ISSN 0188-6266
doi: 10.15174/au.2016.1206
Acta Universitaria
Multidisciplinary Scientific Journal

Measuring temporal wood density variation improves carbon capture estimates in Mexican forests

La inclusión de la variación temporal de la densidad mejora las estimaciones de captura de carbono en bosques mexicanos

Marcos González-Cásares*, José I. Yerena-Yamallel*, Marín Pompa-García*◊

ABSTRACT

Knowing carbon (C) content variations in forests, provides information relevant to assessing climate change. Traditionally, methods for calculating C content are destructive and do not consider variation in wood density (ρ). In this study, temporal variation in C content of *Pinus cooperi* Blanco was determined at a site in the Sierra Madre Occidental, Durango, Mexico. Chronologies of carbon capture in this species were obtained using dendrochronology to date growth rings and allometric relationships to estimate biomass, including ρ. Our results indicate that temporal variation in C is related to temporal variation in ρ. Such variation likely depends on environmental and spatial conditions at site. Comparison of our results with those obtained without taking into account ρ shows that neglecting ρ underestimates C capture by more than 50%, representing a variation of up to 266.51 mg at this site. Our more accurate C estimates are relevant to establishing effects of climate change on C flows in ecosystems. This is the first study to use such methodology to estimate C capture in Mexico, providing important information on C flows and forest productivity for this region.

RESUMEN

Conocer la variación del contenido de carbono (C) en los bosques representa información que contribuye a disminuir el cambio climático. Los métodos tradicionales para cálculo de C son destructivos y excluyen la variación de la densidad de la madera (ρ). Se determinó la variación temporal del contenido de C para *Pinus cooperi* Blanco en un sitio de la Sierra Madre Occidental. Mediante dendrocronología y relaciones alométricas, se obtuvieron cronologías temporales de captura de C. Se comparó con los resultados del mismo sitio sin la ρ. Dicha comparación confirma que omitir la ρ subestima la captura de C más de un 50% del contenido de C real, lo que representa una variación de 266.51 mg para el sitio. Este trabajo adquiere mayor relevancia, ya que no existe, según nuestro conocimiento, un estudio en México que utilice esta metodología, y tiene implicación en el conocimiento sobre flujos de C y productividad forestal.

Recibido: 3 de febrero de 2016
Aceptado: 11 de octubre de 2016

Keywords:
Biomass; *Pinus cooperi*; dendrochronology; densitometry; climate change.

Palabras clave:
Biomasa; *Pinus cooperi*; dendrocronología; densitometría; cambio climático.

Cómo citar:
González-Cásares, M., Yerena-Yamallel, J. I., & Pompa-García, M. (2016). Measuring temporal wood density variation improves carbon capture estimates in Mexican forests. *Acta Universitaria*, *26*(6), 11-14. doi: 10.15174/au.2016.1206

INTRODUCTION

Greenhouse gas emissions continue to increase on a worldwide scale and world's forests have been well documented as providing an extensive carbon sink. Clearly, action must be taken to reduce CO_2 emissions (De la Vega-Meneses & Rivero-Villar, 2014; Valdés-Ramírez, 2011). However, global estimates of nature of that carbon (C) sink may be biased if they use only limited data on carbon amount stored in different forests. While forests of Mexico may provide a massive carbon sink, assessing variability of that carbon sink across the various ecosystems of Mexico will help researcher refine accuracy of their models of carbon sequestration.

Knowing how C content in forest ecosystems has changed over recent years can provide important information on its climate response. Such information can be used to understand climate change behavior and help identify

* Facultad de Ciencias Forestales, Universidad Juárez del Estado de Durango, Río Papaloapan y Blvd. Durango S/N Col. Valle del Sur, Durango, Durango, México, C.P. 34120. Tel.: (618) 825 18 86. Email: marinpompagarcia@gmail.com
◊ Corresponding author.

actions to mitigate it. This information can be obtained through dendrochronological study. This technique provides historical information on environmental conditions of a given place, and is used to study changes in ecology, climatology, environmental chemistry, and geomorphology (Giraldo-Jiménez, 2011).

Current methods for estimating C capture in forests regularly use destructive methods for chemical analysis, having a negative impact on their ecosystems. Hence, it has become important to develop a methodology that does not involve destruction of the tree, without compromising reliability of results. Several studies involving calculation of C in forests have been conducted (Herrero de Aza, Turrión, Pando & Bravo, 2011; Jones & O'Hara, 2012; Martin, Thomas & Zhao, 2013; Martin & Thomas, 2013). However, few studies use dendrochronology for this purpose (Lamlom & Savidge, 2006).

Background for this study is presented in Pimienta, Domínguez-Cabrera, Aguirre-Calderón, Hernández & Jiménez-Pérez (2007), where estimates of biomass (B) and C content for *Pinus cooperi* Blanco were carried out in forests in the municipality of Pueblo Nuevo, Durango. Martínez-Barrón (2014) models C dynamics in forests of this region.

A practical way to calculate C is by estimating B. Návar (2009) proposes an allometric equation for this purpose. This equation uses normal diameter (D) and average density (ρ) to obtain an accurate estimate of C content for an individual tree.

The value most widely used for C concentration in B of trees is 50% (Lamlom & Savidge, 2006; Yerena-Yamallel, Jiménez-Pérez, Aguirre-Calderón, Treviño-Garza & Alanís-Rodríguez, 2012). When using estimates of B in such studies, it is assumed that there is a uniform distribution among all trees, *i.e.*, that ρ is constant. This does not take into account that it varies dependent upon weather conditions and age of tree (Babst *et al*., 2014). The main implication of accepting this premise is that results are not accurate because temporal variations in ρ reflect on B, and thus on the C of a tree. Because width of ring (RW) and its average ring density (ρ) varies according to spatial and environmental conditions, it is necessary to consider these two variables to obtain more accurate estimates of C flows in ecosystems.

Briffa *et al.* (2001) used data on ρ to make a reconstruction of temperature changes over the past 600 years for a region that accounts for nearly the entire northern hemisphere.

Table 1.
Characteristics of the sampling site at Las Rusias, Durango, Mexico.

Attribute	Las Rusias
Location (Long., Lat. °)	105.534944, 23.747306
Average altitude (m)	2905
No. of trees sampled	10
No. of series dated	29
Average normal diameter (cm)	47.2
Average height (m)	18

Source: González-Cásares, Pompa-García, Meléndez-Soto & Solís-Moreno. (2015).

Babst *et al.* (2014) performed an evaluation of B changes above the ground at five sites, using RW and ρ. Subsequently, these estimates of B were validated, and compared with monthly flow data for CO_2. However, to our knowledge, there are no such data for Mexican forests.

In our study, chronologies of C capture in *Pinus cooperi* from Durango, Mexico were obtained using a novel combination of dendrochronology to date growth rings and allometric relationships to estimate B, incorporating variations in ρ. Such data can easily be incorporated into a practical and reliable model to calculate variations in C content of a forest ecosystem over a short-term basis. We hypothesized that neglecting ρ miscalculate cumulative C capture.

MATERIALS AND METHODS

A population of *P. cooperi* located at Las Rusias in the Sierra Madre Occidental in Durango, Mexico (table 1) was selected for study. Deformed or damaged trees were not sampled, neither were those whose growth was influenced by competition for light or nutrients (Pompa-García, Miranda-Aragón & Aguirre-Salado, 2014).

At sampling site, of each individual, at least two radial wood cores were collected from a height of 1.3 m (above ground level) by a non-destructive method using increment borers (Ø = 5.1 mm). Each sample was processed (dried and polished), subsequently each year was recorded and each growth ring was measured (µm). Samples were sent to laboratory of wood anatomy and growth rings at Department of Forest Sciences at the University of São Paulo in Brazil. Using densitometric techniques, (ρ): (g/cm^3) was calculated for each ring. Tree-ring width annual values (radial growth) were used to reconstruct historical tree diameters D (m), assuming circularity in growth rings. We used allometric equation for B estimation of northwestern Mexico forests (Návar, 2009) for *P. cooperi* (1). Thus, B was calculated for the aerial part, as well as thicker roots, as follows:

$$y_i = a(D)^{b1}b2^{p}, \quad (1)$$

where y_i = biomass in components of trees *i*; *D* = Normal diameter; ρ = Average ring density; *a* and *b* are statistical parameters. For total above the ground: *a* = 0.2018 and *b* = 2.2907; while for the thick roots: *a* = 0.0051 and *b* = 2.668.

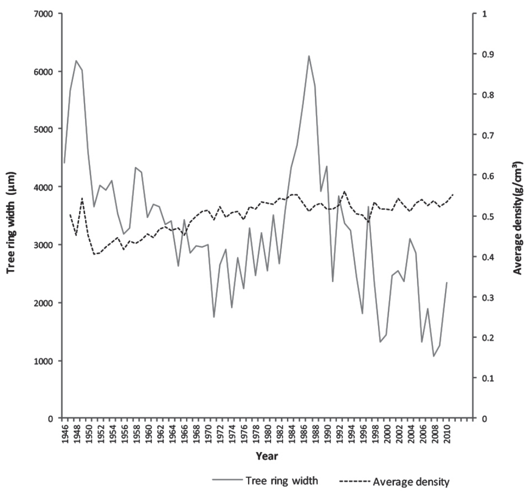

Figure 1. Average ring density (ρ)estimated per year and ring width (µm) for 10 trees selected at the sampling site.
Source: González-Cásares *et al.* (2015).

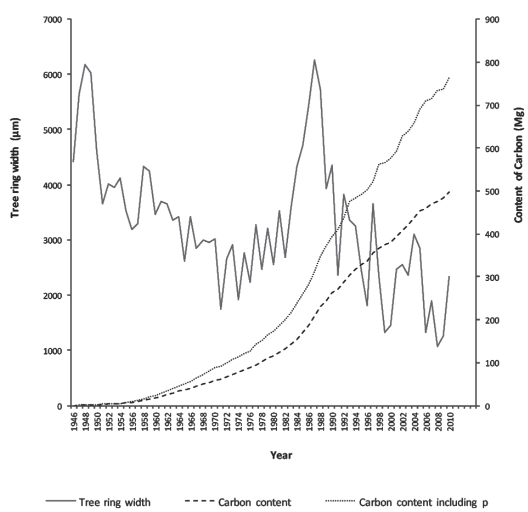

Figure 2. Average cumulative carbon content (mg) estimated with and whithout ρ and ring width (µm) for 10 trees selected at the sampling site.
Source: González-Cásares *et al.* (2015).

RESULTS

Our results showed variation in RW and ρ per year (figure 1). Curves of C content showed uniform growth, related to their annual accumulation of C. There is an increase in total content of C in our results, where ρ is included, compared with data obtained from traditional equation, which assumes a uniform ρ (González-Cásares *et al.*, 2015). This increase represents more than 50% of total C content, confirming that traditional methodologies (*i.e.*, using a constant ρ) underestimate carbon sequestration, and give inaccurate estimates of C capture. We intend to carry out study at different sites to evaluate variation in ρ with respect to various environmental conditions.

Figure 2 shows that during first years of growth, difference between the two estimates is not so large. However, from 1970 onwards, this difference increases markedly, resulting in a noticeable change at present time. We found that trees at this site accumulate more C with age. We also found a negative correlation between total width of the ring and contents of C, where as width decreases, C content increases.

DISCUSSION

Results obtained in the first study conducted at this site (González-Cásares *et al.*, 2015) are markedly lower than those obtained in this study, taking into account ρ, resulting in an increase in C content cumulative average from 497.35 mg to 763.86 mg. However, in the early years of growth (1946-1960) some similarity was observed between two curves of C content. This similarity suggests consistency with annual biomass increases and tree age. Another aspect to be considered when calculating C content is wood formation processes. In this species, earlywood (EW) represents about 82% of the RW, while remaining 18% is latewood (LW), depending on the site (Pompa-García & Domínguez-Calleros, 2015). These differences in growth have implications for forest productivity, carbon cycles and other ecological processes faced by the species. This may be one of the most significant implications of taking into account ρ in this study. Even though this species has a higher percentage of EW compared with LW, it is important to note that LW tissues are more compact, resulting in a greater ρ. This explains what happens at trunk periphery, where despite the fact that RW decreases, C content increases because the

LW volume is greater. Using values of ρ in allometric equation, allows us to assess variations through time, not related to growth processes (Babst *et al*., 2014). To date, few studies in this area have considered differences in EW and LW properties (Pompa-García & Domínguez-Calleros, 2015). We intend to expand our study to other sites to evaluate correlations between RW and ρ with respect to study site (Babst *et al*., 2014; Taki, Nobori & López-Cáceres, 2014) as well as environmental conditions. In particular, summer temperature has been shown to influence RW and ρ of wood (Fan, Bräuning, Yang & Cao, 2009; Grudd, 2008).

CONCLUSIONS

Our results suggest that estimating C, based on an allometric model sustained only by D of a tree results in inaccurate estimate of C content at a given site because variability in ρ that occurs in individual trees has not been taken into account. We clearly show that more accurate results are obtained by measuring and incorporating ρ into estimates of C based on B.

ACKNOWLEDGMENTS

Authors recognize project funding through *Consejo Nacional de Ciencia y Tecnología* (SEP-CONACYT key CB-2013/222522). Also, we acknowledge help of Department of Forest Science of University of São Paulo, for x-ray densitometry analysis. Authors are grateful to Editors and anonymous reviewers for their useful comments and suggestions.

REFERENCES

Babst, F., Bouriaud, O., Papale, D., Gielen, B., Janssens, I. A., Nikinmaa, E., Ibrom, A., Wu, J. Bernhofer, C., Köstner, B., Grünwald, T., Seufert, G., Ciais, P., & Frank, D. (2014). Above-ground woody carbon sequestration measured from tree rings is coherent with net ecosystem productivity at five eddy-covariance sites. *New Phytologist*, *201*(4), 1289-1303.

Briffa, K. R., Osborn, T. J., Schweingruber, F. H., Harris, I. C., Jones, P. D., Shiyatov, S. G., & Vaganov, E. A. (2001). Low-frequency temperature variations from northern tree ring density network. *Journal of Geophysical Research: Atmospheres*, *106*(D3), 2929-2941.

De la Vega-Meneses, J. G., & Rivero-Villar, M. J. (2014). Identificación de fortalezas y debilidades del G8+5 ante la crisis del cambio climático. *Acta Universitaria*, *24*(3), 25-34.

Fan, Z. X., Bräuning, A., Yang, B., & Cao, K. F. (2009). Tree ring density-based summer temperature reconstruction for the central Hengduan Mountains in southern China. *Global and Planetary Change*, *65*(1), 1-11.

Giraldo-Jiménez, J. A. (2011). Dendrocronología en el trópico: aplicaciones actuales y potenciales. *Colombia Forestal*, *14*(1), 97-111.

González-Cásares, M., Pompa-García, M., Meléndez-Soto, A., & Solís-Moreno, R. (2015). Variación espacial y temporal del contenido de carbono en bosques de la sierra madre occidental avances preliminares. *Revista de Ciencias Naturales y Agropecuarias*, *2*(3), 368-372.

Grudd, H. (2008). Torneträsk tree-ring width and density AD 500-2004: a test of climatic sensitivity and a new 1500-year reconstruction of north Fennoscandian summers. *Climate Dynamics*, *31*(7), 843-857.

Herrero de Aza, C., Turrión N., M. B., Pando F., V., & Bravo, F. (2011). Carbon in heartwood, sapwood and bark along stem profile in three Mediterranean *Pinus* species. *Annals of Forest Science*, *68*(6), 1067-1076.

Jones, D. A., & O'Hara, K. L. (2012). Carbon density in managed coast redwood stands: implications for forest carbon estimation. *Forestry*, *85*(1), 99-110.

Lamlom, S. H., & Savidge, R. A. (2006). Carbon content variation in boles of mature sugar maple and giant sequoia. *Tree Physiology*, *26*(4), 459-468.

Martin, A. R., & Thomas, S. C. (2013). Size-dependent changes in leaf and wood chemical traits in two Caribbean rainforest trees. *Tree Physiology*, *33*(12), 1338-1353.

Martin, A. R., Thomas, S. C., & Zhao, Y. (2013). Size-dependent changes in wood chemical traits: a comparison of neotropical saplings and large trees. *AoB Plants*, 5, 10-31. doi: 10.1093/aobpla/plt039

Martínez-Barrón, R. A. (2014). *Modelación de la dinámica del carbono en bosques del estado de Durango* (Master Thesis). Facultad de Ciencias Forestales-Universidad Autónoma de Nuevo León: Linares, Nuevo León, México.

Návar, J. (2009). Allometric equations for tree species and carbon stock for forest of northwestern Mexico. *Forest Ecology and Manangement*, *257*(2), 427-434.

Pimienta de la Torre, D. J., Domínguez-Cabrera, G., Aguirre-Calderón, Ó., Hernández, F. J., & Jiménez-Pérez, J. (2007). Estimación de biomasa y contenido de carbono de *Pinus cooperi* Blanco, en Pueblo Nuevo, Durango. *Madera y Bosques*, *13*(1), 35-46.

Pompa-García, M., Miranda-Aragón, L., & Aguirre- Salado, C. A. (2014). Tree growth response to ENSO in Durango, México. *International Journal of Biometeorology*, *59*(1), 89-97.

Pompa-García, M., & Domínguez-Calleros, P. A. (2015). Respuesta de madera temprana y tardía a la sequía en una conífera mexicana bajo dos condiciones ecológicas. *Revista Ecosistemas*, *24*(2), 37-42.

Taki, S., Nobori, Y., & López-Cáceres, M. (2014). Method for estimation of stem carbon fixation of Japanese black pine by combining stem analysis and soft X-ray densitometry. *Journal for Forestry Research*, *19*(1), 226-232.

Valdés-Ramírez, M. (2011). El cambio climático y el estado simbiótico de los árboles del bosque. *Revista Mexicana de Ciencias Forestales*, *2*(5), 5-13.

Yerena-Yamallel, J. I., Jiménez-Pérez, J., Aguirre-Calderón, O. A., Treviño-Garza, E. J., & Alanís-Rodríguez, E. (2012). Concentración de carbono en el fuste de 21 especies de coníferas del noreste de México. *Revista Mexicana de Ciencias Forestales*, *3*(13), 49-56.