (Int) %	10	10
Insurance rate (Ins) %	3	3
Salvage value (S)=((P•s)/100) $	158 000	70 000
Average investment (AVI)=((P+S)/2) $	474 000	210 000
Loss in resale value ((P-S)/H) $/h	36.57	24.31
Interest ((Int•AVI)/h) $/h	32.92	14.58
Insurance ((Ins•AVI)/h) $/h	9.87	4.38
Total ownership costs (OW) $/h	79.36	43.27
OPERATING COSTS		
Fuel consumption (F) L/h	35	30
Fuel (fc) $/L	0.45	0.45
Lube & oil as % of fuel (fp) %	10	10
Annual repair & maintenance (Rp) $	102 384	47 880
Shift length (sl) h	8	8
Fuel (F•fc) $/h	15.75	13.50
Lube & oil ((fp/100)•(F•fc)) $/h	1.58	1.35
Repair & maintenance (Rp/h) $/h	71.10	33.25
Total operating costs (OP) $/h	88.43	48.10
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	167.79	91.37

[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 the company studied.

[b] Differences due to rounding.

[c] The Washington SLH 78 is no longer manufactured. Purchase price used in the cost analysis is based on similar types of machines manufactured by S. Madill Ltd. or Ross Corporation.

[d] Loaders varied between and within treatment units; however, all were hydraulic. For simplification, the Chapman 172 was costed and applied to all three treatment units.

Appendix II

Labour Cost Summary by Treatment Unit

Crew [a]	All treatment units		Extended rotation		Uniform shelterwood		Clearcut	
	Shifts [b] (h/day)	Hourly rate [c] ($)	Shifts (no.)	Cost [d] ($)	Shifts (no.)	Cost [d] ($)	Shifts (no.)	Cost [d] ($)
Yarding engineer	8	32.45	9.9	2 570	41.5	10 773	65.2	16 926
Hooktender/rigger	8	32.45	9.9	2 570	41.5	10 773	65.2	16 926
Landing person	8	28.81	9.9	2 282	41.5	9 565	65.2	15 027
Chokersetter	8	27.55	9.9	2 182	41.5	9 147	65.2	14 370
Loader operator	8	30.73	9.9	2 434	51.3	12 612	58.3	14 332
Faller	6.5	47.99	12.9	4 024	99.2	30 944	99.9	31 162
Total labour cost				16 062		83 814		108 743

[a] The crew often performed tasks not described by their job titles. However, the rates did not change according to the task.
[b] Shift length excludes lunch.
[c] Hourly rate is based on June 15, 1996 IWA rates, with 35% for fringe benefits.
[d] Difference due to rounding.

Appendix III

Summary of Standardized Harvesting Production and Costs by Treatment Unit [a]

	Extended rotation	Uniform shelterwood	Clearcut
Falling production			
Actual volume felled (m^3)	1 792	8 282	9 311
Actual trees felled/6.5-h shift (m^3)	135.5	73.9	139.2
Standardized volume/tree (m^3)	1.03	1.03	1.03
Calculated volume felled/6.5-h shift (m^3)	139.6	76.1	143.4
Yarding production			
Actual volume yarded (m^3)	1 792	8 282	9 311
Standarized piece size (m^3)	0.93	0.93	0.93
Standardized pieces/cycle (no.)	2.0	2.0	2.0
Standardized cycle volume (m^3)	1.86	1.86	1.86
Calculated volume yarded/8-h shift (m^3)	165.0	171.1	184.1
Costs			
Falling labour ($\$/m^3$)	2.23	4.10	2.17
Yarder ($\$/m^3$)	8.14	7.85	7.30
Yarding labour ($\$/m^3$)	5.88	5.67	5.27
Loader ($\$/m^3$) [b]	4.43	4.27	3.97
Loading labour ($\$/m^3$)	1.50	1.44	1.34
Saw allowance ($\$/m^3$)	0.36	0.51	0.34
Total yarding and loading cost ($\$/m^3$)	22.54	23.84	20.39

[a] Difference due to rounding.
[b] Assume the loader worked the same number of shifts as the yarder.

The Forest Engineering Research Institute of Canada (FERIC) is a private non-profit research and development organization aimed at improving Canada's forest operations related to the harvesting and transportation of wood, and the growing of trees, within a framework of sustainable development.

FERIC is funded through a growing partnership made up of more than 90 leading forest companies, the Government of Canada, and the provinces and territories. Our mission is to provide these members with the knowledge and technology to conduct cost-competitive, quality operations that respect the forest environment.

head office
siège social

580 boul. Saint-Jean
Pointe-Claire, Québec
Canada H9R 3J9
T: 514-694-1140
F: 514-694-4351
E: admin@mtl.feric.ca

western division
division de l'ouest

2601 East Mall
Vancouver, BC
Canada V6T 1Z4
T: 604-228-1555
F: 604-228-0999
E: admin@vcr.feric.ca

eastern division
division de l'est

580 boul. Saint-Jean
Pointe-Claire, Québec
Canada H9R 3J9
T: 514-694-1140
F: 514-694-4351
E: admin@mtl.feric.ca