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FACTORS AFFECTING PRODUCTIVITY OF MACHINED LOGGING IN THINNING USING SMALL SIZE FOREST MACHINES

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Abstract
The aim of the research is to find out changes in productivity depending on the diameter of the tree to be cut as well as the most important factor influencing the reduction of productivity using small size forest machines in thinning in Latvia. The equipment used in the study – both the harvester and the forwarder is Vimek. The results of the research confirm the appropriateness of the exact technique in thinning if diameter of the harvested trees is 3 to 30 cm. The average productivity of the harvester achieved with a harvester head Keto Forest Eco (option 2) in Norway spruce stands with 8 cm weighted average tree reached 9.59 m^3 h^{-1}, in deciduous tree stands with 9 cm weighted average was 10.17 m^3 h^{-1}, but in Scots pine stands with 12 cm average weighted tree diameter reached 10.19 m^3 h^{-1}. By using the Keto Forest Eco Harvester head according to the thinning productivity figures, no significant difference among the tree species was detected. For the forest owner to predict the theoretical productivity of the harvester, it is possible to apply the equation R = K + KD * D, that is statistically significant, R^2=0.85. This equation is applicable to thinnings when the diameter of thinned trees is between 4 and 25 cm. Forwarder's average productivity in thinned stands is 8.63 m^3 h^{-1}.
Key words: productivity, Vimek 404 T5 harvester, thinning.

Introduction

According to the data of the State Forest Register, the forest occupies 51% from the territory of Latvia (3.01 million ha), there are trends in increase of forest area in future (Valsts meža dienests, 2017). Analysing the possible work collateral for small size forest machines, positive trends in the forest regeneration are important, where in 2016 the total regenerated area amounted to 38.6 thousand ha, state-owned forests made up 42%, while other forest owners accounted for 58%. The pre-commercial thinning in 2016 was carried out in the area of 68.6 thousand hectares, and the amount of the commercial thinning made up 10.6 thousand hectares additionally (Valsts meža dienests, 2017). Analysing the previous experience of mechanised thinning, the potential total volume for the small size forest machines is to 117.8 thousand. ha, taking into account the previous experience of mechanised thinning in the range of tree diameter from 1 to 28 cm (Kaleja *et al.*, 2017; Lazdiņš, Zimelis, & Spalva, 2015; Zimelis, Lazdins, & Spalva, 2017).

Vimek harvesters are among the smallest serially harvesters available on the forestry machinery market (Lazdiņš *et al.*, 2016; Zimelis, Lazdins, & Spalva, 2017). Vimek technique is two times smaller than medium-sized harvesters are (4.4 t versus 10 – 12 t). Working both in the private sector and in the public sector, forest owners increasingly require that the technique conforms the accounting system STANFORD standard, what is provided by Vimek (Arlinger & Möller, 2010; Räsänen, Sorsa, & Oy, 2010). Due to its equipment, the theoretical possibilities of using the technique are from the restoration of small drainage ditches to the second commercial thinning. It is possible to calculate the amount of the round wood and wood biomass obtained in pre-commercial and commercial thinning by using algorithms developed for Latvia conditions (Jansons *et al.*, 2017; Kenina *et al.*, 2018; Lībiete *et al.*, 2017; Liepiņš, Lazdiņš, & Liepiņš, 2017) to precisely predict additional revenue from integrated forest management.

The aim of the research is to find out changes in productivity depending on the diameter of the tree to be cut as well as the most important factor influencing the reduction of productivity using small size forest machines in thinning in Latvia.

Materials and Methods

The small size forest machines – a harvester Vimek 404 SE and forwarder Vimek 606 TTW were used in this research. The research was carried out in the territory of forest cooperative L.V. Mežs realising thinning in 13 stands with a total area of 39.23 ha. One forest machinery operator participated in the research. For mechanised logging experiments Vimex 404 SE with a harvester head Keto Forest Extreme (option 1) and Vimek 404 SE with a harvester head Keto Forest Eco (option 2) were used. Shifting time for the mechanised logging was 8 hours. Changes in the labour productivity, depending on the tree species and the tree diameter, are calculated based on the timing in the field work. Damage to after-thinned stands is determined according to the normative documents of Latvia. The equations by I. Liepa have been used for calculating the total volume of the forest stands, where the calculation is carried out for each tree trunk individually (Liepa, 1996).

During the working process working time accounting is carried out with a specialized field computer Allegro II. The computer is equipped with

Table 1

Working elements for time studies in field work

Working time category	Working element numeration	Explanation
Information fields	1	Work cycle number
	2	Diameter of processed tree, d1.3, cm
	3	Number of processed trees per operation
	4	Felled half trunks
	5	Various notes, including brakes, travel, strip-road change etc.
Productive working time	6	Reaching for tree with crane
	7	Positioning of felling head
	8	Cutting of tree
	9	Delimbing and bucking
	10	Delimbing times (show how many times a trunk was dragged through delimbing knives)
	11	Log moving and stacking
	12	Undergrowth cutting
	13	Time spent to drive into a stand
	14	Time spent to leave a stand
	15	Other non-standard operations, including machine maintenance
Unproductive time	16	Tie spent for activities not related to harvesting

the time study program SDI. Working time was split into 10 work elements and other operations (Table 2). Breaks and other activities that do not comply with the table set-time elements were described in notes. Time studies did not include preparatory work, which takes about 1 hour a day, but the working time records include lubricating of moving parts that is normally carried out during the shift. Time tracks were recorded in centiminutes (1min = 100 centiminutes).

For data analysis from the total number of observations (N=16879 pcs.) for further data processing measurements that are missing any of the records were excluded, for example, during the timekeeping, the tree species or the diameter of trees is not recorded. After the selection of data the number of observations used for further processing was N=9985 pcs.

The timekeeping of the forwarder was carried out according to a worked out and approbated methodology for the forwarder timing (Lazdiņš *et al.*, 2016; Rozītis, Zimelis, & Lazdiņš 2017), Vimek 606 TTW was used in the study.

Results and Discussion

Characterization of the prepared tree volume is given in Table 3. Logging is curried out with two different harvester heads. The total logged area with the first version is 20.01 ha, where the average diameter of felled tree is from 5 to 13 cm, but with the second version 19.22 ha. According to the database, the average diameter of the tree is from 7 to 12 cm, which in some cases does not correspond to the measurements made in the forest stands.

Proportion of the number and volume of the logged trees in the distribution of diameter for both harvester heads is reflected in Figure 1. If small size forest machines are used in forest thinning, it is recommended that the operators of the machines preserve small dimension trees. Analysing the data obtained at the 5 cm diameter of the felled tree, the potential productivity of the harvester is 1.72 $m^3 h^{-1}$ ± 0.23, in calculating the number of trees to be processed, 125 trees are required for the preparation of 1 m^3. According to the calculations made in the study, the average number of treated trees per hour is 88 pcs, therefore, the economic justification of the cutting of small diameter trees should be considered (Lazdiņš *et al.*, 2016). In spite of this, the diameter of the felled trees is smaller than recommended. As one of the most effective control mechanisms, there is a possibility to use the log analysis file provided by the harvester tracking system (Arlinger & Möller, 2010; Räsänen, Sorsa, & Oy, 2010), such experience is evident in other countries, however, just from the time when thinning starts.

When analysing productivity indices by the type of the harvester head, significant differences can

Table 2

Characteristics of the felled volume and tree dimensions

Forest stand	Harvester No.	Number of felled trees, pcs	Diameter of average felled tree, cm	Timber volume of felled trees m^3	Volume of average felled tree, m^3
2	1	728	13 ± 5	71.11	0.10
5		2486	6 ± 3	60.53	0.02
6		3787	10 ± 5	290.02	0.08
7		3979	4 ± 5	122.95	0.03
8	2	2660	12 ± 4	222.30	0.08
9		975	11 ± 4	85.47	0.09
10	1	80	10 ± 3	4.38	0.05
11	2	2105	9 ± 3	115.06	0.05
13		409	7 ± 4	17.90	0.04

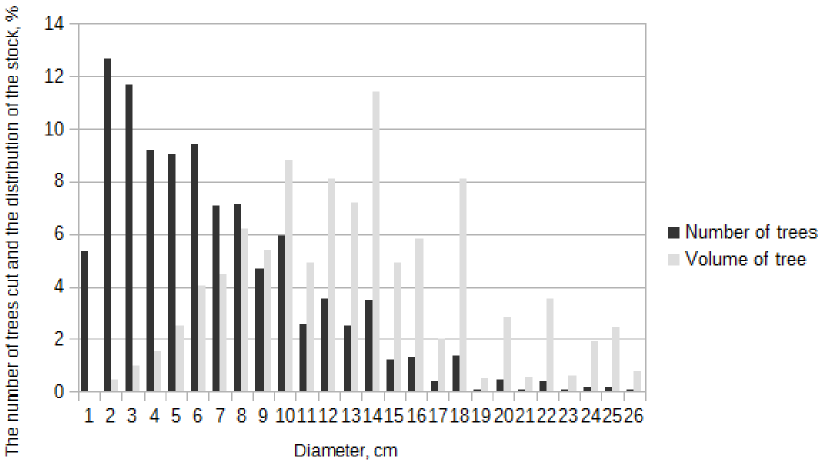

Figure 1. The number of trees cut and the distribution of the stock
of the Keto Forest Extreme harvester head.

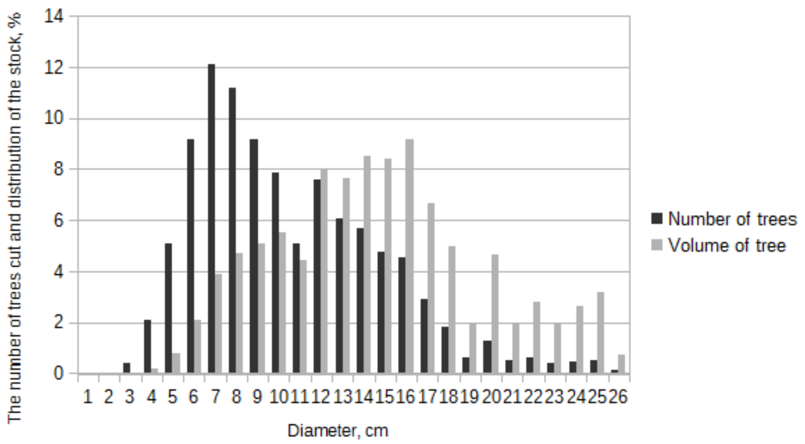

Figure 2. The number of trees cut and the distribution of the stock
of the Keto Forest Eco harvester head.

Table 3

Summary of the labour productivity indicators

Tree species	Harvester No.	Diameter group, cm	Number of observations (N), pcs	Total number of trees in tree group, %	Number of trees cut by productive hour, pcs.	Productivity in productive hour, $m^3 h^{-1}$
Spruce	1	>=5	301	35.9	188	0.98
		6-10	321	38.3	121	4.24
		11-15	197	23.5	88	8.67
		16-20	19	2.3	45	9.78
		21-25	1	0.1	31	11.39
		Average			**95**	**7.01 ± 4.3**
	2	>=5	45	3.4	146	1.51
		6-10	539	40.7	123	4.25
		11-15	456	34.4	82	8.91
		16-20	243	18.4	58	11.88
		21-25	39	2.9	33	13.21
		25<	2	0.2	31	17.77
		Average			**79**	**9.59 ± 6.0**
Deciduous trees	1	>=5	751	24.7	214	1.18
		6-10	1349	44.4	104	3.77
		11-15	612	20.1	87	9.77
		16-20	262	8.6	101	22.21
		21-25	59	1.9	68	27.30
		25<	5	0.2	40	21.96
		Average			**102**	**14.36 ± 10.9**
	2	>=5	261	16.4	129	1.23
		6-10	871	54.6	111	3.93
		11-15	376	23.6	81	8.81
		16-20	73	4.6	43	9.32
		21-25	10	0.6	34	13.46
		25<	3	0.2	36	24.25
		Average			**72**	**10.17 ± 8.1**
Pine	1	>=5	231	19.6	236	1.14
		6-10	500	42.5	85	2.22
		11-15	250	21.2	56	4.44
		16-20	152	12.9	50	8.47
		21-25	40	3.4	42	12.62
		25<	4	0.3	28	11.48
		Average			**83**	**6.73 ± 4.8**
	2	>=5	19	0.9	175	1.33
		6-10	819	40.7	120	3.28
		11-15	793	39.4	92	7.28
		16-20	329	16.3	73	10.96
		21-25	47	2.3	63	17.97
		25<	6	0.3	48	20.29
		Average			**95**	**10.19 ± 7.7**

Table 4

Descriptive statistics of the algorithm and coefficients

Regression summary R^2=0.85 F=372>Significance F=2.82*10^{-21}		
	Coefficients	P-value
K	-1.827090812	0.001
K_D	0.700114608	0.000

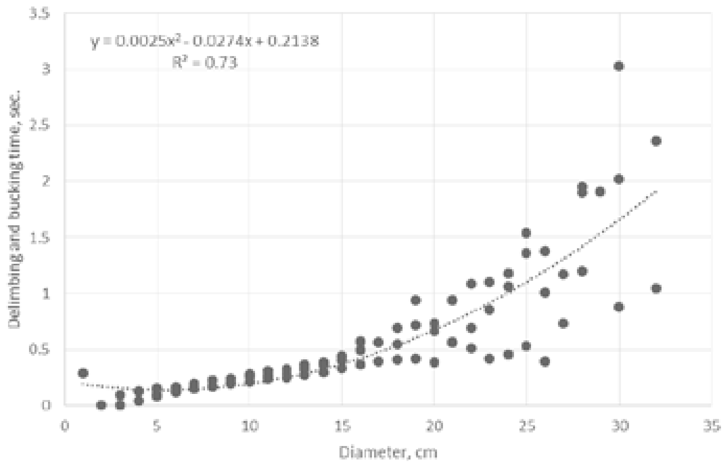

Figure 3. Delimbing and bucking time with Vimek harvester.

be observed working with the second head. At the moment, both harvester head models are available on the market, and Keto Forest Eco could be the most suitable for Latvia conditions, working with it in coniferous forest stands could increase the labour productivity by 14%. When thinning the spruce stands the average productivity of the first harvester head is 7.01 $m^3 h^{-1}$, while the second one is 9.59 $m^3 h^{-1}$. When thinning the deciduous stands with the first harvester head it is 14.36 $m^3 h^{-1}$, but with the second 10.17 $m^3 h^{-1}$. The productivity in pine stands with the first harvester head is 6.73 $m^3 h^{-1}$, but with the second one is 10.19 $m^3 h^{-1}$ (Table 4).

To optimize thinning productivity with a Vimek harvester, it is possible to use linear regression equation for the DBH range from 4 to 25 cm.

$$R = K + K_D * D \quad (1)$$

where:

K – coefficient;

K_D – coefficient;

D – tree DBH, cm.

By using the obtained algorithm, it is possible to predict the productivity index $m^3 h^{-1}$, it can be calculated using the developed mathematical model and coefficients (K=-1.827090812; KD=0.700114608). When calculating the statistical data for productivity per hour, coefficients are calculated and their confidence interval is given in Table 5.

During the processing of statistical data, the reliability of the established formula was initially tested, which, according to calculations, is significant (F> Significance F); the formula can be used to predict the productivity thinning with the Vimek harvester. The analysis of the coefficients used in the formula: the use of K value 1.827090812 is statistically based on the significance level (p=0.001), the use of the K_D value 0.700114608 is statistically based on the significance level (p=0.000). The use of obtained conversion factors in practice is statistically justified. In order to improve the reliability of the formula, it is necessary to include an additional indicator – branch diameter of the stem. From the data collected, the dependence of the time consumed on the treating of the tree depends on a tree diameter (Figure 3).

Forwarder performance in thinning is 8.63 $m^3 h^{-1}$. On average, one load was consumed in 18 minutes, 5 minutes for unloading, an average of 8 minutes for moving around the felling site area, an efficiency of 0.88 for forwarding. The total damage to the remaining trees is on average up to 3%, which does not exceed the quality requirements for the remaining trees in Latvia after the logging.

Conclusions and Recommendations

1. Better productivity indicators for coniferous stands are presented by Vimek harvester with Keto Forest Eco harvester head, but for deciduous stands – Keto Forest Extreme harvester head.
2. The main factor for the change in productivity at the diameter of the trees over 25 cm is the diameter of the branches.
3. The average productivity of a forwarder in thinning is 8.63 $m^3 h^{-1}$ in the cutting sites located at the wood yard area with forwarding distance less than 100 m.

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