

## Comparison of Single-Grip Harvester Productivity in Clear- and Shelterwood Cutting

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### ABSTRACT

An increased interest in the use of shelterwood stands to promote regeneration has led to an interest in how single-grip harvester productivity is affected by shelterwood cutting compared to clearcutting. A comparative time study of a large single-grip harvester was made in a spruce stand in northern Sweden. Three treatments were used. Shelterwood cutting leaving: 1) a sparse stand, 2) a dense residual stand, and 3) clearcutting. Each treatment was replicated three times. Results show that productivity decreases from 64 m<sup>3</sup> per effective hour in clearcutting to 54 and 41 m<sup>3</sup> per effective hour when shelterwoods with 259 and 381 stems ha<sup>-1</sup>, respectively, were retained.

**Keywords:** *single-grip harvester, productivity, shelterwood, clearcut.*

### INTRODUCTION

Sweden has about one million ha of productive wetlands covered by mature Norway spruce (*Picea abies*, L. (Karst)) forests old enough for legal final felling (6). Final felling on such sites has mostly been carried out as clear felling leaving no seed trees nor

shelterwood, and regeneration has typically been done by scarification and planting. This has led to difficulties since regeneration of spruce dominated stands on wet soils is faced with a number of obstacles, e.g., frost, competition from other plants and insect damage (6). Clearcutting in this type of stand further raises ground water levels on the site (10).

An alternative method is to regenerate under a shelterwood. Changes in physical site conditions are then moderate compared to clear felling (11), and there is less change in ground vegetation (5, 7).

The increased interest in shelterwoods for regeneration of spruce has led to an interest in how harvester productivity in shelterwood cuttings compares to productivity in clear felling. A study by Westerberg et al. (14) indicates that productivity of a single-grip harvester does not change if 200 or 400 shelterwood trees per ha are retained compared to clearcutting. However, productivity of single-grip harvesters in thinnings is known to decrease when residual stand density increases (cf. (4, 8)).

The objective of the present study was to investigate if single-grip harvester productivity decreases when a shelterwood cut is done compared to a clearcut, and if productivity in shelterwood cuts is decreased by increased shelterwood density. The second objective was to show what work elements are influenced by the shelterwood treatments.

### MATERIAL AND METHODS

The study was done outside Vitvattnet (63°50' N 19°20' E), 90 km east of Umeå, in the province of Västerbotten, Sweden. Experimental site was a previously thinned spruce dominated stand (96% Norway spruce, 2% Scots pine (*Pinus sylvestris*, L.), 2% deciduous) situated on wet soil in a gentle slope with almost no rocks on the ground.

Treatments were clearcutting (CC), sparse shelterwood (SS), and dense shelterwood (DS), where 0, 200 and 400 trees per hectare should be retained, respectively. Each treatment was replicated three times.

Treatments were randomised to plots prior to plot establishment, plot order is shown in Figure 1. Treatment plots were 13 m wide and long enough to enable harvesting of at least 150 trees per plot. Stem diameter at breast height (dbh) was measured and marked on all trees, average dbh (Table 1) was not

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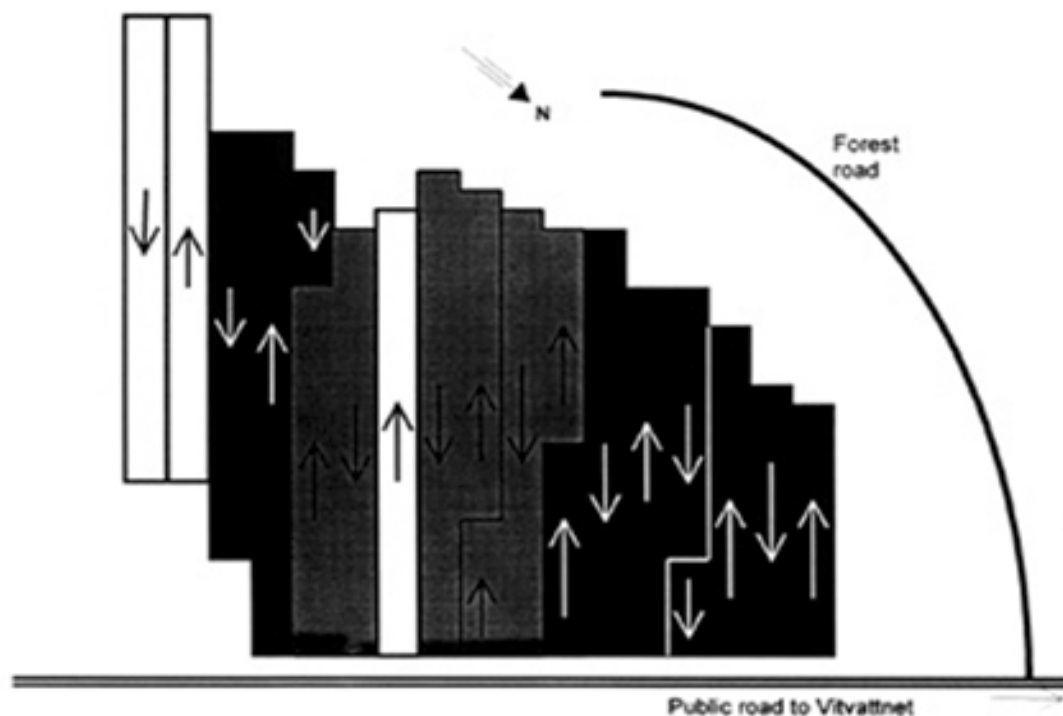


Figure 1. Study design, arrows indicates driving direction. White plots equals clearcutting, grey sparse shelterwood and black dense shelterwood.

Table 1. Description of treatment plots before logging, and of trees extracted. Values given are mean values per ha.

	Before treatment					Extraction			
	Plot size (ha)	Trees	dbh (cm)	Volume (m <sup>3</sup> ) <sup>a</sup>	Mean stem volume (m <sup>3</sup> ) <sup>a</sup>	Trees	dbh (cm)	Volume (m <sup>3</sup> ) <sup>a</sup>	Mean stem volume (m <sup>3</sup> ) <sup>a</sup>
CC	0.27	678	25	331	0.49	678	25	331	0.49
SS	0.46	605	26	326	0.54	346	24	153	0.44
DS	0.65	611	26	321	0.53	230	23	90	0.39

<sup>a</sup>m<sup>3</sup> solid under bark (u.b) calculated according to Brandel (3).

significantly different between plots. Between each 13 m stripe there was a 4 m wide buffer zone with unmarked trees, to avoid harvest of trees belonging to another plot. Trees harvested in this zone were not included in the study. A ditch cut across the study area, and the harvester had to pass it three times. Influence of the ditch on time consumption has been corrected, by applying the average machine speed on the plot to that machine movement.

On all plots, the single-grip harvester was driven as close as possible to the centreline of the plot, and harvesting was carried out in front and on both sides of the machine. Timber harvested were sorted into four assortments, spruce sawlogs, pine sawlogs, softwood pulpwood, and hardwood pulpwood.

The harvester operator selected what trees to harvest in the shelterwood treatments. The operator was instructed to leave an average spacing of 7 m between trees in SS and of 5 m in DS. Retained trees should primarily be large undamaged trees, i.e., dominant and co-dominant trees. To ensure that no shelterwood treatment was harvested with a clearcut adjacent, plots were harvested in the order DS1-DS3, SS1-SS3 and finally CC1-CC3. Prior to each treatment the operator trained in an adjacent area, to ensure that the correct spacing was reached.

The study was done under daylight conditions in April 1996, with good visibility and almost no wind.

The ground was frozen and had patches of snow, but there was no snow in the tree crowns.

Harvesting was done with a large single-grip harvester, FMG 1870, equipped with a Timberjack 762B harvester head on a Timberjack 184E boom. The operator had eight years experience as a harvester operator.

The time study was done as a correlation study with snap back timing (2) using a Husky Hunter computer running Siwork3 software (12). Work was split in seven work elements (Table 2). If more than one work element was performed simultaneously, the time for the work element with the highest priority was recorded. All element times were measured as effective times ( $E_p$ ) (1). Delay times were not included in the analysis. During the time study the number of conversion sites was recorded. Net length of harvester movements was measured after the time study.

For all elements linear regressions were made with volume as independent variable. For data significantly dependent on tree volume, slope and elevation of the regression lines were compared according to Zar (15). Elements not dependent on tree volume were analysed using Tukey hsd tests in SPSS (13). Results of the statistical analyses are considered significant if  $p < 0.05$ .

Table 2. Work elements used in the study.

Work element	Definition	Priority
<i>Felling and processing</i>	Starts when the harvester head is within 1 m from the tree and ends when the last log is cross-cut	1
<i>Movement</i>	When the harvesters wheels are rolling	2
<i>Boom out</i>	Starts when the harvester head is moved from the harvester towards a tree, ends when elements with higher priority starts or when the movement stops	3
<i>Boom in</i>	Starts when the empty harvester head is moved towards the harvester, ends when elements with higher priority starts or when the movement stops	3
<i>Waiting</i>	No part of the machine is moving, but the operator is working with eg. selecting what tree to cut	3
<i>Miscellaneous</i>	Productive work that not belong to any of the elements above	3
<i>Delay</i>	Non-productive time, not included in the analysis	

## RESULTS

The harvester operator retained 259 stems  $\text{ha}^{-1}$  in SS and 381 stems  $\text{ha}^{-1}$  in DS.

Only time consumption for *felling and processing* was dependent of tree volume ( $V$ ) in  $\text{m}^3\text{u.b}$  (Figure 2). There were no significant differences in time consumption for *felling and processing* between treatment CC and SS. However, DS differed from both CC and SS. Time consumption for *felling and processing* can be calculated as:

$$t = 15.8 + 42.0V$$

in treatment CC and SS, and in treatment DS as:

$$t = 17.1 + 51.9V$$

Time consumption per tree for *movement and waiting* increased with residual stand density (Table 3) and for *boom in* it was higher in the shelterwood treatments than in clearcutting.

Observed harvesting productivity for treatments CC, SS, and DS was 64.2 (sd. 1.4), 53.8 (sd. 2.0), and 40.9 (sd. 1.8)  $\text{m}^3\text{u.b. E}_0\text{h}^{-1}$ , respectively.

Table 3. Time consumption (cmin tree<sup>-1</sup>) for work elements not dependent on tree size. Data for treatments not followed by the same letter are significantly different ( $p < 0.05$ ).

Element	Treatment		
	CC	SS	DS
<i>Movement</i>	3.35a	6.85b	10.54c
<i>Boom out</i>	2.94a	3.05a	3.18a
<i>Boom in</i>	1.85a	2.56b	2.82b
<i>Waiting</i>	0.13a	0.67b	1.27c
<i>Miscellaneous</i>	0.79a	1.65a	1.23a

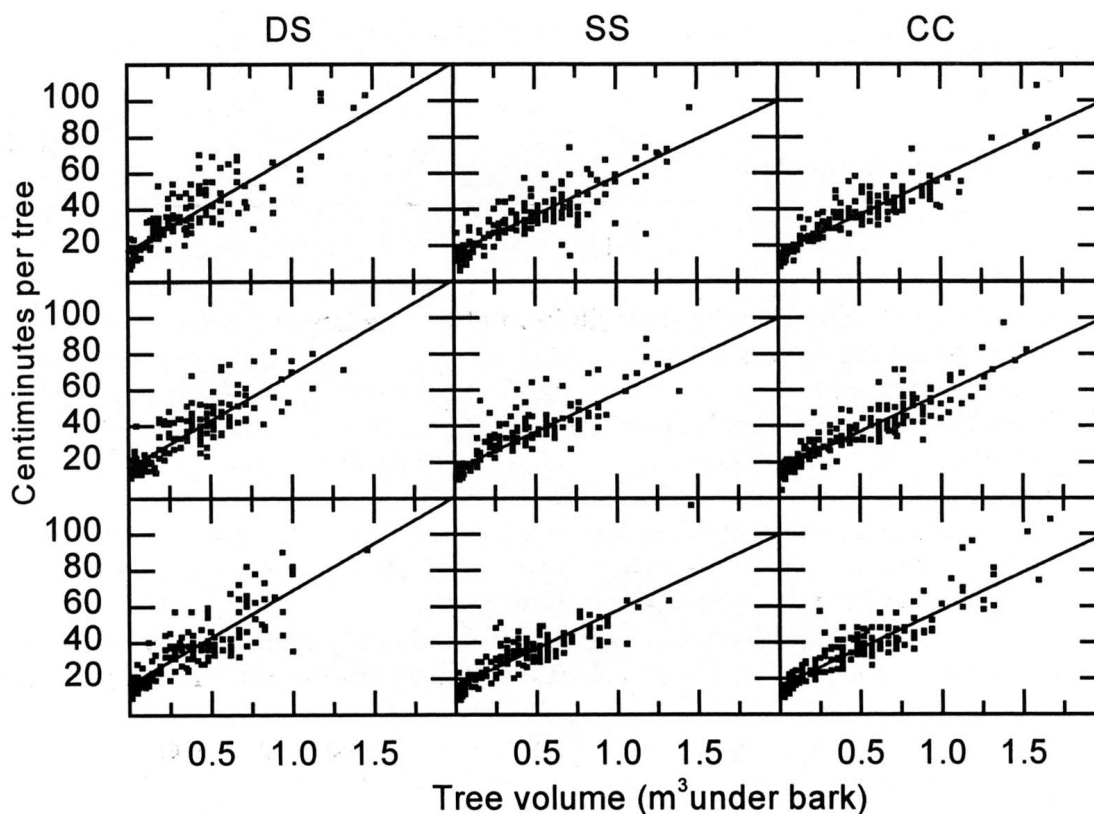


Figure 2. Time consumption per tree for felling and processing over volume separated on treatment and replicate.

Mean distance between conversion sites increased, and the average number of trees harvested at each conversion site decreased, with increased density of residual trees (Table 4). Machine speed was 33 m per minute in all treatments.

Table 4. Mean distance between, and average number of trees harvested at, each machine position. Data for treatments not followed by the same letter are significantly different ( $p < 0.05$ ).

	Treatment		
	CC	SS	DS
Distance (m)	2.9a	3.6b	4.5c
Harvested trees	2.6a	1.6b	1.3c

## DISCUSSION

The study was done under conditions as controlled as possible, making treatment effects pure, and results easy to analyse. Such conditions have some drawbacks. The machine operator felt that it would sometimes have been possible to work with wider swathes, which would have reduced strip road area per hectare in the shelterwood treatments, and would thus have been beneficial from a silvicultural point of view. The clearcutting treatment would probably have achieved a somewhat higher productivity if felling had been done towards already clearcut areas.

Results have been analysed as if study design was completely randomised. However, although treatments were randomised, the order of felling was grouped by treatment. This was necessary since results of the shelterwood treatments would have been influenced had it been possible to fell trees towards clearcut areas. A better solution would have been to use buffer zones of tree length width between the plots but this was impossible for practical reasons.

*Felling and processing* was the only work element dependent on tree size. In DS there was higher time consumption per tree compared to CC and SS. This increase in time consumption was proportional to harvested tree size, indicating that dense residual stands cause more difficulties when harvesting large trees. This is in accordance with Kuitto et al. (9) who

found an increased time consumption for *boom out*, positioning and felling in thinning compared to clear felling, and that felling of big trees took a longer time in dense stands. Time consumption for positioning and felling trees should increase with stand density, as a denser residual stand makes it more difficult to find a direction where the tree can be felled. Logically, there should not be differences in processing times between treatments when residual stand density is increased, unless the operator reduces processing speed or changes his use of the crosscutting automatics. This might be done to enable a more precise placement of the logs and thereby avoid damaging residual trees. Further studies are needed to separate effects of stand density on positioning and felling times from the effects on processing time.

Of the elements non-dependent of tree size the largest differences between treatments were found for *movement*. This difference is caused by fewer harvestable trees per ha in SS and DS, due to the residual stand density, leading to longer machine movements per tree harvested assuming equal swath width (cf. Table 4). This is continued by Klunder and Stokes (8) who found that the increased inter tree distance in shelterwood cuts compared to clearcutting increased walking time for chainsaw workers.

The reduction of harvester productivity with increased residual stand density, can be explained by two factors, a lower volume of the trees harvested and increased time consumption per tree for trees of equal size. The decrease of average harvested tree volume is caused by the shelterwood treatment prescriptions, specifying that large undamaged trees should be retained for the shelterwood stand. Calculating productivity using average times from Table 3 and calculating the *felling and processing* time with the presented functions at a constant harvested stem volume is held of  $0.49 \text{ m}^3 \text{ u.b.}$  gives a productivity of 64.6, 57.5 and 47.7  $\text{m}^3 \text{ s.u.b E}_0 \text{ h}^{-1}$  for treatments CC, SS and DS, respectively. Thus, the increased time consumption per tree in the shelterwood treatments explains approximately 70% of the decrease in productivity shown in the results, the remaining 30% are explained by the reduction in average harvested tree volume.

The reduction in harvested tree size is a direct treatment result, and the reduction this causes to harvester productivity has to be accepted. However, the increase in time consumption for specific work elements can probably be reduced as operator ex-

perience of shelterwood cutting increases.

An issue that remains to be addressed is how harvester productivity, when clear felling shelterwoods, is affected by the need to avoid damage to regeneration. Damage to regeneration cannot be totally avoided during a clear felling of a shelterwood, and studies to quantify damage incurred and to determine acceptable levels are therefore justified. According to Westerberg et al. (14) 35 to 65% of the saplings were damaged in final felling of shelterwood stands.

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