Revista Cubana de Ciencias Forestales

Volume 13, issue 2; 2025, May-August

liberciencia
EDITORIAL CIENTÍFICA UNIVERSIDAD DE PINAR DEL RÍO
UNIVERSIDAD DE PINAR DEL RÍO
HERMANOS SAÍZ MONTES DE OCA
CFORES
REVISTA CUBANA DE CIENCIAS FORESTALES

ISSN: 2310-3469 RNPS: 2347
Revista CFORES, May-August 2025; 13(2): e890

Original article

Estimation of form factors in Cedrela image-based odorata

Estimación de los factores de forma en Cedrela odorata basada en imágenes

Estimativa baseada em imagem de fatores de forma em Cedrela odorata

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Received: 23/02/2025.

Approved: 29/05/2025.

Published: 30/05/2025

SUMMARY

The estimation of the physical volume of standing trees, as well as important attributes derived from this process, such as total biomass or stem carbon content, is essential. In this regard, there is still limited information available for numerous tropical tree species, and non-destructive techniques for obtaining such data are also lacking. Therefore, the objective of this study is to provide an option for estimating form factors without destroying the trees, based on digital images of standing individuals from *Cedrela odorata*, an emblematic species of natural plant formations in the Neotropics. Photographs were taken of 30 standing individuals, with stem diameters at 1.3 m from the surface (Normal Diameter, ND) in each of the trees, which were then processed to adjust the shape of the stem in the longitudinal and transverse sections. In the longitudinal section, it was possible to obtain a shape factor adjustment that the regression slope places at 8.6, which means an 8.6% loss in this section, so the adjustment factor to be applied would be 0.92 (R^2 = 0.95), which represents a cylindrical shape coefficient. In the case of the transverse section, the estimated shape factor is also 0.92. The results demonstrate that the technique can be applied as an alternative for adjusting the shape characteristics of tree stems without destroying the trees.

Keywords: shape coefficient, trees, neotropics, Campeche, Mexico.

RESUMEN

La estimación del volumen físico apolónico de los árboles en pie, así como de importantes atributos derivados de este proceso, tales como la biomasa total o el contenido de carbono en los fustes. Al respecto, aún hay escasa información disponible para las numerosas especies arbóreas tropicales, pero además faltan técnicas no destructivas para la obtención de tales datos. Por eso, el objetivo de este trabajo es el aporte de una opción para la estimación de factores de forma sin destrucción del arbolado, basada en imágenes digitales de los individuos en pie de *Cedrela odorata*, especie emblemática de las formaciones vegetales naturales en el Neotrópico. Se tomaron fotografías de 30 individuos en pie, y diámetro del fuste a 1.3 m de la superficie (Diámetro Normal, DN) en cada uno de los árboles, que fueron luego procesadas para ajustes en la forma del fuste en la sección longitudinal y trasversal. En la longitudinal fue posible obtener un ajuste de factor de forma que la pendiente de regresión ubica en 8.6, que significa un 8.6% de pérdida en esta sección, por lo que el factor de ajuste a aplicar sería de 0.92 (R^2 =0.95), que representa un coeficiente de forma de tipo cilíndrico. En el caso de la sección transversal, el estimado de factor de forma es también de 0.92. Los resultados demuestran que la técnica es factible de aplicarse como alternativa para ajustes de las características de forma en fustes de especies arbóreas, sin destrucción del arbolado.

Palabras clave: coeficiente de forma, árboles, neotrópico, Campeche, México.

RESUMO

A estimativa do volume físico de árvores em pé, bem como de atributos importantes derivados desse processo, como biomassa total ou teor de carbono no caule, é necessária. Nesse sentido, ainda há informações limitadas disponíveis para inúmeras espécies de árvores tropicais, e técnicas não destrutivas para a obtenção desses dados são escassas. Portanto, o objetivo deste trabalho é fornecer uma opção para estimar fatores de forma sem destruição de árvores, com base em imagens digitais de indivíduos em pé de *Cedrela odorata*, uma espécie emblemática de formações vegetais naturais nos Neotrópicos. Foram tiradas fotografias de 30 indivíduos em pé, juntamente com diâmetros do caule a 1,3 m da superfície (Diâmetro Normal, ND) em cada árvore, que foram então processadas para ajustar a forma do caule em seções longitudinais e transversais. Na seção longitudinal, foi possível obter um ajuste do fator de forma que a inclinação da regressão coloca em 8,6, o que representa uma perda de 8,6% nesta seção. Portanto, o fator de ajuste a ser aplicado seria 0,92 (R^2 = 0,95), representando um coeficiente de forma cilíndrica. No caso da seção transversal, o fator de forma estimado também é 0,92. Os resultados demonstram que a técnica pode ser aplicada como alternativa para ajustar as características de forma de troncos de árvores sem destruí-las.

Palavras-chave: coeficiente de forma, árvores, neotrópicos, Campeche, México.

INTRODUCTION

The estimation of the physical volume of standing trees, as well as important attributes derived from this process, such as total biomass or carbon content in the stems, constitutes an area of constant exploration today, and destructive and non-destructive methods have been tested in this regard, highlighting among the latter the use of allometric equations (Paz- Pellat *et al*., 2021). These work best based on field data important for adjusting estimates, such as tree shape factors or coefficients, frequently observed in semi-empirical models (Návar-Cháidez *et al*., 2013) .

The importance of adjustments by factors or shape coefficients to the volumes or biomasses estimated by means of allometric equations not only refers to the fact that, in this way, they make the estimates of the usable wood of a particular tree species more precise, but also of other dendrometric and forestry variables that are essential for the better management of forest resources (Graciano-Ávila *et al* ., 2019) , as well as their more precise economic valuation (Romo-Lozano *et al* ., 2017) . In this regard, there is still little information available for the numerous tropical tree species, but in addition, non-destructive techniques for obtaining such data are lacking (Garate-Quispe & Florez - Castillo, 2023).

Promising are those techniques based on the use of photographic images for non-destructive estimations of form factors (Caamal-Luna *et al* ., 2022 ; Moreno-Te *et al.* , 2022)

The objective of this research has been, then, to explore a method of estimating factors or coefficients of form in the trunks of trees of a species of commercial importance in Campeche, Mexico, the cedar (*Cedrela odorata)*, by using photographic images taken from a group of individuals of this species, processing the images to estimate form factors in both the longitudinal and transverse sections of the stem.

MATERIALS AND METHODS

For this research work, following Caamal *et al*. (2022) and Moreno-Te *et al*. (2022), photographs were taken of complete trunks of 30 standing individuals. When taking the photographs, graduated rulers or staffs were placed adjacent to the trunk, as auxiliary measures that were later used to dimension the scales of the actual shape of the tree to that of the image. In this way, the longitudinal axis of each individual was sectioned every meter, from the base to the apex, until a section with a minimum diameter close to 3 cm was reached, as suggested by Tlaxcala-Méndez *et al* . (2016) . In the photographic images, these sections were distinguished by linear lines and identified as consecutive diameter sections (D1, which is the basal diameter at 10 cm above ground level, DN (Normal diameter at 1.3 m, measured in the field with a diameter tape Forestry Suppliers Inc.), D2, D3, … Dn). Where "n" represents the total number of 1 m sections into which a shaft is divided, (Figure 1).

The DN serves as a reference for this attribute in the image and for subsequent comparisons. The difference between the diameter of a section and the DN was then used as the basis for estimating the change in this variable along the stem. These measurements were then digitized into Excel spreadsheets (Microsoft Office®) to obtain simple linear regression equations or models. The slope of these models was the diameter decay estimator, which then provides the factor or coefficient, so that it should be applied as an adjustment to the estimated volume or biomass for each *C. odorata* individual counted and measured in an inventory.

On the other hand, the shape of the trunk in cross-section was first outlined using a flexible aluminum wire, which followed the contour of the trunk at 1.3 m above the surface (height at the DN), so that the true shape of the cedar stem could be visualized and photographed. With this physical measurement and with the support of graduated rulers as references for the actual size in the images, two figures drawn to scale on cardboard were then cut out. One of these represents the theoretical circle that usually represents the DN in inventories and dendrometric calculations. The other cut-out figure represents the true shape of the tree in cross-section.

ISSN: 2310-3469 RNPS: 2347
Revista CFORES, May-August 2025; 13(2): e890

Once traced, cut out of cardboard, and weighed, both figures were individually and comparatively weighed using a precision analytical balance (0.001 g). The difference in mass between the cut based on the DN and the cut based on the actual stem shape was used, in this case, as an estimate of the area loss in this section and, therefore, of the associated volume or biomass (Figure 2).

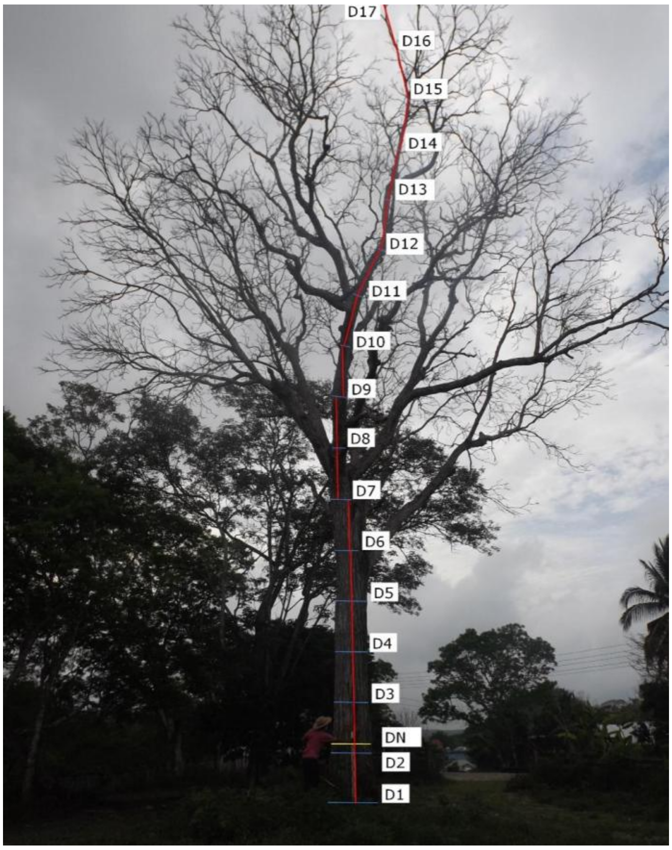

Figure 1. *- Sections marked one meter apart along the longitudinal section of the Cedrela shaft odorata. The transverse lines mark the different estimated diameters based on the Normal Diameter (ND, Yellow Line) scale, established as a reference for the individual (Created by the authors).*

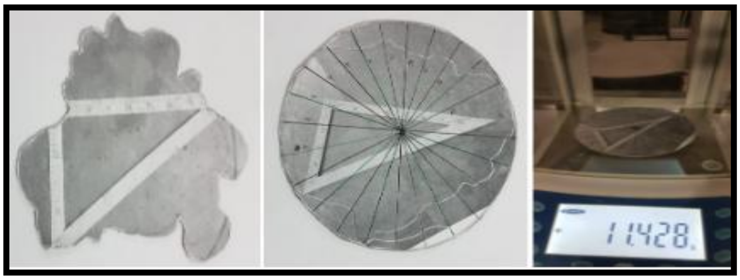

Figure 2. *- Cutouts in cardboard shell of two models of the cross-sectional shape of the shaft at 1.3 m from the surface (DN), and taking the mass of each one using an analytical balance (Own creation)*

In the first case, sectioning the image at extrapolated intervals of 1 m between them, to estimate the decay of the stem shape along its length, from its base (larger diameter) to its apex (smaller diameter). These measurements were then used to model the decay through simple regression equations, considering the slope as the estimator of the longitudinal stem decrease in *C. odorata.* In the second, by estimating the weight of projected sections based on the DN and the shape of the cross section, then cut out of cardboard shell and weighed on an analytical balance. By difference in weights, the proportion of loss of the actual shape with respect to the projection of the theoretical cylinder that is usually used in dendrometry was estimated.

RESULTS AND DISCUSSION

Estimated shape factor in the longitudinal section of the shaft: The work method explored shows that the technique of processing photographic images on the stems allows an estimation of the decrease in the diameter of the main or central stem of the individuals of *C. odorata* , without destroying them, and that this tends to be highly adjusted ($r^2 \geq 0.90$) to a simple linear regression with negative slope (Figure 3), which averaged 8.5521, which implies a decrease in the longitudinal section of the stem that it represents, with respect to the corresponding normal diameters taken in each individual (DN, measured in a standardized way at 1.3 m from the base of the stem), of 0.085521% (Figure 4).

Consequently, it can be deduced that the shape factor to adjust volume or biomass in this species is ff $_L$ = 1 - 0.085521, where ff $_L$ is the longitudinal shape factor, 1 is the unit or totality of the theoretical volume and 0.085521 the factor to be deduced by adjusting the real shape of the stem. In this case, *C. odorata* presents an ff $_L$ of 0.91449 or 0.92, which can be applied to all individuals of the species, at least in the state of Campeche, Mexico. The shape factor or morphic coefficient, as it is also known in the literature, in this case corresponds to values greater than 0.85, which is mentioned by Romahn de la Vega and Ramírez-Maldonado (1994), who place the species as having a cylindrical stem, although others also mention that it can also be paraboloid (Tlaxcala-Méndez *et al.* 2016) (Figure 3).

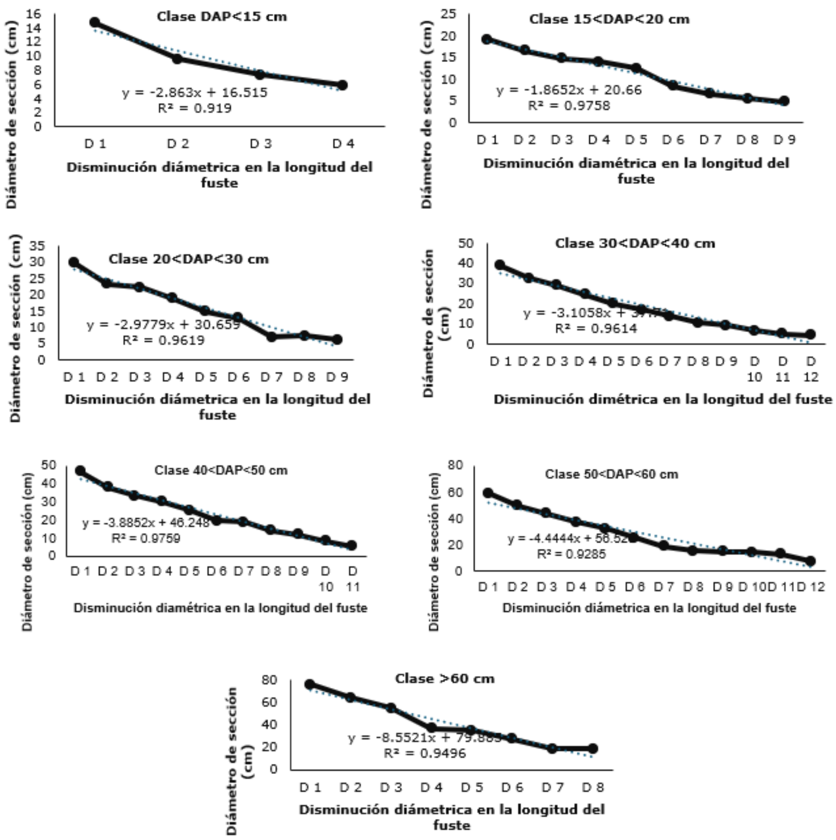

Figure 3. *- Behavior of the decrease in diameter along the longitudinal axis of the stem in Cedrela odorata, with the regression function estimated from photographic images taken on trees of different diameter categories in Campeche, Mexico*

The trend in the decrease in stem diameter in the cedar, *C. odorata,* is predominantly linear, but with a rather gentle negative slope, so the stem appears cylindrical. This is consistent with other approaches and studies on the stem shape in the species and helps in understanding the usefulness of the proposed method, which can be suggested in the non-destructive estimation of other species. However, other authors mention that the shape coefficient in this species (Cf.) is 0.5 to 0.6, which places it as paraboloid in shape (Mendizábal-Hernández *et al.* 2009; González-Rojas *et al*., 2018 ; Carvajal-Arroyo *et al*., 2021) .

In this regard, Caamal-Luna *et al*. (2022) mention that in a preliminary study on the determination of this form factor in *Swietenia macrophylla*, calculations based on photographic images provided data that were consistent with those reported in the literature for this species (Hernández Ramos *et al*., 2018), but not for *Tabebuia rosea* (Gutiérrez-Rodríguez *et al*., 2013) . Therefore, more efforts should be made to verify this technique in other tropical tree species (Figure 4).

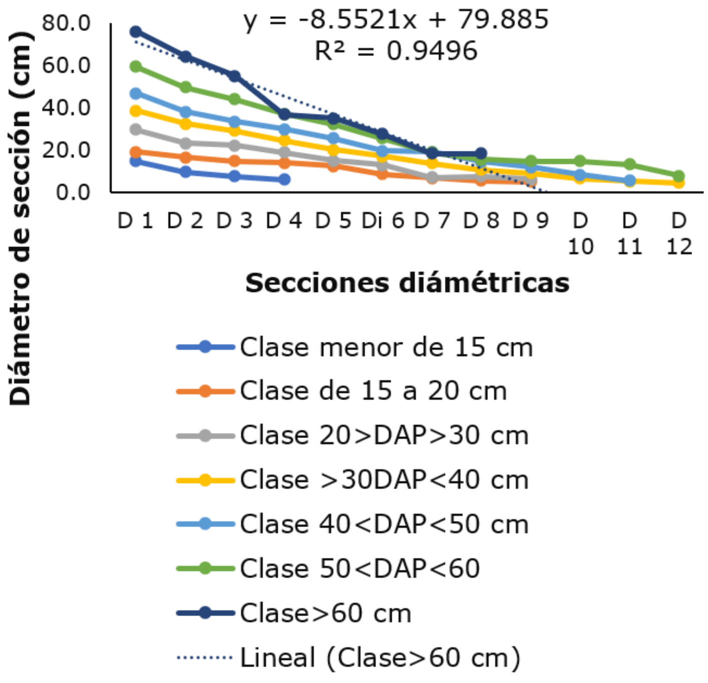

Figure 4. *- Behavior of the diameter decrease in Cedrela odorata L. on the longitudinal axis, with a tendency toward simple linear regression with negative slope, observed in individuals photographed in Campeche, Mexico*

Estimated shape factor in the cross section of the shaft:

By performing an image-based analysis of the cross-section of the trunk, contrasting the cylindrical shape that is theoretically projected from the normal diameter (DN) and that is widely used in dendrometry, against the realistic shape of the trunk in this section, the data summarized in Table 1 were obtained. In these, it can be observed, first, that there is a difference between the circle that is configured from the DN and the real shape that is obtained directly from the *Cedrela odorata* trunks. The indirect estimate gives us an average of 0.92 as a form factor or morphic coefficient in this section (ff_T), which can be applied in volume or biomass adjustments in this species in the state of Campeche (Table 1).

Table 1. *- Estimation of the shape factor in the cross section of the shaft in Cedrela odorata, measured at 1.3 m from the ground surface or normal diameter (ND), in individuals present in Campeche, Mexico*

	Diameter (cm)	**TrimDN (g)**	**Cut out real shape(g)**	**ff_T**	**ff x**
Class less than 15 cm	10.90	2.38	2.37	0.99	0.92
Class 15 to 20 cm	17.38	4.58	4.36	0.96	
Class 20 to 30 cm	25.17	6.36	6.25	0.97	
Class 30 to 40 cm	35.44	9.72	8.49	0.85	
40 to 50 cm class	45.06	11.98	11.12	0.91	
50 to 60 cm class	53.06	9.85	8.67	0.87	
Class > 60 cm	82.20	19.33	16.53	0.85	

*Legend: Codes: DN(g) cutout = mass (in grams) of cardboard cutout circle with normal diameter to scale. Actual shape cutout(g) = mass (in grams) of cardboard cutout of the actual shape of the perimeter of the tree trunk taken at 1.3 m height. ffT = shape factor or morphic coefficient in the cross section of the trunk, expressed as a percentage of the ratio Shape cutout(g)*100/DN(g) cutout. ff x = average of ffT .*

Preliminary studies on the use of this non-destructive technique, based on digital photography and its processing in the cross section carried out by Moreno-Te *et al* . (2022) suggest that in rather cylindrical (ff > 0.85) or paraboloid (0.50 > ff >0.85) tropical species (Romahn de la Vega and Ramírez-Maldonado, (1994) , such as *Ceiba pentandra* , *Swietenia macrophylla* or *Tabebuia rosea* , the fit values by shape coefficients are close to 0.90, which is consistent with the estimate for *C. odorata* , a trunk species with a tendency to be cylindrical or paraboloid as stated by Tlaxcala-Méndez *et al*. (2016). In addition, it is consistent with the statement by Wilson-Bibiano *et al*. (2017) , on the high correlation between the two characteristics of the stem that define its shape, the diameter and the height of the tree, which in cedar reaches an adjustment estimated by the coefficient of determination of the model (R^{2}) of 96%.

CONCLUSIONS

The method of estimating form factors or morphic coefficients based on photographic images, auxiliary measurements and processing of individual photos can be a useful tool when felling trees in the *Cedrela odorata* species is not available or is required. The estimated shape factor in the longitudinal section (ff_L), as well as in the transverse section (ff_T), obtained by the method explained in this document, can be used to adjust the volumes and biomass in this species, in Campeche, Mexico, but they also demonstrate that the tree has, as recognized by other methods, a cylindrical to paraboloid shape in its trunk.

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***Conflicts of interest*:**

The authors declare no conflicts of interest.

***Authors' contributions*:**

The authors have participated in the writing of the work and analysis of the documents.