Comparison of Two Stump-Lifting Heads in Final Felling Norway Spruce Stand

Kalle Kärhä

The use of stump and root wood chips has increased very rapidly in the 21st century in Finland: in the year 2000, the total consumption of stump wood chips for energy generation was 10 GWh, while in 2010 it was approximately 2 TWh. Metsäteho Oy and TTS Research evaluated two stump-lifting devices for the lifting of Norway spruce (*Picea abies*) stumps. The productivity and costs of stump lifting were determined. There was one base machine with one operator in the time study. When lifting stumps with a diameter of 30 cm, the effective hour productivity of stump lifting was 11.2 m^3 solid over bark (sob)/E_0 (4.8 ton_D/E_0) without site preparation using a Väkevä Stump Processor, and when lifting spruce stumps with a diameter of 40 cm, the productivity was 14.9 m^3 sob/E_0 (6.5 ton_D/E_0). When the site preparation (mounding) was integrated into lifting work, the stump-lifting productivity decreased 21–27%. The stump-lifting productivity of the other lifting head (Järvinen) was lower than that of the Väkevä Stump Processor. Some development suggestions for the Järvinen lifting head were presented and discussed. The cost calculations showed that stump-lifting costs are extremely high when stump diameter is less than 20 cm. Therefore, the study recommended a change in the current stump-harvesting guidelines of Finland: The study suggested that all the stumps with a diameter less than 20 cm should be left on the harvesting site.

1 Introduction

The harvesting and use of stump and root wood as a raw material in pulping and energy generation were comprehensively investigated during the 1970's and 1980's in Finland (e.g. Hakkila 1972, 1974, 1976, Mäkelä 1972, Hakkila and Mäkelä 1973, 1974, Kuitto 1984) and in Sweden (e.g. Fryk and Nylinder 1976, Nylinder 1977, Jonsson 1978, 1985). However, activity on this topic ceased due to the costs of stump-wood harvesting being too high at the time. The intensive development of stump and root wood harvesting was recommenced by UPM Forest in Finland in the early 2000's (Paananen and Kalliola 2003, Backlund 2007).

In 2010, the total consumption of forest chips for energy generation in Finland was equivalent to 13.8 TWh (6.9 mill. m^3 solid over bark, or sob) (Ylitalo 2011). Of this amount, 12.5 TWh was used in heating and power plants, and 1.3 TWh in small-sized dwellings in 2010. Of the forest chips used in energy plants (12.5 TWh), 41% came from small-diameter ($d_{1.3} < 10$ cm) thinning wood produced in the tending of young stands. Of the total amount of commercial forest chips used for energy generation, more than one third was produced from logging residues in final cuttings in 2010. Forest chips derived from stump and root wood totalled 16%, while 8% came from large-sized (rotten) roundwood (Ylitalo 2011).

The use of stump and root wood chips has increased very rapidly in the 21st century in Finland: In the year 2000, the total consumption of stump wood chips for energy was 10 GWh (5000 m^3 sob), while in 2010 it was nearly 2.0 TWh (1 mill. m^3 sob) (Ylitalo 2011). Juntunen (2011) has calculated that the total area of stump harvesting was around 20000 ha in 2010.

The best sites in Finland, and therefore those mainly used for the harvesting of stump and root wood, are Norway spruce (*Picea abies* L. Karst.) dominated final cuttings. The period for stump lifting in Finland is limited to May–November when the ground has thawed. There is often a delay of a few months between industrial roundwood harvesting and stump lifting. The delay time allows for an easier extraction of stumps from the ground (e.g. Laitila et al. 2008). Heavy-duty (operating weight around 20 tonnes) tracked excavators are primarily used for the lifting of stumps (Kärhä 2009, 2011a,

2011b). Approximately 200 excavators are currently used for stump lifting in Finland (Kärhä 2011c).

When introducing stump-wood harvesting in the beginning of 21st century, the majority of stump-lifting machines were fitted with a stump rake, i.e. stump-lifting head without a hydraulic splitting knife. Currently, almost all stump-lifting machines are correspondingly equipped with a lifting head with a splitting knife for shearing (e.g. Stump Processors of Väkevä, Pallari, Terosa, Leikko, Euro-steel). Furthermore, some stump-lifting aggregates designed also for forest machines are currently on market in Finland (e.g. Stump Harvesters of Xpower, Terosa, Tunturi). However, today the usage of those stump-lifting aggregates is quite minimal.

There are very challenging targets for the use of forest chips in the future in Finland. The overall target set for forest chips is 8–12 million m^3 sob (16–24 TWh) by 2015, and 13.5 million m^3 sob (25 TWh) by 2020 (Finland's National Forest… 2008, Pekkarinen 2010). These targets project that the harvesting of stump and root wood will double or even triple, over the current harvesting volume.

According to the latest calculations (Kärhä et al. 2010), the potential amount of techno-economically harvestable forest chips is annually 11–28 TWh, of which stump and root wood accounts for 2–11 TWh, depending on the price level for emission rights. It is estimated that the proportion of stump wood chips and chips out of the small-sized thinning wood consumed by energy plants will increase significantly in the future (Kärhä 2007, 2011a).

Development of the supply chain of stump wood chips has contributed to the drastic increase in stump wood consumption. Promising development work has been carried out in the forest, as well as at the energy plants. An important factor in the creation of an operational, cost-effective supply chain has been the development of the stump-lifting technology. However, the cost-effective lifting of stumps in the future requires further development.

Two stump-lifting heads (a Väkevä Stump Processor lifting head and a Järvinen stump-lifting device) were evaluated for lifting Norway spruce stumps in final felling stand. The productivity and costs of stump lifting were determined.

2 Material and Methods

2.1 Lifting Heads

Armas Hirvonen (A Hirvonen Oy) designed and built the Väkevä Stump Processor lifting head (www.ahirvonenoy.net). The Väkevä Stump Processor is currently the most popular stump-lifting head in Finland. So far, the Väkevä Stump Processor lifting head has been supplied for more than 150 stump-lifting machines in Finland and abroad, for instance in Sweden (A. Hirvonen, personal communication, April 16, 2012). The weight of the Väkevä Stump Processor researched in the study was approximately 1.2 tonnes.

The Väkevä lifting head includes two lifting spikes, a hydraulic splitting knife, and a site preparation (mounding) element, as required by the customer (Fig. 1). The stump is sheared with the splitting knife while it is being extracted. The splitting knife is also used for shaking and cleaning lifted stumps.

The working principle of the stump-lifting device developed by Markku Järvinen (Oy Kappeliranta – Kapellstrand Ab) is as follows:

1) The lifting device is moved onto the stump.
2) The clamshell bucket, with four spikes on either side, grabs the stump.
3) The stump is lifted from the ground by means of four lifting cylinders attached to the outer ring of the lifting device. The diameter of outer ring was 1950 mm.
4) The stump is dropped from the lifting device onto the stump heap or windrow on the ground (Fig. 2).

The Järvinen stump-lifting device may be used with excavators, as well as with forest machines. A Yuchai 135 excavator, Timberjack 1470B, and Ponsse HS16 Ergo harvesters have been used as base machines in earlier pilot tests. The version of the Järvinen lifting device in the time study weighed 1.8 tonnes.

2.2 Study Stands

In the time study, both stump-lifting heads were fitted on a Hitachi EX 225 USR (engine power: 122 kW) tracked excavator that weighed 24 tonnes. The excavator operator had six years'
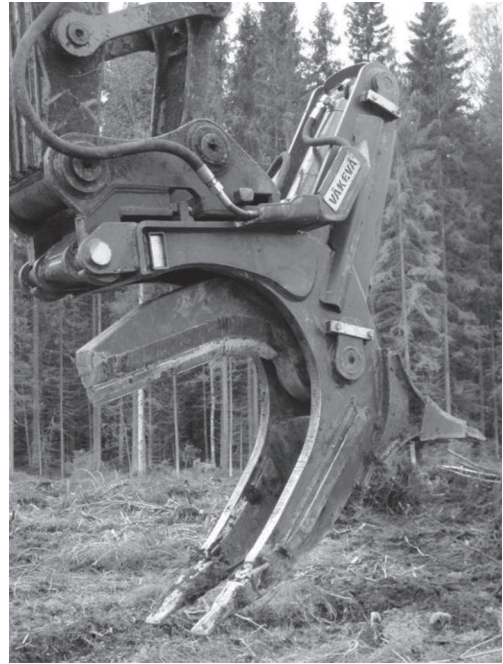

Fig. 1. The Väkevä Stump Processor lifting head researched in the time study. Photo: Kalle Kärhä.

experience in stump lifting with traditional stump rakes and stump-lifting devices with splitting knife. The operator had lifted stumps with the Väkevä Stump Processor lifting head for approximately six months. Respectively, the operator had tested the Järvinen stump-lifting device for less than two days before the time study.

The time studies were carried out at two harvesting sites at Siuntio (60°13´N, 24°10´E) (Stand 1) and Pöytyä (60°55´N, 22°25´E) (Stand 2), Southern Finland, in September 2008 (Stand 1) and September 2009 (Stand 2). All stumps lifted with the Järvinen lifting device were in a clay soil in Stand 1. Most of the stumps lifted with the Väkevä stump-lifting head were also in a clay soil in Stand 1; part of the study within Stand 1 for the Väkevä Stump Processor was characterized by a sandy soil. Study Stand 2 was mainly in a fine sand soil, but also included clay soils.

As the felling area was being converted to arable land, all the stumps were lifted from Stand 1 during the time study. Stand 2 was a normal forest stump-harvesting area, where some stumps were left on site according to the recom-
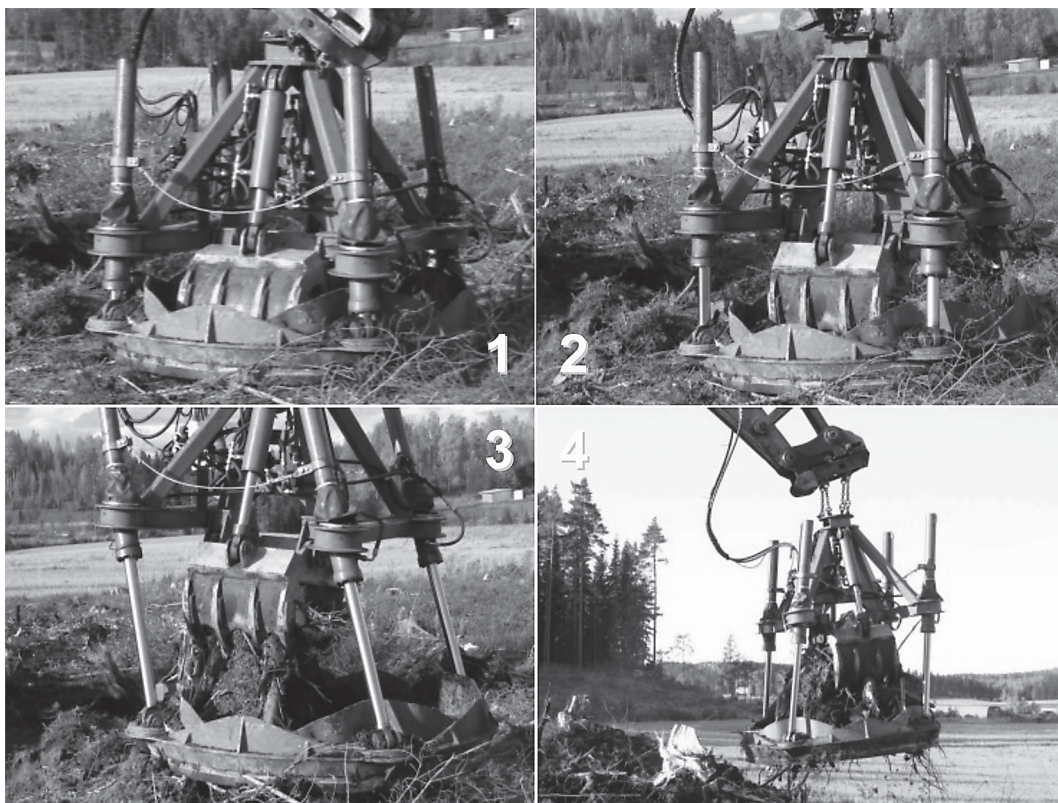
Fig. 2. The work cycle (1…4) of the Järvinen stump-lifting device. Photos: Kalle Kärhä.

mendations set for forest stump lifting in Finland (Äijälä et al. 2010). Industrial roundwood harvesting had been conducted in April, 2008 in Stand 1, and May, 2009 in Stand 2. Roundwood removal was around 340 m³ sob/ha in Stand 1, and 290 m³ sob/ha in Stand 2. Logging residues had been recovered from the time study Stand 1, but not from Stand 2. The ground surface in both stands was even, as well as there were no stones in the ground of both time study stands.

Prior to the study, all the stumps with a diameter greater than 10 cm were measured. The total number of stumps removed in the time study equalled 883 stumps (Table 1). For modelling of stump processing time, stumps of less than 15 cm in diameter, and Scots pine (*Pinus sylvestris* L.) and hardwood stumps, as well as rotten stumps from earlier fellings, were excluded from the time study material. Hence, the final material for modelling of stump processing time with the

Väkevä Stump Processor lifting head included 542 Norway spruce stumps, with an average stump diameter of 32 cm (min: 15 cm … max: 64 cm) (Table 1, Fig. 3). The final material for the Järvinen stump-lifting device consisted of 207 Norway spruce stumps, with an average stump diameter of 38 cm (min: 15 cm … max: 68 cm) (Fig. 3).

Dry mass (kg$_D$) for each Norway spruce stump lifted was calculated applying the function presented by Hakkila (1972) (Eq. 1). The dry mass of stump was converted to solid cubic meters over bark (m³ sob) by the bulk density of Norway spruce stump and root wood (432 kg/m³) (Hakkila 1975). The determined dry mass and the volume of lifted Norway spruce stumps were multiplied by 1.15 to better present the current situation at stump recovering sites (cf. Laitila et al. 2007), due to the heights of the lifted stumps being larger, as well as the dry mass function not including
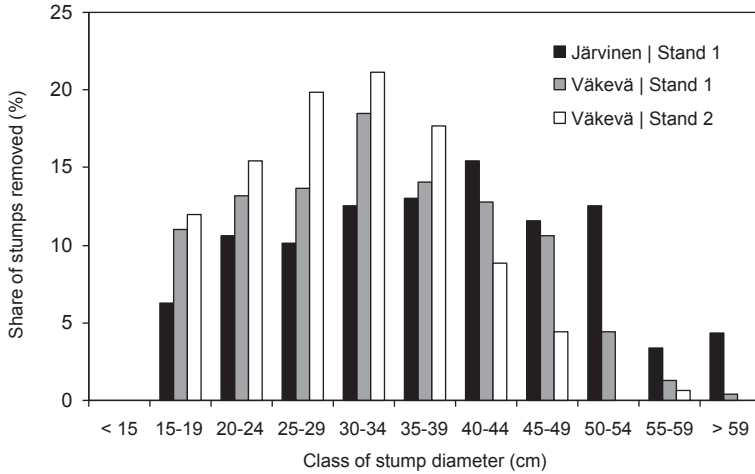
Fig. 3. Norway spruce stump diameter distributions for the Järvinen and Väkevä stump-lifting heads in the time study Stand 1 and 2. Total number of Norway spruce stumps removed 749.

Table 1. Study stands 1 and 2 and materials in the time study.

	Stand 1		Stand 2	
	Järvinen	Väkevä	Väkevä	Väkevä
Lifting head researched	Järvinen	Väkevä	Väkevä	Väkevä
Site preparation (Mounding)	No	No	No	Yes
Total number of stumps lifted in study, stumps	262	263	101	257
Number of Norway spruce stumps in modelling of stump processing time, stumps	207	226	92	224
Calculated removal of Norway spruce stumps				
– Solid volume over bark, m^3 sob/ha	106	67	54	52
– Dry mass, ton$_D$/ha	46	29	23	22
Average stump size of Norway spruce stumps removed				
– Stump diameter, cm	38	33	31	30
– Stump solid volume over bark, dm^3	202	147	126	112
– Stump dry mass, kg$_D$	87	64	54	48

fine roots of stumps when the original study was conducted by Hakkila (1972).

$$y = -7.0 + 0.051 \times x^2 \tag{1}$$

where
y = Dry mass of Norway spruce stump, kg$_D$
x = Stump diameter, cm

2.3 Time Study

The same researcher collected all the time study material using a continuous time study method. In the time study, the work cycle (i.e. all the work elements for processing one stump) was divided into the following elements:

– Moving: Began when the excavator started to move, and ended when the excavator stopped moving to perform some activity.
– Boom-out: Began when the boom was moving

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towards the stump, and ended when the lifting head stack to the stump.

– Lifting, Splitting and Cleaning: Began when the lifting head started to lift up the stump, and ended when the boom was moving towards the pile. Time element included also the shearing of the stump into around 2–5 pieces and cleaning them.

– Piling: Began when the boom was moving towards the pile, and ended when the stump pieces dropped from the head to the pile.

– Smoothing: Filling the stump holes on the ground surface.

– Mounding: Began when the boom was moving towards the ground for preparing a mound, and ended when the mound was finished. The instruction for mounding was to prepare around 1600–1700 mounds per hectare (cf. Maanmuokkauksen koulutusaineisto… 2000).

– Slash removing: The clearing of disturbing logging residues away.

– Delays: Time not related to productive stump-lifting work, e.g. personal breaks, repairing or maintenance of excavator or lifting head. The reason for the interruption was recorded.

2.4 Cost Calculations

The price of the base machine (a tracked excavator of around 22–24 tonnes) was 145 000 € (VAT 0%) in the cost calculation. The price of the Väkevä Stump Processor was 15 000 € (VAT 0%) (A. Hirvonen, personal communication, April 16, 2012), and the price of the Järvinen stump-lifting device was estimated to be 25 000 € (VAT 0%). Total annual working hours were 1500 operating (E_{15}, including delay times shorter than 15 minutes) hours of which a half was performing stump lifting. The depreciation period for the base machine and the lifting heads researched was 5.0 years in the cost calculation.

The operator's salary was 12.5 €/E_{15}-hour with indirect salary costs (59%), including the amount of compensated work trips. The fuel consumption for both machine units was 15 litres per operating hour (0.92 €/l). Repair and service costs were estimated to be 5.0 € per operating hour, administration and maintenance costs 4080 €/a, and insurance fees 1550 €/a. The operating hour cost amounted to 77 €/E_{15} for the Järvinen stump-lift-

ing machine unit, and to 76 €/E_{15} for the stump-lifting machine of the Väkevä Stump Processor.

2.5 Data Analysis

When modelling stump processing times, the time elements of Boom-out, Lifting, Splitting and Cleaning, and Piling were combined for the processing time. Stump processing effective times were modelled by stump-lifting head and by stand applying regression analysis with the stump diameter removed as the independent variable. Moving time was modelled as a function of the total density of stump removal. The different transformations and curve types were tested in order to achieve symmetrical residuals for the regression models and in order to ensure the statistical significance of the coefficients.

3 Results

3.1 Distribution of Effective Working Time

The Väkevä Stump Processor used 61% of the total effective time (excluding delay times) consumption in Stand 1 time study in lifting, splitting and cleaning the stumps (Fig. 4). In Stand 2, correspondingly, the proportion of lifting, splitting and cleaning was 41–49%.

Respectively, in the study of the Järvinen stump-lifting device, one half of the total effective time consumption was used in the stump-lifting operation (Fig. 4). Stump splitting was not actually performed by the Järvinen lifting device. However, some stumps were chopped when the clamshell spikes of the lifting device ripped into them as they were lifted, while some of the stumps came out of the ground intact.

Moving the pieces of stump to the heap and the piling process took 19–30% of the effective time in the time study (Fig. 4). With the Väkevä Stump Processor in Stand 2, mounding took more than one-fifth of the total effective time consumption. Moving the Järvinen lifting device to the stumps took less than one-fifth of the effective time.

Filling the biggest stump holes on the ground after extraction equated to 3–7% of the total effective
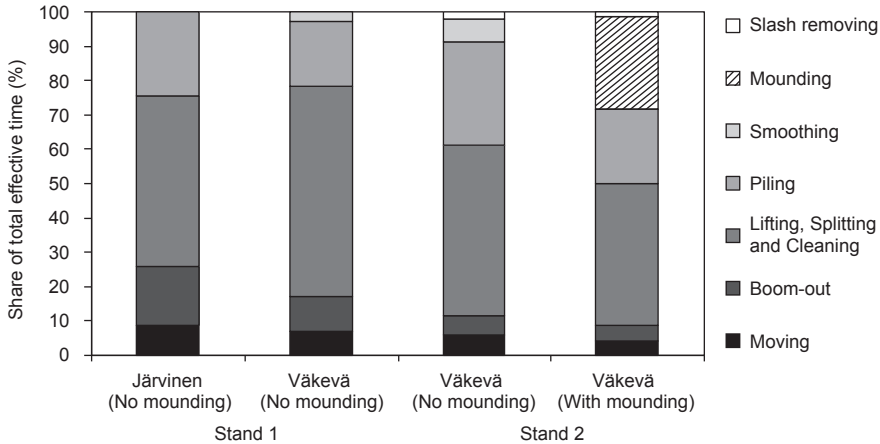
Fig. 4. The average structure of work elements of effective (E_0) working time for stump lifting by stand, by lifting head, and by mounding option in the study.

time, and the share of removing logging residues in Stand 2 was 1–2%. Machine movings from one working location to another at the site took 4–9% of the effective time consumption in the study.

3.2 Moving Time

Moving time was dependent on the total density of stumps removed (Eq. 2). The total density of stump removal was between 284–683 stumps/ha, with an average of 484 stumps/ha in the study. The moving time per processed stump decreased when the density of stump removal increased in the study. When the total density of stumps removed was 500 stumps/ha, the moving time was 3.6 s/stump.

$$y_1 = -0.804 + 2195.6 \times 1/z \qquad (2)$$

where
y_1 = Moving time, s/stump
z = Total density of stumps removed, stumps/ha
$R^2 = 0.918$

3.3 Stump Processing Time

The time consumption for stump processing (including the time elements of Boom-out, Lift-

ing, Splitting and Cleaning, and Piling) was estimated on the basis of stump diameter removed. The separate equations for the Järvinen and Väkevä stump-lifting heads in study Stands 1 and 2, as well as the combined equation of Stands 1 and 2 using the Väkevä Stump Processor are presented in Equations 3–6 (Table 2, Fig. 5).

In the time study stands of the Väkevä Stump Processor, the stump processing time was 48–50 seconds per stump when lifting Norway spruce stumps with a diameter of 30 cm (Fig. 5). When lifting stumps with a diameter of 40 cm, the stump processing time was 71–75 s/stump. With the Järvinen, the stump processing time was 14–19% higher than in the case of the Väkevä in Stand 1, when stump diameter was between 30 and 40 cm.

3.4 Smoothing and Mounding Times

The average effective time consumption of smoothing work was 0.30 E_0-hours/ha at the Väkevä stump harvesting sites where mounding was not conducted. The minimum effective time consumption being 0.17 hours per hectare, and the maximun was 0.59 h/ha. Time consumption in smoothing per stump was derived by dividing the average smoothing time per hectare by the total density of stumps removed (Eq. 7).

Table 2. Functions for Norway spruce stump processing by lifting head and by stand.

Lifting head / Stand Function	R^2	Equation
Järvinen stump-lifting device (in Stand 1) $y_{2J} = 0.465 \times x^{1.415}$	0.534	3
Väkevä Stump Processor in Stand 1 $y_{2V1} = 0.227 \times x^{1.574}$	0.629	4
Väkevä Stump Processor in Stand 2 $y_{2V2} = 0.868 \times x^{1.193}$	0.407	5
Väkevä Stump Processor in Stands 1 and 2 (Combined) $y_{2VC} = 0.459 \times x^{1.378}$	0.522	6

where
$y_{2J}, y_{2V1}, y_{2V2}, y_{2VC}$ = Stump processing time, s/stump
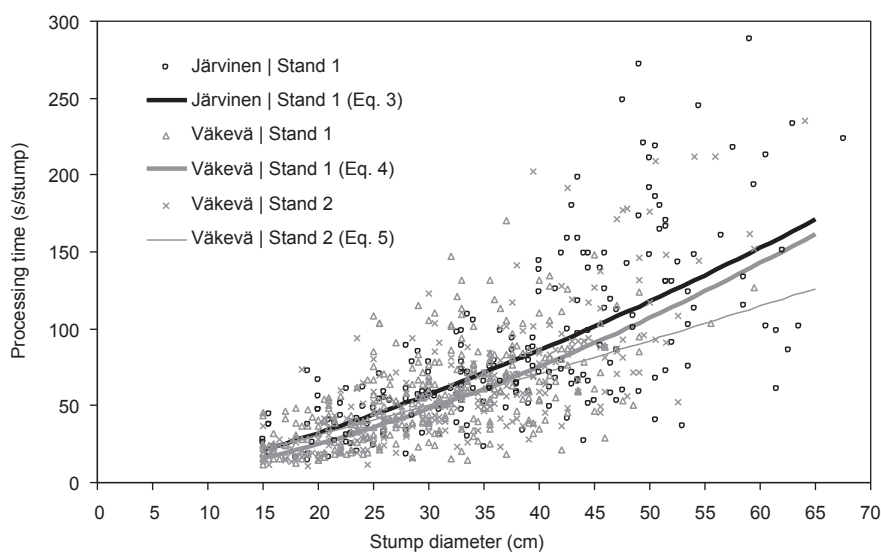x = Stump diameter, cm

Fig. 5. Time consumption of Norway spruce stump processing as a function of the stump diameter removed with the Järvinen and Väkevä stump-lifting heads in Stand 1 and 2.

$$y_3 = 3600/z \times 1/3.33 \qquad (7)$$

where
y_3 = Smoothing time, s/stump
z = Total density of stumps removed, stumps/ha

The average time consumption of site preparation (i.e. mounding) work was 3.30 E_0-hours per hectare in Stand 2 with the Väkevä Stump Processor. Time consumption in mounding work per stump was derived by dividing the average

mounding time per hectare by the total density of stumps removed (Eq. 8). When mounding was carried out, there was no smoothing time in the time study stand.

$$y_4 = 3600/z \times 1/0.31 \qquad (8)$$

where
y_4 = Mounding time, s/stump
z = Total density of stumps removed, stumps/ha

3.5 Productivity

The total effective time (T) by stump-lifting head, by stand, and by mounding option is displayed in Equations 9–15:

Järvinen | Stand 1 | No mounding:
$$T_J = y_1 + y_{2J} \tag{9}$$

Väkevä | Stand 1 | No mounding:
$$T_{V1} = y_1 + y_{2V1} + y_3 \tag{10}$$

Väkevä | Stand 2 | No mounding:
$$T_{V2} = y_1 + y_{2V2} + y_3 \tag{11}$$

Väkevä | Combined (Stands 1 and 2) | No mounding:
$$T_{VC} = y_1 + y_{2VC} + y_3 \tag{12}$$

Väkevä | Stand 1 | With mounding:
$$T_{V1M} = y_1 + y_{2V1} + y_4 \tag{13}$$

Väkevä | Stand 2 | With mounding:
$$T_{V2M} = y_1 + y_{2V2} + y_4 \tag{14}$$

Väkevä | Combined (Stands 1 and 2) | With mounding:
$$T_{VCM} = y_1 + y_{2VC} + y_4 \tag{15}$$

The effective time consumption was converted to m^3 sob/E_0 productivity by applying Equation 16. With the Järvinen stump-lifting device, the effective hour productivity was 10.2 m^3 sob/E_0-h (i.e. 4.4 ton$_D$/E_0 or 99 stumps/E_0) when lifting Norway spruce stumps with a diameter of 30 cm (the density of stump removal: 500 stumps/ha) (Fig. 6). When the stump diameter was 40 cm, the effective hour productivity of stump lifting was 13.3 m^3 sob/E_0-h (5.7 ton$_D$/E_0 or 67 stumps/E_0).

$$P = 3600 \times (v/T) \tag{16}$$

where

P = The effective hour productivity, m^3 sob/E_0-h

v = The volume of a stump, m^3 sob

T = The total effective time consumption for stump-lifting work, s/stump (see Eqs. 9–15)

When lifting stumps with a diameter of 30 cm, the effective hour productivity of stump lifting was 11.1–11.6 m^3 sob/E_0-h (4.8–5.0 ton$_D$/E_0 or 102–112 stumps/E_0) without mounding using the Väkevä Stump Processor in study Stands 1 and 2, and when lifting spruce stumps with a diameter of 40 cm, the productivity was 14.7–15.6 m^3 sob/E_0-h (6.3–6.7 ton$_D$/E_0 or 74–78 stumps/E_0) (Fig. 6). Respectively, with mounding work, the stump-lifting productivity was 8.1–8.3 m^3 sob/E_0-h (3.5–3.6 ton$_D$/E_0 or 78–80 stumps/E_0) and 11.7–12.2 m^3 sob/E_0-h (5.0–5.3 ton$_D$/E_0 or 59–61 stumps/E_0).

3.6 Costs

Stump-lifting costs decreased significantly when stump diameter increased from 15 cm to 20 cm in the study (Fig. 7). When the stump diameter was 30 cm, the stump-lifting costs with the Järvinen were 8.7 €/m^3 sob (i.e. 20.1 €/ton$_D$ or 0.90 €/stump). When using the Väkevä Stump Processor under a similar harvesting condition (stump diameter: 30 cm), the lifting costs were 7.8 €/m^3 sob (18.1 €/ton$_D$ or 0.81 €/stump). When the stump diameter was 40 cm, the stump-lifting costs with the Väkevä were 5.9 €/m^3 sob (13.5 €/ton$_D$ or 1.16 €/stump). Hence, the stump-lifting costs with the Väkevä were 10–12% lower than those of the Järvinen when the stump diameter was 30–40 cm.

When the mounding was integrated into stump lifting, the stump-lifting costs were from 10.8 €/m^3 sob (24.9 €/ton$_D$ or 1.12 €/stump) (stump diameter: 30 cm) to 7.4 €/m^3 sob (17.1 €/ton$_D$ or 1.47 €/stump) (40 cm) (Fig. 7). Thus, mounding increased the costs of stump lifting 26–38% compared to lifting work without site preparation in the study.

4 Discussion and Conlusions

In the research, the stump processing, productivity, and costs of Norway spruce stump lifting using the Väkevä Stump Processor and the Järvinen stump-lifting device were clarified, because there were no published time studies of these stump-lifting heads (cf. Spinelli et al. 2005, von Hofsten and Nordén 2007, Karlsson 2007, Laitila et al. 2007, 2008, Hedman 2008, Laurila and Lauhanen 2008, Lazdiņš et al. 2009, von Hofsten 2010, Jouhiaho and Mutikainen 2010, Jouhiaho et al. 2010, Laitila 2010, Athanassiadis et al. 2011, Erkkilä et al. 2011, Tolosana et al.
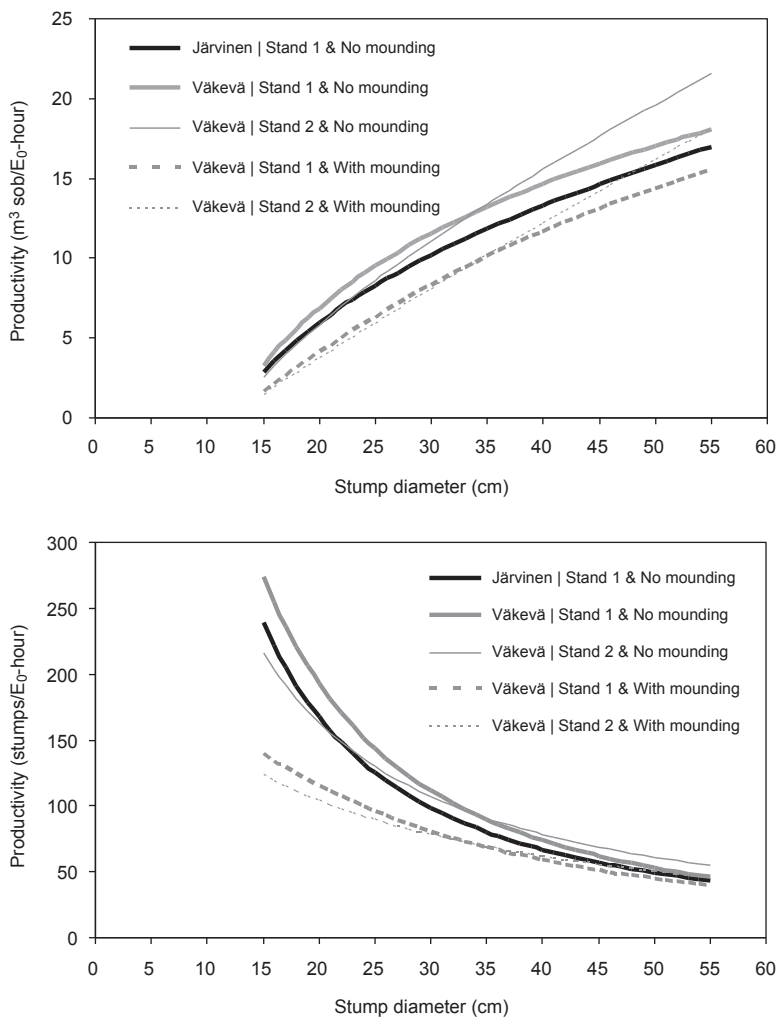
Fig. 6. Calculated effective hour productivity (m^3 sob/E_0 and stumps/E_0) of Norway spruce stump lifting applying the Järvinen stump-lifting head and the Väkevä Stump Processor with and without mounding work in Stand 1 and 2. The density of stump removal was 500 stumps removed per hectare.

2011). Besides, the issue is very important, as the Väkevä Stump Processor is the most commonly used lifting head in Finland. The Järvinen stump-lifting head was still in a prototype stage in the study.

Scots pine stumps were also lifted with both lifting heads in the time study. Since the number of pine stumps was a quite small in the study, the stump processing model for pine stump lifting was not formulated. Consequently, further time studies of Scots pine stump lifting with the Väkevä and Järvinen lifting heads are needed. Recent stump-lifting studies have demonstrated that the productivity of pine stump lifting is lower than in spruce stump lifting (e.g. Karlsson 2007, Hedman 2008, Lazdiņš et al. 2009, Jouhiaho and Mutikainen 2010, Athanassiadis et al. 2011, Erkkilä et al. 2011).

The final study material for stump processing time modelling was 749 spruce stumps (Table 1).
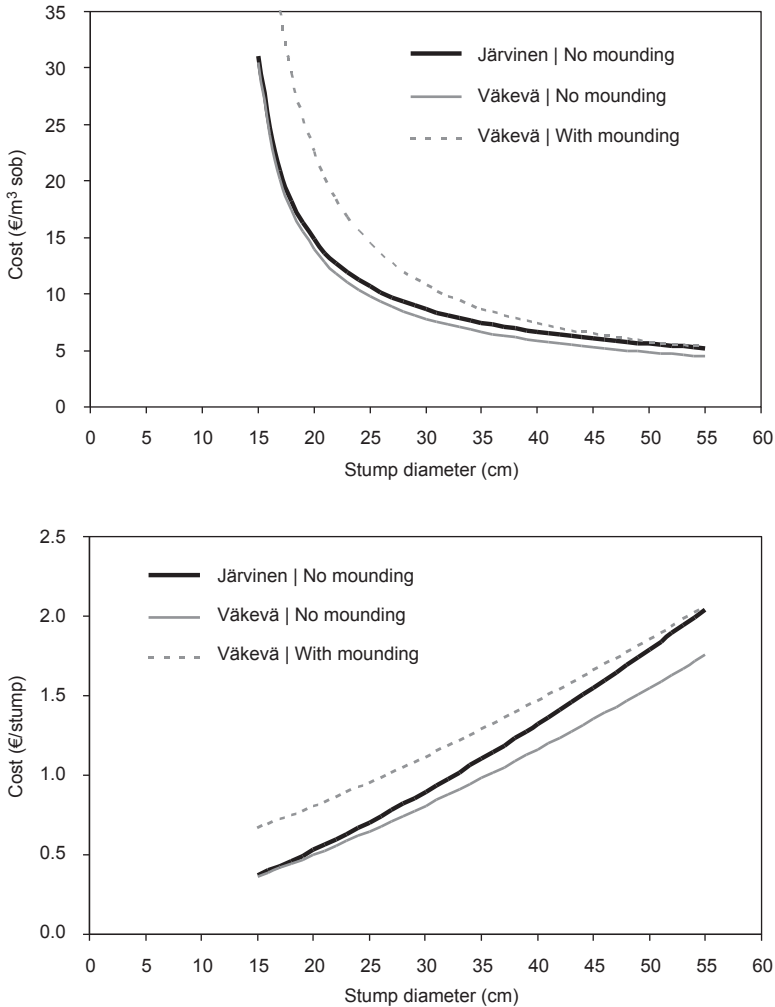
Fig. 7. Costs (€/m³ sob and €/stump) of Norway spruce stump lifting using the Järvinen stump-lifting head and the Väkevä Stump Processor with and without mounding work. The density of stump removal was 500 stumps/ha.

The size of material was relatively large comparing to the study materials of earlier lifting studies (e.g. von Hofsten and Nordén 2007, Karlsson 2007, Hedman 2008, Laitila et al. 2008, Jouhiaho and Mutikainen 2010, Jouhiaho et al. 2010, Laitila 2010, Athanassiadis et al. 2011, Erkkilä et al. 2011). The study data was collected from only one excavator, which operated only one driver in two time study stands located in easy terrain. Many forest work studies have emphasized that

the effect of operator is significant on the productivity in forest machine work. For instance, Sirén (1998), Kärhä et al. (2004) and Ovaskainen (2009) have shown that the differences between operators using the same machines are as great as 35–40%.

The study lay-out (i.e. one machine and one operator) has been similar to many other earlier stump-lifting studies (cf. von Hofsten and Nordén 2007, Hedman 2008, Laitila et al. 2008,

Lazdiņš et al. 2009, Jouhiaho and Mutikainen 2010, Erkkilä et al. 2011). Nonetheless, it must be noticed that the study material in this study is relatively comprehensive, as we can compare two lifting heads with same base machine, with same operator, as well as in same study stand (1) (cf. Harstela 1993). In addition to Scots pine stump-lifting time study with the tested lifting heads, further long-term follow up studies with stump harvesting are needed. Previously, only Jalava (2007) and Athanassiadis et al. (2011) (based on Hedman 2008) have conducted follow up study of stump lifting.

When investigating the study results, it must be recognized that it is extremely difficult to compare stump-lifting productivity data from various studies directly. Many aspects have to be taken into account:

– What type of equipment (basic machine, lifting head with or without a splitting knife) was used,

– What was the working method (only lifting, or lifting and site preparation),

– What was the operator's experience in lifting work, and his/her carefulness and efficiency when cleaning and shearing lifted stumps, and

– What were the harvesting conditions (e.g. stump size, stoniness, soil type (fine sand, sand, clay), maturation time (delay between timber logging and stump lifting).

In the study using the Väkevä Stump Processor, cleaning stumps lifted from clay soil (Stand 1) took more time than those lifted from fine sand soil (Stand 2). The finding is logical because the stumps from clay soil need more shaking than the stumps in sandy soils. The disparity of stump-lifting productivity between a primarily clay (Stand 1) and sand (Stand 2) soil was relatively limited, only 5–6%, when lifting stumps with a diameter of 30 to 40 cm in the study. When the diameter of the lifted stump exceeded 40 cm, there was a significant increase in the disparity of productivity levels in Stands 1 and 2 with the Väkevä Stump Processor.

The cleanliness of stumps lifted was not measured in the study. Nevertheless, based on the observations by a study researcher, the stumps lifted with the Väkevä Stump Processor were visually clean. The cleanliness of lifted stumps is a very important matter because the impurities in

stump material harvested result in extra costs for the next phases (forest haulage, truck transportation and comminution) of the production process of stump wood chips.

The productivity of stump-lifting work with the Järvinen lifting head in the time study was 8–15% lower than the productivity of Väkevä Stump Processor when lifting spruce stumps with a diameter of 30 to 40. This was undoubtedly affected by the fact that the Järvinen lifting device was still in a prototype stage, and that the operator also had little experience with the lifting head. Furthermore, a harvester with more powerful hydraulics would probably have enhanced the lifting work. It is also important to note that there was no rotator between the boom of the excavator and the Järvinen lifting head (see Fig. 2[4]). The lifting device suspended from four short chains caused additional work for the operator, e.g. when placing the lifting head onto the stump to be lifted.

There were four spikes on either side of the Järvinen lifting device clamshell. The spikes should be longer in order to penetrate deeper into the stump. Re-designing the spikes would also give them a better grip on the stump to be lifted. The diameter of the outer ring of the Järvinen lifting device was less than 2.0 meters. The diameter could be larger, e.g. 2.2 to 2.3 meters, especially when lifting large stumps (stump diameter > 40 cm). In the study, the sharp bottom edge of the outer ring easily cut lateral roots up to a diameter of 5 to 10 cm. The lateral roots of larger stumps were thicker, and also were often located so close to the outer edge of the ring that they were not cut easily. In this case whole stumps, "bats", were lifted, causing problems in off- and on-road transportation, as well as in storage.

With the Järvinen stump-lifting device, a large amount of mineral soil was still attached to many of the lifted stumps, although the operator tried to remove it by dropping the stump from a certain height onto the ground. The removal of soil material was also difficult, as Stand 1 was located on soil with clay. In conclusion, with the Järvinen lifting head, the most significant weaknesses were impurities in the stumps lifted, as well as the insufficient size of the stump pieces.

Also, site preparation could not be conducted by the Järvinen lifting head. Thus, in the study, the mounding was only made by the Väkevä Stump

Processor in Stand 2, where the average site preparation time was 3.3 E_0-hours per hectare. If the operating time consumption for mounding is 3.8 E_{15}-h/ha, then the mounding costs are 289 €/ha (76 €/E_{15} × 3.8 E_{15}/ha). The costs are reasonable compared with the average mounding cost level (304–317 €/ha) in Finland in 2010 (Juntunen and Herrala-Ylinen 2011).

When starting to lift stumps in Finland in the beginning of 21st century, the site preparation was very often integrated into stump-lifting work. Currently, the separate lifting and site preparation operations are preferred even if the costs of integrated lifting and site preparation work are competitive. The reason for the separate operations is the fact that the site preparation quality is not adequate after stump wood forwarding (e.g. Laitila 2010, Rönkkö and Ulander 2010).

Based on the time consumption within the studies, it can be stated that the Väkevä Stump Processor is an effective stump-lifting device that enables the harvesting of high-quality stump raw material for energy generation. High-quality stump raw material has the following properties: sufficient size of the stump pieces, and very little mineral soil attached to the stumps. Using the Väkevä Stump Processor without mounding, the combined (Stands 1 and 2) productivity of stump lifting was 11.2 m^3 sob/E_0-h (4.8 ton$_D$/E_0) when lifting stumps with a diameter of 30 cm, and when lifting spruce stumps with a diameter of 40 cm, the productivity was 14.9 m^3 sob/E_0-h (6.5 ton$_D$/E_0). In the study, mounding work decreased the stump-lifting productivity by 21–27%.

The results of this study are similar with earlier Finnish and Latvian stump-lifting research: Laitila et al. (2007, 2008) reported that using the Kantokunkku Stump Processor and the JCB JS 160 L (operating weight 17.5 tonnes) stump-lifting productivity without site preparation is 13.0 m^3 sob/E_0-h when lifting Norway spruce stumps with a diameter of 40 cm. Furthermore, Laitila et al. (2007, 2008) calculated that when integrating the site preparation into stump lifting, the site preparation lowered 29% the productivity.

Correspondingly, with the Pallari KH-160 Stump Processor and the Kobelco SK 210 (21 tonnes) Laitila (2010) presented that the productivity of spruce stump lifting with site preparation is around 8–12 m^3 sob/E_0-h when the stump

diameter varies between 30–40 cm. Lazdiņš et al. (2009) measured that the productivity of Norway spruce stump lifting is 5.5–7.2 ton$_D$/E_0-h (12.7–16.7 m^3 sob/E_0-h) with the average stump diameter of 34 to 36 cm using the Hyundai LB21Lc (22 tonnes) and the CBI Stump Processor. In the research by Jouhiaho and Mutikainen (2010), the average productivity of spruce stump lifting was 13.9 m^3 sob/E_0-h with the average diameter of 37 to 41 cm using the Pallari KHM-140 and the Hyundai 201 LC-7 (21 tonnes).

In the study of Jouhiaho et al. (2010) applying the Pallari KHM-140 and the Hyundai 201 LC-7, the stump-lifting productivity without site preparation was 8.5–11.5 m^3 sob/E_0-h (stump diameter of 30–40 cm) and with site preparation the productivity was 7.0–10.0 m^3 sob/E_0-h. Athanassiadis et al. (2011) reported slightly lower productivity levels for spruce stump lifting than in this study: in their study the productivity in spruce stands with easy terrain and average stump diameters of 20 to 40 cm was 1.2–4.2 ton$_D$/E_0-h (2.8–9.7 m^3 sob/E_0-h) using the Pallari KH-160 Stump Processor and the Hyundai 210 LC and the Volvo EC 210 (23 tonnes).

Äijälä et al. (2010) illustrated in 2010 updated guidelines for stump harvesting in Finland. These guidelines recommend that all the stumps with a diameter less than 15 cm should be left on the harvesting site, while approximately 25 retained stumps per hectare should have a diameter more than 15 cm. Furthermore, when operating on harvesting sites with clay and loamy soils, at least 50 stumps should be retained per hectare according to Äijälä et al. (2010).

The cost calculations of this study showed that the costs of stump lifting are extremely high when lifting stumps with a diameter of 15 cm (cf. Fig. 8). However, the lifting costs of stump and root wood with a diameter of 15 to 20 cm are still high. Hence, the results of this study recommend a change for the stump-harvesting guidelines by Äijälä et al. (2010): The study suggests that all the stumps with a diameter less than 20 cm should be left on the harvesting site.

Acknowledgements

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