Single- and Double-Grip Harvesters – Productive Measurements in Final Cutting of Shelterwood

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ABSTRACT

To compare the performance and cost of two machine types, a time study of single-grip harvesters (SGH) and double-grip harvesters (DGH) was conducted in the final cutting of three shelterwood stands in central parts of Sweden. A randomized block design was used with one block in each stand and the treatments SGH and DGH, respectively. The stands were characterized by dense to relatively dense advanced regeneration under approximately 200 trees/ha. No significant differences were found in mean harvesting time between SGH and DGH or between stands. Fewer trees, but approximately the same volume per hour, were harvested when shelterwood stands were cut as compared with clear-cutting of ordinary stands. Despite few stems per hectare and the dense regeneration hindering the operator's field of view, final cutting was done with fairly high productivity (15.9–34.0 m^3/E15-h) and a low harvesting cost (2.7–6.0 USD/m^3). It was concluded that both machine types gave acceptable results regarding cost and productivity. The SGH could be recommended as a good choice in general due to the low cost per machine hour as compared with the DGH, while the properties of the DGH would be beneficial in shelterwood stands with a large proportion of trees with large diameter (e.g. >7 cm) branches.

Keywords: Time *study, harvesting time, normative time, productivity, cost.*

INTRODUCTION

Conventional forestry practice in Sweden has been to clear-cut, scarify and plant. However, the high cost of silviculture, together with demands from the general public and market concerning environmental considerations in forestry practices has led to increasing interest in natural regeneration [6]. One example of this is natural regeneration of Norway spruce (*Picea abies, L. Karst*) under shelterwood, i.e. under 160 – 400 stems per hectare [17].

The shelterwood system is an old silvicultural method that has been modified and revived in Sweden [20]. One modification is the use of harvesters instead of manual or motor-manual felling. Leikola [12] argued that the development of careful logging methods is one of the most important research tasks in the area of natural regeneration. Westerberg [20] presented a four-stage shelterwood system for regeneration of Norway spruce; (1) Preparatory cutting, (2) Seed cutting, (3) Removal cutting and (4) Final cutting. The harvesting technique used in the three first stages is similar to late thinning in conventional stands and is commonly done with single-grip harvesters (SGH). However, little research has been published on final cutting of shelterwood with SGHs or double-grip harvesters (DGH) since the method still is in the introductory stage. Hence, comparative studies of these machines are needed [7], [19].

Compared to conventional stands, shelterwood stands typically contain trees with a larger mean stem volume. This together with the advanced regeneration will affect harvester performance differently than in conventional stands. Studies of different harvesters made during clear-cutting of ordinary stands show the DGH to have a higher productivity than the SGH when trees exceed 0.5-0.8 m^3/tree [8], [9]. This would suggest that the DGH should be more productive in final cutting of shelterwood as the mean stem volume often is high in these stands. However, Westerberg & Berg [21] found that productivity was higher for a SGH than for a DGH in final cutting of a shelterwood with 200 Scots pine *trees* (*Pinus sylvestris*) per hectare. Mäkelä [14] summarized the results from two studies of final cutting of shelterwood with SGHs and DGHs [13], [18] and concluded that SGHs were best suited for removal of seed- and shelter trees. Mäkelä [15] also concluded that the DGH was the most expensive method when removing seed- and shelter trees in both studies.

As part of the development towards more diversified silvicultural methods in Sweden [20] the use of seed-tree and shelterwood systems increased markedly to 40% of the regenerated area in 1993, and thereafter declined somewhat [4]. Some of the

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shelterwoods created in the early 1990s will soon mature for final cutting. Hence, it was important to compare SGHs and DGHs in final cutting of shelterwood to identify potential difficulties, needs for development and differences in harvesting time and work pattern.

The aim of this study was to compare the productivity and cost of SGHs and DGHs in final cutting of shelterwood. The assumption was that the DGH, although more productive, would turn out to be a more expensive alternative due to its higher operational cost. Consequently, the hypothesis to be tested was that there is no difference between the SGH and the DGH in harvesting time at final cutting of shelterwood (Table 1).

MATERIAL AND METHODS

Experimental sites and design

A randomized block design with three blocks and two treatments was used. Three experimental sites, each used for one block, were selected for the study. The sites were located in Sweden at Avesta (lat. 60°09'N) at Graninge (lat. 63°06'N) and at Lövsjön (lat. 63°01'N). The treatments included final cutting of shelterwood with a SGH and a DGH in each block. The size of the block was 2.0 hectares at Avesta, 3.8 hectares at Graninge and 2.1 hectares at Lövsjön. The ground had high bearing capacity at all sites. The terrain was flat and the surface was even at Avesta and Graninge while there was a moderate slope (11-18”) and a somewhat uneven ground surface at Lövsjön.

Within each block, the centres for circular plots were marked with aluminum sticks in a grid system of 1010 m at Avesta and 1212 m at Graninge and Lövsjön. Each centre was used for circular plots with a radius of 1 m in which the number of plants and plant heights were registered (Table 1). Some of the centres were also used for plots with a radius of 10-20 m, where various properties of shelterwood trees were measured (Table 1).

Time studies

The block at each test site was split into two treatment units and in such a way that the stand properties of the two was as similar as possible (Table 1). Each treatment unit was formed to allow the harvester to work normally without interfering with the adjacent unit. The length or width of the treatment units was not shorter than twice the length of the average tree. Treatment was randomized between the two units

Table 1. Shelterwood stand data and regeneration stand data before final felling.

	Avesta		Graninge		Lövsjön	
	SGH	DGH	SGH	DGH	SGH	DGH
Shelterwood stand						
No. of circle plots	9	12	10	9	8	6
Trees/ha	200	230	210	180	180	200
Mean volume/ha, m^3	140	110	190	190	140	150
Mean DBH, cm	38	32	35	36	37	36
Mean height, m	23	20	26	27	25	25
Pine/Spruce/Birch, 10^{-1}	6/3/1	8/1/1	8/2/0	8/2/0	1/6/3	0/7/3
Regeneration stand						
No. of circle plots	76	114	119	116	111	86
Conifers/ha	25500	12100	6400	6400	25200	12400
Broad-leaves/ha	12700	13400	9200	10 800	10500	3800
Mean height conif. m	1.1	1.2	1.5	1.4	0.7	1.1
Mean height broadl. m	3.0	2.7	2.3	2.4	2.7	2.5

The weather conditions were fairly similar during the studies, except for the deep snow cover at Lövsjön (Table 2). The diameter at breast height (DBH) was measured and marked on all trees in the treatment units. Continuous time studies (cmin) using SIWORK3 [1] software and a Husky Hunter computer were made for defined work cycle elements on each harvester (Table 3). All element times were measured as effective times (E0) [2]. For each processed tree, the DBH and tree species were registered. The volume of the measured trees was calculated according to Näslund [16] using approximately 30 height measured trees per block. All volumes were calculated as solid volume under bark (m^3). The travelling distance was registered for each driving occasion with the help of a measuring line or measuring stick. The working width was measured at every 20 m along the striproads as the distance between marked stumps on one side of the striproad perpendicular to the other side. The area within the working width was calculated as working width multiplied with driven distance divided by the treatment unit area.

Machines and operators

The harvesting at Avesta was done with a Valmet 892/960 SGH and a FMG/ÖSA 706/260 DGH at a cost of 90.4 and 92.6 USD/E15-h, respectively. The harvesting at Graninge and Lövsjön was done with the same operators using a Valmet 892/955 SGH and a Timberjack 1880 Master DGH to a cost of 90.4 and 102.3 USD/E15-h, respectively. Machine costs were chosen as prevailing (Mellanskog Forest Owner Ass.) reimbursement to contractors and harvester types. All operators were experienced and highly skilled. The operators were instructed to work at their normal sustainable pace and to minimize damage in the advanced regeneration. To promote future timber production, the felling instructions were to drive and fell in blank spots of the regeneration. However, if the operator observed single plants in the otherwise blank spots, then he should drive and fell in denser parts of the regeneration.

Table 2. Weather conditions during the time studies.

	Graninge		Lövsjön		Avesta	
	SGH	DGH	SGH	DGH	SGH	DGH
Date of study	94.03.22	94.03.18	93.12.14-16	93.12.04-05	94.03.25	94.03.17
Temp. °C	-1 – -2	-5 – -7	-4 – -8	-2 – -6	0 – -1	-6 – -8
Sight conditions	Clear, sunshine	Cloudy-clear	Cloudy-snowfall	Cloudy	Cloudy-snowfall	Cloudy
Snow;-type -depth, m	Crust 0.3–0.4	crust 0.4	Powder 0.2–0.3	Powder 0.1	Powder 1.3–1.5	Powder 1.3–1.5

Table 3. Definitions of the work cycle elements for the single-grip harvester (*) and for the double-grip harvester (#).

* # **Boom-out:** Begins when the boom is moving towards the tree and ends when the processing or felling unit are 1 m from the stem.
* **Retake:** Begins when the delimber arms on the processing unit opens after have been closed around the stem and ends when the saw is activated.
* **Felling:** Begins when the processing unit is 1 m from the stem and ends when the feed rolls start to turn.
* **Processing:** Begins when the feed rolls start to turn and ends when the last piece of the tree drops from the processing unit. Has higher priority than other elements.
# **Felling:** Begins when the felling unit is 1 m from the stem and ends when the tree is separated from the stump.
# **Boom-in:** Begins when felling ends and ends when the tree is dropped in the processing unit.
# **Processing 1:** Begins when the tree is dropped in the processing unit and ends when the last piece of the tree drops from the processing unit.
# **Processing 2:** Begins when boom-out starts during processing and ends when the last piece of the tree drops from the processing unit or when the boom is no longer operated. Has higher priority than processing 1 and elements connected to boom-work.
* # **Start/wait:** Begins when the last piece of the tree drops from the processing unit and ends when boom-out or driving starts.
* # **Travelling:** Begins when the wheels start to turn and ends when the wheels are still. Has lower priority than the boom-work elements.
* # **Halt:** Begins after driving has ended and ends when boom-out starts.
* # **Miscellaneous:** Other activity related to productive work, e.g. sorting of logs, preparing strip-road with branches, undergrowth/sight clearing, relocation of the harvester during processing or boom-in.
* # **Disturbance:** Begins when disturbance occurs in time elements above and ends when disturbance is over, e.g. backing for difficult branches when processing, minor driving problems.
* # **Interruption:** Time not related to productive work such as breaks, repairing or maintenance of machine, major driving problems.

Calculations and statistical analysis

For the SGH the felling + processing time ($y=a+b*x$) was calculated by linear regression analysis as the function of stem volume (x) and tree species. For the DGH the felling + boom-in + processing 1+2 time was calculated by linear regression analysis as the function of stem volume and tree species.

Differences in mean stem volume and in mixture of tree species between treatments were equalized by merging stand data from the two treatments in each block to common (normative) mean values per block.

The normative felling and processing time were calculated with consideration to the effect of tree species and mean stem volume on the elements felling and processing for the SGH, and felling, boom-in and processing 1+2 for the DGH. The time functions per tree species were weighted to one time function per treatment ($y=a+b*x$). The weighting was done on the basis of each tree species' proportion of the harvested volume per block. These functions were used to calculate harvesting time at an equal mean stem volume per block.

Normative travel time was calculated based on the number of stems per hectare. For each treatment the travel distance per hectare was multiplied by the area of the block and divided by the speed, resulting in travel time per hectare. Driven time per hectare was then divided by the mean number of stems per hectare and block, resulting in normative driven *time* in cmin/tree.

The elements boom-out, start/wait and halt are most likely affected by the number of stems per hectare in the shelterwood and the size, sort and amount of advanced regeneration, but no reliable normative factors or functions were found. The elements disturbance and miscellaneous were included in productive time because they might reveal differences in the harvester's capacity to work in extensive regeneration.

The sum of all elements except felling and processing for the SGH and felling, boom-in and processing 1+2 for the DGH were added as a constant value to the intercept (a) in the normative time functions for the SGHs and the DGHs resulting in a curve for total time per tree over varying mean stem volume. The factor of 0.71 was used as the relation between productivity per effective time (m^3/E_0-h) compared with per gross effective time (m^3/E_{15}-h). The latter includes effective time with the addition of delay times shorter than 15 minutes [2].

An analysis of variance using Microsoft Excel [3] was carried out. If $p<0.05$, the result of the statistical analysis was called significant. The following model was used to test differences in total normative harvesting time per tree between SGH and DGH:

$Y_{ij} = \mu + u_i + t_j + e_{ij}$ where,

Y_{ij} = total normative time consumption per tree in treatment ij

μ = μ total mean

u_i = fixed effect of block i, where i = 1-3

t_j = fixed effect of treatment j, where j = 1-2

e_{ij} = residual effect in block i, treatment j $(0, \sigma_e^2)$

RESULTS

There was no significant difference between SGH and DGH or between blocks in mean harvesting time according to the analysis of variance (Table 4).

Most stems per hectare were harvested in the spruce dominated shelterwood at Lövsjön and the largest trees were harvested in the pine dominated shelterwood at Graninge (Table 5).

Table 4. Analysis of variance for normative harvesting time for the single- and the double-grip harvesters in final cutting of the shelterwood.

Cause of variance	*mean cmin/tree*	*d.f.*	*m.s.*	*F-ratio*	*p-value*
SGH	137				
DGH	135				
Block		2	255.50	0.824	0.548
Treatment		1	2.67	0.0086	0.935
Error		2	310.16		

Table 5. Stand data as means of harvest per treatment unit and normative stand data as means per block.

	Avesta		Graninge		Lövsjön	
	SGH	DGH	SGH	DGH	SGH	DGH
Stand data						
Studied area, ha	0.8	1.2	1.9	1.9	1.1	1.0
Trees/ha	180	240	220	170	240	250
Mean height, m	22	19	26	26	19	19
(SD)	(4)	(4)	(3)	(4)	(7)	(7)
Volume/tree, m^3	0.80	0.52	0.87	1.12	0.56	0.54
(SD)	(0.39)	(0.30)	(0.38)	(0.55)	(0.57)	(0.54)
Volume/ha, m^3	140	130	190	190	120	140
Species mix; Pine/ Spruce/ Birch,10^{-1}	5/4/1	6/1/3	8/2/0	6/4/0	0/9/1	0/8/2
Normative stand data	*SGH and DGH*		*SGH and DGH*		*SGH and DGH*	
Trees/ha	210		190		255	
Mean height, m	20		26		19	
(SD)	(4)		(3)		(7)	
Volume/tree, m^3	0.61		0.98		0.55	
(SD)	(0.36)		(0.48)		(0.56)	
Volume/ha, m^3	130		190		140	
Species mix; Pine/ Spruce/Birch,10^{-1}	7/2/1		8/2/0		0/9/1	

The SGH at Lövsjön had the shortest driven distance, the least working width, i.e. area within reach of boom, and the largest number of harvested trees per set-up place (Table 6). The deep snow at Lövsjön made travel speed low for the DGH as compared with the SGH (Table 6).

The difference in productivity between the two harvesters was largest at Avesta where the SGH had approximately 20% lower mean productivity than the DGH (Figure 1, Table 6). However, the SGHs mean productivity at Graninge and Lövsjön was approximately 9 and 12% higher, respectively, as compared with the DGH (Figure 1, Table 6).

At Avesta the SGH spent 30% of the total time on the elements disturbance, start, and driving (Table 6). The average stem took approximately 22% longer time for the SGH to process than for the DGH at Avesta. The difference in harvesting time between the two harvesters at Graninge and Lövsjön was smaller than at Avesta (Table 6). The SGH had a lower harvesting time, and higher productivity, than the DGH at Graninge and Lövsjön (Table 6). The DGH at Graninge and Lövsjön used 4-6 times as much time on the element miscellaneous as compared with the mean time for miscellaneous in the other treatments.

Table 6. Working pattern, harvesting time and productivity.

	Avesta		Graninge		Lövsjön	
	SGH	DGH	SGH	DGH	SGH	DGH
Working pattern						
Travel distance, m/ha	740	750	850	700	490	630
Travel speed, m/min	14.9	18.5	26.8	15.2	14.2	8.2
Working width, m	17.7	16.2	15.9	19.1	15.6	14.7
Area within working width	1.25	1.17	1.37	1.37	0.73	1.0
Felled trees/set-up place, no	1.2	1.5	2.2	1.5	2.6	2.1
Harvesting time EO, cmin/tree						
Boom-out	10	9	10	8	9	6
Retake	3		1		5	
Felling	33	20	24	21	25	17
Boom-in		21		17		15
Processing	69		57		52	
Processing 1		45		41		32
Processing 2		0		5		6
Miscellaneous	6	7	2	16	9	24
Disturbance	18	4	2	3	3	5
Start/wait	10	5	5	1	6	5
Driving	28	17	15	28	14	30
Halt	2	0	1	0	1	0
Total time[a]	178	128	116	139	123	138
Productivity, m^3/E15-h	19.2	17.2	32.0	34.3	19.4	16.6
Normative harvesting time E0, cmin/tree						
Felling + processing	91		86		76	
Felling + boom-in + processing 1+2	90		82		68	
Travelling	24	19	16	24	14	30
Not norm. productive time	49	25	21	28	33	40
Total time	164	134	123	134	123	138
Productivity, m^3/E15-h	15.9	19.5	34.0	31.2	19.0	17.0

[a] Differences due to rounding

The regression coefficient (b) was generally lower for the DGH than for the SGH (Table 7). The harvesting time curves at Graninge had a flatter slope than at Avesta and Lövsjön (Table 7, Figure 1).

The harvesting costs for the SGH and the DGH, respectively were 5.7 and 4.7 USD/m³ at Avesta, 2.7 and 3.3 USD/m³ at Graninge and 4.8 and 6.0 USD/m³ at Lövsjön.

DISCUSSION

Experimental design

The aim of this study was to compare productivity between two types of harvesters in a new silvicultural method under equal and normal working conditions. This demanded large treatment units which made it difficult to create equal stand properties. The problem was solved by calculating normative stand values. However, there is also the risk for differences in operator performance. Bergstrand [7] discussed the accuracy of time studies on forest technology and the problem with difference in operator performance, which can result in a 20 – 50% variation in machine productivity. He pointed out that it would be necessary to include approximately 400 operators in order to reach a confidence level of 95%, which he concluded to be economically unfeasible. Appelroth [5] argued that analyses of differences between work methods using the comparative time study are incorrect unless work rating is done, because the rate of working can vary unpredictably between zero and maximum for a given operator.

Furthermore, if the rate of working is much below the maximum, the output can not be used for comparison of methods or machines, only for

Table 7. Time functions per treatment and tree species.

		Intercept, a	95% confidence interval	Slope, b	95% confidence interval	r^2
Time functions						
Avesta						
SGH, pine		41.2	19.8–62.6	0.078	0.055-0.100	0.41
SGH, spruce		33.6	15.2-51.9	0.082	0.062–0.102	0.58
SGH, birch		12.5	-19.2–44,2	0.172	0.085-0.260	0.56
DGH, pine		57.0	48.5–65,4	0.049	0.036-0.061	0.29
DGH, spruce		36.1	19.3–52,9	0.067	0.042-0.091	0.52
DGH, birch		27.1	20.6-33‘7	0.196	0.174-0.219	0.78
Graninge						
SGH, pine		43.1	38.4–47,7	0.041	0.036-0.046	0.46
SGH, spruce		36.2	27.4–45,1	0.061	0.050-0.072	0.62
DGH, pine		56.6	47.6–65,7	0.027	0.021–0.033	0.27
DGH, spruce		35.1	29.1–41,2	0.043	0.037-0.050	0.59
Lövsjön						
SGH, spruce[a]		30.8	27.2–34,4	0.082	0.078-0.087	0.86
SGH, birch		30.8	15.7–45,8	0.083	0.058-0.108	0.58
DGH, spruce		32.8	28.9–36,8	0.061	0.057-0.066	0.76
DGH, birch		29.9	22.0-37.8	0.089	0.074-0.104	0.73
Normative time functions						
Avesta:	SGH	36.5		0.088		
	DGH	49.0		0.068		
Graninge:	SGH	41.5		0.046		
	DGH	51.8		0.031		
Lövsjön:	SGH	30.8		0.082		
	DGH	32.4		0.065		

[a] Treatment SGH in Lövsjön consisted of 4% of the total volume of pine but the pine trees were too few to base any functions upon.

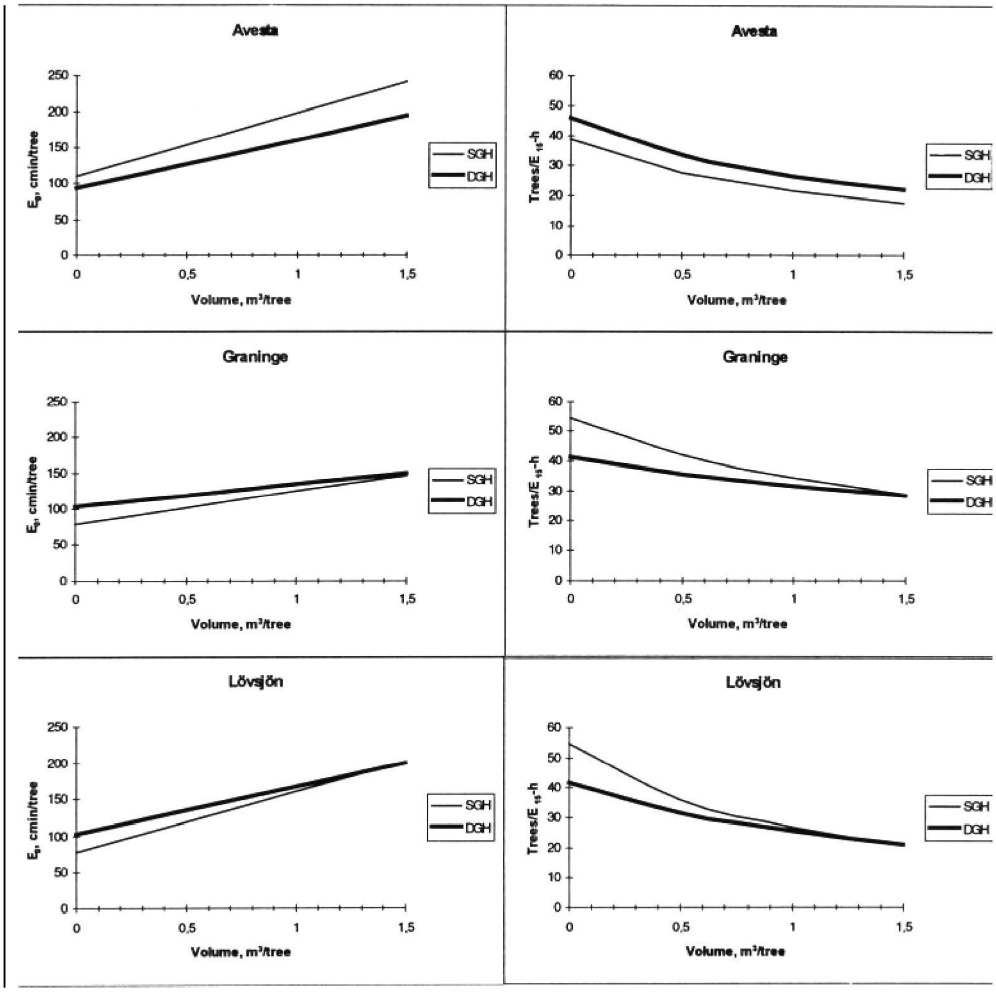

Figure 1. Normative harvesting time, (EO, cmin/tree) per block and treatment and corresponding normalized productivity ($m^3/E15$-h) calculated with factor 0.71 as relation between $m^3/E0$-h compared to $m^3/E15$-h.

comparing the operators. Appelroth [5] suggested that the researcher doing time studies also should do the rating. However, subjective performance rating may be used with an acceptable result under easy conditions, like manual planting, but is doubtful in other operations with more complex sequences of work elements [19]. Bergstrand [7] considered performance rating as very difficult and concluded that the only strategy that could give statistically reliable results from forest technology studies is replication, which we usually can not afford. All the above arguments are relevant and hence, the result in this study must be considered with the human factor, the operator, in mind. However, Bergstrand [7] concludes that this does not exclude comparative studies from resulting in indications and guidance for development of new products and methods, which corresponds with the aim of this study.

Analysis of variance

The large mean stem volume in shelterwood stands makes it reasonable to assume that the DGH should have a higher productivity than the SGH but also higher harvesting cost due to higher machine cost. However, the productivity of the DGH was not found to be higher than of the SGH. Hence, the null hypothesis, i.e. no difference in time consumption per processed tree between blocks and treatments, could not be rejected. Differences between the treatments and blocks when dividing the time consumption in volume dependent elements (e.g. processing and felling) and not volume dependent elements (e.g. boom-out, driving, miscellaneous, etc) was also examined using the same model as in Table 4. No significant differences were found between SGH and DGH ($p=0.870$) and blocks ($p=0.750$) in time consumption for non-volume dependent elements. Hence, there do not seem to be any large differences between SGHs and DGHs concerning boom work and driving in the shelterwood stands. In time consumption for volume dependent elements, statistical differences were found between blocks ($p=0.034$) but not between SGH and DGH ($p=0.166$). The significant differences between blocks are not surprising since there were differences in mean stem volume.

Harvesting cost

With no statistically proven difference in harvesting time and productivity between the two harvesters, the SGH would be the first choice, from an economical point of view, due to a lower machine cost per hour. This was also the case at Graninge and Lövsjön, with Avesta as the exception. However, it is important to remember that stand properties will affect maintenance costs. If a SGH regularly works in stands with a high mean stem volume and large diameter branches, as at Avesta, it is likely that the maintenance cost would rise, resulting in a machine cost closer to the DGH.

Perhaps the only situation where the harvesting cost of the DGH is lower than that of the SGH is where the shelterwood stand consists of trees with large diameter branches, as at Avesta. In stands with few, easily delimbed, trees per hectare the stronger processing unit of the DGH is not an advantage. Where there are few trees per hectare there are also fewer opportunities for the DGH to simultaneously process one tree while felling another. Hence, the DGH, as compared with the SGH, probably reduces its productivity more when converting from final felling of ordinary stands to shelterwood stands, provided that mean stem volumes are equal.

Time functions and productivity

The coefficient of the slope (b) was generally lower for the DGH which indicates that it is less sensitive to variation in tree volume than the SGH. This is in line with experiences from earlier studies [8], [9]. The size of b is also generally lower than given by Brunberg [8] where $b=0.107$ for the SGH and 0.078 for the DGH. The lower regression coefficient in this study may be explained partly by technical development and partly by less variation in tree volume in a shelterwood than in an ordinary stand.

The purpose for transformation from effective (E_0) to gross effective (E_{15}) time is to give an idea of an approximate level of productivity in practice. The relation 0.71 between m^3/E_0-h compared with m^3/E_{15}-h, is chosen in this study because it is an approximation based on experience and was used in earlier machine studies in shelterwood [21]. A comparison between E_0- and E_{15}-time was made by Brunberg [10] who found the relation to be 0.64 – 0.68 depending on whether the element miscellaneous was included or not. Hence, the productivity presented in m^3/E_{15}-h might be over-estimated.

Between the three blocks the average productivity was highest at Graninge for both harvesters. This is probably explained by easily delimbed pine trees, the mean stem volume being 60 to 80% larger and the harvested volume 35 to 45% higher at Graninge than at Avesta and Lövsjön.

Harvesting time

Differences in harvesting time between the two harvesters at Avesta occurred mainly in the elements start/wait, halt, driving and disturbance. A magnetic valve for the tilt-up function of the harvester head on the SGH malfunctioned and was replaced. This problem may have contributed to the time start/wait and halt. The SGH also had problems with delimbing and the main part of the disturbance time occurred during processing. Mean diameter of the branches causing problems while delimbing was measured in a parallel pilot study. The result showed that the SGH had problems when delimbing branches with a mean diameter of 7 cm for pine and 8 cm for birch. Corresponding branches causing problems for the DGH had 2 cm larger diameter. Brunberg [11] found that the SGHs Timberjack 1270/762B and Valmet 911/960 had delimbing problems when branches had a mean diameter of 7.2 and 7.0 cm, respectively, as compared with 9.5 cm thick branches for the DGH Timberjack 1880. Hence, the delimbing problems for the SGH at Avesta might be due large diameter branches.

The fact that the DGH in Graninge had a higher total harvesting time than the SGH, is surprising considering the large mean stem volume. However, the pines at Graninge had small green crowns and thin branches which might have favoured the SGH since the DGH was unable to use the advantage of its powerful processing unit and, hence, could not gain time on the SGH when processing trees with thick branches. The thin branches might have contributed to the time consumption curves having a flatter slope than in other studies, e.g. Brunberg [8],[9]. A lot of the time which the DGH in Graninge spent on the element miscellaneous consisted of clearing the field of view with the boom before felling, which probably contributed to a higher time consumption than for the SGH.

The shelterwood at Graninge had a larger mean stem volume and standing volume per hectare as compared with the shelterwood at Avesta. However, the regeneration was by no means as dense at Graninge as at Avesta. Consequently, the time spent on start, halt and driving could be expected to be lower at Graninge than at Avesta, but they were of equal size. This could be due to the fact that there were fewer trees per hectare at Graninge and that the number of stems per hectare had a larger effect on travelling time and its share of the total time than volume per hectare.

The SGH at Lövsjön encountered more problems in the deep snow than the DGH when felling, sometimes having to "shovel" away snow from around the trees with the harvester head before they could be felled. The trees were also full of cold thin snow which frequently fell down during positioning, obstructing the operator's field of view for a moment. This probably contributed to the increased time for felling as compared with the DGH.

The fact that the curves of harvesting time for the SGH and the DGH in Lövsjön do not cross each other until very large mean stem volumes is probably due to difficulties with driving in deep snow. When comparing time for travelling and travel speed between the two machines it is obvious that the DGH had difficulties. Both machines had chains on the front wheels and belts on the bogies, but the SGH had flat (55 cm) steel pegs welded on the belts, which increased its mobility. Another explanation of the shorter time spent on driving and more trees per processing site for the SGH could be that the trees were standing in groups while they were more scattered on the DGHs part of the block.

Normative harvesting time

Normative time was calculated for factors concerning both harvester types. In addition, normative time of the elements disturbance at Avesta and felling, miscellaneous and driving at Lövsjön was calculated. This was done by reducing the element disturbance for the SGH at Avesta to the mean of the same element of the other treatments. Furthermore by reducing felling, for the SGH at Lövsjön, to the same relative level as was the case between the harvester types at Graninge. It was also done by reducing the miscellaneous and driving for the DGH at Lövjön to the mean of the other treatments. This changed the mean time consumption for the SGH and the DGH to approximately 130 and 127 cmin/tree, respectively. However, we could still not reject the null hypothesis since the p-values were 0.206 and 0.700 for cause of variance in block and treatment, respectively.

CONCLUSIONS

There were differences in productivity between the SGH and the DGH, mainly attributed to the structure of the shelterwood stands. Both harvesters could be a good choice depending on stand data, alternative logging and logistics. The SGH could be recommended as a good choice in general, due to the low cost per machine hour as compared with the DGH, while the properties of the DGH would be beneficial in shelterwood stands with a large proportion of trees with large diameter (e.g. >7 cm) branches.

Despite the few stems per hectare and dense regeneration obstructing the view of the operator, the costs are considered low for final cutting of the shelterwood compared to clearcutting of ordinary stands. Fewer trees but approximately the same volume per hour was processed as in an ordinary stand, which resulted in similar costs.

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