REVISTA BIO CIENCIAS
http://revistabiociencias.uan.edu.mx
https://doi.org/10.15741/revbio.12.e1639
ISSN 2007-3380

Original article / Artículo original

Timber volume for *Pinus leiophylla* Schl. & Cham., in Michoacán, Mexico

Volumen maderable para *Pinus leiophylla* Schl. & Cham., en Michoacán, México

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ABSTRACT

Forest plantations represent a viable alternative for the intensive production and procurement of raw materials, with a shorter growth time for the species. To obtain accurate results, it is necessary to use technical-scientific tools to assist in the decision-making process for effective forest management. This study aimed to select an equation for estimating the volume of individual trees of *Pinus leiophylla* Schl. & Cham. in forest plantations established in the Meseta Purépecha, Michoacán, Mexico. Using data on diameters (d_i) at different heights along the trunk (A_i) and the volume (*Vf*) (m³) of 43 trees, five-volume models were fitted using the statistical software RStudio®. The Schumacher model explains 97.56% of the sample variability, with significant coefficients ($p = 0.01$), an overall deviation of less than 0.018 m³, and an individual bias of 0.0009 m³. Additionally, ANOVA shows that the model fits differ, despite having similar degrees of freedom. The residuals obtained exhibit a normal distribution and an absence of heteroscedastic dispersion. This selected equation can be reliably used (97 %) to estimate the volume of trees in *P. leiophylla* forest plantations.

KEY WORDS: Allometry, temperate forests, mathematical models, forest management.

Please cite this article as/Como citar este artículo: Hernández-Ramos, J., Muñoz-Flores, H. J., Barrera-Ramírez, R., García-Cuevas, X., Hernández-Ramos, A., Buendía-Rodríguez, E. (2025). Timber volume for *Pinus leiophylla* Schl. & Cham., in Michoacán, Mexico. *Revista Bio Ciencias*, 12, e1639. https://doi.org/10.15741/revbio.12.e1639

Article Info/Información del artículo
Received/Recibido: February 19th 2024.
Accepted/Aceptado: February 14th 2025.
Available on line/Publicado: March 07th 2025.

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Revista Bio ciencias
ISSN 2007-3380

RESUMEN

Las plantaciones forestales representan una alternativa viable para la producción y obtención de materias primas de forma intensiva, en un menor tiempo de crecimiento de las especies. Para obtener resultados precisos, se requiere de contar con herramientas técnicas-científicas que ayuden a la toma de decisiones para un manejo forestal adecuado. El objetivo fue seleccionar una ecuación que estime el volumen fustal para árboles individuales de *Pinus leiophylla* Schl. & Cham. en plantaciones forestales establecidas en la Meseta Purépecha, Michoacán, México. Con datos de diámetros (d_i) a distintas alturas sobre el fuste (A_i) y el volumen fustal (Vf) (m^3) de 43 árboles se ajustaron cinco modelos de volumen en el programa estadístico Rstudio®. El modelo de Schumacher explica una variabilidad muestral del 97.56 %, sus coeficientes significativos (p = 0.01), desviación global menor a 0.018 m^3 y un sesgo individual de 0.0009 m^3. Además, el ANOVA señala que los ajustes de los modelos son distintos entre sí, aun cuando comparten un número semejante de grados de libertad. Los residuales obtenidos presentan una distribución normal y ausencia de dispersión heterocedástica. Esta ecuación seleccionada puede ser empleadas de manera confiable (97 %) para estimar el volumen fustal de árboles establecidos en plantaciones forestales de *P. leiophylla*.

PALABRAS CLAVE: Alométria, bosques templados, modelos matemáticos, manejo forestal.

Introduction

Forest plantations (FP) for commercial purposes are part of a strategy to meet the growing demand for forest products, reducing harvesting pressure on natural forests and preventing deterioration. Additionally, they increase timber and non-timber productivity and competitiveness, contributing to the economic development of rural areas (Prado, 2019). The assessment and quantification of FP productivity require technical-scientific tools such as site index labels (Hernández *et al.,* 2022), tapering functions (Tlaxcala-Méndez *et al.,* 2016), forest volume equations (Ramos-Uvilla *et al.,* 2014), whether commercial or total (Hernández-Ramos *et al.,* 2018), and growth and yield systems (Torres & Magaña, 2001). These tools facilitate the planning and application of silvicultural techniques, making production processes more efficient and increasing the estimation reliability (Furtado *et al.,* 2013).

In forest management, variables such as normal diameter (*d*, cm), total height (*At*, m), or clear stem height (*Afl*, m) are necessary for the proper management of forest resources, including

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the estimation of forest volume (*Vf*, m³). This estimation is required for managing both natural stands (Ramos-Uvilla *et al.,* 2014) and forest plantations (Rondón *et al.,* 2014; Gómez *et al.,* 2018). To estimate *Vf* accurately and at a low cost, the use of rates (Ramírez-Martínez *et al.,* 2016; Imaña-Encinas *et al.,* 2019) or updated volume equations generated from statistical techniques (Hernández-Ramos *et al.,* 2018) is necessary.

Modeling allometric relationships of trees has been a useful statistical resource for accurate dimensional estimation (Pompa-García *et al.,* 2011; García-Cuevas *et al.,* 2017). These quantitative tools must be reliable and feasible for saving time during data collection in a forest inventory (Picard *et al.,* 2012).

In Michoacán state, Mexico, volumetric rates have been widely used (Muñoz *et al.,* 2011; Sáenz *et al.,* 2013) because they only require *d* as a predictor variable (Jiménez *et al.,* 1998). However, these mathematical expressions do not account for differences in *At* among individuals (Ramírez-Martínez *et al.,* 2016). For many of the species used in established FPs at the Meseta Purépecha, Michoacán, Mexico, specific information for volume quantification in the development of forest management programs (FMP) is lacking, and a generic equation or one developed for other regions is often used. Therefore, the objective was to select an equation that accurately estimates the volume for individual trees of *Pinus leiophylla* Schl. in forest plantations established in the Meseta Purépecha, Michoacán, Mexico.

Material and methods

The study was conducted on *Pinus leiophylla* FPs established in the Indigenous Community (IC) of Patamban in the Tangancícuaro municipality, Michoacán, México. The IC belongs to the physiographic region of the Eje Neovolcánico Transversal, in the Sierra Meseta Purhépecha. It has a forest area of 11,232.07 ha, characterized by a temperate sub-humid forest ecosystem (Cw1) with summer rains, a mean annual temperature of 12 °C, a minimum of -2 °C, and a maximum of 22 °C, with a mean annual precipitation of 1,850 mm. The predominant soils are of volcanic origin, generally corresponding to ochric andosol (80 %), lithosol, and chromic Cambisol (INEGI, 2024). The *P. leiophylla* plantations are between 19° 44’ N and 102° 17’ W at 2,000 to 2,600 m altitude.

The evaluated FPs are free of pests and diseases with a survival rate of over 75%, ages ranging from seven to 15 years, total heights (*At*) from 5 to 23 m, and diameters (*d*) between 7 and 35 cm. Additionally, the sample of measured trees covered most growth conditions to capture the different stem shapes and sizes, according to Prodan *et al.* (1997) and Torres & Magaña (2001).

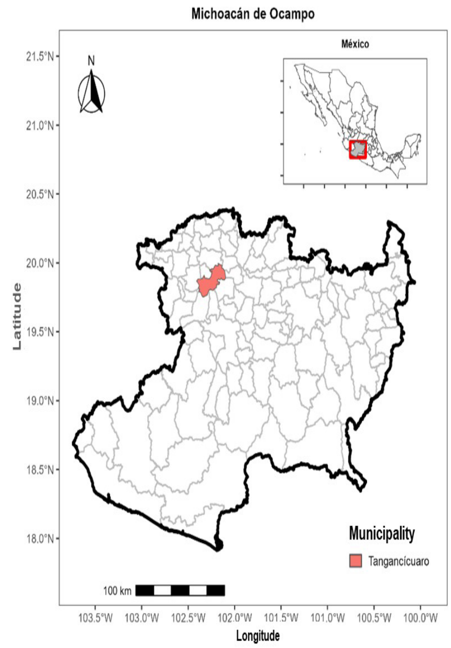

Figure 1. Location of the study area.

Own elaboration.

The sample consisted of 43 dominant trees (263 data pairs) selected using the site index methodology (Torres and Magaña, 2001), which were measured indirectly to obtain the diameter (di) at different heights above the trunk (Ai) with a Bitterlich Relascope. The measured trunk sections were defined based on the visibility of diameters. With the dimensions *d* and *At*, the volume (*V*) per section was estimated using the Smalian formula: $stump = \left[\left(\frac{g_{n-1}+g_i}{2}\right) L\right]$ and the tip with the cone formula: $V_{tip} = \left(\frac{g_n * L}{3}\right)$. Where: V_{stump} = Volume of the log (m^3), V_{tip}= Volume of the tip (m^3), g_{n-1} = Basal area of the largest diameter of the log (m^2), g_i = Basal area of the smallest diameter of the log (m^2), g_n = Basal area of the largest diameter of the tip (m^2), L = Length of the log (m) (Prodan *et al.* 1997; Torres & Magaña, 2001). With this database, two models were fitted to generate rates and three *Vf* models (Table 1) using the *nls* function and the maximum likelihood technique in the *R* program® *version 4.3.2* (R Team, 2023).

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Table 1. Volume equations for forest plantations of *Pinus leiophylla* Schl. & Cham. established in the Meseta Purépecha, Michoacán, Mexico. Own elaboration.

No. and model	Expression	References
1. Dissescu-Stanescu	$Vf = a_1 + a_2 \cdot d^2 + \varepsilon_i$	Ramírez-Martínez *et al*. (2016) and Imaña-Encinas *et al*. (2019).
2. Berkhout	$Vf = a_1 \cdot d^{a_2} + \varepsilon_i$	
3. Spurr	$Vf = a_1 \cdot (d^2 \cdot At)^{a_2} + \varepsilon_i$	Ramírez-Martínez *et al*. (2016) and Hernández-Ramos *et al.* (2018).
4. Constant morphic coefficient	$Vf = a_1 \cdot (d^2 \cdot At) + \varepsilon_i$	Prodan *et al.* (1997) and Torres & Magaña (2001).
5. Schumacher	$Vf = a_1 \cdot d^{a_2} \cdot At^{a_3} + \varepsilon_i$	Rondón *et al*. (2014) and Ramírez-Martínez *et al*. (2016).

Where: *d:* normal diameter (cm). *At*: total height (m). *Vf:* volume (m^3). a_iParameters to be estimated. ε_i: Error term.

The contrasts between the adjusted volume rates and the proposed models were carried out through an analysis of variance (*ANOVA*), at a confidence level of 99% (*p = 0.01*). For this purpose, the null hypothesis (H_o) of equality between the results of the adjustments and the alternative hypothesis (H_a) were used, in which there are statistical differences between the rates and the volume models. Regarding the selection of the model, classical statistics used in forestry studies were considered, where it was included to verify the significance of the values of the parameters (*a = 0.01*), the values of the coefficient of determination (R^2 [6]), the root mean square of the error (*RMSE* [7]) and the Bias [8] (Rondón *et al.,* 2014; Ramos-Uvilla *et al.,* 2014; Ramírez-Martínez *et al*., 2016; Imaña-Encinas *et al.,* 2019).

$$R^2 = \frac{\sum_{i=1}^{n}(y_i - \hat{y_i})^2}{\sum_{i=1}^{n}(y_i - \bar{y_i})^2} \quad [6]$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \hat{y_i})^2}{n-1}} \quad [7]$$

$$Bias = \sum_{i=1}^{n}\left(\frac{y_i - \hat{y_i}}{n}\right) \quad [8]$$

where,y_i, $\hat{y_i}$ and $\bar{y}_i$ are the observed, estimated, and average values, respectively; and n is the total number of data used in fitting the models.

The regression assumptions were verified through the Shapiro-Wilk (SW) test for normality of the residuals where the value of *W* close to unity will indicate a Gaussian bell-shaped distribution. Dispersion of the residuals of the model *versus* fitted values will have to be close to zero and without evidence of a homoscedastic distribution of the residuals, considering that the values of asymmetry and kurtosis should not exceed three standard deviations (Martínez *et al.,* 2014).

Results

Descriptive statistics of data indicate that no variable has asymmetry and kurtosis problems in its distribution (value < 3.0), in addition to the fact that on average the sampled trees increase 47 cm in *At* for each centimeter increase in *d* dimension (Table 2).

Table 2. Descriptive statistics of the sample used for the analysis. Own elaboration.

Statistic parameter	Total height (*At*, m)	Normal diameter (*d*, cm)	d^2 *At*	Bole volume (m^3)
Media	8.4	18.0	0.3338	0.1635
Minimum	3.7	10.0	0.0448	0.0417
Maximum	12.0	31.0	1.1532	0.5365
Standard error	0.2881	0.8811	0.0425	0.0173
Standard deviation	1.8894	5.7776	0.2785	0.1135
Sample variance	3.5700	33.3810	0.0776	0.0129
Kurtosis	-0.3	-0.4	1.5	1.9
Asymmetry coefficient	-0.2	0.6	1.4	1.4

The adjustment results indicated that the Schumacher model presented goodness-of-fit indicators that explained 97.56 % of the sample variability for the combination of dimensions of the variables *d* (10-31 cm) and height (4-12 m). In addition, all coefficients were significant ($p = 0.01$), with an overall deviation of less than 0.018 m^3 and an individual bias of 0.0009 m^3 (Table 3).

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Table 3. Goodness-of-fit statistics and indicators of the proposed expressions for estimating the bole volume of plantations of *Pinus leiophylla* Schl. & Cham. plantations established in the Meseta Purépecha, Michoacán, Mexico. Own elaboration.

No.	Parameters	Estimated value	Standard error	t-value	Pr(>|t|)	R^2	*RMSE*	*Bias*
1	a_1	-0.009784	0.00568	-1.723	0.0925	0.96963	0.01955	<0.00001
	a_2	0.000486	0.00001	36.178	<0.0001			
2	a_1	**0.000288**	**0.00006**	**4.82**	**<0.0001**	**0.97130**	**0.01901**	**0.00078**
	a_2	**2.152000**	**0.06480**	**33.21**	**<0.0001**			
3	a_1	0.423833	0.00815	51.98	<0.0001	0.97262	0.01901	0.00114
	a_2	0.836331	0.02467	33.91	<0.0001			
4	a_1	0.454330	0.00918	49.49	<0.0001	0.94736	0.02605	0.01236
5	a_1	**0.000228**	**0.00005**	**4.651**	**<0.0001**	**0.97561**	**0.01817**	**0.00093**
	a_2	**1.893854**	**0.11206**	**16.901**	**<0.0001**			
	a_3	**0.455958**	**0.17022**	**2.679**	**0.01070**			

Where, Pr(>||t|): Probability at 99 % ($p=0.01$). R^2: coefficient of determination. *RSME:* root square mean error.

Even though statistically the Berkhout expression (Table 2) explains 97.13% of the data distribution (R^2 = 0.9713) and has an overall deviation of 0.1901 m^3 (*RMSE*) and individual deviation of 0.00078 m^3 (*bias*) in relation to the proposed double entry model (Schumacher), this volume rate is a reliable alternative to estimate the *Vf* of these plantations, since the dimension of the *At* is not always available in the field information from a forest inventory to estimate *Vf* within a forest management plan.

The contrasts between rates and volume models through ANOVA indicate that the H_o of equality of adjustments is rejected, and H_a is accepted, where it can be observed that the results are different from each other, even though they share a similar number of degrees of freedom (Table 4). The observed differences are due to the mathematical structure of each proposed expression, both between rate, which only uses *d* to estimate *Vf*, and between volume models that use *d* and *At* as explanatory variables.

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Table 4. Analysis of variance (ANOVA) between the expressions proposed to estimate the stem volume (*Vf*) of *Pinus leiophylla* Schl. & Cham. in forest plantations on the Purépecha Plateau, Michoacán, Mexico. Own elaboration.

Model	Degrees of freedom	Sum of Squares	Mean square	F-value	Probability (Pr>F)
1	41	0.0148			
2	42	0.0285	-0.0137	37.833	<0.0001
3	40	0.0132	0.0153	23.166	<0.0001
4	41	0.0164	-0.0032	9.815	0.0032
5	41	0.0155	<0.0001		

The SW test for the Berkhout (W = 0.93, p = 0.01563) and Schumacher (W = 0.93, p = 0.02134) expressions are close to unity, hence, the frequencies of the residuals tend to normality (Figure 2a and 2c); also, the distribution of the residuals is close to zero, with no heteroscedastic dispersion in the fitted values for both models (Figure 2b and 2d). Therefore, the statistical fit is considered robust and adequate.

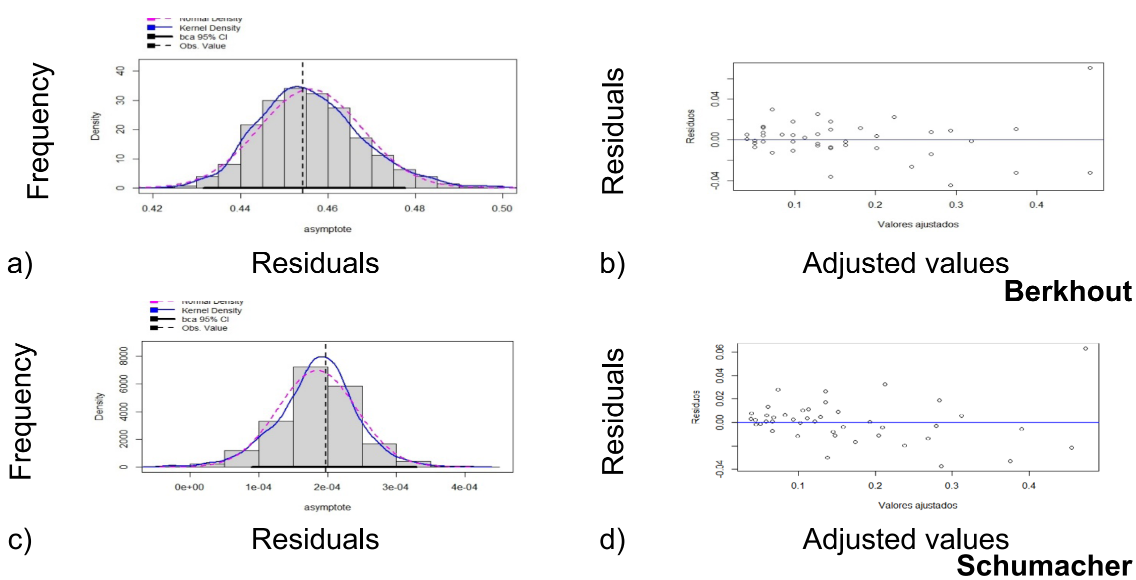

Figure 2. Graphic tests of the assumptions of normality (a and c) and distribution of residuals (b and d) of the expressions proposed to estimate the bole volume (*Vf*) of *Pinus leiophylla* Schl. & Cham. in Michoacán, Mexico.

Own elaboration.

Discussion

The statistical adjustments (R^2 and *RMSE*) and the bias found in this work indicated that both the one-entry expression (Berkhout [2]) and the Schumacher-Hall (5) for estimating *Vf* are feasible for use and reliable implementation within forest management plans for this species in the study area.

Complementarily, the results of the fit (Table 2) in the Spurr (3) and Constant Morphic Coefficient (4) models show that the trunk has a paraboloid type shape (Shape factor (*ff*): 0.42 and 0.45), in agreement with that described by Tlaxcala-Méndez *et al.* (2016) when performing an evaluation of *ff* and taper for trees of different provenances in *Cedrela odorata* L. in Veracruz; and Hernández-Ramos *et al.* (2018) when modeling through ratio functions the commercial volume of *Swietenia macrophylla* King in Quintana Roo, Mexico.

In both cases it was not necessary to perform a linearization of the mathematical expression to obtain the adjustment as performed by Imaña-Encinas *et al.* (2019) for forest plantations of *Eucalyptus urophylla* S. T. Blake in Goiás, Brazil in Hummel volume rates: $log\ (Vf)\ = a_1 + a_2 \cdot log\ (d) + \varepsilon_i$, and Brenac: $log\ (Vf)\ = a_1 + a_2 \cdot log\ (d)\ + a_3 \cdot d^{-1} + \varepsilon_i$, as well as the volume models of Spurr: $log\ (Vf)\ = a_1 + a_2 \cdot log\ (d^2 At) + \varepsilon_i$ and Meyer: $log\ (Vf)\ = a_1 + a_2 \cdot d + a_3 \cdot d^2 + a_4 \cdot (d \cdot At) + a_5 \cdot (d^2 At) + a_6 \cdot d + \varepsilon_i$; or the transformation of the explanatory variables of *d* and *At* with a logarithmic form in the expressions of Husch: $Vf = a_1 + a_2 \cdot log\ (d) + \varepsilon_i$ and Schumacher: $Vf = a_1 \cdot log\ (d)^{a_2} \cdot log\ (At)^{a_3} + \varepsilon_i$.as performed by Gómez *et al.* (2018) in plantations of *Hevea brasiliensis* Müell Arg. in Huimanguillo, Tabasco, Mexico.

The use of one expression or another will depend on the availability of information from the forest inventory since many times the *At* dimension is absent due to the high cost and time represented by its field measurement (García-Cuevas *et al.,* 2017; Ramírez-Martínez *et al.,* 2016). However, it is imperative to highlight that combining the dasymetric variables of *d* and *At* to estimate tree volume contributes to the precision of the estimates (Ramos-Uvilla *et al.,* 2014) due to the high correlation between them (Rondón *et al.,* 2014; Gómez *et al.,* 2018). Contrary to volume rates that assume individuals with the same dimension of *d* have the same *Vf*, these do not consider variations in *At* caused by site productivity (Ramírez-Martínez *et al.,* 2016; Gómez *et al.,* 2018).

The proposed Schumacher-Hall model has been selected to estimate the volume in plantations of *Pinus maestrensis* Bisse in the municipalities of Guisa, Buey Arriba, and Bartolomé Masó, Cuba (Rondón *et al.,* 2014): $Vf = 0.002 \cdot d^{1.454} \cdot At^{0.164} + \varepsilon_i$; and for *Pinus ayacahuite* Ehren with and without bark in Ixtlán de Juárez, Oaxaca, Mexico (Ramírez-Martínez *et al.,* 2016): $Vf = 0.000076 \cdot d^{1.78081} \cdot At^{1.005776} + \varepsilon_i$ y $Vf = 0.00004 \cdot d^{1.769716} \cdot At^{1.171917} + \varepsilon_i$, respectively.

The Berkhout expression (2) was also selected for having no transformed variables for adjustment and its parsimony by Ramírez-Martínez *et al.* (2016) to estimate the volume with and

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without bark of *Pinus ayacahuite* in Ixtlán de Juárez, Oaxaca, Mexico: $Vf = 0.000076 \cdot d^{1.997399} + \varepsilon_i$ .y $Vf = 0.000816 \cdot d^{2.01732} + \varepsilon_i$. Even though the proposed expressions have high precision (*Bias* <0.0009 m^3 individual^{-1}) this may vary according to the conditions of site productivity and the genetic characteristics of the plantations being evaluated, as well as being applied outside the range of the dimensions with which they were adjusted or in crops with inadequate silvicultural treatments (Prodan *et al.,* 1997; Torres & Magaña, 2002; Ramírez-Martínez *et al.,* 2016).

The average *ff* (0.44) resulting from this work for *P. leiophylla* trees in forest plantations in the region of Michoacán, Mexico, differs from the 0.60 used by Muñoz *et al.* (2011) and Sáenz *et al.* (2013) when evaluating plantations in the Sierra Madre Occidental and three potential municipalities in eastern Michoacán, Mexico, respectively. This contrast shows that the constant updating of quantitative silvicultural information is essential since due to different silvicultural activities or the evolution of plantation management itself, there have been modifications in the tapering of individuals of this species.

Conclusion

The expression of Berkhout (one-variable predictor) and Schumacher (two-variable predictor) can be used reliably, with 97 % accuracy, to estimate the volume of established trees in forest plantations of *Pinus leiophylla* in the Meseta Purépecha, Michoacán, Mexico. In addition, these expressions are important quantitative methodologies in the real FP stock calculation of this species, for which, until now, this information was not available.

Author contribution

Conceptualization of the work: XGC, JHR, HJMF, and RBR. Methodology development: HJMF, RBR, AHR, and EBR. Experimental validation: JHR, XGC, and AHR. Data management: RBR, EBR and JHR. Manuscript writing and preparation: JHR, EBR, and XGC. Writing, proofreading, and editing: AHR, RBR and HJMF. Project management: HJMF, JHR, and RBR. Acquisition of funds: RBR, HJMF, and JHR.

"All authors of this manuscript have read and accepted the published version of this manuscript."

Financing

Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, through the project "Estimación de carbono almacenado en plantaciones forestales comerciales de pino en la Sierra Purhépecha, Michoacán" with SIGI identification number: 2-1.6-12202035967-F-M.2.

Acknowledgments

To the Indigenous Community of Patamban, Michoacán, and Mr. Luis Manuel Acosta Ibarra, Technical Service Provider of the same community, for his support in the coordination and information of the commercial forestry plantations established in the region of this community.

Conflict of interest

"The authors declare that they have no conflict of interest."

References

Hernández R., J., Hernández-Ramos, A., Ordaz-Ruiz, G., García-Espinoza, G. G., García-Magaña, J. J., & García-Cuevas, X. (2022). Índice de sitio para plantaciones forestales de *Pinus patula* en el Estado de México. *Madera Y Bosques,* 28(2), e2822308. https://doi.org/10.21829/myb.2022.2822308

Hernández-Ramos, J., Hernández-Ramos, A., García-Cuevas, X., Tamarit-Urias, J.C., Martínez-Ángel, L., & García-Magaña, J. (2018). Ecuaciones de volumen total y de razón para estimar el volumen comercial de *Swietenia macrophylla* King. *Colombia Forestal,* 21(1), 34-46. https://doi.org/10.14483/2256201X.11965

Furtado, B. P., D. H. Breda, M. Lopes da Silva, H. Garcia & M. L. Marques da Silva. (2013). Conversão de árvores em multiprodutos da madeira utilizando programação inteira. *Revista Árvore,* 37(5), 881-887. https://doi.org/10.1590/S0100-67622013000500010

Imaña-Encinas, J., Antunes-Santana, O. & Riesco-Muñoz, G. (2019). Selección de una ecuación volumétrica para *Eucalyptus urophylla* S.T. Blake en la región central del estado de Goiás, Brasil. *Revista Forestal Mesoamericana Kurú,* 16(39), 2-9. https://doi.org/10.18845/rfmk.v16i39.4406

García-Cuevas, X., Hernández-Ramos, J., García-Magaña, J. J., Hernández-Ramos, A., Herrera-Ávila, V., González-Peralta, A. & Garfias-Mota, E. J. (2017). Predicción de diámetro normal, altura y volumen de *Abies religiosa* a partir del diámetro del tocón. *Madera bosques,* 23(3), 61-70. https://doi.org/10.21829/myb.2017.2331528

Gómez G., J. P., Domínguez-Domínguez, M., Martínez-Zurimendi, P. & Ramírez V., G. (2018). Ecuaciones de volumen para estimar la producción maderable de *Hevea brasiliensis* Müell Arg. En plantaciones de etapas adulta y vejez. *Madera y Bosques*, 24(2), 1-18. https://doi.org/10.21829/myb.2018.2421867

INEGI [Instituto Nacional de Estadística y Geografía] (2024). Conjunto de datos vectoriales carta de uso de suelo y vegetación serie VI. Escala 1:250 000, 1ra edición. Disponible en: https://www.inegi.org.mx/temas/usosuelo/#descargas (22 de enero de 2024).

Jiménez P., J., Aguirre C., O. A., Treviño G., E. J. & Domínguez C., A. (1998). Desarrollo de un sistema matemático para la elaboración de tarifas volumétricas en especies arbóreas. *Madera y Bosques,* 4(2), 67-77. https://doi.org/10.21829/myb.1998.421360

Revista Bio ciencias
ISSN 2007-3380

Martínez G., M. A., A. Sánchez V., E. A. Toledo A., & J. Faulin F. (2014). Bioestadística amigable. 3a Edición. Elsevier España, S. L. Barcelona, España. 596 p.

Muñoz F., H. J., Sáenz R., J. T., García M., J. J., Hernández M., E., & Anguiano C., J. (2011). Áreas potenciales para establecer plantaciones forestales comerciales de *Pinus pseudostrobus* Lindl. y *Pinus greggii* Engelm. en Michoacán. *Revista Mexicana de Ciencias Forestales*, 2(5): 29-44. https://doi.org/10.29298/rmcf.v2i5.585

Prado D., J. A. (2019). Plantaciones forestales más allá de los árboles. CORMA sustentable. Santiago, Chile. 168 p. https://cifag.cl/wp-content/uploads/2019/04/Libro-plantaciones.pdf

Pompa-García, M., H. M. de los Santos-Posadas, M. E. Zepeda-Bautista, y J. J. Corral-Rivas (2011). Un modelo dendrométrico para estimación del diámetro normal a partir de las dimensiones del tocón. *Agrociencia,* 45(3), 379-387. http://www.redalyc.org/articulo.oa?id=30219764010

Picard N., L. Saint-André, y M. Henry (2012). Manual de construcción de ecuaciones alométricas para estimar el volumen y la biomasa de los árboles: del trabajo de campo a la predicción. Naciones Unidas para la Alimentación y la Agricultura-Centre de Coopération Internationale en Recherche Agronomique pour le Développement. Roma, Italia. 223 p. https://www.fao.org/4/i3058s/i3058s.pdf

Prodan, M., R. Peters, F. Cox, & P. Real. (1997). Mensura forestal. Serie de investigación y evaluación en desarrollo sostenible. IICA, GTZ. San José, Costa Rica: 586 p. https://repositorio.iica.int/bitstream/handle/11324/15038/CDCR21030929e.pdf

Ramírez-Martínez, A., Santiago-García, W., Quiñonez-Barraza, G., Ruiz-Aquino, F., & Martínez-Antúnez, P. (2016). Modelos de volumen fustal para *Pinus ayacahuite* Ehren. *Revista Mexicana de Agroecosistemas*, 3(2), 61-74. https://www.researchgate.net/publication/313853277_MODELOS_DE_VOLUMEN_FUSTAL_PARA_Pinus_ayacahuite_Ehren_STEM_VOLUME_MODELS_FOR_Pinus_ayacahuite_Ehren

Ramos-Uvilla, J. A., García-Magaña, J. J., Hernández-Ramos, J., García-Cuevas, X., Velarde-Ramírez, J. C., Muñoz-Flores, H. J. & García Espinoza, G. G. (2014). Ecuaciones y tablas de volumen para dos especies de *Pinus* de la Sierra Purhépecha, Michoacán. *Revista Mexicana de Ciencias Forestales*, 5(23), 92-108. https://cienciasforestales.inifap.gob.mx/index.php/forestales/article/view/344

Rondón G., D. N., Barrero M., B., & Lores P., Y. (2014). Modelo de regresión para la estimación del volumen fustal en plantaciones de *Pinus maestrensis* Bisse. *Revista Avances*, 16(3), 202-211. https://www.redalyc.org/pdf/6378/637867045003.pdf

Sáenz R., J. T., Villaseñor R., F. J., Muñoz F., H. J., Rueda S. A. & Prieto R., J. A. (2013). Evaluación de plantaciones de restauración en tres municipios del estado de Michoacán. Folleto Técnico Núm. 32. SAGARPA- Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias-CIRPAC. Campo Experimental Uruapan. Uruapan, Michoacán, México. 24 p.

Tlaxcala-Méndez, R. M., De los Santos-Posadas, H. M., Hernández-De la Rosa, P., & López-Ayala, J. L. (2016). Variación del factor de forma y el ahusamiento en procedencias de cedro rojo (*Cedrela odorata* L.). *Agrociencia,* 50(1), 89-15. https://www.redalyc.org/articulo.oa?id=30243765007

Torres, R., J. M., & Magaña T., O. S. (2001). Evaluación de plantaciones forestales. Editorial. Limusa, México. 472 p.