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INFLUENCE OF OBSTACLES ON VEHICLE MOBILITY AND PRODUCTIVITY IN A MECHANIZED COMMERCIAL THINNING OPERATION

Yasuo Kohata, B.Sc. Forest & M.Sc. Forest

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KEYWORDS: Commercial thinning, Second-growth forests, Harvesting, Partial cutting, Mechanical method, Vehicle mobility, Obstacles, Productivity, Costs, Site disturbance, Soil disturbance, Coastal British Columbia

Abstract

During the summer and fall of 1994, the Forest Engineering Research Institute of Canada (FERIC), in cooperation with Pacific Forest Products Limited and Shortlog Thinning Inc., carried out a study on the influence of obstacles on vehicle mobility and productivity in mechanized commercial thinning operations on Vancouver Island. All trees and obstacles on the study blocks were measured by the FERIC researcher. Maps of these trees and obstacles were made to determine the theoretical treatments and to identify the actual treatments and machine trails. The operations of an FMG Timberjack 1270 harvester and an FMG Timberjack 910 forwarder were monitored to determine the influence of obstacles on thinning productivities, costs, and stand impacts.

Author

Yasuo Kohata obtained a B.Sc.Forest (1974) and a M.Sc.Forest (1976) from the University of Yamagata, Japan. He is a researcher with the Hokkaido Forestry Research Institute of Japan, and worked with FERIC as a visiting researcher for 8 months. During this period, he studied the effect of obstacles on the travel and productivity of a harvester and forwarder in a commercial thinning operation on Vancouver Island.

Disclaimer

Acknowledgements

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Table of Contents

List of Tables

List of Figures

Summary

Commercial thinning in the second-growth forests on Vancouver Island in British Columbia is becoming an important source of fibre. However, such stands frequently retain legacies of the previous forest in the form of large stumps and windfalls which can obstruct ground-based harvesting equipment. During the summer and fall of 1994, the Forest Engineering Research Institute of Canada (FERIC), in cooperation with Pacific Forest Products Limited and Shortlog Thinning Inc., carried out a study on the influence of obstacles on vehicle mobility and productivity in mechanized commercial thinning operations on Vancouver Island. Obstacles were defined as large stumps and windfalls that influenced the equipment's travel path, but did not include standing trees. By quantifying the effect of forest floor obstacles on equipment productivity and residual stand damage, either equipment design or harvest planning may be modified to improve system performance. Specifically, the type and density of obstacles that influence vehicle mobility were characterized, the influence of obstacles on productivity and cost was documented, and the post-harvest residual stand impacts were evaluated.

The study took place in a second-growth forest composed of Douglas-fir, western redcedar, and western hemlock, with a small component of grand fir and big leaf maple. The study area was sampled for obstacle intensity, and three 0.25-ha trial blocks were located to represent light (<200 m^2/ha), medium (200-1000 m^2/ha), and heavy (>1000 m^2/ha) obstacle levels. These sample blocks were intensively surveyed and monitored during harvesting to quantify the relationships of obstacle intensity to machine performance.

Both windfalls and stumps were confirmed as the obstacles to vehicle mobility and productivity. The total number and the total area of obstacles were 196/ha and 198 m^2/ha on Block 1, the Light Obstacle Level block. Windfalls were 83% of the total obstacle area. Within Block 2, the Medium Obstacle Level, the total number of obstacles was 364/ha, comprising an area of 883 m^2/ha with 92% of the obstacle area occupied by windfalls. These figures are greater by 1.9 and 4.4 times respectively compared to those in Block 1. In Block 3, the Heavy Obstacle Level, the total number and the total area of obstacles were 420/ha and 1037 m^2/ha. As in Blocks 1 and 2, most of the obstacle area, 94%, was occupied by windfalls.

Avoiding stumps required the harvester to change travel directions, while windfalls caused the harvester to spend time on clearing. In Block 1, where the obstacle level was Light, the harvester made four trails; in Block 2, with Medium Obstacle Level, the harvester made three trails. However, trails on Block 3, Heavy Obstacle Level, were patterned like a fan. In other words, heavy obstacles severely restricted the harvester's access on this block. Because the forwarder used the trails that the harvester cleared, obstacles did not seriously influence the forwarder's mobility.

The harvester cleared obstacles in order to access the thinning operation. The percentage of cleaning time increased in proportion to obstacle area, and productivity of the harvester decreased gradually with increasing obstacles. Productivity in Block 1 was 12.5 m^3/PMH in spite of the block having the smallest stems of the three, while productivity was 17.8 m^3/PMH in Block 2 and 14.2 m^3/PMH in Block 3. The harvester handled 126 trees/PMH in Block 1, 80 trees in Block 2, and 58 trees in Block 3. The production costs of the harvester were calculated as $11.50, $8.08, and $10.14/m^3 respectively.

Productivity of the forwarder was affected primarily by travel distance and log size, and was not influenced seriously by the obstacles. In Block 1, with a round trip distance of 1109 m, the forwarder produced 9.9 m^3/PMH, while in Block 3 with a round trip distance of 210 m, it produced 14.8 m^3/PMH. The ratio of load time to total time was 37 to 40% in this study. Production costs of the forwarder were $9.33/m^3 in Block 1, $9.34/m^3 in Block 2, and $6.25/m^3 in Block 3.

At 4%, residual tree damage was low in Block 1. However, the percentage of damaged trees was 10% in Block 2 and 8% in Block 3. To achieve low damage, the vehicle's operator must be more careful in areas with heavy obstacles. Exposure of mineral soil was limited to vehicle trails, and calculated as <1% of treatment area in all blocks. Although there was a slight increase in disturbed area according to obstacle level, the small study area does not give a definitive relationship. More study on the relationship between obstacles and site disturbance is suggested.

As mentioned above, the influence of obstacles on machine performance, especially on the harvester's mobility and productivity in commercial thinning, was verified in this study. With the increased harvesting of Coastal second-growth forests, harvest planners need to be aware of the potential impacts of obstacle levels on the performance of ground-based harvesting equipment.

INTRODUCTION

Commercial thinning operations in the second-growth forests on Vancouver Island in British Columbia are becoming an important source of fibre. However, such stands frequently retain legacies of the previous forest in the form of large stumps and windfalls which can obstruct ground-based harvesting equipment. During the summer and fall of 1994, the Forest Engineering Research Institute of Canada (FERIC), in cooperation with Pacific Forest Products Limited and Shortlog Thinning Inc., carried out a study on the influence of obstacles on vehicle mobility and productivity in mechanized commercial thinning operations on Vancouver Island. Obstacles were defined as large stumps and windfalls that influenced the equipment's travel path, but did not include standing trees. By quantifying the effect of forest floor obstacles on equipment productivity and residual stand damage, either equipment design or harvest planning may be modified to improve system performance.

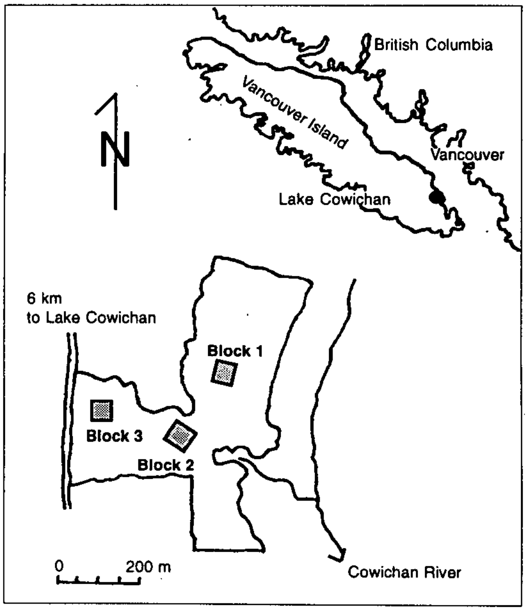


Figure 1. Study site and study block location.

OBJECTIVE

The goal of this study was to quantify the influence of obstacles on vehicle travel and efficiency and to obtain an indication of the impacts on mechanized commercial thinning in second-growth forests. Specifically, the type and density of obstacles that influence vehicle mobility were characterized, the influence of obstacles on productivity and cost was documented, and the post-harvest residual stand impacts were evaluated.

STUDY SITES

This study was carried out in a second-growth forest on Pacific Forest Products Limited's private land in the vicinity of Lake Cowichan on Vancouver Island, British Columbia (Figure 1).

The study site is located on flat, even ground adjacent to the Cowichan River. The biogeoclimatic ecosystem classification of this site is Very Dry Maritime Coastal Western Hemlock (CWHxm) (Green and Klinka 1994). The stand was composed of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), western redcedar (*Thuja plicata* Donn), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), grand fir (*Abies grandis* (Dougl.) Lindl.), and big leaf maple (*Acer macrophyllum* Pursch). The area had been harvested in the 1930's, and old stumps and windfalls of various sizes were found on the forest floor (Figures 2 and 3). Stand age was estimated as approximately 60 years by the FERIC researcher, based on annual ring counts.

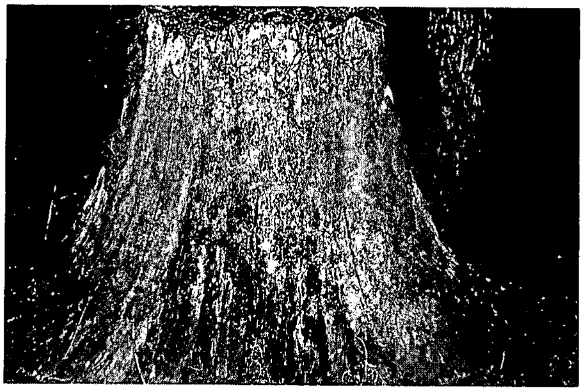


Figure 2. Old stump on study site (diameter - 100 cm, height - 1.25 m).

Trees on the study site were commercially thinned using a ground-based mechanized harvesting system. The largest and best trees were left, while smaller trees and merchantable windfalls were removed. Trees were mechanically felled and processed into short logs which were then forwarded to roadside and sorted. Hunt (1995) conducted a productivity and cost study on this operation and provides additional information.

EQUIPMENT

The contractor, Shortlog Thinning Inc., used an FMG Timberjack 1270 single-grip harvester and an FMG Timberjack 910 forwarder (specifications in Table 1).

Figure 3. Windfalls on the study site (top - butt diameter 40 cm, length 5.4 m; bottom - butt diameter 25 cm, length 6.9 m).

Table 1. Equipment Specifications

	FMG Timberjack 1270 harvester	FMG Timberjack 910 forwarder
Engine output (kW)	114	80
Weight (kg)	16 410	10 000
Load rating (t)	n/a	11
Length overall (m)	10.96	8.23/8.64[a]
Width overall (m)	2.9/2.68[b]	2.85/2.65[b]
Crane reach (m)	8.3	6.2

[a] *Adjustable.*
[b] *Depending on tires.*

The operators of both machines were experienced in thinning. The FMG Timberjack 1270 is a 6-wheel-drive, multi-function harvester equipped with an FMG 762B harvester head with a hydraulic chain saw, two spiked steel feed-rollers, and five delimbing knives (Figure 4). The maximum felling diameter is 600 mm and feed speed is 4 m/sec. The FMG Timberjack 910 forwarder is also a 6-wheel-drive unit, and was equipped with the FMG 120-62 grapple loader (Figure 5).

Figure 4. FMG Timberjack 1270 harvestor.

STUDY METHODS

To assess the effect of obstacles on machine travel, the researcher located three sample blocks of 0.25-ha in size, with increasing levels of obstacle intensity. To locate appropriate sites, a random survey was made before the study, sampling at twenty points within the area to determine the intensity of obstacles. Circular plots 0.01-ha in size were located and all obstacles expected to interfere with machine travel were measured. The footprint areas of these obstacles were projected to a

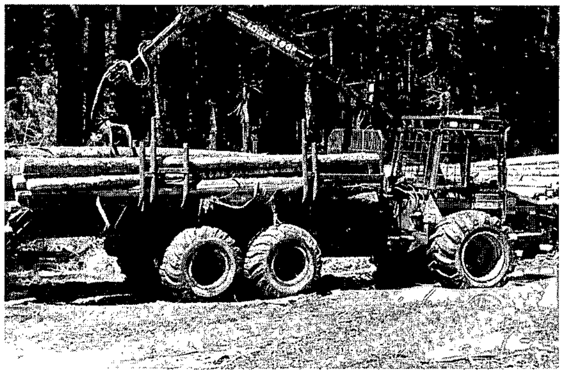


Figure 5. FMG Timberjack 910 forwarder.

per hectare value. This ranged from 2 m²/ha to 1833 m²/ha and averaged 772 m²/ha. Half of the sampling points contained obstacle areas between 200 and 1000 m²/ha. Therefore, three obstacle levels were established for this study, i.e. the area of obstacles less than 200 m²/ha was designated as Light, 200 to 1000 m²/ha was Medium, and more than 1000 m²/ha was Heavy. Three study blocks, 50 m by 50 m (0.25 ha) in size, were selected to represent these obstacle levels (Figure 1).

Pre-treatment surveys were conducted on the three blocks by FERIC. All trees and obstacles were located using a compass and an electronic distance-measuring tool. Maps of these trees and obstacles were made and used to determine the theoretical treatments and to identify the actual treatments and machine trails. Diameters of trees more than 6 cm at breast height (dbh) were measured, and the tree volumes were calculated (but not for big leaf maple). Tree heights were estimated using diameter/height-curve formulas developed from a sample survey for each species. For each obstacle, height, length, and diameter were measured and the projected area was calculated.

To assess the effect of obstacles on actual treatments, the theoretical treatments for the three blocks were proposed by Ken Donkersley, Silviculturist with Pacific Forest Products Limited, and the FERIC researcher. These theoretical treatment prescriptions were based on the cruise data, an inspection of the stand, and the following thinning criteria of the company:

1. Cut 100% of dead trees.
2. Cut 100% of big leaf maple.
3. Cut 50% of western redcedar.
4. Cut small trees less than average diameter.
5. Cut Douglas-fir, grand fir, western redcedar, and western hemlock with undesirable crown or trunk characteristics.

The final selections of the theoretical treatments were confirmed by the Pacific Forest Products silviculturist.

The harvester and forwarder were timed in detail with a hand-held data recorder during all operations on the study blocks. Volume processed by the harvester was obtained from the machine's computer system. FERIC scaled 18 trees manually and confirmed that the difference between actual volume and volume measured by the harvester was less than 1%. To determine forwarded volume, logs were counted by butt size class during detailed timing of the forwarder using five butt classes: less than 14.9 cm in diameter; 15 to 24.9 cm; 25 to 34.9 cm; 35 to 44.9 cm; and >45 cm. The average volumes for each butt class, developed from a log volume survey carried out by FERIC on an adjacent area, were then applied to these log counts to determine load volumes. Travel distances of the forwarder were also measured. Detailed timing data, volume, and distance were used to calculate the productivities of the harvester and forwarder, and costs were calculated using standard FERIC methodology (Appendix III).

FERIC conducted post-harvest surveys to identify all residual trees, measure machine trail area and disturbance levels, and tally residual tree damage on the three study blocks. The maximum length, width, and the depth of areas of exposed mineral soil were measured. Tree damage was measured as the maximum length and width of the scar, and the height from ground to the middle of the damage. After the surveys, actual thinning removal ratios for the three blocks were calculated.

RESULTS AND DISCUSSION

Pre-Treatment Surveys

The terrain on the three established study blocks was flat and even, and the primary feature was obstacles.

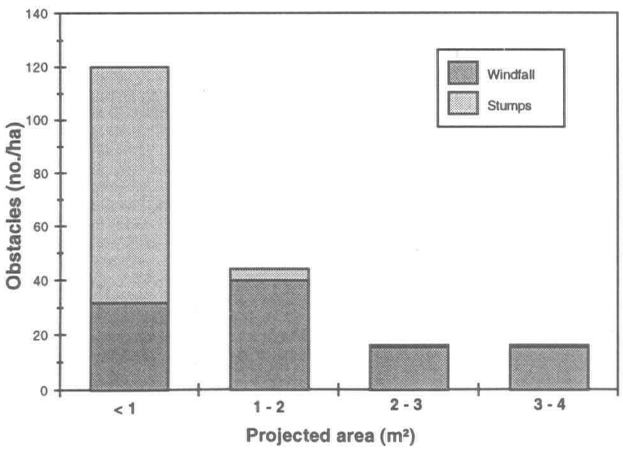
Block 1, Light Obstacle Level. Within this block, the survey showed a tree density of 1456/ha, with a volume of 353 m³/ha (Table 2).

Douglas-fir comprised 81% of the total trees, with the remainder western redcedar, western hemlock, and grand fir (Appendix I, Figure I-1). The average diameter of Douglas-fir was 18.3 cm and most of the larger trees in this block were of this species. Generally, western redcedar and western hemlock had relatively small diameters, i.e. <22 cm. The stand data showed that Block 1 had the smallest trees of the three blocks, with an average volume of 0.24 m³.

Both windfalls and old stumps occurred as obstacles on this block; however, there was no specific orientation of windfalls or location of stumps. This was true on the other two blocks as well. The total number and area of obstacles were 196/ha and 198 m²/ha respectively, with

Table 2. Description of Stand and Obstacles Before Treatment

Obstacle level	Block 1 Light	Block 2 Medium	Block 3 Heavy
Slope	flat	flat	flat
Terrain	even	even	even
Trees			
Number (no./ha)	1456	1568	1024
Net volume (m^3/ha)	353	707	548
Average volume (m^3/tree)	0.24	0.45	0.54
Average diameter (m)	17.2	20.4	25.1
Obstacles			
Windfalls (no./ha)	104	248	312
Stumps (no./ha)	92	116	108
Total (no./ha)	196	364	420
Obstacle area			
Windfalls (m^2/ha)	165	816	976
Stumps (m^2/ha)	33	67	61
Total (m^2/ha)	198	883	1037



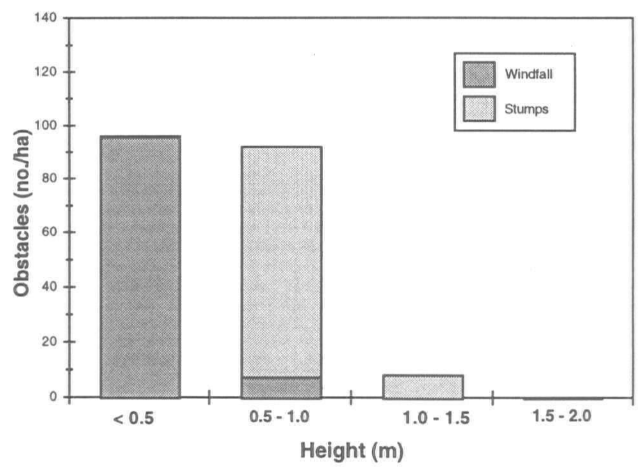


Figure 6. Obstacles on Block 1.

windfalls comprising 83% of the total obstacle area. The area of each obstacle varied from 0.11 to 3.56 m^2 (Figure 6), and 61% of obstacles had an area less than 1 m^2. A windfall 0.3 m high and 18.3 m long had the maximum individual area on this block. The height of each obstacle varied from 0.1 to 1.1 m; however, obstacles >1.0 m in height were <5% of the total obstacle number. Windfalls with a height less than 0.5 m were 92% of the total number, and 91% of stumps were 0.5 to 1.0 m high. The tallest obstacle on this block was a stump 56 cm in diameter and 1.1 m high.

Block 2, Medium Obstacle Level. This block had a density of 1568 trees/ha and volume of 707 m^3/ha. Western redcedar was 44% of the tree number, with 24% grand fir, and 23% Douglas-fir; the remainder were western hemlock and big leaf maple (Appendix I, Figure I-2). The average diameter of western redcedar was 12.1 cm, and 85% was distributed in relatively small diameters (<16 cm). The average volume and diameter of trees within this block were 0.45 m^3 and 20.4 cm respectively.

The total number and area of obstacles on Block 2 were 364/ha and 883 m^2/ha. These figures were, respectively, 1.9 and 4.4 times greater than those on Block 1. The area of windfalls was 92% of the total obstacle area. The area of each obstacle varied from 0.10 to 16.38 m^2

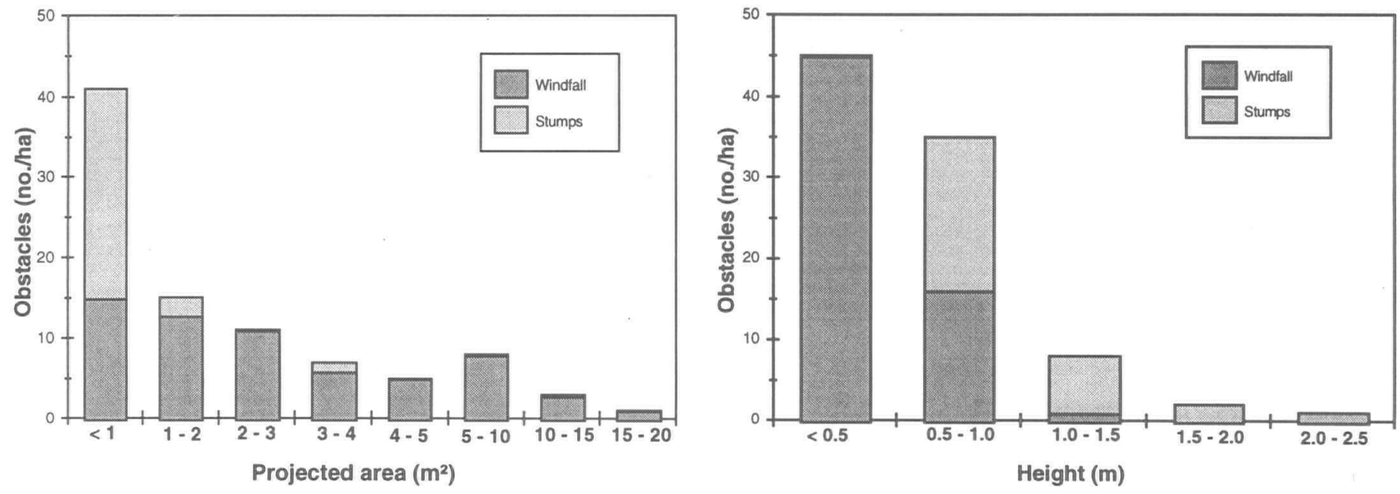


Figure 7. Obstacles on Block 2.

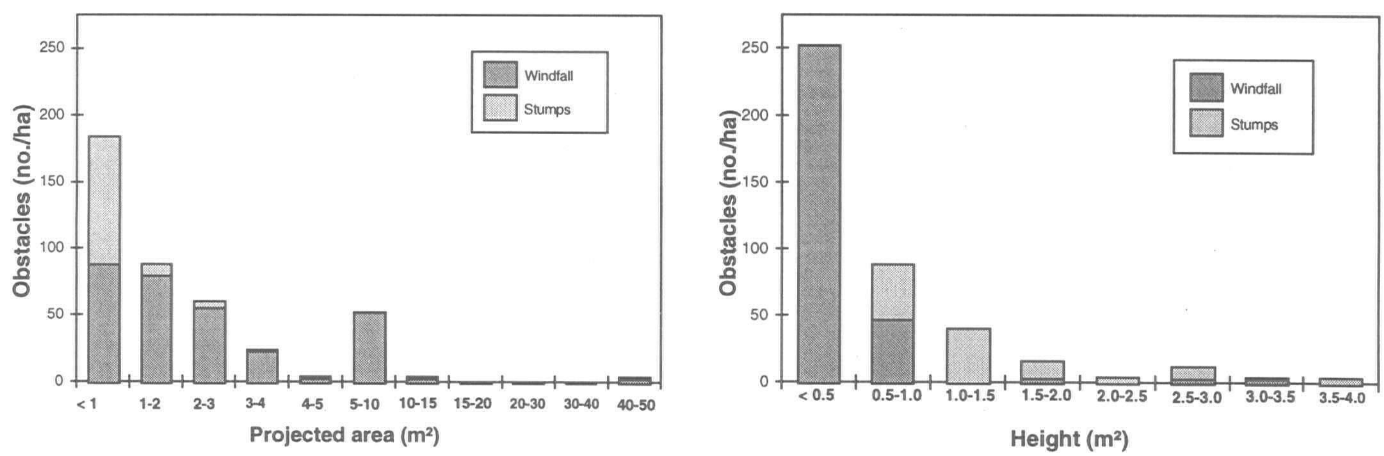


Figure 8. Obstacles on Block 3

(Figure 7). Obstacles with an area <1 m² occupied 45% of the total number, and 74% of obstacles were <3 m². The obstacle with the maximum area on this block was a windfall of 1 m high and 26.2 m long. The height of obstacles varied from 0.2 to 2.1 m; however, obstacles >1.0 m high were <2% of the total number. Windfalls <0.5 m high were 73% of the total number, while 90% of stumps were between 0.5 to 1.5 m high. The obstacle with the maximum height was a stump 60 cm in diameter and 2.1 m high.

Block 3, Heavy Obstacle Level. In Block 3, tree density was 1024/ha, with a volume of 548 m³/ha. The average tree volume and diameter were 0.54 m³ and 25.1 cm respectively. Western redcedar was 64% of total tree number with 20% Douglas-fir; the remainder was western hemlock and big leaf maple (Appendix I, Figure I-3). The average diameter of western redcedar was 18.9 cm, and 85% of western redcedar was between 6 and 20 cm.

The total number and area of obstacles on this block were 420/ha and 1037 m²/ha. These figures were, respectively, 2.1 and 5.2 times as great as those on Block 1. Windfalls comprised 94% of the total obstacle area. The obstacle area varied from 0.10 to 42.08 m² (Figure 8). Obstacles with an area <1 m² were 44% of the total number, and 79% of obstacles were <3 m² in area. A windfall 2.9 m high and 24.9 m long was the obstacle with the maximum area. This windfall had a large root wad and was the largest obstacle in the three study blocks. The height of each obstacle varied from 0.1 to 3.8 m. Obstacles >1.0 m high were 19% of the total number. Windfalls of <0.5 m high were 81% of the total number, while 74% of stumps were between 0.5 and 1.5 m high. The tallest obstacle on this block was a 90-cm-diameter stump, 3.8 m high.

Table 3. Actual and Theoretical Treatments on the Three Blocks

Block	Obstacle level	Actual removal level				Theoretical removal level			
		(trees/ha)	(%)	(m^3/ha)	(%)	(trees/ha)	(%)	(m^3/ha)	(%)
1	Light	1116	76.6	144	40.5	948	65.1	91	25.8
2	Medium	1120	71.4	220	31.1	996	63.5	165	23.3
3	Heavy	644	62.9	134	24.5	536	52.3	107	19.5

Treatment

Block 1, Light Obstacle Level. In this block, the harvester removed 279 trees (1116 trees/ha) and 36 m^3 of standing tree volume (144 m^3/ha) (Table 3), of which 77% was Douglas-fir. Most of the small western redcedar was removed (Appendix II, Figure II-1) and, the average diameter increased from 17.2 to 27.6 cm. The percentage of removed trees was 77% by number, 41% by volume. These figures exceeded the theoretical treatment by 12 and 15 points respectively.

All retained trees, removed trees, windfalls, stumps, and harvester trails on Block 1 are shown in Figure 9. The harvester made four trails to complete the treatment, and windfalls that intercepted the trails were moved by the harvester. As well, the harvester made detours to avoid stumps. However, both windfalls and stumps did not have a great influence on vehicle mobility. In all three blocks, the forwarder travelled on the trails made by the harvester.

Block 2, Medium Obstacle Level. The harvester removed 280 standing trees (1120 trees/ha), with a volume of 55 m^3 (220 m^3/ha) in Block 2. Douglas-fir and grand fir comprised 42% and 39% of the removed volume respectively. As in Block 1, most of the small western redcedar was removed. In the theoretical treatment, all big leaf maple were removed, but in the actual treatment, 24% of maple was retained (Appendix I, Figure II-2). After the actual treatment, the average diameter changed from 20.4 cm to 31.3 cm. The thinning intensity was 71% by tree number, 31% by volume. Both of these figures exceeded the theoretical treatment by eight points.

To remove trees on this block, the harvester made three trails (Figure 10). The middle trail was established as a main forwarding trail before the study, and therefore detailed timing of the harvester along this trail was not collected. Windfalls intercepting the harvester's travel were removed from the trail, and merchantable windfalls were processed. The influence of obstacles on vehicle travel was greater than in Block 1.

Block 3, Heavy Obstacle Level. The harvester thinned 161 trees (644 trees/ha) and 34 m^3 (134 m^3/ha) on this block (Table 3). Western redcedar comprised 76% of the total number of trees removed and 53% of the total volume removed, while Douglas-fir was 39% of removed volume. Most of the small western redcedar was removed, but about 70% of the big leaf maple was retained (Appendix II, Figure II-3). The average diameter increased from 25.1 cm to 38.2 cm. This treatment resulted in a reduction of 63% by number and 25% by volume. These percentages exceeded the theoretical treatment by eleven and five points respectively.

Trails made by the harvester were in the pattern of a fan (Figure 11). Many windfalls and stumps tightly restricted the machine's travel. The harvester also spent

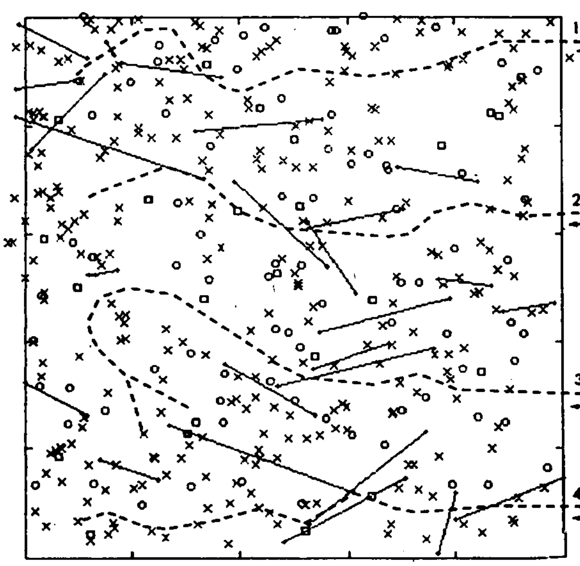


Figure 9. Treatment by the harvester in Block 1. Circles are residual trees, crosses are harvested trees, squares are stumps, solid lines are windfalls, and interrupted lines are the harvester's trails. The numbers along the edge of the map indicate the order of the harvest on the trails. Block size is 50 m by 50 m.

time removing and processing these windfalls. The influence of obstacles, especially windfalls, on the harvester's travel was the most serious of the three blocks.

In all three blocks, both windfalls and stumps restricted the harvester's travel. Time was spent removing windfalls which intercepted travel, and making detours around stumps. However, the thinning objectives were almost achieved in the three blocks. The primary deviation from the prescription was the removal of many of the small western redcedar and the retention of the big leaf maple. This deviation resulted from the harvester operator's selection preference and not the need to avoid obstacles.

Detailed Timing, Productivities, and Costs

Block 1, Light Obstacle Level. In this block, the harvester thinned 322 stems and 31.9 m^3 of merchantable volume, including trees with diameters <6 cm and windfalls. The average volume/stem harvested was 0.1 m^3, at an average time of 0.48 min/stem. During the operation, the harvester cleaned unmerchantable small trees and windfalls, using 24% of the total time (Table 4). Using the detailed timing results, productivity and cost of the harvester on this block was estimated as 12.5 m^3/PMH (Figure 12) and \$11.50/m^3. When productivity is calculated for numbers of trees, the harvester handled 126 trees/PMH on this block.

The forwarder extracted 560 logs with 52.5 m^3 in volume. This volume exceeded the processed volume of the harvester, because some logs outside the block were included in the load. Five loads were made to forward the volume from this block. The average load volume, round trip distance, and time per turn were 10.5 m^3, 1109 m, and 63.68 min respectively. Loading was the most time-consuming activity, amounting to 40% of the total time (Table 5). Productivity of the forwarder in this block was calculated as 9.9 m^3/PMH (Figure 13). Forwarding cost was calculated as \$9.33/m^3.

Block 2, Medium Obstacle Level. Within Block 2, during the study, the harvester processed 206 stems for a volume of 45.9 m^3. Some volume was removed prior to the study when the main forwarding trail was constructed. The average volume/stem harvested was 0.22 m^3, at an average time of 0.75 min/stem. This time was approximately 1.6 times that of Block 1. The harvester spent 33% of the total time on cleaning, i.e. nine points more than in Block 1. Productivity of the harvester

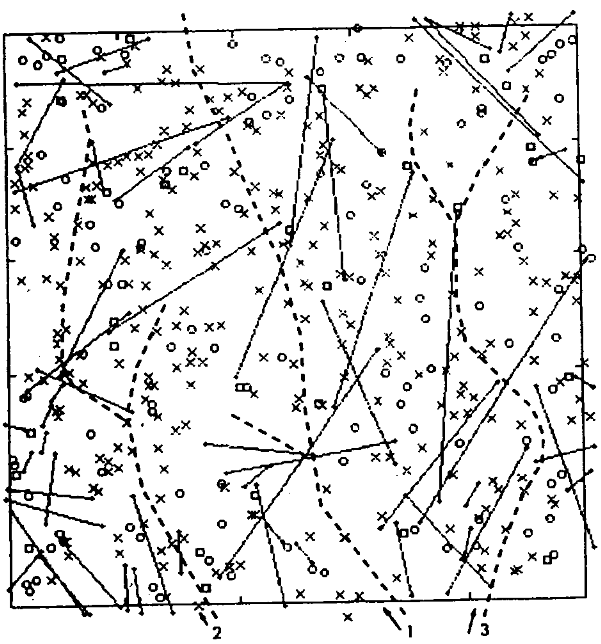


Figure 10. Treatment by the harvester in Block 2. Circles are residual trees, crosses are harvested trees, squares are stumps, solid lines are windfalls, and interrupted lines are the harvester's trails. The numbers along the edge of the map indicate the order of harvest on the trails. Block size is 50 m by 50 m.

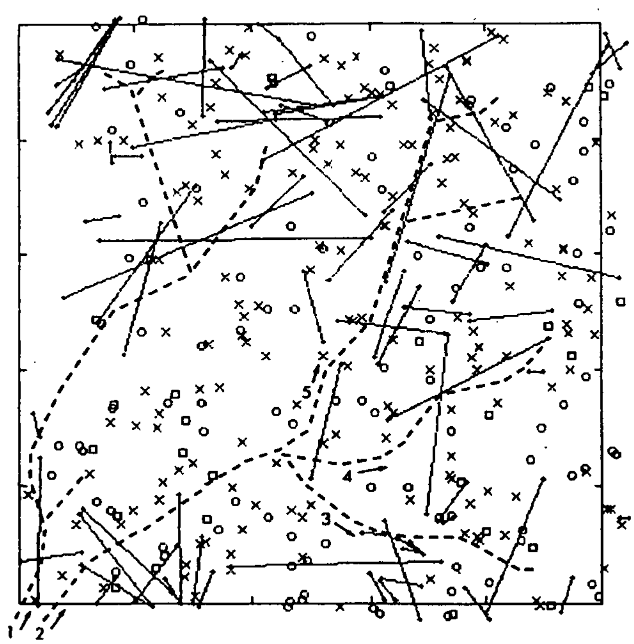


Figure 11. Treatment by the harvester in Block 3. Circles are residual trees, crosses are harvested trees, squares are stumps, solid lines are windfalls, and interruped lines are the harvester's trails. The numbers along the edge of the map indicate the order of harvest on the trials. Block size is 50 m by 50 m.

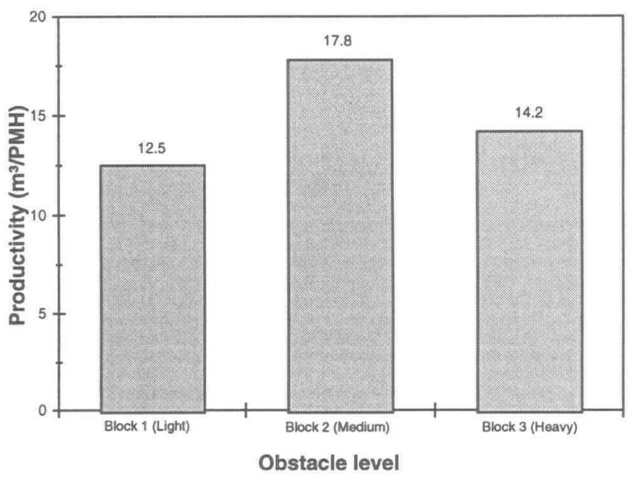


Figure 12. Harvester productivity by block.

was 17.8 m^3/PMH, i.e. 5.3 m^3 greater than in Block 1, with a corresponding lower cost of \$8.08/m^3, \$3.42/m^3 less than in Block 1. The harvester handled 80 trees/PMH on this block.

The forwarder loaded 278 logs with a total volume of 37.8 m^3. This volume was smaller than the volume processed by the harvester, because the forwarder did not load all logs on this block. For the four turns measured, the average load volume, round trip distance, and time per turn were 9.4 m^3, 575 m, and 57.1 min respectively. As in Block 1, loading took the greatest time, 38% of the total time. Productivity and cost of the forwarder were estimated as 9.9 m^3/PMH and \$9.34/m^3. Productivity and cost on Block 2 was almost the same as on Block 1 in spite of a longer forwarding distance in Block 1 because load volume per turn was smaller in Block 2.

Block 3, Heavy Obstacle Level. The harvester processed 171 stems and 42.2 m^3 including merchantable windfalls on this block. The average volume/stem harvested was 0.25 m^3, the largest in the three blocks. The average time/stem was 1.04 min, and this was 2.2 times and 1.4 times longer than for Blocks 1 and 2 respectively. In addition, the cleaning activity was 34% of the total time, exceeding Block 1 by ten points and Block 2 by one point. Productivity of the harvester was 14.2 m^3/PMH which was similar to harvester productivities reported in a previous FERIC study (Andersson 1994). In spite of the existence of heavy obstacles, productivity on this block exceeded that on Block 1 because of the larger tree size. However, productivity was approximately 3.6 m^3 less than Block 2 which had a similar stem volume. The production cost of the harvester was \$10.14/m^3. On Block 3, the harvester handled 58 trees/PMH, less than half the number it treated on the light obstacle block.

Number and volume of logs forwarded were 193 and 30.2 m^3. As with Block 2, this volume was smaller than the processed volume. For the three turns observed, the average load volume, round trip distance, and time/turn

Table 4. Detailed Timing of the Harvester: Summary

Element	Block 1, Light		Block 2, Medium		Block 3, Heavy	
	(min)	(%)	(min)	(%)	(min)	(%)
Swing empty	32.23	24.7	22.64	18.4	24.36	14.5
Fall	15.68	12.0	12.69	10.3	13.55	8.0
Process	21.55	16.5	14.62	11.9	12.67	7.5
Buck	0.82	0.6	1.34	1.0	4.20	2.5
Deck	2.26	1.8	2.39	1.9	1.08	0.6
Move	23.13	17.7	25.25	20.5	42.82	25.5
Clean	31.84	24.4	41.14	33.4	57.81	34.3
Delays	2.78	2.1	1.95	1.6	9.62	5.7
Abort	0.29	0.2	1.20	1.0	2.36	1.4
Subtotal	130.58	100.0	123.22	100.0	168.47	100.0
Sum time[a]	22.34		31.28		9.61	
Total	152.92		154.50		178.08	

[a]*Productive, not timed in detail.*

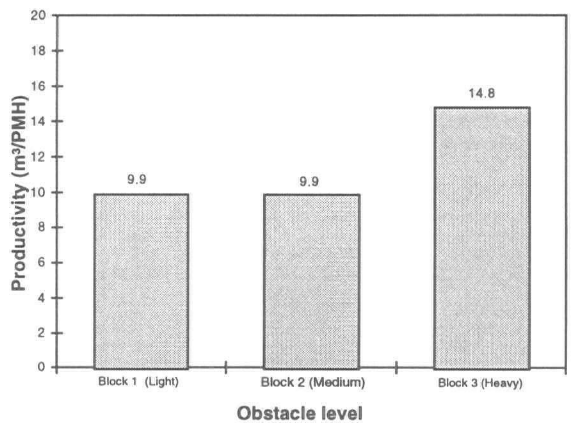


Figure 13. Forwarder productivity by block.

were 10.1 m^3, 210 m, and 40.9 min respectively. Loading used 37% of the total time, i.e. the ratio of load time was similar for all three study blocks. Productivity of the forwarder was estimated as 14.8 m^3/PMH. This relatively high productivity resulted from the shorter travel distance and larger log size than occurred in Blocks 1 and 2. Cost of the forwarder was calculated as \$6.25/m^3. This was the lowest cost of the three blocks.

Residual Stand and Site Impacts

Residual Tree Damage. During the treatment, some residual trees were damaged by the harvester or forwarder, or by impacts from stems and logs during processing and removal.

In Block 1, three trees were damaged. All were located beside a trail, and had a root injury. The average damage was 32 cm in length and 11 cm in width, located 87 cm from the tree concerned. All injuries were scratches in the bark and were less than 5 mm in depth. These were classified as light damage which would not affect the tree's growth. The overall damage level in this block was 4%.

Block 2 had eleven damaged trees along the trails. Root damage was found on five trees and trunk damage was present on six trees. Root damage averaged 22 cm in length, 7 cm in width, and was located 67 cm from the tree, while trunk damage averaged 41 cm in length and 5 cm in width, and was located at 76 cm height from the ground. All damage was classified as light. The ratio of damaged trees to residual trees was 10%, 2.5 times as great as in Block 1.

Within Block 3, there were eight damaged trees: four trees with root injury and four with trunk injury. As in Blocks 1 and 2, all damage occurred along the trails and was light. The average root injury was 53 cm in length and 12 cm in width, and located 72 cm from the tree. Trunk damage averaged 31 cm in length and 16 cm in width, and was located at a height of 55 cm from the ground. The ratio of damaged trees to residual trees was 8%.

Mineral Soil Exposure. Mineral soil exposure was found on vehicle trails in the three blocks. In Block 1, exposed area with <5 cm depth was approximately

Table 5. Detailed Timing of the Forwarder: Summary

Element	Block 1, Light		Block 2, Medium		Block 3, Heavy	
	(min)	(%)	(min)	(%)	(min)	(%)
Travel empty	47.37	14.9	18.14	9.1	10.4	68.7
Load	126.36	39.8	76.69	38.4	44.88	37.3
Travel loaded	60.59	19.1	29.41	14.7	15.23	12.7
Deck	4.93	1.6	3.77	1.9	1.97	1.6
Travel landing	1.14	0.4	3.39	1.7	1.07	0.9
Delays (<10 min)	24.42	7.7	12.26	6.1	4.38	3.7
Subtotal	317.18	100.0	199.78	100.0	120.24	100.0
Sum time[a]	1.20		28.62		2.48	
Total	318.38		228.40		122.72	

[a]*Productive, not timed in detail.*

4.4 m^2/ha, and with depth between 5 and 10 cm the area was 1.6 m^2/ha. Therefore, the total area of exposure was 6.0 m^2/ha, less than 0.1% of treatment area.

Mineral soil exposure in Block 2 occurred more deeply, with four classes present: depth <5 cm, between 5 and 10 cm, between 10 and 20 cm, and between 20 and 30 cm. Exposed area in each depth class was 3.8 m^2/ha, 1.9 m^2/ha, 2.9 m^2/ha, and 6.2 m^2/ha respectively. The total exposed area reached 14.8 m^2/ha; however, this area was 0.1% of treatment area. This block had 2.5 times the exposed mineral soil area of Block 1 and considerably deeper disturbance penetration.

In Block 3, exposed area with depth <5 cm was 5.8 m^2/ha, between 5 and 10 cm was 35.6 m^2/ha, between 10 and 20 cm was 7.9 m^2/ha, and between 30 and 40 cm was 8.8 m^2/ha. The total exposed area was 58.1 m^2/ha, 0.6% of treatment area. This area was 3.9 times that in Block 2 and 9.7 times that in Block 1. The increase in exposed area of Block 3 can be attributed to heavy obstacles on this block. Obstacles restricted the vehicle mobility, and therefore the same trail was travelled many times.

CONCLUSIONS

Over the summer and fall of 1994, FERIC studied a mechanized commercial-thinning operation on Vancouver Island in British Columbia to determine the influence of obstacles on productivities, costs, and site impacts. The study occurred in a second-growth forest composed of Douglas-fir, western redcedar, and western hemlock, with a small component of grand fir and big leaf maple. The study area was sampled for obstacle intensity, and three 0.25-ha trial blocks were located to represent light (<200 m^2/ha), medium (200-1000 m^2/ha), and heavy (>1000 m^2/ha) obstacle levels. These sample blocks were intensively surveyed and monitored during harvesting to quantify the relationships of obstacle intensity to machine performance.

Both windfalls and stumps were confirmed as the obstacles to vehicle mobility and productivity. The total number and area of obstacles was 196/ha and 198 m^2/ha on Block 1, the Light Obstacle Level block. Windfalls were 83% of the total obstacle area. Within Block 2, the Medium Obstacle Level, the total number of obstacles was 364/ha, comprising an area of 883 m^2/ha. These figures are greater by 1.9 and 4.4 times respectively compared to those in Block 1. Windfalls occupied 92% of the obstacle area. In Block 3, the Heavy Obstacle Level, the total number and the total area of obstacles were 420/ha and 1037 m^2/ha. As in Blocks 1 and 2, most of the obstacle area, 94%, was occupied by windfalls.

Avoiding stumps required the harvester to change travel directions, while windfalls caused the harvester to spend time on clearing. In Block 1, where the obstacle level was Light, the harvester made four trails; in Block 2, with Medium Obstacle Level, the harvester made three trails. However, trails on Block 3, Heavy Obstacle Level, were patterned like a fan. In other words, heavy obstacles severely restricted the harvester's access on this block. Because the forwarder used the trails that the harvester cleared, obstacles did not seriously influence the forwarder's mobility.

The harvester cleared obstacles in order to access the thinning operation. The percentage of cleaning increased in proportion to obstacle area, and productivity of the harvester decreased gradually with increasing obstacles. Productivity in Block 1 was 12.5 m^3/PMH in spite of having the smallest stems of the three blocks, while productivity was 17.8 m^3/PMH in Block 2 and 14.2 m^3/PMH in Block 3. The harvester handled 126 trees/PMH in Block 1, 80 trees in Block 2, and 58 trees in Block 3. The production costs of the harvester were calculated as \$11.50, \$8.08, and \$10.14/m^3 respectively. To confirm the influence of obstacles, a study with the same average tree size would be required in future. Productivity of the forwarder was affected primarily by travel distance and log size, and was not influenced seriously by the obstacles. In Block 1, with a round trip distance of 1109 m, the forwarder produced 9.9 m^3/PMH, while in Block 3 with a round trip distance of 210 m, it produced 14.8 m^3/PMH. The ratio of load time to total time was 37 to 40% in this study. Production costs of the forwarder were \$9.33/m^3 in Block 1, \$9.34/m^3 in Block 2, and \$6.25/m^3 in Block 3.

At 4%, residual tree damage was low in Block 1. However, the percentage of damaged trees was 10% in Block 2 and 8% in Block 3. To achieve low damage, the vehicle's operator must be more careful in areas with heavy obstacles. Exposure of mineral soil was limited to vehicle trails, and calculated as <1% of treatment area in all blocks. Although there was a slight increase in disturbed area according to obstacle level, the small study area does not give a definitive relationship. More study on the relationship between obstacles and site disturbance is suggested.

As mentioned above, the influence of obstacles on machine performance, especially on the harvester's mobility and productivity in commercial thinning, was verified in this study. With the increased harvesting of Coastal second-growth forests, harvest planners need to be aware of the potential impacts of obstacle levels on the performance of ground-based harvesting equipment.

References

Andersson, B.O. 1994. *Cut-to-Length and Tree-Length Harvesting Systems in Central Alberta : A Comparison.* FERIC, Vancouver. Technical Report TR-108. 32pp.

Green, R.N.; Klinka, K. 1994. *A Field Guide for Site Identification and Interpretation for the Vancouver Forest Region.* British Columbia Ministry of Forests, Victoria. Land Management Handbook 28. 285pp.

Hunt, J.A. 1995. *Commercial Thinning Coastal Second-Growth Forest with a Timberjack Cut-to-Length System.* FERIC, Vancouver. TN-235.14pp.

APPENDIX I

Distribution of Trees by Species and Diameter Class Prior to Thinning

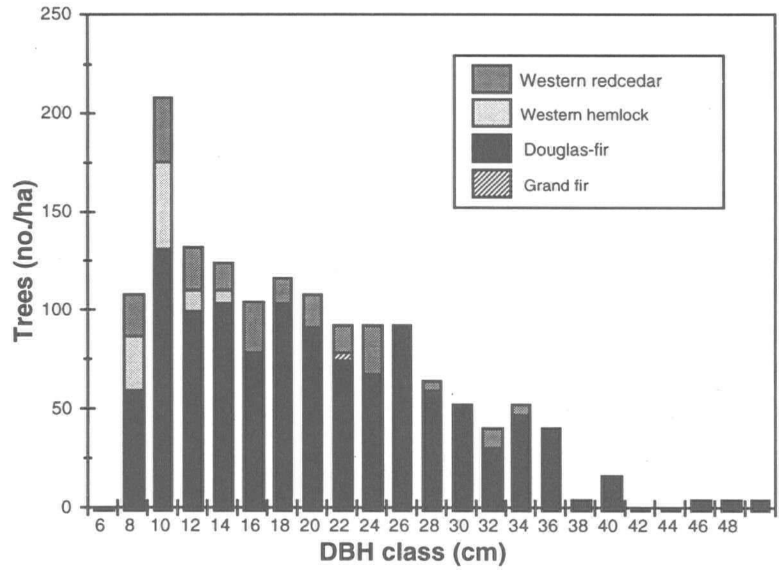


Figure I-1. Distribution of trees within Block 1 - Light Obstacle Level.

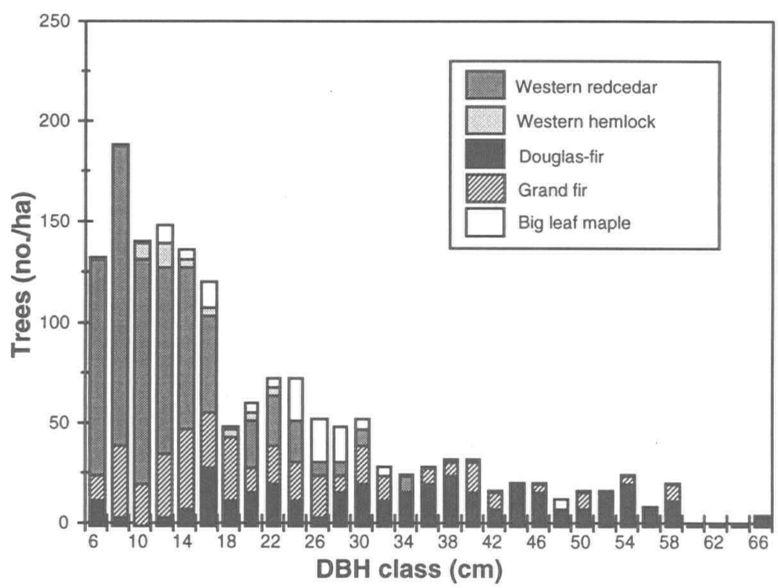


Figure I-2. Distribution of trees within Block 2 - Medium Obstacle Level.

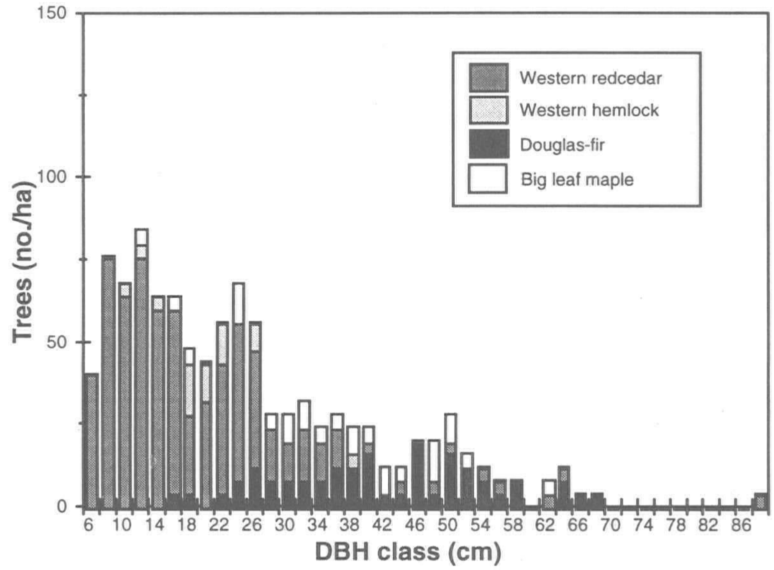


Figure I-3. Distribution of trees within Block 3 - Heavy Obstacle Level.

APPENDIX II

Distribution of Trees by Species and Diameter Class After Actual and Theoretical Treatment

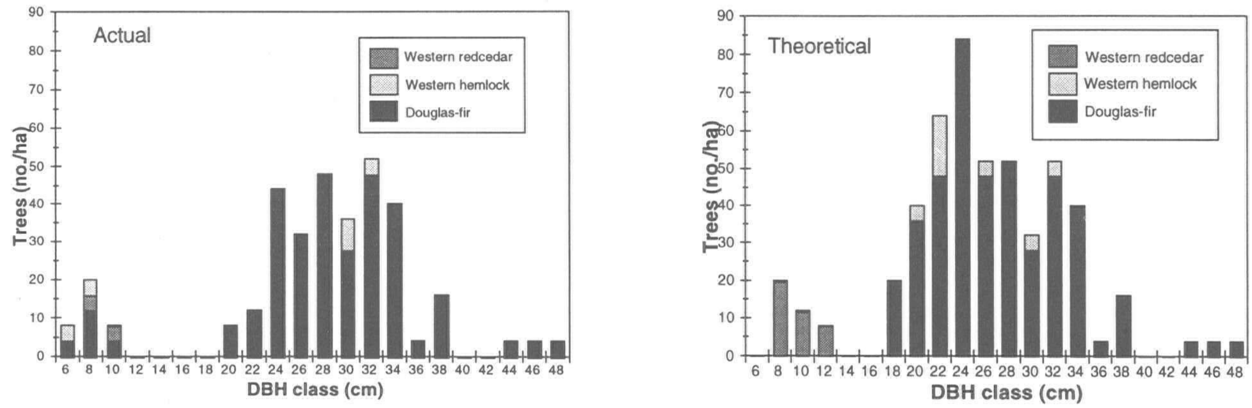


Figure II-1. Distributions of trees after actual and theoretical treatment on Block 1.

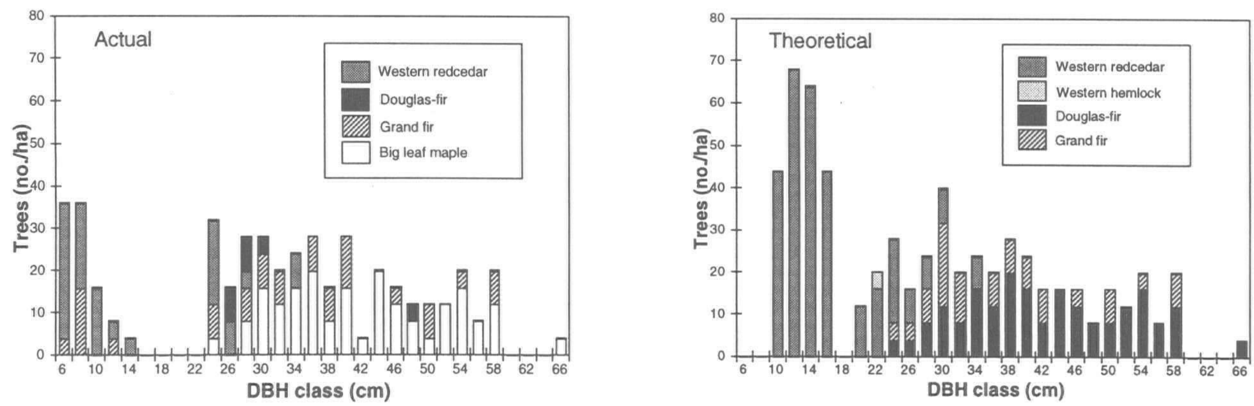


Figure II-2. Distributions of trees after actual and theoretical treatment on Block 2.

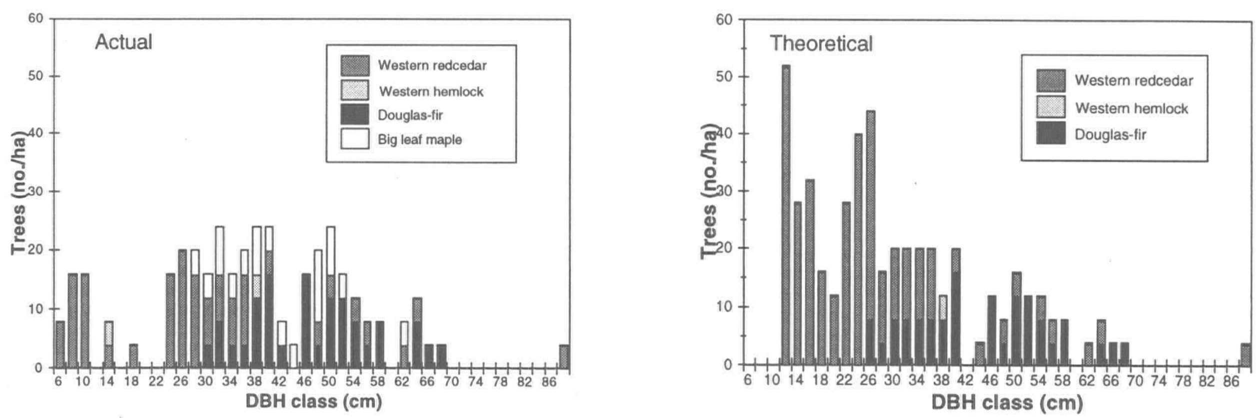


Figure II-3. Distributions of trees after actual and theoretical treatment on Block 3.

APPENDIX III

Machine Costing

	Harvester, Timberjack 1270 (1994)	Forwarder, Timberjack 1010 (1994)[a]
OWNERSHIP COSTS		
Total purchase price (P) $	610 954	345 000
Expected life (Y) y	5	5
Expected life (H) h	10 000	10 000
Scheduled hours/year (h)=(H/Y) h	2 000	2 000
Salvage value as % of P (s) %	30	30
Interest rate (Int) %	10.7	10.7
Insurance rate (Ins) %	2.0	2.0
Salvage value (S)=((P•s/100) $	183 286	103 500
Average investment (AVI)=((P+S)/2) $	397 120	224 250
Loss in resale value ((P-S)/H) $/h	42.77	24.15
Interest ((Int•AVI)/h) $/h	21.25	12.00
Insurance ((Ins•AVI)/h) $/h	3.97	2.24
Total ownership costs (OW) $/h	67.99	38.39
OPERATING COSTS		
Fuel consumption (F) L/h	16.0	12.0
Fuel (fc) $/L	0.39	0.39
Lube & oil as % of fuel (fp) %	24	15
Annual tire consumption (t) no.	1.0	1.5
Tire replacement (tc) $	3 150	3 150
Track & undercarriage replacement (Tc) $	9 500	9 500
Track & undercarriage life (Th) h	6 000	6 000
Annual operating supplies (Oc) $	13 170	3 985
Annual repair & maintenance (Rp) $	52 200	20 497
Shift length (sl) h	10.0	10.0
Total wages (W) $/h	21.78	21.78
Wage benefit loading (WBL) %	35	35
Fuel (F•fc) $/h	6.24	4.68
Lube & oil ((fp/100)•(F•fc)) $/h	1.50	0.70
Tires ((t•tc)/h) $/h	1.58	2.36
Track & undercarriage (Tc/Th) $/h	1.58	1.58
Operating supplies (Oc/h) $/h	6.59	1.99
Repair & maintenance (Rp/h) $/h	26.10	10.25
Wages & benefits (W•(1+WBL/100)) $/h	29.40	29.40
Prorated overtime (((1.5•W-W)•(sl-8)•(1+WBL/100))/sl) $/h	2.94	2.94
Total operating costs (OP) $/h	75.93	53.90
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP)[b] $/h	143.92	92.29

[a] The capital cost for a Timberjack 1010 forwarder was used for the machine cost calculations because the 910 model used in the study is no longer available. Differences in these two models are minor.

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

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