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Use of the threshold segmentation method as an alternative for estimating the volume of forest industry residues

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Abstract: In recent decades, the interest in searching for procedures and strategies to make energetic and economic use of residues from different industries has been an important part of the political agenda. There are several methods to determine the volume of residues from the forestry industry, but they are too time-consuming to apply. The objective of the present study was to establish a simpler and more efficient method to quantify the volume of residues from the forest industry. Ten controlled piles were made with residues from a private sawmill in the city of Durango, Mexico. To calculate the volume, two manual methods and one automatic method were used to calculate the stacking coefficient of the piles, while the water immersion method was used to calculate the real volume. A completely random experimental design was used for the analysis, where an analysis of variance and mean comparisons were performed at a significance level of $P \leq 0.05$. The results of the study show that the threshold segmentation method is faster, more practical and efficient than the other methods used. The estimation of the volume of these residues will contribute to generating sustainable alternatives for the development and use of forest industry resources.

Keywords: residue measurement; sawmill industry; segmentation by threshold; stacking ratio; volume measurement

The sawmilling industry processes roundwood and transforms it into forest products such as beams, boards, planks, timber, and sleepers. This industry represents about 70% of Mexico's annual forest production (Ortiz Barrios et al. 2016). Most studies on this topic focus on determining the volumetric yield of these products, showing a sawmill yield that ranges between 45% and 60% (Luna et al. 2012), so that approximately 40% becomes residues considered of little to no economic value (Fregoso-Madueño et al. 2017).

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Given this panorama, there are many areas of opportunity for the use of these residues and by-products, including energy generation, thermal applications, fuels for transportation and energy services in rural areas. Notwithstanding the above, the manufacture of solid fuels from forest residues obtained from the forestry sector has become an important option because energy can be produced that would solve many of the problems of Mexico's forest regions (Goche-Télles et al. 2016). Only in the field of residual biomass is it possible to create an exponentially growing annual energy yield rate that replaces many energies of a more expensive and environmentally damaging nature, such as all fossil fuels (González 2014). The disposal and devaluation of these residues remain a problem for this type of industry; correct management of these residues involves more detailed knowledge of the volumes and qualities of these residues.

The determination of the volume generated in these industries generally focuses on establishing the relationship between the volume of lumber produced and the volume of the log before sawing, using methods such as the Huber and Smalian methods to calculate the volume of the log. In general, the Smalian method is known to be less accurate than the Huber method, but it is used more frequently, especially when logs cannot be measured in the middle of the log (de León, Uranga-Valencia 2013). However, when it is necessary to estimate the volume of log piles, other methods are used that involve the notion of stacking coefficient to distinguish between the real volume and the apparent volume, where it is applied to photographs of point grids and the surface area is estimated by counting points mainly for the cubing of logs (Rondeux 2010). There are also other methods, such as Shellman's ruler or Bitterlich's template, which use a principle similar to that of the point-centred quarter method, estimating the surface area by counting points (Diéguez Aranda et al. 2003).

On the other hand, the estimation of the volume of firewood, heating wood and small pieces of wood from the forest industry is traditionally quantified by stacking piles (Rondeux 2010). These can present problems of accuracy since they are divided into those that determine the apparent volume and those methods considered exact; the former is the method of special tables and stacking coefficient, while the latter is by immersion or xylometer and ponderal or by weighing (Diéguez Aranda et al. 2003) To overcome the drawbacks of manual measurement, automated measurement methods have been proposed, which use photoelectric, optical or laser means to measure the size of the trunk and calculate the volume, such as the use of a cell phone with a rangefinder to measure the wood trunk, where the accuracy of the measurement reached 98.2%, or the use of image segmentation to detect 3D structural information and measure the size of the trunk, whose error was only 4.8% compared to manual measurement. However, obtaining images in a real environment such as a sawmill is difficult as it is complicated to separate the useful elements of the image from the complex background (Yu et al. 2023). Therefore, there is still a need for more accurate, faster, and less costly estimations. Consequently, the present study aims to establish a simple and efficient method to quantify the volume of residues from the forest industry, and at the same time to be affordable for different environments, as is the case of the industry in Mexico, where 94.4% of the forest area with forest harvesting authorisation is owned by ejidos and communities (Carrillo Anzures et al. 2017).

MATERIAL AND METHODS

Study area

The forest residues were obtained from a private sawmill located on the outskirts of the city of Durango, Mexico. The residues of the *Pinus* spp. come from the first sawmills generated by the main band sawmill. The methods to determine the stacking coefficient (Ca), apparent volume (Va), and thus the calculated volume were determined from ten piles of residues of 0.5 m × 0.5 m × 0.5 m (0.125 m^3 apparent volume; Figure 1).

The Va of the residue piles was calculated with the following Equation (1):

$$Va = l \times h \times w \quad (1)$$

where:

Va – apparent volume of the pile in m^3;

l, h, w – length, height, and width of the pile in meters, respectively.

In each pile of 0.125 m^3, the best arrangement of the residues was sought to try to reduce empty spaces.

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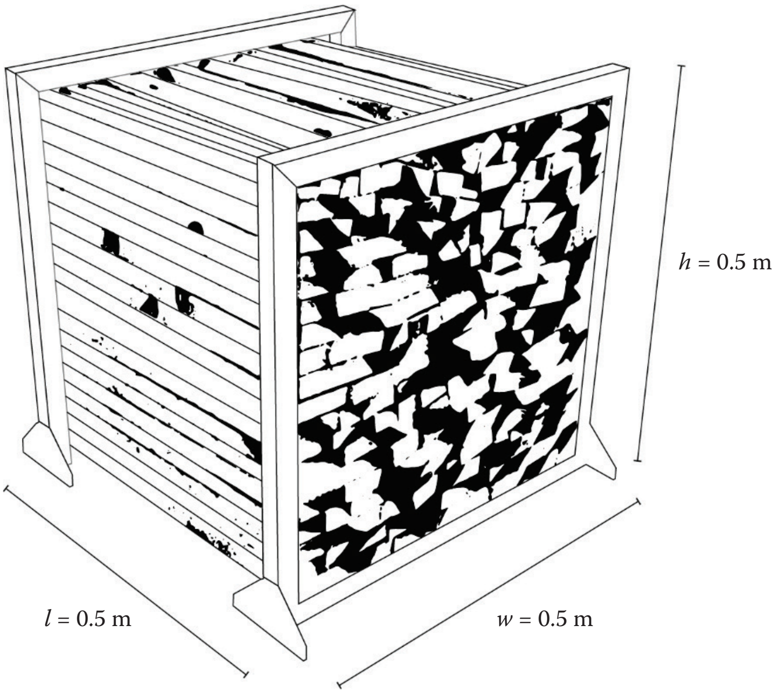

Figure 1. Schematic and measurements of the shaped piles

l, *h*, *w* – length, height, and width of the pile in meters, respectively

Methods for estimating the stacking coefficient

The point-centred quarter method, Shellman's ruler and threshold segmentation methods used in this research to estimate the volume of residues were based on images taken from two faces of the stacks (Figure 2). Images were captured with a Nikon HD digital SLR camera (Nikon, Japan) at a resolution of 6 000 × 4 000 pixels, at a distance of 0.7 m, and at a height of 0.25 m.

Point-centred quarter method. The method consisted of superimposing the images of a template or digital square of 81 interior points (vertices) and 40 exterior points to have a total of 121 points (Galán Larrea et al. 2014). The *Ca* was determined by the ratio between the number of counted points that were presented on wood with the total points of the point-centred quarter method, using the following Equation (2):

$$Ca = \frac{Pm}{Pt} \tag{2}$$

where:

Ca – stacking coefficient;

Pm – number of points falling on the wood;

Pt – number of total points in the mesh or mobile square (Galán Larrea et al. 2014).

For each of the two faces of the piles, the *Ca* was calculated from three repetitions. The first was ob-

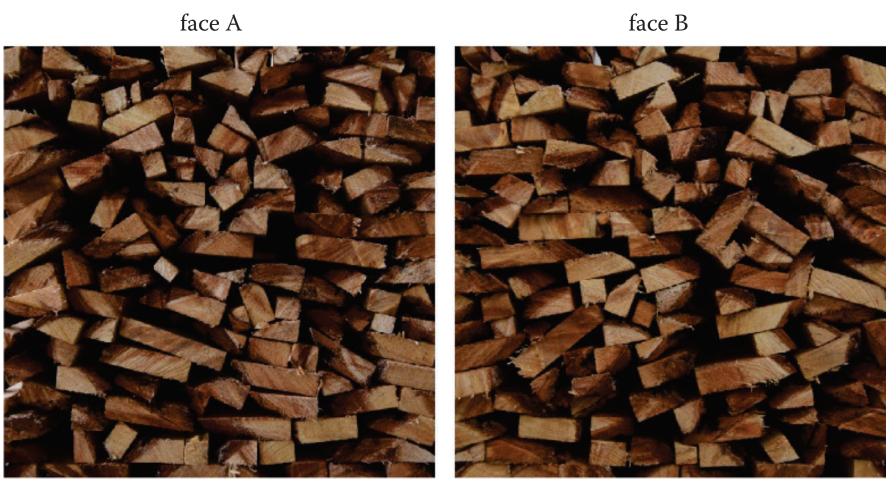

Figure 2. Images of the analysed faces of pile 1

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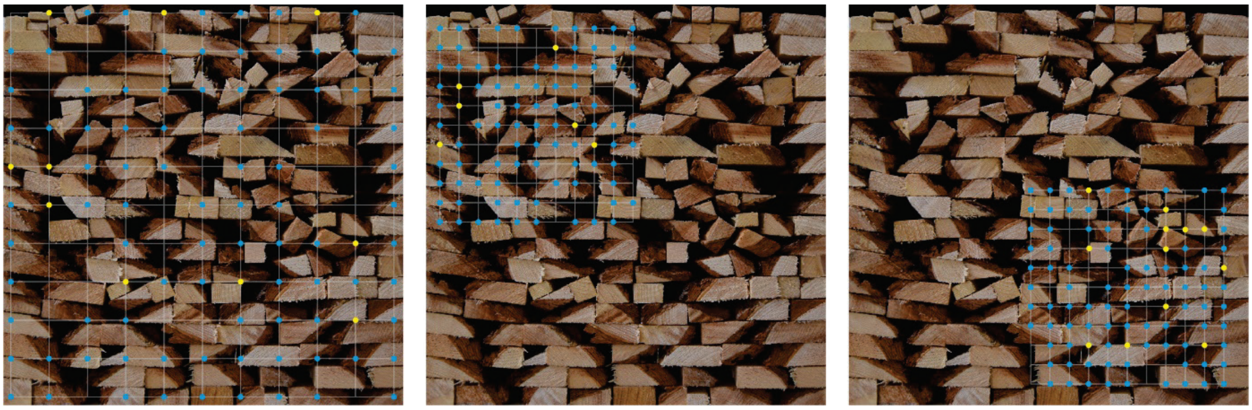

Figure 3. Images of the template overlay on one side of the shaped piles

Blue colour – dots where the template recorded contact with wood; yellow colour – doubtful dots that fall on the edges of wood pieces and were considered half points

tained by placing the template at the centre of the face, covering the entire face, and the other two repetitions were performed at a quarter of the image with the following arrangements: top-left and bottom-right (Figure 3). The mean *Ca* obtained is the estimated *Ca* of the stack.

Shellman's ruler method. The method consisted of superimposing a digital ruler divided into 100 equal parts on two sides of the residues pile. The *Ca* was calculated by quantifying the number of points of the ruler that fall into a gap (*N*), using the following Equation (3):

$$Ca = 100 - \frac{N}{100} \tag{3}$$

where:

Ca – stacking coefficient;

N – number of points that fall into a hole;

100 – number of total points of the ruler (Diéguez Aranda et al. 2003).

In the first repetition, the ruler was placed vertically in the centre and the other two at 45° and 315°, respectively (Figure 4). The average *Ca* obtained is the estimated *Ca* of the pile.

Threshold segmentation:

(***i***) ***Semantic segmentation.*** Semantic segmentation is responsible for classifying pixels with semantic labels with a set of object categories and is applied to all pixels in an image (Minaee et al. 2022). There are multiple semantic segmentation methods; however, the simplest one that can be easily applied to the material that was worked on in this research is the one based on a threshold value (Bradski, Kaehler 2008). In this method, a comparison of the intensity value of each pixel is made with respect to a threshold value (determined according to the problem), and then a new value is assigned to identify it, in this case, 0 for a hole and 255 for wood. This operation is defined in the following Equation (4):

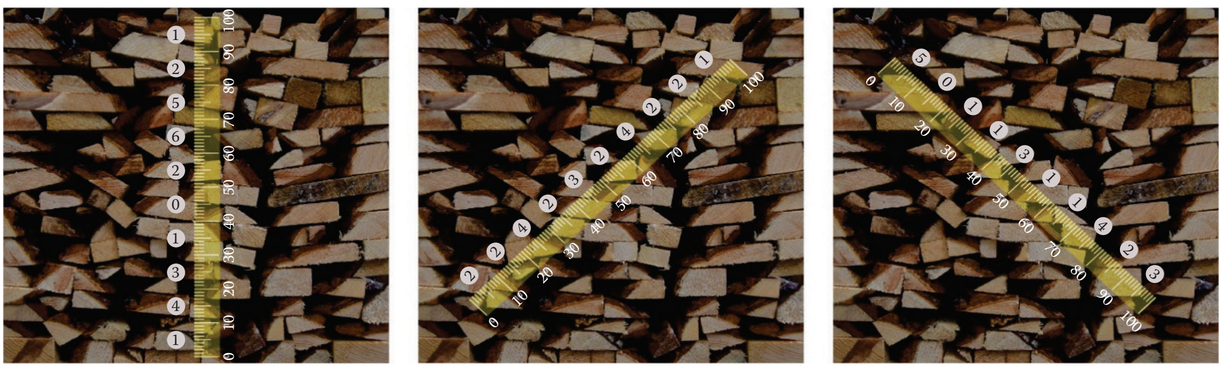

Figure 4. Images of the ruler overlay on one face of the shaped piles

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$$NIm'(x,y) = \begin{cases} 255 & Im(x,y) > threshold \\ 0 & Im(x,y) < threshold \end{cases} \quad (4)$$

where:

NIm' (*x*, *y*) – new image with the classified pixels;
Im (*x*, *y*) – original image;
threshold – value that allows to differentiate the objects present in the image (Figure 5).

(***ii***) ***CIE LAB colour space.*** The CIE LAB colour space was created in 1976 by the International Commission on Illumination (CIE) and describes all human-perceptible colours in a three-dimensional space. It consists of three channels: one called '*L*' for luminance and two called '*a*' and '*b*' for chromaticity (*a* – green and red; *b* – blue and yellow). This has the advantage that the segmentation can be performed independently of brightness fluctuations that may occur due to changing environmental conditions during image capture (Rico-Fernández et al. 2019).

The conversion from RGB space to LAB space involves going to CIE *XYZ* coordinates by a linear transformation and then to LAB by a nonlinear transformation. For the transformation used, see Equations (5–11):

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \leftarrow \begin{bmatrix} 0.412453 & 0.357580 & 0.180423 \\ 0.212671 & 0.715160 & 0.072169 \\ 0.019334 & 0.119193 & 0.950227 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (5)$$

$$X \leftarrow \frac{X}{X_n}, \text{ where } X_n = 0.950456 \quad (6)$$

$$Z \leftarrow \frac{Z}{Z_n}, \text{ where } Z_n = 1.088754 \quad (7)$$

$$L \leftarrow \begin{cases} 116\,Y^{\frac{1}{3}} - 16 \text{ for } Y > 0.008856 \\ 903.3\,Y \text{ for } Y \leq 0.008856 \end{cases} \quad (8)$$

$$a \leftarrow 500\left[f(X) - f(Y)\right] + delta \quad (9)$$

$$b \leftarrow 200\left[f(Y) - f(Z)\right] + delta \quad (10)$$

$$f(t) = \begin{cases} t^{\frac{1}{3}} \text{ for } t > 0.008856 \\ 7.787\,t + \frac{16}{116} \text{ for } t \leq 0.008856 \end{cases} \quad (11)$$

where:

X, *Y*, *Z* – colour space coordinates;
n – standard illuminant D65 values;
L – luminance;
a, *b* – chromaticity;
t – value from *X*, *Y*, *Z* colour space.

Delta takes a value of 128 when the image has a depth of 8 bits. After conversion, the values obtained are as follows: $0 \leq L \leq 100$; $-127 \leq a \leq 127$; $-127 \leq b \leq 127$, for explanation see above.

(***iii***) ***Calculation of the stacking coefficient.*** To obtain the stacking coefficient, threshold segmentation uses the same principle as the Moving Square and Spellman's ruler methods, it also analyses a series of points on the images, counting those that fall on wood and those that fall on hollow to obtain a percentage that is used to infer the real volume

Figure 5. Image conversion to semantic segmentation

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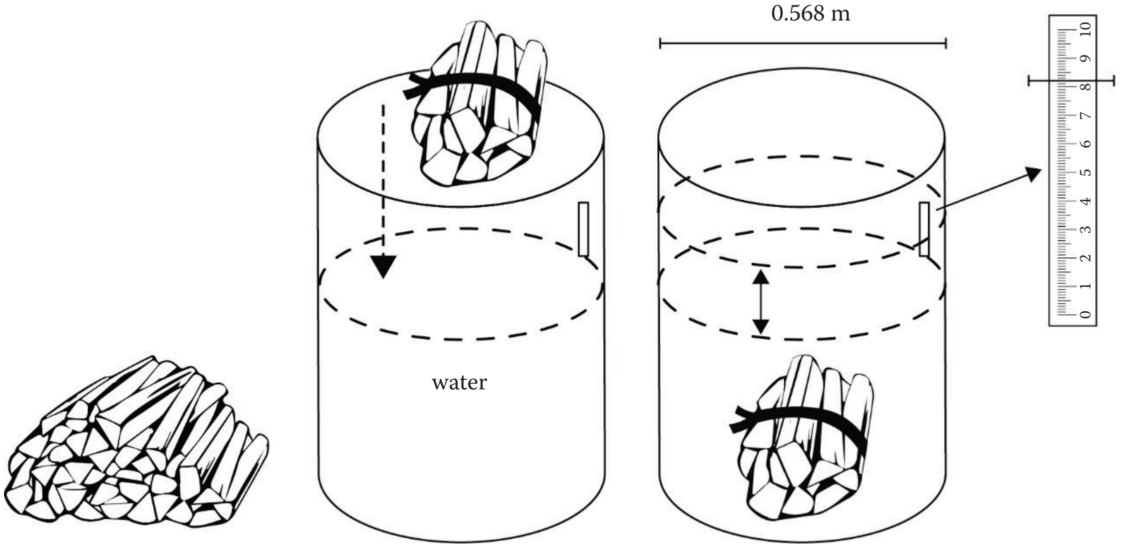

Figure 6. Scheme of the application of the xylometer

of the stack – this method records the total number of pixels that fall on wood to obtain the stacking coefficient, using the following Equation (12):

$$Ca = \frac{wood\ pixels}{total\ pixels} \quad (12)$$

where:
Ca – stacking coefficient.

Obtaining the real volume

The different shapes and irregularities of the sawmill residues make it impossible to implement a simple method to calculate the length, width, surface area and, consequently, the real volume of each residue and, consequently, its pile. Therefore, the xylometer method was used to obtain the real volume of the piles and the results were used as a control. This method is based on Archimedes' principle, which measures the displacement of water generated by the immersion of a body to determine the volume (Figure 6). The volume of water generated by the immersion of the pieces of wood that make up the pile is the closest or most appropriate value to establish the actual volume; despite the difficulties of the execution, the results show a very good correlation with the actual volume of the pile (Pásztory et al. 2018).

In this case, a 220-liter cylinder with a diameter of 0.568 m was used, to which a tape measure was adapted on the inside to measure the displacement of water at the moment of immersion, and then transformed into volume in wood, using the following Equation (13):

$$V = \pi \times r^2 \times h \quad (13)$$

where:
V – volume;
r^2 – radius squared;
h – height.

For the determination of volume by this method, the 10 piles were separated into samples that allowed immersion in the cylinder.

Data analysis

In order to statistically compare the methods used, a completely randomised experimental design was used, where normality tests were performed for the data and analysis of variance using Kruskal-Wallis nonparametric tests ($P < 0.05$). To evaluate the degree of linear association between methods, a Pearson correlation analysis was performed.

RESULTS AND DISCUSSION

Results. The results of the Shapiro-Wilk normality test and Levene's equality of variance test show that the assumptions of normality and variance were not fulfilled, so they were analysed with non-parametric statistics (Table 1). On the other hand, the Kruskal-Wallis test showed significant differences ($P < 0.05$) between the methods for determining the stacking

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Table 1. Shapiro-Wilk and Levene test of the methods compared

Method	Shapiro-Wilk		Levene test		Summary statistics			
	statistic	*P*-value	*F*	*P*-value	minimum	maximum	mean	median
Point-centred quarter	0.9609	0.7970	2.931	0.04657	0.0890	0.0940	0.0916	0.0918
Shellman's ruler	0.9245	0.3967			0.0870	0.1002	0.0917	0.0909
Threshold segmentation	0.8411	0.0455			0.0838	0.0928	0.0887	0.0890
Xylometer	0.8481	0.0552			0.0825	0.0911	0.0887	0.0887

Table 2. Kruskal-Wallis nonparametric analysis of the methods compared

Method	Kruskal-Wallis			
	volume (m^3)	percentage (%)	*P*-value	groups
Xylometer	0.08802	70.41	0.03537	a
Threshold segmentation	0.08871	70.97		ab
Shellman's ruler	0.09170	73.36		b
Point-centred quarter	0.09161	73.29		b

coefficient (Table 2). Figure 7 shows the data obtained from different methods.

The terms 'relationship' or 'association' are equivalent and are used to designate that area of statistics in which the covariation between at least two variables is evaluated. Within this group, linear correlation is a particular case in which such correspondence has well-defined characteristics and is usually measured by Pearson's *R* coefficient (Lalinde et al. 2018). Figure 8 presents the association level of different methods.

Discussion. Although there were significant statistical differences among the methods ($P < 0.035$), it can be seen that the calculation performed by the threshold segmentation method was statistically similar to the real volume determined by the xylometer method, perhaps because it analyses the total number of pixels on the image, which is corroborated by also finding a positive linear correlation value of 0.94 between the two methods. The point-centred quarter method and Shellman's ruler methods for estimating volume were statistically different and did not present positive correlations with the xylometer method, they also overestimated the volume. This could be because the first method only analysed 726 points on the image, while the second method only ana-

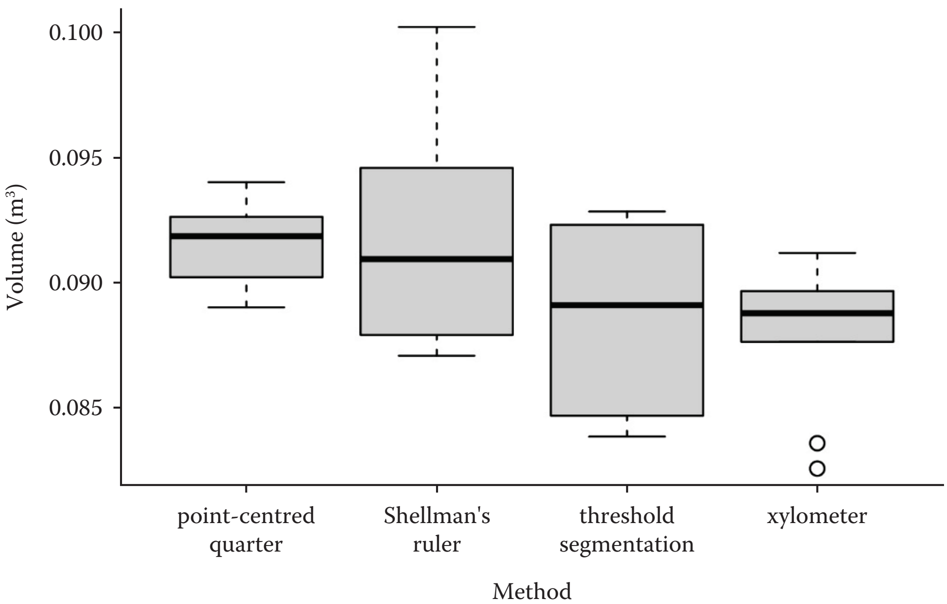

Figure 7. Box plot of the methods compared

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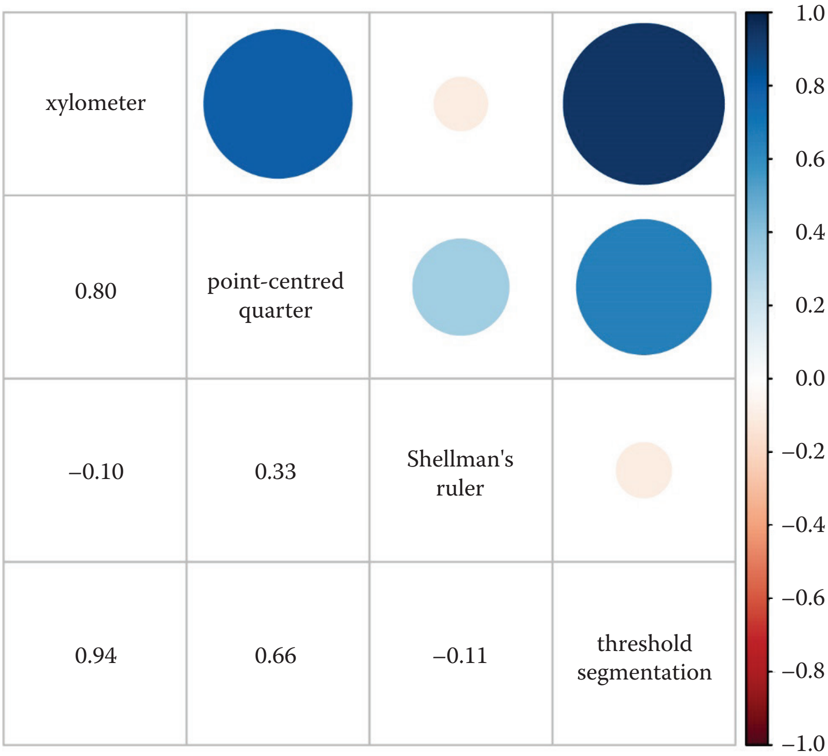

Figure 8. Pearson correlation value among the methods of residue measurement

lysed 600 points. Additionally, both methods were intended to estimate the volume of wood with larger dimensions, like stacked logs, and the approximation they had in the residue piles was fairly good, with differences between the volume estimated by the xylometer method being 2.98% and 2.94%, respectively. These techniques, however, are sensitive to subjectivity and human error and are not time-efficient.

On the other hand, the threshold segmentation method is quite practical and relatively time-consuming. However, the volumes determined by the threshold segmentation method may depend on factors such as image resolution and lighting conditions. However, given the characteristics of the residues analysed in this case, such as the wide range of shades of wood and bark, the threshold segmentation method shows possibilities to adjust the threshold accordingly. Out of the aspects of these methods which require more consideration, it would be especially desirable to evaluate the possibility of further improving its accuracy, so that the procedure would become easy and quick to calibrate (Pásztory et al. 2018).

CONCLUSION

The results of the study show high possibilities for the implementation of the threshold segmentation method as a faster, practical and efficient method for estimating the volume of a residue pile from the stacking coefficient from images. The disposal and devaluation of these residues in the industry is still a problem, so it is recommended to continue testing the threshold segmentation method in different scenarios, to establish it as a tool to obtain more accurate volumes of residues from the forestry industry. The application of these new methods, which work through images, such as threshold segmentation, can contribute to a better understanding and better use of forest resources, strengthening economic, cultural, and social issues. The experiments used in Durango need to be expanded and also to be applied in different environments in Mexico and Latin-America.

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