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Carbon concentration in structures of *Arctostaphylos pungens* HBK: An alternative CO_2 sink in forests

Concentración de carbono en estructuras de *Arctostaphylos pungens* HBK: Un reservorio alternativo de CO_2 en bosques

Pompa-García M[1] & E Jurado[2]

Abstract. *Arctostaphylos pungens* HBK is a dominant species with increasing abundance and distribution in chaparral ecosystems as a result of range management and, possibly, changes in climate. The value of this species for carbon (C) sequestration is unknown, and the standard 50% C out of total tree biomass is used as an approximate value. In this study, we aim to determine the C concentration of the primary components of *A. pungens*. The total C expressed as a percentage of biomass was determined with a *Solids* TOC Analyzer. We found the C concentration to vary among components. Leaves exhibited the highest C concentration (51.70%). Roots (46.11%), stems (47.30%), fruits (47.89%) and twigs (48.40%) had similar C concentration. These results provided superior estimates of C concentration, and reliable information concerning the potential use of *A. pungens* in climate-change mitigation programs.

Keywords: Carbon sequestration; Climate change; Manzanita.

Resumen. *Arctostaphylos pungens* HBK es una especie dominante con una gran abundancia y distribución en los ecosistemas de chaparral como resultado del manejo forestal, y posiblemente cambios en el clima. El valor de esta especie para la captura de carbono (C) es desconocida, y el valor del 50% de la biomasa total del árbol que se utiliza por defecto es una aproximación. En este estudio se determinó la concentración de C en componentes primarios de *A. pungens.* El C total expresado como un porcentaje de la biomasa fue determinado con el *Solids* TOC Analyzer. Se encontró que la concentración de C varió entre componentes. Las hojas exhibieron el valor más alto de concentración de C (51,70%). Las raíces (46,11%), tallos (47,30%), frutos (47,89%) y ramillas (48,40%) tuvieron similares concentraciones de C. Estos resultados proporcionan mejores estimaciones de la concentración de C y constituye una información confiable relacionada con el potencial del uso de *A. pungens* en programas de mitigación del cambio climático.

Palabras clave: Captura de carbono; Cambio climático; Manzanita.

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INTRODUCTION

The potential impact of increased CO_2 in the biosphere has prompted a search for remediation strategies. One such strategy involves plantations of long-lived plants that would incorporate CO_2 into their structure, thereby removing it from the atmosphere for long periods (Cunha-e-Sá et al., 2013). The ability of a plant species to act as a sink for carbon is characterized by at least three factors: (1) the amount of a carbon the species is able to incorporate into its structures; (2) the longevity, or length of time the carbon remains in the carbon-incorporating structures before being released back into the atmosphere, and (3) the ability of a plant species to prosper in a given ecosystem.

The impact of climate-change may be reduced by stabilizing current greenhouse gases in the atmosphere (Dhillon & Wuehlisch, 2013). There is evidence that forests may play a role in removing CO_2 from the atmosphere by capturing CO_2 in reservoirs, thereby off-setting the effect of CO_2 emissions (Lal, 2008). To that end, most researchers have focused on plant species from tropical forests and other fast-growing species (Thomas & Martin, 2012) with little attention to alternative reservoirs that could provide a complementary source of C sinks (Martin & Thomas, 2011). As most areas of the planet are not amenable for establishment of fast-growing species, it is important to investigate alternative types of vegetation. In addition, it is important to do so, using native species that do not represent a threat to local species assemblages as some exotic plants do (Hooper et al., 2005; Dickens & Allen, 2014).

Chaparrals are a C sink alternative. These ecosystems are increasing their cover, replacing oak and pine forests, due to changes in land use (Márquez-Linares et al., 2006). A common species in these ecosystems in Northern Mexico is *Arctostaphylos pungens* HBK, also known as Mexican Manzanita. This is a widespread shrub, common to pine and pine-oak forests and chaparrals in the Southern United States and Mexico. It is a sprawling evergreen shrub with simple ovate leaves and distinctive, smooth red stems. The small, pendulous flowers are borne in dense inflorescences. Flowers are bellshaped, with fused corollas. Flowers range from white to deep pink, and they average 6 mm in length and 3 mm at their widest point. The fruit is a fleshy berry with 1-5 stony segments, each containing 1-3 seeds (Richardson & Bronstein, 2012).

This species is important for wildlife, and is used by rural communities as a source of food, traditional medicine, crafts and firewood (Jurado et al., 2011). It is possible that the current increase in this species cover is related to climate change, particularly after extreme droughts, when oaks and pines succumb to that stress (Márquez-Linares et al., 2006).

To use *A. pungens* to counteract CO_2 emissions acting as a C sink by holding organic C for extended periods (Dhillon & Wuehlisch, 2013), it is necessary to understand the C balance in the ecosystem (Canadell & Raupach, 2008). Political agreements established in the Kyoto Protocol and RED++ require an accurate estimation of the C content in forests (Harvey et al., 2010). Often, the C content in trees and shrubs is assumed to be 50% of biomass, but this estimation does not consider variations between species, plant parts, age of the trees, and site conditions (McClaran et al., 2013; Navarro et al., 2013). Thomas & Martin (2012) found that wood C content varied widely across species, ranging from 41.9 to 51.6% in tropical species, from 45.7 to 60.7% in subtropical/Mediterranean species, and from 43.4 to 55.6% in temperate/boreal species.

In this study, we investigated the capacity of *A. pungens*, a long-lived, hardy native plant species that grows well in degraded forests of Durango, to incorporate carbon in its structures. We did so by measuring how much of the plant dry matter is composed of carbon, and thus determining if this species has the potential for being used in environmental service programs.

MATERIALS AND METHODS

This study was conducted in the mountains of the Sierra Madre Occidental (Fig. 1), which contains high and abrupt elevation variations. The land is used for forestry and cattle grazing, and vegetation includes mainly trees from cold and temperate climates such as *Pinus, Quercus, Arbutus,* and *Juniperus* species (Pompa-García et al., 2010).

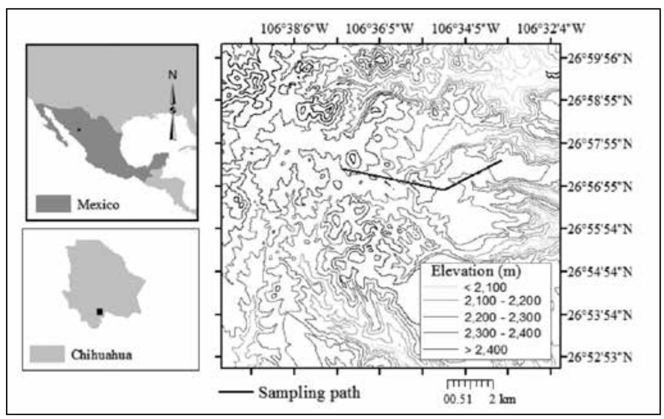

Fig. 1. Location and elevation of the study site in the South of the state of Chihuahua, Mexico.

Fig. 1. Localización y elevación del área de estudio en el sur del estado de Chihuahua, México.

In a 7 km transect, one individual for each category was registered. Height categories ranged from 0.25 to 4 m (e.g., category 1 = 0.25 m-0.75 m; category 2 = 0.76 m-1.25 m, and so on). For each shrub, a fresh, 250 g sample was collected from the four cardinal points. Roots were sampled 20 cm below the soil surface, and stems, twigs (<0.05 cm in diameter), leaves and fruits were collected separately. For collecting purposes, hatchets, scissors and shovels were used.

Samples were taken to the lab following the procedures of Karlik & Chojnacky (2013) and set to dry in a greenhouse at 65 ˚C and 20% moisture until a constant weight was reached. Lamlon & Savidge (2003) recommend breaking down the samples into small particles to better estimate C content. Therefore, samples were processed using a pulverizing mill, Fritsch Pulverisette 2, which yielded fractions smaller than 10 µg. Processed samples were placed in labeled plastic bags following the procedures outlined by Yerena et al. (2012).

Total carbon concentration was obtained using a Solids TOC Analyzer (model 1020A) from O·I·Analytical, which analyzes solid 5-mg samples by means of a thorough combustion at 900 ˚C. Resulting gasses were then measured through an infrared, non-dispersive detector that counts carbon molecules (Monreal et al., 2005). At least 3 replicates were used per sample to obtain a <0.06% standard deviation on carbon concentrations (Lamlon & Savidge, 2003).

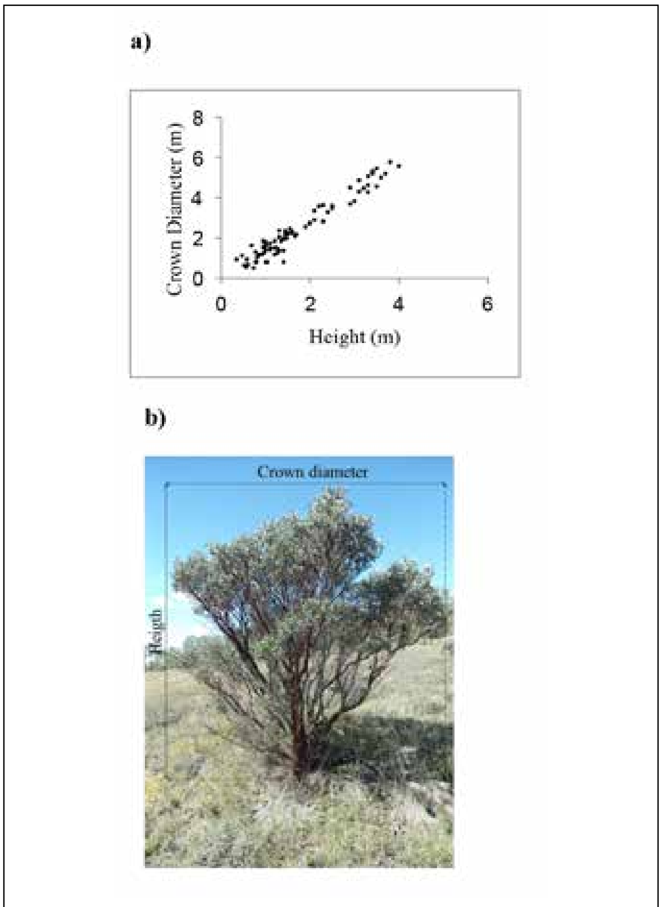

Fig. 2. Dispersion of dasometric field data (a) and measurements considered for *A. pungens* (b) to obtain TB and TC through allometric relations.

Fig. 2. Dispersión de datos dasométricos de campo (a) y dimensiones consideradas para *A. pungens* (b) para obtener TB y TC por medio de relaciones alométricas.

A complete random design was used, and data were analyzed using ANOVA with *SAS* (2004) to determine differences in carbon concentration between plant parts. Tukey tests (α=0.05) were carried out to detect which plant parts differed significantly (p=0.05).

Additionally, 90 more individuals were sampled to determine carbon concentrations on roots and stems representing the size-range in the field (Fig. 2a). Size data included height in m (H), and crown-cover in square meters (CA) (Fig. 2b). Using the allometric relations suggested by Mason et al. (2014), the dry weight of stems (SB) was obtained. Using SB, root biomass (RB) was determined following Mokany et al. (2006). SB + RB provided total biomass (TB) in kg, and total C content in kg (TC).

RESULTS

Carbon concentrations for *A. pungens* varied among plant parts (Table 1). It was highest for leaves (51.70%) and lower in all other plant parts (from 46.11% in roots to 48.40% in twigs). Most values were under the 50% concentration conventionally assumed for plants in forest ecosystems (Bert & Danjon, 2006). Results for carbon sequestration in plant structures are presented in Figure 3.

Table 1. Concentrations of C in different plant parts of *A. pungens.* Different letters indicate different means (p>0.0002).

Tabla 1. Concentraciones de C en diferentes partes de la planta de *A. pungens.* Letras diferentes indican diferentes medias (p>0,0002).

Component	Mean (%)	Tukey *
Roots	46.11	B
Stem	47.30	B
Fruit	47.89	B
Twigs	48.40	B
Leaves	51.70	A

*Means with the same letter are not significantly different, Tukey (α=0.05).

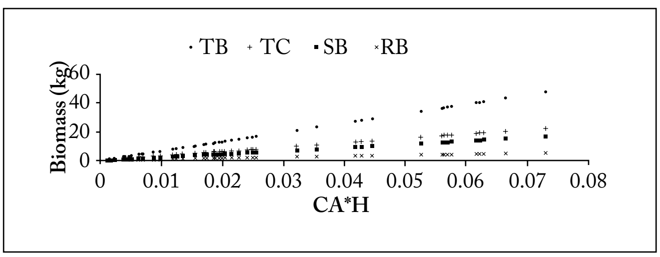

Fig. 3. TB and TC for *A. pungens*. TB is the result of SB+RB; SB= exp(a*ln(CA*H)+b), a=01.0215 b=6.1512. RB=0.489*SB0.89; TC=Carbon concentration SB+RB*TB.

Fig. 3. TB y TC para *A. pungens*. TB es el resultado de SB+RB; SB= exp(a*ln(CA*H)+b), a=1.0215 b=6.1512. RB=0.489*SB0.89; TC=Concentración de carbono SB+RB*TB.

Carbon concentrations in most *A. pungens* plant parts in our study were below the 50% concentration expected for plants in the region (Bert & Danjon, 2006; IPCC, 2006). Allowing for uncertainty values in estimations of TB (Mason et al., 2014), C content found for TC gives a clear idea of the potential use of *A. pungens* as a Carbon sink, and indicates that using the generic value of 50% C leads to over-estimation errors. Our results suggest that C sequestration can be over-estimated by using the 50% C value, as we found this to be 2.69% higher than our experimentally found value for stems, and 3.88% higher than our experimentally found value for roots. This observation is in agreement with McClaran et al., (2013) and Navarro et al. (2013) who emphasized on different C contents between plant species, parts of the plant, plant age and environmental variability.

DISCUSSION

Our results are the first C estimations for different parts of *A. pungens*. Leaves had the highest C concentrations of all the plant parts studied. Yerena et al. (2012) argue that leaves, in spite of having less cellulose, are rich in volatile substances high in C. These volatile substances ranging from 1.3% to 2.5% should be considered when making estimations of C for forest species (Thomas & Martin, 2012). However, volatile substances are soon released into the atmosphere, and therefore do not, in the long term, sequester C from the atmosphere (Cunha-e-Sá et al., 2013). In contrast, roots of *A. pungens* are an important sink of C given that this species has a large root system (Kummerow et al., 1977), which may be an adaptation to growth in degraded environments.

Terrestrial ecosystems are considered to be a primary C sink (Pacala & Socolow, 2004), but information on this topic remains highly general (Thomas & Martin, 2012). More research is required on the direct contribution of ecosystems and certain species acting as C sinks, and also on detailing plant parts and their specific contribution as C sinks (Zhang et al., 2009). In this study, we present the first set of data examining C content in a long-lived, hardy plant that is common in degraded forests in the region. The incorporation of chaparrals as C sinks may be a good alternative that requires further research, as well as competitive economic incentives. Our results provide reliable information that can lead to the determination of the bioenergetic potential of forests in north México where *A. pungens* grows.

As these scrubs are often a key step in the process of ecological succession (González-Roglich et al., 2014), accurate documentation of C content during the succession processes is essential to incorporate degraded lands into C-capture markets under different scenarios of land-use change (Funk et al., 2014). This documentation may also become relevant for the posterity of climate change records (Márquez-Linares et al., 2006). Our results present the possibility of the development of a C-capture sink as an alternative use for land areas that have undergone heavy grazing. This is in agreement with previous studies on scrubs and reconversion strategies in these areas (Paton et al., 2002; Conti et al., 2013).

Additional biomass studies and, thus, of *TC* should not be dismissed for the rest of the components of *A. pungens*. Moreover, it would be beneficial to perform a financial analysis of the income-potential represented by these ecosystems for foresters to evaluate the sale of environmental services and/or conservation areas.

Our results suggest that carbon concentration varies within the structural components of *A. pungens* and also demonstrates that the current notion that carbon content is approximated 50% of plant biomass may under- or over-estimate tree carbon levels.

Carbon concentrations from biomass samples of *A. pungens* ranged from 46.1% to 51.7%, and were highest in leaves compared to other plant parts, such as stems, roots, fruits and twigs.

Allometry variables provide an easy alternative for the estimation of C content for field samples of *A. pungens*. The allometry models used here are in agreement with those found in the literature (Conti et al., 2013; Becerril-Piña et al., 2014; Mason et al., 2014). The inclusion of two variables, combined H and CA, provided a useful value for simple field measurements.

Because our measurements have targeted a species endemic to the forests of northern Mexico, our findings also highlight an important ecological system: degraded forest areas where carbon estimation could lead to the determination of the bioenergetic potential of the chaparral.

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