DOI: 10.2478/frp-2019-0016
Available online: www.lesne-prace-badawcze.pl

Leśne Prace Badawcze / *Forest Research Papers*
Wrzesień / September 2019, Vol. 80 (3): 181–187

ORIGINAL RESEARCH ARTICLE

e-ISSN 2082-8926

Determination of conversion factors for pine and spruce logs in stacks

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Abstract. The aim of this article was to determine the conversion factors for stacked pine and spruce logs with a length of 3–6 m. To this end, we measured stacks and their logs of a total of 3322.12 steres of pine logs and 1468.46 steres of spruce logs. The conversion factors obtained in this work for pine logs of varying lengths negatively correlate with log length. However, statistically significant ($p<0.05$) differences were only observed between the longest logs as well as logs of 3 and 4 m in length. This may be due to various factors (mainly curvature, the presence of buttresses on butt logs and taper) influencing the stacking process of logs of increasing length. For logs with a length of 3, 4 and 5 m, the average value of the conversion factor increased with the log thickness class, although this dependence was not statistically significant. In the case of spruce raw material, the obtained conversion factors are similar to the values determined in previous studies. There was no significant correlation between the length of the log and its average diameter. A prerequisite for using conversion factors for large-sized logs is accurate stacking, where special attention should be paid to the parallel stacking of individual logs, aligning their front and back sides to be flush and forming the stack so that its top plane is parallel to the ground.

Keywords: conversion factor, wood measurements, measurements of wood in stacks, large-sized logs

1. Introduction

In Poland, the volume of harvested pine and spruce logs is most often determined after logging, at the export route, based on the measurement of individual logs, less often by measuring irregular stacks, with the use of conversion factors (Regulation No. 35 ...; Regulation No. 74 ...).

The measurement of single logs is performed for wood stacked for export for one recipient. The condition for such a measurement is to arrange the logs in an orderlymanner, with the top ends to one side. Their volumeis taken from appropriate tables, based on the length and upper diameter under bark.

The measurement of stacked timber volume is performed by measuring the dimensions of the stacks and using a conversion factor appropriate for the type of wood and its length.Conversion factors determine the ratio of raw material volume in a stack under bark (in m^3) to the dimensions of the stack (m[p]) (PN-D-95000).

Photo-optical measurements have also been introduced (Heindl, Stuhlmann 2016; Pachuta, Chojnacki 2018; Pásztory et al. 2018), using a photo of one of the sides of the stack to calculate the volume of the wood it contains. Therefore,in the case of logs, it is recommended to alternate them when stacking (Jodłowski, Sarzyński 2018) or to use formulas allowing the volume to be calculated based on the upper diameter of the logs.

In some countries, the wood measurements in the forest are estimated and the actual measurement occurs in the wood processing plant using legalised measuring devices. These types of devices include lasers, high-resolution digital cameras or X-rays (Wnorowska 2009; Yuntao, Schajer 2014; Gergeľ et al. 2019).

In Poland, research on determining conversion factors has been conducted at the Forest Research Institute from the 1950s (Cichowski 1955) to the present (Witkowska, Jodłowski 2018). However, this researchmainly concerned medium-sized wood. Conversion factors were developed for woodwith lengths from1.00 to 7.00 m. Research onconversion factors for logs, required, amongst others, by changes in wood harvesting and processing technologies, was undertaken in Poland for the first time in 2003 on behalf of the Directorate General of State Fo-

Received: 3.07.2019 r., accepted after revision: 28.08.2019 r.

rests (Witkowska 2003a, b). The research mainly concentrated on pine and spruce raw material of the 1st and partly 2nd thickness classes with lengths of 2.45, 3.00, 4.00 and 5.00 m (only pine logs). In the first case (Witkowska 2000a), 483 m^3 ofpine and 131 $m^3$of spruce raw material were tested, whilst 1257 and 225 m^3, respectively,were tested in the second case (Witkowska 2003b) (Table 1). Owing to difficulties with the availability of raw timber, most of the measurements were performed in forwarding depots, and therefore, wood piles were not typically encountered there. The research had the character of a short-term expert report, which practically precluded the measurement of a larger amount of raw material. More than 90% of the raw material, as expected by the client, was in the first thickness class. Hence, there is a need to expand the research and conduct it under field conditions.

Table 1. Average conversion factors for pine and spruce medium-sized wood, under bark

Wood species	Length [m]	According to a study	
		Witkowska 2003a	Witkowska 2003b
Pine	2.45	0.580	0.580
	3.00	0.571	0.610
	4.00	0.584	0.565
	5.00	0.548	-
Spruce	3.00	0.664	0.670
	4.00	0.671	0.675

2. Material and research methods

The research material, collected in 2008–2009, consists of measurement data from regional directorates of State Forests in Białystok, Katowice, Toruń and Zielona Góra. The study covered large-sized wood with lengths from 3 to 6 m. Obtaining the volume of the raw material was performed by measuringthe stacksand individual pieces (logs) comprising the stacks. Stack volume measurement ispresented in Figure 1.

Figure 1. Elements of irregular stack measurement *(h_0–h_n – height, l – stack length, s – stack width)* (Witkowska, Jodłowski 2018)

Logs of equal length were mechanically placed on supports using forwarders, with thinner ends in one direction. The log ends at the front of the stack were flushedso that they were positioned as perpendicular to the ground as possible. Carelessly arranged stacks, with large visible gaps, crossed logs, and misaligned front-facing ends were not selected for the study.

The length (*l*), width (*s*) and height (*h*) of the stack were measured using a tape and measuring stick with an accuracy of 1 cm.The nominal length of the wood was taken as the length of the stack. The width of the stack was measured along the bottom edge on both sides of the stack. Height measurements were madeevery 1 m on each side of the stack. The height of the supports was not included in this measurement.

When measuring the fronts of wood stacks, the so-called ‘zero measurement’ of stack height was used (Witkowska, Jodłowski 2018). The inclusion of this measureallowed for a more accurate calculation of the average height of the stack. The previous method ofdetermining stackheight by starting height measurements 1 or 2 m from the beginning of the stack was appropriate only for regular stacks; for irregular stacks, it overstated their average height, which resulted in an increase in their volume. During the measurements, we made sure that the height at the ‘zero metre’ (h_0) contained at least two logs. Width was measured along the bottom edge on both sides of the stack.

The surface area was calculated for the front and back of each stack, its elements beingthe arithmetic mean of stack height and width. The arithmetic mean ofhalf of the surfaces of the front and back of the stack multiplied by stack length constituted its volume. It was expressed by the formula:

$$V = l \times [(h_0' + h_1' + \ldots + h_n') \times s'/(n'+1) + \\ + (h_0'' + h_1'' + \ldots + h_n'') \times s''/(n'' + 1)]/2$$

where

V is the stack volume (m (p)),

l is the stack length (logs) (m),

s is the stack width (m),

h is the stack height (m),

$n+1$ is the number of measurements.

The volume of individual logs was calculated based on the mid-diameter under bark and length of the log.To this end, the diameter ofeach log was measured at both ends. Measurements were made with an accuracy of 1 mm. The results of these measurements were used to calculatethe average taper for each stack resulting from measuring all the logs, which served as the basis for calculating the mid-diameters of individual logs. On the basis of the mid-diameters of the logs, rounded down, their volume was calculated. The simplified formula for log volume (m^3) was

$$V = \pi \times l \times \frac{[2d_g + (l \times z)]^2}{160000}$$

where
V is the volume of the logs (m^3),
L is the log length (m),
d_g is the diameter of the thinner (top) end under bark (cm),
z is the taper (cm/m).

The percentage share of raw material in the first, second and third thickness classes (PN-D-95000:2002) was also calculated for each stack. Simplified classes of log thickness based on the upper diameter were adopted and are presented in Table 2 (Regulation No. 74 ...).

In order to characterise and compare the conversion factors for individual log lengths, weighted averages, standard deviations (SDs), standard errors of the mean (SEs) and coefficients of variation (CVs) were calculated.

The one-way analysis of variance was used to examine the variation of the conversion factor depending on the length of the log, and homogeneous groups were distinguished using the Tukey HSD test.

The relationships between the size of the conversion factors and the average log diameter for individual log lengths were tested using the Spearman rank correlation.

The effect of log thickness class on the value of the conversion factor was analysed using the Kruskal–Wallis H test.

The calculations were made using the Statistica 8 statistical package (StatSoft 2006).

3. Research results and discussion

3.1. Large-sized pine wood

The raw material was measured in seven forest districts: Dąbrowa, Gidle, Brzóska, Gubin, Krzystkowice, Świebodzin and Maskulińskie. A total of 3312.12 m^3 [p] of pine logs (61 stacks) were measured, which included 588.07 m^3 [p] at 3 m in length (14 stacks), 787.87 m^3 [p] at 4 m (16 stacks), 582.43 m^3 [p] at 5 m (10 stacks) and 1353.75 m^3 [p]at 6 m (21 stacks). The logs were cut using a harvester. The research results are presented in Table 3.

The values of the conversion factors for individual log lengths, depending on their average diameter, are presented in Figures 2, 4, 6 and 8.

The pine raw material was varied –close to 50% of the logs (1636 m^3 [p]) belonged to the first thickness class. As a result, the dependence of the conversion factor on the share of thickness classes was examined. It was assumed that categorising a stack to a given thickness class was determined by the volume share of the logs in a particular class exceeding 50%. This dependence is illustrated in Figures 3, 5, 7 and 9.

Table 2. Thickness classes

Top diameter under bark [cm]	Thickness class
14–22	1K
23–32	2K
≥33	3K

Table 3. Research results for pine logs

Length [m]	Wighted mean conversion factor (mean ± SE)	Coefficient of variation (CV), [%]
3	0.634±0.011	6,4
4	0.629±0.008	4,7
5	0.610±0.011	5,8
6	0.574±0.007	5,7

Table 3 shows that the conversion factor decreases with the length of the log. The statistical analysis showed the effect of log length on its value; however, statistically significant (p<0.05) differences were observed only between 3- and-6 m logs and 4- and 6-m logs.

Studying the dependence of the conversion factor on average diameter, it was found that it was statistically significant (p<0.05) only for 3- and 4-m long logs, with p=0.003 and p=0.027, respectively.

The average value of the conversion factor for 3-, 4- and 5-m long logs increases with the thickness class of the logs (Figs. 3, 5 and 7), although this relationship was not statistically significant (p-value at 0.295, 0.061 and 0.088 respectively). This relationship was not observed for 6-m long logs.

The generally decreasing average value of the conversion factor with increasing log length may be affected by the curvature of individual pieces. The technical conditions (Regulation No. 74 ...) for pine wood logs allow a curvature in quality classes B and C (determined according to the conversion factor) of 1.5 and 2cm/m, respectively. It accumulates in the case of one -sided curvature on longer pieces,which contributes to the formation of larger gaps in the stack. It is more difficult to achieve better accuracy in positioning longer log lengths.

The values of the conversion factors obtained in this study are higher than those previously calculated (Witkowska 2003a,b). The thickness structure of the measured raw material contributed to this– the raw material of the logs being measured at that time mainly belonged to the first thickness class. In 2009, the raw material was more diverse – the share of higher thickness classes (second and third) was much greater, as it accounted for more than 50% of the

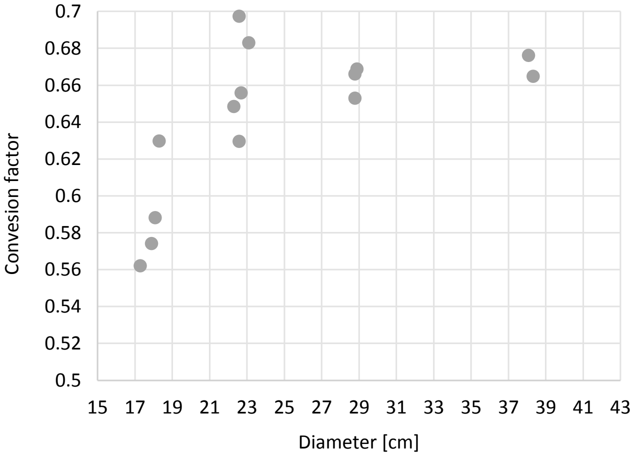

Figure 2. Dependency of the conversion factor on the mean pine log diameter with the length of 3 m

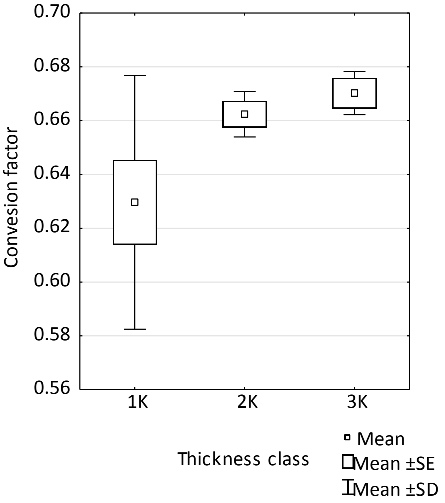

Figure 3. Dependency of the conversion factor on the share of thickness classes for 3 m pine logs

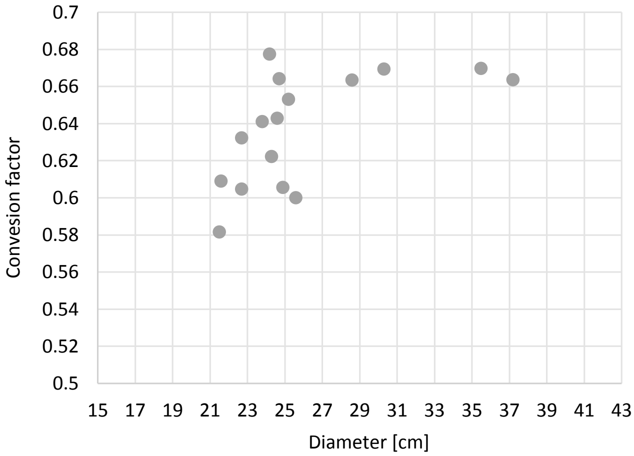

Figure 4. Dependency of the conversion factor on the mean pine log diameter with the length of 4 m

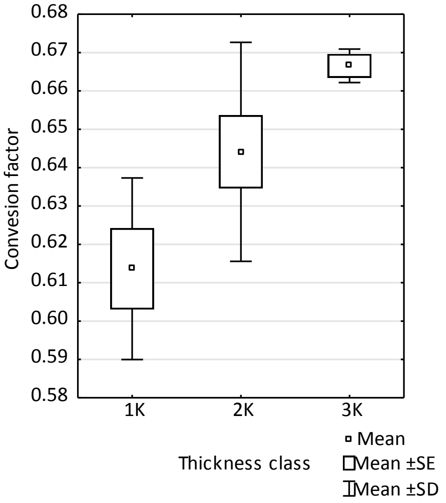

Figure 5. Dependency of the conversion factor on the share of thickness classes for 4 m pine logs

total volume of the raw material. In both cases, however, there is a noticeable tendency for the value of the conversion factor to decrease as the log length increases.

3.2. Large-sized spruce wood

Wood from five forest districts, Bielsko, Jeleśnia, Prudnik, Ujsoły and Węgierska Górka, was studied. A total of 1468.46 m^3 [p] of spruce logs (45 stacks) were measured, including 285.54 m^3 [p] at 3 m in length (19 stacks), 274.27 m^3 [p] at 4 m (11 stacks), 417.20 m^3 [p] at 5 m (8 stacks) and 491.45 m^3 [p] at 6 m (7 stacks). The thickness of the spruce raw material was much less diversified compared to the pine raw material. The logs belonged almost exclusively to the first thickness class– only one stack in which the share of second thickness class logs exceeded 50% was noted. Some logs were obtained with a chainsaw. The impact of the harvesting method on the size of the conversion factor was not studied.

The study results are summarized in Table 4 and Figures 10–13.Owing to the small variation in the thickness of the spruce raw material, the dependence of the conversion factor on the share of volume thickness classes was not analysed.

The average value of the conversion factor for spruce logs generally decreased with the length of the logs; however, the

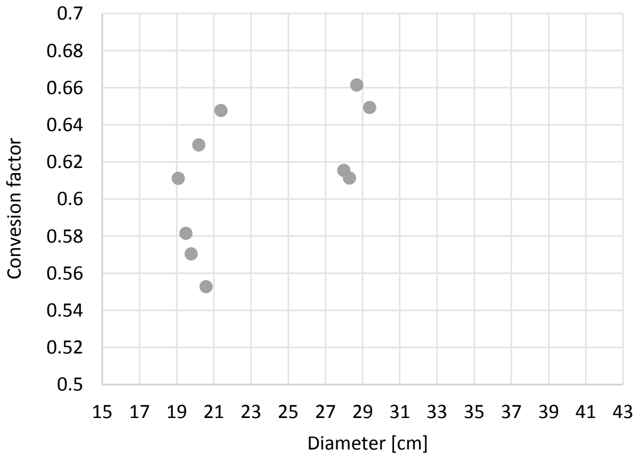

Figure 6. Dependency of the conversion factor on the mean pine log diameter with the length of 5 m

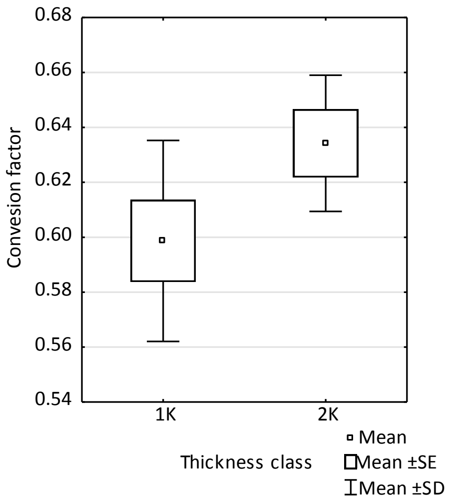

Figure 7. Dependency of the conversion factor on the share of thickness classes for 5 m pine logs

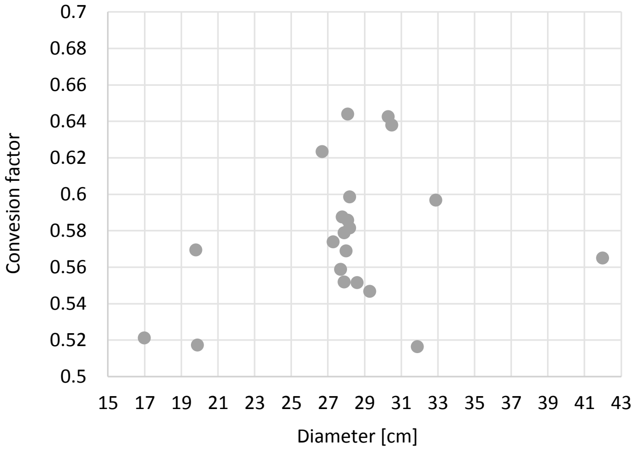

Figure 8. Dependency of the conversion factor on the mean pine log diameter with the length of 6 m

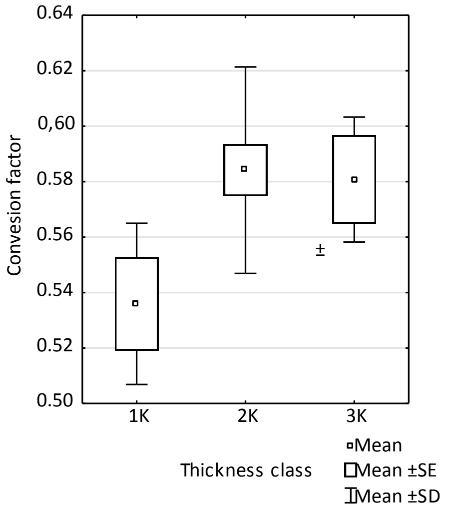

Figure 9. Dependency of the conversion factor on the share of thickness classes for 6 m pine logs

analysis using the Tukey HSD test did not show any significance (*p*<0.05) of the effect of log length on its value. There was also no significant relationship between the conversion factor and the average diameter of individual log lengths. This may have been caused by the small variation in the thickness of the sample as well as the small (compared to the pine) amount of curvature and taper of the spruce logs and the constant thickness of bark along the stem.

Similar values of conversion factors were also obtained in previous studies (Witkowska 2003 a,b). This is due to both the lack of a significant impact of log length on the value of the factor as well as the similar thickness structure of the raw material measured in 2003 and 2009.

4. Summary

The conversion factors obtained in this article for pine logs of various lengths indicate a decrease in the value of the conversion factor with increasing log length. This relationship is visible, althoughnot statistically significant in every case. This may be due to the overlapping influence of various factors (mainly curvature, presence of buttresses on butt logs, taper) on the degree to which the stack is compacted as the length of the logs increases.

For3-, 4- and 5-m long logs, the average value of the conversion factor increases with the log thickness class. This tendency is noticeable but not statistically significant. This relationship does not occur for 6-m long raw material.

Table 4. Research results for spruce logs

Length [m]	Wighted mean conversion factor (mean ± SE)	Coefficient of variation (CV) [%]
3	0.669±0.010	6,5
4	0.637±0.012	6,0
5	0.635±0.022	9,6
6	0.656±0.014	5,9

In the case of spruce raw material, the obtained values of the conversion factors are similar in both previous studies as in the current one. Also, they were found to have nosignificant dependence on the length of the log and its average diameter. This refers to spruce raw material at lengths of 3, 4 and 5 m. Adopting a conversion factor for 6-m long raw material is problematic. Using a conversion factor for 6-m long logs is not recommended because of the low demand for this type of wood and the possibility of making a larger error resulting from the lack of a visible dependence of the conversion factor on the average diameter of the logs.

A basic condition for using conversion factors for large -sized logs is careful stacking, paying particular attention to

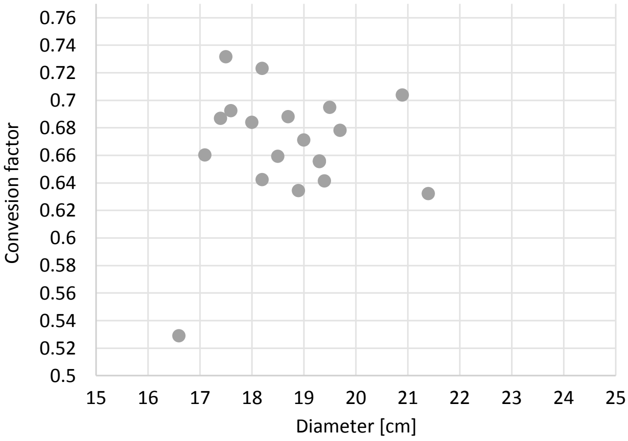

Figure 10. Dependency of the conversion factor on the mean spruce log diameter with the length of 3 m

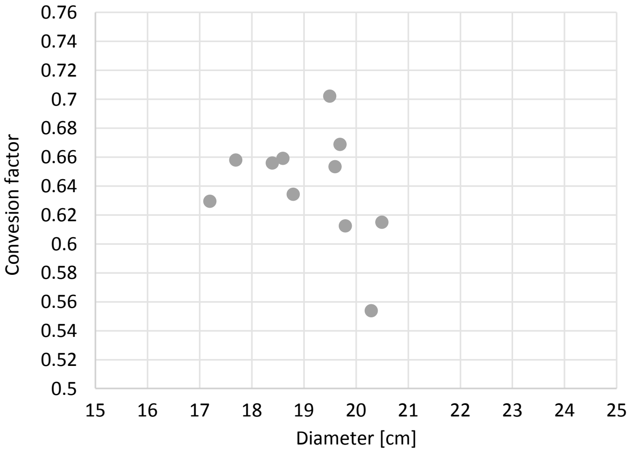

Figure 11. Dependency of the conversion factor on the mean spruce log diameter with the length of 4 m

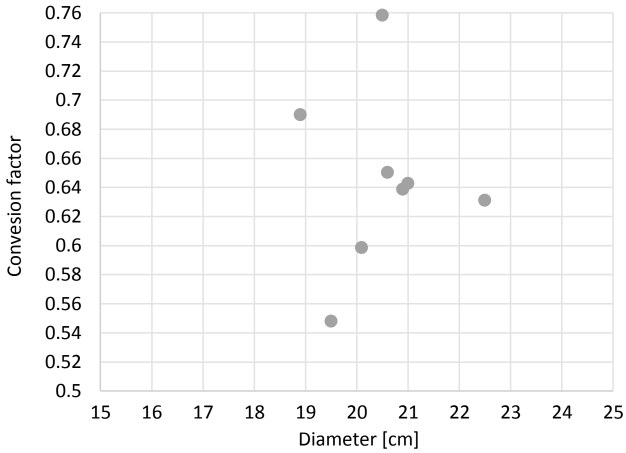

Figure 12. Dependency of the conversion factor on the mean spruce log diameter with the length of 5 m

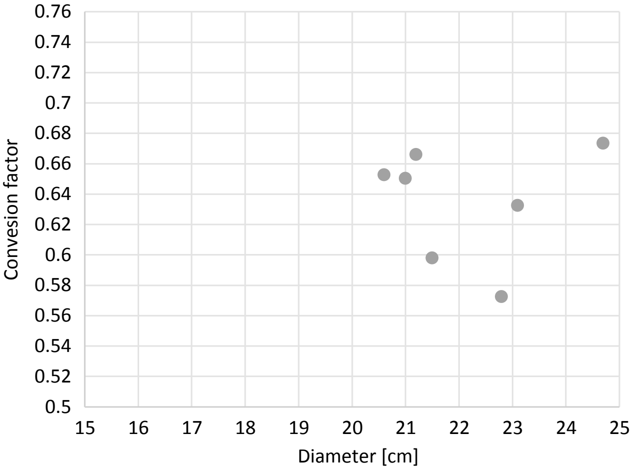

Figure 13. Dependency of the conversion factor on the mean spruce log diameter with the length of 6 m

- making both the front and back sides of the stack accessible for measurements,
- arranging individual logs in parallel and aligning the front and back sides of the stack so that they are flush,
- forming the stack so that its top plane is parallel to the ground – the front and back sides of the stack should have a trapezoidal shape – which will allow errors to be eliminated made when measuring height.

Conflict of interest

The authors declare the lack of potential conflicts of interest.

Acknowledgements and sources of funding

The research was conducted as a part of a research project entitled 'Określenie współczynników zamiennych dla wybranych długości drewna sosnowego i świerkowego wielkowymiarowego w kłodach oraz średniowymiarowego' [Determination of conversion factors for selected lengths of large- and medium-sized pine and spruce logs] commissioned by the General Directorate of State Forests.

The authors would like to thank the employees of the organisational units of State Forests where the research was conducted – the Regional Directorates of State Forests in Białystok, Katowice, Toruń and Zielona Góra as well as the Forest Districts of Bielsko, Brzózka, Dąbrowa, Gidle, Gubin, Jeleśnia, Krzystkowice, Maskulińskie, Prudnik, Świebodzin, Ujsoły and Węgierska Górka.

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Zarządzenie nr 35 Dyrektora Generalnego Lasów Państwowych z dnia 27 czerwca 2019 w sprawie wprowadzenia „Tymczasowych warunków technicznych na drewno iglaste kłodowane (WK) mierzone w stosach łączonych" http://drewno.zilp.lasy.gov.pl/drewno [3.07.2019].

Zarządzenie nr 74 Dyrektora Generalnego Lasów Państwowych z dnia 27 września 2013 w sprawie odbioru i obrotu drewna iglastego wyrabianego w kłodach w jednostkach organizacyjnych Lasów Państwowych http://drewno.zilp.lasy.gov.pl/drewno/Normy [3.07.2019].

Authors' contribution

J.W. – conducting the research, concept of the manuscript, literature review, data analysis, writing and proofreading; K.J. – conducting the research, literature review, data analysis, statistical calculations, proofreading, preparing the final version of the publication.

Translated by: Barbara Przybylska