https://doi.org/10.17221/28/2024-JFS

Over- and under-bark volume estimation of European larch timber produced by mechanised harvesting in Czechia

*Monika Löwe**, *Radim Löwe*, *Martin Jankovský*, *Pavel Natov*, *Jiří Dvořák*

Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Prague, Czech Republic

**Corresponding author: lowem@fld.czu.cz*

Citation: Löwe M., Löwe R., Jankovský M., Natov P., Dvořák J. (2024): Over- and under-bark volume estimation of European larch timber produced by mechanised harvesting in Czechia. J. For. Sci., 70: 381–390.

Abstract: In Czechia, harvesters contributed 43% of the total annual timber production in 2022. It is assumed that harvester technology will continue to be used intensively in the future, even though there is a change in the tree species composition of forests after the recent bark beetle outbreak and an increase in the use of close-to-nature forest management. The aim of this study was to analyse the over- and under-bark volume estimates of European larch timber produced by a harvester in Czechia. This study used the M3s price category for volume estimation. This volume was compared with the M3toDE price category. The M3toDE price category underestimated the over-bark volume by 5.59% compared to the M3s price category. However, for use in forestry practice in Czechia it is currently necessary to use the M3toDE price category. Therefore, the M3toDE price category was used to compare under-bark volumes according to different bark deduction methods. Differences were found between all the five methods investigated. Understanding this sub-issue will help in training operators, acquiring comprehensive knowledge about the functioning of harvester software and maximising the economic effect of the sale of larch timber.

Keywords: bark deduction methods; cut-to-length method; double bark thickness; *Larix decidua*; price categories; StanForD

In recent years, we have seen a dynamic growth in the use of the harvester technology (cut-to-length method; CTL) for felling in Europe (Moskalik et al. 2017). Mechanised harvesting increases productivity and reduces production costs compared to motor-manual felling (Zinkevičius et al. 2012; Spinelli et al. 2014). The increase in the representation of this technology in the total timber felling was also helped by the bark beetle outbreaks in the spruce forests. The CTL method is almost exclusively used for harvesting in some European countries, such as Finland, Sweden, Norway and Estonia (Gellerstedt, Dahlin 1999; Moskalik et al. 2017; Lundbäck et al. 2018). However, this does not apply in all European countries, there are also some barriers to increasing the share of CTL harvesting, such as the large capital expenses needed to purchase the machinery, terrain configuration or species composition in a region (Ferrari et al. 2012). Therefore, a low level of mechanisation of timber harvesting is, for example, in Bulgaria, Romania, Slovakia, and Ukraine (Moskalik et al. 2017). In Czechia, the share of timber produced by harvesters has increased in the last decade and reached 45% in 2022 (MoA 2023).

https://doi.org/10.17221/28/2024-JFS

The harvester technology is optimised for felling mainly in coniferous stands. Out of deciduous tree species, only stands with beech and birch to the age of 50 are considered (Dvořák et al. 2011). Other tree species are, from a technological point of view, problematic for processing. However, even this sector is being innovated and the possibilities of harvester technology are developing. Harvester heads are being modified, which enable debarking or, for example, processing of other types of wood, such as oak (Mederski et al. 2018). European larch (*Larix decidua* Mill.), a coniferous tree suitable for processing by harvesters, belongs to the tree species with a lower representation in the Czech forests. According to data for 2022 (MoA 2023), it was found on an area of over 102 000 ha of forest land, which represented 3.9% of the tree species composition of Czech forests. It is thus the third most represented conifer, after spruce (46.8%) and pine (16.0%). Current studies have shown that it is a geographically indigenous tree species in the territory of Czechia (Pokorný et al. 2023). In the past, however, it was never significantly represented in Czech forests. The reason was also its ecological demands, when it can be considered a light-demanding tree (Bottero et al. 2013), i.e. competitively weak in dense deciduous stands. There is currently no reason not to use this tree species in economic forests. Larch is mainly used for growing mixed stands in the form of individual and group-like mixtures. It helps foresters to increase the tree species diversity of forests. In 2022, the larch was used during the artificial restoration of forests after the bark beetle outbreak on a total area of almost 2 000 ha, which represented 5% of the total annual artificially afforested area (MoA 2023). According to the recommended tree species composition (MoA 2023), the representation of larch in Czech forests should increase to 4.2% in the future. And since larch often forms an admixture of spruce and pine stands, it can be assumed that larch timber will probably occur in higher volumes than today in timber production by harvester technology.

In Central Europe, timber dimensions are measured in bark but sold (volume is calculated) without bark. The bark volume is therefore provided to customers free of charge, and they can continue to use it and profit from it (Jankovský et al. 2023). The standard method of scaling timber in Czechia is to estimate the volume of logs using Huber's formula according to the log length and the midspan diameter measured in the bark with the application of a model deduction for the double bark thickness, as described in the Guidelines. However, larch is not the main economic tree, therefore it has not been given too much attention. The standard tables used for estimating the volume of logs, which are the Guidelines for Timber Scaling in Czechia (GTS; Wojnar 2007) and Tables and Polynomials for Estimating Under-bark Volume of Logs (TP; Černý, Pařez 2002), use the same procedures for determining the double bark thickness for European larch as for Scots pine. Valenta (2015) compiled an equation for determining double bark thickness directly for larch. From this equation, Natov and Dvořák (2018) derived the values for the diameter band bark deduction method (DBM) and the parametric linear bark deduction method (PLM), which they present in the Guidelines for Electronic Scaling of Timber for Harvesters in Czechia (Natov, Dvořák 2018). The harvester software also offers several options for estimating the over-bark volume of produced logs, the so-called price categories, which are based on different algorithms. However, there is only one method (M3toDE) among them, whose algorithm coincides with how timber is traded in Czechia, according to the Guidelines for Timber Scaling in Czechia (Wojnar 2007).

The aim of this study was to find out how the estimated over-bark volumes of larch timber produced by harvesters differ when using different price categories (sectional, very accurate volume M3s *vs*. volume based on the Huber M3toDE formula), and even between different produced assortments. Furthermore, the goal was to analyse the differences between the under-bark volumes of larch timber estimated according to the two bark deduction methods, which can be used in the harvester software, and three other bark deduction methods, which are standardly used in Czech forestry when estimating the under-bark volumes of larch logs.

MATERIAL AND METHODS

Data collection. The data utilised in this study were collected from a John Deere 1270E harvester (Deere & Company, USA) that was equipped with a Waratah 480C harvester head (Waratah Forestry Equipment, Finland). This machine used the TimberMatic control and information system (Version 1.19, 2016), which allows the storage

https://doi.org/10.17221/28/2024-JFS

of data in the unified StanForD Classic standard (Skogforsk 2024). John Deere 1270E harvester belongs to the mid-performance category, which is the most prevalent harvester class in Czechia (MoA 2023). Data collection lasted from March 2017 to June 2018, primarily focusing on final and salvage fellings conducted across Czechia. The harvester predominantly processed coniferous trees, mostly Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*). The dataset used in this study overlaps with that of Löwe et al. (2019) and Sedmíková et al. (2020); however only European larch data were utilised here.

The harvester's control and information system was configured to automatically generate stem files (.stm), which contained various metrics (e.g. length and diameter) for each processed tree (Skogforsk 2007). Each stem of larch was automatically cut into 1–12 logs according to the assortment categorisation setting, with measured diameters provided for every 10 cm of log length, along with M3s volume estimate for each log.

To ensure the accuracy of length and diameter measurements, a control measurement procedure was implemented at the onset of each workday. The Haglöf Digitech Professional II digital caliper (Haglöf Sweden AB, Sweden) equipped with Digitech Tape and Skalman software (Version 6.11, 2016) was used for it. The procedure of control measurement was previously described by Löwe et al. (2019) and Sedmíková et al. (2020).

Data processing. Data contained within the stem files was migrated into the MS Excel file format. This data conversion process was facilitated using the STeMa application developed by Natov in 2016 (Version 1.0, 2016). Following the conversion, the resulting database underwent a thorough screening to eliminate any outliers or extreme values. In total, 637 stem files were analysed, containing data from 4 345 produced logs.

The variables under consideration were as follows:
– Tree species (*TS*): This study exclusively focused on European larch.
– Assortment (*AS*): This variable contained details regarding the classification of the log into assortments based on specified customer requirements.
– Midspan diameter (*MD*): *MD* denoted the diameter of the log (measured in millimetres over bark) in the middle of its required length.
– Top end diameter (*TD*): *TD* represented the diameter of the log (measured in millimetres over bark) at the end of its required length, serving as one of the quantitative parameters for assortment classification.
– Required length (*RL*): *RL* denoted the minimum required length of the log (measured in centimetres) for a particular assortment.
– Total length (*TL*): *TL* contained the real length of the log (measured in centimetres).
– Over-bark volume of a log according to the M3s price category (V_{M3s}): V_{M3s} indicated the volume of the log (measured in cubic metres over bark) estimated using the required length of the log.

Using the M3toDE price category algorithm, we calculated the volume of each log (designated as V_{M3toDE}). This volume estimation is based on the required length and midspan diameter, measured in millimetres, and was rounded down to the nearest whole centimetre using the HKS method (Handelsklassensortierung – trade class sorting; BW-HKS 1983).

The log volume was estimated according to Equation (1):

$$V_{M3toDE} = \pi \times \frac{\frac{MD^2}{4}}{10\,000} \times \frac{RL}{100} \quad (1)$$

where:
V_{M3toDE} – log volume according to the M3toDE price category (m^3 over bark);
MD – midspan diameter (cm);
RL – required length (cm).

The principle of estimating volume according to the M3s and M3toDE price categories is described in detail and graphically illustrated in the study by Sedmíková et al. (2020).

Categorisation of assortments. The harvester produced logs that represented specific assortments. Each assortment met specific requirements of the customer, which included parameters such as tree species, top end diameter, required length, and grade. Upon felling a tree, the harvester operator initially identified the tree species and assessed the timber quality (grade). Subsequently, the machine software proposed to produce a suitable assortment based on predetermined quantitative parameters. This grading method was also used by Löwe et al. (2019).

Bark thickness deduction methods. In Czechia, the Guidelines for Electronic Scaling of Timber for

https://doi.org/10.17221/28/2024-JFS

Harvesters in Czechia, GEH (Natov, Dvořák 2018) were developed. Therefore, to estimate the under-bark volume based on the M3toDE price category, two bark deduction methods, which are listed in GEH and are supported by the control and information system of harvesters, were used. It was the diameter band bark deduction method (DBM) and the parametric linear bark deduction method (PLM). Values and parameters of these bark deduction methods for larch were created in GEH based on the method reported by Valenta (2015). However, the bark deduction method developed by Valenta (2015) could not be used directly in GEH because polynomial functions are not supported in the StanForD.

For comparison, double bark thickness values were calculated commonly in Czechia for all logs according to the methods developed by Valenta (2015). We also added two more methods which are very common in Czechia. Their disadvantage is that they do not differentiate the double bark thickness estimation for European larch separately but use the same values as for Scots pine. These are the Guidelines for Timber Scaling in Czechia (Wojnar 2007) and Tables and Polynomials for Estimating Underbark Volume of Logs (Černý, Pařez 2002).

Below are the individual bark deduction methods and their formulas, or the values that were used in the study.

(*i*) The diameter band bark deduction method (DBM method – usable in the software of harvesters). The double bark thickness values within the DBM were determined for 10 diameter bands published in GEH (Natov, Dvořák 2018) and are shown in Table 1.

(*ii*) The parametric linear bark deduction method (PLM method – usable in the software of harvesters), Equation (2):

$$DBT_{PLM} = a + MD \times b \quad (2)$$

where:

DBT_{PLM} – double bark thickness according to the PLM method (mm);

a, b – $a = 2.02$, $b = 0.0482$ for European larch logs according to the GEH (Natov, Dvořák 2018);

MD – midspan diameter (mm over bark).

(*iii*) The bark deduction method according to Valenta (VAL method – parametric nonlinear function, so it cannot be used in software of harvesters). Valenta (2015) distinguishes two formulas for determining double bark thickness, depending on whether it is a butt log or other logs from the tree trunk. However, since bark deduction methods in GEH (Natov, Dvořák 2018) were derived only from Valenta's formula for other logs, this study used the formula for other logs for comparison, as shown in Equation (3):

$$DBT_{VAL} = (0.55436 + 0.01734 \times MD^{1.29855}) \times 10 \quad (3)$$

where:

DBT_{VAL} – double bark thickness according to Valenta (2015) in mm;

MD – midspan diameter (cm over bark).

(*iv*) The bark deduction method according to the Guidelines for Timber Scaling in Czechia (GTS – parametric nonlinear function, so it cannot be used in the software of harvesters). Since 2002, the Guidelines for Timber Scaling in Czechia (Wojnar 2007) have been used in the timber production and trade of individual assortments. The GTS fully govern a large number of contracts between suppliers and customers. However, for calculating double bark thickness of European larch, the same parameters are used as those that are set up for Scots pine butt logs, as shown in Equation (4):

Table 1. The double bark thickness values of the diameter band bark deduction method (DBM) used for under-bark volume estimation of European larch timber in harvester control and information systems

European larch (*Larix decidua*)	
Midspan diameter (mm over bark)	double bark thickness (DBT_{DBM}; mm)
0–79	6.71
80–149	9.43
150–219	12.86
220–289	16.86
290–359	21.14
360–429	25.71
430–499	30.57
500–569	35.57
570–639	40.86
640–700	46.43

DBT_{DBM} – double bark thickness according to the diameter band bark deduction method according to the guidelines by Natov and Dvořák (2018)

https://doi.org/10.17221/28/2024-JFS

$$DBT_{GTS} = (1.7015 + 0.008762 \times MD^{1.4568}) \times 10 \quad (4)$$

where:

DBT_{GTS} – double bark thickness according to Wojnar (2007) in mm;

MD – midspan diameter (cm over bark).

(*v*) The bark deduction method according to the Tables and Polynomials for Estimating Under-bark Volume of Logs (TP – parametric nonlinear function, so it cannot be used in the control and information systems of harvesters). Tables and Polynomials for Estimating Under-bark Volume of Logs (Černý, Pařez 2002) use parametric nonlinear function with Scots pine parameters for under-bark volume estimation of European larch timber, as shown in Equation (5):

$$DBT_{TP} = (0.25017 + 0.0019147 \times MD^{1.7866}) \times 10 \quad (5)$$

where:

DBT_{TP} – double bark thickness according to the Tables and Polynomials for Estimating Under-bark Volume of Logs (Černý, Pařez 2002) in mm;

MD – midspan diameter (cm over bark).

Under-bark volume estimates. We estimated the under-bark volume (m^3) for each log using all five bark deduction methods (DBM, PLM, VAL, GTS, TP). To estimate the under-bark volumes, only the M3toDE price category was used throughout this study as recommended by Natov and Dvořák (2018). Therefore, Equation (1) was used. However, in this case, the value of midspan diameter (*MD*; cm) used in Equation (1) was the value obtained by subtracting the double bark thickness (*DBT*; mm) from the measured midspan diameter (*MD*; mm over bark), rounded down to the nearest centimetre. By substituting the determined under-bark midspan diameter (cm) into the formula, the under-bark volume (m^3) was calculated. The under-bark volumes, estimated via these five bark deduction methods, were denoted as V_{DBM}, V_{PLM}, V_{VAL}, V_{GTS}, and V_{TP}.

Data analyses. Descriptive statistics were used to obtain average and summary values of individual variables. The Kolmogorov-Smirnov normality test was used for testing of the data normality. Wilcoxon matched pairs test was used to test the differences between over-bark volumes estimated according to the M3s and M3toDE price categories. Friedman's analysis of variance (ANOVA) was used to test the differences between the M3toDE under-bark volume estimates using the DBM, PLM, VAL, GTS, and TP bark deduction methods. For all statistical tests, the $\alpha = 5\%$ level of significance was set. Tests were conducted in the Statistica package (Version 13, 2018). For testing differences between under-bark volume estimates according to each two bark deduction methods, Wilcoxon matched pairs tests were used, followed by the Bonferroni method for *P*-value correction, in the statistical software R (Version 4.2.3, 2023).

RESULTS

In total, 4 345 logs produced from 637 stems of European larch were analysed. Logs were processed by a harvester, and their over-bark volumes were estimated according to two different algorithms of M3s and M3toDE price categories. The mean over-bark volume according to M3s was statistically significantly higher ($P < 0.001$) than the mean over-bark volume according to M3toDE (Figure 1). The total over-bark volume estimated through the M3s price category was higher than that determined by the M3toDE price category. This trend was consistent across all assortment grades, as shown in Table 2. The highest difference was recorded for the roundwood, and that was almost 6%. The total under-bark volume estimated using the VAL bark deduction method was 819.94 m^3, which was 54.09 m^3 (6.6%) more than using the GTS bark deduction method and vice versa by 51.51 m^3 (6.3%) less than using the TP bark deduction method. If we compare this volume with the volumes determined by the harvester software, it was 2.08 m^3 (0.25%) less than when using the DBM bark deduction method and 5.44 m^3 (0.66%) more than when using the PLM bark deduction method.

Significant differences were found [Friedman $\chi2 = 15.176$; *df* (degrees of freedom) = 4; $P < 0.001$] between under-bark volume estimated according to the M3toDE price category using five different bark deduction methods (Figure 2). When comparing the mean under-bark volume estimates for each pair of bark deduction methods, there were statistically significant differences (all the time $P < 0.001$). The mean under-bark volume using the bark deduction method according to Valenta (2015) was 0.1887 m^3. The mean under-bark volume accord-

https://doi.org/10.17221/28/2024-JFS

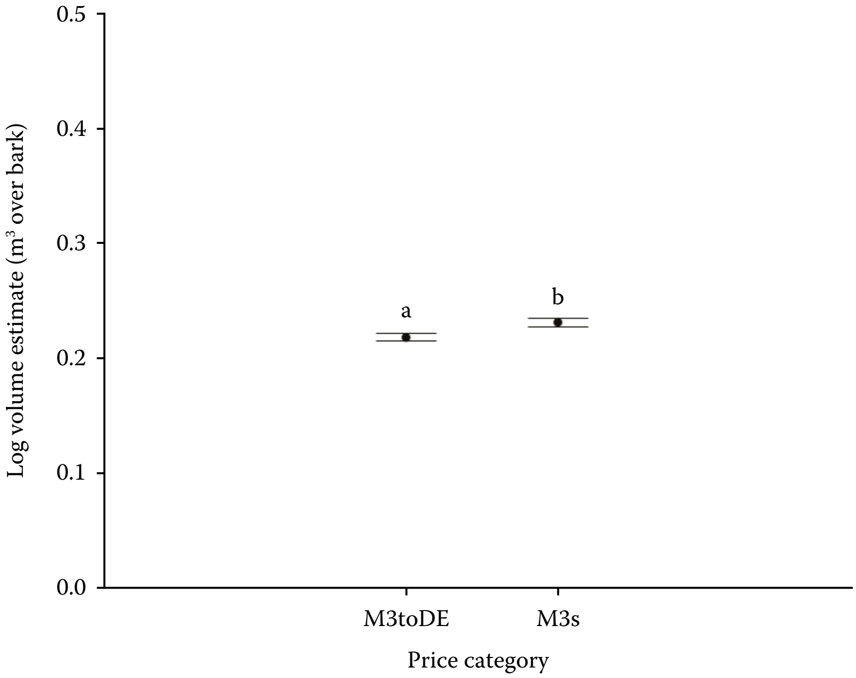

Figure 1. Differences between mean over-bark volumes estimated according to the M3s and M3toDE price categories

a, b – statistically significant differences revealed by the Wilcoxon matched pairs test (α = 5%); bars – indication of standard error

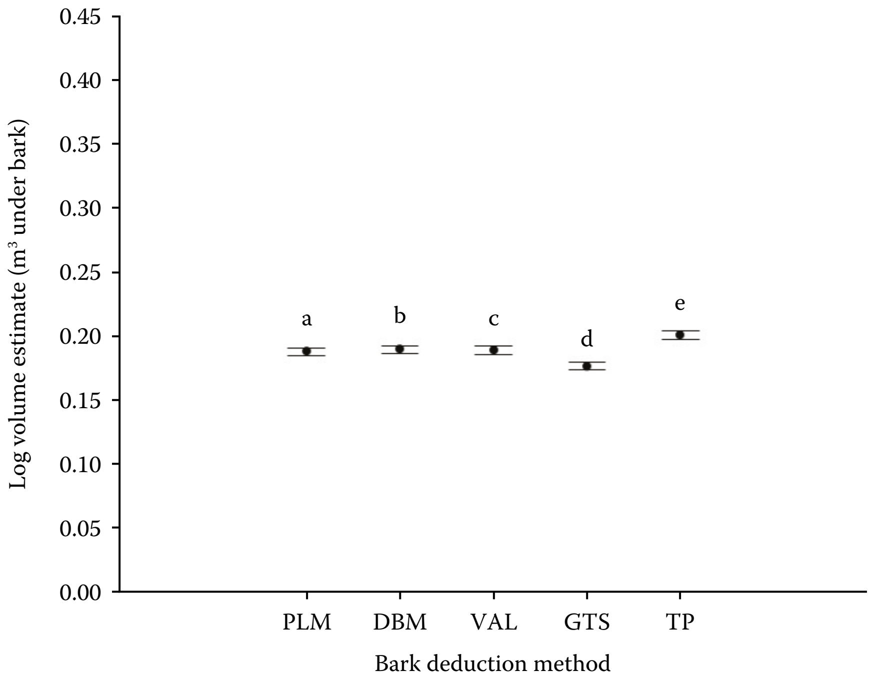

Figure 2. Differences between mean under-bark volumes estimated according to the M3toDE price category using five different bark deduction methods

a–e – statistically significant differences revealed by the Wilcoxon matched pairs test (α = 5%); bars – indication of standard error; PLM – parametric linear bark deduction method (Natov, Dvořák 2018); DBM – diameter band bark deduction method (Natov, Dvořák 2018); VAL – bark deduction method according to Valenta (2015); GTS – bark deduction method according to Wojnar (2007); TP – bark deduction method according to Černý and Pařez (2002)

https://doi.org/10.17221/28/2024-JFS

Table 2. Measured European larch timber parameters, estimated double bark thickness and under-bark volumes, using five different bark deduction methods (DBM, PLM, VAL, GTS, TP)

Parameter of logs	All logs	Assortment grade		
		roundwood	pulpwood	firewood
Number of logs	*n* = 4 345	*n* = 2 023	*n* = 2 140	*n* = 182
Mean *RL* (cm)	324	466	202	172
Mean *MD* (mm o.b.)	254	321	200	125
Total V_{M3s} (m^3 o.b.)	1 003.91	844.94	155.12	3.84
Total V_{M3toDE} (m^3 o.b.)	947.84	794.37	149.67	3.81
RD (%)	−5.59	−5.99	−3.51	−0.78
Mean DBT_{DBM} (mm)	17.14	21.14	13.96	10.15
Mean DBT_{PLM} (mm)	18.17	22.50	14.77	10.00
Mean DBT_{VAL} (mm)	17.42	21.42	14.24	10.32
Mean DBT_{GTS} (mm)	27.22	31.02	24.19	20.71
Mean DBT_{TP} (mm)	9.33	12.31	6.91	4.49
Total V_{DBM} (m^3 u.b.)	822.02	689.59	129.23	3.20
Total V_{PLM} (m^3 u.b.)	814.50	683.67	127.64	3.18
Total V_{VAL} (m^3 u.b.)	819.94	688.22	128.51	3.20
Total V_{GTS} (m^3 u.b.)	765.85	646.66	116.50	2.69
Total V_{TP} (m^3 u.b.)	871.45	729.72	138.21	3.52

n – number of logs; o.b. – over bark; u.b. – under bark; *RL* – required length; *MD* – midspan diameter; V_{M3s} – log over-bark volume estimate according to the M3s price category; V_{M3toDE} – log over-bark volume estimate according to the M3toDE price category; *RD* – relative difference between the total over-bark volume of logs estimated according to the M3s price category and the total over-bark volume estimated according to the M3toDE price category; DBT_{DBM} – double bark thickness according to the diameter band bark deduction method (Natov, Dvořák 2018); DBT_{PLM} – double bark thickness according to the parametric linear bark deduction method (Natov, Dvořák 2018); DBT_{VAL} – double bark thickness according to Valenta (2015); DBT_{GTS} – double bark thickness according to Wojnar (2007); DBT_{TP} – double bark thickness according to Černý and Pařez (2002); V_{DBM} – log under-bark volume estimate according to the M3toDE price category, using the diameter band bark deduction method (Natov, Dvořák 2018); V_{PLM} – log under-bark volume estimate according to the M3toDE price category, using the parametric linear bark deduction method (Natov, Dvořák 2018); V_{VAL} – log under-bark volume estimate according to the M3toDE price category, using the bark deduction method according to Valenta (2015); V_{GTS} – log under-bark volume estimate according to the M3toDE price category, using the bark deduction method according to Wojnar (2007); V_{TP} – log under-bark volume estimate according to the M3toDE price category, using the bark deduction method according to Černý and Pařez (2002)

ing to the diameter band bark deduction method (Natov, Dvořák 2018) was 0.1892 m^3 and deviated least from this value. After that, it was the mean under-bark volume (0.1875 m^3) according to the parametric linear bark deduction method (Natov, Dvořák 2018). In contrast, the volumes according to Wojnar (2007) and Černý and Pařez (2002) deviated the most (0.1763 m^3, resp. 0.2006 m^3).

DISCUSSION

In 2022, harvester technology reached 45% of the total annual volume of timber produced in Czechia (MoA 2023). Even though the structure of forest stands is slowly changing after the bark beetle outbreak and with regard to the changing natural conditions due to climate change, harvester technology has and will have a significant presence in Czech forest management. Despite the fact that the goal of foresters is to establish more diverse forests with a higher proportion of deciduous trees, factors such as suitable terrain conditions in Czechia, the lack of forest workers working in the forest with chainsaws or horses, the development of harvester technology for application in thinning and processing of deciduous trees and still a significant proportion of conifers in forest stands in Czechia, give the assumption to consider the use of harvester tech-

https://doi.org/10.17221/28/2024-JFS

nology as a common harvesting method in Czechia also in the future.

Czechia has become the epicentre of the bark beetle calamity in Europe. In 2017–2019, the spruce bark beetle (*Ips typographus*) damaged 3.1–5.4% of the growing stock of spruce forest stands annually (Hlásny et al. 2021b). The bark calamity reached its peak in 2020, when the total annual volume of timber harvesting in Czechia reached 35.75 million m^3 (MoA 2023). Currently, it seems that the calamity is receding, and Czech forestry is slowly returning to its pre-calamity state, which in the volume of felling represents something between 15–17 million m^3 of timber annually. However, the risk of another bark beetle calamity remains. In the future, it is assumed that bark beetle calamities will occur synchronously in areas with an area of hundreds of kilometres due to extreme climatic events, such as heat waves and droughts (Allen et al. 2015; Hlásny et al. 2021a). At the time of the bark beetle outbreak, not much attention was paid to the education of harvester operators. However, now is the right time for consideration at the state level to set educational requirements for the operators of these machines. The background for this already exists – the Guidelines for Electronic Scaling of Timber for Harvesters in Czechia (Natov, Dvořák 2018) and the modern training centre for operators of harvester technology machines in Trutnov, managed by the Czech Forestry Academy Trutnov. Professionally trained operators will ensure the maximum usability of these machines – their efficiency, correct use with regard to the protection of the forest environment and the fulfilment of all functions of the forest, and the reliability of timber production output data.

That is why it is important to know in detail the harvester control and information system, its setting options and to understand the outputs of timber production. As in previous studies (Löwe et al. 2019; Sedmíková et al. 2020), the results of this study confirmed that the over-bark volumes of timber estimated according to the M3toDE price category were underestimated compared to the reference M3s price category. In the case of larch timber, this difference was 5.59% (5.99% for roundwood) – for comparison, the study by Löwe et al. (2019) found a difference of 5.67%. However, because in Central Europe, the scaling of logs according to Huber's formula is used as a standard, we prefer the M3toDE price category for timber production records and trading in the software setting. In addition, we must not forget to apply a bark deduction – timber is sold with bark, but the sales volume is given as under-bark volume. In the harvester system, only the band or parametric linear bark deduction models can be applied (polynomial is not supported by software).

The Guidelines for Electronic Scaling of Timber for Harvesters in Czechia (Natov, Dvořák 2018) make it possible to select the DBM and PLM methods for bark deduction, both compiled according to the Valenta (2015) model. Valenta (2015) constructed a polynomial model for the bark deduction of larch based on bark measurements of larch logs at various locations in Czechia. The results of this study showed that the estimated under-bark volume by using the VAL bark deduction method (Valenta 2015) was only 0.25% smaller than using the DBM bark deduction method, and 0.66% larger than using the PLM bark deduction method. It is thus possible to use both methods, which, according to Natov and Dvořák (2018), are listed in the GEH. It may be easier for the harvester operator to use the PLM method when setting up the production of assortments for larch because he enters only two parameters. The results of our research show that the under-bark volumes of larch timber were significantly different when using GTS (Wojnar 2007) and TP (Černý, Pařez 2002). The volume according to VAL was 6.6% higher compared to GTS but, on the contrary, 6.3% lower compared to TP.

The differences are due to the fact that for the bark deduction of larch, in the case of GTS, the tables for bark deduction of Scots pine butt logs are used, and in the case of TP, the tables for bark deduction of Scots pine other (normal) logs are used (i.e. larch timber is assigned to the group under Scots pine). Valenta (2015) found that only in short, 2 m long, butt logs was larch bark thickness equal to or greater than that of pine butt logs. The use of these models for larch in forest management can lead to inaccuracies and commercial disputes.

CONCLUSION

The difference found in the produced over-bark volume of larch timber when using the price category M3s compared to M3toDE reached 5.59% (for logs 5.99%), which was comparable to the study by Löwe et al. (2019). However, for use in Czech forestry, due to standardised procedures for scaling

https://doi.org/10.17221/28/2024-JFS

Table 3. Comparison of the total under-bark volume of produced larch timber according to different bark deduction methods used in this study

Bark deduction method	Total volume estimate (m^3 u.b.)	Differences (%) from VAL	Usable in harvester software
DBM (Natov, Dvořák 2018)	822.02	0.25	yes (individual values)
PLM (Natov, Dvořák 2018)	814.50	0.66	yes (linear equation)
VAL (Valenta 2015)	819.94	–	no (non-linear equation)
GTS (Wojnar 2007)	765.85	6.60	no (non-linear equation)
TP (Černý, Pařez 2002)	871.45	–6.30	no (non-linear equation)

u.b. – under bark; DBM – diameter band bark deduction method; PLM – parametric linear bark deduction method; VAL – bark deduction method according to Valenta; GTS – bark deduction method according to the Guidelines for Timber Scaling in Czechia; TP – bark deduction method according to the Tables and Polynomials for Estimating Under-bark Volume of Logs

timber based on the Huber formula, it is currently necessary to use the M3toDE price category. Therefore, this price category was also used when comparing under-bark volumes according to different bark deduction methods. The results revealed that differences exist between all the five methods investigated. However, the volumes estimated by the DBM and PLM methods, which can be used in harvesters, reach low differences compared to the VAL method, 0.25% and 0.66%, respectively. In contrast, the GTS and TP methods, which are used today in Czech forestry to estimate volumes of individual logs, underestimate by 6.6% (the difference between VAL versus GTS) and overestimate by 6.3% (the difference between VAL versus TP). This is due to the use of values from the tables for the bark deduction of Scots pine, not European larch directly, in the GTS and TP methods. Table 3 presents a summary of the compared bark deduction methods.

Detailed knowledge of harvester control and information systems is currently necessary for the operator of these machines. Without this knowledge, it is not possible to ensure the correct and effective use of harvester technology in Czech forests, which have experienced a massive bark beetle outbreak in recent years and are currently transforming stands into more diverse forests with the use of forest management practices that are closer to nature. It is therefore important to pay attention to sub-topics, such as the processing of larch timber and the possibility of estimating its over- and under-bark volume. Understanding this sub-issue will help in training operators and acquiring comprehensive knowledge about the functioning of harvester software. It will also help in maximising the economic effect when trading larch timber, the price of which is higher compared to other economic conifers (spruce, pine, fir). For this reason, the machine operator must correctly determine the tree species (in this case, European larch) and have an appropriately set al.orithm for the production of assortments (including the price category and bark deduction method). In further studies, it is necessary to focus on other sub-issues of the effective use of harvester software and the comparison of common forestry practices in the production and trading of timber in order to be able to explain possible differences, for example, between the records of timber production from a harvester and when using a chainsaw.

REFERENCES

Allen C.D., Breshears D.D., McDowell N.G. (2015): On underestimation of global vulnerability to tree mortality and forest die-off from hotter drought in the Anthropocene. Ecosphere, 6: 1–55.

Bottero A., Garbarino M., Long J.N., Motta R. (2013): The interacting ecological effects of large-scale disturbances and salvage logging on montane spruce forest regeneration in the western European Alps. Forest Ecology and Management, 292: 19–28.

BW-HKS (1983): Gesetzliche Handelsklassensortierung für Rohholz (Forst-HKS) mit Ergänzungsbestimmungen für BadenWürttemberg. Stuttgart, Ministerium für Ländlichen Raum, Ernährung, Landwirtschaft und Forsten: 25. (in German)

Černý M., Pařez J. (2002): Tabulky a polynomy pro výpočet objemu kulatiny bez kůry. Kostelec nad Černými lesy, Lesnická práce: 23. (in Czech)

Dvořák J., Bystrický R., Hošková P., Hrib M., Jarkovská M., Kováč J., Krilek J., Natov P., Natovová L. (2011): The Use of Harvester Technology in Production Forests. Kostelec nad Černými lesy, Lesnická práce: 156.

https://doi.org/10.17221/28/2024-JFS

Ferrari E., Spinelli R., Cavallo E., Magagnotti N. (2012): Attitudes towards mechanized cut-to-length technology among logging contractors in Northern Italy. Scandinavian Journal of Forest Research, 27: 800–806.

Gellerstedt S., Dahlin B. (1999): Cut-to-length: The next decade. International Journal of Forest Engineering, 10: 17–25.

Hlásny T., Merganičová K., Modlinger R., Marušák R., Löwe R., Turčáni M. (2021a): Prognosis of bark beetle outbreak and a new platform for the dissemination of information about the forests in the Czech Republic. Zprávy lesnického výzkumu, 66: 197–205. (in Czech)

Hlásny T., Zimová S., Merganičová K., Štěpánek P., Modlinger R., Turčáni M. (2021b): Devastating outbreak of bark beetles in the Czech Republic: Drivers, impacts, and management implications. Forest Ecology and Management, 490: 119075.

Jankovský M., Dvořák J., Löwe R., Natov P., Nuhlíček O. (2023): Double bark thickness estimation models of common European broadleaved species for harvester timber volume estimation in Czechia. Croatian Journal of Forest Engineering, 44: 95–102.

Löwe R., Sedmíková M., Natov P., Jankovský M., Hejcmanová P., Dvořák J. (2019): Differences in timber volume estimates using various algorithms available in the control and information systems of harvesters. Forests, 10: 388.

Lundbäck M., Häggström C., Nordfjell T. (2018): Worldwide trends in the methods and systems for harvesting, extraction and transportation of roundwood. In: Proceedings of the 6th International Forest Engineering Conference 'Quenching Our Thirst for New Knowledge', Rotorua, Apr 16–19, 2018: 1–3.

Mederski P.S., Bembenek M., Karaszewski Z., Pilarek Z., Łacka A. (2018): Investigation of log length accuracy and harvester efficiency in processing of oak trees. Croatian Journal of Forest Engineering, 39: 173–181.

MoA (2023): Zpráva o stavu lesa a lesního hospodářství České republiky v roce 2022. Prague, Ministry of Agriculture of the Czech Republic: 134. (in Czech)

Moskalik T., Borz S.A., Dvořák J., Ferenčík 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: 231–241.

Natov P., Dvořák J. (2018): Doporučená pravidla pro elektronický příjem dříví harvestory v ČR 2018. Litomyšl, Produkce BPP s.r.o.: 136. (in Czech)

Pokorný P., Hošková K., Prach J., Šída P., Bednář P. (2023): New paleobotanical data prove the native status of European larch (*Larix decidua* Mill.) in North Bohemia. Zprávy lesnického výzkumu, 68: 197–205. (in Czech)

Sedmíková M., Löwe R., Jankovský M., Natov P., Linda R., Dvořák J. (2020): Estimation of over- and under-bark volume of Scots pine timber produced by harvesters. Forests, 11: 626.

Skogforsk (2007): Standard for Forest Data and Communications. Uppsala, The Forest Research Institute of Sweden: 10. Available at: https://www.skogforsk.se/cd_20190114161714/contentassets/b063db555a664ff8b515ce121f4a42d1/stanford_maindoc_070327.pdf (accessed Jan 3, 2024).

Skogforsk (2024): StanForD 'Classic' Documents. Uppsala, The Forest Research Institute of Sweden. Available at: https://www.skogforsk.se/english/projects/stanford/ (accessed Jan 3, 2024).

Spinelli R., Lombardini C., Magagnotti N. (2014): The effect of mechanization level and harvesting system on the thinning cost of Mediterranean softwood plantations. Silva Fennica, 48: 1–15.

Valenta J. (2015): Zjišťování objemu modřínových a douglaskových výřezů. Lesnická práce, 94: 454–456. (in Czech)

Wojnar T. (2007): Doporučená pravidla pro měření a třídění dříví v ČR 2008. 2nd Ed. Kostelec nad Černými lesy, Lesnická práce: 147. (in Czech)

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.

Received: April 5, 2024
Accepted: May 9, 2024
Published online: July 16, 2024