Productivity of integrated harvesting of pulpwood and energy wood in first commercial thinnings

Produktivitet vid integrerad skörd av massaved och energived i förstagallringsbestånd

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Arbetsrapport 308 2011
Examensarbete 30hp E
Euroforester

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ISSN 1401–1204
ISRN SLU–SRG–AR–308–SE

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Master thesis (30 HEC) at the Department of Forest Resource Management.
Euroforester – masters program
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Sveriges lantbruksuniversitet
Institutionen för skoglig resurshushållning
Utgivningsort: Umeå
Utgivningsår: 2011

ISSN 1401–1204
ISRN SLU–SRG–AR–308–SE

Foreword

This master thesis corresponds to 30 higher education credits (HEC) of a 120 HEC masters program. My major subject has been forest management and the masters' thesis was done at the Department of Forest Resource Management at the Swedish University of Agricultural Sciences (SLU) Umeå.

This study was ordered by the company UPM-Kymmene Forest, which is a part of UPM-Kymmene. UPM-Kymmene is a BioFore company and is one of the leading forest companies in the world and is based in Finland. UPM wants to be in front of all development in the forestry sector and to emphasize their ambition the Chef Executive Officer (CEO) and President of United Paper Mills stated, at the annual general meeting in Helsinki on the 21st of March 2010, the following: "*United paper mills leads the integration of bio and forest industries into a new, sustainable and innovation-driven future*" (Anon. 2010d). At this same event the CEO and the Chairman of the Board announced that the company no longer titled itself as a forest company, but from now on will title itself as a BioFore company (Anon. 2010d). By changing the company's designation from a forest company to a BioFore company the energy sector became more important for UPM.

I would like to thank my supervisor at SLU Dan Bergström and my company contacts at UPM Tero Anttila and Matti Markkila for help and support during this work.

I would also like to thank my contacts at the different harvesting companies: JP Metsäkoneurakointi Oy Mikko Perälä, Metsäkonepalvelu Oy Ab Patrik Aittamäki and Veljekset Lehtomäki Oy Marko Lehtomäki for providing me with information and data for the study.

Finally, a very special thank to my girlfriend, Jennifer who has stood by me and provided the much needed support and understanding.

Abstract

The aim of this study was to quantify the productivity and the costs of different harvesting systems (teams), containing harvesters equipped with accumulating harvester heads and forwarders, in first commercial thinnings were an integrated harvest of pulpwood and energy wood were performed. In the beginning the plan was to study and measure 20 sites before and after harvest. Due to storms during the summer of 2010, complete data could only be obtained from 8 of these 20 sites. Seven of these sites were privately owned and one was owned by UPM, all of the sites had been pre-commercially thinned. The mean stem density before harvest was 2578 stems per ha and the mean stem volume was 0.074 m^3solid over bark.

On average 1518 stems/ha was harvested. The mean tree size was 0.077 m^3s of harvested stems, which corresponds to a basal area removal of 11m^2/ha or biomass removal of 59 raw tonnes /ha of which 41.2 raw tonnes (raw density) was pulpwood and 17.9 raw tonnes were energy wood. The thinning quality was good, leaving 1064 stems per ha after harvest and a mean stem volume of 0.105 m^3 solid over bark and a mean whole tree volume of 0.129 m^3 solid over bark. The harvesters' average mean productivity was 5.1 raw tonnes per hour and on average the harvester harvested 128 stems/h and the forwarders' average productivity was 7.8 raw tonnes per hour. The average forwarding distance was 294 m. The harvesters' total time consumption was 363 hours, which gives a mean total time consumption of 14.3 h per ha and 0.23 h per ton. The forwarders total time consumption was 216.5 hours, which gave a mean total time consumption of 8.7 h per ha and 0.15 h per ton. The average costs was 1247 €/ha for the harvesters and 758 €/ha for the forwarders giving an average total costs per ha of 2005 €/ha.

Stem density before harvest affected the harvesters' productivity strongly and the amount of biomass harvested per ha had a clear connection to the harvesting costs (€/tonne).

Keywords: Thinning, whole tree harvest, wood biomass, fuel wood, accumulating harvester head.

Sammanfattning

Syftet med denna studie var att kvantifiera produktiviteten och kostnaden för olika avverkningssystem (lag), som bestod av skördare utrustade med ackumulerande skördaraggregat och skotare, som avverkade förstagallrings där man utförde en integrerad skörd av massaved och energived. I början av studien var det planerat att 20 bestånd skulle mätas innan och efter gallring hade utförts, men pga. av stormar som drabbade Finland under sommaren 2010 så kunde fullständigt data endast samlas in från 8 av de 20 bestånden. Sju av dessa var privat ägda och en var ägda av UPM, alla av bestånden hade röjts sedan tidigare. Medelstamtätheten innan avverkning var 2578 stammar per hektar och medelstamvolymen var 0,074 m^3fast på bark.

I medeltal skördades det 1518 stammar/ha. Medelträdstorleken var 0,077 m^3fast på bark för de skördade stammarna, vilket motsvarar uttag av en grundyta på 11m^2/ha eller ett uttag av biomassa av 59 råton/ha. Av detta var 41,2 råton massaved och 17,9 råton energived. Gallringskvalitén var bra, och efter skörd fanns det i medeltal 1064 stammar/ha, medelstamvolymen var 0,105 m^3fast på bark och medel träd volymen var 0,129 m^3fast på bark. Skördarnas medelproduktivitet var 5,1 råton per timme och i medeltal skördades 128 stammar/timme. Skotarnas medelproduktivitet var 7,8 råton per timme vid ett medelskotningsavstånd av 294 m. Totala tidsåtgången för skördarna var 363 timmar, vilket i medel gav en total tidskonsumtion på 14,3 timmar per ha och 0,23 timmar per råton. Skotarnas totala tidsåtgång var 216,5 timmar, vilket i medel gav en total tidskonsumtion på 8,7 timmar per ha och 0,15 timmar per råton. Medel kostnaden för skördarna per ha var 1247 € och för skotarna 758 €/ha, detta gav en total kostnad per ha på 2005 €.

Stamtätheten innan skörd inverkade starkt på skördarens produktivitet och mängden skördad biomassa per ha hade ett starkt samband med avverkningskostnaderna (€/ton).

Nyckelord: Förstagallring, helträdsuttag, vedbiomassa, skogsbränsle, ackumulerande skördaraggregat.

Index:

1 Introduction

1.1 General forestry statistics and policies

Finland's total area is 338 424 km^2 of which 304 112 km^2 (90%) is land area (Anon. 2008), of the land area about 86% (~ 26 million hectares (ha)), is covered by forests, of which 20 million ha have good wood production capability (Niemelä 2005). Good wood production here meaning an average annual growth of 4.8 m^3 solid over bark (sob) per ha (Peltola et al. 2009). The annual cuttings, during the years 1999 to 2009, average about 59 million m^3sob of which the highest amount was year 2007 when 63.9 million m^3sob were cut and the lowest was year 2009 when 47.7 million m^3sob were cut (including firewood 6.3 million m^3sob) (Anon. 2010c). In year 2008 the annual cutting was 51.7 million m^3sob (excluding firewood) which came from 673 000 ha (Juntunen & Herrala-Ylinen 2009). Of these 673 000 ha, 129 000 ha were final fellings and 544 000 ha were thinnings of which 256 000 ha were first commercial thinnings (FT's) (Juntunen & Herrala-Ylinen 2009). But the following year, 2009, due to the economy, the annual cuttings dropped to 470 000 ha (Juntunen & Herrala-Ylinen 2009) of which 155 000 ha were FT's (Anon. 2009).

Because forestry is so important for the Finnish economy the government started a National Forest Programme (NFP) in year 1999 to ensure the supply of raw material to this nationally important industry (Kärhä et al. 2003). In the NFP it is recommended that during the period 1999-2010 the aim was to annually carry out FT's on 250 000 ha (Kärhä et al. 2003). This objective has not been achieved, although the amount of FT's that has been carried out has increased from 100 000 ha per year in the mid-1990s (Kärhä et al. 2003) to average about 195 000 ha during the years 2005 to 2009 (Anon. 2005; Anon. 2007; Anon. 2009). It is estimated that the amount of FT's that are in urgent need of being harvested has increased to about 500 000 ha (Anon. 2005) and will increase by 150 000 ha annually if nothing is done (Sirén 2007). In the NFP the target for management of FT's and pre-commercial thinnings (PCT's), was set to increase from 150 000 ha annually to 250 000 ha (Anon. 1999). This target was not achieved, but the amount of performed PCT's had increased to an acceptable level according to Hytönen and Kotisaari (2007) from 150 000 ha to about 230 000 ha (Anon. 1999).

1.2 Management and financial aspects of young thinnings

1.2.1 Pre-commercial thinning (PCT)

PCT is a silvicultural action, which is performed in dense young forest stands. The purpose of the action is to regulate the density of the stand by giving the trees that are of higher quality more living space, by felling smaller trees and trees that are of poorer quality (Huuskonen 2008). By doing this you increase the stem wood (timber and pulpwood) production of the trees, which remain in the stand. Besides this you also improve the trees vitality and make them more resistant against different kind of damages caused by insects or fungi (Huuskonen 2008). For the forest owner the PCT operation is an expense.

1.2.2 First commercial thinning (FT)

The FT is a silvicultural action which purpose is also to increase the stem wood production, by harvesting trees that are of poor quality and are less valuable (Huuskonen 2008). Today more and more forest owners are becoming urbanized. In general, they manage their forests in other ways than for optimisation of stem wood values from the forests; this because urban forest owners are usually not as dependent on their forest as a source of income as the forest owners used to be (Laitiala et al. 2009; Anon. 2010b). This means that some forest owners barely manage their forests according to recommended forest management practises (Anon. 2009). Consequently, the amount of stands being neglected of PCT and FT's has increased appreciably in Finland (Hänninen 2009). The FT is costly, time consuming silvicultural action, which hardly gives any revenue to the forest owner (Kärhä et al. 2003).

There are several reasons why the FT's in young dense forests are so costly: 1) the stems are small in size which gives a low yield of round wood per ha (Kärhä et al. 2003); 2) the forwarding operation becomes more difficult, due to the relative high tree density after thinning (Äijälä et al. 2010); 3) the productivity of the harvesting operation can decrease (costs can increase) due to dense undergrowth (Kärhä et al. 2003). In order to reduce harvesting costs in FT and to increase the interest among forest owners to allow the FT to be carried out in their forests, development of new ways of performing loggings in FT's has begun on a national level in Finland (Kärhä et al. 2003).

1.2.3 Government subsidies

To increase the interest among forest owners to have silvicultural actions done in their forests the government has decided on subsidies for actions that enhance sustainable forest. These subsidies are meant to cover some of the costs that follow with these actions (Koistinen 2009). The Kemera aid is a financial support that only private forest owners can apply for from the state when he or she has made a silvicultural action such as PCT in their forest, either by a forest management association, forestry company, and entrepreneur or by doing the work him- or herself (Koistinen 2009). The aid can also be applied for when harvesting energy wood, but only if the wood is sold as fuel to an industry, which produces energy. To get the aid, at least 20 m^3sob energy wood per ha must be harvested from the forest stand (Koistinen 2009).

1.3 Thinning systems

1.3.1 Machinery

To increase the harvesting efficiency, when handling small diameter trees, accumulating harvester heads (AHH's), which are able to cut, accumulate, delimb and cut-to-length several trees per crane cycle, are used (Kärhä et al. 2003). These heads can be used in two main different ways: 1) cutting, accumulating and bunching; 2) cutting, accumulating, delimbing, cut-to-length and bunching (Bergström 2010 pers. comm.). Such heads has been under development for a long time; however, it is only in recent years that the manufacturers have produced good solutions, which are adapted to the harvesting methods. When using AHH's in FT's, it is possible to produce both pulpwood (delimbed stems) and energy wood (i.e. whole tree above felling cut including branches and needles) and thereby increasing productivity (Mäkelä et al. 2002; Kärhä et al. 2003). The above-mentioned harvesting method is called integrated harvest.

1.3.2 Productivity

Mäkelä et al. (2002) studied harvesters equipped with AHH's performing integrated harvest on FT stands of Scots pine (*Pinus Sylvestris*) and mixed tree species. The harvesting method mentioned above was compared to a conventional logging of only pulpwood with single-grip harvester heads in the same kind of stands. In this study it was found that the harvested biomass (m^3sob) per ha increased by 23-33%, when performing the harvest as an integrated harvest compared to harvesting only pulpwood. It was also concluded that the time consumed per volume unit (m^3sob) was about 27% less when using an AHH compared to a single grip harvester head (Mäkelä et al. 2002). In Mäkelä et al. (2002) study it was also found that the productivity (m^3/h) for integrated harvest compared to a single grip harvester was at its greatest between a diameter at breast height over-bark (dbh) of 7-11 cm and the productivity was about 40-50 % higher for the integrated harvest at this dbh.

In Kärhä et al. (2006) study, the productivity between different sized harvesters and combined harvester-forwarders was compared. In this study it was found that the mean volume dm^3 solid over bark (dm^3sob), of the cut trees and the proportion of trees that were cut in bundles with AHH's, had some effect on the productivity. The productivity was higher when cutting smaller trees than cutting somewhat larger trees. The reason for this was because the harvester could accumulate fewer trees during one crane cycle when the trees were larger. Machines that used the AHH without feed rollers for processing, e.g. only cutting, accumulating and bunching whole trees, were more productive when trees smaller than 10 dm^3sob were harvested. But when the trees became larger (20 – 50 dm^3sob), the productivity, m^3 per effective work hour, was between 0.6 – 2.0 m^3 higher per h with AHH equipped with feed rollers (Kärhä et al. 2006).

In Kärhä et al. (2009) study it was found that when performing an integrated harvest, the total yield could increase from 40% up to 100%, depending on what kind of stand that is harvested. In the same study it was also found that the productivity m3/h (effective work time), when performing an integrated harvest, increased from 11% to 37% compared to the conventional way of harvesting with a single grip harvester (Kärhä et al. 2009). The main reason for the increased productivity (m^3/h) in this study was the increase in total yield when performing an integrated harvest (Kärhä et al. 2009).

Kärhä et al. (2008) studied the difference in relative productivity (m^3/h (G_{15})) and harvesting cost, between three different kinds of harvesting methods. The methods were: 1) cutting, accumulating and bunching; 2) cutting, accumulating, delimbing, cut-to-length and bunching; 3) single grip harvesting (conventional harvesting method). In this study it was found that harvesting method 1, had the highest productivity and cost efficiency when the trees were smaller, but as they got bigger (increased dbh), harvesting method 3 had higher productivity and cost efficiency. Harvesting method 2 had the lowest productivity and cost efficiency in the study (Kärhä 2008). To improve the productivity, trees smaller than about 4 cm in diameter at stump height should be pre-cleared before harvesting to render better sight conditions for the operators, and by doing so the productivity should also be improved. The pre-clearing should be done motor manually (Äijälä et al. 2010).

1.3.3 Financial aspects

There are a number of studies where the harvestings costs of harvesters equipped with AHH's has been studied. Laitila (2005) studied the difference between harvesting costs when energy wood was harvested manually or mechanically and between when the energy wood was chipped at a terminal or at the end-user. Kärhä et al. (2003) compared the costs of a number of harvesters equipped with various AHH's, which in some cases performed integrated harvests, and in some cases only harvested energy wood. Kärhä et al. (2003) concluded that the costs were slightly higher when an integrated harvest was performed, compared to when only energy wood was harvested. Mäkelä et al. (2002) concluded that it is more profitable to harvest both energy wood and pulpwood if possible, because when the amount of harvested biomass per ha increases, the total logging costs decreases over time.

Korpilahti and Örn (2002) studied the cost for harvesting operations and revenue the forest owner got from harvests that were performed with harvesters equipped with AHH's. The costs for the harvesting operations in Korpilahti and Örn (2002) were very similar to the costs that Kärhä et al. (2003) reached in their study when integrated harvest was performed. In Korpilahti and Örn (2002) they also compared costs of integrated harvest to the conventional way of harvesting with a single grip harvester. Here it was found that the integrated harvesting method was more expensive to perform. In Korpilahti and Örn (2002) study they also looked at the revenue the forest owner got from the sites, which were harvested in the integrated way, and these did not exceed the revenue the forest owner got from the sites, which were harvested the conventional way with a single grip harvester. This result was reached, although the Kemera aid was taken a count for on the sites that were harvested in the integrated way.

Kärhä et al. (2009) concluded that when the productivity of an integrated harvest increases significantly it affects the harvesting costs positively. In a study done by Oikari et al. (2010), they analyzed the views of different wood harvesting professionals. The professionals were presented with different approaches to increase cost-efficiency in harvesting operations of young forest stands. In this study it was found that most of the participants thought that integrated harvesting was a key factor in increasing cost-efficiency (Oikari et al. 2010). In Oikari et al. (2010) study, it was also found that the forest machine contractors, saw the removal of smaller trees before harvest as the best way of increasing the cost-efficiency.

1.4 Measurements of harvested biomass

In a study done by Mäkelä et al. (2002) it was found that the measuring accuracy of the tree volume measuring instrument used on the AHH's was very unreliable: if only single trees were cut, e.g. no accumulation was used, the stem volume (solid over bark) was always overestimated, between 12-29%; and when several trees were accumulated, the volume was also always overestimated, between 44-68%. The result was surprising because the harvester's measurement unit was calibrated just before the study begun. The main reason for the bad measurement accuracy was thought to be that the harvester's measurement unit was developed to be used to in single tree harvesting. The second reason was that the measurement unit always measured the length of the trees in the bundle according to the longest tree. Due to the uncertainties and the poor measurement accuracy, the majority of forest owners have not been so interested in having their FT performed by harvesters equipped with AHH's (Mäkelä et al. 2002).

1.4.1 Weighting systems

Due to the poor measurement accuracy of harvested tree volume achieved with AHH's, it has been decided on a national level in Finland (year 2007) that when an integrated harvest is performed a forwarder equipped with crane scales shall weigh the biomass instead (Kärhä et al. 2009). The measurement accuracy of crane scales has been tested in several studies and it has been proven to be capable of measuring with an accuracy of ±4% of fresh weight, which is the limit set in Finnish legislation about timber measurement (Heikkilä et al. 2004).

The crane scales accuracy can only be maintained if the scale is calibrated regularly. Today there are no statutory on how and how often the calibration of crane scales should be performed. There are only recommendations that have been made by the Agriculture and Forestry Ministry and Metsä Teho; the crane scales accuracy should be checked every week or when there are changes in circumstances that may affect the scale's accuracy (Melkas 2009). These might be rapid changes in weather conditions or if the scale has hits something very hard (Melkas 2009).

The calibration is done in the following way: a test weight, which weight has to be checked once a year is lifted 20 times, if the deviation of the measurement is under ± 2%, then the scale does not have to be calibrated; if the deviation is over ±2% and the scale shows a deviation either way three times in a row, then the scale has to be calibrated; if the deviation is over ± 4% two times in a row the scale has to be calibrated; if the deviation is over ±7% the scale has to be calibrated and after that the scale has to be tested to make sure that it works correctly (Melkas 2009).

1.4.2 Conversion rates

The conversion rates used for converting the tree biomass from kg to m^{3}sob have been produced for both a national and regional level (Appendix 1: Fig. 12 and Appendix 2). These conversion rates, that are in use today, have been approved by the energy wood measurement committee, which is represented by the following parties: Finnish Energy Industry, Forststyrelsen (Metsähallitus), Ministry of Agriculture and Forestry, L&T Biowatti Oy (Ltd.), The Trade Association of Finnish Forestry and Earth Moving Contractors, Metsäliitto, The Central Union of Agricultural Producers and Forest Owners (MTK), Association of Forest road Carriers, Forestry Development Centre Tapio, Finnish Forest Research Institute (Metla), Stora Enso Oyj, Finnish Sawmills Association, Wood and allied workers´ Union, UPM–Kymmene Oyj and Vapo Oy (Lindblad et al. 2008).

Conversion rates for energy wood (whole trees) between dry and raw mass and the solid volume (kg/m^{3}sob) are produced but the conversion rates can differ dependent on e.g. tree species, weight classes, moisture content and harvesting season (Lindblad et al. 2008; see Appendix 2). The raw density here is defined (kg/m^{3}sob) as the ratio of the raw mass and the raw solid volume and the dry-raw density is defined as the ratio of dry the mass and the raw volume (Lindblad et al. 2008; see Appendix 2). The Ministry of Agriculture and Forestry agreed on conversion rates for pulpwood, which should only be used when small quantities of pulpwood are harvested together with energy wood (which usually is the case when harvesting in young thinning stands) (Anon. 2010a; see Appendix 3).

1.5 UPM's situation

UPM is one of the leading forest companies in Finland and the world. The company changed its title in the winter of 2010 from Forest Company to a BioFore company, combining bio industry and the forest industry (UPM 2010). As the company has changed its definition from a forest company to a BioFore company, the energy sector got a bigger role within the company (UPM being the second largest energy company in Finland) (Anon. 2010h). This in turn has meant that, to be able to be the leading company within the forest sector as well as the bioenergy sector UPM must procure greater quantities of bioenergy, or more correctly more forest biomass (Ojanen 2010).

To manage this, one action that has been done, is to encourage their contracted logging entrepreneurs to acquire AHH's, to increase efficiency by conducting integrated harvesting of pulp and energy wood biomasses (Anttila 2010a pers. comm.).

When using AHH's to produce pulpwood, the quality of the delimbing and measurement accuracy is poorer compared to a single-grip harvester head. For example, a lot of twigs are left on the stem wood and the timber is cut at an approximate length instead of being cut to length (Anttila 2010b pers. comm.). However, UPM have made some changes at their pulp mills to handle these problems; today the pulp mills consider twigs as an extra income since they sell the residue biomass, which comes from debarking process, as fuel to a e.g. power plant (or use it themselves to produce energy). Today they also accept wood at the pulp mills that has been cut to an approximate length (Hallenberg 2010 pers. comm.).

1.5.1 UPM statistics

UPM uses about 20 million m^3sob (Mm^3sob) yearly in Finland (Anon. 2010d). About 10 Mm^3sob of this comes from imports and domestic supply contracts (Anttila 2010a pers. comm.). These 10 Mm^3sob consists of round wood, chips and saw dust. The other 10 Mm^3sob comes from harvest operation, which UPM manages. One Mm^3 comes from FT's, 2.5 Mm^3sob comes from commercial thinnings and 6.5 Mm^3sob comes from regeneration fellings. Between 7.5 and 8 Mm^3sob of this comes from privet forests and between 1.5 – 2 Mm^3sob comes from the companies owned 1 Mha forestland in Finland (Anttila 2010b pers. comm.).

1.6 The specific problem

The productivity model for integrated harvesting that UPM uses at present is based on one, and only one specific harvesting team. In the first face of developing the productivity model the teams harvesting system however consisted of a single grip harvester and a forwarder (Anttila 2010a pers. comm.; see Appendix 4).

In the second face in the late autumn of 2008 UPM contracted an entrepreneur, (same one as above) which used a harvester equipped with an AHH and a forwarder, to perform integrated harvests in FT's. The entrepreneur received an hourly wage to perform these thinnings. This harvesting team's production and time consumption was closely studied (follow-up study) by UPM for 6 months, from the beginning of December 2008 to the end of may 2009. The forwarder used was equipped with a crane scale for measuring of production (amount of biomass procured) (Anttila 2010a pers. comm.). The conversion rates used were in accordance to Lindblad et al. (2008) and Anon. (2010) (see Appendix 2 and 3). The results from this study showed that the production model, when using an AHH in integrated harvests, corresponded quite well to the “latest” production curve from the first face. The follow-up study of the AHH showed that the amount of biomass that was extracted was higher compared to when only pulpwood was extracted (see Appendix 5.) It was concluded that if UPM continues to extract both pulpwood and energy wood (integrated harvest) in FT’s the harvesting costs will be reduced over time (Anttila 2010a pers. comm.).

All the above-mentioned data was collected over a period of one year 2008 - 2009 in the region of Seinäjoki. However, UPM do not have an updated knowledge about harvesting operations were AHH’s are used in integrated harvests (Anttila 2010a pers. comm.).

At UPM, there are certain factors that are known and other factors are assumed to have some affect on the machines productivity. These factors are:
• Tree species (the proportion deciduous/coniferous) / the main tree species (assumed)
• The diameter of harvested mean stem (stem volume) (known)
• The harvesting and forwarding time consumption in the stand (known)

Other things that might affect the productivity is the size of the harvesting area.

In the former follow up study done at UPM no field measurement of stand characteristics before and after harvesting has been performed. The operators of the harvester and forwarders have only notified the size of the harvesting area, harvested mean stem volume (dm^3sob), harvesting time consumption (total time), forest transport distance, the amount of pulp wood (conifer and deciduous trees separately)(raw tonnes), the amount of energy wood (raw tonnes), if area has been pre-cleared of under growth before logging, the suitability for integrated harvest. The last thing that was reported was how suitable the site was for integrated harvest on a scale from 1- 4, where 4 was excellent and 1 was very poor (Anttila 2010a pers. comm.).

To ensure an accurate measurement of the harvested timber as possible UPM has a paragraph in the contract that they sign with the entrepreneurs, which requires the entrepreneur to calibrate the crane scale according to the recommendations set by Metsä Teho and the Agriculture and Forestry Ministry. If the manufacturer of the scale has instructions that the scale should be calibrated more often than these recommendations the manufacturer’s instructions should be followed (Anttila 2010a pers. comm.).

Since the autumn 2009, all harvesting teams performing loggings with AHH’s has had to bid on a payment curve that had been developed using the material that had been obtained from the closely monitored team. Plus the collected forms which the other harvesting teams had filled out (Anttila 2010a pers. comm.).

The bidding procedure goes as following: UPM has about e.g. 200 000 m^3 of timber from FT’s that they will procure e.g. in the area of Vasa. The average forest transport distance and the average amount of biomass (raw tonnes) form these stands are given. Based on this the entrepreneurs will get X amount of € for each 100 meters of forest transport and X amount € for every 20 raw tonnes of biomass. Based on this X amount of € the entrepreneur can bid e.g. 1.18 times X or 0.97 times X. The X in this case is corporate secret that was not allowed to be shown used in the study. Based op on the different offers UPM gets they make their decision on which entrepreneur gets the contract for the whole 200 000 m^3 (Anttila 2010a pers. comm.).

1.7 Hypothesis

Since the present productivity curve is based on material that was collected when the harvesting teams were not so experienced with using AHH's UPM believes that the productivity of the harvesting teams has increased, as they has become more experienced over time, and therefore new data on the harvesting production and time consumption are needed so a new, more accurate, productivity model (payment curve) can be produced and be taken into use (Anttila 2010a pers. comm.).

1.8 The aim

The aim of this study was to quantify the productivity and the costs of different harvesting systems (teams), containing harvesters equipped with accumulating harvester heads and forwarders equipped with crane scales, in first commercial thinnings were an integrated harvest of pulpwood and energy wood were performed.

2 Material and Methods

2.1 General aspects

2.1.1 Study design

In 20 different FT harvesting sites located in central Finland between 61°51'00"N and Latitude 63°26'00"N both stand data before and after harvest as well as harvesting time consumption and production of different harvesting teams were planned to be collected for quantification of their productivities. The sites were planned to be harvested by three different harvesting teams during a period from June to August 2010. All harvesting sites were planned to be measured through field inventories, both before and after harvest. And the corresponding harvesting time consumption and production were supposed to be monitored through follow up studies, e.g. the harvesting teams measured this data themselves.

However, due to the storms that hit the eastern parts of Finland during the summer of 2010, some harvesting sites could not be harvested as planned, this because the harvesting teams were relocated to the storm area to help with the loggings there. As a result of this only complete data (e.g. stand data before and after harvest, harvesting time consumption and production) from eight of the twenty sites could be collected during the study period.

2.1.2 Study areas

Of the eight sites from which complete data were collected, three were located north of Merikarvia (Latitude: 61°51'00"N Longitude: 21°30'00"E), four were located in an 30 km radius from Seinäjoki (Latitude: 62°40'00"N Longitude: 22°51'00"E) and one was located near Jyväskylä in a place called Multia (Latitude: 62°25'00"N Longitude: 24°47'00"E). Seven of these sites were privately own and one was owned by UPM. All of these sites had been PCT (one had been PCT two times) before FT. The reason for the sites being distributed on a large area was to get as much data as possible on different kind of stands and also to find out how productivity varies between stands with characteristics, e.g. trees/ha and average tree size.

All the stands had a tree species mix of Scots pine, Norway spruce (*Picea Abies*) and birch (*Betula Pendula or Betula pubescens,* these were not separated!) and other deciduous trees for instance aspen (*Populus tremula*), alder (*Alnus glutinosa*) and goat willow (*Salix caprea*). The dominant tree species on the sites was Scots pine in all except one in which spruce was the dominant. The sites characteristics before harvest can be seen in Figure1 and Table 1.

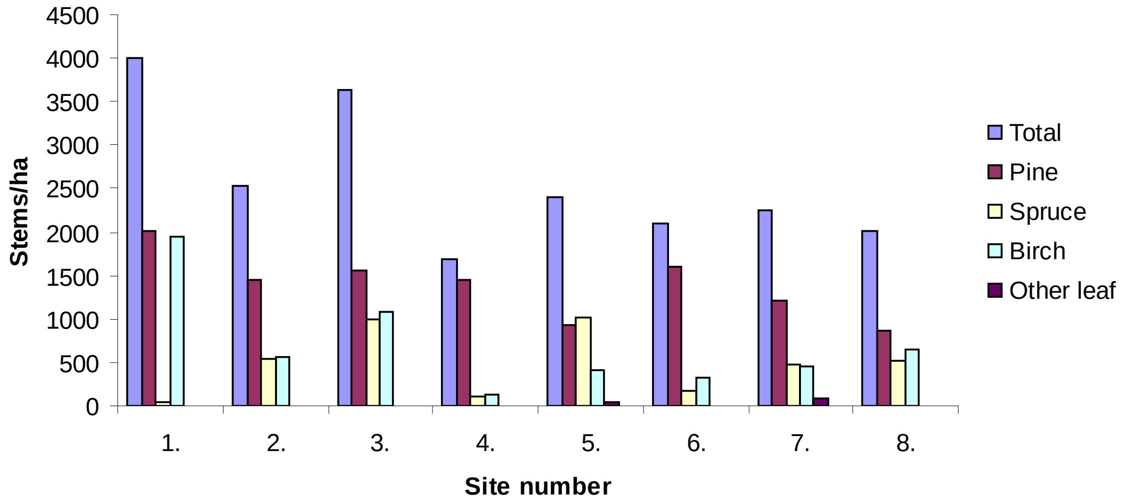

Figure 1 Stem density of the FT stands (sites) before harvest
Figur 1. Förstagallringsbeståndens stamtäthet innan avverkning.

2.2 Stand measurements

2.2.1 Inventory methods before harvest and after

The first step of the stand inventory was to measure the size (ha) of the harvesting sites, the measurement was done by using a computer based map program (UPM Harvesting UI 1.1.27.5; part of UPMs computer system FORIT). This map program has a feature that renders stand area calculations. In order to collect stand characteristics five circle plots was systematically distributed in a line ranging through the site, from short end to short end of the stand (where it was at its widest or longest; see Fig. 2). The size of each circle plot was 0.01 ha (100 m^2; radius = 5.64 m) which means that depending on the size of the inventoried site between about 1 – 3.2% of the area was measured. Subsequently, in each plot, per tree species, the number of trees, the dbh and height were measured. The dbh was measured with a caliper. The height was measured with a hypsometer (Suunto PM-6). Only the height on the average sized (by dbh) tree per tree species was measured in each circle plot; giving the average height per tree species of the plot. The dbh was measured of all trees with a diameter at stump height (at ground base of the tree) over four cm. To make sure that no double measurement or counting was done during the measurements, the trees that had been measured and counted were sprayed with a colorful spray. The mean stem size m^3sob per tree species and plot were calculated with Laasasenaho's (1982) volume functions (see Appendix 7) and the total volume (inclusive branches and needles or leaf) m^3sob of the trees in the circle plot was calculated with a function developed by Repola et al. (2007) (see Appendix 7). The site measurements before harvest was done between 16th of June 2010 and 5th of July 2010.

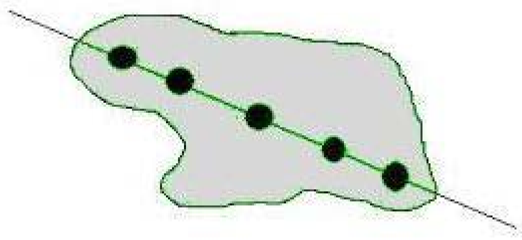

Figure 2. Sketch of the layout distribution of the circular inventory plots for stand characteristics measurements.
Figur 2. Schematisk beskrivning av utläggning av cirkel provytor för beståndsvisa inventeringar.

The average forwarding distance was also measured in field before harvest and also by using the UPM's FORIT computer system (Table 1). The forwarding distance measurement was done with the computer program, by measuring from the center of the site to the place where the timber pile was marked on the map over the harvesting site. To be able to locate the exact location of each plot after the stand being harvested, in each plot a wooden pole was positioned at the center point or the circle. The poles were marked with slivers, so that the harvester and forwarder operators could see them better and avoid felling trees on them. Each pole was also marked with a specific number. After the harvesting operation each plot was again inventoried according to the above mentioned methods and was done between the 4^{th} and 8^{th} of October 2010.

Table 1. Characteristics of FT harvesting sites before harvest
Tabell 1. Förstagallringsbeståndens egenskaper innan avverkning

	Site											
	1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**Mean**	**Max**	**Min**	**sd**
Area (ha)	3.6	2.1	4.6	6.5	3.8	7.9	1.6	1.6	4	7.9	1.6	2
Basal area (m^2)	34	27	38	16	36	23	31	25	29	38	16	7
Stand density (stems/ha)	4000	2540	3640	1680	2400	2100	2240	2020	2578	4000	1680	814
Share of stems per specie (%) (and share of biomass (%))												
Pine	*51(85)*	*57(83)*	*43(78)*	*87(86)*	*38(41)*	*76(83)*	*54(58)*	*43(72)*	*56(73)*	*87(86)*	*38(41)*	*17(16)*
Spruce	*1(1)*	*21(9)*	*27(9)*	*6(6)*	*43(40)*	*9(2)*	*21(20)*	*26(23)*	*19(14)*	*43(40)*	*1(0,5)*	*14(13)*
Birch	*49(14)*	*22(8)*	*30(13)*	*7(10)*	*18(19)*	*15(15)*	*21(21)*	*32(5)*	*24(13)*	*49(21)*	*7(5)*	*13(5)*
Other leaf	*0(0)*	*0(0)*	*0(0)*	*0(0)*	*2(1)*	*0(0)*	*4(1)*	*0(0)*	*3(1)*	*4(1)*	*2(1)*	*1(0.3)*
Mean dbh (cm)	10	10	11	11	13	11	13	11	9	13	10	1
Mean tree height (m)	9	7	8	9	13	9	11	9	9	13	7	2
Mean stem size (m^3sob)	0.050	0.061	0.067	0.051	0.112	0.068	0.115	0.071	0.074	0.115	0.050	0.025
Mean size of whole tree (m^3sob)	0.059	0.075	0.081	0.062	0.139	0.081	0.141	0.091	0.091	0.141	0.059	0.032
Standing volume (m^3sob/ha)	200	155	244	86	269	143	258	143	187	269	86	66
Stand biomass density (raw tonnes /ha)	205	163	254	90	279	146	267	157	195	279	90	67
Forwarding distance (map program)	320	250	430	470	80	620	60	80	289	620	60	209
Soil type (M=mineral, P=Peat)	M	P	M	M	P	P	M	P				

2.3 *Operational measurements and machinery information*

2.3.1 Thinning instructions

The thinning instructions given to the harvesting teams varied depending on what kind of forest stand they were about to harvest (Markkila 2010 pers. comm.): if the stand had been subjected to a PCT, a "low thinning" was performed, meaning that trees of poor quality are removed to give more living space for the remaining trees in the stand; if the stand had not been PCT before, a "thinning from below" was performed, meaning that trees that are small sized are removed firstly (but also dominant trees and trees of poorer quality should be removed) (Äijälä et al. 2010). The density of remaining trees after a "low thinning" and a "thinning from below" was supposed to target a density between 700 – 1200 and 700 – 1400 trees per ha, respectively (Anon. 2006; Äijälä et al. 2010).

The integrated harvest in this study was performed as a two pile harvesting method. Two pile harvesting method here meaning that the pulpwood and energy wood (twigs, tree tops and small trees) are put in separate piles on the harvesting site. These piles are then forwarded to the forest road by the forwarder.

2.3.2 Harvesting teams

Three different harvesting teams were used in the study. All of the workers in the harvesting teams had at least a couple of years of experience of operating with harvesters equipped with AHH's and forwarders in early thinnings. JP Metsäkoneurakointi Oy was the employer of team 1, Metsäkonepalvelu Aittamäki Oy Ab was the employer of team 2 and Veljekset Lehtomäki Oy was the employer of team 3. The all the teams had different machine and equipment compositions although team 2 and team 3 had rater similar (Table 2). All harvesting teams thinned the stands in strip road systems e.g. both the harvester and forwarder operated from the strip road. The teams were located in different areas in mid Finland (Fig. 3)

Table 2. Machine and equipment data for the different harvesting teams (Anon. 2010e; Anon. 2010f; Anon. 2010g)
Table 2. Maskin- och utrustningsdata för de olika avverkningslagen (Anon. 2010e; Anon. 2010f; Anon. 2010g)

	Model	Weight (kg)	No. of wheels	Crane: Model and reach (m)	Crane scale: Model
Team 1					
Harvester	Ponsse Beaver	14 900	8	Ponsse C22 (11)	-
AHH	Ponsse H53	900	-	-	-
Forwarder	Ponsse Wisent	14 900	8	Ponsse K70M (10)	Loadmaster
Team 2					
Harvester	John Deere 1070D	15 000	6	TJ180 (10)	-
AHH	Timberjack 745	815	-	-	-
Forwarder	John Deere 810D	11 500	8	John Deere CF1 (10)	Loadmaster/ Tamtron
Team 3					
Harvester	John Deere 1070D	15 000	8	TJ180 (10)	-
AHH	Timberjack 745	815	-	-	-
Forwarder	Timber Jack 810B	14 000	8	n/a	Loadmaster

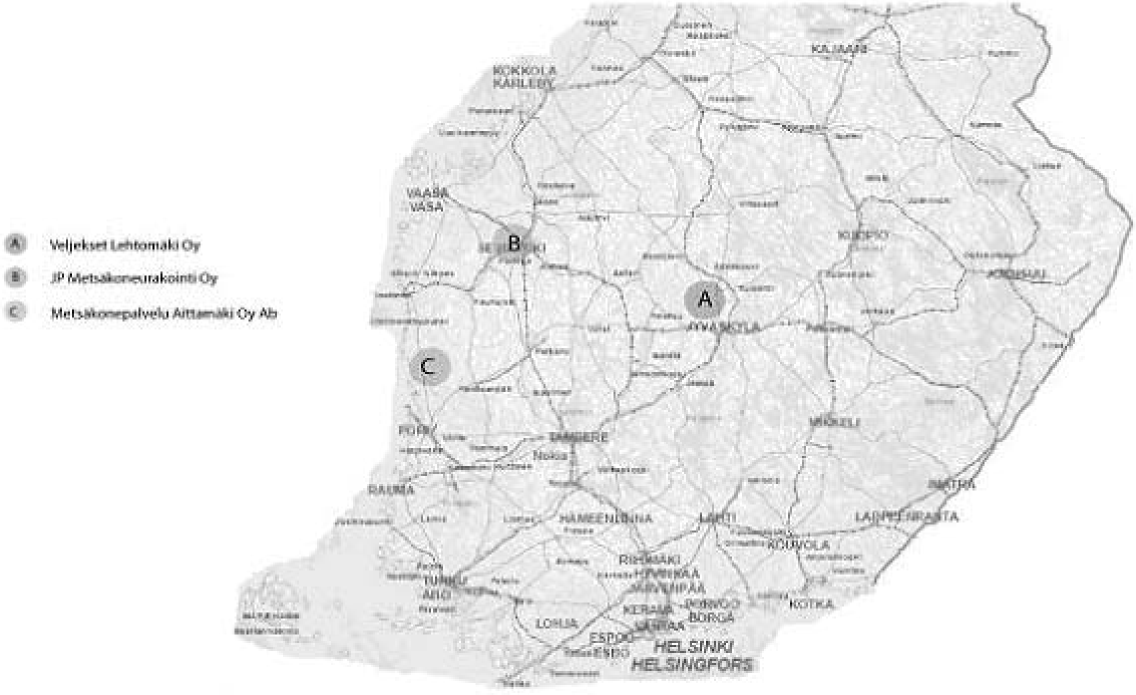

Figure 3. Map of south and central part of Finland in which the different harvesting teams work areas has been marked out with different letters (A: Veljekset Lehtomäki OY, B: JP Metsäkoneurakointi OY, C: Metsäkonepalvelu Aittamäki. (Publication right: Anon 2010i).
Figur 3. Karta över södra och mellersta Finland där de olika avverkningslagens arbetsområden är utmärkta med olika bokstäver. (A: Veljekset Lehtomäki OY, B: JP Metsäkoneurakointi OY, C: Metsäkonepalvelu Aittamäki. (Publikationsrätt: Anon 2010i).

2.3.3 Data collection of harvesting operations

The work time consumption of the harvesters and the forwarders per work site was kept track of by the entrepreneurs themselves. The work time was given as total work time (including both productive work time and non productive work time such as repairs, chain changes, refueling and oil changes and driving to the harvesting area and from the harvesting area to the rest area for both the harvester and forwarder when the shift ends). The harvesting teams also measured the average forwarding distance on each harvesting site (with a odometer attached to the forwarder). The entrepreneurs also reported the production, i.e. the amount of biomass to UPMs FORIT system from. The data that was reported was: the total raw tonnes (raw tonnes) (pulpwood/energy wood) and mean stem volume (m^3sob) of the harvested trees (the mean stem volume measurement was done by the AHH). Besides this the mean stem volume, total tree volume and raw tonnes for sites before harvest, after harvest and harvested raw tonnes were also calculated from the measured values with the help of the different functions (Appendix 7.).

2.3.4 Economy

The hourly costs for total work time for the harvester was set to 105€ and for the forwarder they were set to 117€ per h. These values were taken from UPMs experiential knowledge about harvesting costs (Kohonen 2010 pers. comm.).

2.3.5 Analysis and statistics

The analysis and statistical calculations were made in Microsoft excel.

3 Results

3.1 Thinning data

On average, for all harvesting sites, 1518 stems/ha (sd 933) with a mean tree size of 0.077 m^3sob (sd 0.037) were harvested, which corresponds to a basal area removal of 11m^2/ha or biomass removal of 59 raw tonnes/ha (sd 27). The average thinning strength was 41.3% of removed stems, 30.2% of the removed biomass and 39% of the basal area (Table 3). The thinning strength of the calculated biomass was 42.5 % (Table 3). Of the actual harvested biomass (59 raw tonnes/ha), 41.2 raw tonnes was pulpwood (70%) and 17.9 raw tonnes (30%) was energy wood. Of the pulpwood 28.8 raw tonnes (70%) were conifer wood and 12.2 raw tonnes (30%) were deciduous wood. The average calculated harvested biomass was 86 raw tonnes/ha (sd 36) (Table 3).

The site from which most biomass (raw tonnes) was harvested was site number 7 (98 raw tonnes/ha). Of these 98 raw tonnes/ha, 66.4 raw tonnes were pulpwood and 31.8 raw tonnes were energy wood. The mean tree size on this site was 0.122 m^3sob. The site from which the least biomass (raw tonnes) was harvested was site number 4. From this site only 14 raw tonnes/ha was harvested and of these 14 raw tonnes, 10.4 raw tonnes were pulpwood and 3.2 raw tonnes were energy wood. The mean tree size on this site was 0.078 m^3sob.

Table 3. Data on harvested biomass

Tabell 3. Data på skördad biomassa

	Site											
	1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**Mean**	**Max**	**Min**	**sd**
Area (ha)	3.6	2.1	4.6	6.5	3.2	7.9	1.6	1.6	4	7.9	1.6	2
Basal area (m^2) (% of total)	16(47)	10(37)	15(39)	2(13)	17(47)	8(35)	10(32)	8(32)	11(39)	17(47)	2(13)	5
Stand density (stems/ha)	3025	1500	2860	440	1040	1040	1260	940	1518	3025	440	933
Share of stems per specie (%) (and share of biomass (%))												
Pine	*39(67)*	*49(78)*	*31(48)*	*82(69)*	*35(34)*	*73(78)*	*44(45)*	*43(65)*	*50(60)*	*82(78)*	*31(34)*	*18(15)*
Spruce	*0.5(0.4)*	*20(8)*	*34(21)*	*5(3)*	*33(38)*	*10(2)*	*21(23)*	*26(30)*	*24(16)*	*34(38)*	*0.5(0.4)*	*17(13)*
Birch	*61(33)*	*31(14)*	*35(31)*	*14(28)*	*31(26)*	*17(20)*	*30(32)*	*32(5)*	*31(24)*	*61(33)*	*14(5)*	*14(9)*
Other leaf	*0*	*0*	*0*	*0*	*4(2)*	*0*	*5(0.2)*	*0*	*1*	*5(2)*	*4(0.2)*	*2(1)*
Mean dbh (cm)	8	7	9	11	14	10	12	9	10	14	7	2
Mean tree height (m)	9	8	9	11	12	10	12	9	10	12	8	2
Mean stem size (m^3sob)	0.033	0.036	0.042	0.065	0.104	0.051	0.0101	0.061	0.062	0.104	0.033	0.028
Mean whole tree size (m^3sob)	0.038	0.046	0.053	0.078	0.143	0.062	0.122	0.072	0.077	0.143	0.38	0.037
Standing volume (m^3sob/ha)	81	54	119	29	112	53	128	57	79	128	29	37
Calculated harvested biomass (raw tonnes/ha)	100	59	123	32	128	54	129	63	86	129	32	39
Actual harvested biomass (raw tonnes /ha)	77	51	86	14	42	45	98	59	59	98	14	27
Conifer (% of pulpwood volume)	90	0	78	68	41	77	39	95	70	95	0	32
Deciduous (% of pulpwood volume)	10	0	22	32	59	23	61	5	30	61	0	23
Energywood (% of total harvested volume)	36	100	28	23	32	34	32	17	38	100	17	26
Soil (M=mineral, P=Peat)	M	P	M	M	P	P	M	P				

3.2 *Thinning quality (stand after harvest)*

On average the stem density on the sites after the thinning was 1064 stems per ha (Table 4). The mean stem volume after harvest was 0.105 m^3sob and the mean volume for the whole tree was 0.129 m^3sob (Table 4). The tree species mix on the average site after thinning consisted 70% of pine, 18% spruce, 11% birch and 1% of other deciduous trees (Fig. 4).

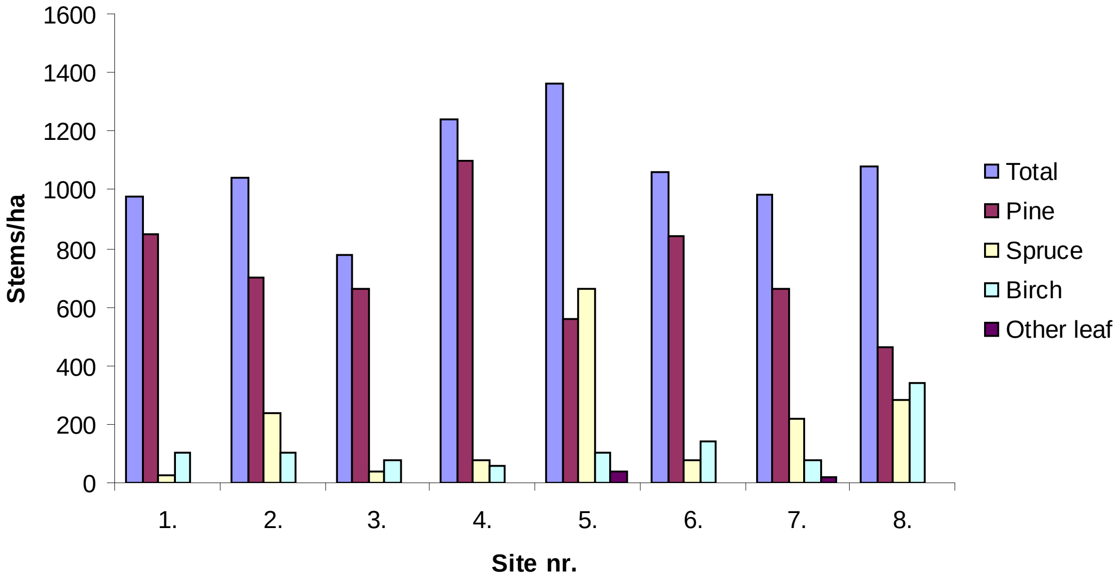

Figure 4. Stem density of harvesting sites after harvest.
Figur 4. Beståndens täthet efter avverkning.

Table 4. Characteristics of harvesting sites after harvest
Tabell 4. Förstagallringsbeståndens egenskaper efter avverkning

	Site											
	1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**Mean**	**Max**	**Min**	**sd**
Area (ha)	3.6	2.1	4.6	6.5	3.8	7.9	1.6	1.6	4	7.9	1.6	2
Basal area (m^2)	18	17	23	14	19	15	21	17	18	23	14	3
Stand density (stems/ha)	975	1040	780	1240	1360	1060	980	1080	1064	1360	780	175
Share of stems per specie (%) (and share of biomass (%))												
Pine	*87(96)*	*67(86)*	*85(95)*	*89(91)*	*41(51)*	*79(90)*	*67(75)*	*43(92)*	*70(85)*	*89(92)*	*41(51)*	*15(19)*
Spruce	*3(1)*	*23(9)*	*5(2)*	*6(5)*	*49(42)*	*8(1)*	*22(12)*	*26(10)*	*18(10)*	*49(42)*	*3(1)*	*18(14)*
Birch	*10(4)*	*10(5)*	*10(3)*	*5(4)*	*7(5)*	*13(9)*	*8(14)*	*31(4)*	*11(6)*	*31(14)*	*5(3)*	*8(4)*
Other leaf	*0*	*0*	*0*	*0*	*3(1)*	*0*	*2(0.1)*	*0*	*1(0.2)*	*3(1)*	*2(0.1)*	*1(0.5)*
Mean dbh (cm)	14	13	17	11	13	12	15	12	13	17	11	2
Mean tree height (m)	12	11	13	10	13	11	13	10	12	13	10	1
Mean stem size (m^3sob)	0.109	0.097	0.150	0.060	0.103	0.080	0.138	0.106	0.105	0.150	0.060	0.029
Mean size of whole tree (m^3sob)	0.132	0.122	0.179	0.074	0.130	0.102	0.188	0.104	0.129	0.188	0.074	0.039
Standing volume (m^3sob/ha)	106	101	117	74	140	85	135	114	109	140	74	23
Stand biomass density (raw tonnes/ha)	112	109	121	79	149	93	157	97	115	157	79	27
Soil type (M=mineral, P=Peat)	M	P	M	M	P	P	M	P				

3.3 *Total time consumption & productivity*

The total time consumption for all harvesters in all sites was 363 h, which gives a mean total time consumption of 0.23 h per tonne and 14.3 h per ha (Table 5). The total time consumption for the forwarders was 216.5 h, which gave a mean total time consumption of 8.7 h per ha and 0.15 h per tonne at an average forest transport distance of 294 meters (Table 6). The average total time consumption per tree for the harvester was 35 seconds and was for the forwarder 26 seconds (Table 5). The time consumption per stem seems to increase with increased stem size harvested (Fig. 5).

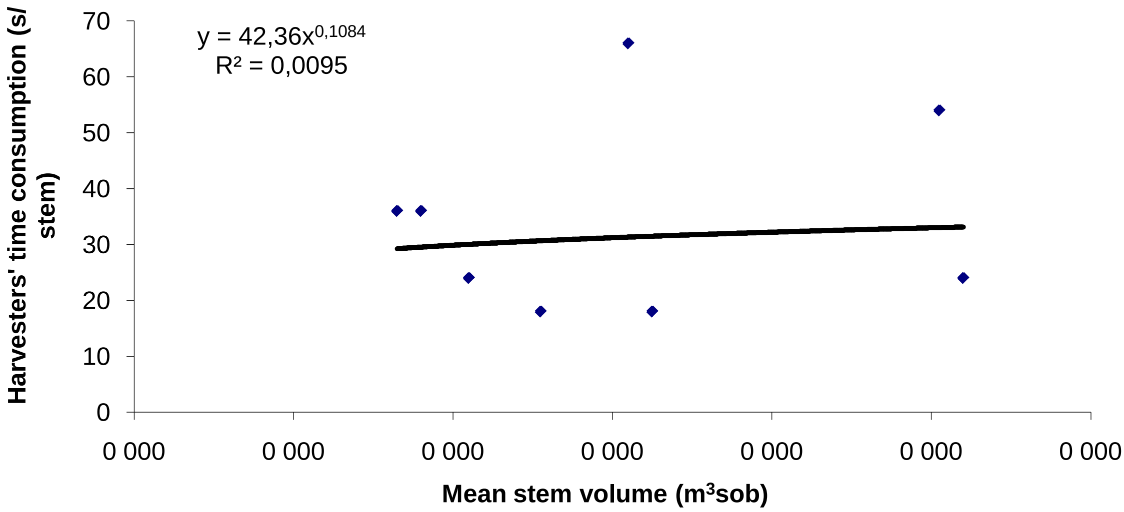

Figure 5. Harvesters' time consumption per harvested mean stem as a function of the mean stem volume.
Figur 5. Skördarnas *tidskonsumtion per skördad medelstam som funktion av medelstammen.*

Table 5. Total time consumption per machine and harvesting site
Tabell 5. Total tidsåtgång per maskin och avverkningsobjekt

	Site											
	1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**Mean**	**Max**	**Min**	**sd**
Harvester (h/ha)	27.9	16.0	21.4	2.3	6.2	4.4	19.1	16.9	14.3	27.9	2.3	9.1
Forwarder (h/ha)	13.3	5.7	5.2	2.0	4.6	6.3	20.3	12.5	8.7	20.3	2.0	6.1
Harvester (s/tree)	36	36	24	18	24	18	54	66	35	66,0	18	17
Forwarder (s/tree)	18	12	6	18	18	24	60	48	26	60	6	19
Harvester (h/raw tonne)	0.36	0.31	0.25	0.17	0.15	0.10	0.19	0.29	0.23	0.36	0.10	0.09
Forwarder (h/raw tonne)	0.17	0.11	0.06	0.15	0.11	0.14	0.21	0.21	0.15	0.17	0.06	0.05

The harvester time consumption per ha increased, when the harvested amount of raw tonnes per ha increased (Fig. 6).

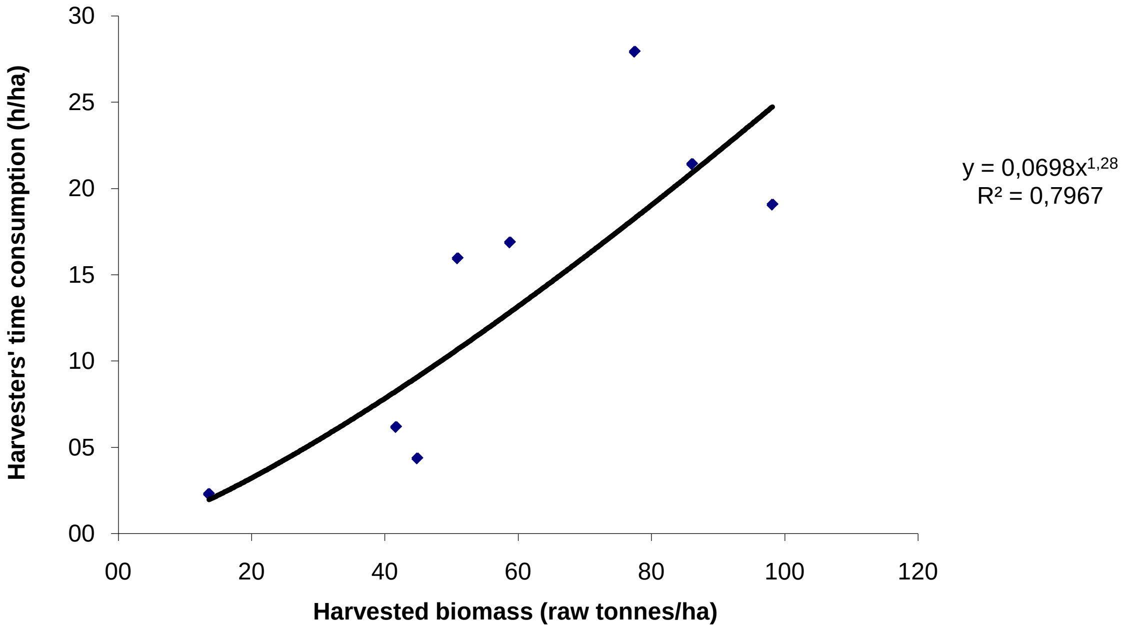

Figure 6. Time consumption for the harvesters as a function of harvested biomass per ha.
Figur 6. Tidskonsumtion för skördarna som funktion av skördad biomassa per ha.

The harvesters' average productivity was 5.1 raw tonnes per h at a mean removal of 59.1 raw tonnes per ha (Table 6). Of this removal, 41.2 raw tonnes (70%) was pulpwood and 17.9 raw tonnes (30%) was energy wood. On site number 6 the harvester's productivity (raw tonnes/h) was at its highest were it produced 10 raw tonnes per h. On this site the harvested mean tree volume (whole tree) was 0.062 m^3sob (Table 6) and the tree species mix of the stems was 83% conifer and 17% deciduous before harvest (Table 1.). On the site were the harvesters' productivity was at its lowest (sites number 1, 2 and 8), the harvested mean tree volume (whole tree) was 0.038, 0.046 and 0.072 m^3sob respectively (Table 6). On these sites the trees species mix before harvest was 51% conifer and 49% deciduous on site nr 1, on site nr 2 the mix was 78% conifer and 22% deciduous and on site 8 the mix was 68% conifer and 32% deciduous (Table 1).

On average the harvesters cut 128 stems per h (sd 7). The most stems per h were harvested on sites number 4 and 6 (Table 6) where the harvested mean tree volume (whole tree) was 0.078 m^3sob and 0.062 m^3sob respectively (Table 3). On the site where the least stems per h were harvested was site number 8 (Table 6). The harvested mean tree volume (whole tree) on this site was 0.072 m^3sob (Table 3).

The harvesters' productivity (raw tonnes/h) increased as the mean size of the harvested whole tree (m^3sob) increased (Fig. 7). The larger the harvested whole tree got, the more stems h was also harvested (Fig. 7).

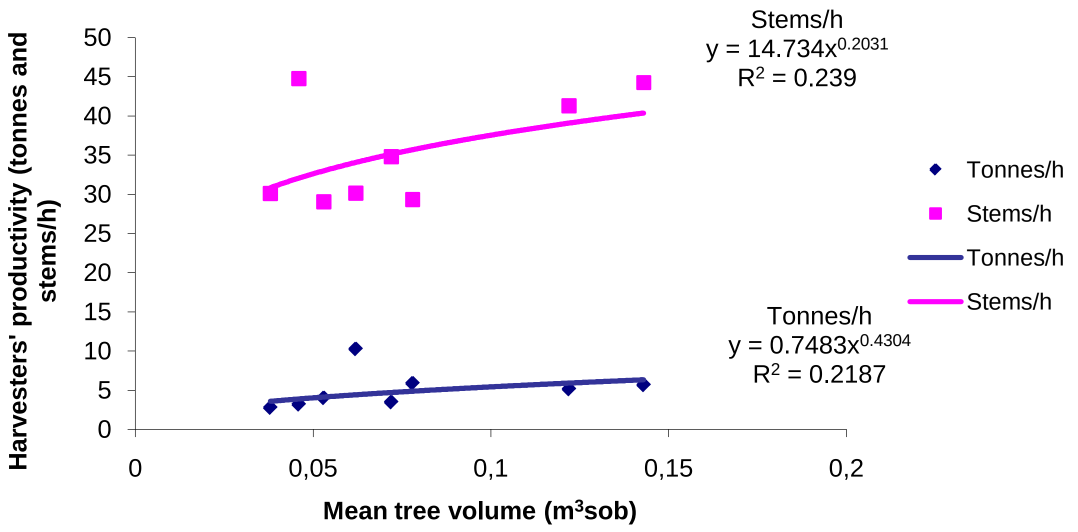

Figure 7. The harvesters' productivity, as a function of the harvested mean whole tree.
Figur 7. Skördarnas produktivitet, som funktion av skördad medelträd.

The harvesters' productivity (raw tonnes/h) decreases somewhat with increasing harvested biomass per ha (Fig. 8).

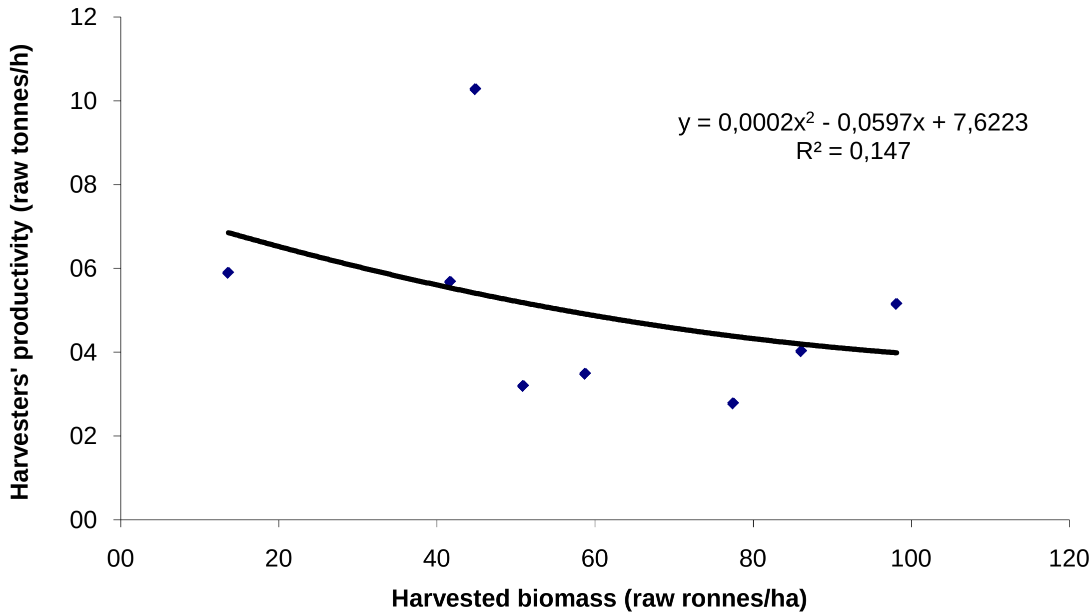

Figure 8. Harvesters' productivity (raw tonnes/h) as a function of the harvested biomass per ha.
Figur 8. Skördarnas produktivitet(råton/h) som funktion av den skördade biomassan per ha.

Table 6. Productivity of the harvesters and forwarders per harvesting site
Tabell 6. Produktivitet på skördarna och skotarna per avverkningsobjekt

	Site											
	1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**Mean**	**Max**	**Min**	**sd**
Harvester (raw tonnes/h)	2.8	3.2	4.0	5.9	5.7	10.3	5.1	3.5	5.1	10.3	2.8	2.4
Forwarder (raw tonnes/h)	5.8	8.9	16.5	6.8	7.6	7.2	4.8	4.7	7.8	16.5	4.7	3.8
Harvester (Stems/h)	100	100	150	200	150	200	67	55	128	200	55	56
Forwarder (Stems/h)	200	300	600	200	200	150	60	75	223	600	60	170
Forwarding distance (m)	350	200	450	450	100	650	50	100	294	650	50	215

The forwarders' average productivity was 7.8 raw tonnes per h at a forwarding distance of 294 m (Table 6). The highest productivity for the forwarder was found on site 3 were the productivity was 17 raw tonnes per h at a forwarding distance of 450 m. The lowest the productivity was on site nr 7 and 8, were the productivity was 4.8 and 4.7 raw tonnes per hour respectively at a corresponding forwarding distance of 50 m on site 7 and 100 m on site 8 (Table 6).

3.4 Costs

The average work costs was 1247.5 €/ha for the harvesters and 758.4 €/ha for the forwarders giving an average total costs per ha of 2005.4 €/ha. The total costs per ha varied between 1346.2 € and 2373.6 € (sd 478.8). The average cost per raw tonnes was 49.5 € (sd 51.50). The highest cost was found in site 4 where the total costs was 15428.6 € or 174.6 €/ton, and the lowest costs were found in site 8 where the total costs was 2153.90 € or 22.9 €/ton. The costs per harvested raw tonnes increased with increase harvested mean stem volume (Fig. 9).

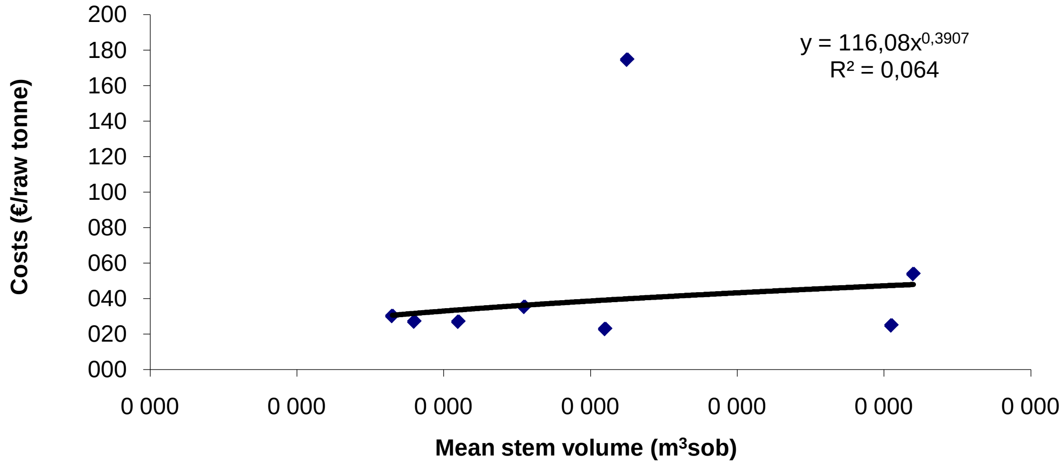

Figure 9. Harvesting costs (€ per raw tonne) as a function of the mean stem volume.
Figur 9. Avverkningskostnader (€ per råton) som en funktion av medel stammen.

The total harvesting costs decreased with increasing harvested biomass (raw tonnes) per ha (Fig. 10).

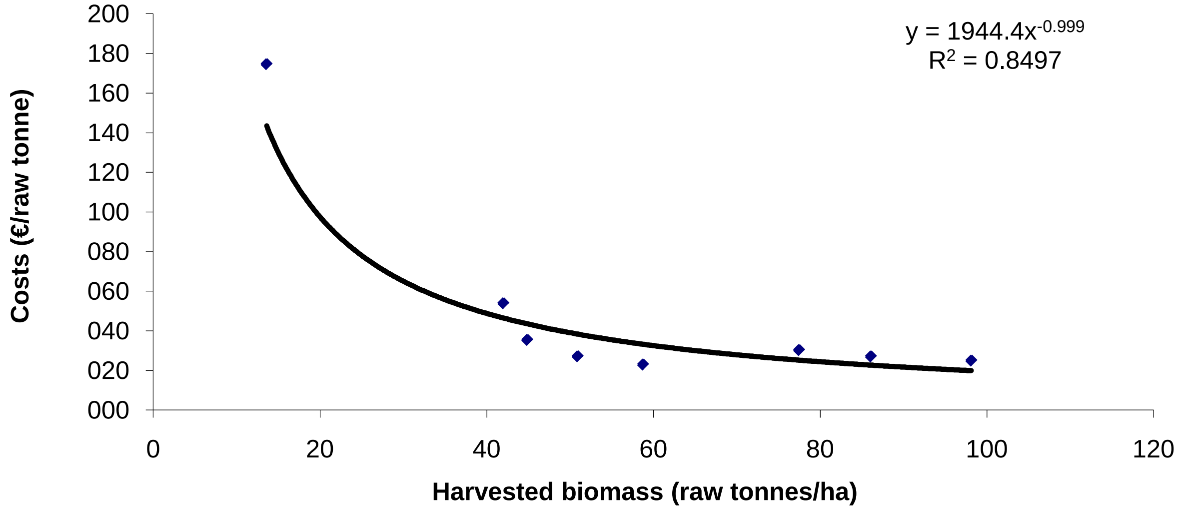

Figure 10. Costs per raw tonne as a function of the biomass harvested per ha.
Figur 10. Kostnader per råton som en funktion av den avverkade biomassan per hektar.

4 Discussion

4.1 Material and methods

In the beginning of this study the plan was that 20 FT sites that were suitable for integrated harvest should be measured before and after harvest. However, due to storms that hit Finland during the summer of 2010 only 8 out of the 20 sites was harvested in, which only complete data could be collected. As a consequence, the results presented in this study did not reach the wished quantity, because if there had been more sites within the study, it would probably have been easier to find out which type of sites that are not suitable for integrated harvest. A larger amount of data would also have affected the functions that were obtained, giving more reliable result which would have render better comparison to other studies. With a larger amount of sites the standard deviation could also have become lower, which in turn would have given more credibility to the study. The standard deviations (sd) in the current study were not so large, for instance for the biomass density per ha before harvest the sd was 67 and for after harvest the sd was 27. These are not too large but, they could have been lower if a qualitative study would have been done.

In each site five circle plots were systematically laid out regardless of the sites size, which might have rendered in-correct data of sites characteristics. If the number circle plots would have been 10-12 per ha, as recommended in Tapio's field table (Anon. 2006), the quality of the measurements would probably been more accurate. However, only five plots were chosen because of the limited time for the field inventory work (field measurements was done on all of the twenty sites before harvest, although only eight of these were harvested and measured after harvest) and also because some of the sites were quite large, the largest was 7.9 ha (Table 2).

The measurement of dbh in the current study was done with a single-handed caliper and the height was measured with a manual hypsometer Suunto PM-6. When going through the literature (Korpilahti & Örn 2002; Mäkelä et al. 2002; Kärhä et al. 2003; Kärhä et al. 2006), for present study, it was not found what kind of instruments they had used. In each circular plot the tree height was only measured on the average tree, which in turn gave poor estimations of e.g. trees biomass and volumes using functions from literature Instead, several trees per plot, representing the diversity of trees in the plot, should have been measured.

The center of the circle plots was marked with at pole. Most of these poles had though been knocked down either by a tree, the harvester or the forwarder, which made it rater time consuming to find the center of the circle plots, but in the end all were still found. Here a GPS would also have been useful, because it would have helped to find the center of the plots, instead of walking around with a paper map and trying to find the plot centers.

The sites were located in a wide spread area and because of this it was difficult to keep track of the harvesting operations and also the time consumption. When comparing the current study to the literature, it was found that in all of the studies some kind of time study had been done, although these were done in a different way than in the current study. In the current study the time was informed by the machine operators, but in others like Kärhä et al. (2003) study the time had been measured by the authors on the harvesting sites. Here it is suggested that if a similar study is done with in UPM, the author should make some kind of time study on site. For if a similar study is done like the current one, some kind of time study should be included.

In this study there were no measurements done on the sites ground conditions, e.g. bearing capacity, surface structure and slopes. This is a measurement, which should have been done, to obtain better data on the sites. If the ground conditions would have been measured it could have been checked, how and if these affect the productivity and the costs of the harvesting operations. When looking at the literature (Korpilahti & Örn 2002; Mäkelä et al. 2002; Kärhä et al. 2003; Kärhä et al. 2006; Kärhä 2008; Kärhä et al. 2009), it was found that these measurements were not in the other studies either. There are though studies were this has been included, like in Ovaskainen et al. (2004), where they tried to limit the ground conditions affect on the productivity as much as possible. Even though they did this, they still found that on sites with worse terrain conditions (bearing capacity, surface structure and slopes) the productivity of the harvesters and forwarders was affected negatively (Ovaskainen et al. 2004). Therefore, the specific ground conditions in the studied sites in time studies are important to measure.

4.2 Harvest, remaining stands and thinning quality

On average the amount of harvested biomass per ha was 59 raw tonnes and the same calculated amount would have been 86 raw tonnes/ha (Table 3.). The reason for the calculated amount being so much higher than the actual amount was thought to be, that the height on each tree was not measured. There for the mean height on the removed trees was most likely over estimated and that could explain the great difference between the actual harvested biomass per ha to the calculated removed biomass per ha. Because the calculated removed biomass was so much higher (on average 57.4%) than the actual harvested amount, the calculated amount was not used in any of the calculations. The calculated amount was only shown in Table 3, but as mentioned above, these were not taken account for in the study. Another reason for the calculated amount being so much higher, is that when the forwarder collects the pulp- and energy wood, it usually cannot collect all of the branches and the pulpwood logs and therefore some are left on the harvesting site, giving this deviation in actual and calculated harvested amount of biomass.

In the current study the mean stem volume after harvest was 0.105 m^3sob and the mean volume for the whole tree was 0.129 m^3sob. This gives a significant increase in the mean stem volume from 0.074 m^3sob before harvest to 0.105 m^3sob after harvest and for the whole tree from 0.091 m^3sob to 0.129 m^3sob. The mean height increased from 9 m before harvest (Table 1) and 12 m after harvest (Table 4). The mean stem dbh was not influenced much by the harvest since it was 11 cm before harvest (Table 1) and 13 cm after harvest (Table 4). When looking at the tree species mixture after harvest it was found that the pines share had increased on each site after harvest (Fig 4). This indicates that the harvesting teams have followed the thinning instructions well, by removing tree species that are not as suitable for these kind of growth spots, since the domination trees species was pine on most of the sites.

Damages on remaining trees due to harvesting and forwarding work and the width of the strip roads and the distance between strip roads (for calculation of the share of strip road area of total harvested area) were not measured. For the harvesting quality analysis the last two would have been crucial to have within the study. Now they were only deemed to be good or bad. The reason for this been so crucial in Finland at least is because the quality of energy wood harvests has become so poor (Äijälä 2010). Most of the remarks that energy wood harvests have got are the large number of damaged trees after harvest (Äijälä 2010). These damages can though usually be traced back to the difficult harvesting conditions (Äijälä 2010). Energy wood harvests have also gotten remarks for the deep tire tracks after harvest and also that the harvest has been to strong, meaning that the stem density after harvest has been below the recommendations (Äijälä 2010). Äijälä (2010) does not mention the reason for this, but the author in current study believes that it cloud have to do with the strip road being too close to each other or to wide.

However, in present study the quality of the harvesting operations, concerning the thinning intensity, was very good. On average, for all sites, the stem density after harvest was 1064 stem per ha (sd 175) (Table 5) which is in line by the thinning instructions given to the harvesting teams and recommendations found in literature (Anon. 2006; Äijälä et al. 2010).

The forwarding distance in this study was measured in many ways, it was both measured by a map program, out in the field and also the operators of the forwarders reported the actual forwarding distance. The deviation between these were very small for instance the average measured harvesting distance was 289 m (Table1) and the average forwarding distance reported by the harvesting teams was 294 m (Table 6). Because the deviation was so small it was decided to use the values reported by the harvesting teams.

4.3 Harvesting productivity and costs

In present study it was found that the productivity (raw tonnes/h) increase with increased stem size harvested, which is consistent with findings by Mäkelä et al. (2002) and Kärhä et al. (2006). In Kärhä et al. (2006) the productivity was 14 m^3/ha a harvested stem volume of 60 dm^3. The productivity in the current study at the same stem volume was about 6 m^3/h (equals about 5 raw tonnes/h) (Table 4). The difference here is that in Kärhä et al. (2006) study the time was given in effective work time not total time as in the current study. To convert from total time (G_{15}) to effective work time, the total time is usually timed with 1.197 according to Kuitto et al. (1994). When timing the current studies productivity with above-mentioned number you get a productivity of 7.2 m^3/h, which is much lower than the productivity in Kärhä et al. (2006) study.

The time consumption per harvested stem was clearly connected to the mean stem volume in Kärhä et al. (2006) study. In Kärhä et al. (2006) study the time consumption per stem increased the most when the stem volume increased from 5 dm^3 to 15 dm^3. After this the time consumption per tree still kept increasing but not as much as when the trees were smaller. The same incensement in time consumption per tree could not be found in the current study (Fig. 6). Here the difference can as in the paragraph above be explained by the time, since it was effective work time in Kärhä et al. (2006) study and total time in the current study, but not completely, here the biggest difference was the absolute values, which again can be traced back to how the time consumption was given in these two studies.

When the stems get larger the harvester equipped with a AHH might only be able to accumulate 2 stems per cycle as when the trees are smaller it can accumulate from 4-5 stems per cycle. According to the current study it would take less time for the harvesters to harvest larger trees than smaller trees (stems/h) (Fig. 7), which is not logical at all, as the harvesting was performed by AHH. A more logic result would have been a result like the one Kärhä et al. (2006) reached were it took less time to harvest smaller trees than larger trees. The result from the current study makes the author suspicious toward the accuracy of the informed time by the harvesting teams. The more logic result was that was the productivity (raw tonnes/h) increased as the mean stem volume increased. The same result was also reach in Kärhä et al. (2003) study.

In Kärhä et al. (2006) study it was found that the smaller the mean harvested stem volume (dm^3) the higher the cost become to harvest the stand. The same result was not reached in present study. This could probably be explained by the scarce amount of sites and thus also scarce amount of data. Korpilahti and Örn (2002) and Kärhä et al. (2003) found that it is more expensive to perform an integrated harvest compared to perform an energy wood harvest. In these studies the aim was to check how the different kinds of harvesting methods affect the forest owners' economy and even though Korpilahti and Örn (2002) included the state subsidies to the revenue calculations they would not have been any profit for the forest owner in either of the studies.

The cost per h for the harvester and forwarder were extremely high in this study, 105€ and 117€ respectively. Normally they would have been between 70 and 80 € for the harvesters and between 50 and 60€ for the forwarders (Kohonen 2010). The reason for the hourly wage being so much higher in this study is because they are based on actual values that are paid as piecework (the entrepreneur gets paid per harvested m^3). But due to that these values are a contract specific secret they could not be used, and there for the higher hourly wages were used to compensate this.

The site from which most pulpwood was harvested in the current study was site number 3 and the site form that the most energy wood (raw tonnes) was harvested was site number 6. The two sites seem quite similar, the difference in costs can be traced back to the forwarding distance, which was 200 m longer on site nr. 6, (which was the more expensive to harvest). Another big difference was the stem volume after harvest, which was 0.139 m^3sob for site nr. 3 and was 0.074 m^3sob for site nr.6. There was also some difference in the height after harvest, but nothing that could explain why there was more energy wood harvested from one and more pulpwood from the other. The only real difference was that site nr 3 was harvested by team C and site nr. 6 by team B.

When analyzing how the amount of biomass/ha affected the costs per ton (€), there was a clear connection to be found between these two; the more biomass that was harvested the less the costs (€) per ton (Fig 9.). The same clear connection can also be found in studies by Kärhä et al. (2003), Kärhä et al. (2006) and Korpilahti and Örn (2002).

The state subsidies were not taken account for in the current study because the forest owner's perspective was not included in the study. Another reason for leaving the subsidies out from this study was because at the writing moment the state subsidies are being renewed, and how much the subsidies will be, and for what kind of sites the forest owners can apply for the subsidies was not clear.

If the state subsidies would have been taken account for in this study, it is thought that it would not have made the harvesting operations profitable for the forest owners. This because the harvesting operations were so expensive that even though the revenue from the energy wood, pulpwood and the Kemera aid would have been summed together the costs for the harvesting operations would still have been large. This is one of the reasons the state subsidies are being renewed to make it more attractive for forest owners to let FT's be performed in their forests.

4.4 Comparison between UPMs former study and the current study

The data that was collected in the current study was quite similar to the former UPM study. The biggest difference was as already mentioned was that in the current study there were measurements done in the field before and after harvest

Because the material was so severely reduced in the current study, it became uncertain to compare the current studies results to the former UPM study. The only thing that could be compared was the costs per ton. When comparing the cost per ton for the current study to the former UPM study it was found that the curves (function) were quite similar, except for an outlier (site 4), that had a cost per ton of 174.6 € (Fig 11. blue dots (New study)).

By removing the outlier (Fig. 11 red dots (outlier removed)) one finds that the cost curves are quite similar to UPMs former study and the current study (Fig.11).

In the former UPM study the average cost per ton was 22.5 € and the average cost per ton was 49.5 € per raw tonnes in the current study. This would give an increase in costs per ton by 120%. If removing the outlier from the calculations the cost per ton decrease by 40% to 31.6 €. To better illustrate the changes in costs per ton the costs from the different calculations was plotted out in Fig. 11.

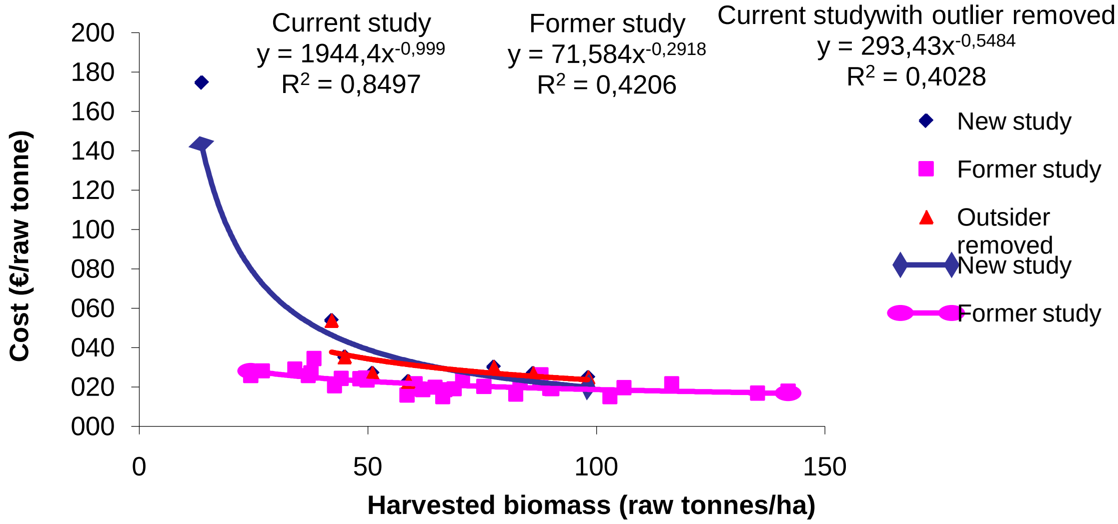

Figure 11. Comparison between UPMs former study, the current study and current study with outlier removed were costs per raw tonne was made as a function of the biomass harvested per ha.
Figur 11. Jämförelse mellan UPMs senaste studie, den nya studien och den nya studien där det avvikande värdet har avlägsnats. Kostnader per råton var gjorda som en funktion av den avverkade biomassan per hektar.

5 Conclusions

- The harvesters' productivity was affected by the amount of biomass (raw tonnes raw density) harvested per ha. The mean stem also had some affect on the harvesters' productivity. The forwarding distance did not affect the forwarders productivity in this study.

- The thinning quality (stems left after harvest) was very good because it fitted well with in the current recommendations for integrated harvest and also traditional FT's.

- The stem density before harvest strongly affected the time consumption for the harvesters. In this study no connection between the tree species mix and the time consumption for the harvesters could be found. The reason for this was that the sites that contained the evenly distributed tree species mix also had the highest tree density before harvest.

- The cost (€/tonne) for integrated harvest decreases as the amount of harvested biomass per hectare (raw tonnes/ha) increases.

5.1 Future studies

An interesting thing to study in upcoming studies would be to see how the tree species mix affects the productivity in the harvester, at least it is thought by the author of the current study, that if you have a stand with 80% pine would be faster to harvest then a stand that has a tree species mix of 50% pine and 50% birch.

What also could be interesting to study would be to make several qualitative studies in different parts of the country and the combine these to a large result. In this way one could also find out in what parts of the country integrated harvest it is better to perform this kind of harvests, meaning were have the costs been the lowest and the productivity the highest. This is something that might interest forest companies, entrepreneurs and also forest owners.

In upcoming studies done in Finland it would be good to include the forest owner’s perspective and the Kemera subsidies should also be included for after that they have been renewed and the regulations agreed up on.

What also could be interesting to study is what kind of harvesting method has a higher productivity when it comes to integrated harvesting; harvesting from strip roads or using harvesting in stands.

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Appendix

Appendix 1. Map over Finland with the borders between the different conversion rate areas from kg to m3

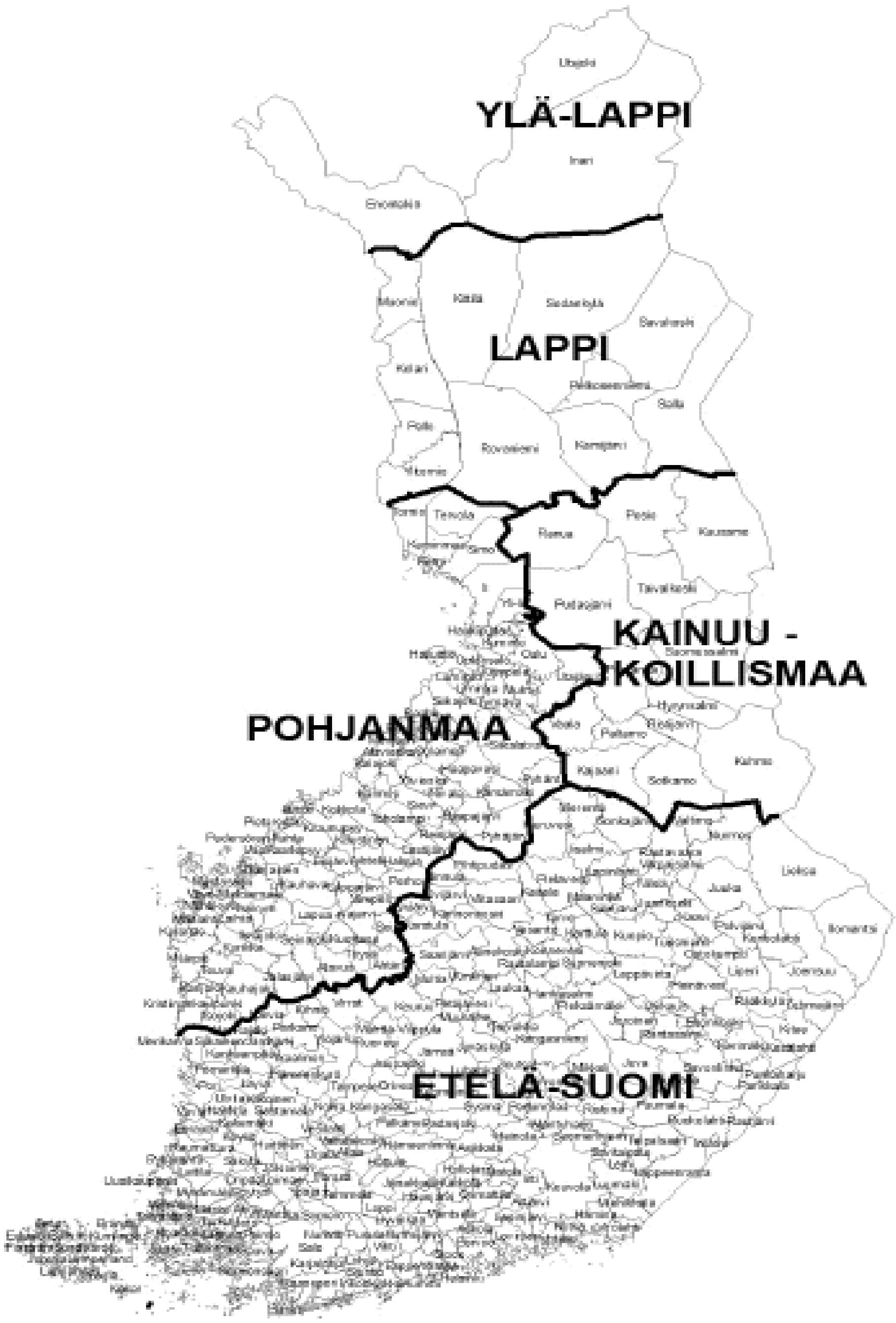

Figure 1. Map over Finland with the borders between the different conversion rate areas from kg to m^3 (Anon. 2010a).
Figur 1. Karta över Finland med avgränsningar mellan områden med olika omvandlingstal från kr till m^3(Anon. 2010a).

Appendix 2. Tables with conversion rates for energywood kg to m3

Table 1. Conversion rates for energywood from kg to m^3 (Moisture content is to be used if known) (Lindblad et al. 2008)
Tabell 1. Omvandlingstal för energived från kg till m^3 (Fukthalten används ifall den är känd) (Lindblad et al. 2008)

Tree species	Weight class**	Moisture content, %	Season	Raw density, kg/m³
Conifer	1	> 55	whole year	1000
	2	> 55	whole year	900
	3	40 – 54	1/5 – 30/9	750
	4	< 40	1/5 – 30/9	600
Birch	1	45	whole year	1000
	2	45	whole year	900
	3	35 - 44	1/5 – 30/9	750
	4	< 35	1/5 – 30/9	700
Other deciduous trees	1	> 50	whole year	900
	2	> 50	whole year	800
	3	40–49	1/5.– 30/9	700
	4	< 40	1/5.– 30/9	600
Mixed tree species*	1	> 50	whole year	1000
	2	> 50	whole year	900
	3	40–49	1/5.– 30/9	750
	4	< 40	1/5.– 30/9	650

* Mixed tree species: Main tree species share is under 70 % of the total volume of the measurement lot.
** Definitions of weight classes:

1. The conversion rate is used when measuring energy wood from thinnings if the e.g. pile of biomass to be measured contains a considerable amount of snow or ice or when the moisture content of the biomass requires it (Found out trough measurement).

2. The conversion rate is used when measuring fresh energy wood from thinnings, the whole year around. It is also used when the biomass moisture content is equal to the moisture content in the mentioned class (see weight class 2 in table 7.) (Found out through measurement.)

3. The conversion rate used when measuring energy wood from thinnings that has dried at least two weeks during the prevailing season. It is also used when the moisture content of the biomass equals the moisture content in the mentioned class (see weight class 3 in table 7.)

4. The conversion rate is used when measuring energy wood from thinnings, which has dried at least a month in good conditions during the prevailing season. It is also used

when moisture content of the biomass equals the moisture content in the mentioned class (Lindblad et al. 2008).

The reason for the use of different raw densities for deciduous and coniferous trees is because the natural moisture content varies more in deciduous trees in spring than it does in coniferous trees (Lindblad et al. 2008).

When it comes to dry-raw density the conversion rates are the following:

Table 2. Dry-raw density for different assortments of energy wood from thinnings (Lindblad et al. 2008)
Tabell 2. Torr-rådensitet för olika energived sortiment från gallringar
(Lindblad et al. 2008)

Assortment	Tree species/Definition	Dry-Raw density, kg/m³
Energy wood from thinnings	Pine	385
	Spruce	400
	Birch	475
	Alder	370
	Aspen	385

The biomasses solid volume with bark can be calculated in the following way:

a) The biomass weight (kg) divided by raw density (kg/m³). The result is given by an accuracy of a tenth of a cubic meter (solid) (0.1 m³).

b) The biomass moisture content (%) is determined by sample measurements (no standard set, only requirement is that it must follow the Finnish wood measurement law of ± 4%). On the basis of moisture content and dry-raw density (kg/m³) the raw density (kg/m³) of the biomass can be calculated. Solid volume with bark is calculated in the same manner as in paragraph a) (Lindblad et al. 2008).

The dry-raw density has been calculated in the following way:

“rg= 100 x r0,g / (100 – u)

Where rg is raw density, r0,g dry-raw density and u moisture content. The dry-raw density used in this calculation is:
a) The dry-raw densities mentioned above
b) The dry–raw densities that have been determinatet by the operator from random samples for the mentioned assortments (no standard set, only requirement is that it must follow the Finnish wood measurement law of ± 4%) (Lindblad et al. 2008).

Appendix 3. Tables with conversion rates for pulpwood from kg to m3

Table 1. Conversion rates for pulpwood in Southern Finland from kg to m^3 (Anon. 2010a)
Tabell 1. Omvandlingstal för *massaved i södra Finland från kg till m^3* (Anon. 2010a)

Conifer pulpwood Southern Finland Month	Fresh Raw density, (kg/m³)	Semi-dry Raw density, (kg/m³)	Birch pulpwood Southern Finland Month	Fresh Raw density, (kg/m³)	Semi-dry Raw density, (kg/m³)
January	950	900	January	922	884
February	943	893	February	907	879
March	927	877	March	885	856
April	905	855	April	858	828
May	885	834	May	836	806
June	870	819	June	822	791
July	863	813	July	819	787
August	866	815	August	827	796
September	878	827	September	846	815
October	896	846	October	870	840
November	919	868	November	897	868
December	939	889	December	917	889

Table 2. Conversion rates for pulpwood in Ostronbothnia from kg to m^3 (Anon. 2010a)
Tabell 2. Omvandlingstal för massaved i Österbotten från kg till m^3 (Anon. 2010a)

Conifer pulpwood Ostrobothnia Month	Fresh Raw density, (kg/m³)	Semi-dry Raw density, (kg/m³)	Birch pulpwood Ostrobothnia Month	Fresh Raw density, (kg/m³)	Semi-dry Raw density, (kg/m³)
January	950	900	January	948	904
February	943	893	February	940	896
March	927	877	March	918	874
April	905	855	April	888	844
May	885	834	May	860	817
June	870	819	June	840	796
July	863	813	July	831	787
August	866	815	August	834	790
September	878	827	September	849	805
October	896	846	October	874	830
November	919	868	November	904	860
December	939	889	December	932	888

Table 3. Conversion rates for pulpwood in Kainuu-Koillismaa from kg to m^3 (Anon. 2010a)
Tabell 3. Omvandlingstal för massaved i Kajanaland-Koillismaa från kg till m^3 (Anon. 2010a)

Conifer pulpwood Kainuu – Koillismaa Month	**Fresh Raw density, (kg/m³)**	**Semi-dry Raw density, (kg/m³)**	**Birch pulpwood Kainuu – Koillismaa Month**	**Fresh Raw density, (kg/m³)**	**Semi-dry Raw density, (kg/m³)**
January	950	906	January	963	900
February	944	900	February	955	892
March	932	888	March	935	872
April	917	873	April	906	843
May	904	860	May	879	816
June	895	851	June	859	796
July	892	848	July	849	786
August	895	851	August	851	788
September	904	860	September	866	803
October	917	873	October	889	826
November	932	888	November	918	855
December	945	901	December	946	883

Table 3. Conversion rates for pulpwood in Lappi from kg to m^3 (Anon. 2010a)
Tabell 3. Omvandlingstal för massaved Lappland från kg till m^3 (Anon. 2010a)

Conifer pulpwood Ostrobothnia Month	**Fresh Raw density, (kg/m³)**	**Semi-dry Raw density, (kg/m³)**	**Birch pulpwood Ostrobothnia Month**	**Fresh Raw density, (kg/m³)**	**Semi-dry Raw density, (kg/m³)**
January	936	895	January	976	929
February	924	883	February	969	922
March	907	866	March	950	903
April	888	847	April	924	877
May	872	831	May	901	854
June	863	821	June	883	836
July	861	820	July	875	828
August	868	827	August	878	831
September	883	841	September	892	845
October	901	860	October	913	866
November	920	879	November	939	892
December	924	893	December	963	916

Table 4. Conversion rates for pulpwood in North Lappi from kg to m^3. (Anon. 2010a)
Tabell 4. Omvandlingstal för massaved Övre Lappland från kg till m^3 (Anon. 2010a)

Conifer pulpwood Ostrobothnia Month	**Fresh Raw density, (kg/m³)**	**Semi-dry Raw density, (kg/m³)**	**Bich pulpwood Ostrobothnia Month**	**Fresh Raw density, (kg/m³)**	**Semi-dry Raw density, (kg/m³)**
January	831	790	January	976	929
February	819	778	February	969	922
March	802	761	March	950	903
April	783	742	April	924	877
May	767	726	May	901	854
June	758	716	June	883	836
July	756	715	July	875	828
August	763	722	August	878	831
September	778	736	September	892	845
October	796	755	October	913	866
November	815	774	November	939	892
December	826	788	December	963	916

Appendix 4. UPM's first study

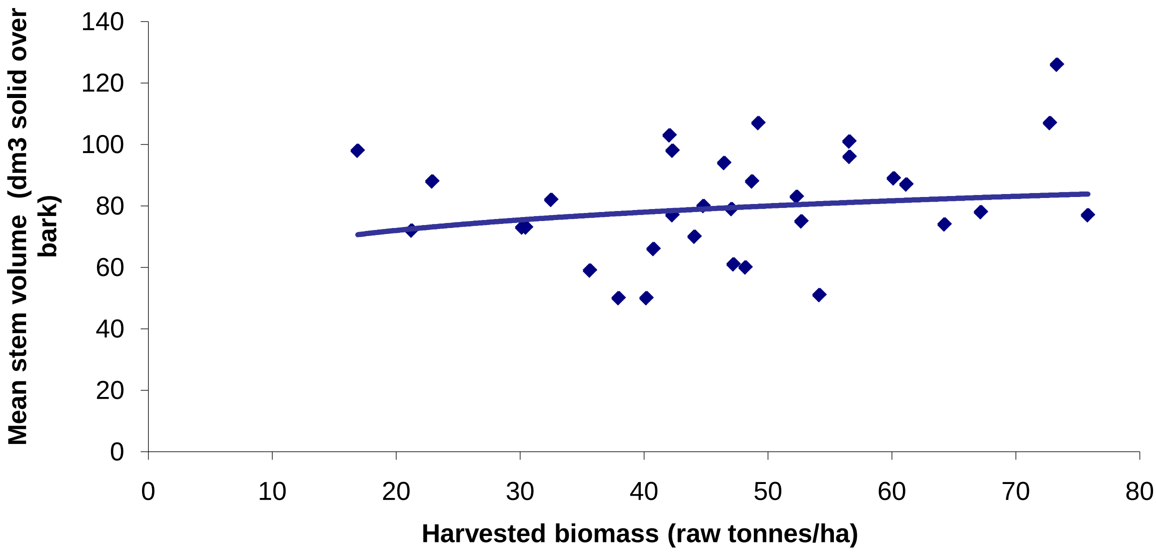

Figure 1. Mean stem volume as a function of raw tonnes/ha.
Figur 1. Medelstam volymen som funktion av råton/ha.

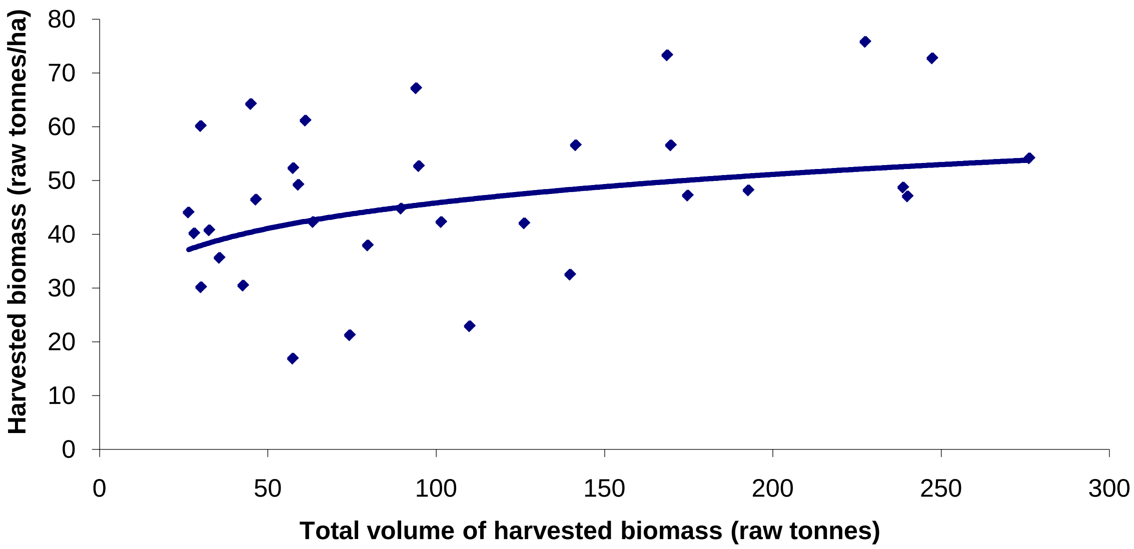

Figure 2. Raw tonnes per hectare as a function of total yield.
Figur 2. Råton per hektar som funktion av totala uttaget.

Appendix 5. UPM's former study

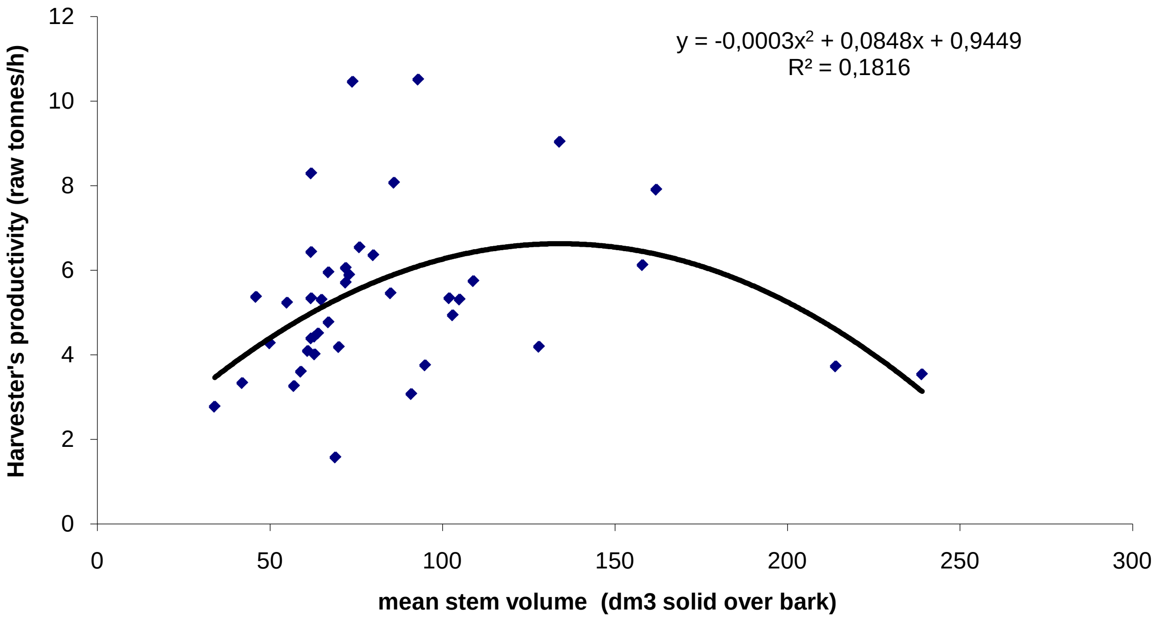

Figure 1. The harvester's productivity as a function of mean stem volume m^{3}sob in UPMs former study.
Figur 1. Skördarens produktivitet som funktion av medel stam volymen m^{3}fpb i UPMs senaste studie.

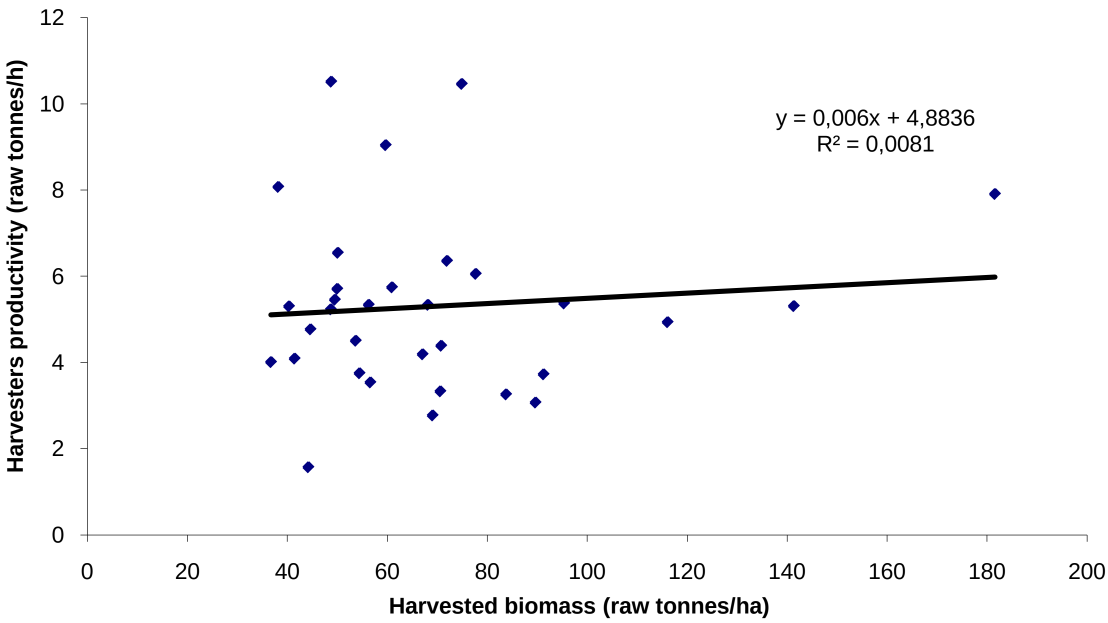

Figure 2 Harvester's productivity as a function of total harvested biomass per ha in UPMs former study.
Figur 2. Skördarens produktivitet som funktion av total skördad biomassa per ha i UPMs senaste studie.

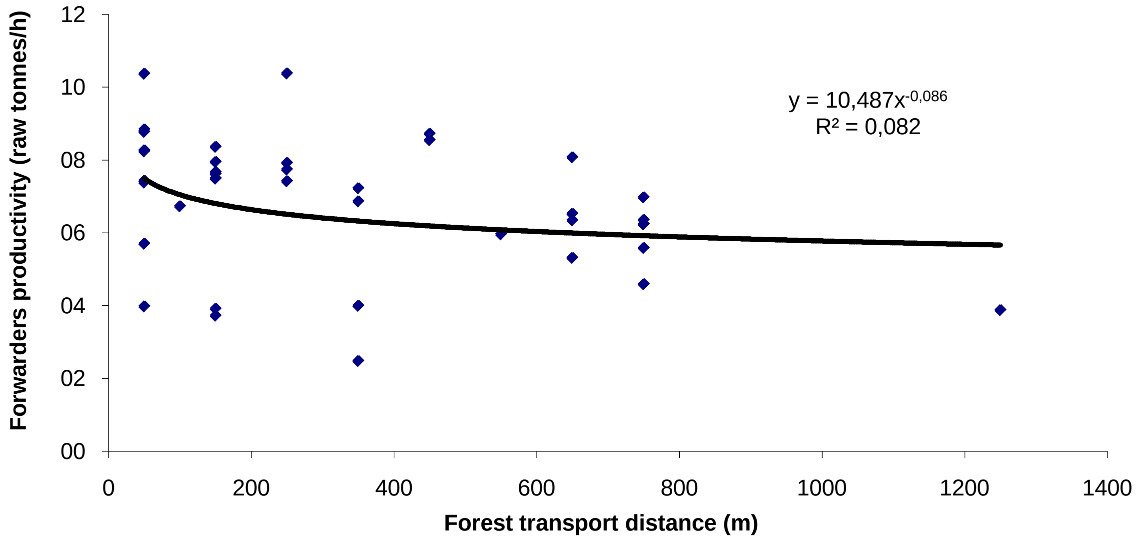

Figure 3. Forwarders productivity per h as a function of the forwarding distance from UPMs former study.
Figur 3. Skotarens produktivitet per h som funktion av skotningsavståndet från UPMs senaste studie.

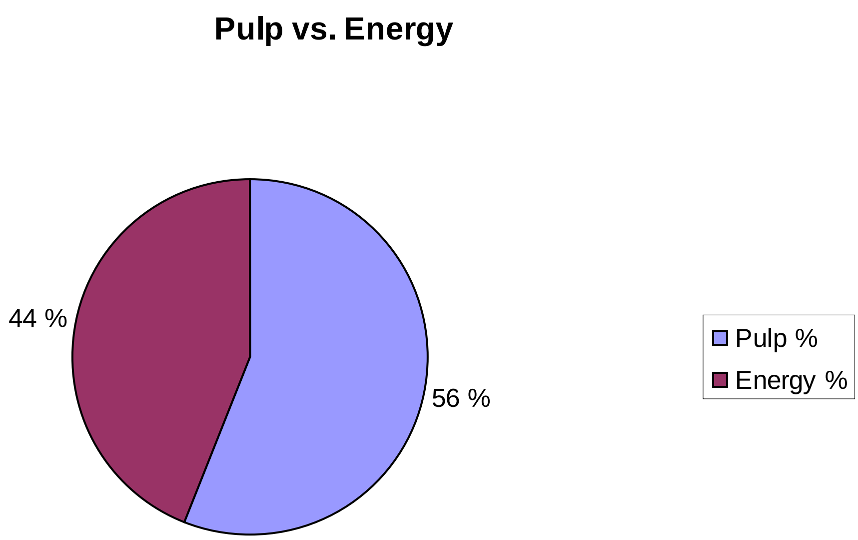

Figure 4.The ratio of harvested biomass pulpwood vs. energy wood in UPMs former study.
Figur 4. Fördelningen av skördad biomassa massaved vs. energived i UPMs senaste studie.

Appendix 6. Field form

DIAMETERS ON THE PLOT			Contract:		Date:		Block:	
Height:								
Stem	Pine	Spruce	Birch	Oth.Leaf	pre-com. th.	Comm.		
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
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Appendix 7. Formulas used to calculate mean stem and whole tree volume

Formulas that were used to obtain the mean steam volume (dm^3sob):

<u>Volume equations (v = dm^3, d = $D_{1,3}$(cm), h = height(m)) by Laasasenaho (1982) standard deviation(Pine: 7.1%, Spruce 7.5%, Birch 8.5 %):</u>

Pine v = 0.036089*d^2.01395*(0.99676)^2*h^2.07025*(h-1.3)^(-1.07209)

Spruce v = 0.022927*d^1.91505*(0.99146)^d*h^2.82541*(h-1.3)^(-1.53547)

Birch v = 0.011197*d^2.10253*(0.986)^d*h^3.98519*(h-1.3)^(-2.659)

Leaf v **=** 0.011197*d^2.10253*(0.986)^d*h^3.98519*(h-1.3)^(-2.659)

The Birch formula is usually used for deciduous trees in studies like the current one (Korhonen 2010 pers. comm.).

Formulas that were used to obtain density for the whole tree (kg):

Pine (Repola et al. 2007)**:**
”

Total (aboveground): $$\ln(y_{ki}) = b_0 + b_1 \frac{d_{Ski}}{(d_{Ski}+12)} + b_2 \frac{h_{ki}}{(h_{ki}+20)} + u_k + e_{ki}$$

Where

y_{ki} = biomass component or total biomass for tree i in stand k, kg
d_{Ski} = 2 + 1.25 d_{ki} (d_{ki} = tree diameter at breast height for tree i in stand k), cm
h_{ki} = tree height for tree i in stand k, m

b_0	-3.215 (0.059)
b_1	9.764 (0.189)
b_2	2.889 (0.188)
Random	
$\mathrm{var}(u_k)$	0.001
$\mathrm{var}(e_{ki})$	0.013

c
“

Spruce (Repola et al. 2007)**:**
”

Total (aboveground): $$\ln(y_{ki}) = b_0 + b_1 \frac{d_{Ski}}{(d_{Ski}+20)} + b_2 \ln(h_{ki}) + u_k + e_{ki}$$

Where

y_{ki} = biomass component or total biomass for tree i in stand k, kg
d_{Ski} = 2 + 1.25 d_{ki} (d_{ki} = tree diameter at breast height for tree i in stand k), cm
h_{ki} = tree height for tree i in stand k, m

b_0	-1.729 (0.059)
b_1	9.697 (0.378)
b_2	0.398 (0.077)
b_3	-

Random

$\mathrm{var}(u_k)$	0.004
$\mathrm{var}(e_{ki})$	0.015

c
"

Birch (Repola et al. 2007)**:**
"

Total (aboveground): $\ln(y_{ki}) = b_0 + b_1 \frac{d_{Ski}}{(d_{Ski}+12)} + b_2 \frac{h_{ki}}{(h_{ki}+22)} + u_k + e_{ki}$

Where

y_{ki} = biomass component or total biomass for tree i in stand k, kg
$d_{Ski} = 2 + 1.25\ d_{ki}$ (d_{ki} = tree diameter at breast height for tree i in stand k), cm
h_{ki} = tree height for tree i in stand k, m

b_0	-3.662 (0.057)
b_1	10.329 (0.182)
b_2	3.411 (0.197)

Random

$\mathrm{var}(u_k)$	0.001
$\mathrm{var}(e_{ki})$	0.007

c
"

Leaf (Repola et al. 2007)**:**
"

Total (aboveground): $\ln(y_{ki}) = b_0 + b_1 \frac{d_{Ski}}{(d_{Ski}+12)} + b_2 \frac{h_{ki}}{(h_{ki}+22)} + u_k + e_{ki}$

Where

y_{ki} = biomass component or total biomass for tree i in stand k, kg
$d_{Ski} = 2 + 1.25\ d_{ki}$ (d_{ki} = tree diameter at breast height for tree i in stand k), cm
h_{ki} = tree height for tree i in stand k, m

b_0	-3.662 (0.057)
b_1	10.329 (0.182)
b_2	3.411 (0.197)

Random

$\mathrm{var}(u_k)$	0.001
$\mathrm{var}(e_{ki})$	0.007

c
"

The birch formula is usually used for deciduous trees in studies like the current one (Korhonen 2010 pers. comm.).