Spatial exploration, dendrometric characteristics and prediction models of wood production in a stand of *Acacia schaffneri* in Durango, Mexico

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Abstract

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Degraded vegetation is the result of a process that affects structural and functional characteristics. Tree species from the *Acacia* genus are very important to the ecosystem in semi-arid lands due to their participation in the recovery of highly degraded areas. One of the most important species among this genus is *A. schaffneri*. The status of a forest stand is determined according to its structure, including height, stratum and density. Remote sensing is a valuable method for estimating volumetric stocks and associated changes in forest populations over established periods of time. The objective of this research was to estimate wood volume of *A. schaffneri* using remote sensing, and to complement that information with the results obtained from an estimation method based on forest measurements. The results obtained showed that the crown area was the dendrometric variable that can be used in a wood volume prediction model. In the exploratory analysis between dendrometric variables and remote sensing showed low and negative associations were observed in the four stations analyzed. There are conservation problems due to anthropogenic activities, among which stands out the intensive grazing that results in a decrease of the natural regeneration capacity of *Acacia schaffneri*.

Keywords

degradation, forest mensuration, grazing, prediction models

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Introduction

Forest resources of arid zones are an important economic source for the inhabitants of these regions who obtain sustenance and raw materials for food production. Among those forest resources are tree species from the *Acacia* genus, which are very important to the ecosystem due to their participation in the recovery of highly degraded arid areas. Degraded vegetation is the result of a process that affects structural and functional characteristics. Forest degradation occurs as a result of human activities, which in turn are driven by a variety of macroeconomic, demographic, technological, institutional and political factors (TAYLOR and HALPERN, 1991; BORRELI and OLIVA, 2001; AJBILOU et al., 2003; STANTURF et al., 2014; VÁSQUEZ-GRANDON et al., 2018). *Acacia* species have been reported that contribute to soil retention (KASAYE et al., 2020) and remediation of heavy metal polluted soil (LANDEROS-MÁRQUEZ et al., 2011), and are highly resistant to fire and drought (GÓMEZ-ACEVEDO and TAPIA-PASTRANA, 2003; RZEDOWSKI and CALDERÓN-DE RZEDOWSKI, 2003). Besides, *Acacia* trees are also used for fuel (NUGROHO-MARSOEM and IRAWATI, 2016), cattle feed, (GEBEYEW, 2015), essential oil production (PAPAEFTHIMIOU et al., 2017), and tannery industry (ADIGUZEL-ZENGİN et al., 2017). All botanical parts of *Acacia* species contain anti-inflammatory and anti-carcinogenic compounds (DELGADILLO-PUGA et al., 2018; LIN et al., 2018).

One of the most important species among this genus is *A. schaffneri*, which is distributed from southern United States to central Mexico along with other *Acacia* species; however, it is not considered as invasive. (VALIENTE-BANUET et al., 2000; MACHUCA-VELASCO et al., 2017). *A. schaffneri* can be either a bush or a tree up to 6 m high (RZEDOWSKI and CALDERÓN-DE RZEDOWSKI, 2003) forming a forest stand, which is a set of trees or other forest vegetation that occupies a certain area and is uniform in their species composition, age distribution, quality and thickness to differentiate itself from the rest of the mass or vegetation that surrounds it. The status of a forest stand is determined according to its structure, including height, stratum and density (VÁSQUEZ-GRANDON et al., 2018). Regarding that, remote sensing is a valuable method for estimating volumetric stocks and associated changes in forest populations over established periods of time (ROSENQVIST et al., 2003; TIMOTHY et al., 2016; ISSA et al., 2020). Previous studies have analyzed the response of spectral indices (RSI) obtained from Sentinel-2 in the estimation of aerial biomass (WANI et al., 2015; HUANG et al., 2016). However, it is advisable to complement the information obtained using RSI with direct field sampling and biomass estimation methods based on dendrometric variables (TORRE-TOJAL et al., 2019; DUNCANSON et al., 2020). Some of the advantages of using RSI include that it facilitates the monitoring of forest populations and biophysical components, changes in land use; and also helps in the determination of scenarios in a reliable manner (BEDÓN and PINTO, 2007). In addition, this method can be applied to monitor large areas (GÓMEZ et al., 2016).

A. schaffneri is highly exploited in rural areas in

Northern Mexico, including the state of Durango; therefore, it is required to establish the structure and volumetric stocks in this state. The objective of this research was to estimate wood volume of *A. schaffneri* using remote sensing (Response of Spectral Indices), and to complement that information with the results obtained from an estimation method based on forest measurements.

Materials and methods

Study area

The study was carried out in a 1,200-ha natural stand of *Acacia schaffneri* in Cuencamé, Durango (northern México), located at the coordinates 24°25'53.09"N, 103°50'41.28"W with an elevation of 2,020 m (Fig. 1) within a central plateau physiographic province consisting of plains formed by alluvial deposits interrupted by mountain ranges and isolated elevations, most of them from volcanic origin. The predominant soils are rendzina and kastanozem. The region climate is temperate semi dry (BS1kw(w)) having a cold Winter and Summer rain, with an annual average temperature of 16.5 °C and an accumulated annual rainfall of 526.6 mm (GARCÍA, 1998). The predominant vegetation in the region mainly consists of arboreal and shrubby species of the Fabaceae family along with natural and induced grassland (INEGI, 2016).

Stand characteristics

Characterization of dendrometric variables was performed using a systematic sampling within stratified sampling units from 20 conglomerates (400 m²) in the *Acacia schaffneri* stand, according to the recommendations of the National Forestry Commission (COMISIÓN NACIONAL FORESTAL, 2015). The variables measured were tree height, crown area and stem diameter at breast height; height was determined using a clinometer considering an established distance (LÓPEZ-LÓPEZ, 2005) with the following equation:

$$H = (A + B) * C,$$

where H is the tree height (m); A is the reading at the crown top (degrees); B is the reading at the stem base (degrees); and C is the distance from the clinometer to the tree (m).

The crown area was estimated based on the largest diameter and the perpendicular diameter using the following equation:

$$CA = LD * MD * 0.7854,$$

where CA is the crown area (m²); LD is the larger diameter (m); and MD is the minor diameter (m).

Usable wood volume

Acacia pruned logs are relatively short in length and cylindrical shape (BORN and CHOJNACKY, 1985). ROMAHN et al. (1994) propose the determination of the usable wood volume using the Huber method (RIAÑO and LIZARAZO, 2017) following this equation:

Fig. 1. Map of the study area in Cuencame, Durango (Mexico).

$$V = Am * L,$$

where V is the usable wood volume (m³), Am is the log middle section area (m²), and L is the log length (m).

Satellite images (Sentinel-2) and spectral indices obtention

The images used in this study were obtained from Earth Explorer portal of the United States Geological Survey (USGS), through the link <https://earthexplorer.usgs.gov/>. The Sentinel-2 mission of the European Space Agency (ESA) provides high resolution images, allowing to improve the available multispectral data services, such as the Landsat and SPOT missions (DENG et al., 2019). The Sentinel-2 mission consists of two satellites, and has a temporal resolution of 5 days, with 13 spectral bands located between the spectral region of visible to short-wave infrared which are as follows: four bands of 10 m of spatial resolution, six bands of 20 m, and three bands of 60 m, with a sweep width of 290 km (ESA, 2016). The Sentinel-2 mission incorporates three bands in the red-edge region, which allows to run spatial studies related to nutritional and stress conditions for plant covers (DELGADO et al., 2011; López-CALDERÓN et al., 2020).

The dates of the downloaded images contemplated the four seasons of the year 2019: for Spring on April 3rd, Summer on July 17th, Fall on October 10th, and for Winter on February 7th, 2020. Images selected had zero concentration of cloudiness to avoid interferences while

working with reflectance. Atmospheric correction was performed by the Dark Object Subtraction method (DOS) (CHAVEZ, 1996), using the Semi-Automatic Classification Plugin in the software QGIS 3.14. Seven spectral indices were generated in order to prove if the information obtained by remote sensing can be used to generate estimation models of dendrometric variables in *Acacia* logs from the Sentinel-2 images. The six spectral indices generated are presented in Table 1.

Statistical analysis

The statistical analysis of the present study consisted of two phases: In the first phase a prediction model was developed using *Acacia* logs dendrometric data, in order to estimate the volume of usable wood by mean of a Principal Component Analysis (PCA) (OLIVARES, 2014). The prediction model was developed once it was established the variable with the largest influence ($p < 0.05$) using Principal Components Analysis correlations. The second phase consisted in determining the possible relation between the dendrometric variables measured in field, the usable wood volume of *Acacia* logs, and derivatives of spectral indices and the 13 bands of each satellite image. The relation was verified by mean of a correlation of Pearson ($p < 0.05$) using the CorrPlot library in R 3.4.3 environment R 3.4.3 (R CORE TEAM, 2015).

Table 1. Spectral indices used to establish association with dendrometric data and usable wood volume in an *Acacia schaffneri* stand of Cuencame, Durango (Mexico)

Index	Equation	
GCI; Green Coverage Index	$GCI = \left(\frac{B09}{B03} \right) - 1$	GITELSON, 2005
SAVI; Soil-Adjusted Vegetation Index	$SAVI = \frac{(B08 - B04)}{(B08 + B04 + 0.428) * (1.428)}$	HUETE, 1988
AVI; Advanced Vegetation Index	$AVI = [B08 * (1 - B04) * (B08 - B04)]^{1/3}$	DEKA et al., 2012
EVI; Enhanced Vegetation Index	$EVI = \frac{2.5 * (B08 - B04)}{((B08 + 6 * B04 - 7.5 * B02) + 1)}$	HUETE et al., 2002
NDVI; Normalized Difference Vegetation Index	$NDVI = \frac{(B08 - B04)}{(B08 + B04)}$	TUCKER, 1979
LAI; Leaf Area Index	$LAI = \frac{Ln \frac{0.69 - SAVI}{0.59}}{0.91}$	GITELSON et al., 2003

Results and discussion

Stand characteristics

The height distribution of the measured *A. schaffneri* trees presented the highest percent (55.5%) of the class ranging from 2 to 4 m, while the percent of trees was gradually decreasing in the remaining classes (Fig. 2). The smallest height class (1 to 2 m) had a low frequency percent (6.9%), meanwhile it was observed there were no trees higher than 9 m. The diameter categories from 20 to 40 cm had 47% of the measured *Acacia* logs, while the thinnest categories (0–20 cm) had 33.34% of the log samples, and none of the logs had a diameter of 80 cm thick. The structural characteristics of the vegetation subjected to anthropic alterations (without silvicultural criteria and objectives) of determined intensity and frequency can alter a stand structure, and eventually it will reflect the alteration degree in the stand (VÁSQUEZ-GRANDON et al., 2018).

The categorical analysis of tree diameter describes the stand demographic status, and also provides of the presence of conservation problems (AJBILOU et al., 2003). Tree diameter distribution is a method to determine uniformity and characteristics of a stand for forest inventories (ASSMANN, 1970). A low percent of individuals of small diameter indicates there is no population regeneration (LÓPEZ-SÁNCHEZ et al., 2020; TAYLOR and HALPERN, 1991). Distribution of tree diameter in a stand must have a single peak with distortion to the left despite forest management (ZHENG and ZHOU, 2010; DE LIMA et al., 2017). The *Acacia* stand does not present this pattern of tree diameter distribution (Fig. 2) because it has been subjected to a hard anthropic intervention mostly by an intensive grazing which compromises the stand

regeneration capacity (BORRELI and OLIVA, 2001). The *Acacia* stand has an unimodal diametric tree distribution with a high percentage of trees with intermediate trunk diameter, indicating a recent decline in the normal regeneration rate of the stand, which can result in a short term aging of the tree population (AJBILOU et al., 2003).

Principal Component Analysis (PCA)

The PCA indicates that the usable wood variable (UW) is highly associated to the crown area (CA), with a correlation rate of 0.79 ($p < 0.05$, Fig. 3). On the other hand, low correlations were found between the UW and log diameter (Di) ($r = 0.51$), and between UW and H (height), with a $r = 0.05$.

The model generated that can be used to estimate usable wood volume by mean of the crown area is as follows (Fig. 4):

$$Y = 0.0015 * X + 0.0017,$$

where Y is the usable wood volume (m^3), and X is the crown area (m^2).

The calculation of the estimated usable wood volume using the obtained model resulted similar to that observed using the dendrometric variables measured on the field (Fig. 5). The model validation parameters can be considered as adequate for all criteria (Table 2).

The exploratory analysis between the dendrometric variables and the usable volume of *Acacia* logs with the generated indices and spectral bands (Fig. 6) mostly showed low and negative associations for the four stations analyzed. Some of the highest positive correlations were: AC and B07_VER ($r = 0.22$), AI and GCI_INV

Fig. 2. Characterization of dendrometric variables of an *Acacia schaffneri* stand of Cuencame, Durango (Mexico).

Fig. 3. Principal Component Analysis between dendrometric variables and usable wood volume of an *Acacia schaffneri* stand of Cuencame, Durango (Mexico).

Fig. 4. Dispersion plot between the values of usable wood and crown area for an *Acacia schaffneri* stand of Cuencame, Durango (Mexico).

Fig. 5. Estimated and observed values of usable wood volume of an *Acacia schaffneri* stand of Cuencame, Durango (Mexico).

($r = 0.31$), DI and B10_VER ($r = 0.27$), MA and AVI_OTO ($r = 0.19$). On the other hand, the highest negative correlations ($p < 0.05$) were: AC and B01_OTO ($r = -0.19$), AI and B02_INV ($r = -0.29$), DI and AVI_INV ($r = -0.22$), MA and B01_OTO ($r = -0.29$). Previous studies have analyzed the response of spectral indices obtained from Sentinel-2 in the estimation of aerial biomass (WANI et al., 2015; HUANG et al., 2016). ASKAR et al. (2018) reported that the NDI 45 and the EVI allow to estimate the aerial biomass in *Acacia auriculiformis* with an R^2 of 0.81. Although the correlations and consequently the determination coefficient R^2 in the present study are much lower, the response of the dendrometric variables of *Acacia* stand addresses to the red border spectrum and to the red spectrum with the AVI index.

Conclusions

Several forest problems including anthropic intervention by intensive grazing compromise the natural regeneration capacity of *Acacia schaffneri* populations. Crown area is a dendrometric variable that can be used for establishing a wood volume prediction model. The exploratory analysis between dendrometric variables and remote sensing using RSI showed low and negative associations in the evaluations performed in all four annual seasons. It is required further evaluation of these two evaluation methods in order to obtain wood volume prediction models in arid zones stands.

Table 2. Model validation parameters of the estimated usable wood volume obtained from the dendrometric data of crown area in an *Acacia schaffneri* stand of Cuencame, Durango (Mexico)

Statistics	Calibration	Verification
Pearson correlation	0.88*	0.89*
Error reduction	0.77*	0.83*
Value of "t"	4.04*	7.16*
Sign test	7*	5*
First significant difference	5*	8*
Durbin-Watson coefficient	2.19	2.18
Efficiency coefficient	0.76	0.82

* $p \leq 0.05$

Fig. 6. Exploratory analysis between the dendrometric variables and the obtained values of usable wood volume using spectral indices and bands of an *Acacia schaffneri* stand of Cuencame, Durango (Mexico).

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