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Original Article

Suitability of Various Volume Equations for Logs Volume Calculation

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ABSTRACT

The optimal equation for calculating log volume should be practical, simple, and useful, and it should, above all, produce the most realistic result. The success of 11 alternative volume equations in calculating the volumes of eastern spruce logs of various lengths was compared as part of the study. The study employed 109 logs that were brought to Ardanuç Ferhatlı Forest Depot for stacking. These 3 m, 4 m, and 5 m long logs had their diameters measured at 0.5 m intervals from the thick end, and the volume of each 0.5 m long section was computed using the Smalian equation, yielding the log volume closest to the truth. The calculated actual log volumes were then compared with the predicted volume values of 11 different log volume equations (including not commonly used equations such as Bruce, Patterson-Doruska, Centroid, Subneilid, and Two-end conic). The log volume equations with mean errors less than zero ($p > .05$) were ranked by mean error, mean absolute percent error, and percent total error. According to the results obtained, the Mean Error (MH), Mean Absolute Percentage Error (MAPE), and Total Percentage Error (TPE) values of the most successful Smalian equation were found to be 0.099, 0.526, and 0.028, respectively, N-Riecke was 2, and the average of the diameters at the ends was 3, followed by the Huber and Centroid formulas.

Keywords: Centroid formula and average of the diameters at the ends formula, Huber formula, Log volume, Newton-Riecke formula, Smalian formula

Introduction

Wood volume estimation is a crucial study area in forestry for the most accurate management and trading of forest resources (Davis et al., 2001; Japheth et al., 2022). Forest products and services should be measured as precisely as possible to reveal the value supplied by forests. The most precious property created from forests is logging, which is the most valuable sort of wood commodity (Şahin, 2015; Şahin et al., 2017; Şahin & Korkmaz 2021).

The log volume can be computed relatively correctly in the factory using today's technologies, but there is still a need to accurately estimate log volumes in the field for research and industrial purposes (Patterson & Doruska, 2004). There are several ways for estimating log volume in the literature, forestry practices, and research, and these procedures often produce outcomes that are very similar to one another. These strategies, however, cannot be used interchangeably and necessitate extensive investigation (Li et al., 2015).

The Smalian, Huber, and Newton techniques are the most well-known cross-section methods for a volume estimate, and these three methods determine the volume based on their cross-sectional area (Cruz de León & Uranga-Valencia, 2013). Huber's equation produces precise answers in the cylinder, truncated paraboloid, and paraboloid shapes, but it gives incomplete results in nyloid and cone shapes. Smalian equation delivers higher volume in various solids of revolution bodies while offering correct results in a cylinder, truncated paraboloid, and paraboloid shapes. Since the Newton-Riecke equation produces accurate values for cone, paraboloid, and nyloid, it is said to be a safer approach to determining the log volume compared to other methods. Apart from this, the Hossfeld equation calculates the correct volume for the paraboloid and cone, while it calculates a smaller volume for the nyloid (Özçelik, 2002). According to Philip (1994), although Newton-Riecke equation gives more accurate results when calculating the volume of irregular logs, it is less preferred than Smalian and Huber equations, which are simple to use (Avery & Burkhart 1994). In Turkey, the Huber equation is used to find the volumes of logs due to its simplicity and usefulness, and the Smalian equation is used to calculate the stocked log volumes due to its practicality (Özçelik, 2002; Özçelik et al. 2008).

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The tree trunk can also be volumized by dividing it into sections of equal length. This method is generally used in scientific research to determine the volume of felled trees, determine the volume of the stand, or determine the volume of very tall and valuable tree trunks. Although some equations are more accurate in volume calculation performance, they may be more difficult to implement and vice versa. The ideal equation for calculating volume, on the other hand, should take the fewest measurements and should be straightforward and useful (Carus, 2002). It is indicated that while estimating the log volume, numerous elements such as the tree sample data set and clarity influence the choice of the equation, additionally, researchers pay attention to the precision and correctness of a chosen volume equation (Mushar et al., 2020).

The comparison of volume equations has been the subject of numerous national (in Turkey) and international researches. Some international research has proven the superiority of various equations in diverse tree species. In their study using the xylometer equation, Williams et al. (1991) found that the Bruce equation performed better in short and long logs, Wiant et al. (1996) found that Bruce's equation performed better than Smalian and that the amount of error varied depending on log length and diameter size, and Filho et al. (2000) indicated that the Huber equation performed better than Centroid and N-Riecke.

In addition, Patterson and Doruska (2004), in their study, stated that the Bruce equation estimated the volume as underestimated in short logs and excessively in long logs and Tewari and Singh (2005) also stated that the Bruce equation offers better results than many equations. According to Özçelik (2006), when the log's length reduces, the diameter difference lowers and the basal areas at both ends become closer to one another, reducing the amount of inaccuracy. According to Güney (2007), "The reliability of the Patterson-Doruska and Bruce methods decreases in parallel with the increase in log length."

The Oriental spruce (*Picea orientalis* (L.) Link.), the subject of the study, covers approximately 30% of the forest areas in the eastern Black Sea region and generates a significant amount of revenue for the region (OGM, 2020). Therefore, the success in volumizing the oriental spruce logs, which have a wide area and widespread wood production in the Eastern Black Sea Region, is important. Based on this idea, the volumes of oriental spruce logs brought to the Ferhatlı Forest Depot in the Ardanuç Forestry Operations Directorate affiliated with the Artvin Regional Directorate of Forestry (in Turkey) were calculated using various equations, and the differences between them were compared. This study aims to introduce the log volume estimation equations and to evaluate how different equations successfully volume the oriental spruce logs of different lengths.

Methods

In total, 109 pieces of oriental spruce logs were brought to the Ferhatlı Forest Depot, which is linked with the Artvin Regional Directorate of Forestry, Ardanuç Forestry Operations Directorate, as material for this study. For the most precise and accurate volume calculation, the lengths of the sample logs and their circumferences in the middle were measured with a centimeter precision tape measure, and the unshelled diameters were also measured with centimeter precision using a caliper. Statistical Package for the Social Sciences 24.0 (IBM SPSS Corp., Armonk, NY, USA) was used to determine the volume error amounts within the scope of the research and to make volumetric comparisons.

As the parameters to be used in the volume equations, the trunk diameters on the sample trees, the diameter values calculated with the q equation, the circumference values in the middle of the log (u), and the total lengths of the logs (L) were measured (Figure 1). Trunk diameter measurements were made as d_0, $d_{0.5}$, d_1,..., d_n, and $d_{1/3}$ at 0.5 m intervals.

First, the section volumes of the 0.5 m logs were computed using the measurements, and total log volumes of each log were calculated by summing them up. Afterward, volumizing was done independently with the related volume equations (1–11) and pairwise comparison was made between these results and the actual volume values.

Equations Used in Log Volumizing

The Huber, Smalian, Newton-Riecke, and average of the diameters at the ends are commonly used volume equations. Apart from these, French Method, Hossfeld, Bruce (1982), Patterson and Doruska (2004), Centroid (Özçelik, 2002; Özçelik, 2006; Li et al., 2015), Subneilid (Tewari & Singh, 2005), and two-end conic (Tewari & Singh, 2005) methods are the other equations that have been researched within the scope of the study (Eqs. 1–11):

$$\text{Huber } V = ML \tag{1}$$

$$\text{Smalian } V = \left(\left(B+S\right)/2\right)L \tag{2}$$

$$\text{N.Riecke } V = \left(\left(B+4M+S\right)/6\right)L \tag{3}$$

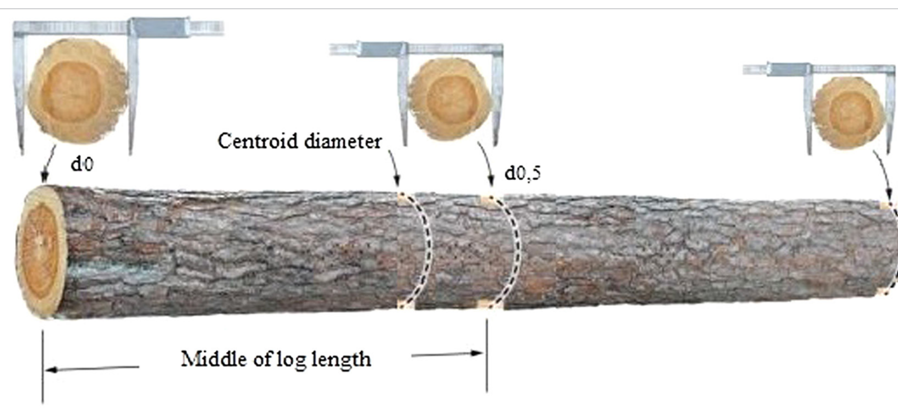

Figure 1.
Some Diameter Measurements Made on Sample Logs.

Average of the diameters at the ends $V = \frac{\pi}{4}.L\left(\frac{d_0 + d_n}{2}\right)^2$ (4)

Hossfeld $V = \left(\left(3G + S\right)/4\right)L$ (5)

French Met. $V = \left(\frac{u}{5}\right)^2.2L$ (6)

Bruce $V = \left(0.25B + 0.75S\right)L$ (7)

P.Doruska $V = \left(\left(PB\right) + \left(\left(1 - P\right).S\right)\right)L$ (8)

Centroid $V = SL + \left(1/2\right)bL^2 + \left(1/3\right)cL^2$ (9)

Subneilid $V = \frac{\pi}{4}.L\left(\frac{d_n + d_{0.5}}{2}\right)^2$ (10)

Two-end conic $V = \frac{\pi}{4}.L\left(\frac{d_n^2 + d_n.d_{0.5} + d_{0.5}^2}{3}\right)^2$ (11)

d_0, d_n, $d_{0.5}$: the thick diameter, thin diameter, middle diameters of the log;

$d_{1/3}$: 1/3 diameter from the thick diameter of the log;

V: log volume;

L: log length (m);

M: basal area (BA) in the middle of the log $\left(M = \frac{\pi}{4}d_{0.5}^2\right)$;

B: BA at the thick diameter of the log;

S: BA at the thin diameter of the log;

G: BA corresponding to 1/3 of the log length from the thick diameter;

u: Circumference in the middle of the log;

C: BA at the point at the distance q of the length of the log from the thick diameter of the log and dividing the log volume into two equal parts;

$P = 0.15 + 136/(0.394.d_0)^3 + 0.002(3.289.L)$ calculated value by equation;

$b = (B - S - CL^2)/L$ calculated value by equation;

$c = (B - C(L/e) - S(1 - L/e))/(L^2 - Le)$ calculated value by equation;

$q = L - ((((((d_0/d_n)^4 + 1)^{0.5} - 2^{0.5})/(2^{0.5}((d_0/d_n)^2 - 1))))L)$ calculated value by equation;

$e = L - q$ the value calculated with the equation.

Goodness-of-Fit Statistics

The goodness-of-fit of the various equations that were tested in the study was evaluated using the mean error (ME, 12), mean absolute percentage of error (MAPE, 13), and percent total error (TPE, 14) values of each calculated log volume value were calculated separately for each log according to the following expressions:

$$ME = \frac{\sum\left(V - V_i\right)}{n} \quad (12)$$

$$MAPE = \frac{\sum\left|V - V_i\right|}{\sum V}x100 \quad (13)$$

$$TPE = \frac{\sum Y - \sum V_i}{\sum V}x100 \quad (14)$$

V is the actual log volume (dm^3), V_i is the log volume calculated from the relevant equation (dm^3), and n is the number of sample log is here.

Following these calculations, the volume equations were ranked from the one with the lowest error to the one with the highest error (with the equation with the lowest error getting 1 point). Then, by adding the scores from the ME, MAPE, and TPE equations, a general ranking was constructed, and the equation with the lowest score was chosen as the most successful equation.

To test the suitability of the volume equations, first of all, one of the parametric test assumptions, the homogeneity of the group variances, was tested. Finally, the "paired samples *t*-test" was performed one by one between the actual volume value (V_g) and the calculated volume values (V_i) with the help of related equations to check the compatibility of the existing equations.

Results

Various statistical information regarding all logs measured within the scope of the study are given in Table 1. In addition, various statistical information about the section volumes, the volume values calculated according to each equation, and the average differences are given in Table 2.

As given in Table 2, the most successful equations for volumizing oriental spruce logs are, in order, Smalian (−0.043 percent error), Newton-Riecke (−0.084 percent error), an average of the diameters at the ends (−0.176 percent error), Huber (0.184 percent error), and Centroid (with 0.193 percent error). Although the mean difference of the Hossfeld equation is small (0.184 percent error), it gives large volume values for small diameter logs (Figure 2) and its use is not statistically significant ($p < .05$, Table 3).

Table 2 shows that the French, Bruce, Patterson–Doruska, Subneilid, and two-end conic equations, the application of which could not be found statistically significant ($p < .05$, Table 3), contain a high rate of error. The graphic comparison of the volume values calculated according to various formulas with the actual volume values is shown in Figure 2, and the radar plot of the error values of the volumes calculated with various formulas is shown in Figure 3. Then, according to the paired sample *t*-test, the equations that were successful in

Table 1.
Descriptive Statistics on Sample Logs

Feature	Minimum	Mean	Maximum	Standard Deviation
(d_0) (cm)	21.7	35.2	57.8	7.6
(d_n) (cm)	20.1	33.0	56.9	7.4
$u_{0.5}$ (cm)	67.3	108.2	180.4	2.6
Length (m)	3.0	3.6	5.0	0.7

Table 2.
Descriptive Statistics for the Calculated Volume Values of Sample Logs (dm³) and Differences

Calculated Volume	Minimum	Mean	Maximum	Mean Differences (%)
Sectional	104.896	349.404	1033.455	
Huber	104.847	350.154	1038.163	0.184
Smalian	103.971	349.305	1032.817	−0.043
N-Riecke	104.555	349.132	1033.975	−0.084
Average of the diameters at the ends	103.856	348.856	1032.753	−0.176
Hossfeld	105.907	350.012	1035.485	0.184
French Method	108.703	357.893	1041.413	2.5
Bruce	100.509	337.942	1024.713	−3.346
P-Doruska	106.817	276.225	761.061	4.076
Centroid	106.751	347.68	1042.833	−0.193
Subneilid	100.909	337.41	1025.562	−3.569
Two-end conic	100.922	337.448	1025.569	−3.606

volumizing the oriental spruce logs were determined (Table 3) and the error amounts (ME, MAPE, and TPE) and success rankings of these equations are given in Table 4. According to statistical test results, all equation variances used in the study were found to be homogeneous ($p > .05$; Table 3).

As given in Table 3, some equations used in the study (Hossfeld, French Method, Bruce, P.-Doruska, Subneilid, and two-end conic equations) were found to be unsuccessful in volumizing the oriental spruce logs at a significance level of .05 ($p < .05$).

As given in Table 4, the equations with the least error in volumizing the logs are Smalian, Newton-Riecke, diameters at the mean ends, Huber, and Centroid equations, respectively.

Discussion

When the data of the study were examined in detail, it was seen that Smalian, Newton-Riecke, average of diameters at the ends, Huber, and Centroid equations could be used successfully in volumizing the oriental spruce logs ($p > .05$). The Smalian equation outperformed in volumizing oriental spruce logs among other equations.

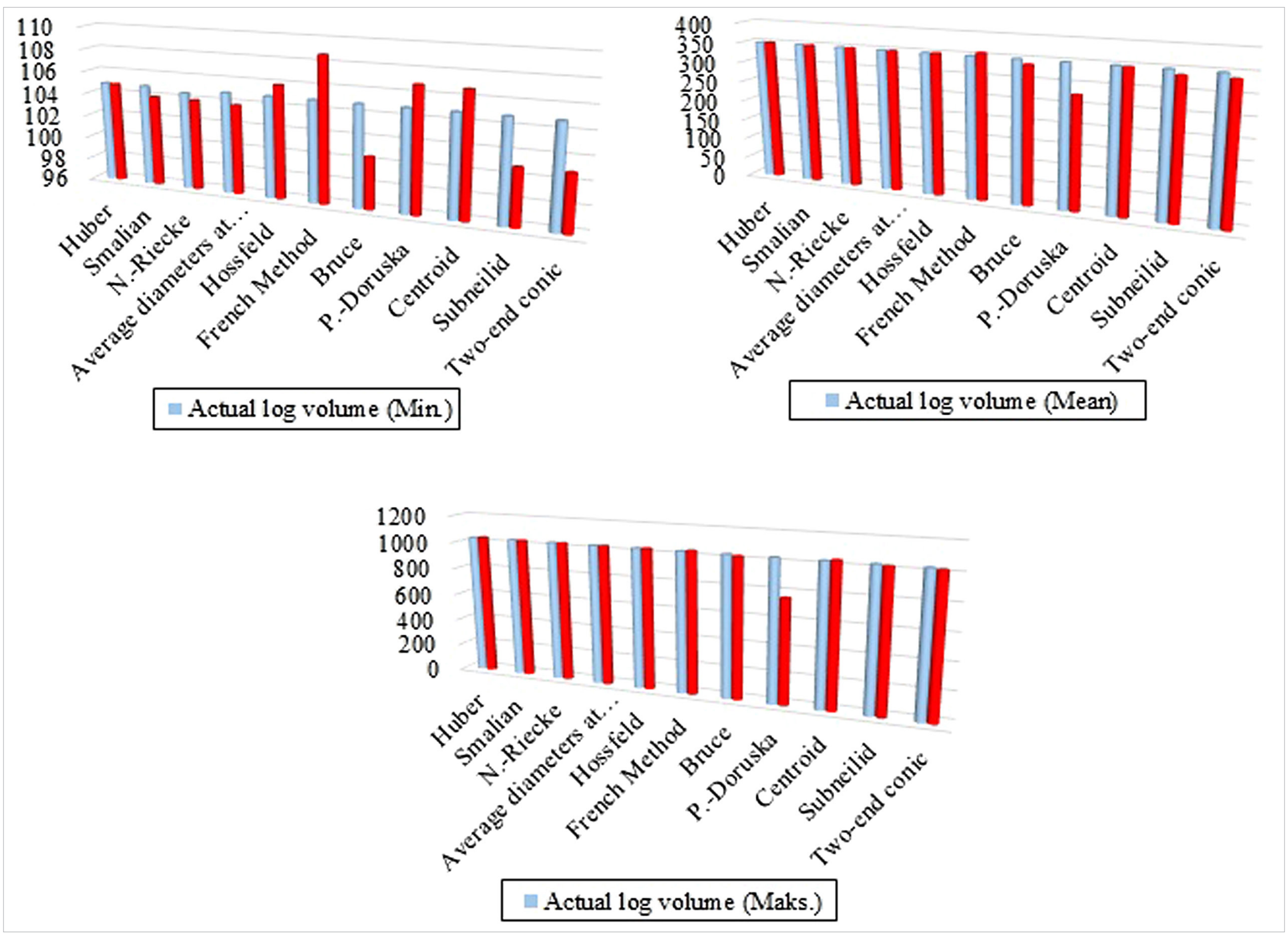

Figure 2.
Comparison of Volumes Calculated According to Various Formulas with Actual (Section) Volumes.

Table 3.
Paired Comparison t *Test Results with Full Measurement*

		Equality of Variance		*t*-Test Results		
Method	Mean Volume (dm³)	Levene Statistics	*p*	*t*	*p*	Standard Deviation of Errors
Sectional	349.912					
Smalian	350.658	.002	.965	−1.882	.062	.396
N-Riecke	349.822	.000	.986	.321	.749	.279
Average of the diameters at the ends	349.641	.000	.998	1.892	.061	.143
Hossfeld	349.374	.001	.979	1.97	.051	.273
French method	350.538	.001	.975	−3.375	.001	.186
Bruce	358.42	.038	.845	−11.844	.000	.718
P-Doruska	338.458	.087	.769	15.98	.000	.717
Centroid	274.409	3.747	.054	3.092	.003	22.462
Subneilid	348.205	.000	.983	1.725	.087	.99
Two-end conic	337.919	.09	.764	16.388	.000	.732
Huber	337.956	.09	.764	16.404	.000	.729

According to the results of the study, in the volumizing of medium quality class oriental spruce ($d_0 \leq 57.8$ cm) logs in the research region:

- the Bruce and Patterson–Doruska equations, which have been recommended as successful in some research, should not be chosen without first testing them in various sizes and log types.
- Hossfeld, French, Subneilid, and two-end conic equations, which are not widely used, did not give appropriate results for volumizing East spruce logs and are not recommended to be used without testing. According to the economic level of the job to be done and by controlling the error rate, the traditional Huber, Smalian, and Newton-Riecke equations can be applied.
- The "Average of the diameters at the ends," which is not used frequently, is a suitable equation option and should be preferred.

It is recommended to use proven equations for volumizing oriental spruce logs within the specified diameter limits. The results of this study can form a basis for future volume studies and it is recommended to use the study findings according to the economic value of the oriental spruce logs to be harvested or researched.

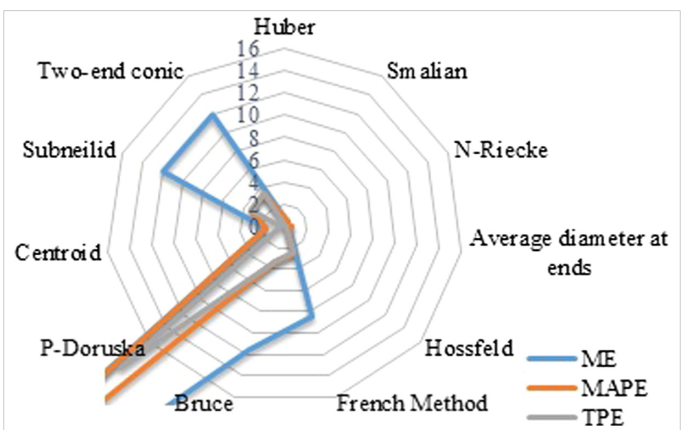

Figure 3.
Radar Chart for Error Values of Various Formulas.

In previous studies conducted in Turkey, Yavuz (1999) suggested the Centroid equation in ash, spruce, and beech logs; Özçelik (2002) reports that the Centroid equation was successful in red pine and cedar logs; Özçelik (2006) also suggested that Patterson–Doruska, Bruce, and Smalian equations can be used for volumizing red pine and cedar logs; Güney (2007) suggested that Huber and Smalian or with less error rate Centroid equation could be used to volumizing red pine and cedar logs and Durkaya and Durkaya (2011) reported that Smalian equation gives less error than Newton-Riecke and Huber equation in volumizing cedar and black pine logs.

Stempski (2021) investigated volumizing methods using various ways in scotch pines of varying lengths in Poland, whereas Lai and Jin (2021) investigated the dual Brunn–Minkowski inequality for log-volume of

Table 4.
Calculated Error Values and Relative Order of Various Volume Formulas

Method	ME		MAPE		TPE		Rank
Huber	.75	(4)	.79	(4)	−.215	(4)	(12)
Smalian	−.099	(1)	.526	(2)	.028	(1)	(4)
N-Riecke	−.272	(2)	.29	(1)	.078	(2)	(5)
Average of the diameters at the ends	−.549	(3)	.544	(3)	.157	(3)	(9)
Hossfeld	.615	*	0.38	*	−0.176	*	*
French Method	8.489	*	2.559	*	−2.43	*	*
Bruce	−11.462	*	3.28	*	3.28	*	*
P.-Doruska	−66.464	*	55.598	*	19.527	*	*
Centroid	−1.724	(5)	1.692	(5)	0.493	(5)	(15)
Subneilid	−11.994	*	3.433	*	3.433	*	*
Two-end conic	−11.956	*	3.422	*	3.422	*	*

Note: *Insignificant volume formulas.
ME = mean error; MAPE = mean absolute percent error; PTE, percent total error.

Table 5.
Error Values of Volume Formulas According to Log Lengths

	ME			MAPE			TPE		
Method	3	4	5	3	4	5	3	4	5
Huber	−.519	4.436	−2.713	.372	1.318	.691	.19	−1.088	.541
Smalian	−.058	−.032	−.395	.434	.716	.373	.021	.008	.079
N-Riecke	−.365	−.558	.692	.183	.424	.268	.133	.138	−.137
Average of the diameters at the ends	−.306	−.597	−1.322	.436	.712	.462	.112	.148	.263
Hossfeld	.697	.522	.519	.288	.505	.341	−.254	−.129	−.103
French method	6.579	5.503	16.835	2.481	2.069	3.34	−2.163	−2.405	−2.725
Bruce	−7.699	−13.237	−21.218	2.808	3.282	4.21	2.889	3.393	4.395
P-Doruska	−68.523	−85.64	−62.799	55.342	63.666	42.742	33.319	26.953	14.233
Centroid	.478	−2.652	−7.676	.997	2.412	1.801	−.174	.662	1.547
Subneilid	−7.991	−13.778	−22.601	2.915	3.416	4.484	3.002	3.536	4.695
Two-end conic	−7.971	−13.729	−22.526	2.907	3.403	4.469	2.994	3.523	4.678

Note: n (3 m) = 58; n (4 m) = 35; n (5 m) = 16.
ME = mean error; MAPE = mean absolute percent error; PTE, percent total error.

star bodies and the equivalent Minkowski inequality for mixed log-volume. However, no other study has been found in the literature comparing so many equations.

Conclusion and Recommendations

Our study is also in line with previous findings. Furthermore, certain variances may develop as a result of the employment of more methods than much earlier research, changes in the region where the logs were acquired and their location on the tree, and the measurement frequency chosen in other studies. The equation of "Average of the diameters at the ends" on the other hand, which has not been evaluated in other studies, gave a significant advantage in our investigation, and it is felt that the relevant equation should not be overlooked in this way. Apart from that, sample logs of various lengths were volumized using the same equations, and the error values of each equation were determined in logs of various lengths (Table 5).

When looking at Table 5, Özçelik (2006) and Güney (2007) agree that as the length of the log increases, the diameter decreases, and so the error rate increases. The number and kind of variables to be measured in each of the equations proposed within the scope of the study varied. As a result, considering the difficulties of the measurement phase and the time lost, alternative volume equations or equations should be preferred according to the importance or economic value of the work in the logs produced.

Very comprehensive measurements and calculations are necessary for the Centroid method, while the Newton-Riecke method involves diameter measurement at three separate sites, which is time-consuming and costly during volume computations. If the harvest is important for economic return, careful measurements should be made and appropriate volume equations should be preferred in order to avoid erroneous volume calculations and economic losses.

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References

- Avery, T. E., & Burkhart, H. E. (1994). *Forest measurement* (4th ed). McGraw Hill Book Co.
- Bruce, D. (1982). Butt log volume estimators. *Forest Science*, *28*, 489–503.
- Carus, S. (2002). Bazı Hacim Formüllerinin Seksiyon, Gövde ve Bağıl Uzunluklara Göre Kıyaslanması. *Süleyman Demirel University journal of forestry Faculty, A*, *1*, 101–114.
- Cruz de León, G., & Uranga-Valencia, L. P. (2013). Theoretical evaluation of Huber and Smalian methods applied to tree stem classical geometries. *Bosque (Valdivia)*, *34*(3), 13–14. [CrossRef]
- Davis, L. S., Johnson, K. N., Bettinger, P., & Howard, T. E. (2001). *Forest management: To sustain ecological, economic, and social values* (4th ed). Waveland Press, McGraw-Hill.
- Durkaya, B., & Durkaya, A. (2011). Comparing different volume formulas using log volume estimations. *Bartın Journal of Forestry Faculty*, *13*(20), 18–22.
- Filho, A. F., Machado, S. A., & Carneiro, M. R. A. (2000). Testing accuracy of log volume calculation procedures against water displacement techniques (xylometer). *Canadian Journal of Forest Research*, *30*(6), 990–997. [CrossRef]
- Güney, İ. H. (2007). *Ağaç ve Tomruk Hacimlerinin Tahmininde Kullanılan bazı Yöntemlerin Karşılaştırılması*. Süleyman Demirel University Institute of Science. Retrieved from https://tez.yok.gov.tr/UlusalTezMerkezi/tezSorguSonucYeni.jsp
- Japheth, H. D., Meer, B. B., & Ubaekwe, R. E. (2022). Volume equations for sustainable forest management of Ngel-Nyaki forest area in Taraba State. *Nature and Science*, *20*(1), 52–60. [CrossRef]
- Lai, D., & Jin, H. (2021). The dual Brunn–Minkowski inequality for log-volume of star bodies. *Journal of Inequalities and Applications*, *2021*(1), 112. [CrossRef]

- Li, C., Barclay, H., & Sidders, D. (2015). *Estimation of log volumes: A comparative study*. Natural Resources Canada, Canadian Forest Service, & Canadian Wood Fibre Centre. Retrieved from https://cfs.nrcan.gc.ca/pubwarehouse/pdfs/36459.pdf
- OGM (2020). Türkiye Orman Valığı. Retrived from https://www.ogm.gov.tr/tr/ormanlarimiz-sitesi/TurkiyeOrmanVarligi/Yayinlar/2020%20T%C3%BCrkiye%20Orman%20Varl%C4%B1%C4%9F%C4%B1.pdf
- Özçelik, R. (2002). Tomruk Hacminin Tahmininde Kullanılan Centroid Metod ve Dört Standart Formülün Karşılaştırılması, *Süleyman Demirel University Journal of Forestry Faculty, A*, *1*, 115–120.
- Özçelik, R. (2006). İstiflenmiş Tomruklarda Kullanılan Hacim Formüllerinin Karşılaştırılması. *Süleyman Demirel University Journal of Forestry Faculty, A*, *1*, 26–32.
- Özçelik, R., Wiant, Jr., H. V., & Brooks, J. R. (2008). Accuracy using xylometry of log volume estimates for two tree species in Turkey. *Scandinavian Journal of Forest Research*, *23*(3), 272–277. [CrossRef]
- Patterson, D. W., & Doruska, P. F. (2004). A new and improved modification to Smalian's equation for butt logs. *Forest Products Journal*, *54*(4), 69–72.
- Philip, M. S. (1994). *Measuring tree and forests* (2nd ed). CAB International.
- Şahin, A. (2015). *Mersin Yöresi Saf Kızılçam (Pinus Brutia Ten.) Meşcerelerinde Hasılat Araştırmaları* [PhDthesis]. Artvin Çoruh University Institute of Science. Retrieved from https://tez.yok.gov.tr/UlusalTezMerkezi/tezSorguSonucYeni.jsp
- Şahİn, A., & Korkmaz, S. S. (2021). Farklı Ağaç Türlerinde Çeşitli Tomruk Hacim Formüllerinin Karşılaştırılması. *Ormancılık Araştırma Dergisi*, *8*(2), 171–179. [CrossRef]
- Şahin, A., Sönmez, T., & Kahriman, A. (2017). Single entry raw wood products table construction for Calabrian pine (*Pinus brutia* Ten.) in Mersin region, Turkey. *Kastamonu University Journal of Forestry Faculty*, *17*(1), 23–35. [CrossRef]
- Stempski, W. (2021). Effect of top log diameter determining method on the Scots pine log volume determination, *Sylwan*. *Sylwan*, *165*(2), 109–116. [CrossRef]
- Syed Ahmad, S. S., Mohd Mushar, S. H., Zamah Shari, N. H., & Kasmin, F. (2020). A Comparative study of log volume estimation by using statistical method. *EDUCATUM Journal of Science, Mathematics and Technology*, *7*(1), 22–28. [CrossRef]
- Tewari, V., Singh, P., & B. (2005). Comparison of Bruce's formula and other methods for log volume estimation, India. *Indian Forester*, *131*(7), 917–924. [CrossRef]
- Wiant, H. V., Patterson, D. W., Hassler, C. C., Wood, G. B., & Rennie, J. C. (1996). Comparison of formulas for estimating volumes of butt logs of Appalachian hardwoods. *Northern Journal of Applied Forestry*, *13*(1), 5–7. [CrossRef]
- Williams, J. G., Mcnab, W. H., & Clark III, A. (1991). *Volume estimators for Pondcypress butt logs* (p. 7). Research Note SE-361. Southeastern Forest Experiment Station, USDA Forest Service.
- Yavuz, H. (1999). Comparison of the Centroid method and four standard formulas for estimating log volumes. *Turkish Journal of Agriculture and Forestry*, *23*, 597–602.