COMPARISON OF HARVESTING PHASES IN A CASE STUDY OF PARTIAL-CUTTING SYSTEMS IN SOUTHWESTERN BRITISH COLUMBIA

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Abstract

Four levels of harvesting (clearcutting, seed tree, shelterwood heavy removal, and shelterwood light removal) were undertaken in 1990-91 in a Coast-Interior transition zone of Southwestern British Columbia to compare both harvesting and forest-renewal activities. FERIC studied both the cable-yarding and ground-skidding activities. The harvesting aspects of this trial are discussed in this report.

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Summary

A joint study of partial-cutting systems was undertaken in 1990-91 by the Vancouver Forest Region of the British Columbia Ministry of Forests, the Boston Bar Division of Fletcher Challenge Canada Limited, and the Forest Engineering Research Institute of Canada (FERIC). The overall objectives were to demonstrate the use of clearcutting, seed-tree, and shelterwood systems for harvesting and regenerating dry Douglas-fir ecosystems in the Coast-Interior transition zone of Southwestern British Columbia. The objectives of FERIC's portion of the study, reported here, were to compare the harvesting activities for the treatments, which used both cable-yarding and ground-skidding systems, and to test the procedures for studying silvicultural systems.

Four treatments were applied to two blocks: clearcutting, seed-tree, and two levels of shelterwood removal. The lower block was harvested using a Skylead C-40 Model 8000 yarder with a Maki Mini-Mak I carriage. This carriage is radio controlled and will yard both vertically (along the skyline) and laterally (perpendicular to the skyline). Felling was done by hand. The upper block was harvested using a feller-buncher and both crawler and rubber-tired skidders. Leave trees were marked prior to harvesting.

With both harvesting systems, the number of trees cut per hour was greater in the clearcutting treatments than in the partial-cutting treatments. The hand faller spent more time planning for each falling activity in the partial cuts, and this slowed his rate of cut. In the upper block, the feller-buncher did not have any difficulty moving within the residual stand, but it spent more time travelling and manoeuvring in the partial-cutting treatment than in the clearcutting treatment. Faller selection of leave trees might be more efficient than premarking when hand falling, if the faller is well trained and experienced. However, with mechanical falling, the trees must be marked because the operator is unable to see the tops of the trees for good selection.

In the cable-yarding operation, there was no clear difference in the productivity of the four treatments. This was true even when the yarding times were standardized to a 100-m yarding distance. In the ground-skidding operation, differences in skidding distance made comparison of productivity impossible.

Overall, the influence of piece size, slope, terrain, and yarding and skidding distance on productivity appear to override the influence of cutting pattern. Total site planning and layout is vital in any harvesting, but its importance cannot be over-emphasized when partial cutting is the harvesting pattern.

The basic evaluation procedures used in FERIC's harvesting studies are also applicable to studies of partial cutting. Particular care is necessary in designing the harvesting study if comparison of cutting patterns is desired.

INTRODUCTION

Clearcutting has been the primary silvicultural system in use in British Columbia for many years; in 1990-91, 92% of the gross wood volume harvested in the province was removed by clearcutting (Province of British Columbia 1992). The term "silvicultural system" designates a planned program of silvicultural treatments over the life of a stand; it includes the harvesting and the follow-up tending to the next rotation (Smith 1986). These systems are often described by their regeneration cutting method. Although the classic silvicultural systems form the basis of a prescription, each prescription is unique to the stand for which it was designed. Partial cutting is a more generic term and is used to describe treatments where fewer than 100% of the stems are harvested. Partial cutting does not specify whether the leave trees have a silvicultural purpose or not.

In addition to operational use in some ecosystems, partial-cutting systems are being tested in a wide variety of new situations (De Long 1991). The objectives of partial cutting are several: create a micro-environment to improve regeneration success, maintain or improve wildlife and fish habitats, facilitate structural diversity, and lessen visual impact of harvesting activities. Public opinion, both local and global, is against clearcutting, and alternatives must be investigated. As silvicultural systems are tested on new sites and ecosystems, their influence on regeneration, fibre economics, and the environment must be evaluated.

The complexity of evaluating options in silvicultural systems requires expertise in many disciplines of forest resource management. The study discussed here was a cooperative project of the Vancouver Forest Region of the British Columbia Ministry of Forests (BCMOF), the Boston Bar Division of Fletcher Challenge Canada Limited (FCCL), and the Forest Engineering Research Institute of Canada (FERIC). The objectives of the BCMOF and FERIC studies, and the details of the trial, are outlined. The harvesting systems used during the trial, are discussed, and information on the machine productivity associated with each harvesting treatment is presented. Some of the pitfalls in conducting comparative studies of this nature are pointed out, as well as the difficulties in obtaining truly comparative information.

Specific responsibilities were assigned to each cooperator. FCCL carried out the operational planning and supervised harvesting, while the BCMOF identified the site, determined the study block locations, assigned treatments, and conducted the biological and site assessments. FERIC monitored the harvesting operations within the operational constraints defined by FCCL and the contractors. Where data from a source other than FERIC are used in this report, the source is identified.

OBJECTIVES

The overall objectives of the study, as established by the BCMOF, were:

- Demonstrate the use of silvicultural systems (clearcutting, seed-tree, shelterwood) for harvesting and regenerating dry Douglas-fir ecosystems in the Coast-Interior transition zone.
- Evaluate establishment and performance of natural and artificial regeneration associated with the above silvicultural systems.
- Investigate the effects of the above silvicultural systems on the seedling micro-environment, understory vegetation, and residual overstory growth.

Results of biological aspects of the study will be reported by the BCMOF as they are determined.[1]

FERIC cooperated in the study by addressing the following specific objectives:

- Evaluate and compare the relative productivity of harvesting phases in the clearcutting, seed-tree, and shelterwood treatment blocks.
- Identify the operational factors that affect or limit the use of partial-cutting systems as compared to clearcutting.
- Determine whether FERIC's procedures for evaluating clearcutting operations are valid for evaluating partial-cutting operations.

STUDY METHOD

During this study FERIC researchers monitored the falling and yarding phases on the four treatment areas of both the cable and ground-based harvesting blocks to determine the phase productivities and the factors that influenced them. Servis recorders were used to monitor shift-level activities of the various harvesting equipment, and detailed-timing techniques were used to compare cycle elements of the equipment activities. Production volumes were determined by deducting post-harvest from pre-harvest cruise volumes for each of the study blocks and adjusting the resulting volumes with the millyard weigh scale summaries to account for cruise/scale differences.

[1] Brian D'Anjou and Bob Green; *Partial Cutting Systems for Regenerating Dry Sites in the Coast-Interior Transition, Project Summary, February, 1992;* Vancouver Forest Region, BCMOF; unpublished, 2 pp.

SITE DESCRIPTION

The study area is located in FCCL's operating area, east of Boston Bar, at the confluence of East Anderson River and Utzlius Creek. The area is within the Coast-Interior transition zone, in the wet warm Interior Douglas-fir biogeoclimatic subzone (IDFww), on a southwesterly aspect, at an elevation of 600-800 metres. Typically, these sites have summer moisture deficits with low precipitation and high temperatures during the growing season, and this makes establishment of regeneration difficult. These sites are also important as deer wintering habitat (Nyberg and Janz 1990).

The study area was divided into two blocks. The upper block ranged in slope from 10 to 30%, with benched topography (Figure 1), while the lower block was steeper in slope, at 50-70%, with well-defined draws. Ground-based harvesting systems were prescribed for the upper block, while cable yarding was used in the lower block. In both cases, Douglas-fir, 110-140 years old, was the primary component of the stand. In each block, one control and four treatments were prescribed. Treatments are described as clearcutting, seed-tree, shelterwood heavy removal, and shelterwood light removal (Figure 2). The overall intent of the treatments was to create a range of overstory shade levels. The post-harvesting density of the various stands followed from this intent. The goals of the three partial-cutting treatments, i.e. seed-tree, shelterwood heavy removal, and shelterwood light removal, are described in Table 1, and the preharvest and post-harvest stand conditions of all treatments are summarized in Table 2. Although the boundaries of the treatment blocks were considered feasible for the operational requirements of the harvesting systems, the limited area of the trials, i.e. small sample size, made it difficult to compare harvesting productivities of the various treatments.

Figure 1. Upper block prior to harvesting.

LEAVE TREES AND TREE STRESSING

The research plan specified that leave trees be selected and that some of them should be stressed to promote cone/seed production. Leave trees improve the success of natural regeneration by providing seed and shelter. Stressing leave trees one year prior to harvesting will increase cone production during the harvesting year when seed beds are most receptive due to site disturbance from harvesting.

The BCMOF was responsible for selecting the leave trees and for stressing some of them. Tree-selection criteria were defined by the BCMOF researchers and related to species, crown size and condition, form, and number per hectare. Leave trees were marked with blue paint near eye level. Some of the leave trees (10-15/ha) were stressed to induce cone production by partially girdling in two overlapping cuts. Information on the criteria for selecting leave trees and the results of stressing can be obtained from the Vancouver Forest Region of the BCMOF.

Table 1. Partial-Cutting Treatment Goals [a]

	Partial-cutting treatment		
	Seed-tree	Shelterwood heavy removal	Shelterwood light removal
Leave trees/ha (no.)	15	40	83
Tree spacing (m)	26	16	11
Estimated post-harvest crown cover (%)	10	25	50
Estimated ratio of volume removed (%)	95	80	65

[a] These treatment goals are compatible with the recommendations of the British Columbia Ministry of Environment for deer wintering range.

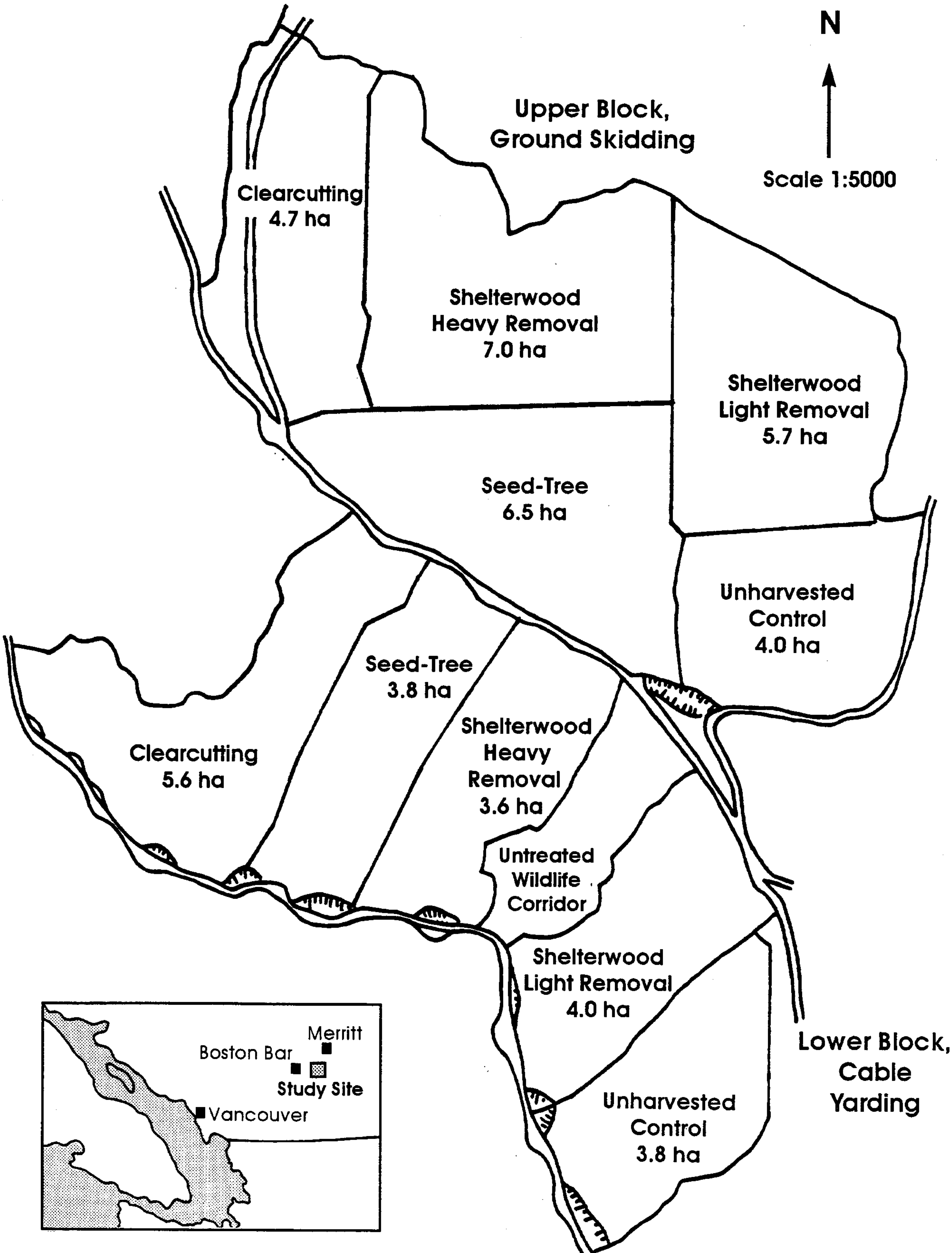

Figure 2. Layout of treatments for cable yarding and ground skidding.

Table 2. Stand Description [a]

	Treatments			
	Clearcutting	Seed-tree	Shelterwood heavy removal	Shelterwood light removal
CABLE YARDING, LOWER BLOCK				
Area (ha)	5.6	3.8	3.6	4.0
Basal area (m^2/ha)				
Preharvest	48	53	59	46
Post-harvest	0	5	13	18
Net volume (m^3/ha)				
Preharvest	408	480	538	371
Post-harvest	0	48	129	156
Tree density (no. trees/ha)				
Preharvest				
Merchantable	326	300	318	385
Unmerchantable	16	30	31	35
Post-harvest				
Merchantable	0	18	40	106
Average tree volume (m^3/tree)				
Preharvest	1.25	1.60	1.69	0.96
Average dbh (cm)				
Preharvest	43	47	49	39
Post-harvest	n.a.	60	65	46
Average tree height (m)				
Preharvest	30.4	32.4	32.4	28.2
GROUND SKIDDING, UPPER BLOCK				
Area (ha)	4.7	6.5	7.0	5.7
Basal area (m^2/ha)				
Preharvest	47	42	50	52
Post-harvest	0	3	12	19
Net volume (m^3/ha)				
Preharvest	352	341	418	452
Post-harvest	0	22	108	177
Tree density (no. trees/ha)				
Preharvest				
Merchantable	484	357	373	326
Unmerchantable	60	23	33	61
Post-harvest				
Merchantable	0	14	58	78
Average tree volume (m^3/tree)				
Preharvest	0.73	0.95	1.12	1.39
Average dbh (cm)				
Preharvest	35	39	41	45
Post-harvest	n.a.	48	51	56
Average tree height (m)				
Preharvest	27.2	30.0	29.9	30.7

[a] Stand and volume information from surveys and cruise completed for BCMOF. Minimum dbh in preharvest cruise was 17.5 cm.

RESULTS: CABLE YARDING, LOWER BLOCK

Equipment

The cable-yarding contractor, Critical Site Logging Inc. of Vernon, British Columbia, used a Skylead C-40 Model 8000 yarder[2] mounted on a Timberjack 380 skidder (Figure 3) and equipped with a Maki Mini-Mak I carriage. The carriage is capable of lateral yarding, which is an important feature in partial-cutting operations. The braking system within the carriage is controlled by radio, allowing the chokerman to manoeuvre logs through standing timber by alternating brake engagement between the mainline (vertical yarding) and skyline (lateral yarding).

Two Timberjack line skidders forwarded the stems from the yarder to the landing, and also skidded stems from those portions of the block not accessible to the cable yarder. Stems were yarded tree length where possible; however, some larger diameter stems were bucked at the stump to accommodate the capacity of the yarder. At the landing, final log manufacturing was completed as necessary and the wood was loaded and hauled to the mill. Although loading and hauling were part of the harvesting operation, these phases were not studied by FERIC.

Crew Organization

The Skylead crew consisted of a faller, yarding engineer, chokerman, hooktender, and skidder operator, all of whom rotated jobs throughout the duration of the operation. This flexible approach to assigning jobs to the crew helped relieve some of the associated monotony and stress, and thereby contributed to maintaining productivity. The owner of the contracting company located the yarding corridors himself, and ensured that they met the requirements of the equipment. Yarding corridors were clearcut to a width of 7 m (Figure 4), and located at 40-m intervals to allow 20-m lateral yarding (in the case of the shelterwood units).

The small size of the treatment areas did not allow harvesting to progress sequentially across the block. To maintain a safe working environment, yarding roads were activated in a dispersed pattern throughout the block. Transport of the wood to the mill occurred the same day as yarding; scaling of sample logs by FERIC was not possible and therefore volumes could not be separated for each treatment unit. The figures used in this report are estimates, based on the pre- and post-harvest cruise data, adjusted proportionately to meet the total scale volume (Table 2).

Falling

Trees were hand felled downhill in a herringbone pattern to each yarding corridor except where topography or safety dictated otherwise. When the faller completed the falling for one or two corridors, he moved to another treatment unit while the yarding was completed. This allowed him to fall with minimal lead time. Although the leave trees were marked in this operation, the faller could make substitutions for safety or if the lean of the tree made it necessary. He exercised this option occasionally, particularly in the shelterwood units.

FERIC researchers studied the falling operation to describe the activities of the faller and to record the number of trees cut (Table 3). Generally, in the clearcutting op-

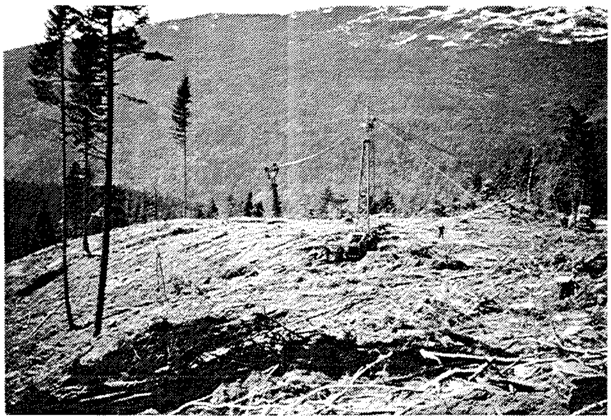

Figure 3. Skylead C-40 Model 8000 yarder working in seed-tree unit, lower block.

Figure 4. Yarding corridor felled in shelterwood light removal unit, lower block.

[2] Skylead yarders and Maki carriages are manufactured in Enderby, British Columbia, by Skylead Logging Equip. Corp.

Table 3. Productivity Summary: Hand Falling, Lower Block

	Treatment			
	Clearcutting	Seed-tree	Shelterwood heavy removal	Shelterwood light removal
WORK SAMPLE RESULTS				
Total productive time sampled (h)	17.4	14.7	7.6	11.7
Distribution of time (%)				
Walking between trees	18.2	20.9	16.0	20.4
Observe and plan fell	11.8	10.8	16.0	17.8
Brushing around tree	2.9	1.1	6.4	1.8
Cut and complete fell	42.8	38.3	29.3	35.4
Delimb and buck	4.4	11.7	8.7	2.7
Minor delays				
Relating to chain saw	14.0	10.6	17.2	17.3
Other	5.9	6.6	6.4	4.6
Total	100.0	100.0	100.0	100.0
TREE COUNT RESULTS				
Falling productivity (no. trees/h)				
Including minor delays				
Merchantable	59	41	39	49
Unmerchantable[a]	18	11	9	10
Total	77	52	48	59
Excluding minor delays				
Merchantable	73	50	51	63
Unmerchantable	22	13	12	12
Total	95	63	63	75
SHIFT LEVEL RESULTS				
Productive time (h)	51.5	40.6	28.4	33.0
Estimated volume felled[b] (m^3)	2722	1955	1752	1022
Estimated productivity (m^3/h)	52.9	48.2	61.7	31.0

[a] A minimum diameter was not used in this classification. Therefore, the ratio of merchantable to unmerchantable will not be the same as that in Table 2.
[b] Based on pre- and post-harvest cruise data provided by BCMOF and FCCL, and millyard weigh scale data provided by FCCL.

eration, more trees were felled per hour than in the partial-cutting treatments. In the seed-tree unit, the trees had more limbs than in the other units; this is reflected in the larger amount of time spent delimbing. Similarly, in the shelterwood heavy removal unit, underbrush was more common and the faller subsequently spent more time clearing around trees. However, the sums of time distributions for the Walking and Brushing categories are similar for all four treatments.

In the shelterwood treatments, the faller spent a greater proportion of productive time observing and planning the falling. This is a logical consequence of the additional decisions required in falling the trees safely, preventing damage to leave trees, and aligning the stems for yarding. Chain-saw related delays (e.g. sharpening the saw) were greater in the two shelterwood treatments than in the other treatments. This was not a consequence of the treatments themselves; a mud slide had occurred several months earlier and had deposited soil on some of the trees in the shelterwood heavy removal unit. This situation caused the saw to dull more rapidly than usual, and may have contributed to the increased delay time associated with chain-saw maintenance.

The tree count results show a greater number of trees felled per hour in clearcutting compared to other treatments (Table 3). Although this unit also had the greatest number of unmerchantable stems cut, the proportion was not different than the seed-tree, and only slightly greater than the shelterwood treatments.

Overall productivity of the faller was strongly influenced by tree size. The higher productivity associated with the shelterwood heavy removal treatment is a consequence of the larger tree size within this unit. The shelterwood light removal had the lowest hourly faller productivity by volume (58% of that for clearcutting), likely due to a combination of relatively small tree size and increased time spent planning and executing falling.

Yarding

The topography and resulting poor deflection prevented cable yarding of some portions of the treatment units. Instead, these areas were ground skidded using the Timberjack line skidders (Figure 5). These ground-skidded areas are not included in the discussion. In the clearcutting unit, the yarder was moved to a lower spur road and the wood was forwarded by the skidder to a lower landing.

In comparing the detailed timing of the yarding operations on each treatment unit, no differences were revealed in the proportion of cycle times for each element (Table 4). The difference in average cycle time is 16%, with

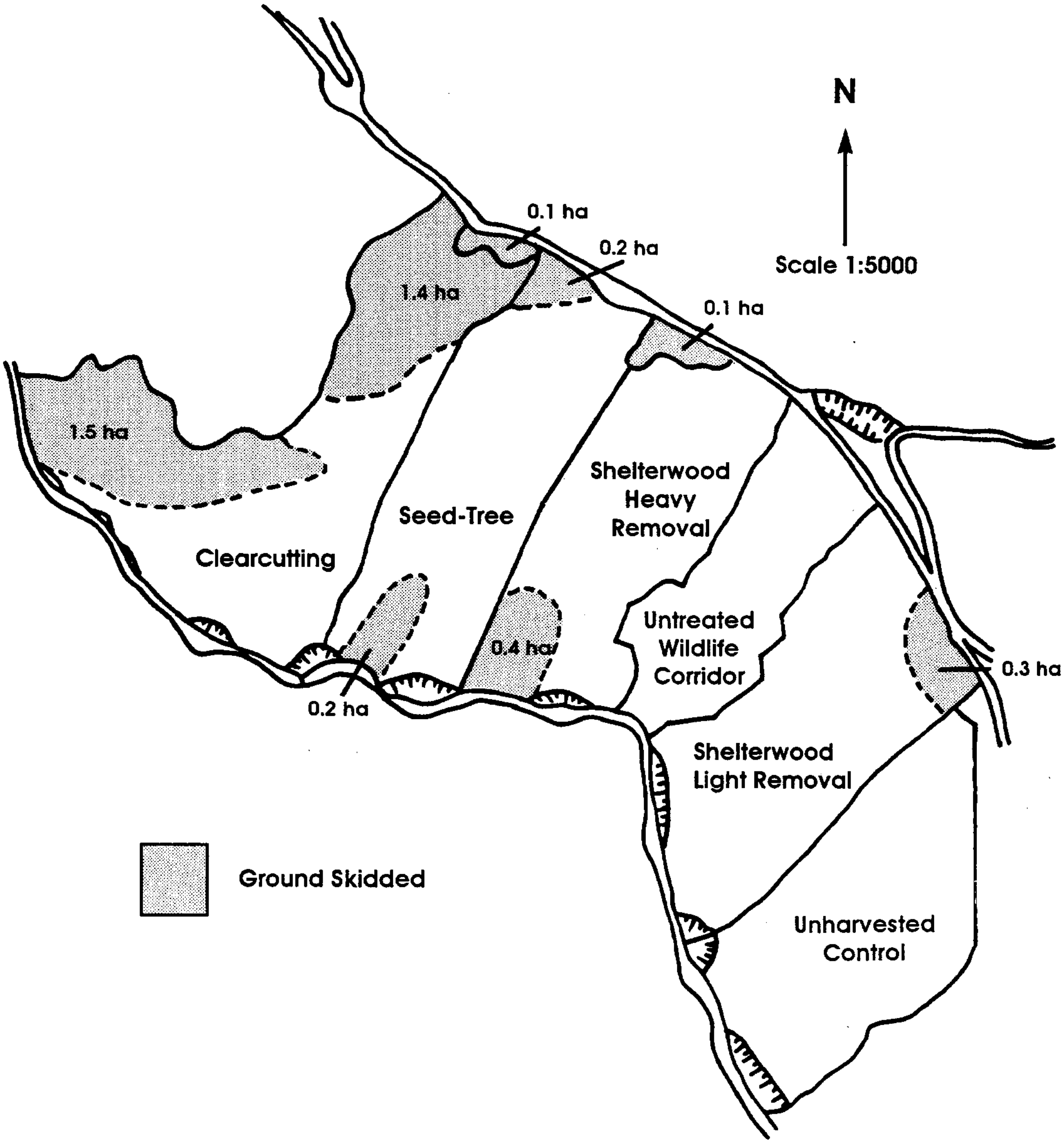

Figure 5. Ground-skidded areas, within cable-yarded block.

Table 4. Productivity Summary: Cable Yarding, Lower Block

	Treatment			
	Clearcutting	Seed-tree	Shelterwood heavy removal	Shelterwood light removal
DETAILED TIMING RESULTS				
Total productive time sampled (h)	9.3	18.0	11.4	17.3
Cycles timed (no.)	153	270	200	269
Average merchantable pieces/cycle (no.)	1.9	1.5	1.4	1.8
Average yarding distance of sampled cycles (m)	156	158	111	97
Cycle elements				
Outhaul				
Average time (min)	0.46	0.46	0.38	0.36
Portion of total cycle time (%)	13	12	11	9
Hook				
Average time (min)	1.18	1.30	1.10	1.29
Portion of total cycle time (%)	32	33	32	33
Inhaul				
Average time (min)	1.02	1.20	1.05	1.10
Portion of total cycle time (%)	28	30	31	29
Unhook				
Average time (min)	0.65	0.77	0.62	0.76
Portion of total cycle time (%)	18	19	18	20
Minor delay				
Average time (min)	0.33	0.26	0.28	0.35
Portion of total cycle time (%)	9	6	8	9
Total cycle				
Average time (min)	3.64	3.99	3.43	3.86
Portion of total cycle time (%)	100	100	100	100
Estimated cycle time, at 100-m yarding distance[a] (min)	3.33	3.66	3.31	3.72
SHIFT LEVEL RESULTS				
Area cable yarded (ha)	2.6	3.4	3.1	3.7
Total productive machine hours (PMH)	49.2	46.2	28.9	38.5
Estimated volume yarded[b] (m^3)	1264	1749	1509	945
Estimated productivity (m^3/PMH)	25.7	37.9	52.2	24.5

[a] (Outhaul + Inhaul) is estimated by regression analysis. The regression equation for the clearcutting treatment was significantly different from the other treatments, but equations for seed-tree, shelterwood heavy removal, and shelterwood light removal treatments were not significantly different from one another. Data were therefore pooled to develop a single regression equation for these treatments, resulting in the following equations:

- For clearcutting treatment:
  Outhaul + Inhaul Time (min) = 0.68 + 0.0051 • (yarding distance)
- For seed-tree, shelterwood heavy removal, and shelterwood light removal treatments:
  Outhaul + Inhaul Time (min) = 0.68 + 0.0063 • (yarding distance)

Cycle times were then estimated for each treatment unit, using the equations, as follows:
Total cycle time = (Outhaul + Inhaul) + Hook + Unhook + Delay.

[b] Based on pre- and post-harvest cruise data provided by BCMOF and FCCL, and millyard weigh scale data provided by FCCL.

the seed-tree being highest (due to the longer yarding distance) and the shelterwood heavy removal treatment being lowest. Average yarding distance for the samples within each treatment unit were very different, with both clearcutting and seed-tree near 160 m, shelterwood heavy removal at 111 m, and shelterwood light removal at 97 m. Note that these average yarding distances refer to the sample only, and do not represent the average yarding distances for the entire treatment unit. Clearcutting did have the longest yarding distance overall; yarding distances for the other three treatments were shorter, but not greatly different from each other.

As part of the analysis, the yarding distance was standardized to 100 m and a cycle time was calculated. The cycle time for shelterwood light removal is the highest, similar to the seed-tree unit. The time for the clearcutting and shelterwood heavy removal treatments are both lower, but similar to each other. The difference between the longest and shortest cycle is 12% at the standardized figures, compared to 16% at the overall averages.

Inhaul includes lateral yarding (to the skyline) as well as vertical yarding (along the skyline). These elements could not be separated in the timing because they often occurred simultaneously. In the partial-cutting treatments, the lateral yarding was carefully executed to prevent damage of leave trees. The damage level to the residual stand was considered very low, indicating yarding was done in a conscientious manner.[3]

When individual elements of the cycle are examined, no differences stand out. The ease of attaching the chokers was, in some cases, complicated by large trees falling on the smaller stems. In the seed-tree unit, the terrain was irregular and the faller had some difficulty falling in a regular pattern. Consequently, the chokerman required more time to hook stems because they were in a tangle. This can be seen by a somewhat larger hook time for this treatment, shared with shelterwood light removal. In the shelterwood light removal unit, the chokerman also spent more time and took more care to place the chokers in a position to minimize damage to residual stems, and pulled more line to hook each turn compared to the other treatments.

The inhaul time for the seed-tree treatment was higher than for the other three treatments. The longer sample yarding distance influenced this time. As well, the terrain in this unit had a point of poor deflection and inhaul speed was slowed to accommodate this.

[3] Bob Green, Vancouver Forest Region, BCMOF; personal communication, November 2, 1992.

The shift level productivity results require careful examination. Portions of the treatment units were harvested by skidders, and these areas and volumes were removed from the calculations. As explained previously, it was not possible to obtain the volumes removed from each treatment from weigh scale information; neither was piece scaling possible. Rather, volumes used were based on the differential between pre- and post-harvest cruises. The data in Table 4 show the lowest productivity for the clearcutting and shelterwood light removal treatments. In the clearcutting unit, longer average yarding distance and smaller piece size combine to provide a lower productivity. In the shelterwood light removal, productivity is influenced by a smaller piece size and the greater yarding time required to protect leave trees within the cutblock. The productivity in the shelterwood heavy removal treatment was twice that in the clearcutting unit, and likely a consequence of the larger piece size and the shorter yarding distance. Figures 6 and 7 illustrate the shelterwood heavy removal and the shelterwood light removal treatment units after harvesting.

Figure 6. Shelterwood heavy removal unit after harvesting, lower block.

Figure 7. Shelterwood light removal unit after harvesting, lower block.

RESULTS: GROUND SKIDDING, UPPER BLOCK

Equipment

The ground-skidding portion of the operation was completed by Hunsbedt Logging Ltd. The equipment consisted of a Caterpillar 227 feller-buncher with a Koehring 60-cm saw head, Caterpillar D6 and D7 crawlers with chokers, an FMC 220 crawler, and one each of a Caterpillar 518 grapple skidder and line skidder. The D6 and grapple skidder were used most, and the FMC and D7 were used when an operator was available.

Crew Organization

The labour complement included one faller, one feller-buncher operator, one buckerman, two skidder operators, one mechanic, and one foreman. The faller was on site only as necessary, and in some cases operated one of the supplemental skidders when he did not have falling duties. Similarly, the foreman periodically operated a skidder.

Falling

Falling began several days before skidding, and was done primarily with the Caterpillar 227 feller-buncher (Figure 8). Large trees beyond the capacity of the machine (greater than 50 cm) were hand-felled, but these were few and could not be differentiated from the volume felled by machine. When the feller-buncher productivity was calculated, the machine was assumed to have handled the total volume scaled.

The results of the work sampling and shift-level studies are in Table 5. The work sample results show the treatments differed in time distribution under Move Between Trees, and Brush.[4] In the clearcutting treatment, the feller-buncher spent 24.7% of its time moving between trees, compared to the shelterwood light removal at 35.7%. This is a substantial difference in activity. The distance between trees in the shelterwood light removal was greater, due to both lower stand density and the fewer number of trees removed than in the other treatments. Under the Brush classification, both the clearcutting and shelterwood light removal treatments had larger portions of time, compared to seed-tree and shelterwood heavy removal. The larger component of unmerchantable trees in the clearcutting unit, and the understory brush and saplings in this and the shelterwood light removal unit, required this more intense activity. In the other classifications of activity, minor differences between treatments are evident, but not large.

Figure 8. Caterpillar 227 feller-buncher with Koehring saw head in shelterwood heavy removal unit, upper block.

When the number of trees cut is examined, the clearcutting and seed-tree treatments clearly have a higher total of trees cut per hour than the shelterwood treatments. It is obvious from these summaries that the clearcutting unit had many unmerchantable stems, with 38% of the total stems cut identified as unmerchantable.

The feller-buncher achieved its highest productivity on the seed-tree unit due to a combination of low proportion of unmerchantable stems, large volume removed per hectare, and generally flat terrain. Both of the shelterwood treatments had considerably lower feller-buncher productivity than the clearcutting treatment (approximately 30% less) and seed-tree treatment (approximately 45% less). The feller-buncher had no difficulty operating in the partial-cutting units. Even with light removal, the distance between leave trees was wide—11 m—and the machine was able to fell and place the trees in bunches without restrictions.

Skidding

The complement of skidding equipment was complex and changed depending on terrain, operator availability, and contractor preference (Figure 9). Skidding distances were different for each treatment unit, and the proportion of area skidded by each machine type was also different. Table 6 presents the cycle time summaries for the Caterpillar D6 crawler and Caterpillar 518 grapple skidder. Table 7 presents a summary of shift-level time for all skidders on the upper block. As would be expected, the grapple skidder (Figure 10) had shorter times for each

[4] The machine was described as "brushing" when the saw head swung against small stems, removing them from the path of the machine. If the saw head was positioned on a stem, this was included as a "cut" and was further described as unmerchantable or merchantable.

Table 5. Productivity Summary: Feller-Buncher, Upper Block

	Treatment			
	Clearcutting	Seed-tree	Shelterwood heavy removal	Shelterwood light removal
WORK SAMPLE RESULTS				
Total productive time sampled (h)	5.0	6.7	11.6	6.7
Distribution of time (%)				
Move between trees	24.7	31.3	33.8	35.7
Swing empty	15.8	14.6	14.0	12.9
Cut	8.8	8.1	8.2	8.4
Swing loaded	15.1	18.9	17.2	15.4
Prepare bunch	3.8	5.7	7.1	4.6
Brush	19.6	12.4	10.1	17.0
Travel to felling area	3.1	3.1	2.1	0.3
Minor delays	9.1	5.9	7.5	5.7
Total	100.0	100.0	100.0	100.0
TREE COUNT RESULTS				
Falling productivity (no. trees/h)				
Including minor delays				
Merchantable	77	89	61	56
Unmerchantable [a]	47	17	15	16
Total	124	106	76	72
Excluding minor delays				
Merchantable	84	94	66	59
Unmerchantable	51	18	16	17
Total	135	112	82	76
SHIFT LEVEL RESULTS				
Total productive machine hours (PMH)	15.7	15.6	29.7	20.6
Estimated volume felled[b] (m^3)	1604	2011	2104	1520
Estimated productivity (m^3/h)	102	129	71	74

[a] A minimum diameter was not used in this classification. Therefore, the ratio of merchantable to unmerchantable will not be the same as that in Table 2.
[b] Based on pre- and post-harvest cruise data provided by BCMOF and FCCL, and millyard weigh scale data provided by FCCL.

component of the cycle and the overall cycle time was one-third that of the D6 crawler. Position, Hook, and Travel Between Bunches for the grapple skidder were larger in the two shelterwood treatments than in the clearcutting and seed-tree. This can be attributed to the relatively larger distance between bunches and the need to manoeuvre to grapple the bunches without damaging leave trees. The trends for the D6 crawler are not as clear.

For the D6 crawler the average number of pieces per turn was lowest on the clearcutting treatment at 5.9, with the other treatments greater by 1.5 or more. This is consistent with the larger Hook times associated with the partial cuts, but the trend does not follow for the grapple skidder, which grappled a consistent number of pieces per turn for each of the four treatments. Damage to residual trees was greater than expected in this block.[5]

[5] Bob Green, Vancouver Forest Region, BCMOF; personal communication, November 2, 1992.

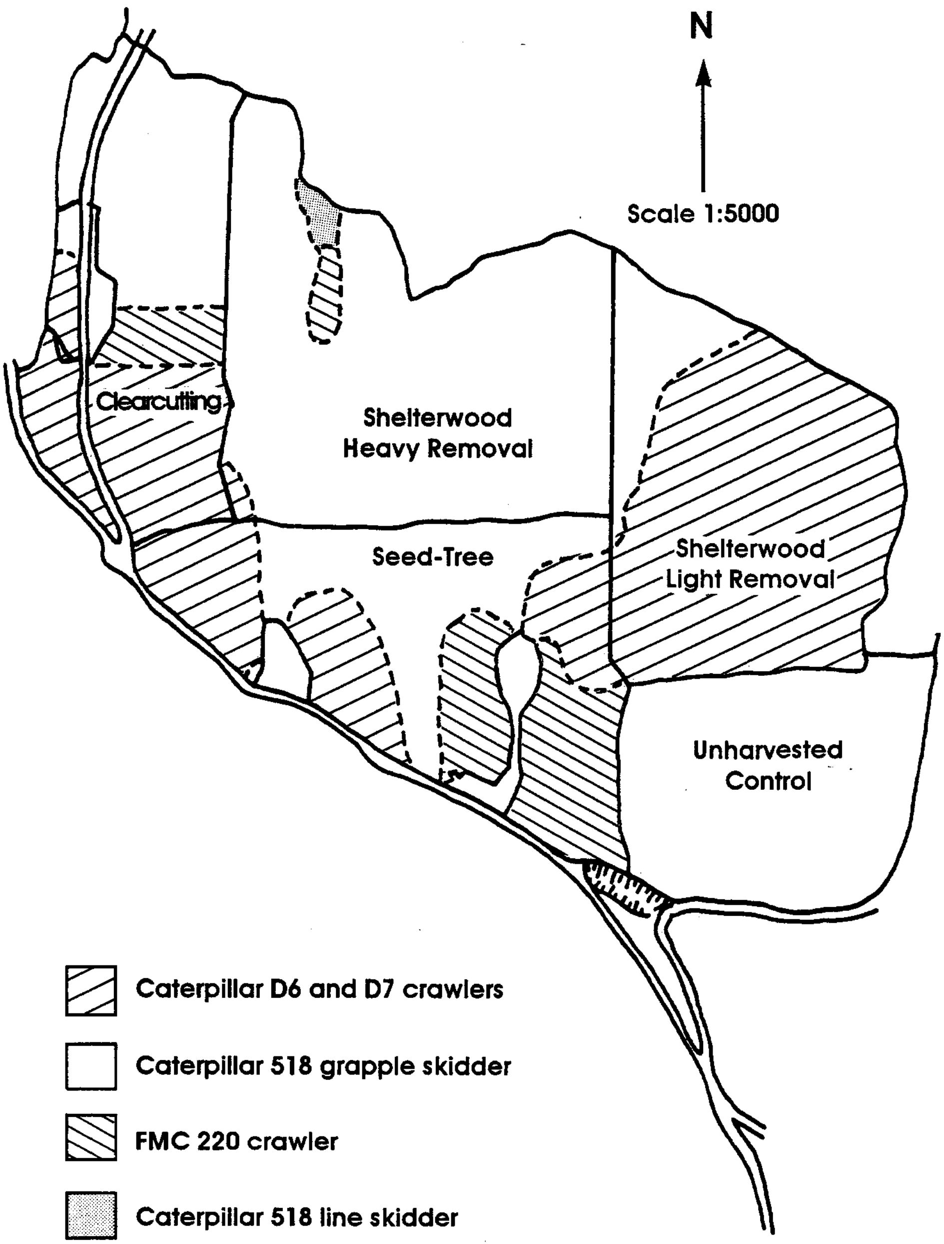

Figure 9. Ground-skidding equipment used in treatment areas, upper block.

DISCUSSION

Operational Feasibility of the Partial-Cutting Treatments

Carrying out the partial-cutting treatments did not present any major difficulty to either the cable-yarding or ground-skidding contractors. In each case, operating procedures were modified to meet the requirements of the treatments, but these modifications in the number of leave trees per ha did not affect harvesting operations. However, even at the lightest cut, only a very small number of leave trees remained (106 trees/ha, or basal area of 18 m^2/ha). In other ecosystems, depending upon the objectives of the harvest, prescriptions may call for twice this density of leave trees. At densities of 200 leave trees/ha, the use of smaller equipment and different operational procedures may be necessary, particularly in the ground-based operations.

A cost analysis was not completed for this study because actual cost of delivering the wood to the road could not be related to the cutting pattern. In another study, Tesch

Table 6. Detailed-Timing Results: Skidding, Upper Block

	Treatment							
	Clearcutting		Seed-tree		Shelterwood heavy removal		Shelterwood light removal	
	D6	Grapple skidder	D6	Grapple skidder	D6	Grapple skidder	D6	Grapple skidder
Total productive time sampled (h)	18.8	6.3	15.5	5.0	3.1	25.5	29.9	7.5
Turns (no.)	66	73	47	58	9	209	70	51
Pieces skidded (no.)	389	381	350	284	389	1064	521	244
Average pieces/turn (no.)	5.9	5.2	7.5	4.9	8.6	5.1	7.4	4.8
Average skidding distance of sampled turns (m)	110	127	103	113	98	211	279	339
Distribution of time (min/turn)								
Travel empty	2.44	0.83	2.11	1.06	2.20	1.51	4.87	2.11
Position	1.56	0.78	1.73	0.40	1.66	0.83	0.93	0.89
Hook	4.65	1.00	5.47	0.95	5.92	1.31	5.95	1.71
Winch	0.49	-	1.53	-	0.46	-	1.64	-
Travel between bunches	0.66	0.46	0.27	0.26	0.34	0.65	0.68	0.59
Travel loaded	2.10	0.92	2.28	0.97	2.45	1.48	4.62	1.66
Unhook	2.66	0.98	3.47	1.50	2.65	1.18	3.71	1.80
Deck	1.64	-	2.62	-	4.65	-	2.55	-
Minor delay	0.89	0.18	0.31	0.03	0.38	0.34	0.64	0.09
Total time (min/turn)	17.09	5.15	19.79	5.17	20.71	7.30	25.59	8.85

Table 7. Shift-Level Results: Skidding, Upper Block

	Treatments			
	Clearcutting	Seed-tree	Shelterwood heavy removal	Shelterwood light removal
Estimated volume skidded[a] (m^3)	1604	2011	2104	1520
Productive machine hours (PMH)				
Grapple skidder	20.3	13.7	62.5	19.2
Caterpillar D6	27.8	23.2	13.4	67.0
Line skidder	7.6	6.8	6.5	0
Caterpillar D7	0	1.3	6.0	7.2
FMC	6.3	7.0	6.0	3.4
Total PMH	62.0	52.0	94.4	97.2

[a] Based on pre- and post-harvest cruise data provided by BCMOF and FCCL, and millyard weigh scale data provided by FCCL.

Figure 10. Caterpillar 518 skidder with swing grapple working in shelterwood heavy removal unit.

and Mann (1991) point out that shelterwood systems always have higher harvesting costs than clearcutting because of re-entries. Harvesting equipment in a partial-cutting operation must be moved to and from the site at least twice to harvest the same volume, and access must be maintained for a longer period of time. This may be offset by reduced silvicultural costs associated with natural regeneration.

Tree Marking

With an experienced crew, marking of leave trees for hand falling may not be necessary. Experienced fallers can identify good leave trees and can fell to spacing prescriptions. In this study, the crowns of some marked leave trees were poor because the markers were not able to see the tree tops within the unopened stand. This difficulty would be alleviated to some extent if fallers are permitted to select the leave trees. With mechanical falling, leave trees must be marked because the operator cannot see the tops of the trees from the machine and has less ability than a hand faller to accurately assess spacing of leave trees.

Falling

Safety is always a concern in a hand-falling operation. In the partial-cutting treatments, the faller was given the option of substituting leave trees if necessary. Within the cable-yarding operation, the trees were felled in a herringbone pattern to improve yarding productivity and reduce damage to leave trees; this was generally achieved. Because the feller-buncher operator can control the direction and speed of falling, damage to leave trees can be reduced, particularly to the crowns, and stems can be positioned more accurately for yarding.

In terms of the number of trees felled per hour, fewer trees were felled on the shelterwood units than on the clearcut and seed-tree units. This supports the logic that falling productivity would be negatively affected by the effort required to minimize damage to leave trees. In this case study, falling in the clearcutting treatments was more productive than in the shelterwood light removal treatments: 40% more productive for the lower block and 25% more productive for the upper block.

Yarding and Skidding

The influence of piece size, slope, terrain, and yarding and skidding distance appear to override the influence of the cutting pattern. When cable-yarding cycle times were standardized to 100 m, a difference of 12% was shown between the shortest cycle (shelterwood heavy removal) and the longest cycle (shelterwood light removal). Numbers of pieces per turn were somewhat different between treatments, but this was likely more an effect of piece size than treatment.

Limitations of the Study

Although variables such as yarding and skidding distances, topography, piece size, and machine use were different for each treatment unit, the productivity information presented in this report is a data set within a growing database on partial-cutting productivity.

When harvesting began, additional difficulties in obtaining comparative information arose. In most study situations, volumes can be obtained from the weigh scale, and these present accurate information for productivity calculations. However, the layout of the blocks, the progression of the harvest, and limited landing space made separation of truck loads by treatment unit impossible for both the cable-yarding and ground-skidding operations. This was further complicated by the congested landing and the hot loading that prevented scaling of pieces by the research team. Consequently, volumes for each treatment unit were estimated using the pre- and post-harvest cruise information, prorated to the weigh scale volume for each block.

In the cable-yarding area, some volume on the block was not accessible to the yarder, and this wood was skidded to lower landings. Although this wood was removed from the cable-yarded area in the productivity calculation, it complicated these calculations. Operationally this situation occurs frequently; however, within a productivity study it can confound the results.

In the ground-skidding block, a similar situation occurred with the FMC 220 crawler, line skidder, and D7 crawler. The machines were on site, and operated only sporadically. As well, the D6 crawler and grapple skidder were used to different extents on the four treatments, and therefore no conclusions could be drawn about volume and time results. The skidding distances in the ground-skidding block were quite different for each treatment unit, and machines skidded from treatment units indiscriminately. This was necessary to maximize productivity on the block.

An objective of the FERIC study was to identify where complications could arise in studies comparing partial-cutting treatments. The techniques used in monitoring the machine productivity and documenting the pre- and post-harvest conditions are valid. However, the study also demonstrated that harvesting productivity is highly sensitive to factors other than cutting pattern.

CONCLUSIONS

The study results reported here are part of a larger cooperative silvicultural systems evaluation conducted by the BCMOF, FCCL, and FERIC in 1990-91. The overall project objectives were to demonstrate the use of clearcutting, seed-tree, and shelterwood systems for harvesting and regenerating dry Douglas-fir ecosystems in the Coast-Interior transition zone of Southwestern British Columbia.

The FERIC study compared the productivity of two harvesting systems (cable yarding and ground skidding) as they functioned in four silvicultural treatment areas (clearcutting, seed-tree, shelterwood heavy removal and shelterwood light removal). Although the study was complicated by a number of layout and operational factors, FERIC did determine the following:

- For the hand-falling operation, the number of trees cut per hour was lower in the partial-cutting treatments than in the clearcutting because the faller spent more time planning the fall.

- In the mechanical falling operation, the same relationship was true; the feller-buncher did not have difficulty operating in the residual stand, but more movement was necessary, therefore reducing productivity.

- The cable-yarding comparison did not demonstrate any significant productivity difference attributable to the cutting treatment.

- Finally, in the ground-skidding operation, both the grapple-skidder and D7 crawler required more time for hooking in the partial-cutting treatment areas than in the clearcutting area.

The second objective of the FERIC study was to identify operational factors that affected, or limited, the efficiency of partial-cutting systems when compared to clearcutting. In this study, no direct influences were identified. However, due to the low residual densities resulting from even the lightest treatments in this study, these results may not be typical for all partial-cutting prescriptions. Falling patterns in the partial-cutting blocks did, however, indirectly influence hook times for both cable and ground-based yarding activities. Hook time for the cable-yarded seed-tree block was increased because the hand faller was unable to maintain a herringbone falling pattern to the skyline corridor due to broken terrain conditions. This resulted in tangles of stems that were more difficult to yard without damage to residual trees. Similarly hook time increased for the ground-based machines as the density of leave trees on the block increased. This was a result of the feller-buncher making smaller and more dispersed bunches as the density of leave trees increased.

The third study objective was to determine if FERIC's evaluation procedures for clearcutting harvesting operations are valid for monitoring partial-cutting operations. This study concluded that FERIC's basic procedures for evaluating clearcutting harvesting operations are applicable to partial-cutting studies. Because productivity results can be influenced by factors other than cutting intensity, particular care is necessary in designing the harvesting study if comparison of cutting patterns is desired.

RECOMMENDATIONS

Both biological and operational information about partial-cutting systems is needed by the forest industry and government agencies in British Columbia to assess the feasibility and consequences of using these cutting patterns. The following recommendations are drawn from the experiences of this study, but they do not reflect a criticism of any of the cooperators in the study, as all cooperators met their defined responsibilities. These recommendations apply specifically to studies where comparison of partial-cutting operations is a primary objective.

(i) All cooperators must be involved in the study planning at the initial stages, before sites are selected and treatments identified, to ensure that each cooperator's evaluation objective can be met and that study results will be credible.

(ii) The basic requirements for conducting a side-by-side comparison of any harvesting alternatives are:
- Terrain, tree size, distribution, and volume must be similar for the treatment units, or each unit should be large enough to encompass the variability present in the stands.
- Skidding or yarding distances should be similar

and equipment must be used in a consistent manner in all treatment units.

- Productive machine hours and productive man hours must be tallied for each treatment unit.
- Volume removed from each treatment unit must be directly measurable.
- Treatment units must be harvested under similar weather and ground conditions.

(iii) A protocol for evaluating silvicultural systems should be developed by FERIC, BCMOF, and Forestry Canada to ensure a common understanding of each agency's study requirements.

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