Silvicultural Result of One-Grip Harvester Operation

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ABSTRACT

A new method for measuring the silvicultural result of thinning is presented in the study. The measuring method was based on rectangular sample plots measured parallel to strip roads. An individual sample plot consisted of eight zones, each 30 m^2 in area. Due to its considerable importance in Finland, the one-grip harvester operation was the harvesting system examined. The research material was collected from 15 stands amounting to a total area of 14.7 ha.

The post-harvesting inventory provided good information on the removed and standing trees, their size and distribution. The number and distribution of standing and removed trees were according to Finnish thinning instructions, and thinning was typical low thinning, in which smaller trees and trees of low quality are removed. The average tree damage percentage, 4.6, is acceptable. However, the proportion of damage varied from 1.1% to 9.1% with different operators. The damage was highest during the summer. Small, superficial damage was typical. The average strip road width was 4.8 m, the distance between strip roads 19.8 m and the rut depth 0.6 cm.

The economic consequences of the damage was estimated using a calculation model. The model estimates the losses caused by strip roads, tree and soil damage. The economic consequences of harvesting damage during the rotation period was 1158 FIM (1 U$ = 5.60 FIM). Strip roads make a significant contribution to the amount of costs.

Due to the high variation in the harvesting quality, both the continuing supervision of the silvicultural thinning result and the training of machine operators are necessary. Thinning spruce stands during the sap period should be avoided due to the high risk of tree damage, and decay following damage. Generally, it is possible to obtain a good silvicultural thinning result with one-grip harvester operation.

Keywords: *Thinnings, tree damage, one-grip harvester, strip roads.*

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INTRODUCTION

Studies of the impact of harvesting operations are well represented in the scientific literature. More than 2500 studies of the environmental consequences of harvesting operations have been made since 1980 [28]. Harvesting damage was studied in 12 European countries by 28 research institutions during the period 1991 - 1997 [27]. Tree and soil damage were the most common topics. The economic consequences of damage were generally not addressed. Less than 2% of the reports included economic considerations [28].

The field of study has been rich, but the research principles and methods applied have been diverse. In Scandinavia, where damage inventory methods have differed between countries and even within countries, there has been a trend to harmonize research methodology. Measuring the width of the strip road and combining the results with economic impacts seems to be one the most difficult problems. In Finland, the measurement and effects of strip roads have been widely studied [10, 11].

The most widely used damage inventory method in Scandinavia was developed in Sweden [1]. The method is based on circular sample plots measured along inventory lines, and it has been used both in Sweden and Finland. In the United States, three sampling methods for measuring tree damage were compared. Circular sample plots measured from systematic measuring lines were the best way to study tree damage [24].

A very important question when estimating the silvicultural harvesting result is the number, quality and distribution of removed and remaining trees. Trees near the strip roads have an important role in the future development of stands. The edge trees of strip roads have more room, light and nutritients than the trees far away from strip roads, and positive growth effects have been reported in many studies [3, 4, 6, 9, 11, 21]. The condition for this positive effect is that the edge trees are not damaged and that there are enough trees to utilize good growth conditions.

Damage inventories based on comprehensive data are expensive. They are necessary, nonetheless, when information on amount of tree and soil damage caused by different harvesting systems is required. The amount of damage varies considerably between stands and operators, and a limited study can give false results. Circular sample plots measured on inventory lines give good information on the quantity and quality of damage. However, information on the quality and distribution of removed and remaining trees is not the best possible.

The present study has three objectives; to present a method for measuring the silvicultural thinning result, to clarify the thinning result of one-grip harvester operations, and to estimate the cost of damage level found in measuring with a Kovalama calculation model [14].

In 1997, the mechanization rate of thinnings in Finland was 77%, an increase of 9% over the previous year [29]. Thinnings are carried out using one-grip harvesters and forwarders. The amount of tree damage in one-grip harvester operations has generally been acceptable, but there has been a great variation between the stands studied. Due to considerable importance, the one-grip harvester operation was selected as the harvesting system examined.

MATERIALS AND METHODS

Description of the inventory method

For this investigation, a new method for measuring the silvicultural result of harvesting was developed. The method was based on rectangular sample plots measured parallel to the strip roads. At the beginning of an inventory, an interval of 1 - 10 m was selected at random and the starting point of the first sample plot placed within this interval on the strip road. Sample plots were subsequently placed at intervals of either 30 m for areas < 1.5 ha or 40 m for areas > 1.5 ha.

The sample plots were determined by first measuring a distance of 10 m along the strip road. After this, four zones of 10 m x 3 m were defined on either side of the strip road. Thus each individual sample plot consisted of eight 30 m^2 zones. The post-harvesting sample plot and measurements are shown in Figure 1.

Cost calculation of harvesting damage

A literature review on studies concerning the consequences of harvesting damage and a Kovalama calculation model using MS Excel software for estimating the losses caused by damage was presented in Finland [14]. The model is based mostly on Scandinavian research results concerning impacts of tree and soil damage.

The model presents the losses in m^3 and in Finnish Marks (1 US $ = 5.60 FIM) and estimates the costs caused by tree damage, soil damage and strip roads. Both growth and quality losses are estimated. Losses by thinning intensity or tree selection cannot be estimated by the model, but losses can be estimated between thinnings or during the whole rotation period. The variables used in the model are number, quality, size and location of damage, strip road width and spacing, rut formation, tree species and forest type.

Study material and machine

The research material was collected from 15 stands amounting to a total area of 14.7 ha. A total of 178 sample plots consisting of 1398 zones were measured. The total area of sample plots was 4.2 ha, 28.6 % of the inventoried area. A total of 8192 stems with the volume of 1085 m^3 was cut from the study stands, of which 586 m^3 was cut in winter, 288 m^3 in spring or autumn and 211 m^3 during the sap period.

The initial growing stock in the stands studied averaged 1169 stems/ha, while the corresponding figure after thinning was 634 stems/ha. The stands were spruce-dominated under going first and second thinning. The machines

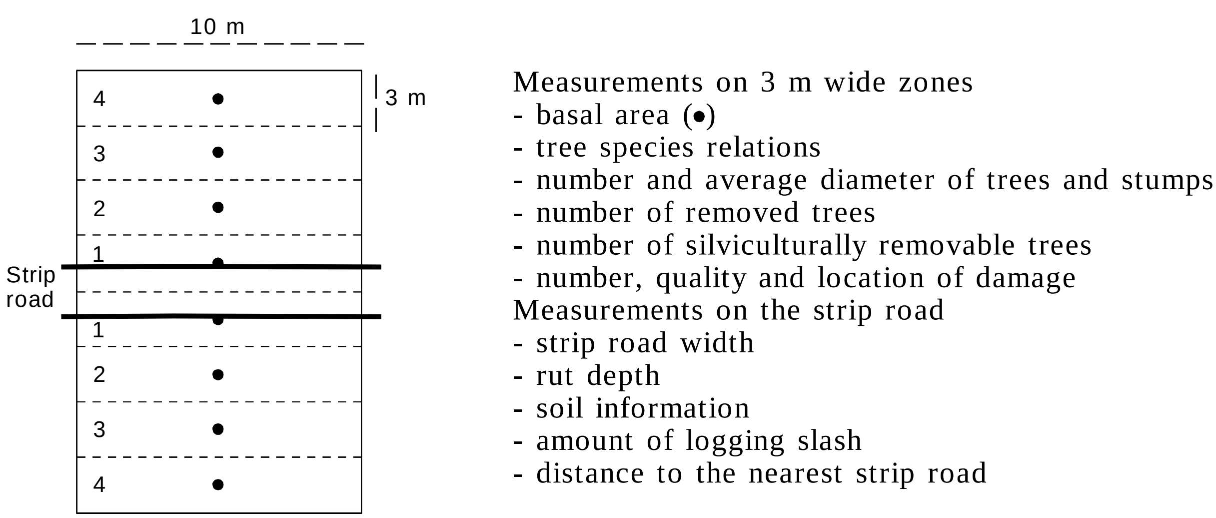

Figure 1. The post-harvesting inventory sample plot.

employed were Valmet 901 one-grip harvesters equipped with Valmet 942 harvester heads. Four operators were included in the study. Pulpwood was cut to 5 m lengths. The study stands were located on easy terrain. A post-harvesting inventory was made prior to forwarding. The results include only the damage caused by the one-grip harvester.

RESULTS

Time consumption of the damage inventory

The time consumed by the damage inventory method employed was studied. Moving between sample plots, marking the boundaries of the plot, and collecting stand, damage and strip road data was included in time accounting. The average effective time/sample plot with a two-man crew was 43 minutes, and varied between 32 - 60 minutes. With a three-man crew, the average time required was 30 minutes/plot, and varied between 25 - 40 minutes. As about 15 sample plots were measured on a 1 ha stand, a three-man crew needed 7.5 hours to make the measurements.

The residual stand and removals

Figure 2 shows the initial growing stock, the residual stand, the numbers of felled and cleaned trees and the basal area per zone. An important feature is the form of thinning. Figure 3 shows the size of standing and removed trees with different operators.

The number, quality and location of tree damage

The amount of damage/ha and damage percentages by operator are presented in Table 1. Table 2 shows the proportion of damage in different measuring zones.

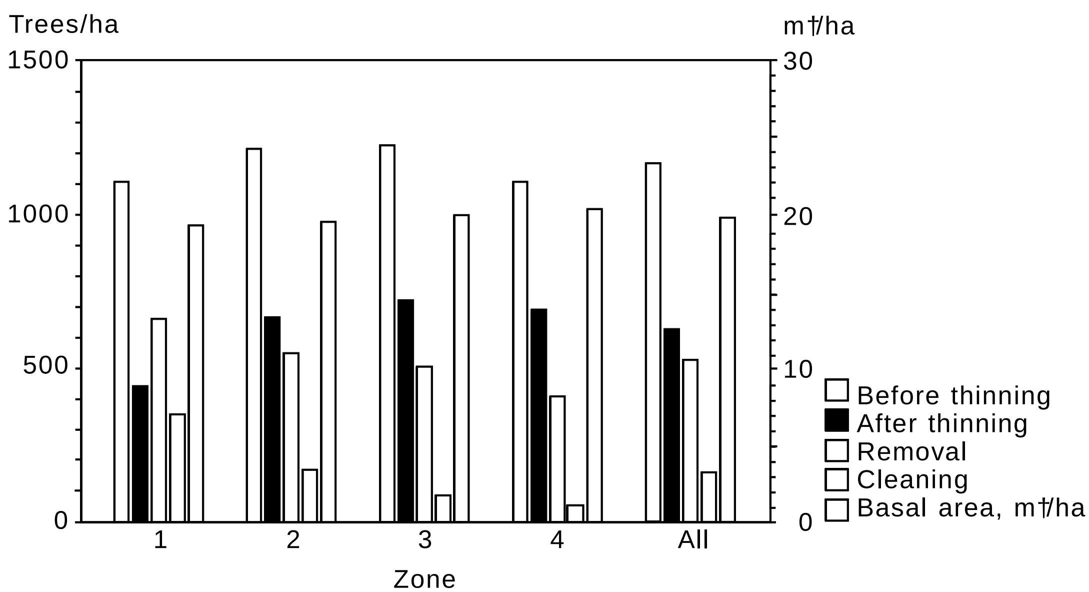

Figure 2. The initial growing stock, the remaining stand, the number of felled and cleaned trees and basal area (m^2/ha) in different zones

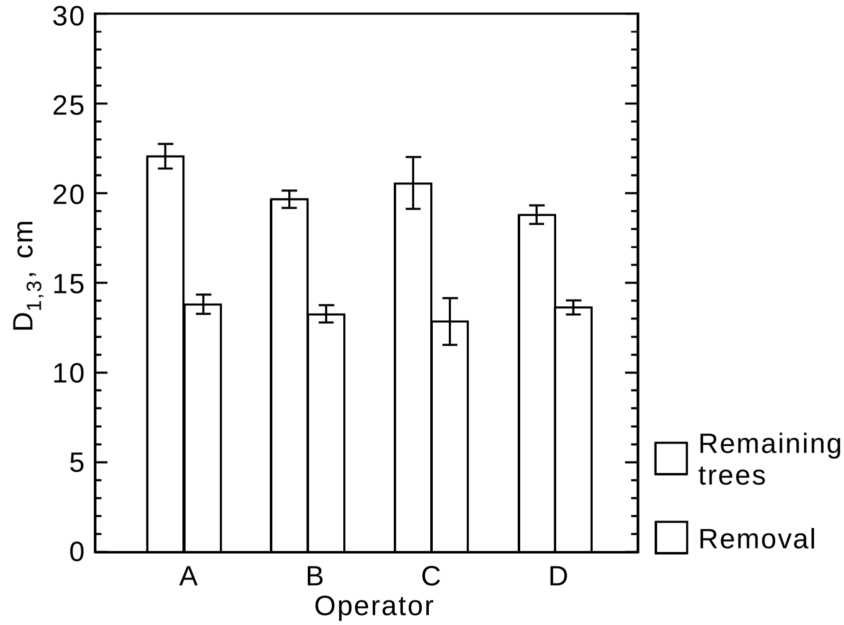

Figure 3. Diameters at breast height ($d_{1.3}$, cm) and 95% confidence limits of standing and removed trees.

Table 1. The amount of damage and proportion of damage by different operators and in average (standard error of the mean presented within parenthesis).

Operator	Damaged trees, n/ha		Damage-%	
	Average	Variation	Average	Variation
A	9.4 (3.1)	6.7 - 15.2	1.8 (0.6)	1.2 - 3.0
B	58.5 (6.4)	26.5 - 96.4	9.1 (1.1)	3.1 -14.0
C	38.2 (10.9)	25.0 - 47.6	7.9 (2.6)	6.1 - 9.4
D	6.2 (2.0)	0.0 - 8.7	1.1 (0.4)	0.0 - 2.3
Average	27.7 (2.7)	0.0 - 96.4	4.6 (0.5)	0.0 -14.0

Table 2. Proportion of damage within different measuring zones. Distances of zones from the centre of the strip road: zone 1: 0 - 3 m, zone 2: 3 - 6 m, zone 3: 6 - 9 m, zone 4: 9 - 12 m.

	Damage- %				
Operator	Zone 1	Zone 2	Zone 3	Zone 4	All
A	0.9	2.2	2.0	0.4	1.8
B	7.9	9.2	9.9	9.2	9.1
C	20.6	1.1	10.9	1.6	7.9
D	1.2	0.4	1.5	1.4	1.1
Average	4.8	4.0	5.6	4.1	4.6

Damage was classified as superficial, when the bark was loosened, but the wood fibres were not damaged. With deep damage the fibres were also damaged. If a tree was broken, the damage was classified as break damage. Of the damage, 91.3% was superficial, 7.8% deep damage and 0.9% break damage. Some 79% of damage was located in stems and 21% in root collars. In the wintertime, the average size of damage was 34 cm^2, in spring and autumn 53 cm^2 and in the summer 48 cm^2. On average the damaged trees were located 5.3 m from the centre of the strip road and stem damage was located 2.8 m from the root collar. Falling trees (41% of damage), trees under processing (25%) and the harvester head (22%) were estimated to be the most common causes of damage.

Strip road width, distance between strip roads and rut formation

The average strip road width, measured by the SLU-method [1], was 4.8 m, the distance between strip roads was 19.8 m and the rut depth 0.6 cm. On 48% of sample plots there was plenty of slash on the strip road.

The distance between strip roads was measured in two ways. From every sample plot, the perpendicular distances to the nearest strip roads were measured. The total strip road length and the area of every study stand were measured to find the calculatory strip road spacing. Strip road widths and spacing are presented in Table 3.

Cost of harvesting damage

The economic consequences of the damage was estimated using a Kovalama model [14]. The model estimates the losses caused by strip roads, and tree and soil damage. In the calculation, a typical spruce stand in Southern Finland was thinned twice during the rotation period. The 1997 price levels used for different assortments were: 220 FIM/m^3 for spruce sawlogs, 130 FIM/m^3 for spruce pulpwood and 100 FIM/m^3 for pine pulpwood. The damage level in the present study was used in the calculation for mechanized cutting, while for forwarding a damage percentage of 1 % was employed. This level is typical in forwarding in Finland [15, 26] Rut depth after forwarding was assumed to be 5 cm. The same strip road network was used in both first and second thinnings. The economic consequences during the rotation period are presented in Table 4.

Table 3. Measured and calculated distances between strip roads and strip road widths.

	Distance between strip roads, m		
Operator	Measured	Calculated	Strip road width, m
A	20.6	20.8	4.88
B	18.9	19.5	4.83
C	18.9	21.7	4.86
D	20.4	19.2	4.60
Average	19.8	19.9	4.76

Table 4. The economic consequences of harvesting damage (m^3/ha and FIM/ha) during the rotation period. The discount percentage used is 3 %. 1 US $ = 5.60 FIM.

	Losses, m^3/ha			Discounted value, FIM/ha		
	Cutting	Forwarding	Total	Cutting	Forwarding	Total
Growth losses						
Strip roads			10.80			711.58
Rutting	0.34	1.00	1.34	25.61	76.83	102.44
Tree damage	0.51	0.21	0.72	39.55	16.52	56.07
Quality losses						
Decay	3.43	1.78	5.21	136.84	150.96	287.80
Total			18.07			1157.89

DISCUSSION

The measuring method presented provides good information concerning the removed and standing trees, their size and distribution. The time required for the measuring method is high, about 30 min/sample plot with a three-man crew. Measuring 10 sample plots/ha takes 5 hours. Due to the high cost, the use of this method in large scale inventories is limited.

The time requirement for measuring circular sample plots from inventory lines in stands smaller than 2 ha is about 80 min/ha [1]. In Finland, a time consumption of 120 min/ha has been reported [25]. Thus, in large scale inventories, circular sample plots provide an efficient way to measure thinning quality. However, when comparing different working methods or strip road spacings with different machinery, exact knowledge on thinning quality is needed. In this case the method presented in this paper may provide a practical solution.

The number and distribution of standing and removed trees were according to Finnish thinning instructions, and thinning was typical low thinning. Thinning instructions are based on the number of remaining trees after first thinnings, in later thinnings a certain basal area, m^2/ha, is obligatory after thinning.

The average level of 4.6% damage of residuals is acceptable. However, the proportion of damage varied from 1.1% to 9.1% with different operators. The risk for damage was highest during the summer. The power needed to loosen root bark of pine and spruce was 40 N/cm^2 in the summer and 60 - 80 N/cm^2 in the autumn [30]. This means that damage risk is highest in the summer.

The damage percentages in this investigation were close to those found in large scale inventories. In Sweden, the average damage percentage using a one-grip harvesters and forwarders was found to be 5.9 [7]. In Finland in inventories between 1993 - 1996 the damage levels have been around 4% [8]. These numbers are low when compared with damage levels found after mechanized harvesting in North-America. Damage proportions greater than 20% after feller-bunchers and skidders have been reported [20, 23]. In thinning of deciduous stands as much as 62% of remaining trees were damaged [17].

Small, superficial damage was typical in the study material. In a large scale inventory, 80% of damage in one-grip harvester operations (forwarding damage included) was found to be smaller than 100 cm^2 [8]. In forwarding there seems to be more deep damage, and damage is also larger in size [7, 26].

The average strip road width, measured with the SLU-method [1], was 4.8 m, the distance between strip roads was 19.8 m and the rut depth 0.6 cm. According to Finnish thinning instructions [19], the distance between strip roads should be at least 20 m. The average strip road width is quite high, but the result also depends on the measuring method. The average number of remaining trees in the study stands was 634 trees/ha, and this results in quite large distances between the trees even outside the strip road zones.

Rut formation by the one-grip harvester was small. Small rut formation by one-grip harvesters, compared with forwarders, has also been reported in Sweden [12, 13]. On a half of the sample plots there was plenty of slash on the strip road. Many studies [2, 5, 18], have demonstrated that branch mats reduce soil damage. If the operator processes trees on the strip road, more branches and tops are available for protecting both soil and roots.

The discounted value of the total losses, 1158 FIM/ha, is acceptable when related to the advantages arising from thinnings. Strip roads make a significant contribution to the amount of costs. A calculation model for damage losses in which the model structure and the results are similar to those presented in this paper has been presented in Sweden [22].

A questionnaire-based study concerning the demands placed on good harvesting machinery was made in Finland [16]. According to the study, forest owners considered that a good silvicultural result is the most important criterion to be placed on harvesting machinery in the future. Good silvicultural thinning results also play an important role in the certification processes of forest companies. Due to the high variation in the harvesting quality, both the continuing supervision of the silvicultural thinning result and the training of machine operators are absolutely necessary. Thinning spruce stands during the sap period should not be allowed due to the high risk of tree damage, and decay following damage. Generally, it is possible to obtain a good silvicultural thinning result with a one-grip harvester operation.

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