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Profitability of pre-clearance in first-thinning Scots pine stands

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Abstract

The impact of undergrowth and its pre-clearance methods on the productivity, costs, and silvicultural result of the winter and summer harvesting of first-thinning Scots pine (*Pinus sylvestris*) stands, and as well as the profitability of pre-clearance were analysed. The density and average height of the Norway spruce (*Picea abies*) undergrowth were found to have a significant impact on cutting productivity. Spruce undergrowth density also affected forwarding productivity. Undergrowth density, height, or pre-clearance method had no effect on the silvicultural result. The density and average height of the spruce undergrowth, the size of the trees to be harvested, the roundwood removal, and the costs for harvesting machinery used affected the calculated pre-clearance limits. The pre-clearance limit refers to the spruce undergrowth level, above which pre-clearance became economically profitable. Based on the findings of this study, when the spruce undergrowth density in a marked pine stand exceeds the pre-clearance limit, the most effective pre-clearance result is achieved when a one-metre radius is cleared around each merchantable stem together with any other spruce undergrowth over 1.5–2.0 m high that may hinder cutting.

Keywords: undergrowth, pre-clearance, profitability, first thinnings, Scots pine, Finland

1. Introduction

According to the National Forest Programme, the estimated need for first thinnings is 250,000 hectares per year in Finland (Anon. 1999). However, during the past five years only 170,000–180,000 hectares per year was carried out (Västilä and Herrala-Ylinen 2001–2005). Moreover, first thinnings are late on a total area of 400,000 hectares (Valkonen 1999). High harvesting costs, particularly cutting costs are the main problems in first-thinning stands. Small stem size, low roundwood removal per hectare, the high number of remaining trees and dense undergrowth mean low productivity and high cutting costs (Kärhä et al. 2004). In 2005, the average harvesting costs in mechanised first thinnings carried out by the forest industries and Metsähallitus were 15.5 €/m³ (cutting 11.0 €/m³; forest haulage 4.5 €/m³) when the average stem size was 86 dm³ and the average roundwood removal 42 m³/ha (Kariniemi 2006). In Finland, first-thinnings yielded 3.6 million m³ in 2005. Two thirds of the first-thinning wood harvested came from Scots pine (*Pinus sylvestris* L.) stands (Kariniemi 2006).

Nevertheless, high cutting costs can be reduced by improving the harvesting conditions, e.g. by means of pre-clearance. There are usually large amounts of non-marketable undergrowth in many early thinning stands. Dense undergrowth restricts the visibility of harvester operator, hinders cutting work, and reduces the productivity of cutting. At the beginning of the 21st century, the current guidelines for undergrowth pre-clearance were made by Metsäteho Oy in Finland (Anon. 2001). When undergrowth is dense and restricts visibility, the directions recommend that a one-metre radius is cleared around each merchantable stem together with any other undergrowth that may hinder visibility (Anon. 2001). It is suggested that good cultivatable undergrowth trees will be left outside clearance. When undergrowth is low, it is recommended that only a one-metre radius is cleared around each merchantable stem (Anon. 2001).

The guidelines present no density or size limits on undergrowth, whenever or whatever clearing method is used (cf. Anon. 2001). Similarly, when pre-clearance is left completely undone. The recommendations of the guide have spread to the field, but still, unfortunately too often all undergrowth trees have been cleared from a stand. On the other

hand, there are plenty of first-thinning sites where no pre-clearance has been carried out, even if there would have been a need for it.

In Finland, unfortunately there is a lack of accurate information about the profitability of pre-clearance in first-thinning stand, e.g.

- what is the effect of undergrowth height on harvesting productivity and costs,
- what is the effect of undergrowth tree species on harvesting productivity and costs,
- when the pre-clearance has to be conducted, and
- what kind of pre-clearance methods have to be used.

Metsäteho Oy analysed the impact of undergrowth and its pre-clearance methods on the productivity, costs, and silvicultural result of the winter and summer harvesting of first-thinning Scots pine stands, as well as the profitability of pre-clearance. The aim was to research when and how pre-clearance has to be conducted in different first-thinning Scots pine stands.

2. Material and methods

The research defined undergrowth as trees under 7.0 cm in breast-height-diameter ($d_{1.3}$), and over 1.1 cm in stump diameter (d_0). Four different pre-clearance methods were tested in the research:

- i) one metre radius cleared around trees of merchantable wood,
- ii) one metre radius cleared around trees of merchantable wood and other undergrowth that hinders cutting cleared, while leaving the cultivatable spruce undergrowth,
- iii) one metre radius cleared around trees of merchantable wood and undergrowth taller than one metre cleared, and
- iv) all undergrowth cleared (total pre-clearance).

In addition, first-thinning wood was harvested from uncleared research plots. There were in all 85 sample plots in the study. The size of the research plots was 20 m \times 50–60 m. The research plots were established in Scots pine dominated first-thinning stands which were 30–50 years old. The research plots were cleared and measured in autumn 2004.

The time studies were carried out on cutting and forest haulage in winter and summer 2005. In all 70 sample plots were included in the harvesting time studies. The silvicultural result was measured after harvesting operations using the inventory method developed by Sirén (1998). The growth and quality losses for remaining merchantable trees in a first-thinning stand were determined by the model of Kovalama (Kokko and Sirén 1996). In total, 678 m³ roundwood (total 5,695 first-thinning trees) was cut. The material of forest haulage was 461 m³. Mainly harvesters for thinnings (weight 13–15 tons) and medium-duty harvesters (15–17 tons) were used in cutting, and medium-duty forwarders (weight 12–15 tons; max. load rating 10–11 tons) in forest haulage.

Harvesting costs were calculated for a harvesting chain including a medium weight harvester (e.g. John Deere 1270D, Ponsse Ergo, Valmet 911.3) (operating hour (E_{15} , including delay times shorter than 15 minutes) cost 78 €/h) and a forwarder (e.g. John Deere 1070D, Ponsse Wisent, Valmet 840.2) (53 €/h). In addition, the cutting costs were calculated for a small harvester (e.g. John Deere 770D, Sampo-Rosenlew 1066) (68 €/h) and for a harvester for thinnings (e.g. John Deere 1070D, Ponsse Beaver, Valmet 901.3) (74 €/h). Additional cubic metre based (€/m³) harvesting costs caused by Norway spruce (*Picea abies* L. Karst.) undergrowth were calculated by comparing harvesting costs with harvesting conditions with no spruce undergrowth. Additional hectare based (€/ha) harvesting costs caused by spruce undergrowth were calculated by multiplying additional cubic metre based costs with cut/hailed wood volume.

In defining the profitability limits of pre-clearance i.e. the pre-clearance limits, the additional hectare based costs caused by spruce undergrowth in cutting and forest haulage were summarized and compared with the pre-clearance costs. Clearance costs were considered as those costs incurred when clearing a one metre radius around merchantable stems and other undergrowth that might hinder cutting (Treatment option 3). Pre-clearance costs were calculated per research plot using Metsäteho's clearance-thinning pricing function. The value of growth and quality losses for remaining trees was not included within the pre-clearance limit calculation because the undergrowth density or size were not connected to growth and quality losses.

3. Results

3.1 Impacts of pre-clearance of undergrowth

When only a one metre radius was cleared around trees of merchantable wood (Treatment method 2), the removal of undergrowth was around half of the initial density (Fig. 1). When using selective pre-clearance methods (clearance of a one metre radius around trees of merchantable wood and other undergrowth that hinders cutting, or clearance of a one metre radius around trees of merchantable wood and undergrowth taller than one metre) (Treatment methods 3 and 4), the undergrowth removal was approximately 80%. The removal of undergrowth was, on average, 97% in total pre-clearance (Treatment method 5).

The clearance method which cleared a one metre radius around trees of merchantable wood and undergrowth taller than one metre (Treatment option 4), affected size distribution the most (Fig. 2). Over half of the undergrowth cleared was 2–4 m high. The average height of standing undergrowth was 2.1 m. When clearing a one metre radius around trees of merchantable wood and other undergrowth that hinders cutting (Treatment option 3), the average height of standing undergrowth was 2.5 m. Uncleared plots, and plots which only had a metre radius cleared around merchantable trees, had an average undergrowth height of 3 m.

The costs were highest in the plots where all undergrowth was cleared – an average of 202 €/ha. The smallest average clearing costs (125 €/ha) were when only a one metre radius was cleared around the merchantable trees. The average clearing costs were higher when removing over one metre tall undergrowth (178 €/ha) than for clearing other undergrowth in addition to the one metre radius (168 €/ha).

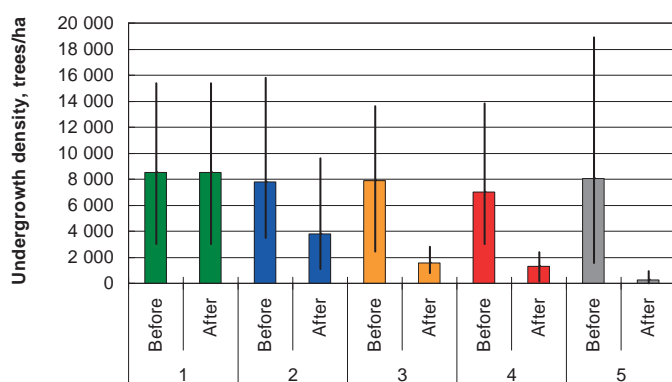


Figure 1. Impact of undergrowth pre-clearance on the density of the undergrowth for each treatment method. The average undergrowth before and after clearance (columns), as well as the variation range of density for each treatment method.

Treatment methods:

- 1 = not cleared
- 2 = one metre radius cleared around trees of merchantable wood
- 3 = one metre radius cleared around trees of merchantable wood and other undergrowth that hinders cutting cleared, while leaving cultivatable spruce undergrowth
- 4 = one metre radius cleared around trees of merchantable wood and undergrowth taller than one metre cleared
- 5 = all undergrowth cleared.

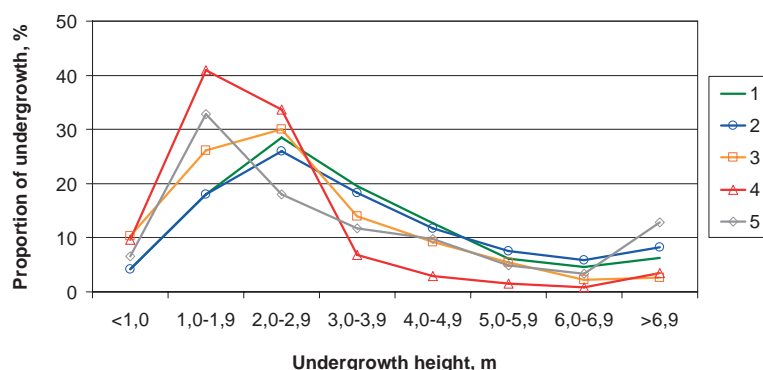


Figure 2. Impact of pre-clearance on the undergrowth height distribution for each treatment method. Undergrowth height distribution after clearance. See treatment methods 1–5 in the Fig. 1.

3.2 Impacts of undergrowth on productivity

The density and average height of the Norway spruce undergrowth were found to have a significant impact on cutting productivity (Figs. 3 and 4). When the density of spruce undergrowth increased, the time consumption increased for moving the harvester head to the butt of removable tree, felling and bringing the stem to the processing point. The time consumption for undergrowth clearance and stacking carried out by the harvester head increased along with the density and average height of the spruce undergrowth. The effect of the average height of spruce undergrowth in cutting productivity was less than with the density of the spruce undergrowth (Figs. 3 and 4).

When the spruce undergrowth density was 2,000 stems per hectare and the average height was 2 m, cutting productivity was 12–14% less than for harvesting conditions where there was no spruce undergrowth. When the density of spruce undergrowth was 10,000 stems per hectare and the average height was 2 m, cutting productivity was 30–34% less. The smaller the merchantable stems harvested, the more cutting productivity decreased along with an increase in spruce undergrowth density and average height (Figs. 3 and 4).

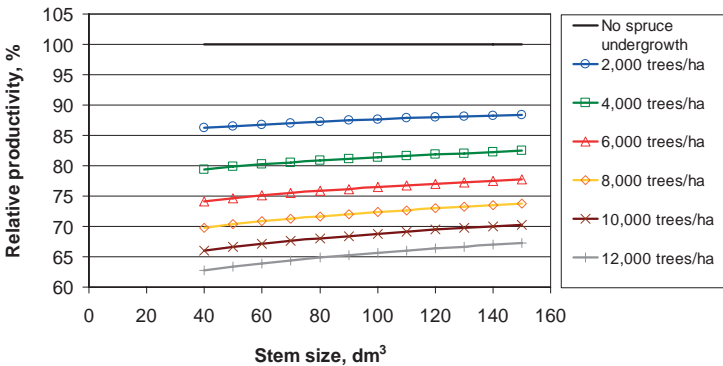


Figure 3. Relative impact of spruce undergrowth density on cutting productivity as a function of stem size harvested in a first-thinning pine stand. The average height of the spruce undergrowth was 2.0 m. The commercial roundwood removal increased from 33 m³/ha (stem size 40 dm³) to 64 m³/ha (150 dm³).

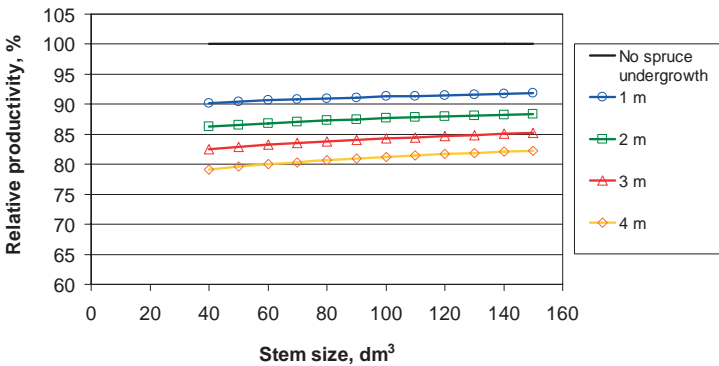


Figure 4. Relative impact of spruce undergrowth height on cutting productivity as a function of stem size harvested in a first-thinning pine stand. Spruce undergrowth density 2,000 trees/ha. The commercial roundwood removal increased from 33 m³/ha (stem size 40 dm³) to 64 m³/ha (150 dm³).

Spruce undergrowth density also affected forwarding productivity. Spruce undergrowth density had a lower impact on productivity in forwarding than in cutting. When the spruce undergrowth was 2,000 stems per hectare, forwarding productivity was only 1–2% less than for harvesting conditions with no spruce undergrowth. When spruce undergrowth density was 10,000 stems per hectare, forwarding productivity was 5–7% less.

The pre-clearance method used affected harvesting productivity through the spruce undergrowth left behind to grow. Broadleaved undergrowth had no significant impact on harvesting productivity either in summer or winter.

3.3 Impacts of undergrowth on silvicultural result

Undergrowth density, height, or pre-clearance method had no significant effect on the silvicultural result. The silvicultural result at the majority of the study sites was good. The average damage percentage (percentage of damaged merchantable trees from the number of remaining merchantable trees) was 4.2%. The average strip road width was 4.4 m.

The current discounted value of growth and quality losses for remaining merchantable trees in the first-thinning stand was an average 77 €/ha. Growth and quality losses in summer (99 €/ha) were clearly higher than for growth and quality losses incurred in winter (63 €/ha). The density or size of undergrowth and the pre-clearance method used had no significant impact on the value of growth and quality losses for remaining trees.

3.4 Profitability of pre-clearance

The density and average height of the spruce undergrowth, the size of the trees to be harvested, the roundwood removed, and the costs for harvesting machinery used affected the calculated pre-clearance limits. The pre-clearance limit refers to the spruce undergrowth level, above which pre-clearance became economically profitable. Pre-clearance was economically profitable when the additional harvesting costs curve exceeded the pre-clearance costs curve.

When the density and average height of the spruce undergrowth or the volume of roundwood removed increased, it was economically profitable to do pre-clearance in first-thinning stands which had a quite low density of spruce undergrowth. Correspondingly, when the size of the trees to be harvested increased, the pre-clearance limits rose. Likewise when using harvesters for thinnings (weight 13–15 tons) or small harvesters (weight under 13 tons) instead of medium-duty harvesters in cutting.

When harvesting of first thinnings was carried out under typical harvesting conditions (average stem size 50–100 dm³; roundwood removal 30–60 m³/ha), the pre-clearance limits ranged from 400 spruce undergrowth trees per hectare to over 10,000 (Table 1). When the roundwood removal was small (20–30 m³/ha) and the clearance was carried out as salary work, pre-clearance was not economically profitable with any spruce undergrowth density with several stem sizes.

Table 1. Pre-clearance limits (number of spruce undergrowth trees per hectare) for first-thinning pine stands, with an average spruce undergrowth height of 1–4 m. Harvesting is carried out using medium-duty forest machines at an operating hour (E_{15}) cost of 78 €/h for the harvester and 53 €/h for the forwarder. Pre-clearance is not economically profitable when the spruce undergrowth density of the marked stand is lower than that presented in the table. Pre-clearance is economically profitable when the spruce undergrowth density is higher than that presented in the table.

	Pre-clearance limit was not determined because roundwood removal from the marked first-thinning stand was either very low (≤ 200 trees/ha) or very high ($\geq 1,500$ trees/ha).
	Pre-clearance was not economically profitable in any harvesting conditions (the additional harvesting costs curve and pre-clearance costs curve did not intersect).

Average spruce undergrowth height 1 m

Stem size, dm ³	Roundwood removal, m ³ /ha								
	20	30	40	50	60	70	80	90	100
40		5,200	2,200	1,400					
50			4,000	2,200	1,600	1,200			
60			8,200	3,400	2,200	1,600	1,200		
70				5,600	3,200	2,200	1,600	1,200	1,000
80				10,800	4,600	2,800	2,200	1,600	1,400
90					7,000	4,000	2,800	2,000	1,600
100					13,000	5,400	3,400	2,600	2,000
110						7,800	4,600	3,200	2,400
120						12,600	6,000	4,000	3,000
130							8,400	5,000	3,600
140							13,200	6,600	4,400

Average spruce undergrowth height 2 m

Stem size, dm ³	Roundwood removal, m ³ /ha									
	20	30	40	50	60	70	80	90	100	
40		1,800	1,000	600						
50		3,600	1,600	1,000	600	600				
60			2,400	1,400	1,000	800	600			
70			4,200	2,000	1,200	1,000	800	600	600	
80			10,000	2,800	1,800	1,200	1,000	800	600	
90				4,400	2,400	1,600	1,200	1,000	800	
100				8,200	3,200	2,000	1,400	1,200	1,000	
110					4,400	2,600	1,800	1,400	1,000	
120					7,200	3,400	2,200	1,600	1,200	
130						4,400	2,800	2,000	1,600	
140						6,400	3,400	2,400	1,800	

Average spruce undergrowth height 3 m

Stem size, dm ³	Roundwood removal, m ³ /ha								
	20	30	40	50	60	70	80	90	100
40	2,800	1,000	600	400					
50		1,600	800	600	400	400			
60		2,600	1,200	800	600	400	400		
70		6,000	1,800	1,000	600	600	400	400	400
80			2,600	1,400	800	600	600	400	400
90			4,200	1,800	1,200	800	600	600	400
100				2,400	1,400	1,000	800	600	600
110				3,600	1,800	1,200	1,000	800	600
120				5,800	2,400	1,600	1,200	800	800
130					3,200	1,800	1,400	1,000	800
140					4,400	2,400	1,600	1,200	1,000

Average spruce undergrowth height 4 m

Stem size, dm ³	Roundwood removal, m ³ /ha								
	20	30	40	50	60	70	80	90	100
40	1,400	600	400	200					
50	3,000	800	600	400	200	200			
60		1,400	800	400	400	200	200		
70		2,200	1,000	600	400	400	200	200	200
80		3,800	1,400	800	600	400	400	200	200
90			1,800	1,000	600	600	400	400	400
100			2,600	1,400	800	600	400	400	400
110			4,400	1,600	1,000	800	600	400	400
120				2,200	1,200	1,000	600	600	400
130				3,000	1,600	1,000	800	600	600
140				4,400	2,000	1,200	1,000	800	600

4. Discussion and conclusions

The results of the research were in line with earlier research results on the pre-clearance of undergrowth (e.g. Lilleberg 1990, 1991, Sirén 1990, Gunnarsson and Hellström 1991, Kuitto et al. 1994, Mäki 2000, Tahvanainen 2001a, 2001b). The research also highlighted the effect of undergrowth height on cutting productivity. The impact of undergrowth on forwarding productivity was also a new finding in this research. The relationship between undergrowth and forwarding productivity has not been previously researched (cf. Gunnarsson and Hellström 1991, Tahvanainen 2001a, 2001b).

Research by Tahvanainen (2001a, 2001b) could not unequivocally state the impact of undergrowth tree species on cutting productivity. This research showed that irrespective of harvesting season (summer/winter), spruce undergrowth has the most significant effect on both cutting and forwarding productivity. The overall density of undergrowth also impacted on cutting and forwarding productivity, but its effect was smaller than that of spruce undergrowth. Broadleaved undergrowth had no significant impact on harvesting productivity either in summer or winter.

In this research, the density and size of the undergrowth or the pre-clearance method used had no effect on the silvicultural result. The silvicultural result in the majority of research sample plots was good: the damage percentage was less than 5% and the strip road width was less than 4.5 m. The main reason that the silvicultural result remained good even in sample plots with very dense undergrowth is most likely due to the operators removing dense undergrowth with the harvester head. Unless the operators did not do so, the number of damaged trees would likely have been greater than it was. The good level of silvicultural result can also be

partly explained by the level of harvester operator experience (7–20 years) in first thinnings of those who participated in the research.

Tahvanainen (2001a) calculated the pre-clearance profitability limits for small harvesters (Nokka Profi and Sampo-Rosenlew 1046X) to be a stem size of 50 dm³ and a roundwood removal of 48 m³/ha. Tahvanainen (2001b) confirmed that pre-clearance in winter was profitable when the density of conifer undergrowth was more than 1,600 trees per hectare. Correspondingly, pre-clearance in summer was profitable when the overall density of undergrowth was more than 6,000 trees per hectare (Tahvanainen 2001a). The results of this study indicated that one or two pre-clearance limits for first-thinning stands cannot be determined when the pre-clearance of undergrowth is economically profitable. The harvesting conditions – the density and average height of the spruce undergrowth, the size of the trees to be harvested, and the roundwood volume removed – and the costs of harvesting machinery used affected the calculated pre-clearance limits in this research.

Based on the findings of this study, when the spruce undergrowth density in the marked pine stand exceeds the pre-clearance limit, the most effective pre-clearance result is achieved when a one-metre radius is cleared around each merchantable stem together with any other spruce undergrowth over 1.5–2.0 m high that may hinder cutting. Pre-clearance work should be carried out ideally a full year in advance of harvesting operations so that the cleared undergrowth stems can settle on the ground. A one-metre radius around each merchantable stem to be cleared should be cut low down, about 10 cm from the stump. Otherwise the stumps can be left longer. Elsewhere it is recommended only to clear the taller (higher than 1.5–2.0 m) spruce undergrowth.

If the spruce undergrowth is predominantly about one metre high, the need to carry out clearance is minimal. The taller the spruce undergrowth, the greater the need to do the clearance. It is important to keep in mind not to pointlessly clear. Part of the spruce undergrowth can be left to fill in patchy or open forest stands. However, it should be remembered that a spruce undergrowth density of 200–500 trees per hectare already weakens cutting productivity so much, that it is worthwhile doing pre-clearance in certain harvesting conditions (cf. Table 1). In addition, it should be noted that undergrowth is also important for forest biodiversity and game habitat.

When the roundwood removal was small (20–30 m³/ha) and the clearance was carried out as salary work, pre-clearance was not economically profitable with any spruce undergrowth density with several stem sizes. In this case, the options from a wood procurement organisation point of view are:

- 1) Leave the stand out of the scope of timber sales,
- 2) Carry out unprofitable pre-clearance and roundwood harvesting,
- 3) Leave pre-clearance undone and carry out roundwood harvesting, and
- 4) Leave pre-clearance undone and carry out energy wood harvesting.

When the roundwood removal is small (about 20 m³/ha), the stand is left out of the scope of timber sales. A second option is to carry out energy wood harvesting. When the roundwood removal is greater, commercial roundwood harvesting with or without pre-clearance become more feasible.

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