Use of Accumulating & Processing Harvesting Heads

Summary

The use of mechanical harvesting systems for timber production is now the most common method within the British forestry sector. Most work is carried out by single grip harvesters which can only process one tree at a time. First thinning is typically when stand height reaches 10-12 m, and mean diameter around 12-14 cm, and is frequently loss-making. The greater use of silvicultural systems other than clearfell, and for reversion of plantation areas on ancient woodland sites back to native species (PAWS), is leading to a greater incidence of stands with prolific natural regeneration, both conifer and broadleaved. There is considerable interest in how to deal with young, dense stands, in a way that is not excessively costly, and that may meet national targets for management and harvesting outputs. This report presents information gathered on an EU-funded research trip hosted in Sweden by their national forest research agency, Skogforsk. The trip included a field study of multi-stem harvesting, and time spent at the Skogforsk offices in Uppsala data-gathering. A time study was conducted on a Valmet 901.4 harvester fitted with an 11.3 m (extended length) crane with a lateral pivot, and a SP451LF head. The head was similar to a conventional single grip models but with an accumulating facility, having the ability to gather a bunch of stems and then process them together. With a removal of stems of average 0.018 m^3fub (7.6 cm diameter) at a rate of 234 stems per hour, gross productivity was 4.2 m^3/shr. The nearest recorded non-accumulating GB working achieved a rate of 2.44 m^3/shr in stems of 0.07 m^3. This report analyses work technique and relevance to GB conditions. Swedish experience is also summarised, detailing the inter-relation between harvesting head type, stem size and work method. Generalised Swedish stand prescriptions are also provided as a template for future work. It is concluded that accumulating harvesting has great GB potential for PAWS and CCF derived stands. Machine and work method changes may allow otherwise financially non-viable stands to be thinned for firewood, woodfuel and fencing.

Introduction

The use of mechanical harvesting systems for timber production is now the most common method within the British forestry sector. The harvester heads used are predominately single grip, and only permit one tree to be processed at a time. The first stand intervention using these heads is when stand height reaches 10-12 m, and mean diameter around 12-14 cm, and is frequently loss-making.

Current forest policy across Great Britain (GB) is for greater use of silvicultural systems other than clearfell (ATC, LISS, CCF[1]) and for reversion of plantation areas on ancient woodland sites back to native species (PAWS). Both these policies frequently lead to prolific natural regeneration, both conifer and broadleaved. There is considerable interest in how to deal with young, dense stands, in a way that is not excessively costly, and that may meet national targets for management and harvesting outputs.

This project is to investigate the ability of multi stem harvester heads to fell and process young natural regeneration material growing in GB stands. Harvested material is likely to be utilized by the woodfuel industry but may also include other small diameter uses such as fencing.

The project reports on a Short Term Scientific Mission (STSM), an EU-funded research trip through COST Action FP0902. The STSM was hosted in Sweden by the national forest research agency, Skogforsk. The STSM was divided into 2 parts; 1) field study of multi-stem harvesting 2) time spent at the Skogforsk offices in Uppsala data-gathering.

Objectives

1. Observe accumulating heads in dense small stands
2. Record working methods
3. Carry out time study to provide indicative outputs and costs.
4. Discuss operational aspects with operator/Skogforsk
5. Knowledge transfer ref costs, outputs, operational aspects, specifics relating to work study of such ops
6. Make recommendations for implementation in the UK

[1] Alternatives To Clearfell, Low Impact Silvicultural Systems, Continuous Cover Forestry

Field Study

Stand Details

The study site was in the south of Sweden near the village of Grimslov. The stand was privately owned, and management and harvesting was carried out by the management company, Södra. The study site was a scheduled trial into interplay of motor-manual pre-cleaning specification and cutting specification on costs and outputs.

Previous Management

The stand had been clearfelled around 15 years previously and replanted with Norway spruce. Birch and spruce natural regeneration was heavy and had already received some respacing before this intervention. The stand after pre-cleaning is shown in Figure 1, and after harvesting in Figure 2.

Figure 1. Stand after pre-cleaning to 5 cm.

Figure 2. Stand after harvesting.

Current intervention

The conventional Swedish approach has been for motor-manual respacing of trees smaller than 8 cm before harvesting, as no pulp could be cut from trees smaller than this. Motor manual cleaning is seen as a more cost-effective option of dealing with small stems than incurring non-productive harvester time to complete the same work. Cutting energy-wood, rather than only pulpwood, provides a market for smaller-diameter material. As such, stems were pre-cleaned to 5 cm in the trial stand rather than 8 cm.

Stand Mensuration

Mensuration was carried out by surveying 6 plots of 0.01 ha (5.64 m radius). Diameter of all trees were measured using callipers. Heights of trees across the range of diameters were taken to produce stand height curves.

Diameter

Stand diameter distribution is presented in Figure 3 and summarised in Table 1.

Figure 3. Stem diameter distribution for stand.

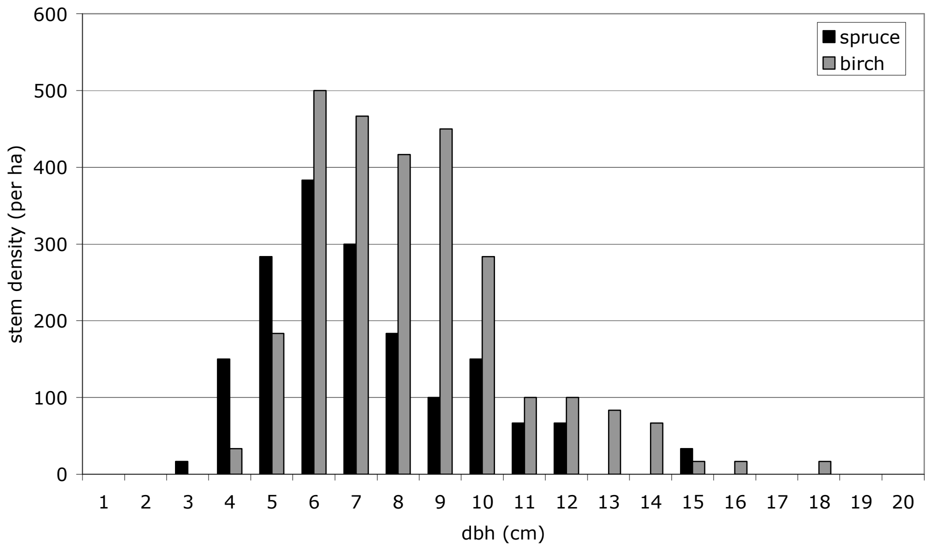


Table 1. Summary of stand size distribution and stocking.

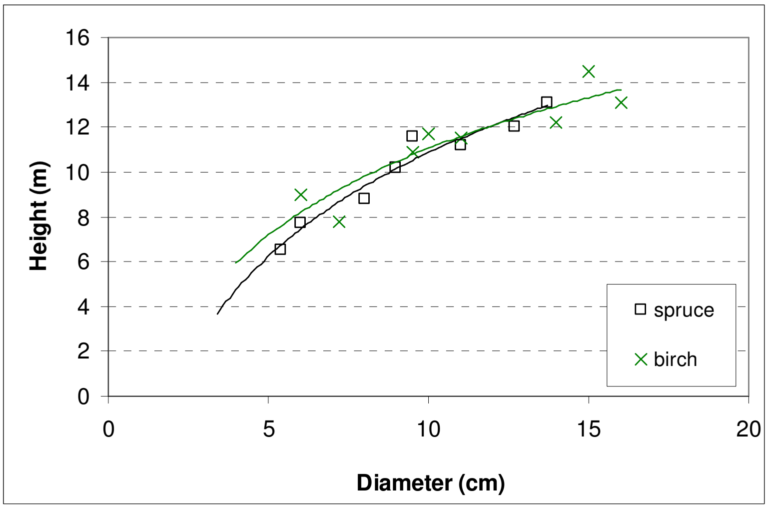
	unit	Spruce	Birch	All
Minimum dbh	cm	2.6	3.9	2.6
Maximum dbh	cm	14.6	17.5	17.5
Median dbh	cm	6.6	8.0	7.4
Mean dbh	cm	7.0	8.3	7.8
Density	Per ha	1733	2733	4466

Total stem density including both birch and spruce, was 4466/ha, the birch forming 61% and the spruce 39%. The birch trees were also larger, with a mean of 8.3 cm compared to 7.0 cm for the spruce, and ranging up to 17.5 cm in diameter, compared to 14.6 cm in spruce.

Height

Stand height curves for both spruce and birch can be seen in Figure 4. Curves for both species can be seen to be very similar. Top height was 13.5 m, equivalent to a yield class of 10.

Figure 4. Stand height curves for spruce and birch.



Volume

Stem volume (commercial >5 cm u.b.) was estimated using Swedish form functions, diameter and height, and is summarised in Table 2. Total volume was calculated as 102 m^3/ha, the birch forming 67% of this. Birch stem volume ranged up to 0.131 m^3, compared with up to 0.099 m^3 in spruce. Stand mean for birch was 0.025 m^3 compared to 0.019 m^3 for spruce and an overall stand median of 0.023 m^3.

Table 2 Estimated tree volume and dry mass.

	Spruce		Birch		Total	
	m^3 fub	DM kg	m^3 fub	DM kg	m^3 fub	DM kg
Minimum	0.002	4.58	0.003	6.83	0.002	4.58
Maximum	0.099	113.42	0.131	148.07	0.131	148.07
Median	0.013	19.30	0.020	28.00	0.017	24.47
Mean	0.019	26.21	0.025	33.36	0.023	30.58
Per Hectare	33.211	45,429	68.521	91,177	101.732	136,606

Total tree dry matter mass (DM kg) was also estimated from volume using Skogforsk conversion factors and is also summarised in Table 2. Tree mass in dry kilograms ranged from 4.58 to 113.32 in spruce and 6.83 to 148.77 in birch. Mean values were 26.21 kg in spruce and 33.36 kg in birch. Stand median was 30.58 kg. Total stand dry mass was estimated as 136,606 kg.

Time Study

Time study of harvesting took place over 2 days. The Skogforsk time study package was used, installed on an Allegro data-logger. Element descriptions are provided in Table 3 and tree codes in Table 4. Further description of the time study package is included in Appendix 1.

Table 3 Time study elements and break-points.

Element	Comment	Start	Stop
Cyclic			
Crane Out		Crane starts to move	Head touches tree
Harvest		Head touches tree	Crane moves from last cut tree
Crane In		Crane starts move	Other element starts
Buck		Feed rollers start	Last piece cut
Put Down		Last piece cut	Crane moves after dropping top
Move		Wheels move	Crane moves
Change crane cycle - F5			
Non-Cyclic			
Stuck		Tree bunch hangs-up	Crane / rollers move freely
Effective Time	Minor delay – productive	End last element	Start new element
Fix	Stack products	End last element	Start new element
Disturbance	Delay - unproductive	End last element	Start new element

Table 4 Tree identification codes – 4 digit sequence.

Study	Initial	Removed
Digit 1	Position	1 = Rack; 2 = Stand
Digit 2	Species	1 = Pine; 2 = Spruce; 3 = Birch
Digits 3-4	Diameter	e.g. 5 cm = 05; 14 cm = 14

The time study was conducted from the harvester cab. The dense nature of the regeneration stand meant that this was the only practical and safe option.

Machine and Work Method

The harvester worked through the stand cutting along pre-marked rack lines. Racks were spaced approximately 20 m apart, requiring the operator to thin into the stand up to 10 m from the rack centre i.e. at close to full crane extension.

Harvester and Head

The harvester used was a Valmet 901.4 fitted with a SP Maskiner 451 LF head. The machine was relatively new (2,600 hours) and worked 16 hours per day in 2 shifts.

The high hydraulic flow provided by the machine was noticeable during working, allowing fast crane movement, reducing this part of cyclic work time and helping to keep a high rate of work.

Crane

The harvester was equipped with an 11.3 m crane that was fitted with a lateral pivot (Figure 5). The pivot was controlled by a ram either side to give around 15° of lateral movement in each direction. The pivot was extremely useful as an aid to harvesting in the dense stands. Using this movement the operator was able to reach into the backs of groups of trees (Figure 5 mid), and around standing residual stems to access trees behind them (Figure 5 right). When used during accumulating cutting the facility was a great time saver as it widened the effective harvesting arc open to the operator, and reduced the need to bring the crane-in, rotate the cab, and move the crane-out to move past standing stems.

Figure 5. Crane lateral pivot (left), slewed left (mid), behind stem (right).

Head

The head used was a conventional single-grip processer with feed rollers, delimbing knives, and a felling chainsaw. The head was bought from the manufacturer with a set of accumulator arms (Figure 6), one of the standard options for the model. Cost is *c*. £5,000 for the accumulator option.

Figure 6. SP451LF harvesting head, & close-up of accumulator arm and back plate.

Figure 7. Accumulating arms holding cut birch.

The accumulator consists of a serrated back-plate (Figure 6, right) and 2 hinged arms. The arms are opened and closed by a ram under manual control of the operator. The arms are hinged in the middle, the outer half of the arm tensioned into a straight position by a spring. When the head is holding cut stems with the feed rollers and delimbing knives, the accumulator arms can be opened past the stems as the outer arms pivot inwards and then spring back straight when clear. The accumulator arms are then retracted, pinning stems against the back plate (Figure 7), allowing the feed rollers and delimbing knives to be opened. A good analogy is the action of how an arm clasps objects towards the body.

Accumulating

In use, the head and accumulating function performed well and reliably. The high position of the accumulating arms providing good leverage, controlling accumulated stems well. Cut stems broke free from the head occasionally, generally as a result of having been cut at an awkward angle leading to them not being gripped properly by the arms.

Spruce was more difficult to accumulate than birch due to the greater branchiness (Figure 8 left). Where spruce was added to birch bunches, the trees were often small (<7 cm) and the trees cut at the end of accumulation. Where spruce consisted of most or all of a bunch, 3 trees of 6-8 cm seemed to be the accumulating limit. The stem diameter was not the limiting factor, rather, the large amount of branch material within a bunch that made accumulation awkward. The straight stems of birch (Figure 8 right) allowed accumulations of up to 6 stems.

Figure 8. Accumulating spruce (left) and birch (right).

The chainsaw performed well, showing no differences between single stem and multi-stem working. A concern was that bunched stems could pinch or snag the bar when handling multiple stems, causing saw jams and chain losses. No evidence was seen of this at all.

Work Method

The standard work method was for the harvester to work along pre-marked racks, cutting all trees from the rack and then thinning to either side. Trees felled from the rack were processed in front of the machine, produce cut to piles at rack-side and brash used as mat material. Trees cut within the stand were processed in the stand to reduce crane movement. When fully accumulated, bunches were only moved to the closest product pile and processed towards the machine, rather than moving to the rack and processing away from the machine. This method reduces crane time, but at the cost of reducing the volume of brash added to the rack.

Rack and Brash Mat

The brash mat created by the normal work method was generally good enough for the mineral soils of the study site. Where the soils were wetter and brash lighter, the mat was not always sufficient to stop rutting, as can be seen in Figure 9 (right).

In very wet areas the operator cut stems to waste and carried out more processing over the rack in order to improve the mat depth. This work was carried out sparingly however as it reduced output.

Processed spruce provided more branch material for the mat due to better depth of crown. The brash also formed a denser and more resilient mat than birch tops.

Figure 9. Racks and brash mat.

Processing

The harvesting head could feed and process bunches of accumulated stems. Delimbing was rougher on bunched material than on single stems as limbs in the centre of bunches could not always be removed flush to the stem. In this study, stems were being cut as energy-wood, the product requiring only a rough delimbing as it was a chip feedstock.

Figure 10 shows a bunch of 3 spruce stems being processed. Some residual limbs can be seen between the visible stems, delimbing only having been achieved on their outsides.

Figure 10. Processing a bunch of spruce.

Figure 11. Piles of processed energy-wood.

The energy-wood cutting specification was for 4.5 m lengths to fit a forwarder bunk, variation allowable from 2.9 m to 5.4 m. Variation in length was predominantly caused by multi-stem processing. Where multiple stems were fed through the head together, progression was not always equal, particularly with material of poorer form.

The most common problem was for one of the bunched stems to veer into the sawbox and jam, the other stems being fed past it. Although this problem was solved easily by reducing grip on the bunch, the problem produced a number of under-length pieces.

Processed material can be seen in Figure 11. Of note is the product orientation in the left picture showing where produce has been processed from separate directions, and the variation in both size and form of material in both pictures.

Cutting Record

The machine keeps a record of stems and volume cut in both single-stem and accumulated cutting (see Figure 12), tree records were filed depending on if the accumulator was activated.

Whilst single-stem working allows the machine to measure tree diameter and lengths accurately, this accuracy suffers when handling several stems at once. The number of stems cut in either mode is recorded accurately however.

Figure 12. Machine cutting record screen.

Harvester Cost

The Valmet was a new machine with upgrades. Total running cost including operator was estimated at around 950 SEK/hour – approx £95.

Operator

The operator was noticeably well trained, skilled and motivated. Whilst experienced with both forwarder, and single-stem harvester working, the operator was relatively new to accumulating work.

The operator received standard pay for performance in-line with standard outputs for the stands harvested. If output was higher, pay increased to reflect the greater work rate. All through the study it was noticeable that the operator was striving to increase stems cut per hour. Even though the operator was cutting at an acceptable rate (240 stems/hour), he was very focussed in trying to improve output further to >300 stems/hour that he had witnessed from a more experienced operator.

The work-rate was relentless and the operator showed high levels of concentration. Breaks were very-much required to sustain rate, following a pattern of shorter but more frequent than in conventional harvesting, so in total taking around the same amount of time.

Results

Accumulation

The proportions of stems cut and processed within a crane cycle are presented in Figure 13. Crane cycles with 3 trees were most common (39%), closely followed by cycles with 2 trees (33%). Cycles of 1 or 4 trees each occurred 13% of the time. Cycles with 5 or 6 stems were both uncommon, each occurring in 1% instances. An average of 5.58 stems per cycle was recorded with a median of 3 stems.

Figure 13. Number of stems per crane cycle.

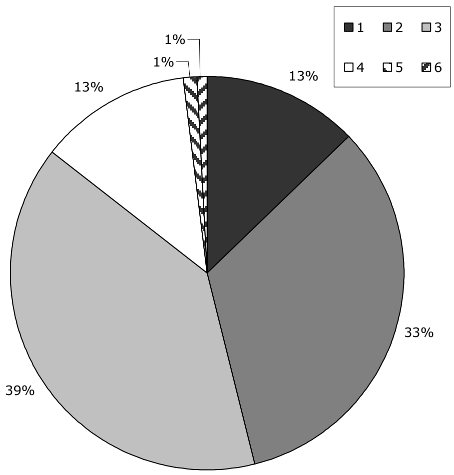
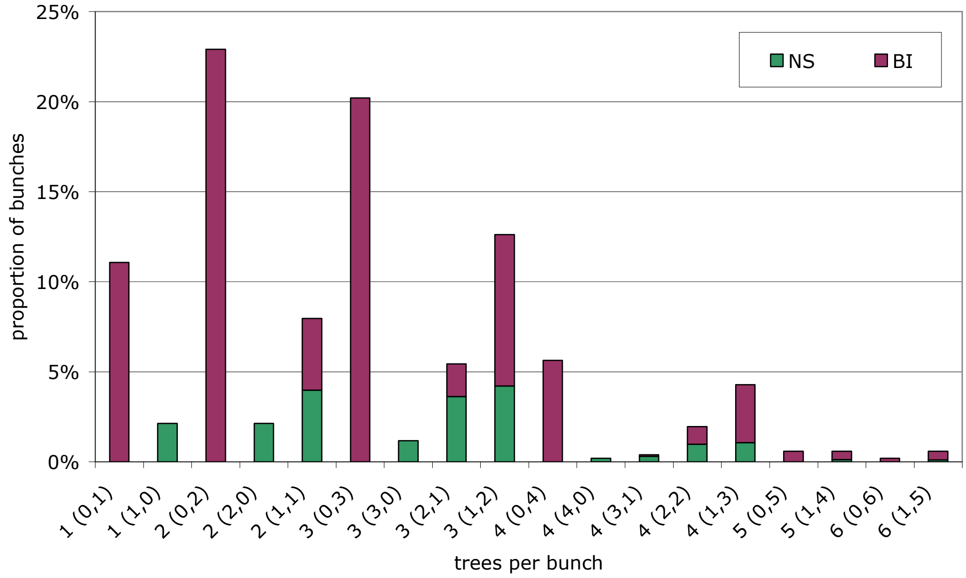


Figure 14 analyses the composition of bunches. Trees per bunch is subdivided by bunch composition. For example, a bunch of 3 stems, 1 spruce and 2 birch, is represented as 3(1,2). Bunches can be seen to be dominated by birch.

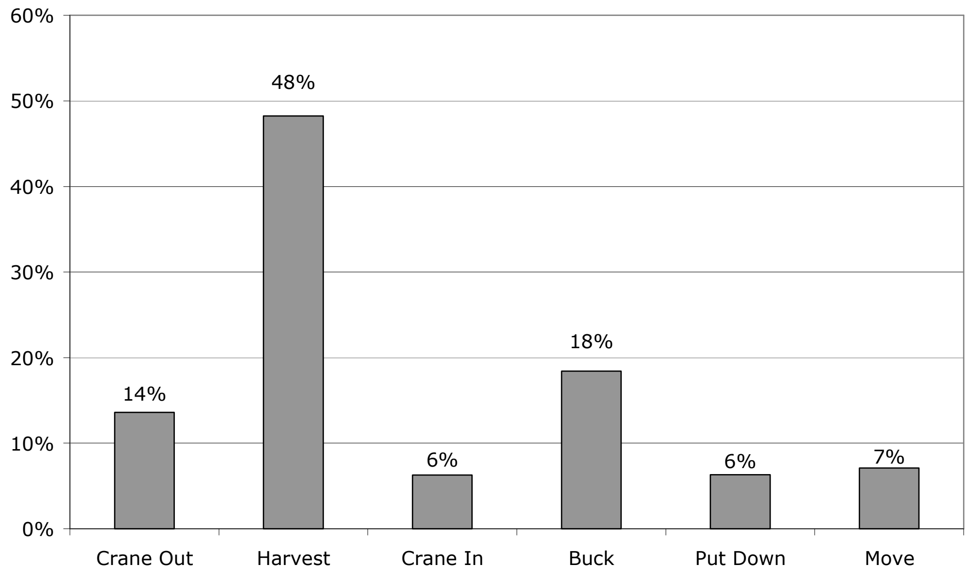
Figure 14. Species breakdown of stems per cycle.



Cyclic Work

Analysis of harvester cyclic work indicates how much work is prioritised to felling, and how much crane-in and crane-out movement, and other work such as processing and dropping the tops is minimised (Figure 15).

Figure 15. Proportional cyclic time consumption.



In typical GB working, felling time (crane-out and harvest) takes 25-30%, with processing (crane-in and buck) also taking 25-30%. Put down, and move elements take up approximately 10-12% and 5-15% of time respectively.

In this study, the components of felling time (crane out & harvest) form 62% of cyclic time, double that of GB work. The time spent processing stems is 24%; low but close to GB levels. Movement time is low for thinning work, but again within GB ranges. Time taken in dropping tops after processing is lower than GB levels, the reduced value likely to be because less brash was actively being worked into the mat.

Non-Cyclic Work

Non-cyclic but productive work was very low in this study; 4.0% of cyclic time. This work primarily consisted of preparing the brash mat, restacking cut produce, and changing the chainsaw chain. Very little time was lost due to bundles hanging-up. This level of time consumption was said to be typical for Swedish work.

Non-cyclic unproductive work, generally personal rest, was equivalent to GB levels of around 18%. The very fast work rate was noticeably hard on the operator and small but regular breaks were required.

Daily maintenance occurred for around 30 minutes at vehicle handover to the 2nd operator. Vehicle checks, fuelling, and lubricants were covered whilst discussing work progress and issues.

Harvester Output

Average Felled Tree Size

Mean felled tree size was 7.6 cm, 0.018 m^{3}fub. This compares to the mean tree size of 7.8 cm and 0.023 m^{3}fub.

Trees Per Hour

Felling rate for the study was recorded as 234 trees per hour. Rate increased over the study from below 200 to finish at around 250 trees per hour. This rate was considered to be normal and satisfactory for the stand.

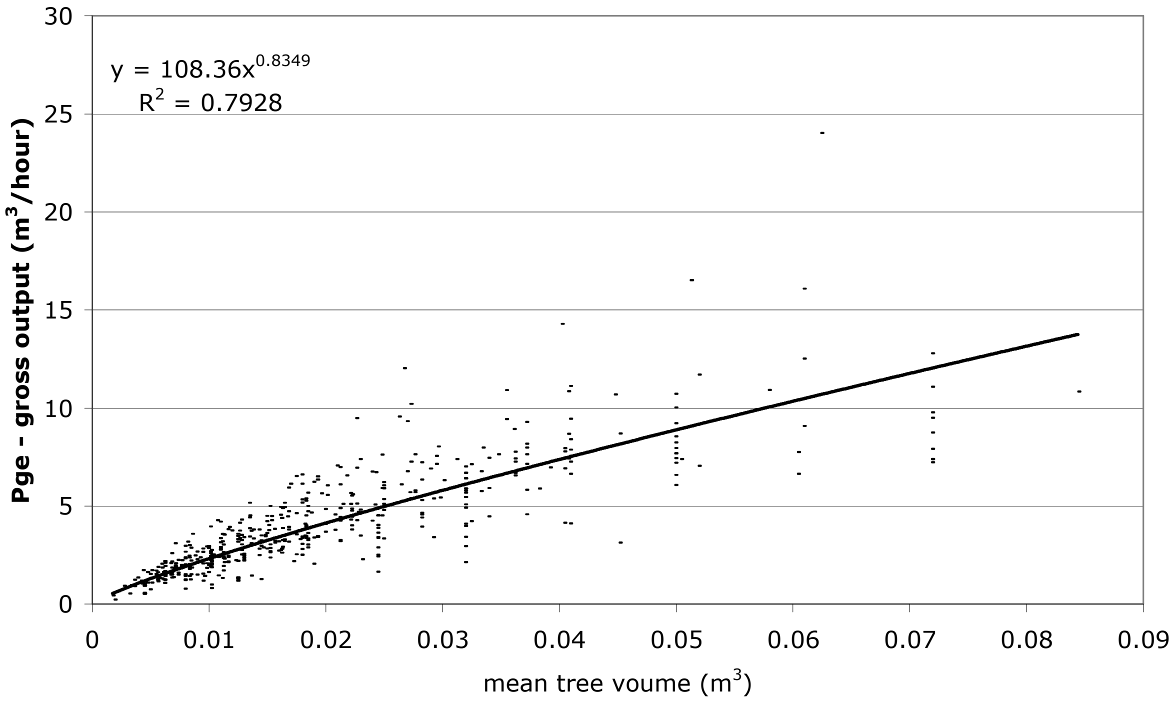
Harvester output curves

Figure 16 presents the recorded gross output (m^3/standard hour) across the range of tree volumes cut. Mean tree volume is that calculated as the mean of stems cut within each crane cycle.

Output was calculated using the under-bark commercial stemwood volume. Energywood volume in theory represents around 10% more than stemwood, taking into account bark, smaller stem portions and branch stubs. There is not, however, full conversion of predicted volume to product volume so these values are maximum possible values.

Allowance for non-cyclic effective work was set as 5%, maintenance and handover as 5%, and for rest and personal as 18% providing a basic time to standard time conversion of 1.298. Using this conversion, a gross output of 4.2 m^3/shr was recorded for the stand.

Figure 16. Gross output curve.



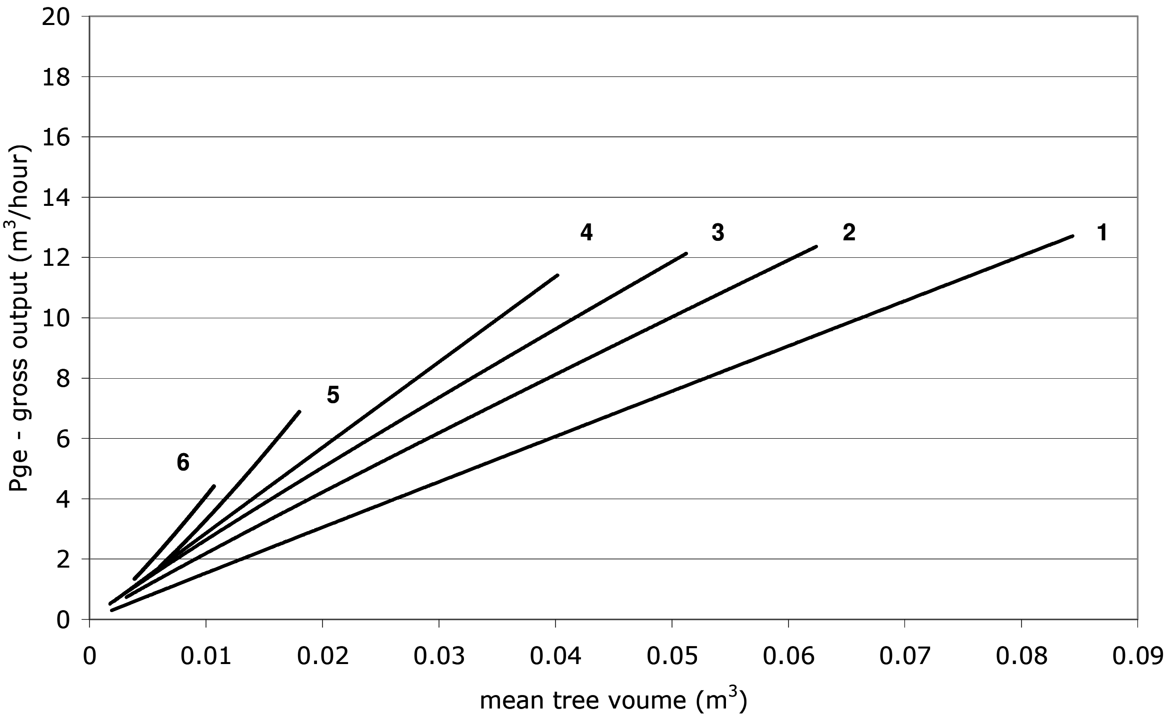
Effect of Accumulation

The effect of accumulation is presented in Figure 17. Output curves are presented for crane cycles where 1, 2, 3, 4, 5 and 6 trees are cut.

Output for a mean tree volume can be seen to rise with the number of stems accumulated per crane cycle. The maximum mean tree value decreases with increasing accumulation however, as space in the head is finite.

As an example, the maximum mean tree value for 6 accumulated stems is around 0.01 m^3. The head is not big enough to hold 6 trees of a larger volume, so if the mean volume was 0.015 m^3, a maximum of 5 trees could be accumulated.

Figure 17. Output curves for increasing accumulation.



Comparison with GB Outputs

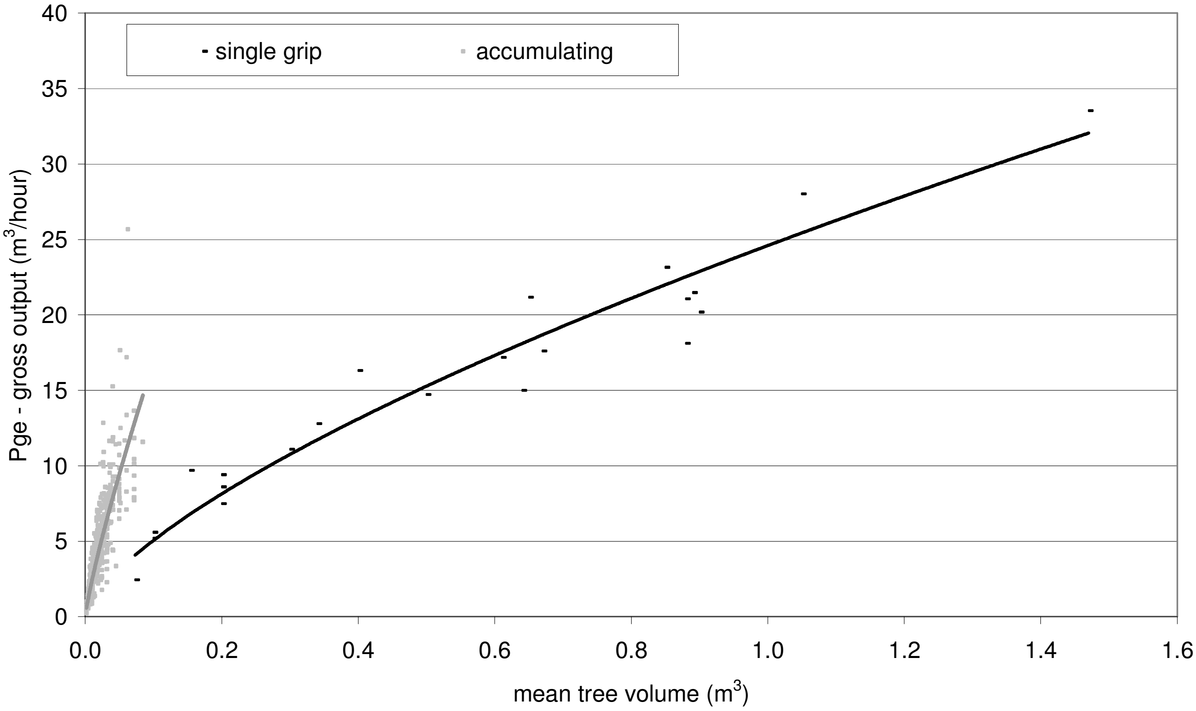
Little information exists of harvesting very small stems in GB conditions. The most applicable source (Webster, 2009) studied harvester felling and processing of Sitka spruce with a mean volume of 0.07 m^3, and a recorded output of 2.44 m^3/shr.

The only full study using an accumulating head (Price *et al*., 2009) took place in a stand of mean stem volume around 0.001 m^3. The output, 0.82 m^3/shr, is not entirely comparable as the vehicle was a harwarder (forwarder fitted with harvesting head), and so output was lost due to time spent in extraction.

In order to present this study in context, a comparison of recorded output was made against outputs recorded in GB studies using standard working practice and single-stem harvesting. Figure 18 presents a curve summarizing a meta-analysis of GB studies with a mean felled tree volume of 0.07 m^3 to 1.47 m^3. Black dashes are individual data points.

The output curve derived from this study is presented in grey, and tree volumes can be seen to be generally considerably smaller than those in the smallest GB study. Despite an average tree volume of a third that of the GB study, outputs are higher; 4.2 m^3/shr compared to 2.44 m^3/shr.

Figure 18. Comparison of single grip - UK studies and accumulating - Swedish study study and GB output curves.



The slope of the accumulating output curve is very much steeper than that of the single-grip GB curve, indicating higher output at given tree sizes. As mentioned previously in “effects of accumulation”, as trees grow larger, the ability of the head to accumulate diminishes. The accumulating output curve will therefore eventually turn into a non-accumulating curve when the crop becomes large enough to force the harvesting of stems individually. This will cause the curve to level off and become less markedly different from the GB curve.

Skogforsk /Sweden Experience

This section summarises extensive research work by the Swedish research agency, Skogforsk. Many thanks go to Maria Iwarsson-Wide, Isabelle Bergkvist, Tomas Nordfjell and Dan Bergström who shared their experience.

Small Tree Harvesting Context

Conflict Stands

Swedish research has identified what are termed as "Conflict-Stands"; stands that have not been cleaned or thinned sufficiently. A change in Swedish forest law led to forest owners no longer being obliged to tend young crops. The young stands pose a conflict of interest; there is low immediate financial viability but silvicultural intervention is required for longer term quality.

Stands are characterised by:

- High stem density – 4,500-10,000/ha
- Small stem volume - 0.015-0.05 m^3u.b.
- 6-11 m stand height

Cut Products

Products commonly cut from conflict stands are presented in Table 5. Volumes are under-bark and would therefore be reduced for over-bark measurement by 10-15%. Fuel products (whole tree & energy wood) receive lower prices than pulp due to the lower size classes, uniformity and quality of product required. Pulp is separated by species, birch prices having risen recently to equivalent with spruce.

Table 5 Products cut from small trees in Sweden.

Product	Characteristics	Specification	Roadside Price
Whole tree	• low fuel quality for large boilers	-	*c.* SEK 80 (£8)/m^3 u.b.
Energy Wood	• mostly delimbed • conifer or BL • better fuel quality for small/mid boilers	4.5 m (2.9 – 5.4 m)	*c.* SEK 200 (£20)/m^3 u.b.
Pulp	• spruce and birch separated	4.5 m (2.9 - 5.5 m, >5 cm top diam, <70 cm butt)	*c.* SEK 320 (£32)/m^3 u.b.

Tree Size

Industry tables exist for diameter-volume relationships for processed and tree-fractions, and volume conversion ratios. Tables take into account variations in tree size classes and common site index values throughout Sweden.

Table 6 provides a generalised diameter-volume and diameter dry matter (DM) conversion.

Table 6 Approximate volume equivalents to small tree diameters.

DBH cm	Vol m^3 u.b.	Kg DM	DBH cm	Vol m^3 u.b.	Kg DM	DBH cm	Vol m^3 u.b.	Kg DM
1	0.0001	0.38	6	0.0097	16.42	11	0.0489	58.58
2	0.0005	1.64	7	0.0146	22.69	12	0.0618	70.32
3	0.0015	3.83	8	0.0209	30.03	13	0.0765	83.18
4	0.0033	7.01	9	0.0286	38.45	14	0.0933	97.18
5	0.0059	11.20	10	0.0379	47.96	15	0.1122	112.32

Harvesting Head Options

Harvesting head options available for small diameter stands at present fall into 3 groups, summarised in Table 7.

Table 7 Harvesting head type summary.

Type	Advantages	Disadvantages
Blade (guillotine or shears)	• reliability / simplicity	• slowest in all diameters • do not process
Disc	• continuous cutting possible • faster in diameter <5 cm	• does not process • slower >8 cm
Chainsaw	• can process • faster >8 cm	• greatest complexity • slower <5 cm

Machinery Ideals

Desirable attributes of multi-stem harvesting have been identified as:

Head

- Stable accumulating mechanism– arms mounted higher on head, taller body
- Reliable accumulating mechanism – cycles effectively

- Processing capacity – rollers and knives
- Accumulating capacity – increasing number of stems that can be effectively managed

Base Machine

- Agile
- Stable
- Good hydraulic flow
- Long crane (11+ m)

Harvesting Approaches

Common Outputs

Below are 2 common intervention types for conflict stands, summarised for stand attributes, and indicative harvesting output and cost. N.b. costs and revenues are based on current Swedish conditions.

The “clean and thin” stand is slightly smaller than break-even size and so typically makes a loss. To achieve a high cutting rate, a disc head is likely to be used.

The “small thin” is carried out using a saw head. Due to the larger stem volumes and higher value produce cut, it is likely to achieve a profit if felling rate is achieved.

“Clean and Thin”

- Tree volume - 0.01-0.025 m^3 u.b. (6.0-8.5 cm)
- Accumulation – 4-7 tree/cycle
- Work rate – 350-600 stems/hour
- Common Output – 6 m^3/shr (4-7 m^3/shr)
- Max Output - 8.5 m^3/shr
- Manual Cleaning – SEK 4000-7000 (£400-700/ha)
- Harvester Cost – SEK 175-250 (£17.5-25.0/m^3)
- Forwarding Cost – SEK 40-70 (£4.0-7.0/m^3)
- Net revenue – SEK -2000 to -6000/ha (-£200 to -£600/ha)

Rule of Thumb Break-even Stand for Accumulating Saw-head

- Tree volume - 0.025 – 0.035 m^3 u.b. (8-9 cm)
- Density – 2,000/ha
- Standing Volume – 50 m^3/ha
- Work rate - 200 stems/hour

“Small Thin”

- Tree volume - 0.025-0.06 m^3 u.b. (8.5-12.0 cm)

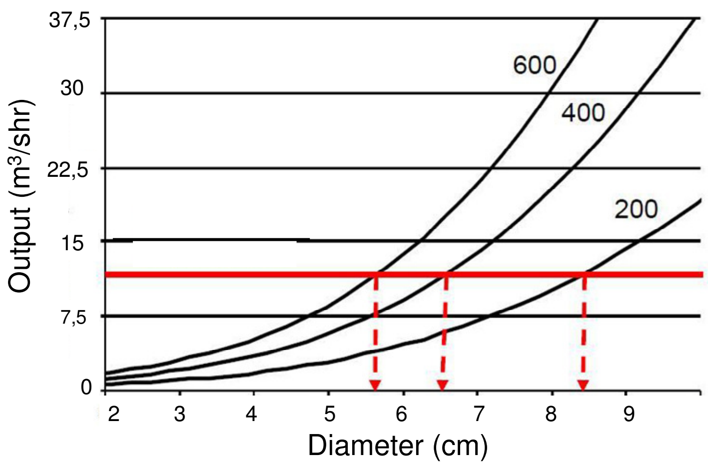
- Accumulation – 1.5-4 tree/cycle
- Work rate – 250-375 stems/hour
- Common Output – 11 m^3/shr (7-15 m^3/shr)
- Max Output - 16 m^3/shr
- Harvester Cost – SEK 60-120 (£6.0-12.0/m^3)
- Forwarding Cost – SEK 30-60 (£3.0-6.0/m^3)
- Net revenue – SEK 0 to 7000/ha (£0 to £700/ha)

Break-Even

Figure 19 describes the relationships between average felled diameter, cutting rate (stems per hour) and output (m^3/shr). Break-even point is shown at around 11 m^3/shr as an example and will move with vehicle cost and roadside prices.

Breakeven can be seen to occur at a cutting rate of around 200 stems/hour in a small thin, and 450-500 stems/hour in a clean and thin.

Figure 19. Break-even point defined by tree dbh and felling rate for a range of cutting rates



Systematic Thinning

Non-selective thinning has been investigated to provide a lower-cost alternative in stands of very small tree volume. Disc harvesting-heads have been found to be cheaper than saw when cutting more than 4 stems per crane cycle and in stems of volume <0.025 m^3 (*c*. 8.5 cm). Disc saws offer the potential to “sweep cut”; cutting a swathe with the head accumulator arms open to rapidly collect a bundle.

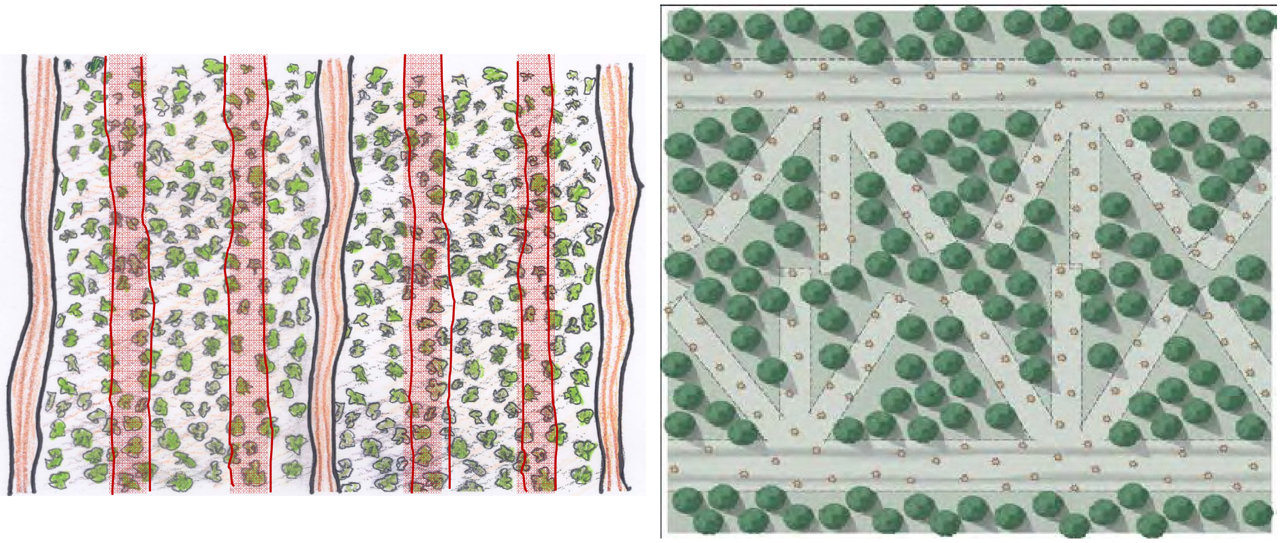
Where “sweep cutting” is possible in stems of 4-8 cm diameter, 20-40 stems can be cut per crane corridor, yielding 150-300 kg per crane corridor and vehicle outputs of

6-10 m^3/shr.

Geometric Thinning uses the main rack system but trees are cut along crane corridors in a regular pattern. The fan Pattern (figure 20, right) removes around 66% of stand volume, whereas simple perpendicular corridors have been found to remove around 50% of volume.

Line Thinning as another alternative has been trialled in stands of density >3000/ha and tree size <0.04 m^3 cut 2 temporary racks between main racks spaced 20 m apart (see figure 20, left).

Figure 20. Systematic thinning: line thinning (left) and geometric "fan" (right).



The effect of tree size on work element proportion

The relative proportions of element time consumption will vary with average tree size.

Crane-out, move, crane-in and buck are likely to all take roughly the same time per accumulation cycle, regardless of tree size.

Time consumption for cutting stems (harvest element) will vary with stem size. It is necessary to make each accumulation as large as possible to spread time consumption over as large a volume as possible. In smaller stems this requires cutting more stems, hence an increase in overall time consumption. It is therefore important to minimise crane movement whilst accumulating so that felling-time per volume cut does not unduly increase.

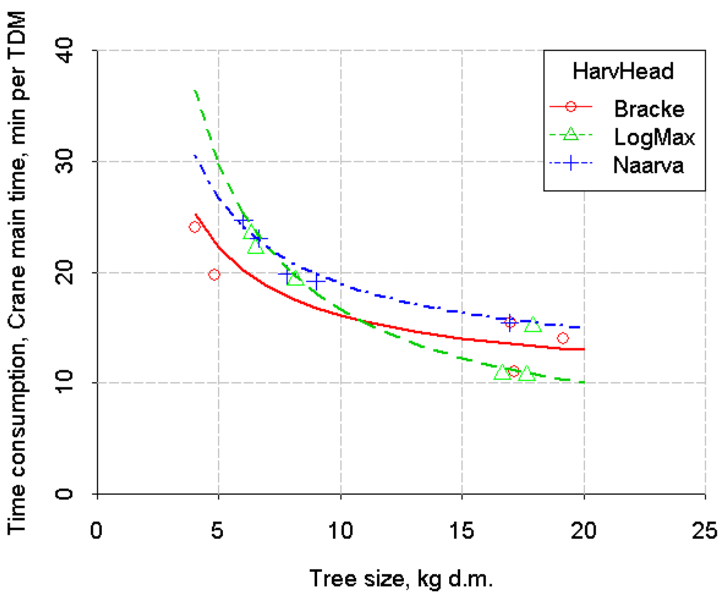
Experience suggests that the proportion of time spent felling varies as follows:

- Average diameter 4 cm – *c.* 80%
- Average diameter 7-8 cm – *c.* 50%

Other element proportional time consumption will alter accordingly. The faster felling can be achieved per stem, the lower this fell / total crane time is per volume – hence circular saw heads (e.g. Bracke) becomes more efficient for stems <5 cm.

Figure 21 illustrates how time consumption per dry ton decreases with increasing tree size. The Bracke disc-saw head can also be seen to become more efficient than the LogMax chainsaw head at tree sizes less than *c.* 10 kgDM (5 cm). The Naarva shear head is generally the least productive, but does become more efficient than the LogMax in very small trees (<4 cm).

Figure 21. Time consumption per dry ton for 3 harvesting head types.



Mixed Cutting

Cutting of different products, pulp and energy wood for example is possible.

Experience suggests that it is only worthwhile financially if at least 10 m^3 can be cut of the more valuable product per hectare. This allows for the extra cost associated with the harvester processing to different piles and for the forwarder to extract and stack separately.

Forwarding

Typical forwarding costs associated with different product types are presented in Table 8.

Table 8 Forwarding Costs

Product	Typical Cost SEK/m^3 (£/m^3)
Pulpwood	55-60 (5.50-6.00)
Energywood	75 (7.50)
Roughly delimbed tree sections	80-90 (8.00-9.00)
Whole trees (w/ compactor)	95 (9.50)
Whole trees (w/o compactor)	100 (10.00)

Stand Prescriptions

Generalised stand approaches in Sweden are summarised in Table 9.

Table 9 Generalised stand prescriptions.

Stems/ha	Mean Volume m^3 u.b.	Prescription	Comments
>5500	0.0015-0.02	Geometric thinning Energy wood Manual pre-cleaning	-
4500-5500	0.02-0.03	Energywood	-
3500-5000	0.03-0.04	Energywood or Combined Energywood / Pulpwood	15 m^3 o.b. (10 m^3 u.b.) assortment minimum in combined working
3000-4500	0.04-0.05	Pulpwood or Energywood	High leaf % = energy Low quality = energy
		Combined Energywood / Pulpwood	15 m^3 o.b. (10 m^3 u.b.) assortment minimum in combined working
<3500	>0.05	Pulpwood	

Conclusions

The stand studied for this project had developed mostly from natural regeneration and shared similarities with many GB stands associated with PAWS and CCF management.

Average tree size was very small, 7.8 cm (0.023 m^3fub), with a mean felled size of 7.6 cm (0.018 m^3fub).

Machine output was high considering the stand; 4.2 m^3/shr. This compares to the closest GB study of single-grip harvesting where output was 2.44 m^3/shr in an average stem size of 0.07 m^3, 3 times larger than in this study.

High outputs are achieved by removing all unnecessary crane movements and maximising accumulated volume in each crane cycle. This keeps time consumption per harvested volume to a minimum, but has the disadvantage that not all brash is incorporated into the mat. This will limit the potential output gain on more sensitive sites.

Machine output will become closer to that of a standard non-accumulating harvester as stem size increases. In larger stem sizes, accumulation will either not be possible or will not be desirable as more valuable product specifications will be cut.

Machine output was a combination of the accumulating head, longer and articulated crane, work method, and operator ability. Outputs above those expected for conventional single-grip harvester working are likely with the adoption/increase of any of these, but optimal results are only likely to occur with full change.

The observed machine was not restricted to working in small stems. The Valmet 901 is suitable for thinnings and clearfell, the addition of modified crane and head merely extends its ability to accumulating work. This makes the system particularly flexible. Machine changes, work pattern, and operator training, lower the financially viable minimum stem size without impinging on ability in conventional stands.

Experience from accumulating harvesting in Sweden provides a detailed understanding of issues on which to base future work and research.

Commercially interventions are generally viable in stands with average diameters of more than 8.5 cm, requiring felling at 250 stems per hour or higher. Higher roadside prices would decrease the minimum viable diameter and/or allow a reduced felling rate.

In very small stems, the use of geometric thinning and sweep-felling using disc-saw heads may allow a commercially viable operation, depending on markets. Disc saw heads at present are slower in larger sizes and cannot delimb, making them a more specialised option.

Recommendations

Operational/working practice

- Effective accumulating harvesting has the potential to move the break-even point into smaller tree sizes in GB conditions without restricting harvester utility in conventional sizes.
- The studied harvester specification and work practice have very high potential for dealing with the natural regeneration associated with CCF and PAWS stands in GB conditions.
- The ability to delimb will allow the production of firewood and higher grade woodfuel from small stem thinnings. Fencing may also be possible.
- Considerable research and trials are needed to identify required adaptation of machinery and work techniques of accumulating harvesting to GB conditions.
- Conventional practice could benefit from using aspects of the work techniques.
- Suggestions for further work are presented in Appendix 2.

Cost/output

- Unit harvesting cost in small tree sizes can be reduced.

Health and Safety

- No implications.

Country policy

- No implications.

Existing FC publications

- No Implications.

References

Price, M. (2011) *Tractor based mechanized harvesting in sweet chestnut coppice*. FCPR040, Technical Development, Forest Research, Ae.

Price, M., Roux, S., Webster, P. and Saunders, C. (2009) *Woodfuel production from small diameter stems.* IPIN 34/08, Technical Development, Forest Research, Ae.

Webster, P. (2008) *Woodfuel production from a thinning operation*. IPIN 30/07. Technical Development, Forest Research. Ae.

Contact

Martin Price
Centre for Forest Resources & Management
Technical Development
Linmere
Delamere
CW8 2JD

01606 324957
martin.price@forestry.gsi.gov.uk

TD reference 251.46.11

Appendices

Appendix 1

Time Study Package

The Skogforsk time study programme differs in a number of ways from the Technical Development package TDB menu.

The Skogforsk package works by pre-setting elements to keys. In this study, cyclic keys were set from D (crane out) to I (move), but could have been set from A to F if desired. The time-stamp is activated by pressing the key itself and not Enter as in TDB menu. This holds the advantage that activity can be interpreted right to its end, rather than inputting the element code early and finishing with Enter. The removal of the need to input with Enter also reduces required keystrokes and so can allow higher input rate.

Work is recorded directly within crane cycles; this would require post-hoc analysis in TDB menu as all data-inputs are recorded as a single line with no allocation to felling cycle. The delineation of cycle is achieved by pressing F5 during the study to indicate a new cycle has started.

Elements that are recorded several times within the crane cycle are amalgamated rather than kept as separate records. For example, crane movement-out interrupted by stacking products could take 10 cmin and 4 cmin. TDB menu would record these events separately whereas the Skogforsk programme would record that crane-out duration in that crane cycle lasted for 14 cmin.

The package downloads as a delimited text file, each row providing values for all preset codes for a crane cycle. This data presentation makes it a simple process to calculate output curves for a study.

The ability to preset keys is also a very useful function as cyclic work can be set to progress along a line of keys. This allows the studyman to easily record in sequence without needing to often look to find keys; particularly useful in high intensity study and study during the dark.

The package can also be set to progress automatically after particular element inputs. In the configuration used, felling was recorded as "harvest" using the E key. When this element began, the E key was pressed immediately which automatically progressed input to tree codes. When a tree identification code was inputted, this automatically moved the system to ask for input of a subsequent stem. The felling time was finished by pressing E again to allocate all time to felling and stop tree code input:

• Crane-out	– D	– end element
• Felling begins	– E	– automatic data cue for tree code - Time allocated to E
• Tree 1	– 1309	– automatic data cue for 2nd tree code
• Tree 2	– 1307	– automatic data cue for 3rd tree code
• Tree 3	– 1307	– automatic data cue for 4th tree code
• Felling ends	– E	– cancels cue for 4th tree. - Time during data input allocated to E

Time study intensity was very high – average code input was at a rate of every 4.5 seconds. This compares to harvesting in single-tree studies where input is at the rate of every 10-15 seconds.

This study type could be completed using TDB menu if tree data was not recorded. The full input is most-likely to be impossible with TDB menu due to the requirement to time-stamp with Enter.

This study type is only possible from the harvester cab – the dense stand would not allow sufficient view of working when on foot.

Appendix 2

Further Work

The scope for future GB work is wide and diverse:

- trials of new machine; 10+m crane, accumulating head, lateral pivot etc.
    - Production of standard output curves
    - Work across range of GB stand types
        - CCF, PAWS etc.
        - “Conventional” early thinnings
        - Undermanaged “woodfuel”
- retro-fit possibilities
    - Viability of fitting accumulating heads to existing machines
    - Viability of using feed rollers as accumulator
    - Output improvements possible through retrofit and work improvement
- Application of work principles to existing fleet
    - Effect of altering work practices on non-modified fleet
- Accumulating-working effects on the brash mat
    - Effect of limiting boom movement
    - Viability of brash mats produces for crop/soil types
    - Output reductions associated with increasing brash mat
- Development of bunch-volume measurement by harvesters
    - Linking of machine production file to extracted product volumes
- Cost and output effects of pre-cleaning
    - Identify work specifications and costs effectiveness
- Break-even models for GB firewood and fencing combinations
    - Identify product yields from crop types
    - Identify viability of production e.g. fencing from bunches
    - Develop work method for mixed cutting
- Investigation into geometric thinning
    -
- GB yield and volume conversion
    - Creation of GB small-tree yield tables
    - Stand yields
    - GB product conversion percentages
    - GB conversion factors volume:weight etc.