



Tree diversity and structure in an *Abies vejarii* Martínez at the south of Nuevo León state

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Abstract:

To evaluate species diversity and tree density in natural forests of *Abies vejarii* in south *Nuevo León*, a directed sampling was applied in four Permanent Forest Research Sites of 2 500 m², at 100 m high between each community. Tree diameter information was recorded for normal diameters greater than 7.5 cm. Species composition, diversity, density of individuals, basal area and dominance by species between altitudinal gradient were determined. A statistical analysis was performed with the hypothesis of equality of medians with Kruskal-Wallis nonparametric test; the effect of distance at altitude was evaluated by means of species rarefaction curves and tablecloth tests. It was a total of 553 individuals of 7 families, 10 genera and 15 species. Pinaceae and Fagaceae reached the highest importance value index; the first contributed with most species. The average forest density was 523 ha⁻¹ individuals with an average basimetric area of 30.44 m²ha⁻¹. The Shannon-Weiner index (H') varied from 1.47 to 1.76. The mantel test did not recognize significant differences in the distance between the communities ($p > 0.05$); the Kruskal-Wallis test and the rarefaction curves revealed that the richness of species varied significantly ($p < 0.05$). The most frequent diameters are less than 40 cm. It is concluded that the greatest diversity of species occurred in the lower elevation community and the structure corresponds to that of an irregular mature forest without management.

Key words: *Abies vejarii* Martínez, rarefaction curves, altitudinal gradient, diversity indexes, *Kruskal-Wallis* test, tablecloth test.

Fecha de recepción/Reception date: 4 de agosto de 2017

Fecha de aceptación/Acceptance date: 27 de noviembre de 2017.

Introduction

From 47 to 52 *Abies* (fir) species have been recorded in the world, all of them in the northern hemisphere; they form pure or mixed masses associated to *Pinus* spp. and *Quercus* spp. (Xiang *et al.*, 2007; Granados *et al.*, 2007; Farjon and Filler, 2013). In Mexico, the genus comprises ten species (Martínez-Méndez *et al.*, 2016), which cover around 144 thousand hectares (FAO, 2010a); its greatest concentration occurs at the center of the country (Rzedowski, 1978; Sánchez *et al.*, 2006).

The conservation of these ecosystems is important; however, the geographical extension of the *Abies* populations is currently being reduced due to ecological, social, economic and climate change problems (Alvarado *et al.*, 1991, Fagre and Peterson, 2002; Saavedra *et al.*, 2003; Encina *et al.*, 2008). Several species of the genus are in some risk category, such as *Abies vejarii* Martínez, which is one of the six endemic species of Mexico (Semarnat, 2010; Gernandt and Pérez-de la Rosa, 2014; Martínez-Méndez *et al.*, 2016).

This species grows in very specific areas of the *Sierra Madre Oriental* of the states of *Coahuila*, *Nuevo León* and *Tamaulipas* with small populations (Farjon, 2013). For this reason, it is considered of great scientific interest to know the population dynamics of these relict masses through the diversity and arboreal structure of their communities.

The main elements that determine the composition, diversity and structure of plant communities depend on the size of the area (Aguirre, 2002; Condit *et al.*, 2002). The population dynamics of the species in forest ecosystems is considered as an indicator of the succession of vegetation, and of the climatic changes in the ecotone of the ecosystems (Camarero and Gutiérrez, 2004). Disturbances such as landslides, overgrazing and fire promote changes in the composition and diversity of species that vary according to altitude (Stephenson and Mantgem, 2005; Cuyckens *et al.*, 2015).

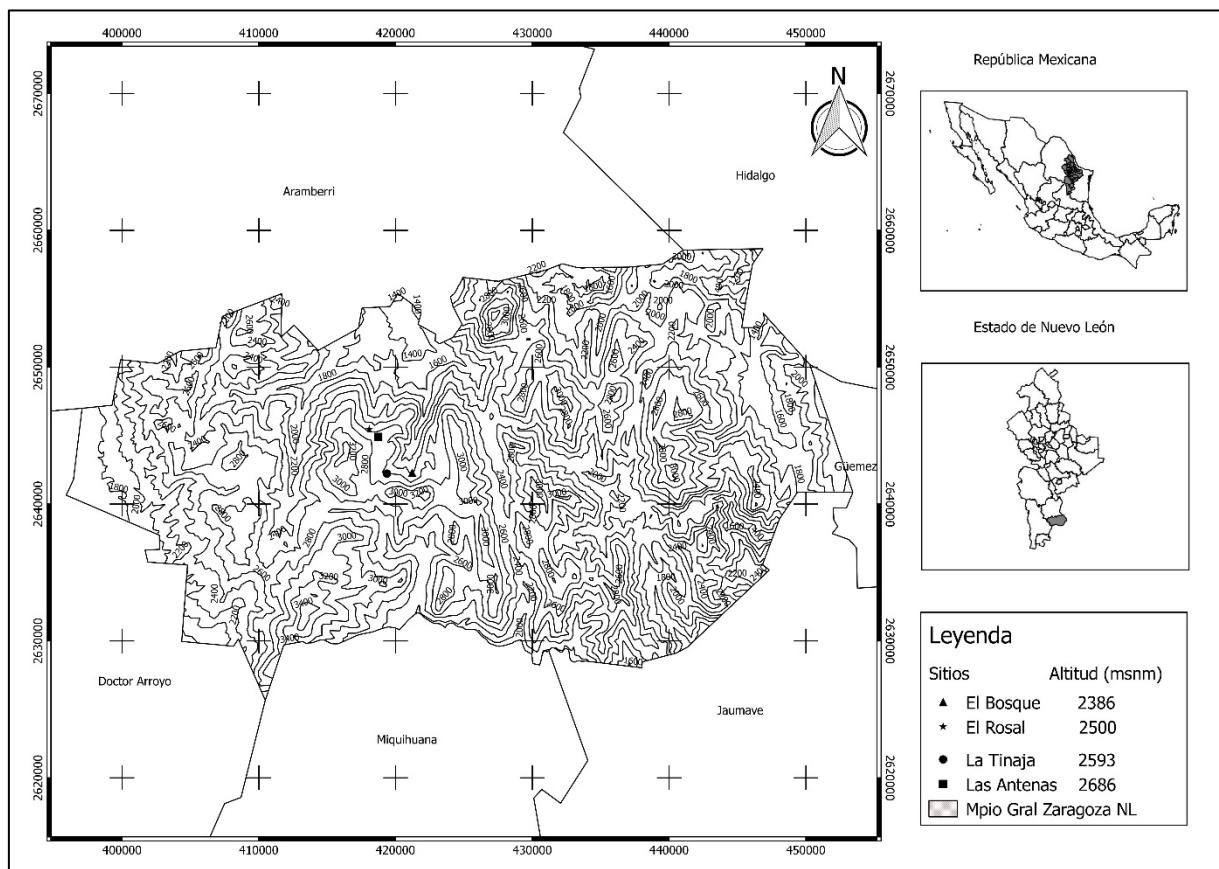
The altitudinal gradients in particular are closely associated to environmental modifications, which imply in turn, a change in biodiversity (Meraz *et al.*, 2017); in addition, elevation is an important factor that directly conditions environmental variables and, indirectly, population variables such as growth and mortality (Homeier *et al.*, 2010; Girardin *et al.*, 2010, Blundo *et al.*, 2012, Anderson *et al.*, 2013).

The change of index values within and between communities provides information on interspecific competition on the structure of a stand (Castellanos *et al.*, 2010). Therefore, the objective of this work was to describe the composition of the community, the diversity of species and the structure of the population of trees in four forest ecosystems with the presence of *Abies vejarii* along an altitudinal gradient, in the south of *Nuevo León*, Mexico.

Materials and Methods

Study area

Forest stands were selected with the presence of *Abies vejarii* in the *La Encantada ejido* of the *General Zaragoza* municipality of *Nuevo León*, Mexico, which is located at the coordinate of 23°54'18.36" north and 99°47'44.04" west, in an altitudinal range of 2 400 to 2 700 m. The data was obtained from four sites named by the location (Figure 1).



Sitios = Locations; Altitud = Altitude

Figure 1. Sampling locations in the study area.

According to the national information system of weather stations and the WorldClim, the average annual temperature ranged between 12.6 °C and 14.8 °C, with an average annual rainfall of 800 mm (Conagua, 2010; Fick and Hijmans, 2017). The surface of the terrain is rugged with steep slopes. The climate in the area is of the C (E) (w₂) type, subhumid semicold with summer rains (Inegi, 2010). The natural vegetation corresponds to a coniferous forest destined to the provision and improvement of forest environmental services.

Methodology

A directed sampling design was implemented, in which the strata were stands in different conditions of natural development, determined by their altitude (Figure 2). The sampling covered an area of 10 000 m² (1 ha⁻¹), resulting from the survey of four sites, each with an area of 2 500 m² (50 m × 50 m), where the methodology recommended by Corral *et al.* (2009) was applied. Information was recorded for tree species larger than 7.5 cm in diameter; the variables quantified were: species, number of trees, the normal diameter (DN_{1.30}), total height (ht) and crown diameter (north-south and east-west), as well as the distances from the central tree to each of the trees within the site. The diameter was measured with a Haglöf tree caliper of 80 cm and a Forestry Suppliers diametric tape of 5 m; for the height a Vertex Forestor Haglöf hypsometer was used; while a 30 m Lufkin longimeter was used for the crown diameters. A botanical collection of all associated plant species was made for later identification.



Figure 2. Composition and structure of the forest dynamics of *Abies vejarii* Martínez in the *La Encantada ejido, Nuevo León*. Images of each site where the characteristics of each ecosystem studied are illustrated.

Data analysis

The database elaborated with the record of the individuals in the sampling sites was quantitatively analyzed to obtain the relative density, relative frequency and relative dominance to calculate the Importance Value Index (IVI) of the arboreal species, which is obtained from the sum of the three variables (Curtis and McIntosh, 1950; Mueller-Dombois and Ellemberg, 1974; Mostacedo and Fredericksen, 2000; Treviño *et al.*, 2001).

The diversity of tree species was determined through the Shannon diversity index for each community (Shannon and Weaver, 1949), which is an algorithm that describes this component as distance-independent and reflects the heterogeneity of a community over the basis of two factors: the number of species present and their relative abundance (Castellanos *et al.*, 2008). (equation 1):

$$H' = - \sum_{i=1}^S P_i * \ln(P_i) \quad (1)$$

Where:

$P_i = n_i/N$ = Rate of individuals found in the i^{th} species

n_i = Number of individuals of the i species

N = Total number of individuals of all species of that kind of vegetation in the forest

\ln = Natural logarithm

The dominance of species was calculated using the Simpson index (1949), a weighted diversity index towards the most abundant species in the sample; when the index increases, diversity decreases and is generally expressed from 0 to 1 (equation 2):

$$S' = \sum_{i=1}^S P_i \quad (2)$$

Where:

P_i = Shannon's information function

The equity index refers to the degree of relative dominance of each species in each site, which quantifies equality as the proportion of diversity observed in relation to the maximum expected diversity whose values vary between 0 and 1, the higher the index, greater equality of the species. It is calculated according to Pielou (1966) with the following mathematical expression (3):

$$E' = H' / \log S \quad (3)$$

Where:

H' = Shannon index

S = Number of species

The richness of species within each community was determined by Margalef's index (Margalef, 1968) through equation (4):

$$D_{mg} = H' / \log S \quad (4)$$

Where:

S = Number of species

N = Number of individuals

The analysis of the structural composition was considered the comparison of the distribution of the diametric categories and to determine if there are significant differences in the diversity and in the tree structure between the four altitudinal gradients, the non-parametric Kruskal-Wallis test was used (equation 5) (Kruskal and Wallis, 1952), with the null hypothesis of equality of medians and with a level of significance of 95 %. This is because, previously, the data were subjected to Kolmogorov-Smirnov (K-S) normality tests, which did not present a normal distribution.

$$H = \left[\frac{12}{N(N+1)} \sum \frac{R_i}{n_i} \right] \quad (5)$$

Where:

N = Total number of elements

R_i = Average interval of the i group

n_i = Number of elements of the i group

The effect of the abundance of individuals on the number of species between the altitudes was evaluated, for which rarefaction curves were constructed for each altitude of the forest, according to the number of species and the number of

individuals sampled (Colwell, 2000; Colwell *et al.*, 2012; Oksanen *et al.*, 2017); this made it possible to compare the species richness between elevations. In addition, the Sørensen index was applied among the sites in order to know the percentage of shared species (Chao *et al.*, 2005).

Finally, from the geographic coordinates and the altitude, the beta diversity was evaluated by the relationship of the geographical distance between the sampling sites of each altitude based on tablecloth tests with the statistical package of vegan in *R* (Rosenberg and Anderson, 2011). To compare the spatial structure, a distance matrix was elaborated in the four sites based on the floristic composition of each one, with its X and Y coordinates. All procedures for diversity were carried out using the R Project statistical package (R Core Team, 2017).

Results and Discussion

In the four parcels of $2\ 500\ m^2\text{ha}^{-1}$ an average of 523 trees of 15 species, 10 genera and 7 families were recorded. Of these, 6 families comprising 9 genera, 11 species and 154 individuals, were registered in *El Bosque*; 4 families representing 6 genera, 7 species and 105 individuals were consigned in *El Rosal*; 6 species belonging to 5 genera, 3 families and 97 trees in the *La Tinaja* plot; and the *Las Antenas* site gathered 167 individuals belonging to 6 species, 4 genera and 3 families (Table 1).

Table 1. Floristic richness, number of trees and diversity indexes for the four sites of southern *Nuevo León*.

Variable	Sites			
	<i>El Bosque</i>	<i>El Rosal</i>	<i>La Tinaja</i>	<i>Las Antenas</i>
Number of species	11	7	6	6
Number de genera	9	6	5	4
Number of families	7	4	3	3
Density (ind. ha ⁻¹)	616	420	388	668
Basimetric area (m ² ha ⁻¹)	27.78	48.62	23.99	21.38
Shannon	1.76	1.47	1.69	1.6
Simpson	0.79	0.73	0.8	0.79
Equity	0.73	0.75	0.94	0.89
Margalef	1.98	1.28	1.09	0.97
Altitude	2 386	2 500	2 593	2 686
Exposure	North	North	North	North
Latitude	23°53'24.9" N	23°55'07.6" N	23°53'22.6" N	23°54'49.4" N
Longitude	99°46'26.3" O	99°48'17.8" O	99°47'31.5" O	99°47'54.8" O

The number of tree species in this study was similar to that from several authors in temperate forests with *Abies*, which ranged from 5 to 13 (Encina *et al.*, 2008; García *et al.*, 2012; Ávila *et al.*, 2012; Guerrero *et al.*, 2014). Diversity was influenced by the structure of the forest and the composition of species (FAO, 2010b).

In general, there were seven tree families in the study area taxonomically well-represented. Pinaceae has the maximum number of species (6), followed by Fagaceae (4); Cupressaceae, Ericaceae, Rutaceae, Taxaceae and Ulmaceae had only one species. On the basis of density, Pinaceae contributed with 56.5 %,

followed by Fagaceae (27.3 %), Cupressaceae (7.2 %), Taxaceae (5.16 %), and Ericaceae 3.25 %. For the Importance Value Index, Pinaceae contributed with 54.8 % followed by Fagaceae (25.33 %), Cupressaceae (8.35 %), Taxaceae (5.54 %) and Ericaceae with 3.76 % (Table 2). In addition to this, Valdez *et al.* (2003) described a locality in *Nuevo León* at 2 100 masl, where there is an association made up by *Picea martinezii* T. F. Patt, *Cornus florida* L., *Ilex rubra* S. Wats, *Quercus greggii* (A. DC.) Trel., *Abies durangensis* var. *coahuilensis* (I. M. Johnst.) Martínez, *Carya ovata* (Mill.) K. Koch and *Taxus globosa* Schltdl.

Table 2. Families of greater relevance based on the Importance Value Index (IVI) and the number of species, genera and trees.

Number	Family	Number of species	Number of genera	Number of trees	IVI %
1	Pinaceae	6	4	296	54.8
2	Fagaceae	4	1	143	25.33
3	Cupressaceae	1	1	38	8.35
4	Taxaceae	1	1	27	5.54
5	Ericaceae	1	1	17	3.76
6	Rutaceae	1	1	1	1.12
7	Ulmaceae	1	1	1	1.1
Total		15	10	523	100

The diversity indexes are calculated mainly to compare the diversity and abundance of species in different habitats on a similar scale and the higher the value, the greater the species richness. The diversity analysis of tree species shows that the location with the lowest altitude *El Bosque* showed the highest diversity considering the Shannon index (H') (1.76), as well as the highest Margalef index with 1.98 and the lowest value of equity (Simpson's index) with 0.73.

In this sense, in forests similar to the study area, García *et al.* (2012) found that the Shannon diversity index was 1.82 and 2.0, corresponding to the maximum diversity of the *Sierra Madre Oriental* of the state of *Nuevo León*; whereas, Martínez (2014) carried out a study on plant succession of a forest of *Abies guatemalensis* Rehder in western Guatemala, and obtained results in richness of species from 3.67 to 3.95. This variation can be attributed to the availability of light, management practices, competition from other plants and grazing activities (Alexander *et al.*, 2006).

The analysis of the floristic structure shows that in the lowest locality the dominant species is *Abies vejarii* (IVI = 29.42), with two codominant species, *Quercus affinis* Scheidw (18.53) and *Quercus mexicana* Bonpl. (17.23) to form a forest of *Abies* - *Quercus*. In the 2 500 m, the forest changes its structure to have two dominant species, *Abies vejarii* (29.47) in the high stratum and *Cupressus* sp. (31.46) in the middle stratum. When climbing the floor of 2 593 m in altitude, the dominant trees are *Quercus affinis* (24.07) and *Picea martinezii* (22.59), and *Abies vejarii* (16.91) is codominant. At the highest altitude site, *Quercus affinis* (24.74) is dominant and *Pinus ayacahuite* Ehrenb. et Schltld. (20.91) and *Abies vejarii* (18.39) are codominant (Table 3).



Table 3. Density (trees ha^{-1}), Importance Value Index (IVI), and Basimetric Area (AB) of the species in the four study sites.

Spp	El Bosque			Spp	El Rosal			Spp	La Tinaja			Spp	Las Antenas		
	IVI	N ha^{-1}	AB		IVI	N ha^{-1}	AB		IVI	N ha^{-1}	AB		IVI	N ha^{-1}	AB
AbVe	29.4	224	10.3	CuAr	31.4	152	18.0	QuAf	24.0	68	8.7	QuAf	24.7	192	6.0
QuAf	18.5	124	5.7	AbVe	29.4	144	16.0	PcMa	22.5	128	5.0	PiAy	20.9	152	4.8
QuMe	17.2	100	6.7	PiAy	14.4	44	5.6	AbVe	16.9	64	3.8	AbVe	18.3	160	2.9
QuPo	9.21	36	2.9	PsMe	11.6	32	5.6	PiAy	14.2	44	3.2	PiTe	18.2	88	5.1
PcMa	8.7	52	0.8	QuAf	8.5	40	2.7	TaGl	13.0	48	2.0	ArXa	12.68	64	2.3
TaGl	8.7	56	0.6	PiPs	2.2	4	0.2	PiPs	9.0	36	1.0	QuFu	5.0	12	0.8
PsMe	1.9	8	0.1	TaGl	2.2	4	0.1								
ZaFa	1.6	4	0.1												
PiAy	1.5	4	0.1												
UICr	1.5	4	0.8												
ArXa	1.5	4	0.5												

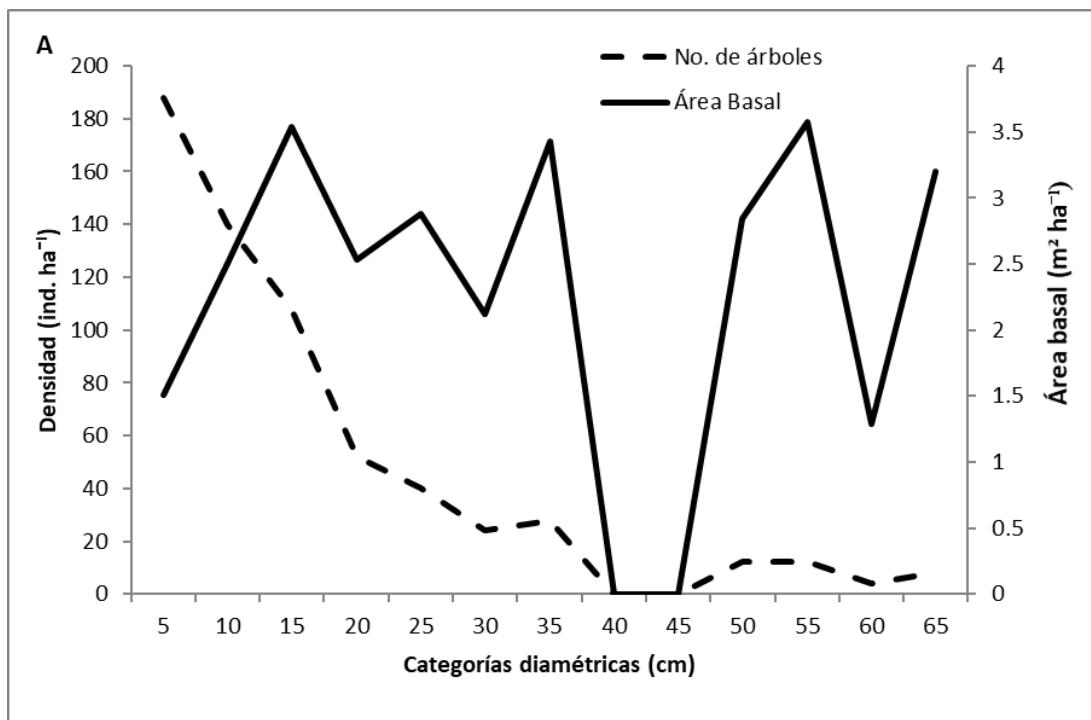
Spp = Species; AbVe = *Abies vejarii*; ArXa = *Arbutus xalapensis*; CuAr = *Cupressus arizonica* Greene Kunth; PcMa = *Picea martinezii*; PiAy = *Pinus ayacahuite* Ehrenb. ex Schltdl.; PiPs = *Pinus pseudostrobus* Lindl.; PiTe = *Pinus teocote* Schiede ex Schltdl. & Cham.; PsMe = *Pseudotsuga menziesii* (Mirb.) Franco; QuAf = *Quercus affinis*; QuFu = *Quercus fulva* Liebm.; QuMe = *Quercus mexicana*; QuPo = *Quercus polymorpha* Schltdl. & Cham.; TaGl = *Taxus globosa* Schltdl.; UICr = *Ulmus crassifolia* Nutt; ZaFa = *Zanthoxylum fagara* (L.) Sarg.

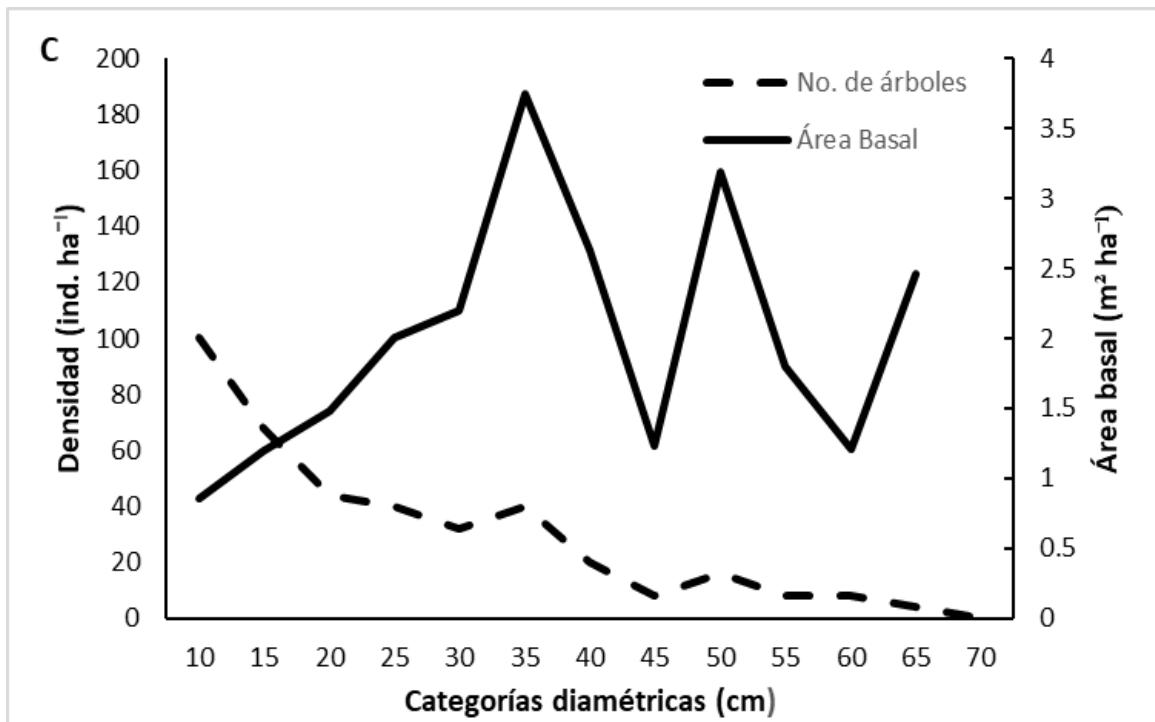
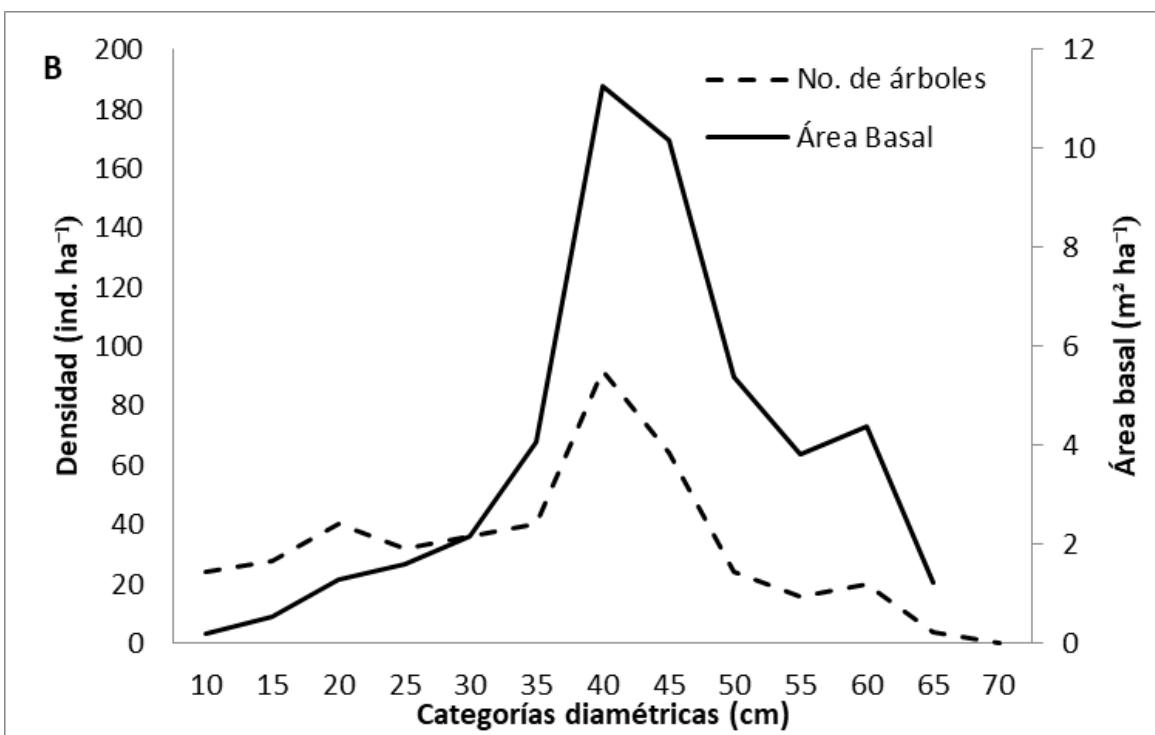
In all localities, conifers are the group with the greatest species associated to *Abies*, which coincides with what was recorded by other authors (Rzedowski, 1978, Sánchez and López, 2003, Encina *et al.*, 2008).

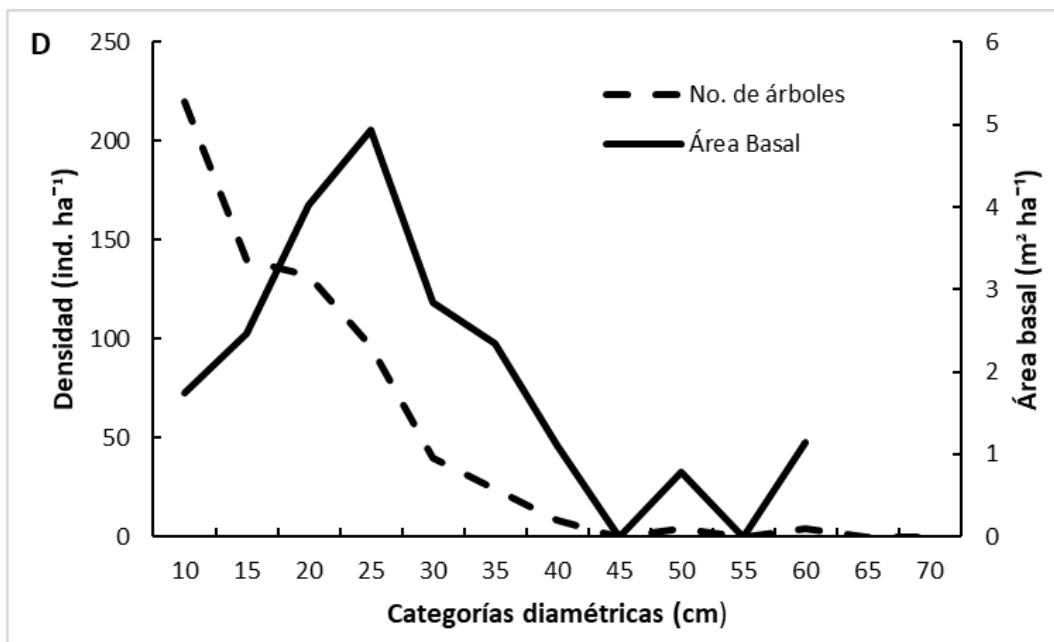
The density of tree species was different along the altitudinal gradient; the highest was determined at the *Las Antenas* site (668 individuals ha^{-1}) and the lowest at *La Tinaja* (388 individuals ha^{-1}); these values are comparable with those of other authors in temperate forests of northeast Mexico, Jiménez *et al.*

(2001) with 297 individuals ha^{-1} ; Aguirre *et al.* (2003), 420-777 individuals ha^{-1} ; Návar (2010), 424-700 individuals ha^{-1} ; Ávila *et al.* (2012), 150-185 individuals ha^{-1} ; and Hernández *et al.* (2013) 716-940 individuals ha^{-1} . The calculated basimetric area was $21.38 \text{ m}^2 \text{ ha}^{-1}$ to $48.62 \text{ m}^2 \text{ ha}^{-1}$ and the average for the four sites was $30.44 \text{ m}^2 \text{ ha}^{-1}$ (Table 3).

The distribution of trees in the different diametric categories describes the characteristics of a mature forest without management in three of the four sites, where the largest number of trees is concentrated in the smaller diameter classes, but the highest dominance per basal area is that of the major categories (Figure 3). These characteristics are attributed to the high competition and to the intolerance to the shade of some species (Castellanos *et al.*, 2008).







A = *El Bosque*; B = *El Rosal*; C = *La Tinaja*; D = *Las Antenas*.

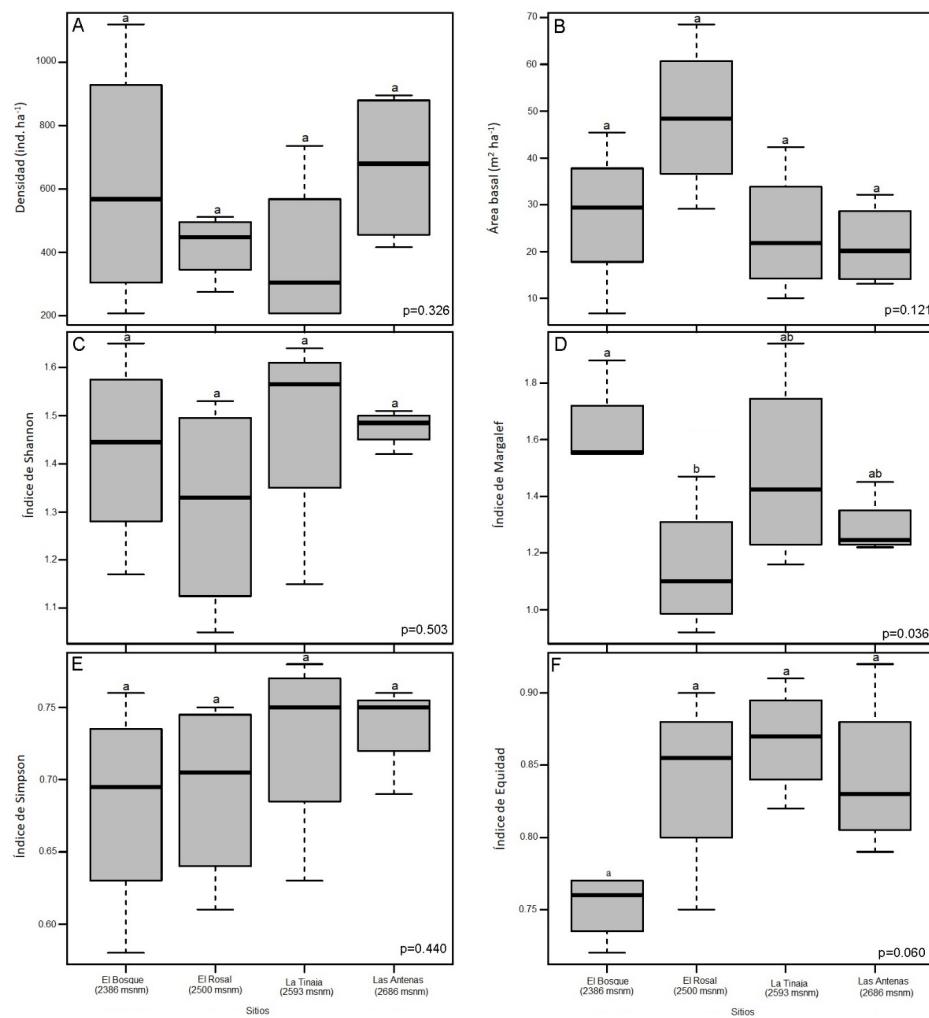
Densidad = Density; Área basal = Basimetric área; No. De árboles = Number of trees; Categorías diamétricas = Diametric classes

Figure 3. Distribution of the tree density and basimetric area in the stands, based upon the diametric classes.

The diametric conformation and the basal area for each forest mass in the sites may be due to the composition of the species, the age of the trees, the disturbances and the succession strategies of the tree strata (Yu *et al.*, 2009; Price *et al.*, 2011). Neumann (2001) states that the regular distribution provides the maximum space and optimal growth conditions for each individual, while that of conglomerates causes increase losses. Zenner and Hibbs (2000) point out that distribution patterns have been linked to different processes such as tree mortality, competition, regeneration, hole creation and seed, which could be responsible for the observed spatial patterns.

However, in addition to the above, the Kruskal-Wallis test shows that the diversity and the structure of the stands did not have significant statistical differences

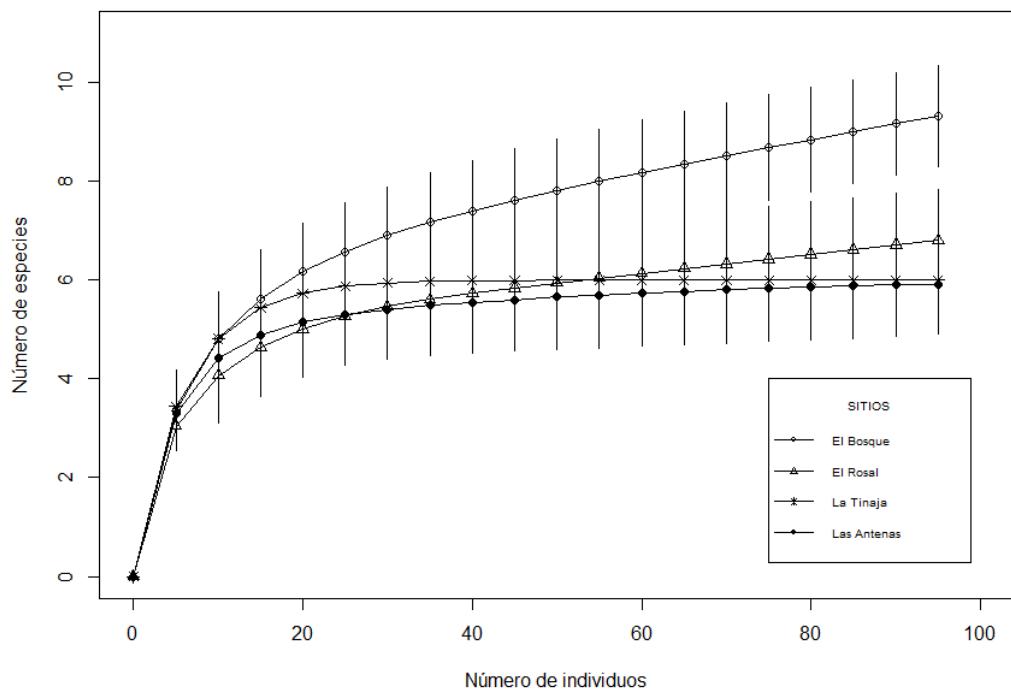
between the altitude intervals ($p > 0.05$), except for the Margalef index, which was slightly lower than the stands of higher altitude ($p < 0.05$), which indicates that there was a significant difference in the species richness in the altitudinal interval (Figure 4). Probably this pattern is explained as the species that develop at different altitudes experience diverse environmental conditions and factors such as the age of the trees, the type of stand depending on the composition of the tree species or the effect of the treetops that induce contrasting selection pressures that can lead to differentiation or acclimatization among populations (Sagar *et al.*, 2008; Smith *et al.*, 2008; Coote *et al.*, 2013; Latreille *et al.*, 2017).



A = Density; B = Basimetric area; C = Shannon index; D = Margalef index; E = Simpson index; F = Equity index among the four sites. Values with different letters are significant (Tukey-Kramer; $p \leq 0.05$).

Figure 4. Graphs of the Kruskal-Wallis test.

The analysis of the rarefaction curves of the estimated species for the altitudinal gradient presented asymptote in approximately nine species; in general, 97 individuals were needed to achieve the maximum species richness and in the confidence intervals there was an overlap in three plots, so they did not present significant differences in the species richness. *El Bosque* was slightly above the three sites, that is, there is a higher concentration of species richness in the lower locality of 2 386 masl (Figure 5).



Número de especies = Number of species; Número de individuos = Number of individuals; Sitios = Sites.

Figure 5. Rarefaction curve of the species richness and the number of individuals among the communities along the altitudinal gradient.

One of the factors that seems to have influenced the low diversity is the distance that separates one community to another and with the type of forest under study. Therefore, this information reveals that temperate forest species show a certain equity in relative abundance (Návar-Cháidez and González-Elizondo, 2009; López-Hernández *et al.*, 2017).

The comparison of the four forests when using the Sørensen index showed that the floristic similarity in the four sites on average was 44 %. This similarity is consistent since mixed conifer forests harbor groups of dependent species (Gao *et al.*, 2014; Junyan *et al.*, 2014).

The replacement of species with geographic distance and altitude between the four sites did not correlate positively ($p > 0.05$); that is, the distance between the sites and the altitude of each one had no effect on the floristic composition of the studied forest. This result may be associated with environmental factors such as forest type, topographic and climatic variations, soil and location (Suding *et al.*, 2008, Hirota *et al.*, 2009).

Conclusions

The floristic composition and structural dynamics of the *Abies vejarii* forest here studied are of great ecological importance due to its restricted population distribution and its exceptional value for the conservation of the biodiversity of the relict masses of northeastern Mexico. In addition, it facilitates the description of

these vulnerable ecosystems in the face of climate changes, based on responses at different altitudes in the interactions between species.

Forests with this species in the region are heterogeneous and contain communities formed mainly by the species of *Abies*, *Quercus* and *Pinus* for their dominance along the gradient. The change in diversity using the Shannon, Equity and Simpson indices did not vary significantly between the sampling sites; however, through the Margalef index and the rarefaction curves, the highest species richness along the altitudinal gradient occurred in the lower elevation community and only 44 % of the species showed a similarity between the communities.

The distribution of the trees by diametric classes confirmed that 90 % of the specimens corresponded to diameters of small dimensions smaller than 40 cm, characteristic of an irregular mature forest not managed, and 70 % for basimetric area. Finally, it is worth mentioning that this slight variation is influenced by the distance that separates one community with another that was 300 m high. These factors contribute to the understanding of the influence of environmental elements on the development of temperate forests.

Acknowledgements

The authors thank the authorities of *La Encantada ejido*, *General Zaragoza* municipality, *Nuevo León* State, for their facilities. The *Facultad de Ciencias Forestales* of the *Universidad Autónoma de Nuevo León* for the financial support through the *Programa de Apoyo a la Investigación Científica y Tecnológica, "Análisis de la estructura, diversidad y volumen de ecosistemas forestales con especies arbóreas amenazadas en el sur del estado de Nuevo León"* PAICyT CT245-15, under Dr. Eduardo Javier Treviño Garza. To the work team in the field: Humberto López Alejandro, Israel López Martínez and Valeria Araceli Valdés Castillo.

Conflict of interests

The authors declare no conflict of interests.

Contribution by author

Rigoberto González Cubas: planning, taking of the field data, information analysis and writing of the document; Eduardo Javier Treviño Garza and Marco Aurelio González Tagle: planning, information analysis and review of the document; Álvaro Duque Montoya: statistical analysis of information; Martín Gómez Cárdenas: research planning and review of the manuscript.