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COMPARISON OF THE ACCURACY OF METHODS FOR CALCULATING THE VOLUME OF STANDING EUROPEAN BEECH TREES

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Abstract

The paper presents results of the analysis of the accuracy of calculating the volume of standing trees, calculated according to the method used in forestry practice, based on the principle of full calipering of all marked trees with the following calculation of mean height and standing volume according to the method of uniform volume curves. This volume was compared with the exact method for calculating the volume of actual removals including small wood in the beech stands of Little Carpathians in the territory of Lesy Slovenskej republiky, š.p. (Forests of the Slovak Republic, State Enterprise), branch establishment in Smolenice. The values of marked felling (standing trees) and the values of removals including logging residues left on the site will be compared and the difference expressed in percent. The difference between the values in percent is fitted with the accuracy of calculated standing volume (marked logging) established by the author of the method for calculating uniform volume curves, i.e. Halaj. A model curve is chosen by means of the directly detected value of mean stand quantity (mean height, mean diameter, age, site class etc.). The system of uniform volume curves links up with these quantities and gives volumes of individual trees for all diameter classes and corresponding heights. The method of uniform volume curves is used in Slovakia to calculate the volume of marked logging. Results of the analysis show that the volume of standing trees calculated according to the method of uniform volume curves is in reality underestimated by about 5% as compared with the actual volume of processed wood mass including logging residues left on the site. Thus, the calculation inaccuracy in forestry practice is exceeded by the above mentioned 5% as compared with the permitted deviation established through the method of uniform volume curves. Solution of this problem is a proposal submitted to the National Forest Centre in Zvolen for the elaboration of volume tables for the new ecotype of European beech.

Keywords: cubing tables, logging, volume of marked felling, calculation accuracy

INTRODUCTION

Effective procedures enabling the determination of accuracies of volumes of a standing stem, of individual standing assortments with acceptable accuracy, belong among the basic dendrometric tasks (Šmelko, 2007). In the history of forestry research, hundreds of studies have been devoted to the laws concerning the stem form and the use of wood mass, which resulted in the creation of a high number of tools in the form of tables, equations, methodological procedures for determining tree volume and standing volume, including wood assortment (Assman, 1968). Various methodological procedures allow achieving various accuracy of the detected quantity and their laboriousness and financial demands of the implementation differ as well (Šmelko, 2007). In general, higher accuracy requires higher financial costs (Rahman, Khanam and Pelkonen, 2017), but this higher accuracy is usually required at higher economic values of the assessed stands (Schweier, Molina-Herrera and Ghirardo, 2016), for example if valuable assortments are present or volume levels reach thousands of m^3 (Aravanopoulos, 2016).

The standing volume or the volume of standing trees is the volume of all trees forming a stand. Knowing its total quantity and its breakdown by tree species, diameters and possibly also quality classes (Klvač and Delvin, 2013) is necessary for the assessment of management results, control of forest production capacity, planning of economic measures, derivation of logging possibilities and for conceptual studies of forestry management development (Stupak *et al.*, 2007) as well as wood processing industry (Halaj, 1955; Šmelko, 2007). It is surveyed periodically in all stands when drawing up a forest management plan, usually once in every 10 years.

The choice of method is influenced primarily by the purpose and required accuracy of the standing volume determination (Ranius *et al.*, 2018). In Slovakia, direct methods and estimation methods are used for practical purposes of forest management planning (Snall *et al.*, 2017), and the underlying principle is that the standing volume should be most accurately determined in rather old stands and stands significant in terms of value and economy. Accordingly, in compliance with the applicable legislation on forest management planning, the selection of detection method differs depending on the forests categories, economic form of forests, management method, actual condition of forest stand (stand diversity), required accuracy and economic efficiency (Halaj, 1955).

This paper deals with the accuracy issues of calculating the volume of standing trees in forestry practice. In Slovakia, the method applied most commonly is the method of uniform volume curves. The accuracy of the calculation in forestry practice is expressed as a percentage difference between the volume of marked logging versus the volume of actual removals. The accuracy results of the standing trees volume calculation in forestry practice will be compared with the accuracy reported by Halaj (1955), author of the uniform volume curves, Hubač (1982), and Šmelko (2007).

MATERIALS AND METHODS

Determining the Volume of Standing Trees in Forestry Practice

In connection with the practical application of uniform volume curves, it should be noted that (Šmelko, 2007):

- the standing volume is determined separately for individual trees in the stand and together for the stand as a whole;
- the standing volume is expressed in m^3 of large-size timber wood without bark on the stem and it is considered for trees with at least 8 cm in diameter measured at a height of 130 cm above the ground inclusive of the outside perimeter of the tree bark;
- the formation of large-size timber wood starts at different age depending on the tree species and quality of the habitat (site class) (Recchia *et al.*, 2016), in most tree species it does not start before the age of 20–25 years;
- the practically achievable accuracy of individual methods with 95% reliability is as follows (Hubač, 1982): full calipering +5%, representative methods +10% or +15% (depending on the selected and pre-calculated selection plan), differentiated growth tables +15%, undifferentiated growth tables +20%, ocular estimates +25% (Halaj, 1955);
- in cases where the alternative use of full calipering of the increment as well as the relascopic method is possible, full calipering should be preferred in stands with a small area and a high degree of diversity, as the representative survey would no longer be economically efficient (Hubač, 1982);
- the determination of the standing volume generally consists of two basic stages: measurement of the standing volume parameters (diameter, height, basal area and other mensurational variables) and calculation of the volume itself.

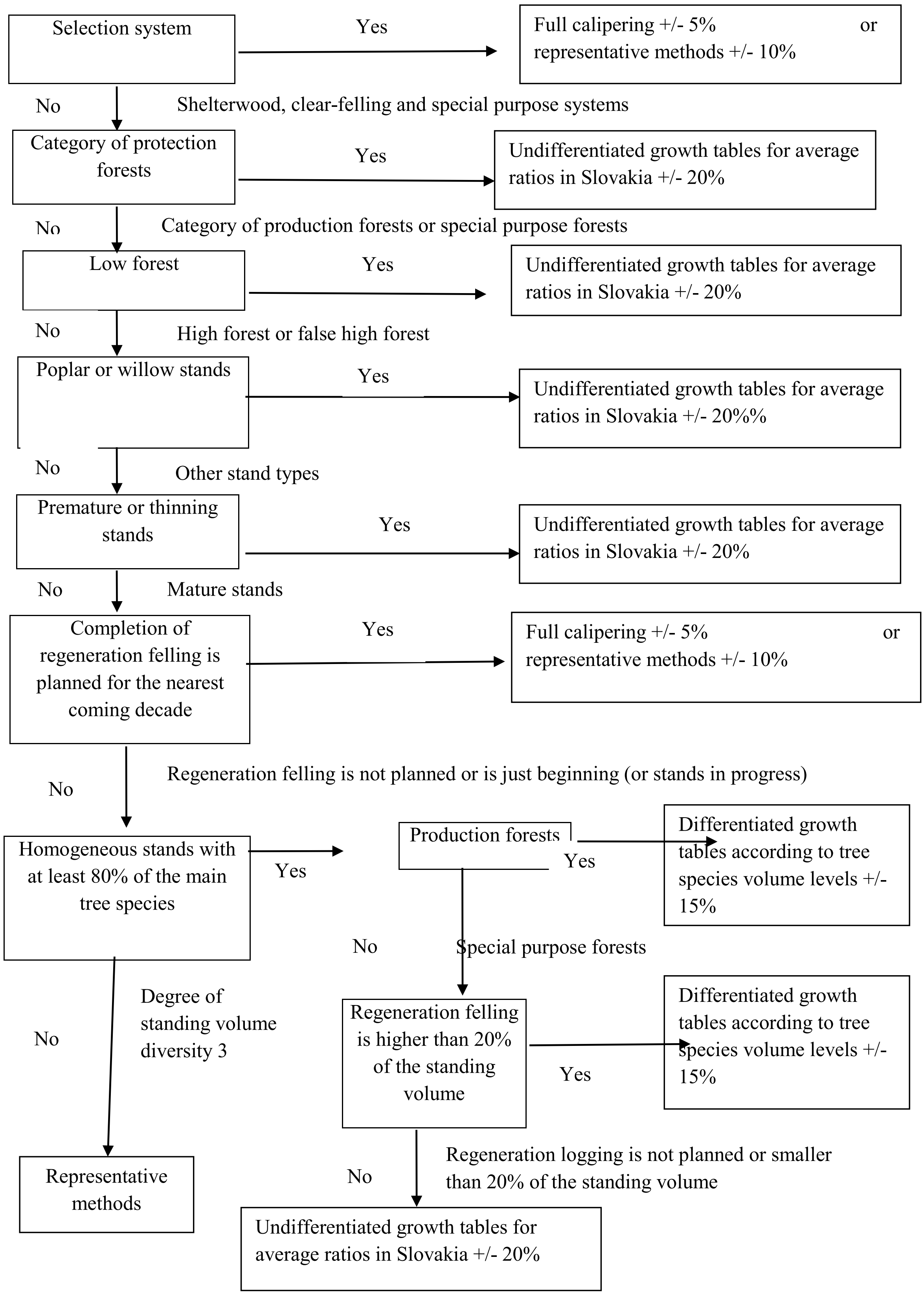
Determination of standing volume by direct measurement consists practically of the following consecutive operations:

- measuring diameters (calipering) – classifying trees into diameter classes;
- measuring tree heights – the number of measured heights depends on the applied method of volume calculation;
- calculating the standing volume – the choice of the calculation method depends on the condition of the stand;
- calculating the stand density and representation of wood species in the stand of a known area.

Decision Algorithm for the Selection of the Method of Standing Volume Determination

Specific procedures, i.e. algorithms, have been developed to determine the standing volumes for individual forest forms, forest categories, and forest management systems.

The chart presents the use of the most suitable methods of determining the standing volumes for individual forest forms, forest management systems, forest categories, and tree species composition of the forest in a given unit of spatial distribution of the forest. The most suitable method of detecting the standing volumes also determines the accuracy of volume calculations.



1: *Decision Algorithm for the Selection of the Method of Standing Volume Determination (Šmelko, 2007)*

Input Quantities for Surveying the Accuracy of the Volume Calculation of Marked Logging

The survey was carried out within the territory of branch establishment in Smolenice belonging to the organization of Lesy Slovenskej republiky, š.p. (Forests of the Slovak Republic, State Enterprise), namely in beech stands in the foothills of the Little Carpathians (Lapin *et al.*, 2002). Units of spatial division of the forest, where the forest beech occurred, were selected and only this value was taken into the survey. The volume of marked felling was compared to the actual removals. Analyses were performed for all types of logging except salvage cutting, i.e. for improvement intentional felling under 50 years of age, improvement intentional felling over 50 years of age, and regeneration intentional felling. As required by the author, the accuracy of the uniform volume curve method was established at ± 10% of the calculated removal volume. This value calculates upon the systematic error of the human factor in measuring the heights, diameters and calculating the standing volume itself.

Methods

Selection of Units of Spatial Forest Division with a Difference between the Volume of Marked Intentional Felling and the Volume of Actual Removals

A list of individual units of spatial division of the forest is created. This list includes only units, where both regeneration and improvement felling have been completed already and European beech is the predominant species in them, i.e. units of spatial division of the forest with a representation of 70% and more. After the felling, a survey was carried out in the individual units of spatial forest division by means of the information system, where in some cases the volume of marked felling did not correspond to the volume of actually removed wood mass. The survey focused on cases where the actually removed volume was higher than the planned logging (volume of marked felling) excluding logging residues Korsmo (1995). The internal information system of the enterprise of Forests of the Slovak Republic, namely the web portal titled WebLES 2 (2018), was used to elaborate this section.

Summary of Data from the Performed Removals by the Assortments Produced

After selecting the individual units of spatial forest division where cutting had already been completed, the amount of harvested wood mass was determined. Details about this quantity can also be found in the WebLES 2 information system, namely in the electronically registered production and payroll cards marked as "LF 41". The total amount of harvested wood mass was summarized by assortments and tree species, and subsequently it was assigned to individual units of spatial forest division according to the types of logging. These data can be summarized back up to 2006, because the WebLES 2 information system was launched in that year.

Comparison of Quantities of Wood Mass in m³ in Terms of the Planned Physically Marked Felling and the Actually Removed Wood Mass

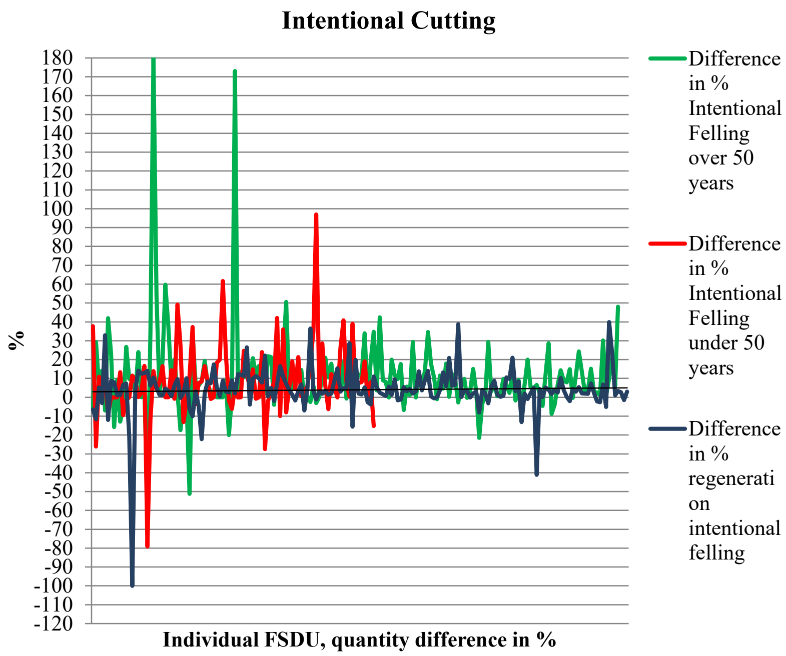
Based on the two above sub-items, a groundwork document was elaborated for individual units of spatial forest division with predominant European beech. This document will include planned felling in m^3, implemented felling in m^3 and a possible difference. When comparing individual units of spatial forest division, specific cases, where the volume of actual removals is higher than the planned volume, were taken into account. This comparison was performed in Microsoft Excel, where the values are summarized and a simple function of subtracting the value of the planned volume and actual removal volume reveals the differences between these volumes. The value of the marked felling volume should be higher than the value of the actually removed volume, as the amount of marked logging also includes the logging residues including the unprocessable part and the harvested assortments together. The actual removals include the volume of harvested assortments, or the volume of processed own production, and therefore the volume of the actual removals should be lower than the physically marked logging and its calculated volume. Individual units of spatial division of the forest, where the value of actual removals was higher than the planned logging, were further investigated to determine the causes of the difference.

Finally, the data were evaluated in summary and the entire survey is concluded with a survey of descriptive statistics. The graphical representation was created using the input quantities of differences between marked felling and actual removals expressed in percentage, where the individual points represent the units of spatial forest division with their respective difference values.

RESULTS

The results obtained consist of the following data: volume of marked felling versus volume of actual removals. The survey covered all types of logging except salvage cutting, i.e. for improvement intentional felling under 50 years of age, improvement intentional felling over 50 years of age, and regeneration intentional felling. Percentage differences were graphically expressed for individual units of spatial forest division.

The chart illustrates that extreme values occur in all types of logging. They are most common in the improvement intentional felling under 50 years of



2: *Differences in all felling systems expressed in percent*

age and, on the contrary, the least common in the regeneration intentional felling. Extreme values are differences in harvested volumes at the level of ± 50% of implemented felling compared to the volume of marked felling. As evident from the chart, this value reached an astronomical level of almost 175% increase compared to the marked felling in some units of spatial forest division. The largest deviation can be observed in improvement intentional felling over 50 years of age. Overall, it can be concluded from the chart that the value was always higher than the marked felling in almost all units of spatial forest division.

Tab. I demonstrates the following: In the case of improvement intentional felling under 50 years of age, the most common mean value of marked felling reached 64.7 m^3, but the most common median reached 31 m^3. These values are similar to implemented felling; however, they are clearly always higher by up to 10%. In this logging, own production was implemented almost exceptionally, which also follows from the values presented in the table. The difference between the marked felling and actual removals in the improvement intentional felling under 50 years of age fluctuates around the level of 3.9 m^3 and a percentage of 8.8%. This value is permissible for the calculation of the volume using the uniform volume curves, but it is always positive in most of the surveyed units of spatial forest division.

Tab. II demonstrates the following: In the case of improvement intentional felling over 50 years of age, the most common mean value of marked logging reached 240.1 m^3, but the most common median reached 130 m^3. These values are similar to the actual removals, however, they are clearly always higher by more than 10%, i.e. the mean value of actual removals reached 260.5 m^3, but

I: *Descriptive statistics for the survey of improvement intentional felling under 50 years of age*

Marked felling	m^3	Actual removals	m^3	Own production	m^3	Difference	± m^3	Difference	%
Mean	64.7	Mean	69.3	Mean	0.5	Mean	3.9	Mean	8.8
Mean error	9.7	Mean error	10.3	Mean error	0.2	Mean error	1.2	Mean error	2.1
Median	31.0	Median	31.7	Median	0.0	Median	1.5	Median	5.8
Max-min difference	535	Max-min difference	579.8	Max-min difference	10.8	Max-min difference	101.8	Max-min difference	176.1
Minimum	0	Minimum	0	Minimum	0	Minimum	-57.0	Minimum	-79.1
Maximum	535	Maximum	579.8	Maximum	10.8	Maximum	44.8	Maximum	97.0
Sum	6 082	Sum	6 446	Sum	40.5	Sum	363.9	Sum	828.1
Number	94	Number	94	Number	90	Number	94	Number	94

II: *Descriptive statistics for the survey of improvement intentional felling over 50 years of age*

Marked Felling	m³	Actual removals	m³	Own production	m³	Difference	± m³	Difference	%
Mean	240.1	Mean	260.5	Mean	2.7	Mean	18.9	Mean	11.0
Mean error	21.7	Mean error	23.0	Mean error	0.4	Mean error	2.2	Mean error	1.7
Median	130.0	Median	160.9	Median	0.0	Median	7.2	Median	7.5
Max-min difference	1 917.0	Max-min difference	1 923.5	Max-min difference	20.5	Max-min difference	157.3	Max-min difference	237.8
Minimum	0.0	Minimum	0.0	Minimum	0.0	Minimum	-41.7	Minimum	-56.8
Maximum	1 917.0	Maximum	1 923.5	Maximum	20.5	Maximum	115.6	Maximum	181
Sum	42 009.0	Sum	45 323.6	Sum	429.1	Sum	3 314.6	Sum	1 930.7
Number	175.0	Number	175	Number	161.0	Number	175	Number	175

III: *Descriptive statistics for the survey of regeneration intentional felling*

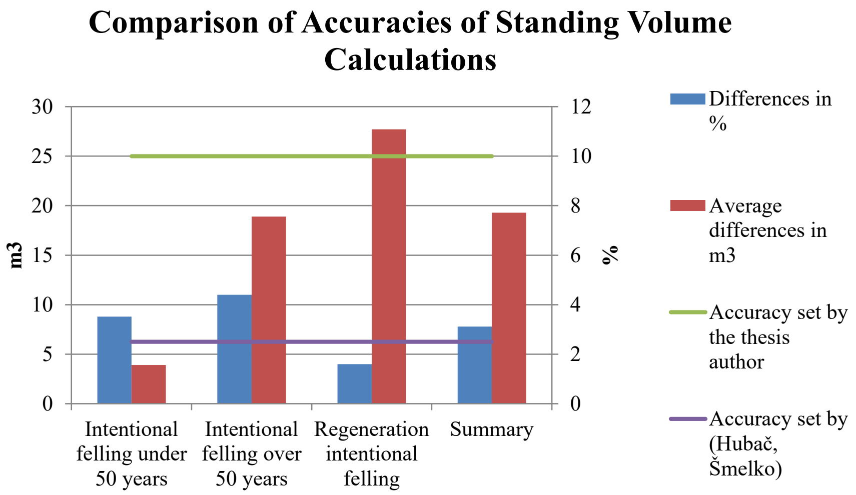
Marked felling	m³	Actual removals	m³	Own production	m³	Difference	± m³	Difference	%
Mean	743.8	Mean	775.9	Mean	1.8	Mean	27.7	Mean	4.0
Mean error	57.1	Mean error	59.8	Mean error	0.2	Mean error	6.1	Mean error	0.9
Median	450.0	Median	459.2	Median	0.0	Median	10.6	Median	3.4
Max-min difference	3 014	Max-min difference	3 072.8	Max-min difference	19.44	Max-min difference	1 132.1	Max-min difference	139.9
Minimum	1	Minimum	0.93	Minimum	0	Minimum	-422.0	Minimum	-100.0
Maximum	3 015	Maximum	3 073.77	Maximum	19.44	Maximum	710.1	Maximum	39.9
Sum	132 402	Sum	137 338.46	Sum	288.6	Sum	4 936.5	Sum	711.7
Number	178	Number	178	Number	163	Number	178	Number	178

IV: *Descriptive statistics for the survey of all types of intentional felling*

Marked felling	m³	Actual removals	m³	Own production	m³	Difference	± m³	Difference	%
Mean	403.8	Mean	425.9	Mean	1.8	Mean	19.3	Mean	7.8
Mean error	27.8	Mean error	29.1	Mean error	0.2	Mean error	2.6	Mean error	0.9
Median	140.0	Median	153.6	Median	0.0	Median	6.6	Median	5.1
Max-min difference	3 015	Max-min difference	3 073.8	Max-min difference	20.5	Max-min difference	1 132.1	Max-min difference	281
Minimum	0	Minimum	0	Minimum	0	Minimum	-442.0	Minimum	-100
Maximum	3 015	Maximum	3 073.77	Maximum	20.5	Maximum	710	Maximum	181
Sum	180 493	Sum	189 108	Sum	758.26	Sum	8 614.9	Sum	3 470.5
Number	447	Number	447	Number	414	Number	447	Number	447

the most common median reached 160.9 m³. In this logging, own production was implemented at mean values of 2.7 m³. Moreover, own production was not implemented in all surveyed units of spatial forest division. The maximum own production value reached up to 20.5 m³. The mean value of difference between the marked felling and the actual removals in the improvement intentional felling over 50 years of age fluctuates around the level of 18.9 m³ and a percentage of 11.0%. This value is out of the permissible tolerance for the calculation of volume using the uniform volume curves, as the accuracy tolerance for the calculation of the harvested volume using the uniform volume curve method is up to 10.

Tab. III demonstrates the following: In the case of regeneration intentional felling, the most common mean value of marked logging reached 743.8 m³, but the most common median reached 450 m³.



3: *Comparing the accuracy of standing volume calculations*

These values are similar to the actual removals, however, they are clearly always higher by up to 5%, i.e. the mean value of actual removals reached 775.9 m^3, but the most common median reached 459.2 m^3. In this felling system, own production was implemented at mean values of 1.8 m^3. Moreover, own production was not implemented in all the surveyed units of spatial forest division. The maximum own production value reached up to 19.44 m^3. The mean value of difference between the marked felling and actual removals in the regeneration intentional felling fluctuates around the level of 27.7 m^3 and a percentage of 4.0%. This value is an excellent result of the calculation of volume using the uniform volume curves, as the accuracy tolerance for the calculation of the harvested volume using the uniform volume curve method is up to 10%.

Tab. IV demonstrates the following: In the statistical evaluation of the surveyed data for all completed intentional felling, the most common mean value of marked logging reached 403.8 m^3, but the most common median reached 140.0 m^3. These values are similar to the actual removals, however, on the side of the completed logging, they are clearly always higher by up to 10%., i.e. the mean value of actual removals reached 425.9 m^3, but the most common median reached 153.6 m^3. For all types of intentional cutting, the mean value of own production reached the level of 1.8 m^3. However, it was also not implemented in all the surveyed felling systems. The maximum own production value reached up to 20.5 m^3. The mean value of difference between all the marked felling and all the actual removals in intentional felling fluctuates around a level of 19.3 m^3 and a percentage of 7.8%. This value is a sufficient result of the calculation of volume using the uniform volume curves, as the accuracy tolerance for the calculation of the harvested volume using the uniform volume curve method is up to 10%. Moreover, we must immediately take into account the total volumes of implemented felling, where the difference compared to the marked felling volumes is 8.7 thousand m^3 of large-size timber wood mass!

Comparing the Calculation Accuracies of Marked Felling Volume versus Actual Removals with Other Papers

The differences in volumes between the marked felling and actual removals were demonstrated graphically and compared with the accuracy of standing volume calculation according to the author of uniform volume curves and other papers dealing with this issue. The accuracy of the calculation was divided according to the individual systems of intentional felling.

The accuracy of the uniform volume curves method is expressed as a percentage and it was found as difference between the volume of standing trees and the volume of removed wood including small wood. The chart illustrates that the accuracy of marked felling volume calculation using the uniform volume curves method, as reported in available papers, was determined at a level of 2.5%. The accuracy stated by Halaj (1955), the author of the uniform volume curves himself, was at a level of 2.2%. The chart clearly shows that, when considering the total value for all logging, this value is exceeded by 5% compared to the permitted accuracy value. From this we can conclude that the tables of uniform volume curves actually underestimate the volume of standing trees by 5% compared to the actual volume of wood mass. The input data for the chart were included in Tabs. I–IV.

DISCUSSION

The accuracy of the uniform volume curve method, as aimed by the author, was established at ± 10% of the calculated removal volume. However, when thinking about it, this value is too high and it calculates upon the systematic error of the human factor (Lazdinš, Kaleja and Zimelis, 2014) in measuring the heights, diameters and calculating the standing volume itself (Fernandez-Puratich *et al*., 2017). Nevertheless, in the case of improvement intentional felling over 50 years of age, the accuracy value was exceeded by 11% in comparison to the actual removals volume calculation. Contrastingly, Hubač (1982) states the accuracy of the volume calculation using the uniform volume curves method applied to the European beech at ± 2.5%, which is a value 4 times lower than the accuracy determined herein. Likewise, Halaj (1955) reports the accuracy of determining the standing volume with a mean error of ± 2.2%. Taking this value into account, the tolerance for all felling systems would be exceeded by almost 200%, which is an alarming number, and for long-term planning in forestry operations, such a situation would be impermissible (Heinimann, 1999). It might lead to a situation when a smaller quantity of European beech would be planned for the sale (Johansson *et al*., 2006) yet, more wood mass would be actually harvested and that would result in creating a stock of unmarketable wood (Kató and Műlder, 1983) with no sales planned. Ultimately, the harvested wood (Laitila, Kilponen and Nuutinen, 2013) might be stored on the roadside landing and until a purchaser is found, which can sometimes take a month or so, its quality can deteriorate significantly. For example when selling III.D assortments to the purchaser directly from the forest (Han and Murphy, 2011; Rahman, Khanam and Pelkonen, 2017) damping is unacceptable and damping and later also mildew occur in harvested wood during prolonged storage (Moskalik, Sadowski and Zastocki, 2016; Lazdinš, Kalēja and Zimelis, 2014; Natov *et al*., 2017). A log thus produced would lose its price (Naimi *et al*., 2016) on average by € 8/m^3 which may ultimately be liquidating for the company.

As stated by Hubač (1982), the error rate for measuring diameters in the mean diameter classes amounts to 3% and for marginal diameter classes, the error rate reaches a level of 8–15%. Another possible cause is incorrect height measurement (Liu and Westman, 2009) and the use of forest management plan data, which may not directly correspond to the marked trees and their heights. A more detailed examination of the measurement of heights in the field demonstrated a relatively frequent failure to observe the exact distance from the foot of the measured tree (Karjalainen *et al*., 2001). Concerning the height measurements, (Juračka, 2018) reports the accuracy of height measuring at ± 2%.

Abroad, methods are used to calculate the volume of wood of standing trees, ie fluid displacement, graphical method, standard sectional method and aper line, especially in the United States and England. The most accurate is the graphical method, in which the accuracy of the volume is up to 1%, with the remaining methods the accuracy is in the range of 5–15%. The big disadvantage of the graphic method is too time consuming and impossibility to use in forestry (Brack, 2001).

This leads to only one possible cause, namely that the underestimation of volume tables specifically for European beech trees was confirmed (Poljanec and Kadunc, 2013). In this respect, a conclusion was made that they underestimate the volume by 5%, i.e. in fact there is more wood mass than the tables of uniform volume curves indicate (Assmann, 1968). The system of uniform volume curves (uniform mass curves) in Slovakia was dealt with by Halaj (1955). From the surveys performed, he identified that parameters with the greatest influence on the course and shape of the height curve include tree species, mean diameter, and mean height. The influence of other factors (age, site class, vegetation region) proved to be very small (Karlsson and Tamminen, 2013) and practically negligible, therefore the method of uniform volume curves is applicable in homogeneous and mixed stands with a degree of tree diversity of 1 or 2 if they show a clear single-peak distribution of diameters by diameter classes (Šmelko, 2007). Furthermore, as argued by Halaj (1955), uniform volume curves (uniform mass curves) were compiled for spruce, beech, and fir trees for the vegetation regions of the Upper Hron River and Orava River. Subsequently, these tables were tested in 1950–1953 and, according to the experience of Slovak enumeration officers, they proved to be applicable for the entire territory of Slovakia (Fernandez-Puratich *et al*., 2017).

CONCLUSION

The logging residues left on the site formed by large-size timber wood and small wood are converted into wood chips. The average value of dendromass left on the site was surveyed and determined per 1 m^3 of logging and it was divided into large-size timber wood amounting to 0.03 m^3 and small wood amounting to 0.07 m^3 of wood mass. In total, the amount of convertible logging residues of beech wood represents a share of 0.1 m^3 per 1 m^3 of harvested wood.

Another recommendation is to submit a proposal for the development of new cubing tables for the so-called European Beech of Little-Carpathian ecotype. These tables would need to be created for the harvested wood indicating the volume of wood without bark measured in bark and tables of uniform volume curves or volume tables for the calculation of the volume of standing wood mass before the start of felling. Based on this thesis, the National Forestry Centre in Zvolen will be

submitted a proposal to develop new uniform volume curves and tables for a new confirmed tree ecotype: European Beech of Little Carpathians.
Last but not least, it is recommended to change the standing volume calculation from the uniform volume curves method to the method applying classical volume tables. This method would only require a higher number of measurements for individual diameter classes. With the method of classical volume tables, the diameter classes are graded by 2 cm and the error rate of inclusion into the correct diameter class would be eliminated. As reported in Juračka (2018) the method of volume tables is the most accurate for determining the volume of standing trees (standing volume) and reaches a deviation of ± 1% from the calculated volume. Under the current operating conditions of Lesy SR, it is realistic to use classical volume tables, as they would represent only a minimal increase in labor intensity compared to the currently used methods, namely a specific increase in the number of height measurements for each thickness grade.

REFERENCES

ASSMANN, E. 1968. *Theory of forest yield* [in Slovak: *Náuka* o *výnose lesa*]. Bratislava: Príroda.

ARAVANOPOULOS, F. A. 2016. Breeding of fast growing forest tree species for biomass production in Greece. *Biomass & Bioenergy*, 34(11): 1531–1537.

BRACK, C. L. 2001. *Forest Measurement and Modeling – Measuring trees, stands and forests for effective forest management*. Computer-based course resources for Forest Measurement and Modeling (FSTY2009) at the Australian National University.

FERNANDEZ-PURATICH, H., OLIVER-VILLANUEVA, J.-V., LERMA-ARCE, V. *et al.* 2017. A study of Paulownia spp. as a short-rotation forestry crop for energy uses in Mediterranean conditions [in Spanish: Estudio de Paulownia spp. como cultivo forestal de rotación corta para fines energéticos en condiciones mediterráneas]. *Madera y Bosques*, 23(3): 15–27.

HALAJ, J. 1955. *Tables of uniform mass curves for determining the mass of stands* [in Slovak: *Tabuľky jednotných hmotových kriviek pre určovanie hmoty porastov*]. Bratislava: State Agricultural Publishing House n. p.

HAN, S-K. and MURPHY, G. 2011. Trucking Productivity and Costing Model for Transportation of Recovered Wood Waste in Oregon. *Forest Products Journal*, 61(7): 552–560.

HEINIMANN, R. 1999. Ground-based harvesting technologies for steep slopes. In: *Proceedings of the International Mountain Logging and 10th Pacific Northwest Skyline Symposium*. Corvallis, OR: Department of Forest Engineering, Oregon State University, pp. 1–16.

HUBAČ, K. 1982. *Dedrometric methods* [in Slovak: *Dendrometria*]. Textbook. Zvolen: VŠLD Zvolen.

JOHANSSON, J., LISS, J-E., GULLBERG, T. and BJORHEDEN, R. 2006. Transport and handling of forest energy bundles-advantages and problems. *Biomass & Bioenergy*, 30(4): 334–341.

JURAČKA, M. 2018. *Conversion coefficients of forest harvest residues for spruce and pine trees* [in Czech: *Převodní koeficienty lesních těžebních zbytků pro dřeviny smrk a borovice*]. Diploma thesis. Brno: Mendel University in Brno.

KARJALAINEN, T., ZIMMER, B., BERG, S., WELLING, J., SCHWAIGER, H., FINÉR, L. and CORTIJO, P. 2001. *Energy, carbon and other material flows in the Life Cycle Assessment of forestry and forest products. Achievements of the Working Group 1 of the COST Action E9*. Discussion Paper 10. Joensuu: European Forest Institute.

KARLSSON, K. and TAMMINEN, P. 2013. Long-term effects of stump harvesting on soil properties and tree growth in Scots pine and Norway spruce stands. *Scandinavian Journal of Forest Research*, 28(6): 550–558.

KATÓ, F. and MÜLDER, D. 1983. Qualitative Gruppendurchforstung der Buche. *Allgemeine Forst und Jagdzeitung*, 154: 139–145.

KLVAČ, R. and DELVIN, G. 2011. *Forest Biomass Processing Glossary*. 1st Edition. Prague: Lesnická práce, s. r. o.

KORSMO, H. 1995. Weight equations for determining biomass fractions of young hardwoods from natural regenerated stands. *Scand. J. For. Res.*, 10: 333–346.

LAITILA, J., KILPONEN, M. and NUUTINEN, Y. 2013. Productivity and Cost-Efficiency of Bundling Logging Residues at Roadside Landing. *Croatian Journal of Forest Engineering*, 34(2): 175–187.

LAPIN, M., FAŠKO, P., MELO, M., ŠŤASTNÝ, P. and TOMLAIN, J. 2002. Climate areas 1:1 000 000 [in Slovak: Klimatické oblasti]. In: *Atlas of the country of the Slovak Republic* [in Slovak: *Atlas krajiny Slovenskej republiky*]. Bratislava: MŽP SR and Banská Bystrica: SAŽP.

LAZDIŅŠ, A., KALĒJA, S. and ZIMELIS, A. 2014. Factors affecting productivity and cost of solid biofuel in mechanized forest ditch cleaning. *Research for Rural Development*, 2: 90–96.

LIU, C. and WESTMAN, C. J. 2009. Biomass in a Norway spruce–Scots pine forest: a comparison of estimation methods. *Boreal Env. Res.*, 14(5): 875–888.
MOSKALIK, T., SADOWSKI, J. and ZASTOCKI, D. 2016. Some technological and economic aspects of logging residues bundling. *Sylwan*, 160(1): 31–39.
NAIMI, L. J., COLLARD, F., BI, X., LIM, C. J. and SOKHANSANJ, S. 2016. Development of size reduction equations for calculating power input for grinding pine wood chips using hammer mill. *Biomass Conversion and Biorefinery*, 6: 397–405.
NATOV, P., DVOŘÁK, J., SEDMÍKOVÁ, M., LÖWE, R. and FERENČÍK, M. 2017. Comparison of harvester-produced timber volume with the standing timber volume determined by volume tables. *Zprávy lesnického výzkumu*, 62(1): 1–6.
POLJANEC A. and KADUNC A. 2013. Quality and timber value of European beech (*Fagus sylvatica* L.) trees in the Karavanke region. *Croatian Journal of Forest Engineering*, 34(1): 151–165.
RAHMAN, A., KHANAM, T. and PELKONEN, P. 2017. People's knowledge, perceptions, and attitudes towards stump harvesting for bioenergy production in Finland. *Renewable & Sustainable Energy Reviews*, 70: 107–116.
RANIUS, T., HAMALAINEN, A., EGNELL, G., OLSSON, B., EKLOF, K., STENDAHL, J., RUDOLPHI, J., STENS, A. and FELTON, A. 2018. The effects of logging residue extraction for energy on ecosystem services and biodiversity: A synthesis. *Journal of Environmental Management*, 70: 409–425.
RECCHIA, L., DAOU, M., RIMEDIOTTI, M., CINI, E. and VIERI, M. 2016. New shredding machine for recycling pruning residuals. *Biomass & Bioenergy*, 33(1): 149–154.
SCHWEIER, J., MOLINA-HERRERA, S. and GHIRARDO, A. 2016. Environmental impacts of bioenergy wood production from poplar short-rotation coppice grown at a marginal agricultural site in Germany. *Global Change Biology Bioenergy*, 9(7): 1207–1221.
SNALL, T., JOHANSSON, V., JONSSON, M., ORTIZ, C., HAMMAR, T., CARUSO, A., SVENSSON, M. and STENDAHL, J. 2017. Transient trade-off between climate benefit and biodiversity loss of harvesting stumps for bioenergy. *Global Change Biology Bioenergy*, 9(12): 1751–1763.
STUPAK, A., ASIKAINEN, A., JONSEL, M., KARLTUN, E. and LUNNAN, A. 2007. Sustainable utilization of forest biomass for energy. Possibilities and problems: policy, legislation, certification and recommendations and guidelines in the Nordic, Baltic and Other European countries. *Biomass and Bioenergy*, 31(10): 666–684.
ŠMELKO, Š. 2007. *Dendrometric methods* [in Slovak: *Dendrometria*]. Zvolen: Technical University of Zvolen.
LESY SR. 2018. *WebLES 2: Lesy SR information system* [in Slovak: *WebLES 2: Informačný systém Lesy SR*]. [Intranet]. Available at: https://intranet.lesy.sk/Foresta/WebLES/ [Accessed: 2018, April 23].

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