DOI: 10.2478/frp-2019-0004
Available online: www.lesne-prace-badawcze.pl

Leśne Prace Badawcze / *Forest Research Papers*
Marzec / March 2019, Vol. 80 (1): 45–53

ORIGINAL RESEARCH ARTICLE

e-ISSN 2082-8926

Harvester efficiency in trunk utilisation and log quality of early thinning pine trees

Piotr S. Mederski[1*], Konrad Werk[1], Mariusz Bembenek[1], Zbigniew Karaszewski[2], Mariusz Brunka[1, 3] Kwiryn Naparty[1, 4]

[1]Poznań University of Life Sciences, Faculty of Forestry, Department of Forest Utilisation, ul.Wojska Polskiego 71A, 60–625 Poznań, Poland; [2]Wood Technology Institute, ul. Winiarska 1, 60-654 Poznań, Poland; [3]Rytel Forest District, Rytel-Dworzec 4, 89-642 Rytel; [4]Pniewy Forest District, ul. Wolności 4, 62-045 Pniewy, Poland

*Tel. +48 61 8487761, e-mail: piotr.mederski@up.poznan.pl

Abstract. Obtaining high harvester efficiency in young pine stands during early thinning is achallenging management practice. One of the difficulties lies in achieving the optimal use of the tree trunk for assortments and obtaining satisfactory timber quality. The objective of this research was to find out 1) how much of the tree trunk can be processed by a harvester to produce logs, and 2) the quality of the assortments in terms of log length accuracy and delimbing quality. The work was carried out in a 31-year-old pine stand in northern Poland with the Vimek 404 5T harvester with the Keto Forst Silver head for early thinning. Eighty sample plots were set up within the stand for detailed tree analysis after harvesting. The total length of the assortments from each tree was measured as well as the minimal top diameter (under bark). Additionally, the lengths of the bottom, middle and top logs were measured as well as the height of the knots after delimbing. On average, 70% of the total tree height was used for assortments and logs were processed up to a mean top diameter of 5.3 cm under bark. The length accuracy was very high: 90% of the logs had the expected length, more than 9% had a commercially acceptable length, while only 0.7% of the logs were too long. After delimbing, the knots were of a maximum height of 2 cm. Using the Vimek 404 5T harvester in the 31-year-old pine stand was an effective solution for trunk processing and obtaining quality assortments.

Keywords: *Pinus sylvestris* L.; Vimek 404 T5; bucking accuracy; quality of delimbing

1. Introduction

The harvesters usually used for thinning and felling work in coniferous tree stands are also sometimes used in mixed or deciduous stands (Mederski 2013; Mederski et al 2018a; Moskalik et al. 2017). The species structure of forests in Poland, with mainly coniferous species occupying 69.6% of the forest area (Leśnictwo 2014) favors mechanized harvesting (Mederski et al. 2016). At the same time, progress has been observed in the mechanized logging of stands in younger age classes, using processors (Stańczykiewicz et al. 2011; Stańczykiewicz et al. 2015) and harvesters (Mederski et al. 2018b) in early thinning.

Since the beginning of the last decade, the number of harvesters used in Poland started to intensively increase (Mederski et al.2016). In 2008, a total of 419 harvesters and forwarders were being used in the country. In three years, this number increased almost twofold to 836 units, which was the largest increase in the number of machines in all of Europe (Żabierek, Wojtkowiak 2013). Research on changes in the number of harvesters shows that in 2014, the there were about 460 of them used in the State Forests, and in 2015 about 530 (Mederski et al. 2016).

The use of harvesters affects the quality of obtained logs. The quality of logs should be understood as the accuracy of delimbing, the accuracy of processing assortments in terms of length and thickness, the absence of cracks after bucking, damage to the trunk surface in the form of cuts to the bark and wood from the delimbing knives, and damage to the trunk surface from the spikes of feed rollers (Karaszewski et al. 2016b). As a result of logging work, both with a chainsaw and a harvester, defects may occur in the form of

Received: 24.02.2019, reviewed: 8.03.2019, accepted: 25.03.2019.

too high knots, circular and straight cracks, as well as chipping and splitting. Defects may also occur as a result of the work of the harvester head – the lateral surface may become distorted from the delimbing knives and the spikes of the feed roller may result in incisions in the top layer of wood (Karaszewski et al., 2016a).

Difficulties in logging of broadleaved species with harvesters are due to the trees' morphology. Broadleaves are characterized by bigger curvatures, extensive crowns, and large diameter branches (Mederski et al 2018a). Harvester head also cuts assortments and their length is usually measured by a measuring wheel located in the central part of the head frame. Depending on the characteristics of the raw material, such as the curvature, the presence of bark, or icing – inaccuracies may occur when cutting the assortments.

Difficulties in cutting assortments from coniferous and broadleaved trees were the reason for undertaking research on the accuracy of cutting assortments from different parts of the trunk. At the stump, the occurrence of buttresses and flares can be expected. In the apical, heavily branched parts of the trees, there are branches as well as frequent curves. The best part of the tree in terms of the absence of defects is the middle part of the trunk, which was confirmed, among others, by the studies of Różański (1993) and Mederski et al. (2018).

A comparison of the accuracy of cutting was also studied in oak and alder stands, during the vegetation period and outside of it. It was shown that greater length accuracy was obtained during the growing season; moreover, alder assortments were characterised by better length accuracy compared to oak assortments (Karaszewski et al. 2017).

Karaszewski et al. (2016b) addressed the issue of the accuracy of delimbing alder wood in comparison with pine and spruce wood. The authors confirmed the best delimbing quality on the middle part of alder trunks and the middle part of spruce trunks, while the worst quality delimbing occurred at the top of the alder trunks. The studies of Kusiak and Śliwiński (2014) found that delimbing pine assortments with a chainsaw was more accurate than with a harvester. At the same time, the harvester was able to obtain a more accurate length of trunks and logs compared to motor-manual logging.

The accuracy of cutting assortments can be particularly important for selected methods of wood processing. Assortments that are too long may pose difficulties for the paper industry, while too short logs are undesirable, among others, in the production of pallets or for garden furniture (Bembenek et al. 2015).

One of the first papers in the literature describing the extent of utilizing timber trunk and assortment quality with the use of a harvester was published by Mederski (2013). The study showed that the harvester may encounter difficulties in processing and delimbing pine and birch assortments already in III age class tree stands, and especially in older, IV age class stands. Bearing in mind the results of the above-mentioned research, it was decided to analyze the effectiveness of logging timber with a harvester during early thinning in a 31-year-old pine stand. The objective of this research was to determine 1) the efficiency of trunk utilisation by a harvester , and 2) the quality of the assortments in terms of bucking accuracy and delimbing quality.

2. Material and methods

2.1. Study area

The research was carried out in a 31-year-old pine stand, in the Bobolice Forest District (Regional Directorate of State Forests in Szczecinek, Table 1).

Sample plots were designated along eight strip roads. The sample plots of 100 m^2 each (10×10 m) were located on both sides of the strip road, five areas on the left and five on the right side of each strip road. The last meter of the sample plot on the left was the first meter of the plot on the right (Fig.1).

The plots were consecutively numbered (a total of 80 plots), the corner trees were marked with a painted horizontal bar at eye level. The trees intended for thinning were also marked with paint, two diagonal strips at a height of approx. 1.5 m. The marks were visible from each of the neighboring roads. The measurements taken of the trees to be removed were:

1) DBH, twice crossed to the nearest 0.1 cm, the result was rounded up to 0.5 cm;

2) tree height with a HAGLOF EC II clinometer with an accuracy of 0.1 m, the result was recorded with an accuracy of 0.1 m.

2.2. The harvester used

The Vimek 404 T5 thinning harvester with a 4.6 m long Mowi 2046 crane (Table 2) was used for the treatment (Fig. 2). The harvester was equipped with a Keto Forst Silver head, with a maximum cutting diameter of 30 cm (Table 2).

For a 2.15 m wide harvester, roads with a width of approx. 3 m were prepared by removing one row of trees. The roads were 20 m apart (distance measured between the axes of the roads).

The Keto head, which allows trunks up to 25 cm in diameter to be delimbed at a speed of 4 m s^{-1}, was equipped with three cutting knives (Table 2).

Two types of assortments were made from the harvested trees: pulp wood and chip wood. In both cases, the expected length was 2.50 m. To obtain the expected length, the length in the harvester computer was set with an excess of 5 cm, i.e. 2.55 m with a deviation of ± 0.02 m.

Table 1. Stand characteristics, as for 1st January 2015

Compartment	Area [ha]	Stand layer	Share, species	Age [years]	DBH [cm]	Height [m]	Stock [m^{3}ha^{-1}]
108h	11.27	Main stand	90% Pine	31	13	11	137
			10% Birch	31	13	12	10
			sporadically Spruce	31			
			sporadically Larch	31			
		Shrub layer	Birch				
			Spruce				
			Juniperus				

DBH – diameter at breast height

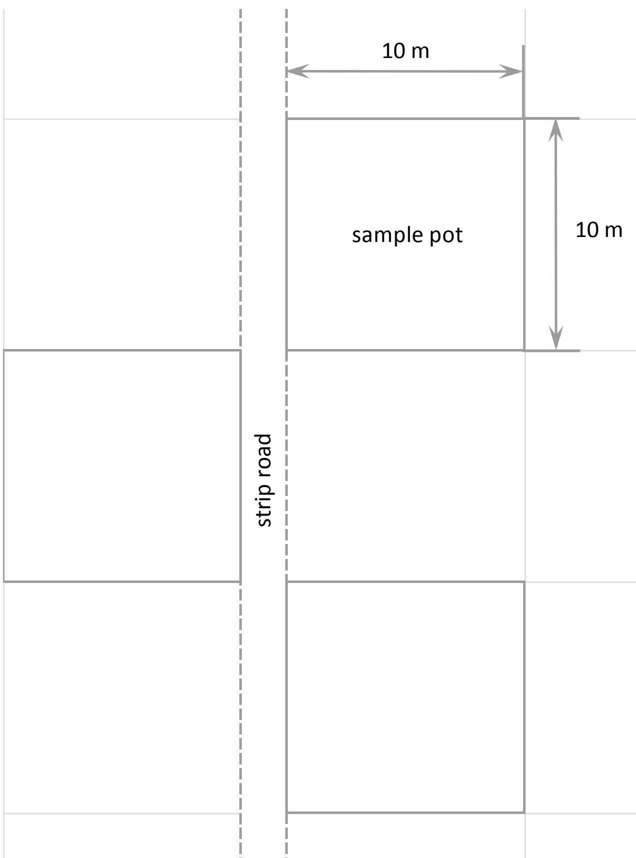


Figure 1. Layout of sample plots along strip road

Figure 2. Harvester Vimek 404 T5 during bucking of assortments

2.3. Utilization of the trunk for assortments

In order to determine how much of the trunk was used for the assortments, the number of pieces of logs made from one tree was recorded. The number of logs multiplied by the length (2.5 m) was the total length of the assortments obtained from one tree. In addition, on a sample of 70 trees, the upper diameters without bark (single horizontal measurement) on the last logs obtained from the highest, apical parts of the tree were measured.

Table 2. Technical data of Vimek 404 T5 harvester and harvester head Keto Fors Silver

Harvester Vimek 404 T5	
Engine	
Make, type	CAT 2.2 (T)
Number of cylinders	4
Maximum power	44.7 kW
Capacity	2216 cm^3
Crane	
Make, type	Mowi 2046
Length	4,6 m
Gear box	
Gear box drive	Hydraulic engine
Gear box transmission	Mechanical
Hydraulic system	
Pressure	220 bar
Flow	120 l min^{-1} maximum
Size	
Tires	405/70-24
Length	3350 mm
Width	2150 mm
Height of the cabin roof	2.8 m
Clearance	400 mm
Weight	4.1 t with head
Harvester head Keto Forst Silver	
Height without rotator	1050 mm
Height with rotator	1250 mm
Width (opened)	830 mm
Width (closed)	580 mm
Weight	297 kg
Maximal cutting diameter	300 mm
Maximal delimbing diameter	250 mm
Number of delimbing knives	3
Maximal working pressure	200 bar
Optimal oil flow	120 l min^{-1}
Length of chaisaw bar	14"
Type of feeding mechanism	drum with caterpilar
Feeding force	10 kN
Maximal tree weight	400 kg
Maximal feding speed	4 m s^{-1}

2.4. Bucking accuracy

In order to determine bucking accuracy, the trunk length from the bottom, middle and top parts of the trees was measured, 70 items from each zone. The logs from the middle zone of the tree were determined as one or several logs obtained from between the bottom and top parts of the trunk. The length was measured to an accuracy of 1 cm.

2.5. Delimbing quality

In order to determine the delimbing quality, the height of the knots (h) and their width (s) at the base were measured (Fig. 3).The height was determined as the distance from the lateral side to the highest point above the base of the knot. For measuring the height, the final part of the knot was not taken into account in the height measurement, because it was often long and very thin, and may have resulted in an uncertain correct height. The width was measured at the base of the knot, perpendicular to its axis and the axis of the trunk.

Height and width were measured to an accuracy of 1 mm. Knots with a base of less than 1 cm (in the bark) were not considered. All measured knots were divided into four height categories: 1) low: 0 – 10 mm; 2) medium: 11 – 30 mm; 3) high: 31 – 50 mm; 4) very high: >50 mm.

The method of measuring the height of knots after delimbing is not described in the standards. Due to the lack of unequivocal guidelines on measuring the height of a knot (e.g. whether to take into account the thin strip of wood and bark at the highest point of the knot after a branch was severed), a decision was made for the purpose of this study to measure the height of the knot as shown in Figure 2. At the same time, it was assumed that pulp wood and chip wood meet the conditions of having been properly prepared by the harvester if they were delimbed to a good or adequate degree.

In this study, a knot was defined as the remnant of a branch protruding out from the side of the log, according to the nomenclature used in the standard (PN-D-95000:2002).

Descriptive statistics were used in the data analyses. The variability of the characteristic depending on the examined factor was determined by the coefficient R^2. All calculations were made using Excel spreadsheets.

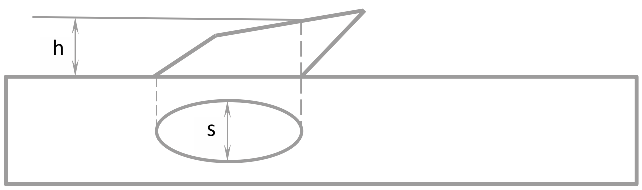


Figure 3. Knot feature measurements: h – height [mm], s – width [mm]

3. Results

3.1. Utilization of the trunk for assortments

The harvested trees had an average DBH of 11.6 cm and a height of 12.0 m, with the thickest trees at 25.0 cm (Table 3). An average of three to four logs with an average length of 8.45 m was obtained from one tree.

The length of the remaining tree tops amounted to an average of 3.58 m, or about 30% of the height of the tree. The total length of the obtained logs depended on the DBH of the tree (Fig. 4), but also on its height (Fig. 5). In the second case, this dependence was stronger (R^2=0.60).

The utilization of the trunk was also determined in the form of the upper diameter of the last log obtained from the highest part of the tree, which amounted to an average of 5.3 cm without bark (tab. 4).

3.2. Bucking accuracy

The majority (22%) of logs obtained at the length set by the harvester computer (2.55 m) were from the middle part of the trunks (fig. 6).

In general, 19% of the logs did not meet the condition of the expected length, i.e. they did not fall within the range of 2.50 to 2.57 m (fig. 6).The largest percentage of trunks of the expected length were obtained from the middle part of the trunks (87%), the least from the top part (74%). The assortments from the middle zone were characterized by the lowest variation in length (standard deviation of 0.05), the most varied lengths were obtained from the assortments of the top zone (standard deviation 0.11; tab. 4).

The average length of the middle logs (2.54 m) was the closest to the length set in the harvester computer (2.55 m).

3.3. Delimbing quality

The obtained assortments were generally well delimbed, and the average height of knots amounted to a little over 1 cm only on the delimbed logs (tab. 5).

The highest knots appeared on the bottom and top logs. The lowest knots were observed on the middle logs, about 25% lower than on the knots on the bottom logs. In general, the height of the knots was slightly dependent on their thickness, which was indicated by the low coefficient R^2=0.14. Over 70% of the knots did not exceed a height of 10 mm, and medium-sized knots constituted about 25% of all analyzed remains of branches (fig. 7).

Table 3. Parameters of harvested trees and obtained assortments, descriptive statistics

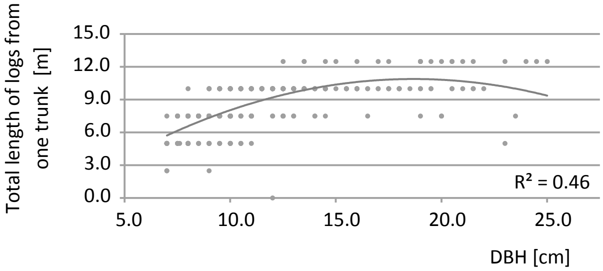
	DBH [cm]	Height [m]	Number of logs from one trunk	Total length of logs from one trunk [m]	Remaining tree top [m]
Mean	11.60	12.00	3.40	8.45	3.58
Median	10.50	12.10	3.00	7.50	3.50
Minimum	7.00	5.90	0.00	0.00	0.00
Maximum	25.00	17.80	5.00	12.50	8.40
Standard deviation	3.75	1.89	0.85	2.13	1.38
N	347	347	347	347	347

4. Discussion

4.1. Utilization of the trunk for assortments

The utilization of the trunk for assortments is a very important element of the efficiency of mechanized logging. Achieving an efficiency that guarantees a favorable economic result is very difficult in stands of younger age classes (Mederski et al. 2018b), in which operators' have little interest in cutting assortments from the thinnest trunks for the sake of high efficiency. At an average tree height of 12 m, the total length of the harvested yields reached an average of 8.45 m at an average mean top diameter of 5.3 cm without bark. This diameter is similar to the minimum top diameter for pulp wood of the PN-D-95018:1991 standard (withdrawn on August 1, 2014) or in the ordinances of the General Directorate of State Forests (Regulations 33 and 34), which assumes the production of medium-sized timber from a size of 5 cm without bark.

Difficulties in fully utilizing the usable stock were observed during the logging of pine and birch with a harvester (Mederski 2013). Using a Sampo Rosenlew harvester with a Keto 150 LD head to log pine trees aged 46 and 61 years resulted in an upper diameter with bark of 9.4 and 10.6 cm respectively (average values). For birch, these values were higher and amounted to 12.3 and 16.2 cm, respectively. In each of the analysed cases, the size of the upper diameter correlated with DBH, however, this dependence was weakest for the 46-year-old pines (correlation coefficient of 0.43). In other studies determining the effectiveness of using oak stock (61 years) obtained using a Ponsse Ergo harvester with a H7 head, the upper diameter with bark was 13.3 cm (mean value), and its size was also related to DBH (Mederski et al. 2018). In this study, the relationship between the top diameter and DBH was not determined because during harvesting, assortments from several trees were laid in one bunch and it was difficult to determine the tree from which a given top log assortment was made. At the same time, the upper diameter parameter for top log assortments was characterized by the smallest standard deviation (tab. 4), which suggests that regardless of diameter, the diameter of the upper part



Rycina 4. Relationship between total length of logs and DBH

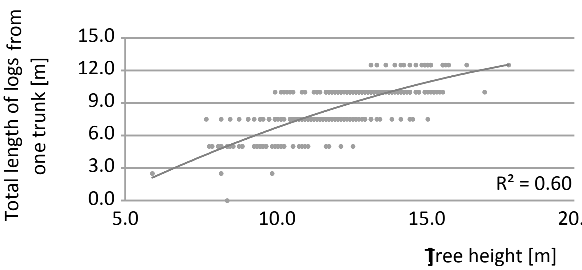


Figure 5. Relationship between total length of logs and tree height

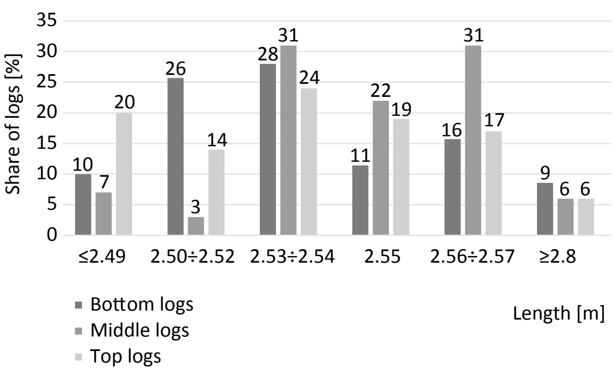


Figure 6. Histograms of lengths of bottom, middle and top logs

Table 4. Parameters of bottom, middle and top logs, descriptive statistics

	Bottom logs		Middle logs		Top logs	
	Length [m]	Top diameter [cm]	Length [m]	Top diameter [cm]	Length [m]	Top diameter [cm]
Mean	2.53	9.57	2.54	8.17	2.50	5.32
Median	2.53	9.10	2.55	7.60	2.54	4.90
Minimum	2.15	5.00	2.21	3.90	2.12	2.90
Maximum	2.97	21.10	2.60	18.80	2.60	15.40
Standard deviation	0.09	3.32	0.05	2.68	0.11	1.78
N	70	70	70	70	70	70

Table 5. Parameters of knots from bottom, middle and top logs, descriptive statistics

	Bottom logs		Middle logs		Top logs	
	Width [mm]	Height [mm]	Width [mm]	Height [mm]	Width [mm]	Height [mm]
Mean	20.41	10.40	19.45	7.53	17.78	9.73
Median	18.00	5.00	20.00	5.00	15.00	7.00
Minimum	10.00	0.00	10.00	0.00	10.00	0.00
Maximum	99.00	130.00	55.00	60.00	50.00	72.00
Standard deviation	11.68	15.69	7.63	8.79	7.53	10.19
N	287	287	452	452	459	459

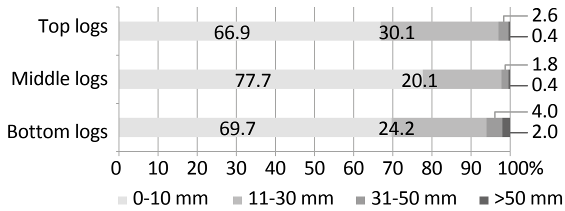


Figure 7. Share of knots with different heights on bottom, middle and top logs

of the tree was relatively constant. This parameter indicates that the Vimek 404 T5 Harvester with the Keto Forst Silver head performed very well in producing assortments of the top parts of 31-year-old pine. The factors that affected the good results of delimbing and bucking accuracy are mainly the thin branches (about 2 cm, tab. 5) and straight trunks observed during the study.

4.2. Bucking accuracy

The analysis of all logs showed that 81% fulfilled the condition of the expected length, from 2.50 to 2.57 m (fig. 6). The deviation of ±2 cm set by the operator should be considered as proper, the excess of 5 cm was also well chosen. The share of logs with lengths from 2.53 to 2.54 cm was significant: 28% from the bottom, 31% from the middle and 24% from the top (fig. 6). The bottom and middle logs did not exceed 2.62 cm in length. The exception was one log, 2.97 m long. This length was most likely due to the particular situation that hindered delimbing, and not from a measurement error.

In terms of chip wood, overly long logs only cause transport problems. In the analyzed case, the longest pieces were 2.60 m and can be considered acceptable.

In both cases, too short pulp and chip logs are a loss for the timber buyer when calculating volume. Volume measurement and calculation is based on a standard length – too short logs reduce the volume of the purchased raw material, and about 12% of all logs of the analyzed sample were too short. This may be the subject of a complaint from the buyer, which increases the costs of obtaining and preparing the raw material for sale. Nevertheless, shorter than expected assortments of medium-sized wood for general purposes will not disqualify it for further processing. These logs, after being prepared in drum debarker, can be chipped and designated for technological processing.

It is also worth noting that the errors in length measurement in bucking assortments occur not only when logging with a harvester, but also when bucking with a chainsaw. Analysis of the obtained lengths of deciduous assortments made using a chainsaw showed that with a tolerance of ±2 cm, deviations in the set length occurred in 30% of cases (Zinkevičius et al.2012) .

The close share of bottom and top assortments deviating from the required dimension contradicts the studies of Nieuwenhuis and Dooley (2006). These authors observed deviations from -5% to +7% in the case of cutting spruce longwood and shortwood, stating that the accuracy of length measurement is better for bottom longwood than for logs cut from the upper part of the stem. On the other hand, the lack of differences between the lengths of assortments made from the bottom and top part of the trunks were also confirmed by Mederski et al. (2008), when analyzing this feature for aspen shortwood and longwood.

As the cause of the measurement errors, Nieuwenhuis and Dooley (2006) indicated the particularly strong branching of the spruce, leaving snags behind after delimbing, as well as curvatures occurring at the top part of the stems. Even though the occurrence of top zone assortments deviating from the expected size can be explained by similar causes in the present study of 31-year-old pine, i.e. errors occurring due to branching, the causes of the low accuracy in the bottom zone are not conclusive.

The studies of Bembenek et al. (2014) on the accuracy of producing birch and aspen assortments confirmed that the thicker assortments (over 14 cm at the upper end without bark) had a more accurate length compared to thinner ones (less than 14 cm at the upper end without bark).

In our study, the maximum upper log diameter did not exceed 21 cm without bark, and the average ranged from 5.3

cm (top logs) to 9.5 cm (bottom logs). It should be remembered that bucking accuracy is also influenced by the fit of the head to the parameters of the tree being cut and the work technique, which affects the accuracy of the length measurement by the operation of the measuring wheel.

4.3. Delimbing quality

According to the standards (PN-D-95018:1991 and PN-D-95019:1991), pulp and chip wood should be properly delimbed from a very good to an adequate degree. Very good delimbing means that the branches should be removed evenly with the lateral surface of the wood. Adequate quality means that knots can be up to 5 cm long, occasionally longer. At the same time, the regulations in force (Regulation 2012a, b) specify that pulp wood wood obtained with a harvester can be delimbed to a good degree (permissible knots up to 3 cm long, occasionally longer). The larger share of higher (up to 30 mm) snags in top zone assortments resulted from the difficulty of delimbing the flexible branches from the top parts of the trunk. At the same time, the highest knots (over 30 mm) appeared more frequently on the bottom zone assortment, because the thickest branches were present in the lower part of the trunk (tab. 5).

Pulp wood wood obtained from the bottom zone and/or partly from the middle zone of the trunk had up to 95% of its knots up to 3 cm (from the bottom zone) or 98% (from the middle zone) (fig. 7). If you take the remaining 2 to 5% as an occasional occurrence – the obtained assortments met the requirements of the applicable regulations (although it should be remembered that the PN-D-95000:2002 standard describes the length, not the height of the knots). The decided majority of top zone assortments were chip wood assortments, in which knots up to 5 cm long are allowed. In the present study, over 99% of snags did not exceed 5 cm in height in the top zone assortments.

Usually, the height of the knots after delimbing depends not only on the thickness of the branches, but also on the species. Mederski (2013) found that the height of the knots after delimbing assortments of older pine and birch trees (IV age class) was greater than on assortments of younger trees (III age class). At the same time, birches exhibited greater differences.

5. Conclusions

The utilization of the trunk for assortments during logging with a Vimek 404 T5 harvester and Keto Forst Silver head proved to be very effective, for both pulp wood and chip wood. On average, about 70% of the height of the tree was used, and the average upper diameter without bark was 5.3 cm. At the same time, assortments were made, whose smallest upper diameter without bark was 2.9 cm, which confirms the possibility having the Vimek 404 T5 harvester producing chip wood.

The vast majority (81%) of all logs were of the expected length. The largest number of undersized logs among the top zone assortments suggests that the need to produce chip wood should be verified, with the simultaneous allocation of the entire branched top part of the tree to chipping.

The delimbing quality was similar in all parts of the trunk. The largest share of the lowest snags was found on assortments made from the middle zone of the trunk. At the same time, the highest percentage of the highest snags was observed in the bottom zone assortment, although similar heights occurred on top zone logs. In general, the delimbing quality met the applicable regulations applied in the State Forests.

The use of the Vimek 404 T5 harvester with the Keto Forst Silver head in the 31-year-old pine stand made it possible to fully utilise the trunk for the assortments, and simultaneously obtain satisfactory parameters of length and delimbing quality.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgements and source of funding

The research presented in this work was partially financed by the Ministry of Science and Higher Education as part of its support for the Research Potential of the Forest Utilization Department for 2015.

References

Bembenek M., Mederski P. S., Karaszewski Z., Lacka A., Grzywinski W., Wegiel A., Erler J. 2015. Length accuracy of logs from birch and aspen harvested in thinning operations. *Turkish Journal of Agriculture and Forestry* 39: 845–850. DOI 10.3906/tar-1406-39.

Karaszewski Z., Bembenek M., Mederski P.S., Rosińska M., Tsioras P.A. 2017. Bucking accuracy of alder and oak harvested in coppice stands during and after growing season. *Annals of Warsaw University of Life Sciences – SGGW Forestry and Wood Technology* 100: 66–71.

Karaszewski Z., Łacka A., Bembenek M., Mederski P.S., 2016a. Rozmiar uszkodzeń i strat olszowego drewna łuszczarskiego pozyskanego harwesterem Valmet 911.4 z *głowicą 360.2. Sylwan* 160(12): 1002–1009. DOI 10.26202/sylwan.2016060.

Karaszewski Z., Mederski P.S., Noskowiak A., Rosińska M., Łacka A., Bembenek M. 2016b. Delimbing quality and bucking accuracy of alder, pine and spruce logs harvested by Valmet 911.4. *Annals of Warsaw University of Life Sciences – SGGW Forestry and Wood Technology* 95: 56–61.

Kusiak W., Śliwiński K. 2014. Ocena jakości wyrabianych sortymentów drzewnych w technologii ręczno-maszynowej i maszynowej. *Studia i materiały CEPL w Rogowie* 39: 67–76.

Leśnictwo 2014. Główny Urząd Statystyczny, Warszawa.

Mederski P.S. 2013. Możliwości zastosowania harwestera do pozyskiwania drewna w mieszanych drzewostanach brzozowo-sosnowych. Wydawnictwo UP w Poznaniu, 109 s. ISBN 978-83-7160-707-5.

Mederski P.S., Bembenek M., Karaszewski Z., Pilarek Z., Łacka A. 2018a. Investigation of Log Length Accuracy and Harvester Efficiency in Processing of Oak Trees. *Croatian Journal of Forest Engineering* 39(2): 173–181.

Mederski P.S., Karaszewski Z., Rosińska M., Bembenek M. 2016. Dynamika zmian liczby harwesterów w Polsce oraz czynniki determinujące ich występowanie. *Sylwan* 160(10): 795–804. DOI 10.26202/sylwan.2016030.

Mederski P.S., Venanzi R., Bembenek M., Karaszewski Z., Rosińska M., Pilarek Z., Luchenti I., Surus M. 2018b. Designing Thinning Operations in 2nd Age Class Pine Stands – Economic and Environmental Implications. *Forests* 9(6): 335. DOI 10.3390/f9060335.

Moskalik T., Borz S.A., Dvořák J., Ferencik M., Glushkov S., Muiste P., Lazdiņš A., Styranivsky O. 2017. Timber harvesting methods in Eastern European countries: A review. *Croatian Journal of Forest Engineering* 38(2): 231–241.

Nieuwenhuis M., Dooley T. 2006. The effect of calibration on the accuracy of harvester measurements. *International Journal of Forest Engineering* 17(2): 25–33.

PN-D-95018:1991. 1991. Surowiec drzewny. Drewno średniowymiarowe. Wspólne wymagania i badania. Polski Komitet Normalizacyjny.

PN-D-95019:1991. 1991. Surowiec drzewny. Drewno małowymiarowe. Wspólne wymagania i badania. Polski Komitet Normalizacyjny.

PN-D-95000:2002. 2002. Surowiec drzewny – Pomiar, obliczanie miąższości i cechowanie. Polski Komitet Normalizacyjny.

Różański H. 1993. Wydajność i dokładność wyróbki drewna harwesterem wysięgnikowym Lokomo FMG 990/756. *Przegląd Technik Rolniczej i Leśnej* 10: 18–19.

Stańczykiewicz A., Sowa J.M., Szewczyk G. 2011. Uszkodzenia drzew i odnowienia w wyniku ręczno−maszynowego pozyskania drewna z wykorzystaniem urządzeń agregowanych z ciągnikami rolniczymi. *Sylwan* 155(2): 129−137. DOI 10.26202/sylwan.2009233.

Stańczykiewicz A., Sowa J.M., Leszczyński K., Kulak D., Szewczyk G. 2015. Uszkodzenia drzew i odnowienia w wyniku pozyskania drewna z użyciem urządzeń agregowanych z ciągnikami rolniczymi w trzebieżowych drzewostanach świerkowych. *Sylwan* 159(3):201–210, 2015. DOI 10.26202/sylwan.2014070.

Zarządzenie 2012a. Zarządzenie nr 33 Dyrektora generalnego Lasów Państwowych z dnia 17 kwietnia 2012 roku w sprawie wprowadzenia Ramowych warunków technicznych na drewno średniowymiarowe ogólnego przeznaczenia – S2AP. [Regulation 2012a. Regulation No. 33 of the Director General of State Forests of 17 April 2012 on the introduction of the Framework technical conditions for medium-sized timber for general purposes – S2AP.]

Zarządzenie 2012b. Zarządzenie nr 34 Dyrektora generalnego Lasów Państwowych z dnia 17 kwietnia 2012 roku w sprawie wprowadzenia Ramowych warunków technicznych na drewno średniowymiarowe użytkowe – S2B. [Regulation 2012b. Regulation No. 34 of the Director General of State Forests of 17 April 2012 on the introduction of Framework technical conditions for medium-sized commercial timber – S2B.]

Zinkevičius R., Steponavičius D., Vitunskas D., Činga G. 2012. Comparison of harvester and motor-manual logging in intermediate cuttings of deciduous stands. *Turkish Journal of Agriculture and Forestry* 36: 591–600. DOI 10.3906/tar-1103-46.

Żabierek R., Wojtkowiak R. 2013. Liczba harwesterów i forwarderów w Polsce. *Drwal* 9: 22–23.

Authors' contribution

PSM, MB, ZK – study concept and structure of the scientific article; PSM, KW – statistical analysis; PSM, ZK, MB – literature review; PSM, KW, MB, ZK, MB, KN – manuscript writing, verification of results and corrections.