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Article

Estructura y diversidad de un bosque de galería en el noreste de México

Structure and diversity of a gallery forest in northeastern Mexico

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Resumen

Se determinó la estructura y diversidad de la comunidad arbórea de un bosque de galería en el noreste de México. En el año 2017, en el municipio Allende, Nuevo León se establecieron de manera aleatoria 15 sitios de muestreo de 10 × 5 m, donde se midieron los individuos de porte arbóreo con un diámetro a la altura del pecho (DAP = $d_{1.30\ m}$) ≥ 8 cm. La evaluación de la estructura horizontal, se hizo mediante el Índice de Valor de Importancia y de la vertical con el índice de *Pretzsch*. Para la diversidad se calcularon los índices de *Margalef* y *Shannon-Wiener*. Se registraron nueve taxones, pertenecientes a igual número de géneros y familias. La comunidad bajo estudio presentó una abundancia de 2 187 N ha^{-1}, con un área basal de 496.3 m^2 ha^{-1}. La especie que registró mayor abundancia, dominancia y frecuencia fue *Taxodium mucronatum,* con un valor de *IVI* de 52.4 %, seguida de *Platanus rzedowskii* (*IVI* = 23.2 %) y *Carya illinoinensis* (*IVI* = 8.8 %). El valor del índice de *Pretzsch* fue de 2.03, con A_{max} de 3.29 y A_{rel} de 61.87; lo que indica una diversidad estructural media en los estratos de altura. La comunidad tuvo un valor de D_{Mg} = 1.52 para el índice de *Margalef*, y un valor promedio de 0.58 para el índice de *Shannon-Wiener*; por lo que, es baja su riqueza y diversidad.

Palabras clave: Índice de Valor de Importancia, índice de *Pretzsch*, índice de *Shannon-Wiener*, *Platanus rzedoswkii* Nixon & J. M. Poole, *Taxodium mucronatum* Ten.

Abstract

The structure and diversity of the tree community of a gallery forest in northeastern Mexico was assessed. In 2017, at *Allende* municipality, *Nuevo León*, 15 sampling sites of 10 × 5 m were randomly established, where the individuals of arboreal size with a normal diameter ($d_{1.30\ m}$) ≥ 8 cm were measured. The horizontal structure was evaluated with the Importance Value Index, and the vertical structure, with Pretzsch's index. For diversity, the Margalef and Shannon-Wiener indexes were calculated. Nine species were registered, belonging to nine genera and nine families. The evaluated community had 2187 N ha^{-1} abundance, with 496.3 m^2 ha^{-1} basimetric area. The species with the highest abundance, dominance and frequency was *Taxodium mucronatum*, with 52.4 % of *IVI* value followed by *Platanus rzedowskii* (*IVI* = 23.2 %) and *Carya illinoinensis* (*IVI* = 8.8 %). Pretzsch's index was 2.03, with a A_{max} of 3.29 and a A_{rel} of 61.87, which indicates medium structural diversity in the high strata. The D_{Mg} value (Margalef index) of the community was 1.52 and average value of 0.58 for the Shannon-Wiener index, which indicate that the evaluated community has low richness and diversity.

Key words: Importance Value Index, Pretzsch Index, Shannon-Wiener Index, *Platanus rzedoswkii* Nixon & J. M. Poole, *Taxodium mucronatum* Ten.

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Introduction

Gallery forests develop along water courses; they constitute an ecotone between aquatic and land communities (Naiman and Décamps, 1997). The benefits of this type of vegetation both, for wildlife and for human beings, have been widely documented (Lees and Peres, 2007). Besides providing a safe habitat for fauna species and serving as natural biological corridors, gallery forests prevent overflowing of rivers (Granados-Sánchez *et al.*, 2006).

Although human populations usually settle near water bodies, the vegetation associated to rivers and streams is also affected by the change of land use and other anthropic activities (Belsky *et al.*, 1999). Thus, stockbreeding, agriculture, tourism, and the extraction of timber for construction have reduced plant richness and abundance of these ecosystems (Canizales *et al*., 2010; Poff *et al.*, 2012). From these actions and the occurrence of natural phenomena such as hurricanes and cyclones, it is often found today that these vegetal communities have changed their structure and their floristic composition (Granados-Sánchez *et al.*, 2006).

In northeastern Mexico, gallery forests are very common along rivers born in the Eastern *Sierra Madre* (Treviño *et al.*, 2001). Particularly in the state of *Nuevo León*, there is a large number of them, both permanent and temporary (Martínez *et al.*, 2003). However, not all those that exist in the region have been studied from the ecological point of view, and their current status is unknown (Treviño *et al.*, 2001). In order to carry out future restoration studies in negatively impacted gallery forests, this knowledge is necessary. For this reason, the objective of the present study was to assess the structure and diversity of the arboreal community of a gallery forest located in *Allende* municipality in *Nuevo León*, Mexico.

Materials and Methods

Study area

The study was carried out in a gallery forest adjoining a submontane shrub and a Tamaulipan thornscrub in northeastern Mexico, specifically in the *Allende* municipality in *Nuevo León* State. The community is in a mature condition without apparent anthropic disturbance and is difficult to access. Its geographical coordinates are 25º13’45” N and 100º03’18” W. The climate is dry (BS_Ohw), according to Köppen´s classification modified by García (1988) for Mexico. The mean annual temperature ranges between 20 and 22 °C, and the warmest months are July and August, while the lowest temperatures occur in December and January, with a mean of 13 to 14 °C.

Vegetation analysis

A 4 Km long stretch with an altitude range of 450 to 490 masl was considered; 15 rectangular sampling sites measuring 50 m^2 (10 × 5 m) each were established at random for a total sampling surface area of 750 m^2. The sites were located at the shores of the river, parallel to the riverbed, which flows from south to north (Canizales *et al.*, 2010); all the individuals with tree size with a DBH ($d_{1.30\ m}$) ≥ 8 cm were included. The dasometric variables evaluated were total height (*h*) and diameter breast height ($d_{1.30\ m}$), which were measured with a Vertez III™ hypsometer and a Forestry Supliers Inc™ diametric tape, respectively.

Data analysis

The horizontal structure of each species was evaluated by determining its abundance according to the number of individuals; its dominance, in terms of its basimetric area, and its frequency, based on its presence in the sampling plots. The results were used to obtain a weighted value at taxon level known as Importance Value Index (*IVI*), which acquires percentage values on a scale of 0 to 100 (Müeller-Dombois and

Ellenberg, 1974). The relative abundance (AR_i, for its acronym in Spanish) per species was estimated using the following equation:

$$AR_i = \left(A_i \Big/ \sum_{i=1...n} A_i \right) \times 100$$

Where:

A_i = Absolute abundance

The relative dominance (DR_i, for its acronym in Spanish) was estimated using the formula:

$$DR_i = \left(D_i \Big/ \sum_{i=1...n} D_i \right) \times 100$$

Where:

D_i = Absolute dominance.

The relative frequency (FR_i, for its acronym in Spanish) was calculated using the following equation:

$$FR_i = \left(F_i \Big/ \sum_{i=1...n} F_i \right) \times 100$$

Where:

F_i = Absolute frequency = P_i/NS

P_i = Number of sites where the species occurs

iNS = Total number of simple sites

The horizontal characterization of the vegetal community was carried out using the Importance Value Index (*IVI*), which is the sum of the percentage values of abundance, dominance and frequency; the value determines the presence of each taxon within the community and is defined as (Whittaker, 1972; Moreno, 2001):

$$IVI = \frac{\sum_{n}^{i=1}(AR_i, DR_i, FR_i)}{3}$$

Where:

AR_i = Relative abundance of species *i* with respect to the total abundance

DR_i = Relative dominance of species *i* with respect to total dominance

FR_i = Relative frequency of species *i* with respect to total frequency

The characterization of the vertical structure of the taxa was carried out by using the vertical species distribution index (*A*) (Pretzsch, 2009), in which three altitude zones were defined: zone I, 80 %-100 % of the maximum altitude of the area; zone II, 50 %-80 %, and zone III, 0 to 50 %. This index (*A*) serves to determine the structural diversity in the vertical distribution of the species and is estimated by the following formula:

$$A = -\sum_{i=1}^{S}\sum_{j=1}^{Z} p_{ij} \times ln p_{ij}$$

Where:

S = Number of species present

Z= Number of altitude layers

p_{ij} = Percentage of species in each zone, estimated with the following equation:

$$p_{ij}=n_{i,j}/N$$

Where

$n_{i,j}$ = Number of individuals of the same species (i) in the zone (j)

N = Total number of individuals

Pretzsch's index needs to be standardized for purposes of comparison; this is done using the A_{max} value, estimated as follows:

$$A_{max} = ln(S \times Z)$$

Thus, the value of A can be standardized using this equation:

$$A_{rel} = \frac{A}{ln\,(S \times Z)} \times 100$$

Richness and diversity were determined by Margalef's index (D_{Mg}), which is based on the quantification of the number of species present (specific richness), and the Shannon-Wiener index ($H´$), based on the proportional distribution of the abundance of each taxon (Moreno, 2001). The values thus obtained were compared using the Student's t-test of a single sample, which compared the mean value of the indexes estimated in this study with the reference value of other studies. Prior to the analysis, normality was verified using the Shapiro-Wilks test (Zar, 2010).

The structure of the community was described in terms of the abundance of each species using rank-abundance curves (Magurran, 2004). The Null, preemption, lognormal, Zipf and Mandelbrot models were tested. The parameters were estimated using the maximum likelihood method, and the selection of the best model was based on the Akaike Information Criterion (AIC) in terms of the lowest value. The analysis was carried out using the R software, version 3.2.1.2 (R Core Team, 2017), with the Vegan package (Oksanen *et al.*, 2016) and with the support of the RStudio platform (RStudio Team, 2016).

Results and Discussions

Horizontal structure

Nine taxa belonging to an equal number of genera and family were registered. The assessed community exhibited an abundance of 2 187 N ha^{-1}, with a basimetric area of 496.3 m^2 ha^{-1}. The species that exhibited the greatest abundance, dominance and frequency was *Taxodium mucronatum* Ten., with an IVI value of 52.4 %, followed by *Platanus rzedowskii* Nixon & J. M. Poole (*IVI* = 23.2 %) and *Carya illinoinensis* (Wangenh.) K. Koch (*IVI* = 8.8 %). These amounted to 84.4 % of the *IVI* of the community, while 15.6 % corresponded to the remaining six (Table 1).

Table 1. Abundance, dominance, frequency and importance value index (*IVI*) of the species registered in the study area.

Species	**Abundance**		**Dominance**		**Frequency**		**IVI**
	N ha^{-1}	**%**	**m^2 ha^{-1}**	**%**	**Sities**	**%**	
Taxodium mucronatum Ten.	1 307	59.8	336.0	67.7	11	29.7	52.4
Platanus rzedowskii Nixon & J. M. Poole	547	25.0	73.7	14.8	11	29.7	23.2
Carya illinoinensis (Wangenh.) K. Koch	133	6.1	33.8	6.8	5	13.5	8.8
Fraxinus berlandieriana A. DC.	93	4.3	24.6	5.0	3	8.1	5.8
Morus nigra L.	27	1.2	11.0	2.2	2	5.4	2.9
Celtis laevigata Willd.	40	1.8	2.5	0.5	2	5.4	2.6
Quercus virginiana Mill.	13	0.6	9.5	1.9	1	2.7	1.7
Caesalpinia mexicana A. Gray.	13	0.6	5.1	1.0	1	2.7	1.4
Citrus sinensis (L.) Osbeck	13	0.6	0.1	0.0	1	2.7	1.1
Sum	2 187	100	496.3	100	37	100	100

Four genera (*Carya, Platanus, Fraxinus*, and *Taxodium*) are regarded as characteristic of this type of vegetation in Mexico (Enríquez-Peña and Suzán-Azpiri, 2011). Treviño *et al.* (2001) recorded 21 and 16 species for the tree stratum of two rivers in central *Nuevo León*, while Canizales *et al.* (2010) cited seven taxa along a river with different degree of anthropogenic disturbance in the same state. In such studies, as in the present work, *Taxodium mucronatum* is considered one of the most abundant species. In the research documented herein, unlike the previous ones, *Platanus rzedowskii* was observed to be abundant, while *P. occidentalis* L. was not.

Estrada-Castillón *et al.* (2013) registered both *Platanus* species at the *Cumbres de Monterrey* National Park and point out that these are usually associated with genera of boreal forests, including *Quercus* and *Carya*, as indicated in the present study. Likewise, Nixon and Poole (2003) mention that the two species occur very close to each other in certain riparian systems of northeastern Mexico and are the most conspicuous in this type of vegetal community in the temperate areas of the Eastern *Sierra Madre*.

Citrus sinensis — an exotic species widely used for the production of oranges in *Allende*— was calculated with a density of 13 N ha^{-1}; therefore, its seeds dispersed by birds (Verea *et al.*, 2009) have germinated in the study areas, despite their difficulty of access.

Total abundance was 2 187 N ha^{-1}; in this regard, Canizales *et al.* (2010) estimated a total abundance of 970 N ha^{-1} for a gallery forest community with a low degree of anthropic disturbance; Burton *et al.* (2005) determined a value of 1 233 N ha^{-1} and a lower level of abundance for a community closer to an urban center (950 N ha^{-1}) in southeastern United States. This indicates that the anthropogenic disturbance and the touristic activity registered by the authors affect the abundance of tree individuals, though to lesser degrees, as the gallery forest community analyzed in the present study was located in an area of difficult access exhibiting no apparent alteration.

According to the importance value index, *Taxodium mucronatum* registered 52 % and *Platanus rzedowskii*, 23.2 %. Canizales *et al.* (2010) mentioned *T. mucronatum* as having the highest ecological importance value index in three different anthropic disturbance conditions in the *Ramos* river, located in *Allende, Nuevo León*, but did not record *P. rzedowskii*. However, Treviño *et al.* (2001) cite *P. occidentalis*, followed by *T. mucronatum,* as the ecologically most important species for the same location, and *T. mucronatum*, with the highest *IVI*, followed by *P. occidentalis* and *Populus wislizenii* Sarg., in the *Cabezones* river.

Vertical structure

The maximum height for the trees in the present study was 15.5 m, based on which the stratification was performed in order to estimate the *A*-index. Stratum I (high) is formed by three species and was scarcely represented, by 9.15 % of the individuals and 12.08 % of the basimetric area. Stratum II (medium) was formed by six taxa and had the largest number of individuals (55.49 %) and basimetric area (68.76 %). Stratum III (low) consists of eight species, with 35.37 % of the individual and 19.16 % of the basal area (Table 2). The most abundant taxon in all the strata was *Taxodium mucronatum*, followed by *Platanus rzedowskii*; this indicates that the vegetal community exhibits the incorporation of individuals of the low stratum (III) that abound in the higher strata (I and II). The value of Pretzsch's index was 2.03, with a

A_{max} of 3.29 and a A_{max} of 61.87, indicative of an average structural diversity in the height strata, for the values close to 100 % imply that all the species are distributed equally between the three height strata (Mora-Donjuán *et al.*, 2014; Rubio *et al.*, 2014). It is important to mention that there is little literature where this index is used in relation to gallery forests.

Table 2. Values of *Pretzsch*'s vertical index for the study area.

Species	**Abundance**			**Dominance**		
	N ha^{-1}	**Of the total**	**Of the stratum**	**m^2 ha^{-1}**	**Of the total**	**Of the stratum**
Stratum I						
Carya illinoinensis (Wangenh.) K. Koch	13	0.61	6.67	0.85	0.17	1.42
Platanus rzedowskii Nixon & J. M. Poole	67	3.05	33.33	9.62	1.94	16.05
Taxodium mucronatum Ten.	120	5.49	60.00	49.49	9.97	82.53
Total	200	9.15	100	59.96	12.08	100
Stratum II						
Carya illinoinensis (Wangenh.) K. Koch	67	3.05	5.49	24.59	4.96	7.21
Celtis laevigata Willd.	13	0.61	1.10	1.72	0.35	0.50
Fraxinus berlandieriana A. DC.	53	2.44	4.40	6.39	1.29	1.87
Platanus rzedowskii Nixon & J. M. Poole	240	10.98	19.78	35.04	7.06	10.27
Quercus virginiana Mill.	13	0.61	1.10	9.45	1.90	2.77
Taxodium mucronatum Ten.	827	37.80	68.13	264.11	53.21	77.38
Total	1 213	55.49	100	341.30	68.76	100
Stratum III						
Caesalpinia mexicana A. Gray.	13	0.61	1.72	5.13	1.03	5.40
Carya illinoinensis (Wangenh.) K. Koch	53	2.44	6.90	8.35	1.68	8.78
Celtis laevigata Willd.	27	1.22	3.45	0.76	0.15	0.80
Citrus sinensis (L.) Osbeck	13	0.61	1.72	0.14	0.03	0.15
Fraxinus berlandieriana A. DC.	40	1.83	5.17	18.25	3.68	19.19
Morus nigra L.	27	1.22	3.45	11.02	2.22	11.59
Platanus rzedowskii Nixon & J. M. Poole	240	10.98	31.03	29.01	5.84	30.51
Taxodium mucronatum Ten.	360	16.46	46.55	22.43	4.52	23.59
Total	773	35.37	100	95.10	19.16	100
Overall total	2 187	100	300	496.36	100.00	300

Richness and diversity indexes

The diversity in the area was lower (*H´* = 0.58) than that estimated by Canizales *et al.* (2010) in a gallery forest classified as the best preserved one in their study and exhibited no significant differences (*t* = -1.433, *df* = 14, *p-value* = 0.173). On the other hand, for the community with a degree of anthropogenic disturbance classified as alarming, these authors registered a lower value, but a significant difference (*t* = 3.711 *df* = 14, *p-value* = 0.002) with respect to the present study (Table 3).

Table 3. Comparison between Shannon-Wiener indices in gallery forest communities of various localities.

Authors	***H´***	***t***	***df***	***p***
Present study (*Allende* river, *Nuevo León*)	0.58	-	-	-
Canizales *et al.,* 2010 (preserved *Ramos* river, *Nuevo León*)	0.74	-1.4332	14	0.1737
Canizales *et al.,* 2010 (disturbed river *Ramos*, *Nuevo León*)	0.18	3.7115	14	0.002324
Treviño *et al.,* 2001 (*Cabezones* river, *Nuevo León*)	2.67	-19.164	14	1.92E-11
Treviño *et al.,* 2001 (*Ramos* river, *Nuevo León*)	1.74	-10.62	14	4.41E-08
Burton *et al.,* 2005 (Sand Creek 41.km distance from an urban center, USA)	2.19	-14.755	14	6.33E-10
Burton *et al.,* 2005 (Clines Branch 30.58 from an urban center, USA)	2.92	-21.461	14	4.13E-12
Santiago *et al.,* 2014 (*La Fragua* stream, *Jalisco*)	1.8	-11.172	14	2.33E-08
Santiago *et al.,* 2014 (*Chiquito* stream, *Jalisco*)	2.6	-18.521	14	3.04E-11

H´ = Value of the *Shannon-Wiener* index; *t* = Student's *t* value, *df* = Degrees of freedom; *p* = *p* value.

As for the richmess of species, compared to that of Canizales *et al.* (2010), there are no significant differences in terms of the two conditions of the gallery forest analyzed by the authors (Table 4). According to Canizales *et al.* (2010), anthropogenic activity has a negative impact on the diversity and abundance of species; therefore, the values were lower in vegetal communities with greater anthropic disturbance. In relation to the study by Treviño *et al.* (2001) on the *Cabezones* and *Ramos* rivers, the diversity was greater than in the research documented herein; the statistical comparison indicated that there are significant differences with respect to the value registered in *Allende, Nuevo León* (Table 3). A comparison with the researches on gallery forests by Burton *et al.* (2005), in an urbanization gradient, and by Santiago *et al.* (2014), in an altitude gradient, shows the existence of a statistical difference with regard to the diversity observed in this study; the former two recorded higher values (Table 3).

Table 4. Comparison between Margalef's indexes of gallery forest communities of various localities.

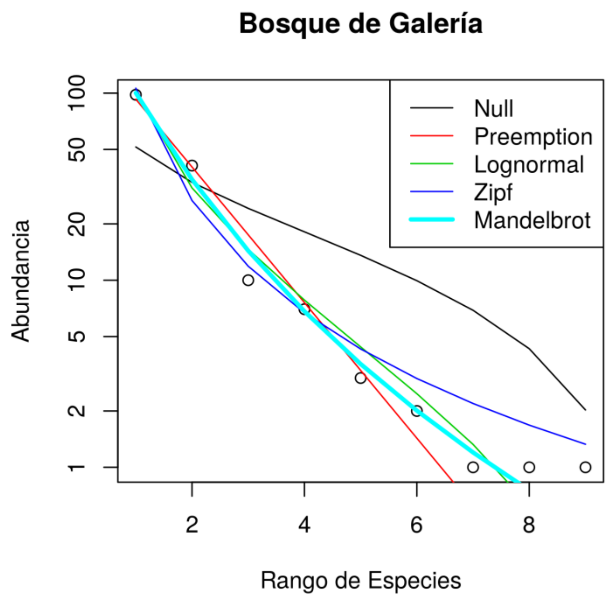
Author	D_{Mg}	***t***	***df***	***p***
Present study (*Allende* river, *Nuevo León*)	1.52	-	-	-
Canizales *et al.,* 2010 (preserved *Ramos* river, *Nuevo León*)	0.44	1.422	14	0.176
Canizales *et al.,* 2010 (disturbed *Ramos* river*, Nuevo León*)	0.5	0.897	14	0.384

D_{Mg} = Value of Margalef's index, *t* = Value of Student's *t*, *df* = Degrees of freedom; *p* = Value of *p*.

The Margalef's index determined by the present research is three times higher than the one documented by Canizales *et al.* (2010); yet, no significant differences resulted with respect to either the preserved (t = -1.422, df = 14, *p-value* = 0.176) or the disturbed (t = 0.897, df = 14, *p-value* = 0.384) vegetal community.

Species' rank-abundance curve

Figure 1 shows the rank-abundance curve for all the species registered in the vegetation samples. This curve is graphically adjusted to the Mandelbrot (AIC=40.83), Preemption (AIC=41.80) and Lognormal (AIC=42.80) distributions, but not to the Null distribution (AIC=119.75). Therefore, the abundance of species in the area may be described by the Mandelbrot, Preemption and Lognormal models, as the distribution of species adjusts to these, both graphically and analytically. However, the best fit was for the Mandelbrot model. According to it, one or a few taxa are highly abundant and predominant in the vegetal community, as well as at the initial stages of the succession (Magurran, 2004). This model has been regarded as one of the best for describing the distribution of the abundance of species (Fischer *et al.*, 1943).



Abundancia = Abundance; *Rango de especies* = Species´rank

Figure 1. Species' rank-abundance curve for the gallery forest and functions adjusted to this curve.

The Preemption model, also known as preferential niche or geometric series model, had a slightly smaller adjustment than the previous one; this implies that a few abundant species are present in a large proportion on one part of the hyperspace of the niche, and therefore, their occurrence varies with those situations in which the habitat is sequentially occupied (Aguirre *et al.*, 2008). Alanís-Rodríguez *et al.* (2017) observed that the geometric model was the one that best adjusted to a mesquite forest in central Nuevo *León*, in northeastern Mexico. The authors suggested that this is a typical structure for a severely disturbed environment. However, the studied community is not subjected to a severe disturbance; therefore, the Mandelbrot model, with a better fit, is the one that best describes the community, since the species analyzed in the gallery forest respond to specific factors that determine the ecology of the community, including environmental factors like geomorphology, the water flow or organic matter flow, or biological factors of its own, such as a rapid growth and being shade-intolerant.

Enríquez-Peña and Suzán-Azpiri (2011) point out that the elements that affect the reproductive growth of *Taxodium mucronatum* Ten. include the availability of water, the fertility of the soil and pollution. Likewise, one of the characteristics of *T. mucronatum* is its rapid growth (Rolston, 2001), which is important for its development at the initial stages of the natural succession; furthermore, the species is shade-tolerant during the first stages of its life (Conafor, 2018). In the case of the *Platanus* genus, its intolerance to shade may cause mortality to increase at the germination stage under advanced successional conditions, since it has a high crown coverage (Conabio, 2018), but germinates and develops adequately in areas with little coverage (Carranza, 1994).

Conclusions

The study area exhibits high abundance compared to the gallery forest with some type of anthropic disturbance, which may indicate the good conservation status of the riparian community. According to the vertical structure, the dominance in the low and middle strata of *T. mcronatum* and *P. rzedowskii* indicates that there is an incorporation of individuals in the first stages of life and regeneration in the community. The richness and diversity are slightly smaller than that of other riparian communities, even when located near the area, but larger than that of sites with a high degree of disturbance due to tourism. The Mandelbrot model showed the best fit in terms of the abundance of species, which is determined by various factors.

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Conflict of interests

The authors declare no conflict of interests.

Contribution by author

Eduardo Alanís-Rodríguez: design and structure of the manuscript, data analysis, and drafting of the manuscript; Ernesto A. Rubio-Camacho: capture of data and statistical analysis; Pamela A. Canizales-Velázquez: coordination of field work, field data collection and review of the document; Arturo Mora-Olivo: field data collection, data analysis and review of the document; Miguel Ángel Pequeño-Ledezma: field data collection and review of the document; Enrique Buendía-Rodríguez: data analysis, drafting and review of the document.

References

Avery, T. E. and H. E. Burkhart. 1983. Forest Measurement. McGraw-Hill. New York, NY, USA. 458 p.

Álvarez-González, J. G.; R. Rodríguez-Soalleiro. y A. Rojo-Alboreca. 2007. Resolución de problemas del ajuste simultáneo de sistemas de ecuaciones: heterocedasticidad y variables dependientes con distinto número de observaciones. Sociedad Española de Ciencias Forestales 23: 35-42. Doi:10.31167/csef.v0i23.9603.

Belmonte S., F. y F. López B. 2003. Estimación de la biomasa de una especie vegetal mediterránea (tomillo *Thymus vulgaris*) a partir de algunos parámetros de medición sencilla. Ecología (17): 145-151. https://dialnet.unirioja.es/ejemplar/87016 (4 de febrero de 2019).

Berlanga R., C. A., L. A. González L. y H. Franco L. 1992. Metodología para la evaluación de lechuguilla en condiciones naturales. Folleto Técnico Núm. 1. Campo Experimental Saltillo CIRNE-INIFAP. Saltillo, Coah., México. 22 p.

Brown, S. 1997. Estimating biomass and biomass change of tropical forests: a Primer. (FAO Forestry Paper - 134). FAO. Rome, Italy. 55 p.

Cano P., A., O. Martínez B., C. A. Berlanga R., E. E. Villavicencio G. y D. Castillo Q. 2006. Guía para la evaluación de existencias de sotol (*Daylirion cedrosanum* Trel.) en poblaciones naturales del Estado de Coahuila. Folleto Técnico Núm. 43. Campo Experimental Saltillo CIRNE-INIFAP. Saltillo, Coah., México. 20 p.

Chandrasekharan, C., T. Frisk. y J. Campos R. 1996. Desarrollo de productos forestales no maderables en América Latina y el Caribe. Serie Forestal Núm. 5. Dirección de productos forestales, FAO. Roma para m´rica Latina y El Caribe. Santiago, Chile. 63 p. http://www.fao.org/3/a-t2360s.pdf (20 de febrero de 2019).

Comisión del CODEX *Alimentarius* (CODEX). 2017. Programa conjunto sobre normas alimentarias de la FAO/OMS. Informe de la 3ª. sesión del Comité del CODEX sobre especias y hierbas culinarias. 44ª. sesión CICG. Ginebra, Suiza. pp. 17-22. http://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FMeetings%252FCX-736-(03%252FReport%252FFinal%252520Report%252FREP17_SCHs.pdf (2 de julio de 2017).

Cruz de L., G. and L. P. Uranga-Valencia. 2013. Theoretical evaluation of Huber and Smalian methods applied to tree stem classical geometries. Bosque 33(3): 311-317. Doi: 10.4067/S0717-92002013000300007.

Cruz C., F., R. Mendía S., A. A. Jiménez F., J. A. Nájera L. y F. Cruz G. 2016. Ecuaciones de volumen para *Arbutus* spp. (madroño) en la región de Pueblo Nuevo, Durango. Investigación y Ciencia 24(68): 41-47. http://www.redalyc.org/jatsRepo/674/67448742006/html/index.html (13 de noviembre de 2019).

Flores M., F., D. J. Vega-Nieva, J. J. Corral-Rivas, J. G. Álvarez-González, A. D. Ruiz-González, C. A. López-Sánchez y A. Carillo P. 2018. Desarrollo de ecuaciones alométricas de biomasa para la regeneración de cuatro especies en Durango, México. Revista Mexicana de Ciencias Forestales 9(46): 157-185. Doi: 10.29298/rmcf.v9i46.119.

Foroughbakhch, R., G. Reyes, M. A. Alvarado V., J. Hernández P. and A. Rocha E. 2005. Use of quantitative methods to determine leaf biomass on 15 woody shrub species in northeastern Mexico. Forest Ecology and Management 216(1/3): 359–366. Doi: 10.1016/j.foreco.2005.05.046.

Foroughbakhch, R., J. Hernández-Piñero, M. A. Alvarado-Vázquez, E. Céspedes-Cabriales, A. Rocha-Estrada and M. L. Cárdenas-Ávila. 2009. Leaf biomass determination on woody shrub species in semiarid zones. Agroforestry Systems 77(3): 181–192. Doi: 10.1007 / s10457-008-9194-6.

Gaillard B., C., M. Pece, M. Juárez d. G., G. Gómez. y M. Zárate. 2013. Modelización de funciones para estimar biomasa aérea individual de piquillín (*Condalia microphylla* Cav, Ramnacea) y tala chiquito (*Celtis pallida* Torr, Celtidacea) en la provincia de Santiago del Estero, Argentina. Revista de Ciencias Forestales - Quebracho 21(1-2): 46-57. https://www.researchgate.net/publication/262434949_Modelizacion_de_funciones_para_estimar_biomasa_aerea_individual_de_piquillin_Condalia_microphylla_Cav_Ramnacea_y_tala_chiquito_Celtis_pallida_Torr_Celtidacea_en_la_provincia_de_Santiago_del_Estero_Arg (7 de marzo de 2019).

Gómez-García, E., F. Crecente-Campo y U. Diéguez-Aranda. 2013. Tarifas de biomasa aérea para abedul (*Betula pubescens* Ehrh.) y roble (*Quercus robur* L.) en el noroeste de España. Madera y Bosques 19(1): 71-91. Doi: 10.21829/myb.2013.191348.

Gujarati, D. G. y D. C. Porter. 2010. Econometría. McGraw-Hill. México, D.F., México. 921 p.

Huff, S., K. P. Poudel, M. Ritchie and H. Temesgen. 2018. Quantifying above ground biomass for common shrubs in northeastern California using nonlinear mixed effect models. Forest Ecology and Management (424): 154–163. Doi:10.1016/j.foreco.2018.04.043.

Instituto Nacional de Estadística y Geografía (Inegi). 2006a. Conjunto de datos vectorial Edafológico escala 1:250 000 serie II. Continuo Nacional (Monterrey). https://www.inegi.org.mx/app/biblioteca/ficha.html?upc=702825236182 (7 de septiembre de 2018).

Instituto Nacional de Estadística y Geografía (Inegi). 2006b. Conjunto de datos vectoriales escala 1:1 000 000. Precipitación media anual. https://www.inegi.org.mx/app/biblioteca/ficha.html?upc=702825236182 (7 de septiembre de 2018).

Instituto Nacional de Estadística y Geografía (Inegi). 2007. Conjunto de datos vectoriales escala 1:1 000 000. Temperatura media anual. https://www.inegi.org.mx/app/biblioteca/ficha.html?upc=702825236182 (7 de septiembre de 2018).

Instituto Nacional de Estadística y Geografía (Inegi). 2008. Conjunto de datos vectoriales escala 1:1 000 000. Unidades climáticas. https://www.inegi.org.mx/app/biblioteca/ficha.html?upc=702825236182 (7 de septiembre de 2018).

Jiménez-Pérez, N. D. C. and F. G. Lorea-Hernández. 2009. Identity and delimitation of the American species of *Litsea* Lam. (Lauraceae): a morphological approach. Plant Systematics and Evolution 283(1-2): 19-32. Doi: 10.1007 / s00606-009-0218-0.

Jiménez-Pérez, N. D. C., F. Lorea-Hernández, C. K. Jankowski and R. Reyes-Chilpa. 2011. Essential oils in mexican bays (*Litsea* spp., Lauraceae): Taxonomic assortment and ethnobotanical implications. Economic Botany 65(2): 178–189. Doi:10.1007/s12231-011-9160-5.

López-Merlín D., L. Soto-Pinto, G. Jiménez-Ferrer y S. Hernández-Daumás. 2003. Relaciones alométricas para la predicción de biomasa forrajera y leña de *Acacia pennatula* y *Guazuma ulmiflora* en dos comunidades del norte de Chiapas. Interciencia. 8:334-339. http://ve.scielo.org/scielo.php?script=sci_arttext&pid=S0378-18442003000600005&lng=es&nrm=iso (21 de octubre de 2019).

Ludwig J. A., J. F. Reynolds and P. D. 1975. Size-biomass relationships of several Chihuahuan Desert shrubs. The American Midland Naturalist. 94 (2): 451-461. Doi: 10.2307/2424437.

Méndez G., J., O. A. Turlan M., J. C. Ríos S., y J. A. Nájera L. 2012. Ecuaciones alométricas para estimar biomasa aérea de *Prosopis laevigata* (Humb. & Bonpl. ex Willd.) M.C. Johnst. Revista Mexicana de Ciencias Forestales 3(13): 57-72. Doi: 10.29298/rmcf.v3i13.489.

Návar, J., J. Nájera and E. Jurado. 2002. Biomass estimation equations in the Tamaulipan thornscrub of north-eastern México. Journal of Arid Environments 52(2): 167-179. Doi:10.1006/jare.2001.0819.

Návar, J., E. Méndez, J. Graciano, V. Dale and B. Parresol. 2004. Biomass equations for shrub species of Tamaulipan thornscrub of North-eastern México. Journal of Arid Environments 59(4): 657–674. Doi:10.1016/j.jaridenv.2004.02.010.

Ordóñez D., J. A. B., R. Rivera V., M. E. Tapia M. y L. R. Ahedo H. 2015. Contenido y captura potencial de carbono en la biomasa forestal de San Pedro Jacuaro, Michoacán. Revista Mexicana de Ciencias Forestales 6(32): 7–16. Doi: 10.29298/rmcf.v6i32.95.

Pedrosa, I., J. Juarros-Basterretxea, A. Robles-Fernández, J. Basteiro y E. García-Cueto. 2015. Pruebas de bondad de ajuste en distribuciones simétricas, ¿qué estadístico utilizar? Universitas Psychologica 14(1): 245-254. Doi:10.11144/Javeriana.upsy13-5.pbad.

Picard, N., L. Saint-André y M. Henry. 2012. Manual de construcción de ecuaciones alométricas para estimar el volumen y la biomasa de los árboles: del trabajo de campo a la predicción. Las Naciones Unidas para la Alimentación y la Agricultura y el Centre de Coopération Internationale en Recherche Agronomique pour le Développement, Montpellier, Rome. 223 p.

Prodan, M., R. Peters, F. Cox. y P. Real. 1997. Mensura Forestal. Agroamerica. San José, Costa Rica. 586 p.

Protección de la Fauna Mexicana A.C. (Profauna). 2008. Zona Sujeta a Conservación Ecológica Serra de Zapalinamé. PROFAUNA. Saltillo, Coah., México. 87 p.

Ramos-Uvilla, J. A., J. García-Magaña, J. Hernández-Ramos, X. García-Cuevas., J. C. Velarde-Ramírez., H. J. Muñoz-Flores. y G. G. García E. 2014. Ecuaciones y tablas de volumen para dos especies de *Pinus* de la Sierra Purhépecha, Michoacán. Revista Mexicana de Ciencias Forestales 5(23): 92-109. Doi: 10.29298/rmcf.v5i23.344.

Registro Agrario Nacional (RAN). 2018. Perimetrales núcleos agrarios SHAPE Entidad Federativa Coahuila. https://www.inegi.org.mx/app/biblioteca/ficha.html?upc=702825236182 (7 de septiembre de 2018).

Sáenz R., J. T. y D. Castillo Q. 1992. Guía para la evaluación de cortadillo en el estado de Coahuila. Folleto Técnico Núm. 3. Campo Experimental Saltillo CIRNE-INIFAP. Saltillo, Coah., México. 13 p.

Schreuder, H. T. and M. S. Williams. 1998. Weighted linear regression using D^2H and D^2 as the independent variables. USDA Forest Service. Fort Collins, CO, USA. 10 p.

Segura, M. y H. J. Andrade C. 2008. ¿Cómo construir modelos alométricos de volumen, biomasa o carbono de especies leñosas perennes? Agroforestería en las Américas (46): 89-96.

Statistical Analysis System (SAS). 2017. SAS/ETS® 14.3 User's Guide. SAS Institute Inc. Cary, NC, USA. n/p.

Schreuder, H. T. and M. S. Williams. 1998. Weighted Linear Regression Using D2H and D2 as the Independent Variables. USDA Forest Service. Fort Collins, CO, USA. 10 p.

Thomson, E. F., S. N. Mirza and J. Afzal. 1998. Predicting the components of aerial biomass of fourwing saltbush from shrub high and volume. Journal of Range Management 51: 323-235. Doi: 10.2307/4003418.

Van Der Werff, H. y F. Lorea. 1997. Flora del bajío y regiones adyacentes. Fascículo 56. familia: Lauraceae. INECOL. Xalapa, Ver., México. 58 p.

Velasco B., E., A. Arredondo G., M. C. Zamora-Martínez y F. Moreno S. 2009. Modelos Predictivos para la Producción de Productos Forestales No Maderables: Lechuguilla. Manual Técnico Núm. 2. CENID-COMEF. INIFAP. México, D.F., México. 56 p.

Villavicencio G., E. E. y H. Franco L. 1992. Guía para la evaluación de existencias de palma samandoca (*Yucca carnerosana* Trel.) en el estado de Coahuila. Folleto Técnico Núm. 2. Campo Experimental Saltillo CIRNE-INIFAP. Saltillo, Coah., México. 18 p.

Villavicencio G., E. E., A. Hernández R., C. N. Aguilar G. y X. García C. 2018. Estimación de la biomasa foliar seca de *Lippia graveolens* Kunth del sureste de Coahuila. Revista Mexicana de Ciencias Forestales 9(45): 187-207. Doi: 10.29298/rmcf.v9i45.139.

Walpole, R. E., R. H. Myers., S. L. Myers. y K. Ye. 2012. Probabilidad y estadística para ingeniería y ciencias. 9ª edición. Pearson Educación de México. Naucalpan, Edo. de Méx., México. 816 p.