Effect of undergrowth on the harvesting of first-thinning wood

Kalle Kärhä


Abstract. The effect of different pre-clearance methods on future harvesting conditions and the clearance costs were studied. In addition, the effect of undergrowth and pre-clearance methods on the work productivity, costs, and silvicultural result of the winter and summer harvesting of first-thinning Scots pine (*Pinus sylvestris*) stands, as well as the profitability of the pre-clearance, were analysed. Four different pre-clearance methods were tested in the study. Even first-thinning wood was harvested on some uncleared research plots.

The density and average height of the Norway spruce (*Picea abies*) undergrowth were found to have a significant effect on the cutting productivity. The density of spruce undergrowth also affected the forwarding productivity. The undergrowth density and 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 of the harvesting machinery used affected the calculated limits for a pre-clearance. The pre-clearance limit refers to the level of spruce undergrowth, above which pre-clearance became economically justified. 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 circular area (1 m radius) is cleared around each merchantable stem, as well as any other spruce undergrowth over 1.5–2.0 m high that may hinder the cutting.

Key words: undergrowth, pre-clearance, wood harvesting, first thinnings, Scots pine, Norway spruce, Finland

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Introduction

According to the National Forest Programme, the estimated need for first thinnings is 250,000 hectares per year in Finland (Anon., 1999). During the 2000’s, however, only 167,000–183,000 hectares were thinned annually (Västilä & Herrala-Ylinen, 2001–2005; Salakari et al., 2006). Moreover, the first thinnings were 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, a high number of remaining trees and dense undergrowth mean low productivity and high cutting costs (e.g. Kärhä et al., 2004). In 2005, the average harvesting costs in mechanised first thinnings carried out by the Finnish forest industries and Metsähallitus were 15.5 €/m³ (cutting 11.0 €/m³ and forest haulage 4.5 €/m³) when the average stem size was 86 dm³ and the average roundwood removal 42 m³/ha (Kariniemi, 2006). These corresponding first thinnings yielded 3.6 million m³

Nevertheless, the high cutting costs can be reduced by improving the harvesting conditions, e.g. by means of pre-clearance. Many early thinning stands usually contain large amounts of non-marketable undergrowth. Dense undergrowth restricts the visibility of the harvester operator, hinders the cutting work, and reduces the productivity of cutting (Anon., 2001). At the beginning of the 21st century, the guidelines for undergrowth pre-clearance in Finland were drawn up by Metsäteho Oy (Anon., 2001). When undergrowth is dense and restricts visibility, the guidelines recommend that a circular area (1 m radius) be cleared around each merchantable stem, as well as any other undergrowth that may hinder visibility (Anon., 2001). It is suggested that undergrowth trees of high quality should not be cleared. When the undergrowth height is low, it is recommended that only a circular area (1 m radius) be cleared around each merchantable stem (Anon., 2001).

The guidelines do not give any density or size limits on the undergrowth in accordance with when or what clearing method is used (cf. Anon., 2001). Similarly, they do not give any instructions about when pre-clearance can be omitted. Although the recommendations of the guidelines have already been adopted in the field, unfortunately all the undergrowth trees have in many cases been cleared from a stand. On the other hand, there are also plenty of first-thinning sites where no pre-clearance has been carried out, even though there would have been a need for it.

In Finland, there is currently a lack of accurate information about the effects of undergrowth on thinning and on the profitability of pre-clearance in first-thinning stands, 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 should the pre-clearance be conducted and,
- what kind of pre-clearance methods should be used.

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

**Material and methods**

**Pre-clearance methods and research plots**

Four different pre-clearance methods were tested in the study:

i) a circular area (1 m radius) cleared around trees of merchantable wood,

ii) a circular area (1 m radius) cleared around trees of merchantable wood, as well as other undergrowth that hinders cutting, but leaving some good quality Norway spruce (*Picea abies* (L.) Karst.) undergrowth,

iii) a circular area (1 m radius) cleared around trees of merchantable wood, as well as undergrowth taller than one metre cleared, and

iv) all undergrowth cleared (total pre-clearance).

In addition, some first-thinning wood was harvested from uncleared research plots for comparison. The research plots were located in separate groups of five sample
plots (cf. the above treatments) within as homogeneous as possible study stands. The location of the sample plots was randomised. A total of 17 five sample plot groups were established, giving a total of 85 sample plots in the study. The size of the research plots was 20 m × 50–60 m. The research plots were established in pine-dominated first-thinning stands which were 30–50 years old. The research stands were located at Janakkala (60°52’N, 24°36’E) in Southern Finland and at Ruokolahti (62°17’N, 28°50’E) in Eastern Finland.

The research plots were cleared and measured in autumn 2004. Three circular sample plots were established on each research sample plot. In the sample plot inventories, the plot undergrowth was determined for each stem in terms of tree species, stump diameter ($d_{1.3}$), height and stem status (cleared/uncleared). The undergrowth was defined as trees under 7.0 cm in DBH ($d_{1.3}$), and over 1.1 cm in stump diameter (cf. Tahvanainen, 2001a; Tahvanainen, 2001b). The trees of merchantable wood were defined as trees of DBH ≥ 7.0 cm.

The sample plots contained an average of ca. 8000 undergrowth stems per hectare before clearance. Undergrowth density varied by sample plot from 1530 to 18 930 undergrowth trees per hectare. The undergrowth on the research sample plots was broadleaf-dominated before clearance, with an average of 61% deciduous stems and range 0–96%. At least one third of the undergrowth was spruce, with a range of 2–100%. On the average 2% of the total undergrowth density was pine. The majority of the undergrowth on the sample plots was 1–4 metres high. The average height of the undergrowth was 2.8 m with a range of 1.4–5.9 m.

**Time study**

Harvesting during winter was carried out in January–March 2005. Time studies on cutting and forest haulage were conducted at 40 sample plots. Cleared undergrowth was well compressed on the ground before the harvesting operations. A total of 3164 trees and 391.7 m$^3$ were cut during the winter. Of the felled timber, 92% was pine, 7% spruce, and 1% broadleaf species. Cutting was conducted according to the thinning guidelines of UPM Forest and Stora Enso Wood Supply Finland. All merchantable tree removals were cut as pulpwood. The recommended bolt length was 5 m, and the shortest allowed length 2.7 m.

Summer harvesting was conducted in June, July and September 2005. A total of 30 sample plots were cut during this season. Forest haulage was carried out on 25 sample plots. Forest haulage could not be carried out on five sample plots due to the poor bearing capacity of the ground. A total of 2531 trees and 286.5 m$^3$ were cut during the study in summer. Of the felled timber, 92% was pine, 7% spruce, and 1% broadleaf species, i.e. the tree species distribution was the same as in winter. A total of 246.7 m$^3$ roundwood was hauled during the summer.

The same person collected all the time-study data using a continuous time-study method (cmin) in which the work cycle was divided into the following time elements:

- **Cutting:** Moving, Boom-out and felling, Transferring stem to processing point, Deliming and cross-cutting, Undergrowth clearance, Miscellaneous times (e.g. planning, moving poles, tops and branches), and Delay (i.e. time not related to productive cutting work).
- **Forest haulage:** Driving empty, Loading, Driving for loading, Driving loaded, Unloading, and Delay (i.e. time not related to productive forwarding work).

The initial stand density of the time-study sample plots varied from 668 merchantable trees ($d_{1.3}$≥ 7.0 cm) to 2 245 merchantable trees per hectare, with an average density
of 1365 trees/ha. An average of 711 trees/ha were cut on the time-study sample plots, with a range of 280–1347 trees/ha. The proportion of thinnings was high, 51% on the average. The majority of the trees harvested in the study had a volume of 30–129 dm$^3$. Substantially larger trees were also cut on the sample plots, which considerably raised the average harvested stem size: the average stem size was 129 dm$^3$. The average merchantable roundwood removal on the sample plots was 86 m$^3$/ha, with a range of 29–162 m$^3$/ha.

Harvesters for thinnings (mass 13–15 t) and medium-duty harvesters (15–17 t) were mainly used in the cutting (Timberjack 1270B, Timberjack 1070, and Ponsse Cobra HS10). Five sample plots were cut with a Farmi Track 775, a light-duty track-based harvester (mass approx. 10 t). In forest haulage, mainly medium-duty forwarders (mass 12–15 t; max. load rating 10–11 t) were used (Lokomo 909, Timberjack 1010B, Timberjack 810C, Valmet 840-6, Timberjack 1410B-6, and Ponsse Caribou S10).

Six different harvester operators and seven different forwarder operators participated in the time studies. One harvester operator participated in the study both in the winter and in the summer. This operator provided time-study material from a total of 30 sample plots. The other operators involved in the time studies only participated either in the winter or in the summer. All of the harvester operators were highly experienced in cutting first thinnings: their experience ranged from 7 to 20 years. The experience in forest machine work of the forwarder operators involved in the study ranged from 2 to 30 years.

**Cost calculation of the harvesting machinery**

Harvesting costs were calculated for a wood harvesting system including a medium-duty harvester (e.g. John Deere 1270D, Ponsse Ergo, Valmet 911) and a medium-duty forwarder (e.g. John Deere 1010D, Ponsse Wisent, Valmet 840). The cost calculations were prepared using the following given values. The purchase price of the medium weight harvester was 317 000 € (VAT 0%) and for the medium weight forwarder 175 000 € (VAT 0%). The depreciation period for the harvester in the cost calculations was 4.6 years, and for the forwarder 5.2 years. An interest rate of 4.2% was applied.

In the calculations, the wood volume to be harvested was estimated to be 35 124 m$^3$/year/harvesting system. The proportion of thinnings was 40%. The productivity per operating (E$_{15}$, including delayed times shorter than 15 minutes) hour of cutting was 9.9 m$^3$/E$_{15}$ (thinnings) and 18.0 m$^3$/E$_{15}$ (clear cuttings) for a medium-duty harvester. In forwarding the corresponding figures were 11.0 and 15.0 m$^3$/E$_{15}$. The transferring (moving) costs of the harvesting system were 8274 €/a in the cost calculations.

The operator’s salary was 10.44 €/h with indirect salary costs (65.2%) added. The fuel consumption of the medium-duty harvester and forwarder was 11.0 l/E$_{15}$. The chain bar costs, chain costs, and chain oil costs were estimated to be 7732 €/a. Repair and service costs were estimated to be 10.33 €/E$_{15}$ for the harvester, and 7.54 €/E$_{15}$ for the forwarder, administration and maintenance costs 10 960 €/year/system, and insurance fees 4082 €/year/system. Based on the given cost values, the operating hour costs for a medium-duty harvester were 78 €/E$_{15}$ and for a medium-duty forwarder 53 €/E$_{15}$.

In addition, the cutting costs were calculated for a small harvester (e.g. John Deere 770D, Sampo-Rosenlew 1066) and for a harvester for thinnings (e.g. John Deere 1070D, Ponsse Beaver, Valmet 901). The purchase price used for a small harvester was 214 000 € (VAT 0%), and for a harvester for thinnings 279 000 € (VAT 0%). The operating hour productivity for thinnings was 7.5 m$^3$/h for a small harvester, and 9.0 m$^3$/h.
for a harvester for thinnings. The productivities used for clear cuttings were 14.0 and 17.0 m$^3$/E$^{15}$. The annual felling volume of a small harvester was 20 300 m$^3$/a, and of a harvester for thinnings 24 400 m$^3$/a. The share of thinnings was 90% for both harvester machines. Fuel consumption was 10.0 (small harvester) and 11.0 l/E$^{15}$ (harvester for thinnings). With the above figures factored in, the calculated operating hour costs for a small harvester were 68 €/E$^{15}$ and for a harvester for thinnings 74 €/E$^{15}$.

**Inventory and consequences of the silvicultural result**

The silvicultural result was measured after the wood harvesting operations using the inventory method developed by Sirén (1998). The remaining stand quantity and the extent, quality and location of tree damage were measured at each zone of the silvicultural result sample plot. The width of the strip road was measured at each silvicultural result sample plot by determining the distance, perpendicular to the centre line of the strip road, from the edge of the nearest tree to the left and to the right of the road and then adding these two distances together (Anon., 2003). All depressions in the strip roads over 10 cm deep from the ground surface were measured at each silvicultural result sample plot.

The growth and quality losses for the remaining merchantable trees in a first-thinning stand were determined by the model of Kovalama (Kokko & Sirén, 1996). The average 2004 stumpage prices by roundwood assortment (Aarne & Ollonqvist, 2005) were used in the growth and quality loss calculation. The growth and quality losses were discounted to the current value using an interest rate of 3%.

**Calculation of pre-clearance limits**

Wood harvesting costs were calculated for a harvesting system comprising a medium-duty harvester (operating hour costs 78 €/h) and a medium-duty forwarder (53 €/h). In addition, cutting costs were calculated for a small harvester (68 €/h) and a harvester for thinnings (74 €/h). Additional cubic metre based (€/m$^3$) wood harvesting costs caused by the presence of spruce undergrowth were calculated by comparing the harvesting costs with those in harvesting conditions with no spruce undergrowth. Additional hectare-based (€/ha) wood harvesting costs caused by spruce undergrowth were calculated by multiplying the additional cubic metre based costs by the cut/hauled wood volume.

When determining 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 circular area (1 m radius) around the merchantable stems, as well as other undergrowth that may hinder cutting (Treatment option 3). Pre-clearance costs were calculated by research plot using Metsäteho’s Clearance-thinning pricing function. The value of growth and quality losses for the remaining trees was not included in the pre-clearance limit calculation because the undergrowth density or size was not connected to the growth and quality losses.

**Data analysis**

The time consumption for each work element was determined and time consumption equations for the individual elements were drawn up (Kärhä et al., 2006). The winter and summer study materials were combined. The effective time consumption (cmin/tree) for cutting was calculated using Equation 1.
\[ y = x_1 + x_2 + x_3 + x_4 + x_5 \]  
where
\[ \begin{align*}
  y &= \text{effective time consumption, cmin/tree} \\
  x_1 &= \text{moving, cmin/tree} \\
  x_2 &= \text{boom-out, tree felling and transferring to processing point, cmin/tree} \\
  x_3 &= \text{delimbing and cross-cutting, cmin/tree} \\
  x_4 &= \text{undergrowth clearance, cmin/tree} \\
  x_5 &= \text{miscellaneous times, cmin/tree}
\end{align*} \]  

The effective time consumption for forest haulage (min/m³) was determined using Equation 2.

\[ y = \frac{(x_1 + x_2 + x_4 + x_5)}{k} + x_3 + x_6 \]  
where
\[ \begin{align*}
  y &= \text{effective time consumption, min/m³} \\
  x_1 &= \text{time consumption when driving with empty load, including preparations, min} \\
  x_2 &= \text{loading time consumption, min} \\
  x_3 &= \text{miscellaneous loading time consumption, min/m³} \\
  x_4 &= \text{driving for loading time consumption, including preparations, min} \\
  x_5 &= \text{driving loaded time consumption, including preparations, min} \\
  x_6 &= \text{unloading time consumption, min/m³} \\
  k &= \text{load size, m³}
\end{align*} \]  

Any load which was not full was excluded when applying the forest haulage time consumption equations. The total forest haulage study material amounted to 460.8 m³. The number of loads included in the calculations was 45. The average load size was 9.8 m³, and the average load size in winter 8.9 m³ and in summer 11.7 m³.

Pearson’s correlation analysis (r) was used to determine the dependences within the material. The differences between different harvesting seasons and treatment methods were analysed using the Mann-Whitney U-test and the Kruskal-Wallis one-way analysis of variance test (χ²). A stepwise regression analysis was used in constructing the clearing cost models and the cutting and forest haulage time consumption equations. The suitability of the regression models was evaluated graphically (regression model residuals, observations vs. model) and numerically (significance (t-values) and degree of determination (R²) of regression model coefficients).

**Results**

**Effects of pre-clearance of undergrowth**

When only a circular area was cleared around trees of merchantable wood (Treatment method 2), the undergrowth removal was about half of the initial density (Figure 1). When using selective pre-clearance methods (clearance of a circular area around trees of merchantable wood as well as other undergrowth that hinders cutting, or clearance of a circular area around trees of merchantable wood as well as undergrowth taller than one metre) (Treatment methods 3 and 4), the undergrowth removal was approximately 80%. The average removal of undergrowth was 97% in total pre-clearance (Treatment method 5).
When only a circular area was systematically cleared from around the merchantable trees, pre-clearance had no effect on the tree species ratio or size distribution of the undergrowth. “Selective” clearance methods, i.e., clearance of other undergrowth which hinders cutting, in addition to the circular area clearing, and clearance of undergrowth over one metre in height in addition to the circular area clearing, significantly affected the proportion of undergrowth tree species: the proportion of spruce undergrowth increased and the proportion of broadleaf tree species decreased.

The clearance method which cleared a circular area around trees of merchantable wood as well as other undergrowth that hinders cutting (Treatment option 3) had the greatest effect on the size distribution of the undergrowth (Figure 2). Over half of the undergrowth cleared was 2–4 m high. The average height of the standing undergrowth was 2.1 m.

When clearing a circular area around trees of merchantable wood as well as undergrowth taller than one metre (Treatment option 4) had the greatest effect on the size distribution of the undergrowth (Figure 2). Over half of the undergrowth cleared was 2–4 m high. The average height of the standing undergrowth was 2.1 m.

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When clearing a circular area around trees of merchantable wood as well as other undergrowth that hinders cutting (Treatment option 3), the average height of the standing undergrowth was 2.5 m. Uncleared plots, and plots which only had a circular area cleared around merchantable trees, had an average undergrowth height of over 3 m.

The costs were highest on the plots where all the undergrowth was cleared – an average of 202 €/ha. The smallest average clearing costs (125 €/ha) occurred when only a circular area was cleared around the merchantable trees. The average clearing costs were higher when removing undergrowth over one metre tall (178 €/ha) than for clearing other undergrowth in addition to the circular area (168 €/ha).
The density and average height of the spruce undergrowth were found to have a significant impact on cutting productivity (Figures 3 and 4). When the density of the spruce undergrowth increased, the time consumption for moving the harvester head to the butt of the removable tree, felling, and transferring the stem to the processing point, increased. The time consumption for undergrowth clearance and compression carried out by the harvester head increased along with increasing density and average height of the spruce undergrowth. The effect of the average height of the spruce undergrowth on the cutting productivity was less than that of the density of the spruce undergrowth (Figures 3 and 4).

When the spruce undergrowth density was 2000 stems per hectare and the average height 2 m, the cutting productivity was 12–14% less than for harvesting conditions where there was no spruce undergrowth. When the density of the spruce undergrowth

Effects of undergrowth on productivity

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

When the spruce undergrowth density was 2000 stems per hectare and the average height 2 m, the cutting productivity was 12–14% less than for harvesting conditions where there was no spruce undergrowth. When the density of the spruce undergrowth
was 10 000 stems per hectare and the average height 2 m, the cutting productivity was 30–34% less. The smaller the merchantable stems harvested, the more the cutting productivity decreased along with an increase in the density and average height of the spruce undergrowth (Figures 3 and 4).

Spruce undergrowth density also affected the forwarding productivity. The denser the spruce undergrowth in the stand, the more time was spent performing miscellaneous loading tasks: attempting to drop undergrowth trees caught in the bunch, or removing undergrowth trees that had entered the load along with the bolt bunch. The spruce undergrowth density had a lower impact on productivity in forest haulage than in cutting. When the spruce undergrowth was 2000 stems per hectare, the forwarding productivity was only 1–2% less than that for harvesting conditions with no spruce undergrowth. The forwarding productivity was 5–7% less when the spruce undergrowth density was 10 000 stems per hectare.

The pre-clearance method affected the harvesting productivity via the spruce undergrowth left to grow. A broadleaved undergrowth had no significant impact on the harvesting productivity in either summer or winter.

**Effects of undergrowth on the 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 out of the number of remaining merchantable trees) was 4.2%. The damage percentage of the winter sample plots (3.7%) was lower than that of the summer sample plots (5.1%). Due to the wide damage percentage range, the difference in damage percentage between winter and summer was not, however, statistically significant (U=370.5; \( p=0.073 \)).

The average strip road width was 4.37 m. Strip roads were wider on the summer sample plots (4.56 m) than on the winter sample plots (4.23 m) (U=389.5; \( p<0.05 \)). There was no significant difference in strip road width between the harvested sample plots cleared using the different treatment methods (\( \chi^2=4.58; p=0.334 \)).
The average current discounted value of growth and quality losses for the remaining merchantable trees in the first-thinning stand was 77 €/ha (Figure 5). Growth and quality losses in the summer (99 €/ha) were significantly higher than those incurred in the winter (63 €/ha) \((U=269.5; p<0.01)\). The density or size of the undergrowth and the pre-clearance method had no significant impact on the value of the growth and quality losses for the remaining trees.

**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 the harvesting machinery affected the calculated pre-clearance limits. The pre-clearance limit refers to the spruce undergrowth level above which pre-clearance became economically justified. Pre-clearance was economically justified when the additional wood 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 justified to perform pre-clearance in first-thinning stands that had a relatively low density of spruce undergrowth. Correspondingly, when the size of the trees to be harvested increased, the pre-clearance limits also increased. This was also the case when using harvesters for thinnings (mass 13–15 t) or small harvesters (mass under 13 t) instead of medium-duty harvesters in cuttings.

When the harvesting of first-thinning wood was carried out under typical harvesting conditions (average stem size 50–100 dm³; roundwood removal 20–60 m³/ha) (cf. Kärhä, 2006), the pre-clearance limits ranged from 200 to over 10 000 spruce undergrowth trees per hectare (Tables 1–4). When the roundwood removal was small (20–30 m³/ha) and the clearance was carried out as paid work, pre-clearance was not at all economically justified for any spruce undergrowth density (Tables 1–4).

**Figure 5.** Effect of undergrowth pre-clearance on the value of growth and quality losses to the remaining merchantable trees for each treatment method in winter and summer. Average growth and quality losses (columns), as well as the variation range of growth and quality losses for each treatment method. See treatment methods 1–5 in Figure 1.
Table 1. Pre-clearance limits (number of Norway spruce undergrowth trees per hectare) for first-thinning Scots pine stands, with an average spruce undergrowth height of 1.0 m. Harvesting is carried out using medium-duty forest machines at an operating ($E_{15}$) hour 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 pine stand was either very low (≤ 200 trees/ha) or very high (≥ 1 500 trees/ha).

Pre-clearance was not economically profitable in any harvesting conditions (the additional wood harvesting costs curve and pre-clearance costs curve did not intersect).

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<thead>
<tr>
<th>Stem size, dm³</th>
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Table 2. Pre-clearance limits for first-thinning Scots pine stands, with an average spruce undergrowth height of 2.0 m. See the interpretation of the table in the Table 1.

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Discussion and conclusions

This study is the most extensive one conducted to date into the effects of undergrowth on harvesting: 70 sample plots were included in the harvesting time studies. 678 m$^3$ of roundwood (5,695 first-thinning trees) were cut. The forest haulage material was 461 m$^3$. The material used in the modelling can also be considered to be extensive compared to earlier time studies on first-thinning wood cutting and forest haulage (e.g. Kuitto et al., 1994; Rajamäki et al., 1996; Ryynänen & Rönkkö, 2001; Tahvanainen, 2001a; Tahvanainen, 2001b; Väkevä et al., 2001; Nurminen et al., 2006).

The growing stock of the sample plots was pine-dominated: more than 90% of the total volume of timber felled was pine. For this reason, the study material can only be primarily used in studies on the harvesting of pine-dominated first-thinning stands. The study succeeded in including a broad range of first-thinning pine stand types in terms of the density, size, structure and tree species of the undergrowth.

Table 3. Pre-clearance limits for first-thinning Scots pine stands, with an average spruce undergrowth height of 3.0 m (see Table 1).

<table>
<thead>
<tr>
<th>Stem size, dm$^3$</th>
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<th>70</th>
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Table 4. Pre-clearance limits for first-thinning Scots pine stands, with an average spruce undergrowth height of 4.0 m (see Table 1).

<table>
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K. Karhä
An average of over 3000 undergrowth stems per hectare remained on the sample plots after pre-clearance, of which 41% was spruce. On most part of the plots, however, the density of the spruce undergrowth remained below 4000 trees/ha. The number of plots with dense (>8000 trees/ha) spruce undergrowth in the studied stands was relatively low. Including more areas with a dense spruce undergrowth would have been beneficial for the purposes of modelling the effects of undergrowth.

A dense spruce undergrowth reduced the productivity of both cutting and forest haulage in the study. Furthermore, cutting productivity was reduced along with increased average height of the spruce undergrowth. The effect of spruce undergrowth on productivity was similar both in the winter and in the summer. For this reason, only one set of cutting and forest haulage time consumption models were calculated for the winter and summer harvesting of first-thinning Scots pine stands.

Comparison with earlier pre-clearance studies is problematic for a number of reasons:
- What size of growing stock in terms of stump diameter or diameter at breast height has been considered as undergrowth?
- What has been the measured height of the undergrowth? What have been the proportions of different tree species?
- How long before harvesting has the pre-clearance been carried out? Have the cleared undergrowth trees had time to become compressed on the ground?
- When have the harvesting operations been carried out? In winter or in summer?
- What kind of harvesting machinery has been used? Small harvesters, harvesters for thinnings, or medium-duty harvesters?
- What working method has the harvester operators involved in the studies used? Clearing of a small amount of undergrowth during cutting work, or cutting without clearance?

The results of the study were in line with earlier results on the pre-clearance of undergrowth (e.g. Lilleberg, 1990; Sirén, 1990; Gunnarsson & Hellström, 1991; Lilleberg, 1991; Kuitto et al., 1994; Mäki, 1999; Tahvanainen, 2001a; Tahvanainen, 2001b). The research highlighted the effect of undergrowth height on cutting productivity. The impact of undergrowth on forwarding productivity was also a new finding in this study. The effect of undergrowth height on wood harvesting productivity, and the relationship between undergrowth and forwarding productivity, have not been studied earlier (cf. Gunnarsson & Hellström, 1991; Tahvanainen, 2001a; Tahvanainen, 2001b).

Research by Tahvanainen (2001a; 2001b) was not unequivocally able to determine the impact of undergrowth tree species on cutting productivity. Our study showed that, irrespective of the harvesting season (summer/winter), spruce undergrowth has the most significant effect on both cutting and forwarding productivity. The overall density of the undergrowth also had an impact on cutting and forwarding productivity, but its effect was smaller than that of spruce undergrowth. Broadleaf undergrowth had no significant impact on the harvesting productivity of pine either in summer or in winter.

In this study, the density and size of the undergrowth or the pre-clearance method used had no effect on the silvicultural result. The silvicultural result on the majority of the 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 why the silvicultural result remained good even on sample plots with a very dense undergrowth was most likely due to the fact that the operators removed dense undergrowth with the harvester
head. If the operators had not done this, the number of damaged trees would probably have been much greater. The good silvicultural result was probably also partly due to the high experience of the harvester operators who participated in the study: they had 7–20 years’ experience in first-thinning work.

In the studies of Tahvanainen (2001a; 2001b), the density of the undergrowth and the clearance method used affected the amount of tree damage in summer especially: the average damage percentage in summer on uncleared sample plots was 9.0%, on partially cleared (a circular area around the merchantable trees) sample plots 5.9%, and on totally cleared sample plots 5.3%. In winter the average damage percentage was 0.4% on totally cleared sample plots and 1.4% on uncleared sample plots.

Total stand pre-clearance, i.e. when virtually all undergrowth trees are cleared from the stand, typically incurs considerable costs: the average cost of total clearance in the study was 202 €/ha. When only a circular area was cleared around the merchantable trees on the research sample plots, the pre-clearance costs were the lowest, on an average 125 €/ha. Clearance around the butt of merchantable trees facilitated the positioning of the harvester head on the butt of the tree during felling. However, on the average half of the undergrowth on the sample plots was left standing. When dense and larger in size, this remaining standing undergrowth obstructs the movement of the harvester head to and from the point of felling, thus requiring undergrowth clearance and compression to be carried out by the harvester head. Stands usually contain some undergrowth trees that are considerably larger in size. These trees should also be removed when clearing around the butts of merchantable trees.

When clearing a circular area (1 m radius) around the butt of merchantable trees and all the undergrowth over one metre in height, the clearance instructions are straightforward: the clearing saw operator does not need to decide which individual undergrowth trees should or should not be removed. Secondly, the advantages of clearance of all undergrowth over one metre in height, in addition to the undergrowth over a circular area, is further supported by the fact that this method clears relatively larger undergrowth than when the method also involves clearance of other undergrowth that obstructs cutting. However, the clearance of all undergrowth over one metre in height in addition to the circular area clearance method can also be viewed as generating unnecessary work, because it includes clearance of tall broadleaf undergrowth which, in this study, was not shown to have a significant effect on harvesting productivity. In both the clearance of other undergrowth that hinders cutting in addition to the circular area clearance method and the clearance of all undergrowth over one metre in height in addition to the circular area clearance method, the proportion of spruce undergrowth increased, i.e. pre-clearance was primarily aimed at broadleaf undergrowth. On the basis of the study results, this is not justified.

Pre-clearance of other undergrowth that obstructs cutting is not necessarily easy, as the degree to which an undergrowth tree obstructs cutting strongly depends on whether or not it is positioned between the harvester and the tree to be felled. An undergrowth tree may also restrict the visibility of the operator when selecting the tree to be removed. If positioned in front of the harvester head, it can obstruct the movement of the head when positioning to cut at the butt of the selected tree, or when moving the felled tree to the processing position. On the other hand, depending on the position of the strip road, the undergrowth tree might remain behind the tree to be felled, thus not interfering with the harvesting.

Important factors related to undergrowth and to its pre-clearance are the harvester operator’s working method and tolerance threshold towards undergrowth that obstructs cutting: some operators clear away even the smallest undergrowth. Other
operators will clear no undergrowth whatsoever with the harvester head, either tolerating the interference caused or not regarding undergrowth as a major hindrance to their cutting work. None of the harvester operators involved in this study cleared all the undergrowth during cutting. On the other hand, it is difficult to say how much unnecessary undergrowth clearance the operators may have carried out. One important observation, however, was that undergrowth clearance still took place even on totally cleared sample plots. This could also be interpreted as a reflection of low tolerance towards obstructive undergrowth among the harvester operators who participated in the study.

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 circular area (1 m radius) is cleared around each merchantable stem, as well as any other spruce undergrowth over 1.5–2.0 m high that may hinder cutting. Pre-clearance work should ideally be carried out one full year in advance of wood harvesting operations so that the cleared undergrowth stems become compressed on the ground. The undergrowth in the circular area around each merchantable stem should be cut as low as possible to leave a ca. 10 cm stump. In other parts of the stand it is recommended that only the taller (higher than 1.5–2.0 m) spruce undergrowth is cleared, and their stumps can be higher.

If the spruce undergrowth is predominantly about one metre tall, there is only minimal need to carry out clearance. The taller the spruce undergrowth, the greater the need to perform clearance. On the other hand, unnecessarily pre-clearance should be avoided as much as possible: part of the spruce undergrowth can be left to eventually fill in patchy or open stands. However, it should be remembered that, because a spruce undergrowth density of 200–500 trees per hectare already strongly reduces the cutting productivity, it is worthwhile carrying out pre-clearance in certain harvesting conditions (cf. Tables 3 and 4). In addition, it should be noted that undergrowth is also important for forest biodiversity and as a game habitat.

Tahvanainen (2001b) calculated that pre-clearance in winter is profitable when the density of the conifer undergrowth is more than 1600 trees per hectare. Correspondingly, pre-clearance in summer was profitable when the overall density of the undergrowth was more than 6000 trees per hectare (Tahvanainen, 2001a). The results of our study indicated that only two pre-clearance limits for first-thinning stands cannot be determined when the pre-clearance of undergrowth is economically justified. The harvesting conditions (i.e. 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 the harvesting machinery used affected the calculated pre-clearance limits in this study.

When the roundwood removal was small (20–30 m³/ha) and the clearance was carried out as paid work, pre-clearance was not economically justified for any spruce undergrowth density with several stem sizes. In this case, the options from a wood procurement organisation point of view are:
1) Exclude the stand from the scope of timber sales,
2) Carry out unprofitable pre-clearance and roundwood harvesting,
3) Leave the pre-clearance undone and carry out roundwood harvesting and,
4) Leave the pre-clearance undone and carry out energy wood harvesting.

When the roundwood removal is small (about 20 m³/ha), the stand is excluded from 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.
Undergrowth pre-clearance was approached in the study only from the point of view of the productivities and costs calculated in the study. Pre-clearance of dense undergrowth can also be viewed as offering other advantages, such as improved forest work satisfaction and safety for the machine operator. No attempt was made in this study to determine these benefits, which are relatively difficult to evaluate.

The definition of pre-clearance limits pre-supposes that clearance work is conducted as paid work by professional forest workers. If the forest owner has the means to do so, independent pre-clearance by the owner himself is a profitable undertaking, because this considerably improves the possibilities of selling the stand compared to the situation for a first-thinning stand containing substantial undergrowth.

Acknowledgements. I wish to extend my thanks to the personnel of Stora Enso Wood Supply Finland, Tornator Oy, and UPM Forest for their assistance in selecting the research stands and organizing the harvesting operations, to Reima Liikkanen and Teemu Kallio for collecting the time-study material, to Sirkka Keskinen and Jarmo Lindroos for assisting in the data analyses, and to John Derome for revising the English language.

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