COMPLEX FOREST MANAGEMENT SYSTEM BASED ON SMALL SIZE FOREST MACHINES

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Abstract. The aim of this study is to clarify the possibilities for applying compact class logging machines in Latvian conditions. The equipment evaluated in the study is the Vimek harvester and forwarder. The possibility of using both machines in forest operations from ditch clearing to final felling has been evaluated in terms of productivity and economy. The productivity of the Vimek harvester can be characterized by polynomial equations. Statistical significantly higher productivity in pre-commercial thinning was observed in spring trials in forest areas with or without extracted undergrowth trees in comparison to areas with dense undergrowth vegetation. Statistically significant difference was observed in artificially and naturally regenerated stands – in naturally regenerated stands better figures were obtained during the extraction of small trees ($D_{13} < 17$ cm), in artificially regenerated stands – in the extraction of bigger trees. The Vimek harvester was equipped with a specialized felling head with a circular saw and chain (Bracke C.12) in early tending and felling-bunching head with a chain feed roller (Keto-Forest Eco) in thinning. The productivity achieved in small ditch clearing was 187 $m \cdot h^{-1}$, while clearing of larger ditches resulted in an average productivity of 107 $m \cdot h^{-1}$, the productivity of early tending is 0.2 $ha \cdot h^{-1}$. Harvesting productivity highly depends on the average tree diameter, but the average value is 9.0 $m^3 \cdot h^{-1}$. The productivity in final felling in grey alder stands is 11.5 $m^3 \cdot h^{-1}$. In all cases productivity is expressed as efficient work hours. The prime cost of log production (extraction and delivery) ranges from 22.9 $EUR \cdot m^{-3}$, but the cost of ditch clearing and early tending can be estimated from the average hourly cost of 63 $EUR \cdot h^{-1}$.

Keywords: productivity, Vimek, thinning, early tending.

Introduction

The forest cover in Latvia rapidly increased from 23 % in 1923 to 52 % in 2016 [1-2]. The increase in the forest area is also predictable in the future due to a continued natural overgrowth of unused agricultural land as well as its artificial afforestation. As the areas increase, the number of forest stands to be tended also increases, ranging from young stands to stands where commercial thinning should be carried out. When planning the thinning of stands, one should also think about performing high quality work that positively affects both the increment of the stand and its value [3;4]. To improve planning and harvesting, it is necessary to use the appropriate machinery and technology characterized by high performance, work safety, productivity and efficiency [5-7].

Thinning is required to form a forest stand of optimal density, which is resistant to wind and snow damage and which has a proportional ratio of tree stems and crowns. In forest types with fertile soil, thinning needs to be carried out more often. If not thinned timely, too close growing trees grow tall and thin, become unstable and bend downwards after tending; moreover, due to the competition from the surrounding trees they branch off, forming the crown at the end of the stem from some branches. Such crown arrangement does not provide enough nutrient production and trees lag behind in growth.

This study examines complex harvesting with small size machinery ranging from thinning of young stands to regeneration felling. In the project, the stands are divided by their height. In the selected stands, thinning has been carried out using different methods based on evaluation of the productivity and costs depending on the height of the forest stand, availability of valuable timber and undergrowth. The machinery used in the study was equipped with a standard cutting head (Keto ECO Forest), ditch excavation bucket and young stand thinning equipment (Bracke C12).

Materials and methods

The distribution of the number of felled trees by their diameter classes in different felling types is described using quartiles by dividing the data set into equal parts, where 25 % of the data represent the smallest values, 50 % represent the median and 75 % represent the highest values. The data obtained show that the diameters of the felled trees range from 1 to 20 cm. The smallest average diameter was stated in the clearing of overgrowth on agricultural land, but the largest average diameter, respectively, in the final felling (Fig. 1). Data processing reveals individual extremes that do not describe the overall trend in the site and have been removed from the mathematical data processing. For example, the overgrowth trees felled along the ditches, mostly with a diameter of 1 to 10 cm, have to be mentioned, but the diameter of some individual felled trees ranges from 15 to 18 cm, which does not objectively characterize the overall situation, thus artificially increasing the productivity rates.

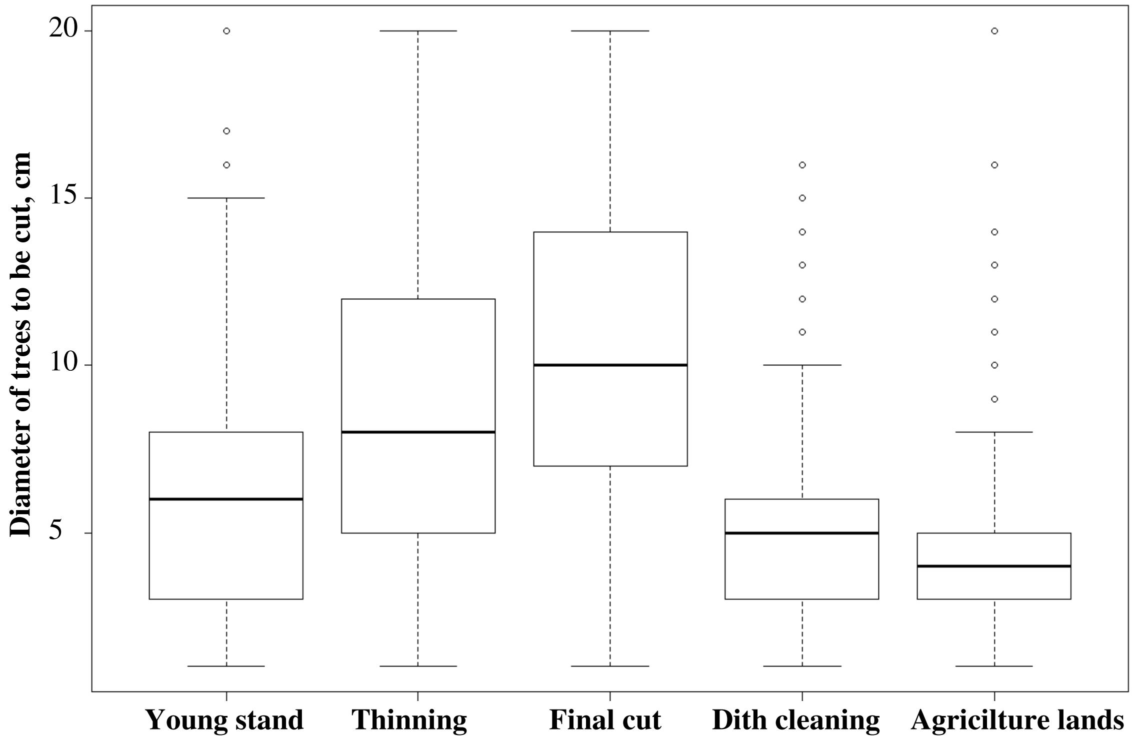

Fig. 1. **Characteristics of diameter of average felled tree in different felling types**

Small class machinery was applied in the study - the harvester and forwarder Vimek. The harvester Vimek 404SE and forwarder 606SE were used. The study was carried out in the areas of the Forestry Services Co-operative Society "L.V.Mežs". The data for the study were obtained by carrying out silvicultural tasks using machinery in the stands with the height of 6 m. The stands in the project were divided according to the type of the planned felling: young stands, where composition thinning of the stand was planned, commercial thinning of the growing stock and final felling (only grey alder stands), ditch overgrowth clearing and overgrowth clearing on agricultural lands, (Table1). The methods applied in the study are the following: *thinning of young stands* – the study work method is the assortment technology where wood is left in the felling site after felling, or it is collected and forwarded to the upper landing (UL). In the work method that involves collecting the prepared material, additionally the impact of undergrowth, small trees and sortimentation on the productivity indicators is analyzed; *commercial thinning* research work method is the assortment technology (cut-to-length), in which wood is collected and forwarded to the upper landing (UL) after felling. Additionally, the effects of clearing of undergrowth and small trees on the productivity indicators are analyzed; *final felling* – the research work method is the assortment technology. The harvesting method tested is preparation of round timber in final felling in grey alder stands; clearing *of overgrowth on agricultural lands* **–** after felling, the wood is left on the field or collected for forwarding to the upper landing (UL). The overgrowth of woody plants and shrubs in the testing areas is harvested completely; and the *establishment of furrows for collecting runoff water* to improve the surface water discharge in forest stands. In the areas of mineral soil wetlands and in case of necessity also on drained mineral soils in the forest types, where the trial thinning of young stands and commercial thinning have been carried out and high-resolution LiDAR data are available, the network of the furrows for collecting runoff water had been planned for the drainage of wet gullies and recording of deep furrow digging work time was performed; clearing *of woody plant overgrowth from drainage ditches* and cleaning of the ditch bed from the debris. The testing harvesting method is preparing round timber in overgrowth clearing.

Table1

Distribution of thinned sites

Type of felling	Area, ha	Number of sites
Thinning of young stands	15.2	11
Commercial thinning (of growing stock)	129.49	79
Final felling	16.92	21
Clearing of overgrowth on agricultural lands	3.3	1
Creation of furrows for collecting runoff water	2	1
Clearing of woody plant overgrowth from drainage ditches	3	2

Working time records with a specialized farm type computer at Allegro CX were carried out in production conditions. The field type computer is equipped with the timing programme SDI. The elements released for the logging process work time records and other work operations by cutting types are different (Table 2) [8]. The notes specify the reasons for work breaks and other activities that do not match the work time elements specified in the table. The work time records do not include machine preparation for the work that takes approximately 1 hour a day, but the work time records do include lubrication of the moving parts carried out during the shift.

Table2

Work elements for time studies in field work in different types of cutting

<table>
<tr><th rowspan="2">Work time category</th><th rowspan="2">Work element numeration</th><th colspan="2">Explanation</th></tr>
<tr><th>Thinning of young stands, Commercial thinning, Final felling, Clearing of overgrowth on agricultural lands, Clearing of woody plant overgrowth from drainage ditches</th><th>Creation of furrows for collecting runoff water</th></tr>
<tr><td rowspan="5">Infor-mation fields</td><td>1</td><td>Work cycle number</td><td>Work cycle number</td></tr>
<tr><td>2</td><td>Diameter of processed tree, d 1.3, cm</td><td>-</td></tr>
<tr><td>3</td><td>Number of processed trees per operation</td><td>-</td></tr>
<tr><td>4</td><td>Felled half ridges</td><td>-</td></tr>
<tr><td>5</td><td>Different notes, including braces, travel, strip-road change, etc.</td><td>-</td></tr>
<tr><td rowspan="10">Productive work time</td><td>6</td><td>Reaching for tree with boom</td><td>Reaching ditch with crane</td></tr>
<tr><td>7</td><td>Positioning of felling head</td><td>Positioning of digging head</td></tr>
<tr><td>8</td><td>Cutting of tree</td><td>Digging</td></tr>
<tr><td>9</td><td>Delimbing and bucking</td><td>Soil removal (displacement)</td></tr>
<tr><td>10</td><td>Delimbing times (how many times trunk is dragged through delimbing knives)</td><td>Time spent on driving into stand</td></tr>
<tr><td>11</td><td>Log moving and stacking</td><td>Time spent on leaving stand</td></tr>
<tr><td>12</td><td>Undergrowth cutting</td><td>Other non-standard operations, including machinery maintenance</td></tr>
<tr><td>13</td><td>Time spent on driving into stand</td><td>-</td></tr>
<tr><td>14</td><td>Time spent on leaving stand</td><td>-</td></tr>
<tr><td>15</td><td>Other non-standard operations, including machinery maintenance</td><td>-</td></tr>
<tr><td>Unproduc-tive time</td><td>16</td><td>Time spent for activities not related to harvesting</td><td>-</td></tr>
</table>

Results and discussion

Thinning of young stands. In the work method, where the *wood is left in the felling site after felling***,** the average diameter of the felled tree is 7 cm, but its height is 7 m. The productivity indicator characterized by the number of trees handled in the productive work hour is 383 trees. Although the harvester working head used in the trial is not equipped with a multi-stem accumulation mechanism, when actively working with delimbing knives and feed rollers, it is possible to simultaneously handle several stems that allow to increase the productivity rates. This work technique can be used in the work methods that do not intend to produce assortments, such as pulpwood, sawlogs, veneer, etc. A relatively large number of trees felled during the productive work hour can be explained by the use of the sawing function at an open harvester head, which also significantly increases the productivity rates. In the work method where *wood is collected after felling*, standard harvesting work techniques are used that include both forwarding by using strip roads (SR) and division of operations by sectors. Unlike the standard harvesting technique, the displacement distances provided for the Vimek harvester between parking and harvesting sectors are shorter, but the harvesting angles remain the same. This method tested the productivity changes by retaining small trees with an average diameter of 5 to 7 cm, or removing them as well as undergrowth (trees with 1-5 cm average) impact on productivity (Fig. 3). The results obtained show that *small tree removal* results in a 14 % increase in the time spent on sawing, which leaves the impact on productivity. If the work task involves energy wood preparation, the yarding place should be planned for stacking it, which in young stand thinning operations is sometimes practically impossible. Better productivity rates are reported by retaining small trees of 5.94 $m^3 \cdot h^{-1}$ (on SR small trees are cut). By comparing *the impact of undergrowth* on the productivity changes, the project felling areas are divided into two parts, where in one part before harvesting with gasoline power saws (GPS) all undergrowth trees with an average diameter of up to 5 cm have been cut down, while in the other part they are planned to be sawn using machines, performing the thinning of young stands. The difference in the productivity calculated between these methods is 23 %, indicating the need to plan the thinning of undergrowth trees with GPS prior to harvesting.

The work methods used *in commercial thinning are* related to the retention of small trees or their removal, and the impact of undergrowth on the productivity has been studied. In this type of felling, trees with an average diameter of 5 to 7 cm are considered to be small trees, but undergrowth trees or shrubs are those with an average diameter of up to 5 cm. In the areas where small trees or undergrowth are felled with a GPS prior to commercial thinning, and defined in the study as areas without undergrowth or small trees, the best rates have been achieved in the work method where small trees are salvaged at 9.69 m for 3 h -1. Similar to young stand thinning, the standard harvesting methods and techniques have also been applied in commercial thinning. When harvesting forest stands where small trees are planned to be removed, an 11 % reduction in productivity should be considered, which can be explained by the additional time consumption for cutting down small trees. In forest stands where undergrowth has not been removed with GPS prior to harvesting, there is a 13 % reduction in productivity.

The methods associated with the removal of overgrowth *on agricultural lands* envisage both leaving wood scattered and also collecting it for further processing. The best productivity rates (183 pieces h_{15}^{-1} or 3.53 $m^3 \cdot h_{15}^{-1}$) have been achieved by using a method that involves leaving the wood scattered after felling. It should be taken into account that, using this method within the framework of the trial, it was not possible to systematically use the possibility of handling several trees simultaneously due to the location, number and branching of the woody plants, which makes productive work difficult.

When assessing the productivity changes depending on the diameter of the felled tree, it should be concluded that significant changes in the productivity of removing overgrowth, using a work method that requires the wood after removal to be left scattered, are observed by sawing trees, the diameter of which is more than 7 cm. Using the work method that requires wood to be collected after felling, the reported average productivity rates are lower than for the first work method, and the increase in productivity is observed up to the point when the diameter of the felled tree reaches 13 cm, then a rapid downturn trend in the productivity is observed, Fig. 2 .

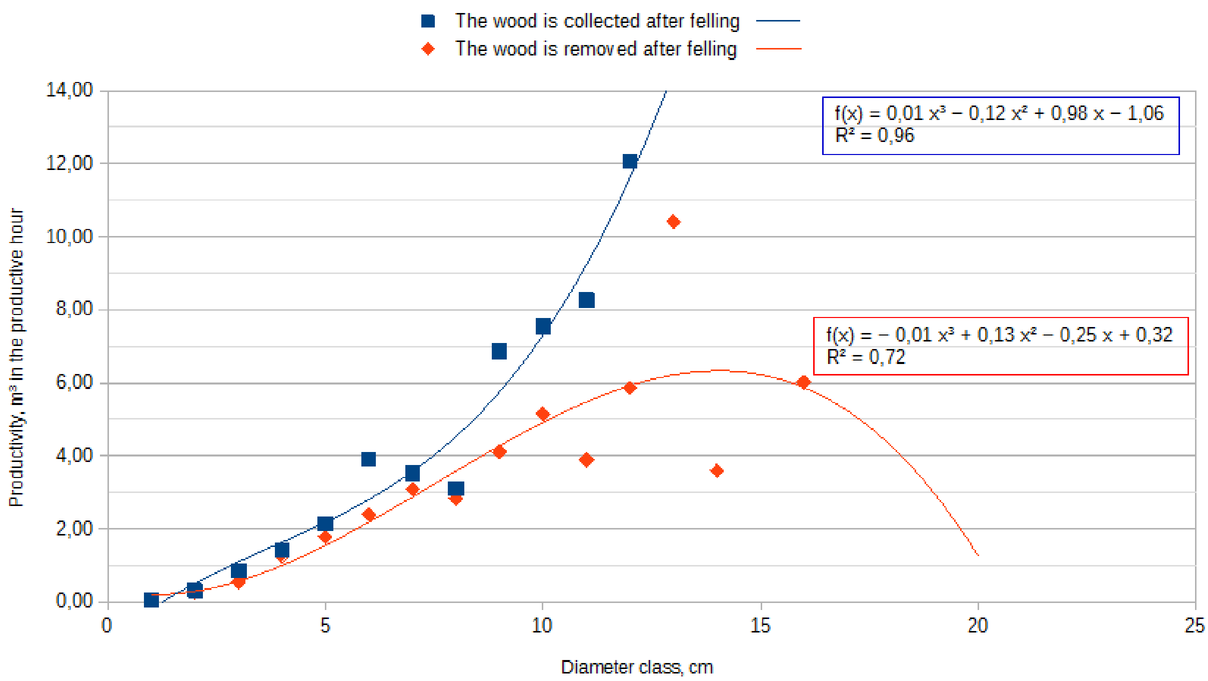

Fig. 2. **Characteristics of diameter of average felled tree in different felling types**

In final felling, only grey alder stands with a small admixture of other tree species have been studied. This is due to a rapid reduction in productivity with the diameter of the felled tree increasing over 22 cm. Similar conclusions concerning the equipment suitable to the tree diameters have also been obtained from the previous studies [8]. Undoubtedly, this does not prevent from sawing of larger dimension trees, since the harvester head can maximally handle stems with a diameter of up to 32 cm (at the root collar). In the stands selected for the project where machined harvesting has been planned, undergrowth trees (up to 6 cm) were cut first. The achieved productivity at the average felled tree of 13 cm is 10.41 $m^3h_{15}^{-1}$, the number of prepared trees is 67 pieces h_{15}^{-1}.

Until now, in clearing of ditch overgrowth in Latvia, small-scale harvesting machinery was not used due to several factors, one of which is the width of ditches which tends to exceed 8 m. When clearing the overgrowth along the ditches of such width, a boom with a reach of 10 m is required and it is typical of medium class harvesting machines. In private forests the situation is different. Frequently, there are ditches with a width of up to 5 m that are suitable for removing of ditch overgrowth using the Vimek harvester, because the boom reach is sufficient to handle all the trees growing in the excavated soil. In the trial sites where the ditch overgrowth removal was carried out (average felled tree 5 cm, Fig.10) the reported productivity rates are 2.04 $m^3 h_{15}^{-1}$ (excluding driving). The decline in the productivity in removal of overgrowth is observed, when the diameter of the felled tree increases over 14 cm. Also in this case the highest time consumption is for delimbing and bucking operations. In comparison with the final felling, the trees felled have more branches already at smaller dimensions. It is due to the easy access of light to trees, resulting in branches of considerably larger dimensions.

Conclusions and recommendations

1. Harvester productivity is significantly affected by the diameter of the trees of up to 5 cm (undergrowth trees), so that there is no reduction of 22 % it is required to remove the undergrowth using GPS, therefore the claim of significant productivity changes in the work methods associated with machined undergrowth removal using the standard harvester head has been confirmed. Cutting down the trees with a diameter of 1-5 cm (undergrowth trees), there is a 22 % reduction in the harvester productivity in young stands, and in commercial thinning it is 13 % compared to the work method, in which trees of such dimensions are cut down using GPS.

2. When carrying out thinning of young stands and performing commercial thinning of trees with the diameter of 5-7 cm (small trees), the decrease in the productivity is up to 14 %.
3. When planning thinning of young stands with an average tree diameter of above 7 cm, the most appropriate work method is the production of standard assortments additionally preparing energy wood. With such a scenario, the productivity reduction is up to 7 %, but it is possible to additionally obtain up to 22 % of the energy wood out of the harvested commercial wood, thus compensating for the loss of productivity with additional revenue.

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