Are there any differences in carbon concentration among species of high conservation value forests in Northern Mexico?

¿Hay variaciones en la concentración de carbono entre especies de bosques de alto valor de conservación en el norte de México?

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Originales: *Recepción:* 14/02/2017 - *Aceptación:* 25/08/2017

Abstract

Despite the publication of numerous studies about carbon (C) concentration in various tree components, few have investigated the C variation in spatially restricted tree species. We evaluated differences in C concentrations among four conifer species of High Value Conservation Forests (HVCF) in northern Mexico. Total carbon concentration (TOC) analyses were performed for *Cupressus lusitanica* Mill*, Picea chihuahuana* Mtz., *Abies durangensis* Mtz*.,* and *Pseudotsuga menziesii* Mirb. Carbon concentration varies within the structural tree component, but no significant difference was found when the aerial samples were classified based on the point of cardinal extraction from where they were taken. The species, *P. menziesii, A. durangensis,* and *P. chihuahuana* showed the lowest C concentration in the stems, while *C. lusitanica* had the highest.

Keywords
carbon-storage • carbon flux • tree compartments • cardinal direction

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Resumen

A pesar de la publicación de numerosos estudios sobre la concentración de carbono (C) en diversos componentes del árbol, pocos han investigado la variación entre especies de distribución restringida y sus componentes. Se investigaron las diferencias en las concentraciones de C entre las cuatro especies de coníferas de alto valor de conservación (Bosques HVCF) en el norte de México. Se realizó un análisis de la concentración total de carbono (TOC) para *Cupressus lusitanica* Mill., *Picea chihuahuana* Mtz., *Abies durangensis* Mtz., y *Pseudotsuga menziesii* Mirb. La concentración de C varía dentro del componente estructural de árbol, pero no se encontró ninguna diferencia significativa en la concentración de C según la orientación de la extracción cardinal de muestras de tejidos aéreos. Las especies, *P. menziesii* Mirb., *A. durangensis* Mtz. y *P. chihuahuana* Mtz., resultaron tener la menor concentración de contenido de carbono en los tallos, mientras que *C. lusitanica* Mill. tuvo la mayor.

Palabras clave

almacenamiento-carbono • flujo de carbono • compartimentos de árboles • orientación cardinal

Introduction

Forest ecosystems are the major biological sink of atmospheric CO_2, capable of mitigating part of the emissions of this greenhouse gas (7, 8). Global forest ecosystems account for approximately 90% of the annual carbon (C) flux between the atmosphere and terrestrial ecosystems (5, 9). Nevertheless, several studies around the world report that ongoing global climate change could alter forests, from composition to structure (2, 12). Therefore, the forest ecosystems are decreasing their capacity to mitigate the imminent hazardous effects of global warming by acting as global carbon sinks (8, 24).

Among forest ecosystems, high conservation value forests (HCVF) are those areas of outstanding and critical importance due to their environmental, socio-economic, cultural, biodiversity, and landscape value (4) (https://ic.fsc.org/en/what-is-fsc/what-we-do/strengthening-standards/high-conservation-values). HCVF were first defined by a non-profit organization for use in forest certification. The concept is increasingly being used for other purposes, such as conservation and natural resource planning, landscape mapping, and the promotion of social values (1, 4).

In this regard, accurate knowledge of carbon (C) concentration in forest biomes is crucial for converting estimates of forest biomass into forest C stocks (36).

In the vast majority of assessments, C concentration has been assumed 50% of tree biomass (20). However, recent prominent efforts have sought to demonstrate that wood C concentration is highly variable among co-occurring species (36).

Noticeable forest C accounting methodologies (18, 21, 22) suggest to fraction field samples into tree components (*e.g.*, leaves, twig, branches, trunk, bark and roots), then perform chemical analyses of these tissues. For instance, Martin and Thomas (2013), extracted 190 cores from 59 native trees species in Central America. Figueroa *et al.* (2005) sampled trees from Southern Mexico using a destructive approach. In a similar study, Yerena *et al.* (37) studied compartments of trees and shrub species on Tamaulipan thornscrub.

Recently, Yerena *et al.* (2012b) evaluated C concentration in the stem of 21 species of conifers growing in the northeastern part of Mexico. All these studies were carried out dismissing the cardinal direction of samples, and ultimately, sample size. To our knowledge, all previous works in Mexican ecosystems followed the methodology of Gayoso and Guerra (2005), which consists of collecting samples from the cardinal points. Consequently, it is necessary to test whether samples are statistically different from the four cardinal points. Furthermore, correlation of C concentrations among components are proof of certain physiological processes within the components (30). Consequently, this association could improve the understanding of carbon flux among different components.

In Northern Mexico, there is a relict forest where four representative tree species are co-occurring: *Picea chihuahuana* Mtz, *Abies durangensis* Mtz, *Cupressus lusitanica* Mill, and *Pseudotsuga menziesii* Mirb. This particular ecosystem has been considered a high conservation value forest (HCVF) and was recently certified by a non-profit organization dedicated to the promotion of responsible forest management worldwide.

The area is characterized by other pine-oak associations, having above-average precipitation rates, and providing exceptional scenic beauty. It is a high-conservation value forest free of recent management plans (*e.g.*, logging) according to the Local Forest Management Program (1, 4).

For these reasons, this HCVF constitutes an ideal experimental site for dynamic C assessment in forests. Furthermore, studying species from this HCVF could improve knowledge on the issue at hand. By hypothesizing that concentrations of C among components and species are statistically different, and some linear relationships among them are expected, we aimed to examine the differences of C concentrations in these species. To the best of our knowledge, no such effort has been made to date. Therefore, we attempted to (1) explore whether there is a significant variation of C concentration according to the four cardinal directions (*i.e.*, N, W, E, S) (2), assess if there is a significant variation among species and components, and (3) to quantify correlations in C concentration among tree compartments.

Materials and methods

Study area

The study area is located in the Sierra Madre Occidental, which represents an important protected forest that includes rare conifers, such as the genera *Picea*, *Abies*, *Cupressus* and *Pseudotsuga*, which occur as protected relicts that have a high conservation status (1).

The mixed-conifer forests usually also include one or two *Pinus* species (*P. durangensis*, *P. leiophylla*, *P. strobiformis*, and/or *P. pseudostrobus*) that are often associated with *Quercus* and *Arbutus* species (1).

The specific site is a highly preserved location in south-central Durango and belongs to a common-based property known as El Brillante (figure 1, page 186).

The Santa Bárbara site is considered as a community-protected area.

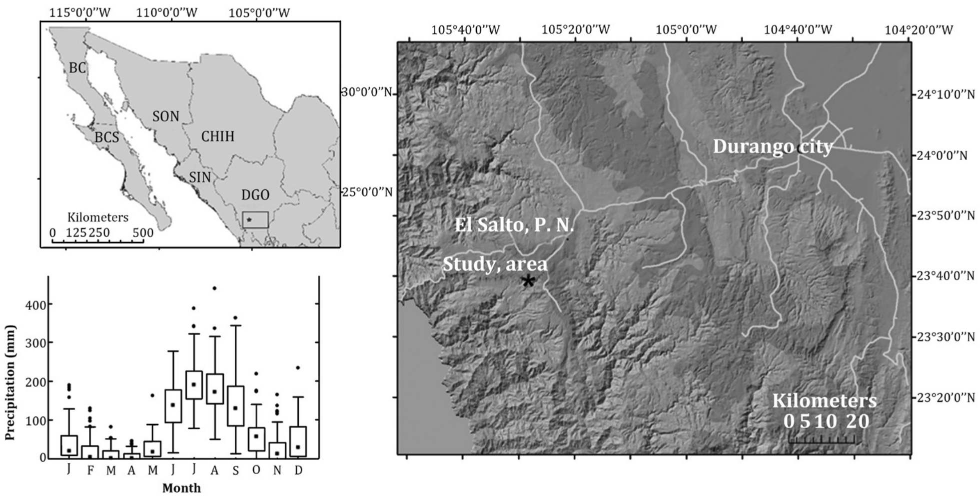

Figure 1. Location of the study area (The Santa Bárbara site) and climate conditions in south-central Durango that belongs to Sierra Madre Occidental.

Figura 1. Localización del área de estudio (sitio Santa Bárbara) y condiciones climáticas en el centro-sur de Durango que pertenece a la Sierra Madre Occidental.

According to the technical manager, 30 years ago, the study area was isolated from logging and forest management as a strategy for conservation and the generation of various ecosystem services. This site has a permanent stream and it is limited to the south and east by the plateau pine forests, while the western side flows into the steep, canyon-like gorge known as Quebrada del Infierno. The four tree species, *Picea chihuahuana, Abies durangensis, Cupressus lusitanica,* and *Pseudotsuga menziesii*, are found in this particular site within a limited area of about 20 ha.

The climate is temperate sub humid with a cool and humid summer because of the influence of the monsoon and dry conditions in the spring and winter.

The type of soils found in the study area includes Cambisols, Lithosols, Regosols, and Phaeozems (1, 4).

Data and lab processing

Following Henry *et al.* (2011), a selective sample design of 17 trees was applied. Undamaged trees, with a diameter breast height (dbh) larger than 40 cm, with no deformities or signs of competition for light or nutrients were included.

In each tree, a 50-g sample of aerial parts was collected from each cardinal point (*e.g.*, N, S, W, E). The process was repeated for leaves, branches, and twigs (< 5 cm in diameter).

The sample cores were collected at 1.3 m from the ground using a Pressler borer, hatchet and scissors to avoid destructing the tree. Samples were taken to the lab following the procedures of Karlikand Chojnacky (2013) and immediately placed in paper bags to minimize the loss of volatile C (18, 20).

The samples were dried at an environmental temperature until a constant weight was reached. Following the Lamlon and Savidge (2003) procedure, the samples were broken down into small particles to better estimate C concentration using a pulverizing mill (Fritsch pulverisette 2), which produced particles smaller than 10 µg. Total carbon concentration (TCC) was obtained using a Solids TOC Analyzer (model 1020A) from O·l·Analytical, which analyzes solid 5-mg samples (at least three replications) by means of thorough combustion at 900°C. Resulting gasses were then measured through an infrared, non-dispersive detector that counted carbon molecules (38).

Statistical analysis

The R-based Kruskal–Wallis post-hoc test (*i.e.*, the Tukey and Kramer approach) (17, 32, 35) was used to test for mean differences in the C concentration among species, cardinal directions, and their components.

The test was carried out using the "PMCMD" package (29). A level of statistical significance equal or lower than 0.05 was chosen for this study.

Finally, correlation tests were performed using Pearson coefficient to determine the statistical association ($p < 0.05$) of C concentrations when the components mentioned above were compared (33).

Results

Results indicate that no significant differences in C concentration were found in each tree component for every cardinal point. The lowest values of correlation were found in the leaves, between the west and north points ($p = 0.57$). Meanwhile, the maximum values corresponded to leaves oriented north-south (1), branches oriented east-west (1), branches oriented south-west (0.93), branches oriented west-east (1), and twigs oriented north-south (1).

The results varied significantly for various components of the species studied (table 1, page 188). That is, the total concentration of carbon found in the components of above ground biomass depends on the species, ranging from 45.57% (*C. lusitanica*) to 52.72% (*P. menziessii*).

The mean C concentration for *P. menziesii* varied from 48.78% (stem) to 54.41% (leaf), with the former being significantly different from the other components.

Likewise, *A. durangensis* exhibited a variation of 47.46% in stem issue and 49.27% in leaf tissue. These were statistically different to other components, much like the branches. When it comes to the species variation *C. lusitanica* showed a variation from 45.57% (branches) to 52.15% (stem). Tests for variance showed that the stem component was statistically significant from the others.

The average C concentration for *P. chihuahuana* ranged from 47.51% (stem) to 50.63% (twig). The stem turned out to be significantly different from branches and twigs, while twigs showed a significant difference from the stem and leaves.

Table 1. Average carbon concentration per component for the species studied.

Tabla 1. Concentración de carbono promedio por componente para las especies estudiadas.

Component	*Pseudotsuga menziesii*	*Abies durangensis*	*Cupressus lusitanica*	*Picea chihuahuana*
Stem	48.78±1.01 B	47.46±1.82 B	52.15±0.88 A	47.51±2.01 C
Leaf	54.41±2.03 A	49.27±2.32 A	48.43±2.15 B	47.83±1.56 BC
Branch	52.72±0.12 A	47.48±0.14 B	45.57±1.84 C	49.89±2.31 BA
Twig	52.47±2.04 A	48.25±1.22 BA	46.51±1.61 CB	50.63±1.54 A

Means with different letter are statistically different (Tukey p = 0.05).

Medias con diferentes letras son estatísticamente diferentes (Tukey p = 0,05).

The results of correlation tests, which determined the statistical relationship between C concentration and the components, showed a significant association. Leaves, branches, and twigs kept a positive linear correlation altogether. Leaves and branches had a result of r = 0.63, (p < 0.001), which is the same for leaves and twigs with a result of r = 0.61, (p < 0.001). Branches and twigs yielded r = 0.83, (p < 0.001), suggesting that C concentrations in these components are closely associated (figure 2).

Discussion

Our results revealed no significant difference in C concentration in any component of all cardinal points. A possible explanation for this finding may be due to nutrients being absorbed by the roots, which are distributed equally throughout the tree itself (38). Moreover, the cardinal directions do not seem to affect C concentration.

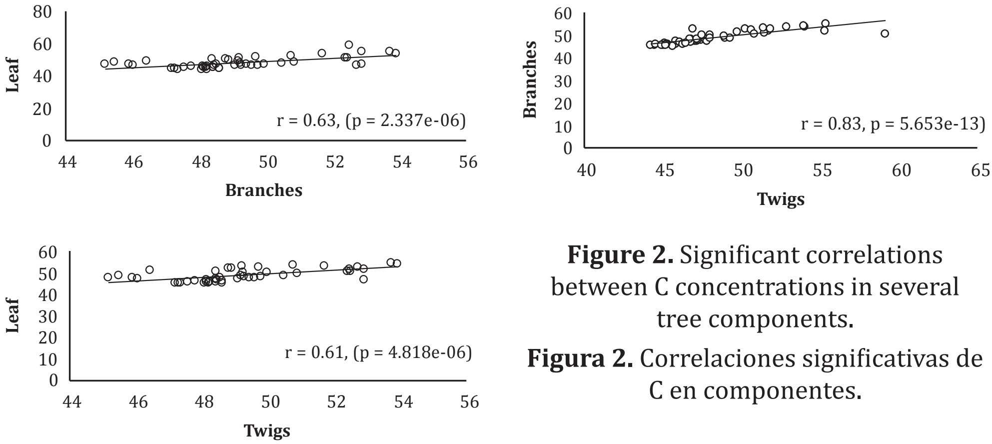

Figure 2. Significant correlations between C concentrations in several tree components.

Figura 2. Correlaciones significativas de C en componentes.

Unlike other previous works in Mexican ecosystems (15, 38, 39), this results suggest that it is not necessary to collect samples from the four cardinal points. Variations between cardinal directions were negligible suggesting that C concentration is evenly metabolized across aerial parts of trees (13, 20). Although the economic implications of this type of sampling are beyond the reach of our work, this finding brings relevant information in terms of economic efficiency without compromising the statistical reliability of the results.

Several studies about carbon fluxes have been developed in Mexico and worldwide (6, 15, 31, 37, 39).

However, this one is among the first efforts that contributes to the knowledge of carbon variation in co-existing HCVF species of northern Mexico. The results may improve future research about what we know about these forests in terms of carbon concentrations.

The stems of three out of the four species studied turned to have a lower concentration of carbon, except for *C. lusitanica*. Such similarity is attributed to the family Pinaceae, whose species are characterized by a high chemical composition of cellulose, hemicellulose, and starches (22).

Additionally, physiological characteristics common in species of the same family (28) and habitat in which the species thrive may represent the conditions to which the similarities are attributed to carbon concentrations (3).

The high averages found in the leaves of *A. durangensis and P. menziesii* can be attributed to the fact that they are depositories for high rates of volatile compounds. In turn, they showed a significant difference in C concentrations when it comes to tree structures (36). This implies that these volatile compounds are involved in differing concentrations for tree structures. Some authors argue that even though leaves contain a smaller quantity of cellulose, they exhibit a high carbon concentration thanks to the photosynthetic processes occurring there (26, 37).

The highly positive degrees of linear association imply an existence of physiological processes within these components.

For Martin *et al.* (2013), this physiological interaction establishes a strategy for mature trees to achieve a biochemical stability to prevent further decay. Recent studies have tested this hypothesis for several species at risk of mortality (14). This insight implies direct involvement in the productivity of the tree, as a decrease in C concentrations suggests a loss of vigor in the foliage.

Although these ecosystems are characterized by low humidity restrictions, the results obtained reclaim importance, given that water limitations are forecasted for the upcoming years in this region (34). Most projections for the dynamic models for carbon are based on water dependence (27). This means a high evapotranspiration demand in the near future could be a cause of decline for these forests.

Since the partition of biomass in woody species is assigned mostly in the stems (19), these results have implications about the accuracy of C estimates (*e.g.*, biomass) when using allometric equations (25). That is, incorporating the intra specific variations of C, it is possible to improve what we know about C flux. Therefore, applying 50% of C concentration would imply overestimating the concentration of C for some species. For example, Martin *et al.* (2015) and Wang *et al*. (39) presented numerical evidence from the generated errors. A quantitative evaluation of these errors could be addressed in future research.

These results suggest that carbon concentration varies within the structural components of HCVF species. It also demonstrates that the current notion that carbon concentration is approximately 50% plant biomass may be biased.

The species, *P. menziesii, A. durangensis,* and *P. chihuahuana*, turned out to have the least amount of carbon concentration in the stems, while *C. lusitanica* had the most. The total C concentration highly depends on the type of species.

When it comes to estimating C, no significant differences in concentrations were found, even when using a cardinal sample point from aboveground biomass. Nonetheless, this approach has a positive impact in terms of effort and economy. Leaves, branches, and twigs demonstrated positive linear relationships in C concentration, suggesting the presence of uniform C flux within these tissues. This discovery provided knowledge about C flux in these species.

Conclusions

These results show that carbon concentration varies within the structural components of HCVF species. They also demonstrate that the current notion that carbon concentration is approximately 50% plant biomass may be biased.

The species *P. menziesii, A. durangensis,* and *P. chihuahuana*, showed the lowest C concentration in the stem wood, while *C. lusitanica* presented the highest. These results should contribute to the knowledge of more accurate estimates of carbon stocks in forest ecosystems. Furthermore, reliable C concentration estimations are crucial for taking better global warming mitigation policies.

These results also suggest that it is irrelevant the cardinal origin of tree samples to estimate C concentration. Unlike other works in Mexico, we did not find any statistical difference among the four cardinal points. Correlation of C concentrations among tree components suggest certain uniform physiological processes within tissues. The implications of these findings could help better understand the precise role of forest ecosystems in mitigating the effects of greenhouse gases (GHG). For instance, to insure proper payments for biomass credits, cost-effective sampling for estimating GHG emissions reductions from forest ecosystems is critical.

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Acknowledgments

Funding was provided by CONACYT through the 222522 project. Many thanks to the Ejido el Brillante, Dr. Javier Bretado, and his staff for helping in the collection of field data. We also thank the Direccion General de Vida Silvestre, SEMARNAT, Mexico for technical permit. In addition, many thanks to the editor and reviewers for their valuable comments.