

Analyzing the Views of Wood Harvesting Professionals Related to the Approaches for Increasing the Cost-Efficiency of Wood Harvesting from Young Stands

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A lot of viable guidelines are currently available for more cost-effective harvesting of energy wood and industrial roundwood (i.e. pulpwood) from young stands. The study ranked the proposed potential approaches for increasing the cost-efficiency of small-diameter ($d_{1,3} < 10$ cm) energy wood and industrial roundwood harvesting from early thinnings. Research data, based on a total of 40 personal interviews, was collected in early 2008. The interviewees were divided into four wood harvesting professional groups: 1) Managers in wood procurement organizations, 2) Forest machine contractors, 3) Forest machine manufacturers and vendors, and 4) Wood harvesting researchers.

In the opinion of the respondents, there is great potential to increase the cost-efficiency of wood harvesting through improving harvesting conditions (i.e. effective tending of seedling stands, delaying harvesting operations, and pre-clearance of dense undergrowth). The interviewees also underlined that harvesting methods can be rationalized, e.g. multiple-tree handling in industrial roundwood cuttings, crane scale measurement, integrated wood harvesting, and careful selection of stands for harvesting. The strong message given by the interviewees was that the education of forest machine operators must be made more effective in the future. There would be significant possibilities for cost savings in young stands, if methods and techniques with the most potential were utilized completely in wood harvesting.

Keywords early thinnings, cost-efficiency, energy wood, industrial roundwood, costs, gap analysis, opinion survey.

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1 Introduction

In Finland, forest management and wood production are based on thinnings. There are usually two or three industrial roundwood thinnings before a final cutting. According to the National Forest Programme, the estimated annual need for first thinnings is 250 000 hectares (Finland's National... 1999). Based on the latest forest inventory calculations the target for first thinnings should be around 300 000 hectares per year during the next ten years (Korhonen et al. 2007). During the 2000's, however, only 167 000–206 000 hectares were thinned annually (Juntunen and Herjala-Ylinen 2007, 2008).

In 2008, 4.0 mill. m³ (8.0 TWh) of commercial forest chips were used for energy generation in Finland (Ylitalo 2009). Less than one quarter (1.9 TWh) of the total amount of forest chips were produced from small-diameter ($d_{1.3} < 10$ cm) trees in young stands (Ylitalo 2009).

In this study, young stands and early thinnings were determined as stands:

- from which wood harvested is only energy wood and/or pulpwood, and
- where the mean diameter at breast height is less than 16 cm, but more than 7 cm, and
- where the height of dominant trees is more than 7 m in Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst.) dominated stands, and more than 9 m in broadleaf stands (see Paananen et al. 2000).

Around two thirds of the wood harvested from first thinnings comes from Scots pine-dominated stands in Finland (Kärhä 2007a). During the 2000's, the average stem size has been 81 dm³, the average industrial roundwood removal 44 m³ ha⁻¹, and the forest haulage distance 291 m (Kärhä 2007a). In 2008, the average harvesting (cutting and forest haulage) costs of pulpwood in mechanized first thinnings carried out by the Finnish forest industries and Metsähallitus were 16.5 € m⁻³ (Kariniemi 2009). When producing whole-tree chips from young stands for energy generation, the total supply chain costs are approximately 18–24 € MWh⁻¹ of which the harvesting costs are around 40–50% (cf. Petty

and Kärhä 2008). In the beginning of 2009, the mean price of forest chips at the gate of energy plant was around 18 € MWh⁻¹ (Polttoaineiden hintataso... 2009).

Several national production targets have been set to increase the annual use of forest chips by 5 million m³ (10 TWh) year⁻¹ by 2010, by 8–12 mill. m³ (16–24 TWh) year⁻¹ by 2015, and by 12 mill. m³ (24 TWh) year⁻¹ by 2020 (Finland's National... 1999, Uusiutuvan energian... 2003, Finland's National... 2008, Long-term climate... 2008). These targets project that the harvesting of small-sized thinning wood will be tripled or even quadrupled, over the current harvesting volume. In order to increase the harvesting volumes of energy wood and pulpwood in young stands, the harvesting costs will have to be reduced significantly.

Several research papers have discussed the problems of harvesting small-diameter wood in early thinnings. Studies carried out by Metsäteho Oy (Kärhä 2007b) and the University of Joensuu (Oikari 2007) reviewed these papers and listed the different potential approaches for reducing the harvesting costs in young stands. The potential approaches were classified into four categories (Table 1).

It seems that a lot of viable guidelines are currently available for more cost-effective harvesting of pulpwood and energy wood from young stands. Many of the most profitable guidelines have, however, not been utilized properly in Finland, and a similar situation is probably evident in other countries as well. The adoption of suitable guidelines needs to be promoted. Kärhä (2007b) and Oikari (2007) stated that if the methods and techniques with greatest potential were utilized fully in wood harvesting, there would be significant possibilities for cost savings in young stands. Cost savings of at least 5–10% can be achieved and, in some cases even 30–40%, compared to current wood harvesting costs in early thinning (Kärhä 2007b, Oikari 2007).

Suitable guidelines can be promoted by conducting expert sampling during an opinion survey to elicit the views of professionals concerning wood harvesting approaches. The method is most effective when a researcher needs to study a certain field with knowledgeable experts within (Allen 1971, McDonald et al. 2003, Neuman

Table 1. Classification of potential approaches for more cost-efficient energy wood and pulpwood harvesting from young stands (cf. Kärhä 2007b, Oikari 2007). Some selected studies of the different potential approaches are listed in parentheses.

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- 1) Improving harvesting conditions:
 - Effective tending of seedling stands (Ylimartimo et al. 2001, Huuskonen and Hynynen 2006)
 - Delaying harvesting operations (Huuskonen 2008)
 - Pre-clearance of spruce undergrowth (Tahvanainen 2001, Kärhä 2006a)
 - New wood production methods:
 - Intensive first thinning (Kärhä 2006b)
 - Energy wood harvesting as a part of wood production chain (Sirén et al. 2006)
 - Creating clusters of stands (Tanttu et al. 2002)
 - Larger stand reserve volume (Jylhä et al. 2006).
 - 2) Rationalization of harvesting methods:
 - Multiple-tree processing (Lilleberg 1994, Bergkvist 2003, Gingras 2004)
 - Crane scale measuring (Hämäläinen et al. 2006, Kärhä 2007c)
 - Harvesting as whole trees (Heikkilä et al. 2005)
 - Careful selection of harvested trees and stands (Kärhä 2006c)
 - Fewer timber assortments (Brunberg and Arlinger 2001, Nurminen et al. 2006)
 - Integration of pulpwood and energy wood harvesting:
 - Whole-tree bundling (Jylhä et al. 2007, Kärhä et al. 2007)
 - Two-pile cutting method (Tanttu and Mutikainen 2004, Kärhä 2008).
 - 3) Better utilization of harvesting machinery:
 - Harwarders (Lilleberg 1997, Rieppo and Pekkola 2001, Bergkvist et al. 2003)
 - Machines requiring lower investments:
 - Small harvesters (Kärhä et al. 2001, 2004, Sirén and Aaltio 2003)
 - Tracked excavator-based harvesters (Väätäinen et al. 2004, Bergroth et al. 2007)
 - Maximization of load size and enlarging of load space (Korpilahti 1997, Kärhä 2006c)
 - More working hours for harvesting machinery (Kärhä 2007b, Väätäinen et al. 2008)
 - Larger harvesting companies and networks (Palander et al. 2008).
 - 4) Development of harvesting machinery and working methods:
 - Advanced automation and developing machinery (Löfgren and Wästerlund 2004, Löfgren 2005)
 - Improvement of the cutting work process (Ovaskainen et al. 2004)
 - Training of harvester operators (Freedman 1998, Yates 2000, Ovaskainen 2005)
 - More efficient use of operators (Kariniemi 2006).
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2003). The expert sampling is suitable for this study, as the field of harvesting of pulpwood and energy wood from young stands is limited to a number of professionals in Finland.

The objective of this study was to rank the proposed approaches for increasing the cost-efficiency of small-diameter energy wood and industrial roundwood (i.e. pulpwood) harvesting from early thinnings. This was done by interviewing wood harvesting professionals and analyzing their answers related to the approaches. Most potential approaches are going to conclude to promote wood harvesting guidelines in young stands.

2 Material and Methods

2.1 Sample and Questionnaire

The population consisted of Finnish wood harvesting professionals for pulpwood and energy wood harvesting from young stands. The total amount of the population was 237 people. The population was divided into four wood harvesting professional groups: Managers in wood procurement organizations (58), Forest machine contractors (124), Forest machine manufacturers and vendors (34), and Wood harvesting researchers (21).

The representatives in roundwood and energy wood procurement organizations were persons who were managers and directors in their companies working with management, planning, and R&D issues. Forest machines contractors were entrepreneurs who harvested wood mainly from early thinnings. The representatives in forest machine manufacturers and vendors were those who worked in sales and development duties on their company. The researchers were research scientists who had conducted several wood harvesting studies in young stands.

Purposive sampling was used in this study. Further, additional deviant cases that substantially differ from the dominant pattern of population were selected using non-proportional quota sampling (a special type of purposive sample), which is a bit less restrictive. In this method, the minimum number of sampled units was specified for each group. We were not concerned with having numbers that match the proportions in the population. Instead, we simply wanted to have enough cases (10 cases) to assure that we will be able to discuss small groups in the population. This method is a type of non-probability sampling in that it is typically used to assure that smaller groups are adequately represented in the sample. This kind of case selection is highly relevant for energy wood harvesting research, as they are constantly looked upon for knowledge and information.

Neuman (2003) describes purposive sampling as being acceptable when a researcher wants to identify particular types of experts for an in-depth investigation. In this method the researcher chooses the sample based on who they think would be appropriate for the study. This is used primarily when there is a limited number of individuals that have expertise in the area being researched. According to Neuman (2003), purposive sampling can also be used with both qualitative and quantitative research techniques, and the method stays robust even when tested against random probability sampling.

The sample can also be taken from knowledge from previous studies (McDonald et al. 2003). The process of deciding how to choose experts for the study is described by Allen (1971). According to Allen, it is especially important to be clear on expert qualifications when using purposive sam-

pling. Therefore, we set criteria on what would make a good expert. Based on the criteria, a list of qualifications was composed. This was also one way of ensuring reproducibility, because it was a systematic way of choosing the experts and to describe the selection method in detail. The idea was that researchers who conduct the same study could be able to produce similar results.

This study was implemented by conducting the expert sampling during an opinion survey to elicit the views of professionals. Interviewees were persons with known or demonstrable experience and expertise in cost-efficient harvesting of energy wood thinnings and first thinnings. Research data, based on a total of 40 interviews, was collected during January and February, 2008.

Before the interviews, the questionnaire was tested in four real interviews. The feedback resulted in useful amendments to the question form. The questionnaire had three parts: In the first part, the study groups' background information was determined using relevant questions. In the second part, the interviewees were asked to evaluate the importance of a number of factors related to problems in energy wood and industrial roundwood harvesting in early thinnings. The five-step Likert scale was used 1 = "No meaningful problem", 2 = "Of little meaningful problem", 3 = "Moderately meaningful problem", 4 = "Meaningful problem" and 5 = "Very meaningful problem".

In the third part of the questionnaire, the significance of different potential approaches for more cost-efficient harvesting of energy wood thinnings and first thinnings was investigated, and the interviewees evaluated how comprehensively each approach is currently used in harvesting operations in Finland. The questionnaire covered a total of 32 different approaches in energy wood harvesting and 29 in industrial roundwood harvesting (Appendices 1 and 2). The interviewees also had the option to give their own approaches, in addition to those on the lists. The interviewees answered using the five-step Likert scale as follows for significance: 1 = "No significant approach", 2 = "Of little significant approach", 3 = "Moderately significant approach", 4 = "Significant approach" and 5 = "Very significant approach" and for current utilization degree of the approach: 1 = "Very poor utilization", 2 =

"Poor utilization", 3 = "Satisfactory utilization", 4 = "Good utilization" and 5 = "Excellent utilization".

2.2 Data Analysis

This study applied gap analysis methodology for determining the potential of each approach to increase the cost-efficiency of wood harvesting in young stands. Using results of gap analysis most potential approaches were concluded for suitable wood harvesting guidelines in young stands. The potential of the approach was achieved by subtracting the current utilization score of the approach from the significance score of the approach (Eq. 1).

$$P_i = S_i - U_i \quad (1)$$

where

P_i = potential of the approach i to increase the cost-efficiency of wood harvesting

S_i = significance of the approach i for more cost-efficient wood harvesting, 1, ..., 5

U_i = degree of utilization of the approach i in current wood harvesting, 1, ..., 5.

The data was analyzed using SPSS-X (SAS Institute, Cary, NC, USA) (SPSS Inc... 1988). Several wood harvesting professional groups were considered using nonparametric analysis of variance (the Kruskal-Wallis test). Professional groups, two at a time, were compared using the Mann-Whitney U-test. These tests were used to determine whether two independent samples (groups) came from the same population and that the variable values (answers) did not show a normal distribution. The former test revealed whether the groups being tested were different, after which we localized significant differences using the Mann-Whitney U-test in paired comparisons. The interactions between variables were also studied by the Chi-square goodness of fit test (ordinal data). The Chi-square test (contingency table) was further applied to binary (nominal) data, i.e., to data that were put into classes. The conclusions drawn from these tests were considered significant at $p = 0.05$.

3 Results

3.1 Problems in Wood Harvesting

The ten most important problems are reported in the Tables 2 and 3. The interviewees highlighted that currently the primary problem is poor harvesting conditions in the industrial roundwood harvesting of early thinnings. On the harvesting conditions, the respondents emphasized that the small stem size of the removal, low roundwood removal per hectare and stand, dense undergrowth, and poor carrying capacity of the terrain were the most critical factors in young stands (Table 2). Professionals answered quite homogeneously. Only forest machine contractors' opinions on "Dense undergrowth" or "Ineffective tending of seedling stand" significantly differed statistically from the other groups.

On the other hand, the interviewees expressed that the primary problems when harvesting energy wood from young stands is the lack of professional forest machine operators, low cutting productivity, and the small stem size of the removal (Table 3). The managers in wood procurement organizations pointed out significantly that the shortage of professional forest machine operators was a very serious problem in both industrial roundwood and energy wood harvesting in early thinnings (Tables 2 and 3).

The respondents disclosed that poor harvesting conditions are also a very significant problem in the energy wood cutting of young stands. For the harvesting conditions the respondents emphasized the small stem size of the removal, low energy wood removal per hectare and stand, dense undergrowth, and poor carrying capacity of the terrain. The forest machine contractors underlined that dense undergrowth is the biggest problem in the pulpwood and energy wood harvesting of early thinnings (Tables 2 and 3). Their opinions differed statistically significantly from the other groups. There was also more variation between professionals' answers for energy wood harvesting problems, because opinions differed more often statistically significantly in energy wood harvesting than in industrial roundwood harvesting.

Table 2. The most serious problems currently experienced in industrial roundwood harvesting in young stands according to each interviewee group and the average for all groups. Scale: 1 = "No meaningful problem" ... 5 = "Very meaningful problem". Some answers showed a statistically significant difference between interviewee groups based on paired comparisons in the Mann-Whitney U-test.

Problem	Interviewee group				Average	Stat. significant differences between groups A...D
	Managers in wood procurement organizations	Forest machine contractors	Forest machine manufacturers	Wood harvesting researchers		
	A	B	C	D		
	Significance of problem, 1 ... 5					
Small size of removed trees	4.2	4.3	4.4	4.4	4.3	
Low roundwood removal per hectare	4.1	4.5	4.3	4.3	4.3	
Lack of professional machine operators	4.7	4.2	3.7	4.4	4.3	A-C*
Low cutting productivity	4.3	4.5	3.8	4.3	4.2	
Dense undergrowth	3.9	4.7	4.0	3.6	4.1	B-C*, B-D**
Ineffective tending of seedling stand	3.8	4.5	3.7	3.8	4.0	A-B*, B-D**
High wood harvesting costs	4.1	4.0	3.4	4.3	4.0	C-D*
Low roundwood removal per stand	3.5	4.0	4.4	3.7	3.9	
Lack of machine operators	4.2	3.8	3.6	4.0	3.9	
Poor carrying capacity of the terrain	3.6	3.7	3.5	3.6	3.6	

* p<0.05; ** p<0.01; *** p<0.001

Table 3. The most serious problems currently experienced in energy wood harvesting from early thinnings according to each interviewee group and the average for all groups. Scale: 1 = "No meaningful problem" ... 5 = "Very meaningful problem". Some answers showed a statistically significant difference between interviewee groups based on paired comparisons in the Mann-Whitney U-test.

Problem	Interviewee group				Average	Stat. significant differences between groups A...D
	Managers in wood procurement organizations	Forest machine contractors	Forest machine manufacturers	Wood harvesting researchers		
	A	B	C	D		
	Significance of problem, 1 ... 5					
Lack of professional machine operators	4.7	4.2	4.0	4.4	4.3	A-C*
Low cutting productivity	4.5	4.4	3.8	4.6	4.3	C-D*
Small size of removed trees	4.6	4.4	4.0	4.2	4.3	
Lack of machine operators	4.4	4.1	4.0	4.0	4.1	
High harvesting costs of energy wood	4.6	4.2	3.2	4.4	4.1	A-C*, C-D*
Low energy wood removal per hectare	3.6	4.3	4.1	4.0	4.0	
Low energy wood removal per stand	3.3	4.3	3.6	3.6	3.7	A-B*
Poor carrying capacity of the terrain	4.1	4.0	3.1	3.3	3.6	A-C*, A-D*, B-C*
Uncertainty of Kemera support levels	3.9	4.0	3.2	3.2	3.6	
Dense undergrowth	3.2	4.7	3.5	2.9	3.6	A-B**, B-C**, B-D**

* p<0.05; ** p<0.01; *** p<0.001

Table 4. The most significant approaches to achieve more cost-efficient industrial roundwood harvesting in young stands according to each interviewee group and the average for all groups. Scale: 1 = "No significant approach" ... 5 = "Very significant approach". Some answers showed a statistically significant difference between interviewee groups based on paired comparisons in the Mann-Whitney U-test.

Approach	Interviewee group				Average	Stat. significant differences between groups A...D
	Managers in wood procurement organizations A	Forest machine contractors B	Forest machine manufacturers C	Wood harvesting researchers D		
Pre-clearance of dense undergrowth	4.6	4.8	4.3	4.5	4.6	B-D*
Effective tending of seedling stand	4.7	4.8	4.3	4.0	4.5	
Improving the training of new operators	4.4	4.5	3.9	3.8	4.2	
More working hours for harvesting machinery	4.2	4.4	3.7	4.0	4.1	
Careful selection of operator candidates	4.2	4.9	3.9	3.3	4.1	A-B**, A-D*, B-C*, B-D**
Developing cutting techniques and working methods	3.7	4.1	4.1	3.9	4.0	
Development of machine technology	4.0	4.1	3.7	4.0	4.0	
Careful selection of stands for harvesting	4.2	4.3	3.5	3.7	3.9	
Broadening the practical training	4.2	3.9	3.8	3.7	3.9	
Multiple-tree handling	3.5	3.9	3.4	4.6	3.9	A-D*, C-D*

* p<0.05; ** p<0.01; *** p<0.001

3.2 Approaches for More Cost-Efficient Wood Harvesting

In industrial roundwood harvesting, the respondents considered that the most significant approach to achieve more cost-efficient wood harvesting is comprehensive pre-clearance of dense undergrowth (Table 4). Particularly, the forest machine contractors highlighted the significance of pre-clearance. In the opinion of the interviewees, the second most important approach was effective tending of seedling stands, and the third was improving the training of new forest machine operators.

Other meaningful approaches were more working hours for harvesting machines, careful selection of operator candidates, developing cutting techniques and working methods, development of machine technology, careful selection of stands for harvesting, broadening the practical training, and multiple-tree processing.

The wood harvesting researchers considered multiple-tree handling as the most important approach for more cost-efficient roundwood cuttings in early thinnings (Table 4). Forest machine

contractors' opinions on "Careful selection of operator candidates" differed statistically significantly from the other groups.

The interviewees estimated quite homogeneously that the most important approach for more cost-efficient energy wood harvesting from young stands is to boost the training of new forest machine operators (Table 5). The second was careful selection of harvested stands.

The managers in wood procurement organizations stressed that the most important approach for more cost-efficient energy wood harvesting is crane scale measuring (Table 5). Correspondingly, the forest machine contractors considered that the most significant approach is careful selection of forest machine operator candidates. The forest machine manufacturers stressed the importance of developing cutting techniques and working methods, and researchers, more working hours for harvesting machinery (Table 5).

Table 5. The most significant approaches for achieving more cost-efficient energy wood harvesting from early thinnings according to each interviewee group and the average for all groups. Scale: 1 = "No significant approach" ... 5 = "Very significant approach". Some answers showed a statistically significant difference between interviewee groups based on paired comparisons in the Mann-Whitney U-test.

Approach	Interviewee group				Average	Stat. significant differences between groups A...D
	Managers in wood procurement organizations A	Forest machine contractors B	Forest machine manufacturers C	Wood harvesting researchers D		
Improving the training of new operators	4.4	4.5	4.0	4.0	4.2	
Careful selection of stands for harvesting	4.3	4.4	3.8	4.1	4.2	
Careful selection of operator candidates	4.3	4.9	4.0	3.4	4.2	A–B*, B–C*, B–D**
Developing cutting techniques and working methods	4.1	4.2	4.2	4.1	4.2	
Crane scale measuring	4.6	4.4	3.4	4.1	4.1	
More working hours for harvesting machinery	4.0	4.4	3.9	4.2	4.1	
Harvesting energy wood as whole trees	4.4	4.3	3.6	4.1	4.1	
Development of machine technology	4.2	4.1	3.7	3.9	4.0	
Maximization of load size	3.9	4.3	3.6	3.8	3.9	
Broadening the practical training	4.2	4.1	3.7	3.6	3.9	

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

3.3 Potentials of the Approaches for Better Cost-Efficiency

Gap analysis was used to reveal where interviewees' satisfaction is most falling short of requirements (Eq. 1). The greatest potential for improving the cost-efficiency of industrial roundwood harvesting was careful selection of forest machine operator candidates (Table 6). Pre-clearance of undergrowth and the effective tending of seedling stand had the second and third largest potentials for boosting the cost-efficiency of roundwood harvesting.

In addition, multiple-tree handling and broadening the practical training had considerable potential. The following approaches also had great potential for increasing the cost-efficiency of wood harvesting: delaying first-thinning operations in a controlled manner, improving the training of new operators, crane scale measuring, and integrated energy wood and pulpwood harvesting using the two-pile cutting method and bundling (Table 6).

The greatest potential to improve the cost-efficiency of energy wood harvesting from young stands in Finland was the implementation of energy wood harvesting as a part of the wood production chain (Table 7). There was also considerable future potential in the careful selection of operator candidates for forest machines and in crane scale measuring.

Other approaches with high potential for achieving higher cost-efficiency in wood harvesting at the energy wood harvesting sites included delaying harvesting operations in a controlled manner, boosting the training of new machine operators, pre-clearance of dense undergrowth, broadening the practical training, integrated energy wood and pulpwood harvesting with bundling, utilization of increasingly simplified harvesting machinery, and developing cutting techniques and working methods (Table 7). There were more often statistically significant differences in the potential approaches between professionals in energy wood harvesting than in industrial roundwood harvesting.

Table 6. Approaches with the greatest potential to improve the cost-efficiency of industrial roundwood harvesting in young stands. The potential of each approach to increase the cost-efficiency of wood harvesting in young stands was calculated by subtracting the current utilization score of the approach from the significance score of the approach. Scale: 0 = "No potential" ... 4 = "Huge potential". Some answers showed a statistically significant difference between interviewee groups based on paired comparisons in the Mann-Whitney U-test.

Approach	Interviewee group				Average	Stat. significant differences between groups A...D
	Managers in wood procurement organizations	Forest machine contractors	Forest machine manufacturers	Wood harvesting researchers		
	A	B	C	D		
Significance of approach, 0 ... 4						
Careful selection of operator candidates	2.5	3.3	1.8	0.7	2.1	A-D*, B-C*, B-D**
Pre-clearance of dense undergrowth	1.7	2.7	1.9	1.9	2.1	
Effective tending of seedling stand	2.0	2.4	1.9	1.5	2.0	
Multiple-tree handling	1.9	1.8	1.4	2.7	2.0	C-D*
Broadening the practical training	1.9	1.7	1.7	1.5	1.7	
Delaying first thinning in a controlled manner	1.2	1.8	1.5	1.5	1.5	
Improving the training of new operators	1.8	1.7	1.3	1.2	1.5	
Crane scale measuring	1.9	2.1	1.0	0.6	1.4	
Integrated harvesting with the two-pile cutting meth.	1.5	1.0	1.3	1.5	1.3	
Integrated harvesting with bundling	2.1	0.7	0.9	1.6	1.3	A-B*, B-D*

* p<0.05; ** p<0.01; *** p<0.001

Table 7. Approaches with the greatest potential for improving the cost-efficiency of energy wood harvesting from early thinnings. Scale: 0 = "No potential" ... 4 = "Huge potential". Some answers showed a statistically significant difference between interviewee groups based on paired comparisons in the Mann-Whitney U-test.

Approach	Interviewee group				Average	Stat. significant differences between groups A...D
	Managers in wood procurement organizations	Forest machine contractors	Forest machine manufacturers	Wood harvesting researchers		
	A	B	C	D		
Significance of approach, 0 ... 4						
Energy wood harvesting as a part of the wood production chain	2.5	2.0	2.3	1.5	2.1	
Careful selection of operator candidates	2.3	3.2	1.6	1.0	2.0	B-C**, B-D**
Crane scale measuring	2.8	1.6	1.5	1.8	1.9	A-B**, A-C*, A-D*
Delaying harvesting operation in a controlled manner	1.4	2.0	1.7	1.8	1.7	
Improving the training of new operators	2.1	1.4	1.2	1.9	1.7	A-C*, C-D*
Pre-clearance of dense undergrowth	1.2	2.5	1.7	0.7	1.5	B-D*
Broadening the practical training	1.9	1.7	1.3	1.0	1.5	
Integrated wood harvesting with bundling	2.2	0.7	1.0	2.0	1.5	A-B*, A-C*, B-D**, C-D*
Utilization of more simple harvesting machinery	1.6	1.8	1.8	0.6	1.5	
Developing cutting techniques and working methods	1.5	1.4	1.5	1.4	1.5	

* p<0.05; ** p<0.01; *** p<0.001

4 Discussion and Conclusions

In purposive sampling it is important to lessen bias within the sampling population and to have some idea of the variation in the sample. When a sample is representative, it becomes valid over the realm it represents, providing external validity. However, interpretation of results is limited to the population under study. In this study also the results based on the group of 10 experts can be generalized for the group of forest machine contractors (124) of this study. To be valid over a greater realm or to form the basis for a theory, the study can be repeated for confirmation in a different population, still using a non-probability method (Bernard 2002). Purposive sampling, when used appropriately, is more efficient than random sampling in practical field circumstances (Karmel and Jain 1987, Bernard 2002), because the random member of a community may not be as knowledgeable and observant as an expert informant (Tremblay 1957). There is no cap on how many experts or groups should make up a purposive sample, as long as the needed information is obtained (Bernard 2002).

When an expert sample is measured correctly, it becomes valid for the sample, thus providing internal validity. The professionals reacted quite consistently to separate statements and questions about increasing the cost-efficiency of harvesting small-diameter energy wood and industrial roundwood from early thinnings, forming a fairly homogeneous sample in this respect. Therefore, the results suggest that the guidelines associated with views of roundwood harvesting and energy wood harvesting were important and well-understood by professionals. However, the professionals also showed statistically significant differences in some opinions about the cost-efficiency of wood harvesting. If these differences have any practical relevance for selecting guidelines on wood harvesting, the group of professionals should have a special expertise of wood harvesting approach in question. We did not measure and analyze interviewees' expertise, but its possible effects on results are considered when ranked approaches are interpreted and discussed.

In this study, boosting the training of new machine operators, broadening the practical train-

ing, and careful selection of operator candidates proved to be of decisive importance for improving energy wood and industrial roundwood harvesting. This is logical, because such questions have been very topical matters in wood harvesting during recent years in Finland. The strong message given by the interviewees was that the education of forest machine operators must be made more effective in the future. Otherwise, there will be lack of professional operators in energy wood and industrial roundwood harvesting. The results indicated that the training structure for forest machine operators will have to be examined very carefully in the near future.

In the opinion of the respondents, there is a great potential to increase the cost-efficiency of wood harvesting in the future through improving harvesting conditions (i.e. effective tending of seedling stands, delaying harvesting operations, pre-clearance of dense (spruce) undergrowth, and new wood production methods (implementation of energy wood harvesting as a part of the wood production chain) (see Tables 4–7).

The main reasons for poor harvesting conditions and high harvesting costs in young stands are usually total failure to tend seedling stands, intentionally delaying the tending work, or ineffective implementation of the tending work. Therefore, it is vitally important for cost-effective wood harvesting to carry out the tending work in seedling stands on time and intensively enough. If a seedling stand has been tended properly, there is normally a good possibility to delay energy wood harvesting or first thinning. When wood harvesting operations are delayed in a controlled manner, better harvesting conditions (i.e. the trees to be harvested are bigger and removals are larger) can be achieved.

Many early thinning stands contain large amounts of non-merchantable undergrowth. This may restrict the visibility of the machine operator, hinder the harvesting work and reduce the productivity of harvesting work. Kärh  (2006a) reported that the density and average height of Norway spruce undergrowth have a significant impact on cutting productivity. 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 density of spruce undergrowth also affects the forwarding productivity (Kärhä 2006a). However, the undergrowth density has a significantly lower impact on productivity in forest haulage than in cutting (see Kärhä 2006a).

The interviewees also underlined that harvesting methods can be rationalized, e.g. multiple-tree handling in industrial roundwood cuttings, crane scale measurement, integrated pulpwood and energy wood harvesting, and careful selection of harvested stands (see Tables 4–7).

The smaller the trees to be harvested, the better are the possibilities to apply multi-tree handling and, subsequently, the greater the potential cost savings in energy wood and industrial roundwood harvesting (e.g. Lilleberg 1994, Bergkvist 2003, Kärhä 2006c). Almost all of the energy wood harvester heads used in harvesting energy wood from young stands in Finland have been equipped with accumulation properties, and multiple-tree processing is very common.

On the other hand, multiple-tree handling has been relatively neglected recently in harvesting pulpwood from early thinnings. Nonetheless, the findings of earlier studies have underlined that it is very profitable to apply multi-tree processing when harvesting small-diameter trees in early thinnings. For instance, Lilleberg (1994), Bergkvist (2003), and Gingras (2004) reported that the ability to handle more than one stem at a time increases the productivity of industrial roundwood cutting by an average of 20–30% compared to handling one stem at a time.

In Finland, most of the whole-tree stems felled when harvesting energy wood from early thinnings have a breast height diameter of 3–8 cm and, typically, whole-tree removal is 40–70 m³ ha⁻¹ (cf. Kärhä 2006c). There are significant correlations between the average stem size removed from the stand, removal density, and whole-tree removal: 1) the smaller the felled stems, the larger the removal density, and 2) the smaller the felled stems, the smaller the whole-tree removal (Kärhä 2006c). As there is a significant relationship between the size of the felled trees and the cutting costs, it is very important not to cut trees that are too small in early thinnings.

Kärhä (2006c) emphasized that, in order for whole-tree harvesting to be cost-effective, trees with a breast height diameter of 1–2 cm should not be harvested for energy wood at all. On the basis of the study by Kärhä (2006c), the guidelines for whole-tree harvesting are as follows:

- no individual trees with a breast height diameter of below 5 cm should be cut, whereas
- trees with a 3–4 cm breast height diameter growing in clumps can be cut.

The findings of this study showed that there are significant possibilities for cost savings in young stands, e.g. pre-clearance of dense undergrowth, multiple-tree handling in industrial roundwood cuttings, integrated wood harvesting, and careful selection of stands for harvesting. The figures of cost savings are so great that they can not be overlooked. Therefore, the most profitable guidelines must be effectively implemented and utilized immediately.

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Total of 62 references

Appendix 1. The potential approaches for more cost-efficient harvesting of industrial roundwood in the questionnaire.

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1. Effective tending of seedling stands
 2. Pre-clearance of dense undergrowth
 3. Intensive first thinning
 4. Delaying first thinning in a controlled manner
 5. Creating clusters of stands
 6. Larger stand reserves for forest machine entrepreneurs
 7. Developing organization of wood harvesting
 8. Multiple-tree handling
 9. Crane scale measuring
 10. Fewer timber assortments
 11. Decreasing the top diameter of pulpwood
 12. Enlarging the load space of forwarder
 13. Careful selection of harvested stands
 14. Integrated wood harvesting with the two-pile cutting method
 15. Integrated wood harvesting with whole-tree bundling
 16. Utilization of more small harvesters
 17. Utilization of more tracked excavator-based harvesters
 18. Utilization of more harwarders
 19. Utilization of more simple harvesting machinery
 20. Larger wood harvesting entrepreneurs
 21. Close co-operation between the operators
 22. Networking of wood harvesting entrepreneurs
 23. More working hours for harvesting machinery
 24. Improving the training of new operators
 25. Careful selection of operator candidates
 26. Broadening the practical training
 27. Developing cutting techniques and working methods
 28. Increasing automation in machinery
 29. Development of machinery technology
 30. Other approach, what?

Appendix 2. The potential approaches for more cost-efficient harvesting of energy wood in the questionnaire.

-
1. Effective tending of seedling stands
 2. Pre-clearance of dense undergrowth
 3. Delaying thinning operation in a controlled manner
 4. Energy wood harvesting as a part of wood production chain
 5. Creating clusters of stands
 6. Larger stand reserves for forest machine entrepreneurs
 7. Developing organization of wood harvesting
 8. Multiple-tree handling with felling heads
 9. Multiple-tree handling with feeding harvester heads
 10. Crane scale measuring
 11. Energy wood harvesting as whole trees
 12. Energy wood harvesting as delimbed stems
 13. Maximization of load size in forwarder
 14. Enlarging the load space of forwarder
 15. Careful selection of harvested stands
 16. Careful selection of harvested trees
 17. Integrated wood harvesting with the two-pile cutting method
 18. Integrated wood harvesting with whole-tree bundling
 19. Utilization of more small harvesters
 20. Utilization of more tracked excavator-based harvesters
 21. Utilization of more harwarders
 22. Utilization of more simple harvesting machinery
 23. Larger wood harvesting entrepreneurs
 24. Close co-operation between the operators
 25. Networking of wood harvesting entrepreneurs
 26. More working hours for harvesting machinery
 27. Improving the training of new operators
 28. Careful selection of operator candidates
 29. Broadening the practical training
 30. Developing cutting techniques and working methods
 31. Increasing automation in machinery
 32. Development of machinery technology
 33. Other approach, what?