FOREST ENERGY FOR A SUSTAINABLE FUTURE

Composite Report from the R&D Programme

Efficient Forest Fuel Supply Systems 2011-2015

FOREST FUEL

– TECHNOLOGY AND METHODS FOR HARVEST AND ASH RECYCLING

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Today, primary forest fuel is extracted in the form of whole or partly delimbed trees in thinnings, as energy wood (usually defective roundwood), as logging residue after final felling, or as stumps. The various assortments differ in terms of harvesting method, but subsequent handling – forwarding, comminution and onward transport – is very similar.

In the period 2009 to 2013, the cost of harvest and terrain transport increased somewhat for all forest fuel assortments. In 2013 average costs per m³ of chips were SEK 52 for energy wood, SEK 43 for logging residue, i.e. branches and tops from final fellings, SEK 80 for small trees, and SEK 81 for stumps. The greatest potential for an increased harvest of primary forest fuels lies in stumps and small trees. Biomass prices have fallen in recent years, and costs must be reduced in all parts of the supply chain to retain profitability in the forest fuel business and to generate income for the forest owner.

Logging residue

Today, logging residue is harvested in most final fellings in southern and central Sweden. The work methods and technology used for residue-adapted harvesting and forwarding of residues can be regarded as mature and well proven, so fine-tuning of techniques and methods is becoming an increasingly important part of the work to improve efficiency. Planning tools like STIG and Grotsporre improve the planning and simplify the forwarding work, while considerably reducing the risk of ground damage.

The first productivity standard for residue forwarding was presented in 2013, based on long-term productivity statistics and detailed time studies. The main factor affecting productivity is the amount of harvested material per hectare, but load quantity, transport distance and terrain difficulties are also significant. However, whether the logging residue is forwarded fresh or dried first on the clear-cut does not affect the productivity of residue forwarding.

Even if the technology is mature, technological development continues, including improvements to load carriers and grapples. Compacting load carriers and other special constructions give higher payloads than simple home-made constructions, but are not suitable for roundwood forwarding. Removable load carriers, such as the Hultdins load carrier, enable greater payloads of logging residue than the home-made modifications, and are suitable for contractors who often switch between forwarding roundwood and logging residue. Such contractors also need a

grapple that works well for both assortments, such as the asymmetric grapple, or a grapple that can quickly be adapted to the task at hand, such as the HSP combi-grapple.

The move towards more flexible technology means that roundwood and residue can be forwarded using the same machine. This reduces relocation costs and improves profitability of logging residue harvest, especially from small felling sites, and also gives the contractor flexibility.

The residue bundler was a machine that improved the efficiency of residue forwarding. The bundler compacted residues into 3-m long 'residue logs', which can be transported using an ordinary roundwood forwarder. However, high relocation costs along with a high cost per hour for the bundler means that that the technology requires meticulous planning and rather large cuts in order to be profitable.
In Sweden, bundling of forest fuel has almost completely stopped, but the use of bundlers and technical development continues in Spain.

Residue is still largely forwarded in the period of snow-free ground and, in order to maximise machine utilisation, contractors must be able to forward roundwood during the rest of the year. One alternative is to forward the residue immediately after felling, and allow it to dry in stacks on the roadside. An in-depth literature study has shown that this method has advantages in terms of logging technology and silviculture but, as fresh residue contains more needles, more plant nutrients are removed from the stand compared to when the residue is dried on the clear-cut. However, it is unclear whether this affects the forest's future biomass production.

The placement and covering of the residue stacks at the landing affects the quality of the logging residue. When uncomminuted material is stored, a number of factors must be considered, such the logistics on the landing, regulations regarding road safety and, in certain cases, how tree-living insects are affected by the appearance of the stack.

Forest fuel from thinning operations

There is great potential to increase the harvest of forest biomass for fuel in early thinnings, where small trees are removed, but the assortment has become less attractive due to high logging costs in combination with falling demand and prices for forest fuel. Over 1.4 million hectares of forest in Sweden has not been pre-commercially thinned, so there is a great need to find less costly technologies and methods for harvesting small trees in early thinnings, and this is a driver for further development work.

The key to viability in harvesting small trees in thinning is the capacity to handle more than one tree at a time. When using multi-tree handling harvester heads, the potential is greatest in stands with a low mean stem size (0.02-0.05 m^3) and where many stems are extracted per hectare. Studies show that multi-tree handling can increase productivity by 15-50 percent. A follow-up of multi-tree handling in forestry companies shows that harvester productivity increased by 17 percent where the mean stem size was 0.02 m^3 and by 11 percent where the mean stem size was 0.05 m^3. The opportunity for realising this potential is greatest when only one assortment is harvested.

The Flowcut harvester head has been developed for logging in stands of small trees. It works with continual cutting and accumulation, which allows geometric crane corridor thinning. This is a principle that, according to simulations, can triple productivity in very early thinnings. A first in-field test of the functionality and performance of the Flowcut felling head shows a potential to increase harvester performance in early dense thinning. The principle for cutting and accumulation was operational, but improvement is needed.

The machine manufacturer Bracke has a prototype head for felling, accumulating and compacting small trees, the Bracke MAMA. This is equipped with a circular saw and feed rollers, while Flowcut uses a saw blade that is fixed at both ends and lacks the ability to buck.

In order to realise the potential for multi-tree handling, Skogforsk, in collaboration with an instructor and several companies, has compiled examples of good practice into a working method called thinning in sections. An evaluation of this type of thinning in a simulator environment has shown that the method can increase productivity by up to 18 percent.

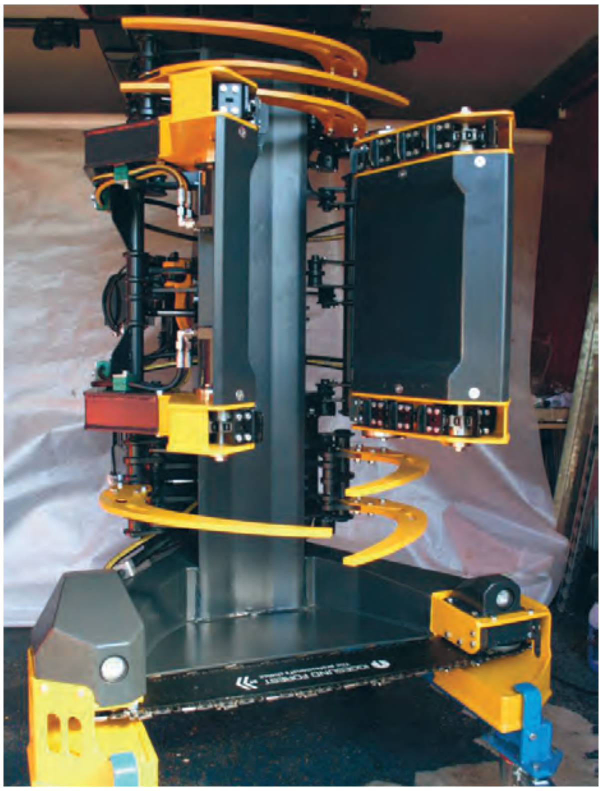

PHOTO: LENNART JANSSON/MEKFAB AB

Flowcut. A felling head prototype for continuous felling of small trees.

In order to streamline forwarding and onward transport in thinning of small trees, a bundling unit developed by the Finnish company Fixteri has been tested. The unit is mounted on a harvester, and the benefit is greater compaction compared with whole-tree harvest, while utilising most of the biomass. Evaluations indicate good performance in bundling – the greatest potential for improving the concept lies in equipping the unit with a more efficient harvesting head.

Much of the harvester's time in stands of small trees is spent on crane operation. The Cintoc harwarder for forest fuel has two partly automated cranes, one for separation and one for processing. The hope is that this can improve productivity in thinning of small trees.

There are several methods for estimating volumes in a stand where there is potential for harvesting small trees; this report, for example, presents methods for analysing felling in dense stands and on roadsides. Apart from analyses at stand level, there are also methods for analysing the individual tree, where different methods of handling the material in harvest of small trees affect the quantity of biomass harvested. In order to quantify how much of the biomass is extracted when small trees are harvested, bundles were weighed after whole-tree extraction, after partial delimbing, and after pulpwood bucking.

There is concern about an increased risk of damage caused by, primarily, snow and wind when dense stands of small trees have been thinned. However, in inventories of 14 stands, two to four years after first thinning, on average only 3.6 percent of the stems were affected by such damage.

Earlier studies of harvest of small trees have often involved pine-dominated stands. In order to broaden the perspective, the removal of birch shelterwood and forest fuel harvest in stands of Lodgepole pine have also been studied. When birch shelterwoods were removed, the proportion of damaged spruce after felling was found to be low, but the small mean stem volume made profitability of the extraction low.

There are no provisions regarding lowest final felling age for Lodgepole pine in the Swedish Forestry Act, so the stands can be felled at any age. In final felling of a 33-year-old Lodgepole pine stand, it was observed that productivity in whole-tree harvest can be high, but the extraction method may remove a large amount of nutrients, despite the concentrations of nutrients in Lodgepole pine being lower than in Scot's pine and spruce.

Stump harvest

The environmental impact of stump harvest is a controversial issue, which is why the Forest Stewardship Council, FSC, has set strict limits on which areas may be harvested on certified land until the environmental

Very little ash recycling takes place today, but technical developments are ongoing, and there is a growing need to find another use for ash as landfill capping is completed.

consequences have been investigated in more detail. This has created an uncertainty that has slowed technical development. Stump chips are a forest fuel with high production costs, approximately SEK 180/MWh at the industry gate and, as demand and prices for forest fuel declined during the 2013-14 and 2014-15 incineration seasons, stump harvest has stagnated.

However, development has not stopped completely. The contractor company, TL-GROT AB, has focused on the environmental issues, and has developed a stump harvester with an improved extraction method that cuts the roots approximately 30 cm outside the stump. This means that considerably fewer thin roots (< 5 mm) are pulled out with the stump compared with conventionally extracted stumps, and this significantly reduces ground impact. The method also reduces the amount of contaminants attached to the stump, which simplifies later handling and improves fuel quality.

One factor that has caused particular concern in conjunction with stump harvest is the reduction in quantity of thick dead wood. Recent research has shown that a large number of organisms colonise stumps, but it is unclear how dependent these organisms are on logging stumps, or whether logging stumps simply comprise an emergency substrate when there are no better alternatives.

In order to obtain an indication of how many stumps are actually left in the ground, an inventory was carried out of stump-harvested clear-cuts at Sveaskog and Holmen Skog AB. In normal stump harvest, a large number of stumps were left, up to 25 percent of the total number. Most of these had been left deliberately. They were relatively evenly spread over the clear-cut, and represented all diameter classes from the original stand. Of the stumps left in the ground, at least one-third were in principle undamaged, and could therefore still comprise a good substrate for various organisms.

A decision-support model for stump harvest has been developed, making it possible to select suitable areas for stump harvest and estimate the economic outcome. The model calculates the distance from every stump to the nearest landing, and then estimates the cost of harvesting and forwarding the stumps. The stumps are classified according to how profitable they would be to harvest. Input data for the model is production data and GPS-logged harvester routes, together with data about the felled stand

Technology for ash recycling

The increasing use of forest fuel in Sweden has triggered a debate on ash recycling. The debate is motivated and ash recycling is not without controversy, as there is a great deal of uncertainty about its actual benefits. On the one hand, ash recycling raises the pH in the soil and reduces the risk of long-term negative impact on the nutrient balance after forest fuel harvest. On the other, there is a risk of damage to the remaining stand, while the short-term effect on growth does not cover the cost of the activity. For these reasons and others, ash recycling is performed on a relatively small scale, and much of the ash that could be returned to the forest is used for other purposes, such as in roadbuilding or as capping material in landfills.

Returning ash to the forest is costly, as it involves the use of yet another machine in the stand. Usually, relatively small forwarders with specially designed disc spreaders are used. With the aim of reducing spreading costs, Skogforsk has examined whether ash recycling could be combined with other activities in the stand. One example is to temporarily fit a disc spreader on the forwarder that is already on the site.

The various stages in traditional ash recycling were studied to provide data for system comparisons. Preliminary results show that a forwarder spreading ash has a lot of down time waiting for ash deliveries, so a solution whereby logging residues are forwarded and ash applied using the same machine seems promising. Another advantage is that the investment cost can be divided between several players if they collaborate by using the same equipment. Interest in ash recycling is growing, as many landfills will soon be finally capped, and large volumes of ash will be available for recycling in the next few years.

Work environment in forest fuel handling

In view of the long-term growing demand, more people have started to work in the production of forest fuels. A good work environment is necessary in order to attract and retain machine operators. The work environment relating to forest fuel handling involves challenges that do not arise in other areas of forestry. The Swedish Work Environment Authority carried out a survey in 2009-2011 of the shortcomings and success factors in the sector.

The biggest challenges are the whole-body vibrations that occur in all machine work, the risks of mould and dust when handling mainly stored material, and the noise generated by comminution machines and how this affects operators and the environment. In order to disseminate knowledge of how to promote a good work environment in forest fuel production, information material based on current research has been produced by Dalarna University (www.du.se/arbetsliv_skog). The aim is to support everyday work concerning the work environment in forest fuel handling, and the compilation comprises six modules; Purchase of Equipment, Planning, Forwarding, Stump Harvest, Comminution, and Machine Development/Manufacture.

Forwarder-mounted chipper equipped
with a high-tipping chip bin.

DAMAGE AFTER EARLY THINNING

Örjan Grönlund & Mia Iwarsson Wide, Skogforsk

'Dense young stands' is a management system where a denser stand, around 4000 stems per hectare, is retained after pre-commercial thinning than in conventionally managed stands. In the subsequent first thinning, more stems are extracted so that the stand density after thinning is comparable to that in a conventionally managed stand.

In dense young stands, and stands in which no pre-commercial thinning has been carried out, the trees in the remaining stand are thin and have high crowns due to the high stand density prior to thinning. Furthermore, extraction rate in the first thinning is relatively high. Earlier research has indicated that both these factors contribute to an increased risk of, particularly, snow and wind damage after thinning in such stands.

The aim of this project was to identify stand and tree characteristics that can explain the occurrence of damage in dense stands after first thinning.

The study involved 14 dense, pine-dominated stands in central Sweden. Inventories were carried out on a total of 160 sample plots of 100 m² two to four years after thinning. On the sample plots, breast height diameter and tree species for all standing trees, stump diameter and species of felled trees, and the proportion of the sample plot lying within strip roads were recorded. The heights of three sample trees per plot were also recorded. Damaged trees were divided into three classes:

1. Broken, leaning, fallen trees (i.e. trees damaged by snow and wind).
2. Trees damaged in felling or forwarding.
3. Other damage.

The sample plots contained between 500 and 4400 stems per hectare before thinning, and the basal area weighted mean diameter was 13.3 cm. Mean extraction was 1080 stems per hectare. The inventory of damage showed that 3.6 percent of the stems showed snow and wind damage, 0.9 percent felling damage, and 0.7 percent damage of unknown cause.

The statistical analysis showed few correlations between the frequency of tree damage and stand and tree characteristics. The characteristic that best explained the occurrence of damage was damage previously recorded in the stand. Sample plots with smaller basal area weighted diameters before thinning tended to have a higher frequency of damage. Consequently, in the 14 surveyed thinnings, only a relatively small part of the damage could be explained by tree and stand characteristics affected by the stand management. The damage that was observed is assumed to be more dependent on weather conditions and location than on factors affected by the thinning operation.


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BIOMASS RECOVERY RATES FOR SMALL TREES

Örjan Grönlund & Mia Iwarsson Wide, Skogforsk

The growing use of forest fuel in the years 2007-2012 encouraged greater harvests of biomass from Swedish forests. In thinning, this can be done by harvesting whole trees, but whole trees are difficult to compact, causing low payloads in forwarding and onward transport.

By reducing the pressure exerted by the harvester feed wheels on the tree, and using blunt delimbing knives, the branches can instead be snapped, and only some are completely removed from the stem. This creates an assortment called partly delimbed energy wood.

In order to find out how much of the biomass is removed using different delimbing methods, delimbing of spruce, pine and birch trees was studied. Trees were sorted in three diameter classes, breast height diameters of 6-8, 8-12 and 12-18 cm. Ten bundles of each diameter class and tree species combination were weighed first as whole trees, and then partly delimbed by the harvester. In the next stage, the bundles were separated into individual trees that were delimbed and topped. Finally, the stems were bucked to pulpwood logs. After every step, the trees/stem parts were weighed. The aim of the treatments was to simulate harvesting of four different types of wood:

1. Whole-trees
2. Multi-tree handled, partly delimbed energy wood
3. Fully delimbed whole stems
4. Conventional pulpwood.

As tree properties affecting the delimbing process vary over the year, the study was carried out on three occasions, two under summer conditions and one under winter conditions.

The results from the studies gave a conversion table per species and diameter class. The conclusion was that the thicker the trees, the smaller proportion of material removed during delimbing. The studies also showed that a greater proportion of the biomass fell off during the winter, when the branches can be expected to be more brittle and break easily.

The measured weights of whole trees, stemwood, and branches used in the study were compared with existing biomass functions for small trees. There was a large variation between actual weights and estimated weights according to the biomass functions, but no systematic deviations were observed for any of the biomass functions. However, the biomass functions generally predicted a lower weight than that measured for small trees, and the opposite applied for larger trees. The biomass functions for spruce showed greatest correspondence with the measured trees.

Future work

- Dissemination and implementation of conversion factors and conversion tables as support for calculations and comparisons regarding harvest of fuel assortments or pulpwood.

Table 1. Recovered amount (%) of total biomass for partly delimbed energy wood and pulpwood according to tree species and breast height diameter.

DBH	6-8 cm	8-12 cm	12-18 cm
Partly delimbed energy wood			
Scots pine *(Pinus sylvestris)*	91	86	79
Norway spruce *(Picea abies)*	81	80	75
Downy birch *(Betula pubescens)*	89	86	88
Pulpwood			
Scots pine *(Pinus sylvestris)*	70	69	71
Norway spruce *(Picea abies)*	52	56	61
Downy birch *(Betula pubescens)*	60	63	88

Multi-tree handling has been carried out since the 1980s, and was developed with the aim of increasing harvester productivity in first thinnings. However, more recently, the method has become widely used when small trees are harvested as forest fuel in early thinning.

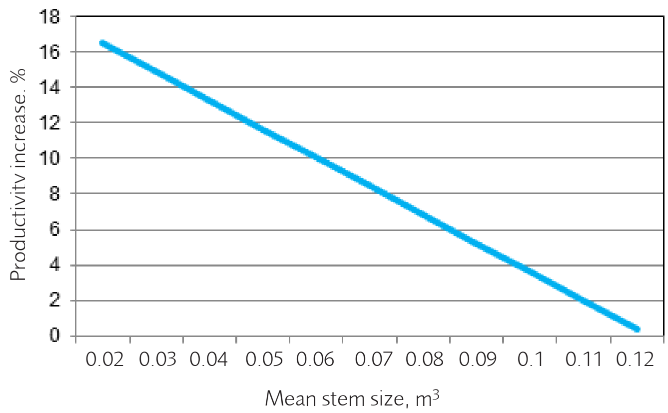
MULTI-TREE HANDLING INCREASES PRODUCTIVITY

Torbjörn Brunberg & Mia Iwarsson Wide, Skogforsk

Studies of harvester productivity when using multi-tree handling have shown varied results. In order to obtain a reliable estimate of the potential of multi-tree handling in practical logging, data from existing studies has been combined with follow-up data provided by a number of forest companies.

Time per boom cycle is shortest when the trees are processed one-by-one, but time per handled tree can be shortened if multi-tree handling is applied effectively. However, the time gain per tree is reduced as the number of trees accumulated increases, so there is an optimal number of trees per boom cycle. This optimum depends on the volume of the handled trees, the tree species, and the number of extracted stems per hectare. Analyses of the operational follow-up shows that the average degree of accumulation falls with increasing mean volume of stems in the harvest. Multi-tree handling is used in 60 percent of the boom cycles where the mean stem volume is 0.03 m^3, and only in 20 percent of the cycles where the stem volume is 0.10 m^3.

The conclusion is that the main factor affecting harvest productivity in first thinnings is the number of felled stems per hectare. This has a greater effect than the mean stem volume of the felled trees, but these two factors are strongly correlated. As the mean stem volume is the main factor in the cost models currently used, a model was constructed where the increase in productivity for multi-tree handling was only dependent on mean stem volume. The model, which involves a correction for the study material generally overestimating productivity, shows that multi-tree handling is expected to increase productivity by 0 to 17 percent when the mean stem volume harvested is in the interval 0.12 down to 0.02 m^3. The potential is greatest in stands with a low mean stem volume (0.02-0.05 m^3) and where a large number of stems are extracted per hectare.



Estimated productivity increase resulting from multi-tree handling in relation to single-tree handling vs mean stem volume of the harvested trees.

When thinning dense stands of small trees, the harvester operator is faced with the problem of many stems and a low economic value for each stem. The operator is forced to make many decisions in a short time, and must use a rational method to maintain a high level of productivity and reduce the mental work load.

THINNING IN SECTIONS

Örjan Grönlund, Martin Englund & Mia Iwarsson Wide, Skogforsk

Crane operation accounts for much of the time och used in thinning work and significantly influences fuel consumption for the harvester, while the risk of damage to the remaining stand increases with the number of crane operations. Together with Peter Larsson, Progalli Skog AB, Skogforsk has collected and compiled examples of good working practice in early thinnings and integrated them in a work method called 'thinning in sections'. The aim is to minimise crane operations by harvesting trees in sections perpendicular to the harvester, by efficiently applying multi-tree handling, and by positioning the machine so that most work involving the crane is done close to the machine.

In 2014, a systematic evaluation was carried out of the productivity and work load involved in thinning in sections. Five experienced harvester operators were studied in Skogforsk's simulator. The simulator study was divided into three parts. Firstly, the operators spent a day getting to know the simulator environment, and the following day they were studied while thinning using their 'usual' work method. The operators then underwent training in thinning in sections, and were encouraged to use the method in their ordinary work. Three months after the training course, they returned to the harvester simulator, where they thinned the same stand again using the thinning in sections method.

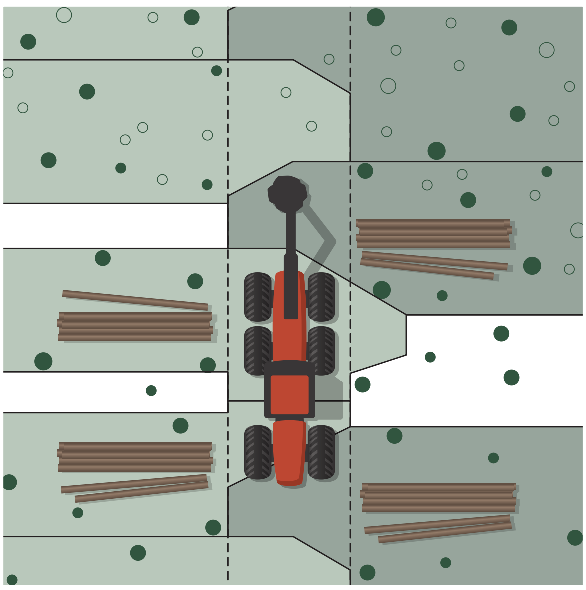


ILLUSTRATION: PER TORNEUS

Diagram showing thinning in sections.

In order to measure operator performance, continual time studies were carried out with pre-determined work processes. The software in the harvester simulator recorded the distance moved by the boom tip during thinning and, from this, the average number of crane movements per felled stem was calculated. The work load was studied using six cameras that recorded the number of head movements per felled stem, and also by the operators completing a self-assessment questionnaire. On the final day in the simulator, the extent to which the operators applied the method of thinning in sections was assessed.

The five operators performed a total of 60 thinning operations that lasted, on average, 16.5 minutes each, and in which the operators felled an average of 56 trees. The operators moved the boom tip an average of 11.26 metres per felled stem, and turned their heads an average of 33 degrees per felled stem.

Three of the operators improved their productivity by between 6 and 18 percent with the new working method. Two of these were considered to apply the thinning in section method more or less completely, but the third to a much lower degree. The productivity of the other two operators remained unchanged. One of these applied the thinning in section method completely, while the other had only changed the working method to a very small degree. The number of boom operations was reduced by an average of 4.3 percent when thinning in sections was applied.

Both the recorded and the experienced work load were largely unchanged after the change in work method. The exceptions were one operator whose number of head

The simulator can be developed into an efficient study environment for comparing different technologies and methods.

movements increased while productivity was also increased, and another whose number of head movements was reduced per felled stem but whose productivity was unchanged.

Earlier studies have shown that operators attain roughly the same level of productivity in the simulator as in reality, but there have been relatively few studies of how a harvester simulator can be used to study changes in work load.
In conclusion, the study shows that thinning in sections can help to increase the productivity of harvester operators considerably, but no effect was shown regarding work load. The conclusions are supported in follow-up studies by companies that have changed the work method, which show an increase in productivity of 10 to 25 percent when thinning in sections is introduced. These follow-ups have also shown positive consequences in the forwarding work, with reduced fuel consumption and a reduced work load for the operator.

Thinning in sections – instructions

For each machine position along the strip road, find an area where the main extraction will take place – it is this area that is called a section. The depth of the section is determined by the reach of the crane, and the width of the section is determined by the stem density. Sections in dense parts of the stand should be quite narrow, while they can be wider in less dense parts.

The sections should be established perpendicular to the strip road, and the harvested wood should be piled where the extraction in the section is greatest. Process the stems into piles on the same side of the strip road as they are standing. Fell the trees within approximately three metres from the tyre side inwards over the strip road, and feed them out into the section, but fell those trees outside the three-metre limit outwards, and feed them towards the machine. Make sure that the entire section is thinned before moving on to the next. Complete the section by reinforcing the strip road with branches, if conditions require this.

By being consistent and working within the section limits, boom movements are shortened, damage is minimised, and the stand is well thinned. The work can be carried out calmly and methodically, and the timber ends up perpendicular to the strip road, in a good position for the forwarder.

Future work

In order for forest fuel extraction in shelterwoods of birch to be viable, logging costs must be reduced through development of harvesting technology and work methods. Promising current development themes are felling heads for continual felling and part-automation of work processes.

FOREST FUEL FROM BIRCH SHELTERWOODS

Örjan Grönlund, Skogforsk

Birch shelterwoods are used as a nurse crop to reduce the risk of frost damage to young spruce trees on fine-grained soils and low-lying ground. A birch shelterwood should be managed in such a way that it can be harvested at low cost, while the understorey spruce trees can benefit from the protection without their growth being too inhibited by the overstorey. One of the major challenges is to ensure profitability as the birch shelterwood is gradually removed. Increasing demand for forest fuel is generating opportunities for revenue from this activity.

We studied productivity, costs, and frequency of damage to the spruce plants in the understorey during harvesting and forwarding of the birch trees that form the shelterwood. Shelterwoods were felled in two districts, Toftaholm and Odensjö (Table 1), and three 100-m long experimental plots were established in each district. During harvesting both energy wood and pulpwood were produced on all plots.

The felled material was weighed with a crane scale during forwarding, and samples were taken to determine moisture content. Based on the dry weight and time study data, productivity in tonnes of dry matter (tonne DM) per effective work hour (G0h) was calculated for both harvesting and forwarding (Table 2).

After the shelterwood removal, almost no birch trees were left in any of the stands, leaving approximately 1400 spruce trees per hectare in Toftaholm and 2600 in Odensjö. Of these, 5.9 percent were damaged in Toftaholm and 10 percent in Odensjö, which was lower than the expected proportion of damage.

The shelterwood removals did not provide the landowners with a net income. Based on the observed productivities, average hourly machine costs, and local timber pricelists, the net cost of shelterwood removal was estimated at approximately SEK 6000 per hectare, irrespective of district.

Today, shelterwoods of birch are mainly used to ensure successful regeneration, and thereby avoid other costs involved in establishing a new stand. However, this study shows that shelterwood removal is costly even if forest fuel is harvested, but the risk of damage to the remaining stand seems to be low.

Table 1. Description of stand before removal of shelterwood.

	Odensjö		Toftaholm	
	Spruce	Birch	Spruce	Birch
Stems/ha	3658	2225	1750	2390
Mean height (m)	7.5	11.2	4.3	9.2
Mean diameter (cm)	7.0	8.9	4.3	7.1
Volume (m^3/ha)		104.7		50.7

Table 2. Productivity in tonnes of dry matter (tonne DM) per effective work hour (G0h), in felling and forwarding.

	Odensjö	Toftaholm
Felling	2.99	2.38
Forwarding - energy wood	5.00	4.46
Forwarding - pulpwood	6.24	4.64

As a complement to Scot's pine and Norway spruce, Lodgepole pine began to be introduced to Sweden on a large scale in the 1970s. The species was seen as a good alternative that displayed strong growth, less damage from moose browsing, and wood characteristics similar to Scots pine.

FINAL FELLING OF LODGEPOLE PINE

Örjan Grönlund & Tomas Johannesson, Skogforsk

The stronger growth was regarded as a possible solution to counteract a feared timber shortage and as a way of increasing the level of felling. Establishment of Lodgepole stands was intensive in the 1970s and 1980s, and there are now approximately 600,000 ha of Lodgepole pine in northern Sweden.

Lack of knowledge about suitable provenances to use in Sweden and which site indexes were suitable for plantation with Lodgepole pine resulted in some of the current stands being of very poor quality, with thick branches and crooked stems. As Lodgepole pine is not covered by the provisions in the Forestry Act about lowest permitted age for final felling, there is greater freedom about how the species can be managed. In areas where quality development has been poor, one option may be to carry out final felling and extract the timber as forest fuel.

Skogforsk has studied harvesting, forwarding and chipping productivity, as well as drying effects and nutrient removal, in final felling of a 33-year-old Lodgepole stand in Alanäs, northwest Jämtland. In the stands, 2056 stems grew per hectare, with a mean diameter of 13.1 cm and mean height of 13.1 m. The harvested volume was 225 m^3 of biomass, total quantity of biomass over the stump cut, per hectare, and harvested mean stem volume was 0.07 m^3. Two harvesting methods were studied: whole-tree extraction and residue-adapted pulpwood harvest.

Productivity in felling, forwarding and chipping was studied through continuous time studies. As the harvesting methods involve different machines performing different tasks, system costs had to be compared, as comparisons for each individual machine were not possible. After correcting for the variation in extracted volume per hectare between the harvesting methods, the time taken for felling, forwarding and chipping was 36 percent higher for residue-adapted pulpwood extraction than for whole-tree extraction (Table 3). A contributing factor to this was that the operators were more experienced at whole-tree extraction, and because the handling of the logging residue took time. Residues comprised a quarter of the extracted material, but accounted for nearly half of the forwarding time.

The harvested biomass was left to dry on the clear-cut between felling in May and forwarding in September 2014, and samples for moisture content determination were taken continually during the period. As Lodgepole pine has a large quantity of needles, the hope was the whole trees would dry more effectively than the delimbed and cut stemwood sections. However, this was not the case, and at the end of the experiment, pulpwood and logging residues had dried better than the whole trees.

Nutrient removal was analysed through samples from different fractions of representative trees in the stand. The nutrient concentration in Lodgepole pine is low, as it is a resource-efficient tree species. Despite this, the analyses showed that the large quantity of green mass on Lodgepole pine means that extraction of all available biomass can considerably affect access to nutrients on the felling site.

The conclusion is that harvesting, forwarding and chipping is made most effective through whole-tree extraction. However, cut and completely or partly delimbed trees dry better on the clear-cut during the summer season than whole trees. In order to reduce the risks of excessive nutrient removal, parts of the green mass should also be left on the clear-cut.

Table 3. Productivity in felling, forwarding and chipping, expressed in tonnes of dry matter per effective work hour (tonne DM/G_0h).

	Whole-tree extraction	Stemwood	Logging residue
Harvester	EcoLog 860C, LogMax 4000B head		
Harvester productivity	4.51	3.26	-
Forwarder	Valmet 860.3, residue grapple with grapple saw		
Forwarder productivity	6.02	6.29	2.29
Chipper	Eschlböck 92, Claas Xerion 5000		
Chipper productivity	30.29	28.48	21.96

Chipping of whole-tree-harvested Lodgepole pine stems stored in stacks.

STORAGE OF LOGGING RESIDUE

Lars Eliasson, Skogforsk & Bengt Nilsson, Linnéuniversitetet

Increased utilisation of logging residues for energy production can replace fossil fuels with a domestic raw material. However, it is important that the residues are extracted in a sustainable way, so that it does not affect the future growth of the forest or is detrimental to the environment. The Swedish Forest Agency recommends that residue should not be extracted in forests with high natural values, or in a way that affects conservation measures taken during the harvesting operation, such as deadwood retention. Furthermore, at least one-fifth of the residues should be left on the clear-cut.

Since the 1980s, the recommendation has been that logging residues should be stored on the clear-cut over the summer, partly so that the material can dry to increase the effective energy value, and also because the needles should drop off. Heating plants do not want to incinerate needles, as this causes problems in the boiler and increases NOx emissions. It is also thought to be important that the nutrients in the needles are left on the clear-cut. Residue extraction in conjunction with final felling increases the removal of nutrients, which can have a negative effect on forest production. In field experiments with whole-tree extraction, spruce growth was impaired, but not pine. In those cases where the needles had been left on the clear-cut, height increment for spruce was at the same level as if only stemwood had been extracted.

Storing residue on the clear-cut means that the residue must be forwarded using a different machine to the one that forwarded the roundwood, so another machine must be moved to the site. Residue forwarding is also concentrated to periods of snow-free ground, which seems illogical if a stand with low bearing capacity has been felled during the winter to avoid ground damage. In addition, a clear-cut with

residue piles cannot be scarified and planted in the first summer after felling. All in all, this has led to increasing interest in forwarding the residue directly after felling, and drying it in stacks on the roadside.

In order to describe the state of knowledge about the advantages and disadvantages of storing residue on clear-cuts, the ESS programme carried out a literature review.

Results

Even if the ambition is to remove 'all' logging residue from a clear-cut, some is always left; in normal cases this is normally 20 to 40 percent, regardless of whether the residue is forwarded fresh or stored on the clear-cut. Most of the residue, 10 to 30 percent, is left between the piles on the clear-cut, because it is neither technically possible nor financially worthwhile to process all trees to ensure that the branches and the tops end up in a residue pile. Approximately 10 percent is left under the residue piles, because it is not worthwhile gathering all residue from the bottom of the piles. Doing so would also increase the risk of contamination in the residue. On weak ground, where branches and tops must be used to reinforce base and strip roads, even more residue is left on the clear-cut.

The quantity of needles that drop off during clear-cut storage has been studied using two methods. Some studies have measured the quantity of needles under the residue piles and compared this with the total quantity of needles, while other studies have involved chipping the piles and measuring the quantity of needles in the chips, which is then compared with the quantity of needles in chips from piles that were chipped directly after felling.

Studies of needle litter under residue piles stored for a summer on the clear-cut show that between 20 and 70 percent of the needles drop off and, in most locations, the residue piles had lost between 20 and 30 percent of the needles. In experiments where the quantity of needles was measured after chipping, between 60 and 95 percent of the needles had disappeared after a summer of storage on the clear-cut. One difference between the studies can be that the needles loosened from the branches in the residue piles get stuck in the pile, and drop off during forwarding and chipping instead.

The studies show that there is a great variability between sites in the quantity of needles that drop off the residue during clear-cut storage. This can depend on the weather during the storage period and the microclimate in the piles. Needles loosen more readily from dry branches, and more needles seem to drop off during loading if the piles are drier. If it assumed that 20 percent of the residue is left on the clear-cut between the piles, and 30 percent of the needles in the piles drop off during clear-cut storage, then 44 percent of the total quantity of needles is left in clear-cut storage compared with 20 percent when fresh residue is forwarded.

Moisture content is also of interest from a commercial perspective. In a study of six sites in Götaland, logging residue from half the sites was forwarded directly after felling, and the other half after the residue had dried over the summer. The mean moisture content was then measured to 36 percent for the stacks of directly forwarded residue, and 31 percent in stacks where the wood had been dried on the clear-cut before forwarding. The time of forwarding seems to have had a small effect on the moisture content of the residue at the time of delivery.

However, in a Finnish comparative study, the moisture content was 28 percent when residue was stored for nine months on the clear-cut and three months in a stack at the roadside, and 42 percent for residue that had been forwarded 'fresh' and stored in roadside stacks for a year.

Probably, the choice of where and how the residue pile is placed has at least as big an effect on the drying process as if the residue had been dried on the clear-cut before it was forwarded. It must also be remembered that residue in small piles on the clear-cut are quickly remoistened by rain and damp weather conditions, while the covered residue stacks are not affected as much.

Conclusions

The difference in fuel characteristics between clear-cut stored residue and residue stored in stacks at the roadside is often marginal, so the difference between the two systems can be difficult to define. The moisture contents are similar and, in both cases, needles are left in the material. Differences between clear-cuts seem to affect the material more than when the material is forwarded to larger stacks.

The argument for storing and drying residue in small piles on the clear-cut so that the needles can drop off can be questioned. Not 'all' residue and 'all' needles are removed in forwarding of newly-felled residue, and not 'all' needles are left in forwarding of clear-cut stored residue; It is not possible to say whether this difference is big enough to affect the long-term growth of the new forest to any noticeable extent.

When forest production is compared, consideration should also be taken to the fact that the clear-cut can be replanted one year earlier when residue is forwarded directly after felling, compared with when the residue is stored on the clear-cut. In areas felled in the winter, the risk of ground damage is reduced if the residue is forwarded directly after felling while the ground is frozen, compared with when forwarding is postponed until the following autumn.

MORE EFFICIENT TECHNOLOGY FOR STUMP HARVEST

Henrik von Hofsten, Skogforsk

Stump harvest or stump extraction has been practiced in Scandinavian forests since the Middle Ages. Up until the 1970s, it was mainly pine stumps that were harvested with metal rods, spades and winches, in order to extract pine tar.


The Stelpa stump head

In the early 1970s, concern arose that the pulp industry would have problems with supplies of raw materials, and attention turned to the possibilities of using, primarily, spruce stumps for pulp chips. The lifting devices that were developed then are still in use today, although some improvements have been made. Broadly speaking, the conventional lifting devices are based on powerful grapple pliers that are used to split and pull up the stump. The method works relatively well, but requires great power and often causes major disturbance to the ground. However, in the past decade, there have been some new technical developments in the field, with the focus now on producing fuel chips from the stumps.

The first completely new approach to stump harvesting in Nordic conditions was the **Rotary stump cutter**. It loosens the stump before lifting by sawing/grinding off the thick roots with a rotating drum that is placed over the stump.

In studies, the principle has been shown to work quite well, but the machine is sensitive to rocks and stones and works best on sedimentary soils or other soils with few large stones and rocks (stones smaller than a tennis ball present no problems). Similar machines have been used since the 1960s in southern Europe in conjunction with clearing poplar and eucalyptus plantations, and are mainly fitted behind agricultural tractors.

The productivity of the rotary stump cutter, calculated in number of stumps/hour, is comparable with many conventional machines. However, because most of the thick roots are not extracted, productivity in terms of stump biomass per hour is only 50-60 percent of a conventional stump harvester. On the plus side, the roots that are left largely undisturbed in the soil mean that the bearing capacity of the ground is not reduced to any great extent, which is a great advantage when it comes to forwarding.

The amount of disturbed ground is less than one-fifth of the amount disturbed when extracting stumps with a conventional lifting device.

The TL-GROT stump head
– prototype under development.

The Xteho stump head.

Xteho is a Finnish lifting device with four grapple claws that are placed over the stump, after which the claws are forced into the wood and press up the stump. The four claws are also equipped with a 'splitting iron' on the inside, so that the stump is split into four parts during the removal. Another feature is that the grapple claws can vibrate, so that contaminants are loosened from the stump and roots. There is no need to shake the entire lifting device, which considerably improves the work environment for the operators.

Xteho performs well compared to conventional lifting devices, and gives clean and high quality stump material. The disadvantage is that the head hangs freely from the boom tip, so the operator cannot use the crane for support when moving the machine, which is common with caterpillar excavators. Xteho is also rather too heavy (2.5 tonnes) for most wheeled forest machines.

The effect of Xteho on the ground must be regarded as moderate, but fitted on an excavator the caterpillar tracks can certainly be a disadvantage on certain types of ground. Because the operator cannot use the crane to help in movements, there is a lot of slipping and rotating, particularly in sharp turns.

One recently developed lifting device designed specifically to minimise both ground impact and the quantity of contaminants is the **TL-GROT** stump head. With two 'claws' and one 'thumb' that shoot out, it is relatively easy to cut off a buttress a short distance out from the stump, while the stump is twisted upwards towards the claws and thereby lifted slightly.

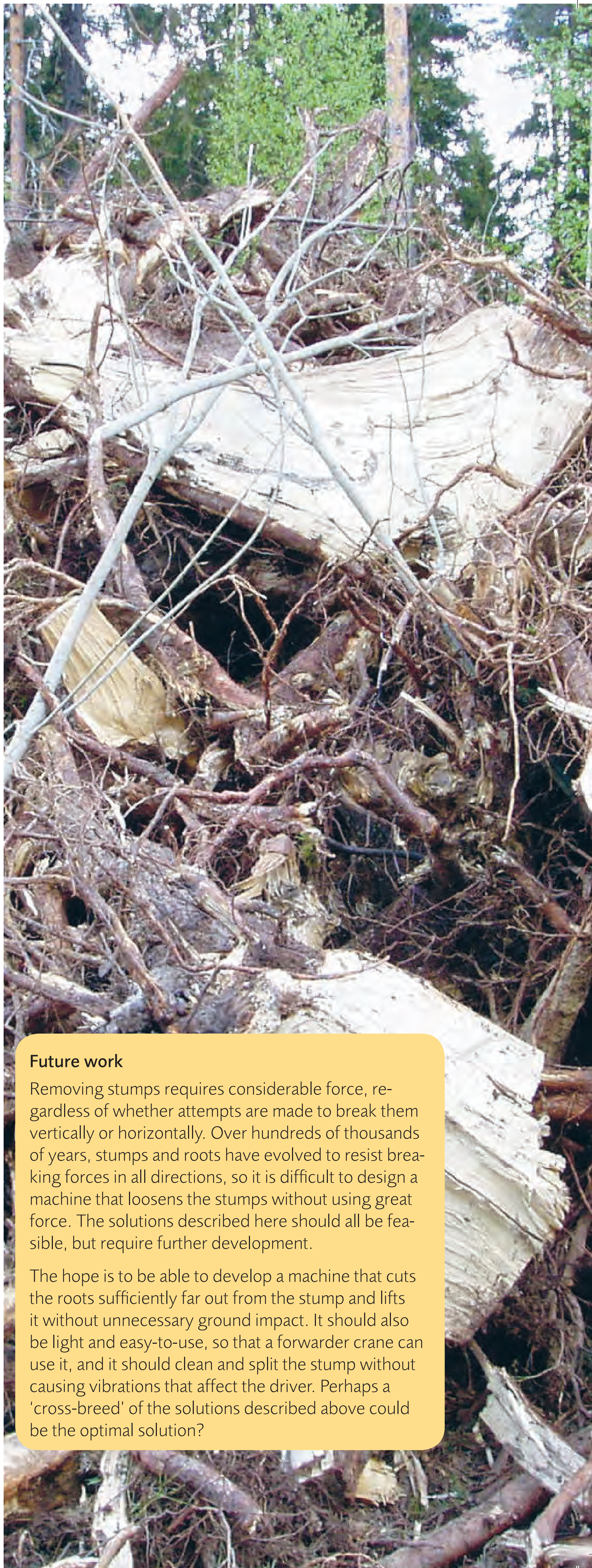
The head sits in a rotator, so can be turned in several directions to cut more roots before the final lift. Because the lifting device is still under development, no comprehensive studies have been carried out. However, a smaller study showed that ground impact was considerably reduced, particularly the size of the cavity after the stump, whose area was only a third of that created by a conventional device. The number of remaining roots was almost halved, while the mean diameter at the rupture surface of the remaining roots increased from just under 5 mm to 15 mm, which also indicates that the quantity of remaining fine roots is drastically reduced.

Drills. One interesting solution for stump harvest, which to the best of our knowledge has yet to make any impact, is a drill that is used to first crack the stump in the ground and then the stump parts are lifted with a claw. The biggest advantage should be that the method does not require a lot of power in the crane, because the buttress is partly broken by the screw. Ground impact would probably be less than for conventional devices. A disadvantage can be that it is difficult to further split a loose stump part with widespread roots. The loose stump part would simply roll away before the screw could grip it.

CBI/Lasco Stump Screw is a variation of the same concept, but with a slightly different design. The productivity has been tested by METLA in a thinning stand. The drill was used to crack the stump in the ground before it was lifted by the forwarder. The productivity was only 30 percent compared with conventional technology in final felling stands, but at the same time the ground impact was only 50-60 percent of that caused by conventional technology.

The **Järvinen** lifting device places a ring on the ground around the stump, after which the stump is gripped and pulled upwards through the ring, which serves as a counterweight. The ring can break off roots of up to approximately 10 cm. However, certain improvements are needed, because the machine cannot harvest stumps whose roots are too thick, nor can it split or clean stumps, which are important aspects for a viable stump harvester head.

In an experiment carried out by SLU in Umeå, an attempt was made to twist stumps loose from the ground. The hypothesis was that the roots would be less resistant to a lateral force than a vertical one. The aim was to develop a technology that would not need great breaking force and heavy base machines. However, the experiment showed that the torque required to twist the stumps loose would be too high – far higher than the torque that can be generated today by a rotator. Somewhat lower torque was needed to cut off the roots laterally around the stump, but even this was more than current machines can generate. Ground impact was not improved noticeably, because many roots did not break off before the entire stump started to rotate.



Future work

Removing stumps requires considerable force, regardless of whether attempts are made to break them vertically or horizontally. Over hundreds of thousands of years, stumps and roots have evolved to resist breaking forces in all directions, so it is difficult to design a machine that loosens the stumps without using great force. The solutions described here should all be feasible, but require further development.

The hope is to be able to develop a machine that cuts the roots sufficiently far out from the stump and lifts it without unnecessary ground impact. It should also be light and easy-to-use, so that a forwarder crane can use it, and it should clean and split the stump without causing vibrations that affect the driver. Perhaps a 'cross-breed' of the solutions described above could be the optimal solution?

Spruce stump with emergence holes of the pine longhorn beetle, a common species that regenerates in many forms of dead wood.

Spruce stump that has grown over an old stump should not be harvested.

ENVIRONMENTAL EFFECTS OF STUMP HARVEST

Henrik von Hofsten, Skogforsk

The environmental effects of stump harvest have been a source of constant debate since stump harvesting took off at the start of the 2000s. Many concerns have been put forward, such as that stump harvest would be a serious threat to the biological diversity because of removal of vital substrate, and that the ground impact would be unacceptably high. The effect on the carbon balance has also been debated. In order to investigate these issues, a theme programme has been carried out in two four-year periods (Theme Stumps) at SLU in Uppsala. Like ESS, the theme programmes have largely been financed by the Swedish Energy Agency, but also by SLU and forestry companies. Read more at www.slu.se/stubbar

One question that quickly arose was how many stumps are left on a clear-cut after stump harvest. This was examined by conducting an inventory of ten stump-harvested clear-cuts in Bergslagen and on a larger clear-cut (approximately 10 ha) in Västerbotten. On the Bergslagen clear-cuts, data was also collected from the harvester that had done the felling, in order to compare the number of cut trees in each stand with the number of remaining stumps.

The inventory showed that up to 25-30 percent of the stumps were left on the clear-cuts. The distribution over the diameter classes was good, and stumps of all sizes remained in the stands. One important and natural reason for leaving a stump was that it was at the edge of the clear-cut or a ditch. Another reason was that the stump was near a conservation site, such as an anthill, high stump, eternity tree or similar. In total, 60 percent of the stumps left in the ground were left for these reasons. The other 40 percent had, quite simply, been missed by the machine operator, the equivalent of approximately 66 stumps per hectare.

The crab-of-the-woods fungi (Laetiporus sulphureus) is a typical deciduous tree fungi; its presence signals that the stump should not be lifted.

Measurement of the affected ground around a stump cavity left by the TL-GROT stump head. Each square is 15 x 15 cm.

Theme Stumps has identified a sizeable number of organisms such as mosses, lichens and insects that colonise felling stumps. For some of the insects, successful regeneration requires that the stump is intact and has no bark abrasion. In the inventory above, approximately 80 percent of the stumps were undamaged or only very slightly damaged.

Ground impact after stump removal is an important issue. A field study carried out by SLU, Umeå, showed that on average 6.1 m² of the ground surface was impacted per lifted stump, and the area of impact increased with stump size. In total, 60 percent of the ground was affected, half from stump removal, and half by the tracks left by the machines that had driven on the clear-cut in conjunction with felling, stump removal and scarification.

The root rupture diameter is also interesting, since it reflects how much of the ground is damaged in the stand. The finer the roots that accompany the stump, the higher too is the ash content and nutrient loss. The quantity of remaining roots also affects the ash content of the stump material and the bearing capacity of the ground in forwarding. In the SLU study, the root rupture diameter averaged only 5 mm. Neither the ground impact nor the root rupture diameter were affected by the time span between felling and stump extraction.

In an experiment to reduce ground disruption and associated contaminants, Skogforsk tested a new lifting device, developed by TL-GROT AB. The device is designed to cut off the roots approximately 30 centimetres outside the stump, in order to leave more of the smaller roots in the ground. The results of the first test operations showed that the theory seemed to be correct. Compared with the SLU study above, the number of remaining roots on the lifted stumps decreased by more than a half, and the diameter at the rupture surface was tripled. Because more thin roots were left in the ground, the impacted area decreased to approximately 40 percent of that found in the SLU study.

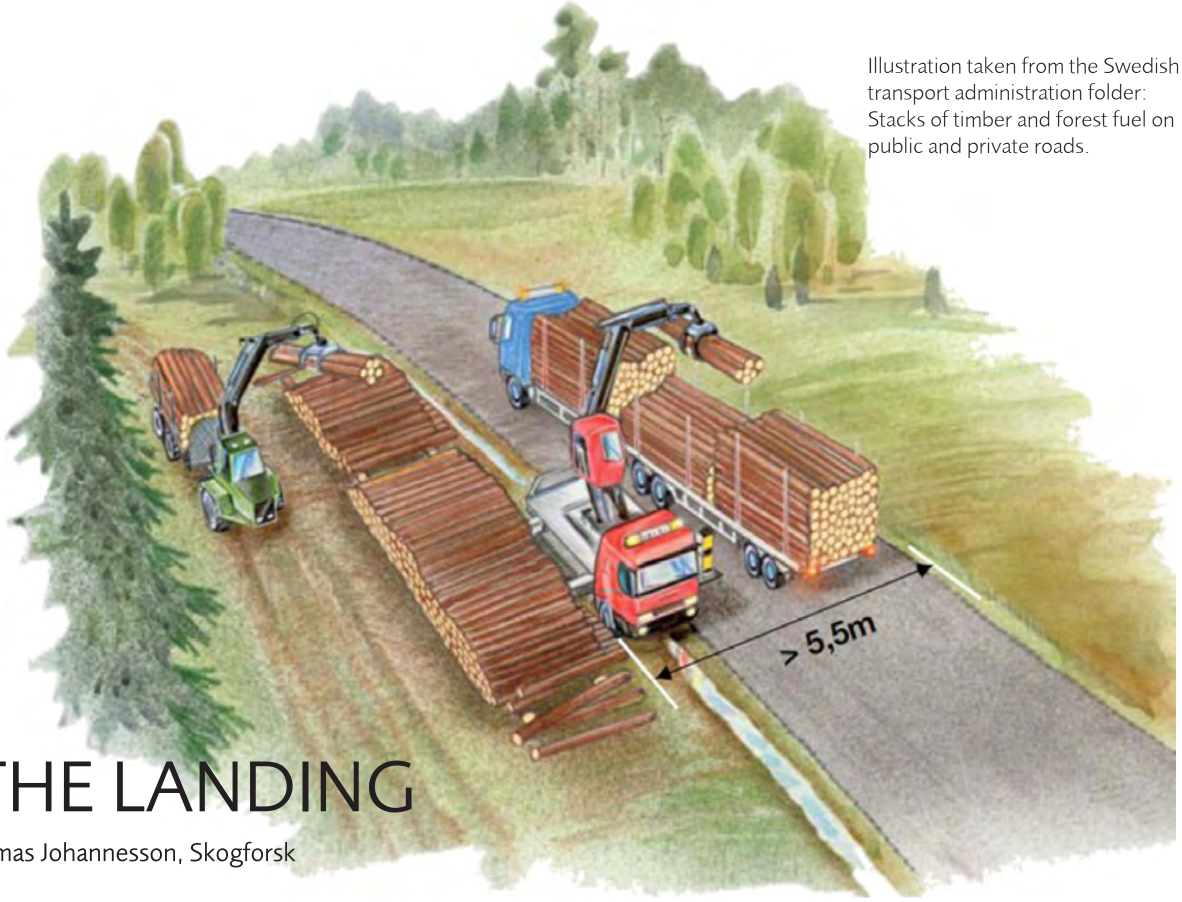


Illustration taken from the Swedish transport administration folder: Stacks of timber and forest fuel on public and private roads.

THE LANDING

Tomas Johannesson, Skogforsk

Stacking timber on the roadside requires a permit from the body responsible for maintaining the road; for public roads this is the Swedish Transport Administration. Applications can be submitted for a general permit that applies for certain roads in a county, via the Swedish Transport Administration website.

The permit must be supplemented en with an application at the start of felling for each individual project. For roads or situations to which a general permit does not apply, an application can be submitted for a specific permit in the same way. Stacks of stumps are not covered by the general permits, because they are regarded as being far too irregular in shape and may cause serious damage in the event of a collision.

Together with the ESS programme and representatives from the forestry sector, the Swedish Transport Administration has developed a regulatory framework and guidelines for stacks of timber and forest fuel. The aim is to reduce risks to traffic and for the personnel who handle and transport the material. The safety distance from roadside to a stack of wood depends on the permitted speed on the road – two metres at 50 km/hour, three metres at 60 to 80 km/hour, seven metres at 90 km/hour, and nine metres at 110 km/hour.

In the preparatory work on the new regulations, our request for consideration for the special requirements relating to forest fuel was respected, for example that the piles must be accessible to the machines that are to comminute the forest fuel.

The Swedish Transport Administration accepts six weeks of roadside storage for roundwood stacks and no less than 18 months for stacks of forest fuel. It is positive that forest fuel piles can be stored for such a long period, as these assortments are not in demand all year round. The landing is used as interim storage, where the forest fuel stacks are normally allowed to dry over a summer season. The extended storage time for forest fuel stacks does increase the risk of exposure for other road users, so it is extra important that activities and planning regarding the landing are handled correctly.

The stack must be placed in such a way that it does not hinder road maintenance, such as snow clearance, nor may it block roadside ditches. The ideal height of a stack is 3-3.5 metres, and it must not be higher than 4.5 metres above the road surface when it is to be loaded onto trucks for onward transport or chipped with a chipper truck.

The side of the stack facing the road must have an even surface, with no protruding logs or other tree parts that could penetrate a vehicle in the event of a collision. It may be necessary to trim parts of forest fuel stacks to make the surface on the side facing the road even. No part of the pile may lie within the safety distance.

It is important to avoid overhead electricity cables. For low-voltage cables, the minimum permitted distance is two metres between the stack and the crane. For high-voltage cables of max 40 kV, the safety distance is four metres, and for cables of higher voltage six metres. In practice, a safety distance of 15-25 metres is recommended, depending on the length of the timber or forest fuel, the working area of the crane, and the voltage in the cables.

Loading and transport

According to the traffic regulations, anyone placing a vehicle along a road to load or unload must ensure that other road-users can detect the vehicle in time. The driver may use a warning triangle, warning lamps, hazard warning lights or flashing lights built into the ramp of rear lights or timber stakes. There is also a special warning sign (sign X6 according to the Road Signs Ordinance) showing that accessibility on a road is reduced because of a temporary obstacle. The sign can be reinforced with a yellow flashing light to signal the need for special caution. Side marking shields can be used to direct traffic past the truck if necessary (sign X3).

Fuel quality

In addition to successful use of the landing from safety and logistical aspects, the time of storage is significant for reducing the moisture content of the fuel. Generally, it can be argued that ambitious planning of the landing improves profitability. If the moisture content decreases, the increased revenues usually cover the costs of the extra work involved, as shown in the example below.

Example: If an alternative site for the landing can be found that offers better drying conditions, so that the moisture content decreases from 50 to 45 percent, the value of a forwarder load increases by approximately SEK 130. This corresponds to extra forwarding time of no less than ten minutes (equivalent to an extra total forwarding distance of approximately 250 metres). Shorter extra distance and/or greater reduction in moisture content is pure profit.

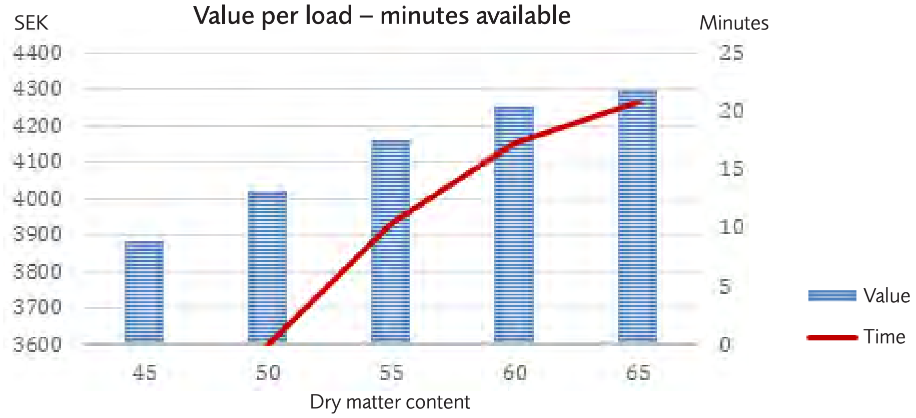


Figure 1. The blue columns show the value of a forwarder load with different moisture contents on delivery. The red line shows how many extra minutes the forwarder can invest in order to reduce moisture content while retaining the net value of the biomass.

Conditions for the calculation:

- The calculation is based on fresh logging residue forwarded to the landing.
- The fresh residue has a moisture content of 50 percent, which corresponds to an energy content of 0.87 MWh per m³ of chips.
- A forwarder load contains the equivalent of 25 m³ of chips. The load volume is not affected by the moisture content.
- The hourly cost of the forwarder is SEK 800.

How to create good conditions for drying:

- The ground surface should be dry and well-drained, and free from stones and undergrowth that may contaminate the residues during handling and cause delays during comminution.
- The landing should be exposed to sun and wind.
- The cover should be applied carefully so that the covering paper remains intact and is not damaged by the wind.

Large variations can often be observed in moisture content of fuel deliveries from the same district, where the conditions for the logging residue should in theory be equal, but where the stacks have been placed in different locations. In certain cases, a more careful choice of landing site would probably have improved overall profitability for the fuel deliveries from a cutting site.

GROUND DAMAGE

Lars Högbom, Skogforsk

Ground damage caused by machine traffic during harvesting operations is a major problem that is attracting increasing attention, both in and outside forestry. In order to minimise the problem, training and information are required, and greater knowledge about the factors that influence ground damage.

Greater extraction of logging residues risks increasing ground damage for two reasons: the total number of transports in the forest terrain increases, and tops and branches are removed that could otherwise be used to protect the ground.

We have followed up a number of logging sites in central Sweden. The aim was to develop guidelines for how, when and where fuel assortments can be harvested in conjunction with regeneration felling.

Ground damage in conjunction with logging has increased in recent years. The Swedish Forest Agency's Polytax shows that the proportion of severe cases of ground damage in connection with stream crossings increased from 4 to 18 percent between 1999 and 2007. The figures are an average figure for the felled area where streams are present.

There are currently no indications that ground damage will decrease in the future. On the contrary, in fact; extraction of both roundwood and forest fuel assortments is expected to increase in the next 20 years, and forestry will be moving into areas with increasingly difficult conditions. In combination with an expected climate change, this will lead to increased extraction on more difficult areas.

Examples of the effects of using, and not using, branches and tops to reinforce tracks. The picture above, and the one to the right, were taken 15 m apart on the same type of ground and on the same day.

About the study

In order to obtain a representative selection of samples, we based our study on all reported fellings in 2010 from four counties around Lake Mälaren (Stockholm, Uppsala, Södermanland, and Västmanland). This gave a total of 4728 fellings. Of these, 60 were selected at random from each county. In the years 2011-2013, these 240 sites were visited; three were excluded for various reasons, so the final total was 237.

In the study, we focused on ground damage close to various types of watercourses and, to avoid delimitation problems, we treated all occurrences of water in a standard way. The limit for 'close to water' was set to 30 metres.

Every wheel track was assessed separately, i.e. every vehicle movement gave two wheel tracks. Within each site, the general distribution of ground damage was placed in four classes – none, sporadic occurrence, occurrence and general. The rut depth was also assessed in four classes: 0-5 cm, 5-25 cm, 25-50 cm and >50 cm. Rut depths were only measured on the sites where we had recorded damage close to water.

Some results

- Of the 237 sites visited, 211 were felled and 26 unfelled.
- 142 of the felled sites were adjacent to water in some form.
- Of these 142 sites, 99 had incidences of damage to varying extents. In total, 1088 individual cases of ground damage were recorded.
- 484 of the cases of damage were in direct contact with water, and the rest lay within the 30-metre zone, but outside the actual water area.
- Of the direct damage, 447 cases occurred on crossings, and 37 where machines had been operated along watercourses.
- 236 cases of damage caused visible sludge transport, 223 caused damming, 125 caused removal of humus, and 108 lacked visible negative effects.
- The 12 most damaged sites accounted for over half of the damage.
- Two sites had more than 10 cases of damage per hectare.

The general pattern was that areas of peat and fine-grained soil showed most damage. However, there were areas of fine-grained soil with no damage, which indicates that the time of felling is very important.

The data also showed that ground reinforcement measures, such as bridges, log mats, tops and branches, had been used to a significant extent to prevent damage from machines.

One of the aims of the study was to see whether extraction of logging residue caused more ground damage. Since residue had been extracted on virtually all sites, it was difficult to analyse this aspect. Other factors than residue extraction have had greater impact.

The conclusion was that a small number of sites accounted for most of the damage and that the soil type – hardly surprisingly – was very significant. The finer the grain of soil, the greater the proportion of damage. The time of felling was also important, since there were sites with fine-grained soil that showed no damage.

Future work

- The results of this study can be used to improve procedures and planning tools, such as digital maps.


PHOTO: ANN HEDLUND/HÖGSKOLAN DALARNA

OPERATOR WORK ENVIRONMENT

Ann Hedlund & Ing-Marie Andersson, Högskolan Dalarna

Since 2009, the work science group at Dalarna University has been studying work environment issues relating to the handling of forest fuel. In the earlier ESS programme, the focus was on knowledge exchange between contractors, the attractiveness of the forest energy sector, client responsibility, mould, and systematic improvements to the work environment. In the 2011-2014 programme period, further studies have been carried out on noise, dust and mould, whole-body vibrations, and repair work. Operator views on working conditions and work environment risks have been collected via a questionnaire survey.

Noise

Chipping and grinding of forest fuel generates noise levels that are so high that the operator must take measures to prevent harm. The levels vary between different types of machine combinations, and operators in crane cabs are especially vulnerable. A well-insulated operator environment and closed windows and doors reduce exposure to noise. Noise levels around the machines are high, so anyone working in the vicinity must use ear protectors.

At a distance of 200 metres from the comminution site, noise levels usually exceed recommended levels for residences, work premises and recreational areas. In such conditions, the machines can be placed, for example, behind natural barriers, so that the noise is buffered, and operation can be avoided in early mornings, evenings and at weekends.

Dust and mould

Earlier studies have indicated high levels of dust and mould in conjunction with the handling of logging residue. In case studies carried out in 2012/2013, in a period of high precipitation, no high levels of dust and mould were recorded. The studies showed that the highest peaks of exposure occurred when the operator got in and out of the cab, and when changing blades in the comminution machine. Elevated dust levels were also observed when the operator carried out service and maintenance work outside the cab. Operators are recommended to keep windows and door closed, to change air filters regularly, and to place the machine appropriately in relation to wind direction, to reduce the risk of exposure to dust and mould.

Whole-body vibrations

In a smaller study of comminution of logging residue, the level of whole-body vibrations was so high that measures to prevent harm were needed in approximately half of the cases. It was mainly crane movements while feeding residue into the chipper that affected vibration levels.

Harmful vibration levels have been recorded in connection with stump harvest. In these cases, the vibration levels were affected by ground conditions in the form of surface structure and bearing capacity, and how firmly the stumps were fixed in the ground. Exposure peaks also occur when stumps are shaken, when the cab rotates, and when the harvester head is used to push stumps along the ground or to even out the ground. The operator can reduce vibration levels by adapting operation to the terrain conditions and by synchronising crane handling.

Service an repair

Service and repair work is often heavy, dirty and risky. Good work environment solutions can be created already at the development and manufacture stage of machinery. Important areas to consider are access paths, placement of service points, access for daily inspection, elimination of power sources, and manuals. Operators and service personnel can minimise their risks by reading the service manual carefully, and by using protective equipment, ladders and appropriate tools. It is also important to handle chemicals carefully.

What machine operators think

A questionnaire completed by machine operators showed a high level of use of protective equipment.

Operators who worked with comminution reported more problems than those working with stump harvest and forwarding. The operators experience less discomfort inside the cab than outside in terms of noise, cold and draughts, and dust.

More than half of the operators working with comminuted material reported problems caused by various degrees of mould odour.

Overall, the mental workload was experienced as greater than the physical.

Most of the operators reported a risk of accidents in their work, the most common being cuts and slipping, followed by falling.

Information material for better work environment

In order to disseminate knowledge about work environment issues, a module-based implementation material in the form of PowerPoint slides with associated instructions has been developed. The modules are Purchasing, Planning, Forwarding, Stump Harvest, Comminution, and Development/Manufacture. The material is available at www.du.se/arbetsliv_skog

ILLUSTRATION: ANN HEDLUND/DALARNA UNIVERSITY

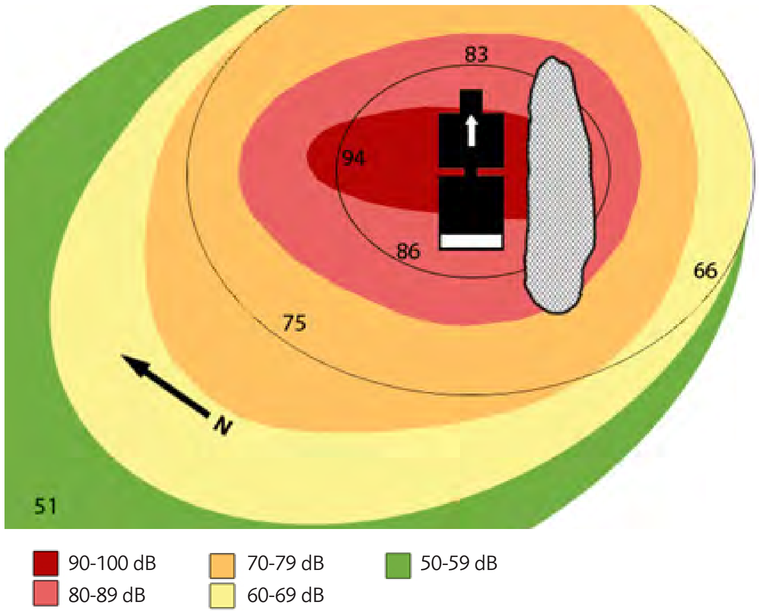


Figure 1. Noise-level contours around a forwarder-mounted chipper. The inner ring is 5 metres from the machine, the outer ring is 25 metres away, and the measurement figure in the bottom left is 200 metres away.

Future work

Further research and development is needed to

1. Reduce
   - noise during comminution
   - vibrations during comminution and stump harvest
   - the number of accidents and severe injuries, particularly during service and repair.
2. Identift the causes of high mental workload, and use organisational and other measures to enable improvements to the work situation.
3. Generate more knowledge about work environment conditions in stump harvest.