



Fitodiversidad y estructura de un bosque de pino-encino en la Sierra Madre del Sur, México

Phytodiversity and structure of a pine – oak forest in the Sierra Madre del Sur, México

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Resumen

En un bosque de *Pinus-Quercus* en la Sierra Madre del Sur en el estado de Guerrero, se evaluó la fitodiversidad y estructura de la vegetación. Se establecieron cinco parcelas circulares de 1 000 m². Se realizó un censo de todas las especies leñosas con un DAP > 10 cm. A cada individuo se le tomaron medidas dendrométricas de altura total (*h*), diámetro (*DAP*) y diámetro de la copa. Se estimó la densidad, la cobertura, la frecuencia y el Índice de Valor de Importancia, así como la diversidad mediante el Índice de *Margalef* (*D_{Mg}*) y el Índice de *Shannon-Wiener* (*H'*). La estructura vertical se describió mediante el Índice de *Pretzsch*. En total se registraron cinco especies pertenecientes a dos familias y dos géneros. La familia con mayor presencia en el lugar de estudio fue Fagaceae con tres especies. *Pinus oocarpa* registró el mayor valor de importancia, de 63.53 %, en contraste con *Quercus rugosa* con 3.23 %. El índice de diversidad vertical de *Pretzsch* reveló la mayor ocurrencia de especies en el estrato bajo, con 50.4 % de los individuos; de los cuales *P. oocarpa* aportó 51. Se concluye que la comunidad vegetal estudiada está en proceso de regeneración activa y posee baja diversidad y una riqueza de especies reducida.

Palabras clave: Bosque mixto, diversidad, fitodiversidad, indicadores ecológicos, Índice de *Pretzsch*, bosques de *Pinus – Quercus*.

Abstract:

The condition of the vegetation of a pine forest in the *Sierra Madre del Sur* in the state of *Guerrero*, Mexico, was evaluated. Five 1 000 m² circular plots were established. A census of every > 4' DBH woody species was made. The height (*h*), diameter (*DBH*) and canopy diameter were measured for each tree. Density, coverage, and frequency were estimated. The importance value index was calculated as well as diversity through the *Margalef* Index (*D_{Mg}*) and the *Shannon-Wiener* Index (*H'*). The vertical structure was described by *Pretzsch* Index. In total, five species which belong to two families and two genera were recorded. The family with the greatest presence in the study was Fagaceae with three species. The specie with the highest value of importance was *Pinus oocarpa*, 63.53 %, in contrast to *Quercus rugosa* with 3.23 %. The vertical diversity index of *Pretzsch* recorded the highest occurrence of species in the low stratum, with 50.4 % of the individuals; of which *P. oocarpa* contributed by 51 individuals. It is concluded that the evaluated plant community is in an active regeneration state and has low diversity as well as scarce species richness.

Key words: Mixed forest, diversity, phytodiversity, ecological indicators, *Pretzsch* Index, *Pinus – Quercus* forests.

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Introduction

Forests contribute to the provision of environmental goods and services, such as the conservation of biological diversity, carbon sequestration, regulation of the hydrological cycle and climate (Seppelt *et al.*, 2011). After the tropical forest, *Pinus-Quercus* forests are one of the most diverse ecosystems in the world; they are found in the United States of America, Mexico, Guatemala, El Salvador, Nicaragua, Honduras and Cuba (Mora and Alanís, 2016).

The structure of these forests is recognized as a key indicator of fitodiversity, ecological stability and the development of stands (Franklin *et al.*, 2002), along with density and diversity are important characteristics for the quantitative description of vegetation (Gadow *et al.*, 2007). In this sense, trees are the main elements of the ecosystem structure (Del Río *et al.*, 2003) and an adequate indicator of biodiversity to assess the status of the forest stand (Ozdemir *et al.*, 2012).

According to Magurran (2004), measures of richness provide an understandable and instantaneous expression of diversity, and indicators of horizontal structure such as density, dominance and frequency; they describe the relationship between species of a population (Hernández *et al.*, 2013; Saravanan *et al.*, 2013), and they have been frequently used in vegetation studies (Castellanos *et al.*, 2010; Alanís *et al.*, 2011; Méndez *et al.*, 2014), from their great intuitive appeal.

However, in the part of the *Sierra Madre del Sur* that belongs to the state of *Guerrero*, few studies have been developed regarding the current state of the *Pinus-Quercus* forests. In this context, the present investigation evaluates the fitodiversity and structure of a *Pinus-Quercus* forest in the *Sierra Madre del Sur*, Mexico. This research will generate information about the current state of the vegetation, which could be used for the development of ecological restoration programs.

Materials and Methods

Study Area

The study described below was conducted in an area of *Pinus-Quercus* forest in the *Atoyaquillo ejido*, *Coyuca de Benítez* municipality, which is part of the *Sierra Madre del Sur* in the state of *Guerrero*, Mexico. The area is located at 17°09'46.34 "north and 100°03'55.76" west. The altitudinal interval is from 1 000 to 1 100 m. The average annual rainfall is 1 100 mm (Figure 1) (Inegi, 2002).

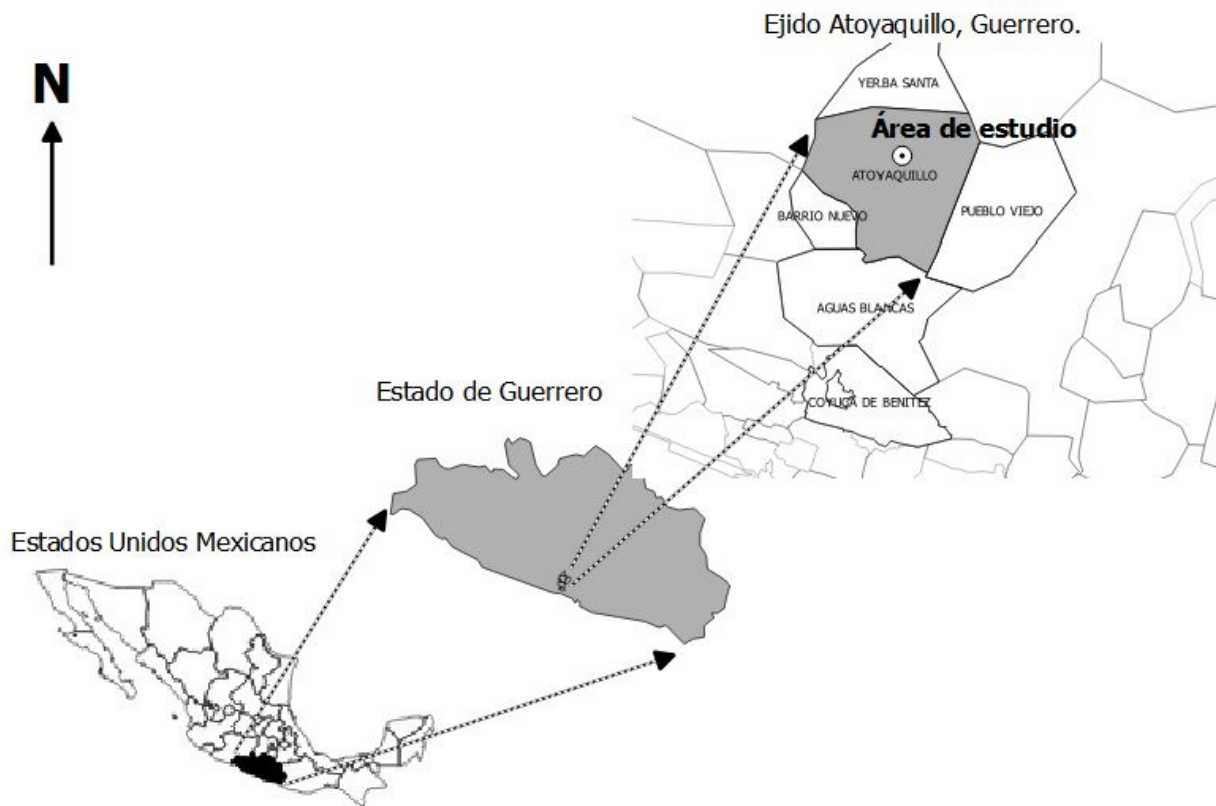


Figure 1. Location of the study area.

Analysis of vegetation

To evaluate the condition of the vegetation of a *Pinus-Quercus* forest, five 1 000 m² circular plots (radius =17.84 m) were established. This design was chosen because only one control point is required at the center, unlike rectangular or square plots that consider four (McRoberts *et al.*, 2015). They were randomly distributed in areas that presented the same physiographic conditions of slope, exposure and altitude. In the sampling plots, a census of all woody species with a DBH > 10 cm (d0.10 m) was carried out. The variables quantified for each individual were: total height (*h*), with a *Suunto* Pm-5 hypsometer; the diameter (*DBH*), with a 1270mm *Haglöf Mantax Blue* caliper; and a crown diameter with a *Truper*[®] fiberglass measuring tape of 100 m (north - south and east - west).

The density by species was determined with respect to the total number of trees; coverage, depending on the area of the cup; and its frequency based on the presence of the species in the sampling plots. The calculated variables were used to calculate the Importance Value Index (IVI), which is a weighted value at the taxon level, and which acquires percentage values on a scale of 0 to 100 (Mostacedo and Fredericksen, 2000).

Data analysis

To evaluate the contribution of the species to the structure of the plant community of interest, the estimation of the following variables was used: abundance, coverage, frequency and value index of importance. For the species richness the Margalef index (D_{Mg}) was used and for the alpha diversity the Shannon-Wiener index (H') (Magurran, 2004) (Table 1).

Table 1. Formula used to determine the indexes for horizontal distribution, of species diversity and vertical structure.

Formula	Num.	Description
$De_{rel} = \left(\frac{De}{\sum_{i=1...n} De} \right) * 100$	(1)	De = Absolute density De_{rel} = Relative density per species
$De = \frac{N_i}{S}$	(2)	N_i = Number of de individuals of the i species S = Swamping surface area (ha)
$Do = \frac{G_i}{S}$	(3)	Do = Absolute dominance G_i = Basimetric area of the i species S = Surface area (ha)
$Do_{rel} = \left(\frac{Do}{\sum_{j=1...n} Do} \right) * 100$	(4)	Do_{rel} = Relative dominance of the i species in regard to total dominance Do = Absolute dominance
$Fr = \frac{P_i}{NS}$	(5)	Fr = Absolute frequency Fr_{rel} = Relative frequency of the i species in regard to total frequency
$Fr_{rel} = \left(\frac{Fr}{\sum_{j=1...n} Fr} \right) * 100$	(6)	P_i = Number of sites in which the i species is present NS = Total number of sampling sites
$IVI = \frac{De_{rel} + Do_{rel} + Fr_{rel}}{3}$	(7)	De_{rel} = Relative density per species in regard to total density Do_{rel} = Relative dominance of the i species in regard to total dominance

		Fr_{rel} = Relative frequency of the i species in regard to total frequency
		D_{Mg} = Margalef's index
$D_{Mg} = \frac{(s-1)}{\ln(N)}$	(8)	s = Number of present species \ln = Natural logarithm N = Total number of individuals
		H' = Shannon-Wiener index
$H' = -\sum_{i=1}^s p_i * \ln(p_i)$	(9)	S = Number of present species N = Total number of individuals
		N = Total number of individuals
$p_i = n_i/N$	(10)	n_i = Number of individuals of the i species \ln = Natural logarithm
		S = Number of present species
$A = -\sum_{i=1}^s \sum_{j=1}^Z p_{ij} * \ln p_{ij}$	(11)	Z = Number of vertical strata
$A_{max} = \ln(S * Z)$	(12)	
		P_{ij} = Species percentage in each zone; it is calculated by the following equation: $p_{ij} = n_{i,j}/N$
$A_{rel} = \frac{A}{\ln(S * Z)} * 100$	(13)	$n_{i,j}$ = Number of individuals of the same i species in the j zone N = Total number of individuals

The vertical structure of the vegetation was characterized with the index of A (Pretzsch, 2009) (Table1), which considers minimum values of 0 and maximum of A_{max} , and in which the vegetation is represented in three strata, according to the

maximum recorded height: stratum I: 80 %-100 % of the maximum height of the vegetation; stratum II: 50 %-80 %, and stratum III: from 0 to 50 %.

If A is equal to 0, the stand is constituted by a single species in a single stratum, whereas A_{max} occurs when all the species are in equal proportions in the stand and in the different strata (Pretzsch, 2009).

Results and Discussion

Diversity

The Margalef index (1951) yielded a value of 0.72, which implies a low diversity according to the same author's measurement criteria, in which values lower than 2.0 indicate a low species richness. The Shannon index (1948) of 0.78 stands for a low diversity according to the parameters of the same author. In an investigation conducted under the same methodology in a temperate forest of the *Sierra Madre del Sur* of Mexico, Méndez *et al.* (2014) obtained a similar value in the Margalef index, but higher in the Shannon index.

In another investigation, Alanís *et al.* (2011) recorded higher values in both indices in a study on tree regeneration after fire in the *Chipinque* Ecological Park (northeast of Mexico); López *et al.* (2017) calculated higher figures when evaluating the composition and diversity of forest species in temperate forests of the state of *Puebla*, based on the same dasometric variables estimated in this study. Graciano *et al.* (2017) also obtained outstanding values when studying pine - oak forests in different regions of northeastern Mexico. The low diversity of tree species in this type of ecosystem is attributed to the high frequency of *Pinus* and *Quercus* genera in these plant communities (Mora and Alanís, 2016).

Species richness

A richness of five species was recorded, which belong to two families and two genera (Table 2). Of the two families, Fagaceae is represented by three species, while the Pinaceae family only two. Méndez *et al.* (2014) found five families and the same number of species in a *Pinus-Quercus* forest of the *Sierra Madre del Sur* after a fire. Juárez *et al.* (2014) accounted for a lower number of species in a forest of the *Sierra de San Carlos* in *Tamaulipas*, Mexico; whereas Torres *et al.* (2006), Alanís *et al.* (2011), Zacarías *et al.* (2011), Hernández *et al.* (2013), Graciano *et al.* (2017), López *et al.* (2017) and Rubio *et al.* (2017) registered a greater number of species in different regions of Mexico in this plant association, compared to this study. This low species richness could be due to the influence of anthropogenic factors such as agriculture, illegal logging, local use of species and the constant fires from illegal crops in the region.

Table 2. List species in the study area.

Scientific name	Common name	Family
<i>Pinus maximinoi</i> H. E. Moore	Pino	Pinaceae
<i>Pinus oocarpa</i> Schiede ex Schltdl.	Ocote	Pinaceae
<i>Quercus crassifolia</i> Benth.	Encino blanco	Fagaceae
<i>Quercus elliptica</i> Née	Encino amarillo	Fagaceae
<i>Quercus rugosa</i> Née	Barrilillo	Fagaceae

Ecological indicators

Density

A total number of 254 individuals (N) ha⁻¹ were counted, 88.19 % (224 N ha⁻¹) from which are pines and 11.81 % (30 N ha⁻¹), oaks. *Pinus oocarpa* had the highest density (77.95 %; 198 N ha⁻¹), and in contrast, *Quercus rugosa* had the lowest value (0.79 %; 2 N ha⁻¹). Torres *et al.* (2006), Alanís *et al.* (2011), Méndez *et al.* (2014), Graciano *et al.* (2017) and López *et al.* (2017) recorded a higher number of trees per hectare at different regions of pine-oak forests of Mexico.

There is a great variety of species that stand out as the most abundant in pine-oak ecosystems in Mexico. Méndez *et al.* (2014) in an analysis of post-fire regeneration in a forest in the Sierra de Guerrero, *Pinus radiata* D. Don., in a characterization study of post-fire regeneration too, Alanís *et al.* (2011) considered *Quercus polymorpha* Schltdl. & Cham. as an outstanding species in temperate forests of northeastern Mexico; Graciano *et al.* (2017) as well as Hernández *et al.* (2013) in the same type of ecosystem, selected *Pinus cooperi* C. E Blanco and *Pinus arizonica* Engelm. López *et al.* (2017) referred to *Pinus montezumae* Lamb. in temperate forests of Puebla (Table 3).



Table 3. Ecological importance of the species at the study area.

Scientific name	Density		Dominance (crown area)		Frequency		IVI
	Absolute	Relative	Absolute	Relative	Absolute	Relative	
	N ha ⁻¹	A _r	m ² ha ⁻¹	A _r			
<i>Pinus oocarpa</i>	198	77.95	10 891	70.96	5	41.67	63.53
<i>Pinus maximinoi</i>	26	10.24	2 561	16.69	2	16.67	14.53
<i>Quercus elliptica</i>	12	4.72	536	3.49	1	8.33	5.52
<i>Quercus crassifolia</i>	16	6.30	1 273	8.29	3	25.00	13.20
<i>Quercus rugosa</i>	2	0.79	88	0.57	1	8.33	3.23
Total	254	100	15 349	100	12	100	100

Dominance (coverage)

The total coverage in the area studied was 15 348 m² ha⁻¹, which suggests a coverage > 100 %, and, therefore, a crown overlap is confirmed, a percentage with which Alanís *et al.* agree (2011); Hernández *et al.* (2013) recorded a lower coverage (88.76 %) in their research in a temperate forest of *Chihuahua*.

Of the two genera of interest, *Pinus* predominates with 87.64 % coverage (13 452 m² ha⁻¹), while *Quercus* occupies the remaining percentage (1 897 m² ha⁻¹). The results of Alanís *et al.* (2011) and Sánchez *et al.* (2014) also pondered *Pinus* with the highest dominance, as well as various authors. At the species level, *Pinus oocarpa* had the highest relative coverage with 70.96 % (10 891 m² ha⁻¹), and *Quercus rugosa* only 0.57 % (88 m² ha⁻¹) (Table 3).

Frequency

Pinus was present in all the sampling plots, in particular *Pinus oocarpa* (41.67 %) and *Quercus* in three; *Quercus elliptica* and *Quercus rugosa* had the lowest relative frequency (8.33 %) and were only identified in one plot (Table 3). This behavior of the pines was ratified by Jiménez *et al.* (2001), Torres *et al.* (2006), Alanís *et al.* (2008), Hernández *et al.* (2013), Méndez *et al.* (2014), Delgado *et al.* (2016), Graciano *et al.* (2017) and Hernández *et al.* (2013) in their respective investigations; but Zacarías *et al.* (2011) and Alanis *et al.* (2011) highlighted *Quercus* as the most frequent genus.

Importance Value Index (IVI)

Of the two genera studied *Pinus* reached 78.05 % of IVI value, and *Quercus* 21.95 %. At the species level *Pinus oocarpa* obtained the highest value with 63.53 % and the lowest was *Quercus rugosa* with 3.23 % (Table 3). The authors who confirmed the highest frequency of pines, also do so for IVI, but do not coincide with the species with the present investigation. Alanís *et al.* (2010), Alanís *et al.* (2011) and Zacarías *et al.* (2011) registered *Quercus* with the highest IVI in their research experiences.

Diameter and heights classification

In the histogram it is observed that an exponential trend line decreases as the diametric classes increase. The categories of 10-20 cm and 20-30 cm gather more than 50 % of the individuals included in the study, which acts as an indicator of active regeneration due to the high recruitment level of individuals in the area.

The third category also houses a significant number of individuals, but categories greater than 40 cm of DAP group a smaller amount. The results indicate a forest in regeneration and growth in which the most abundant population is grouped in the first diametric categories (Figure 1). Regarding heights, in the category of 11-20 m,

the largest number of trees is concentrated, followed by the interval of 0 - 10 m; and finally the smallest group falls within the category of 21 - 30 m (Figure 2).

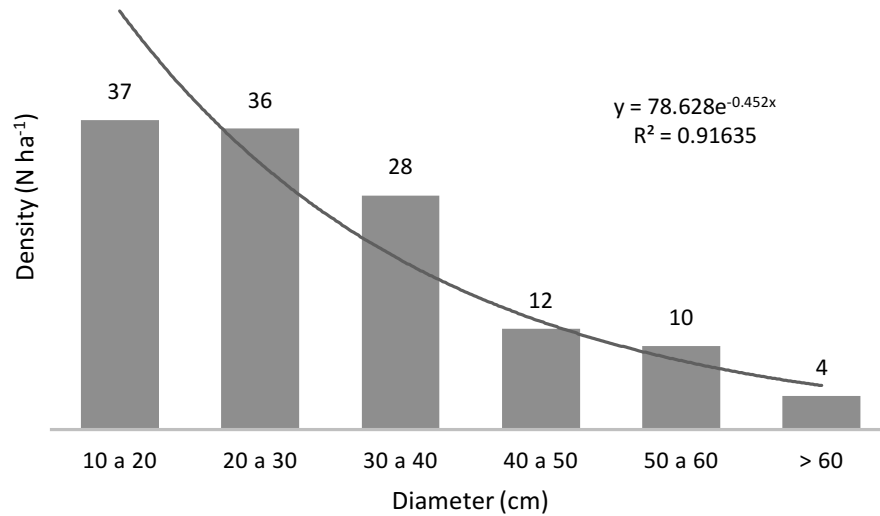


Figure 1. Diametric category distribution in a *Pinus-Quercus* forest in the la Sierra Madre del Sur, Guerrero, Mexico.

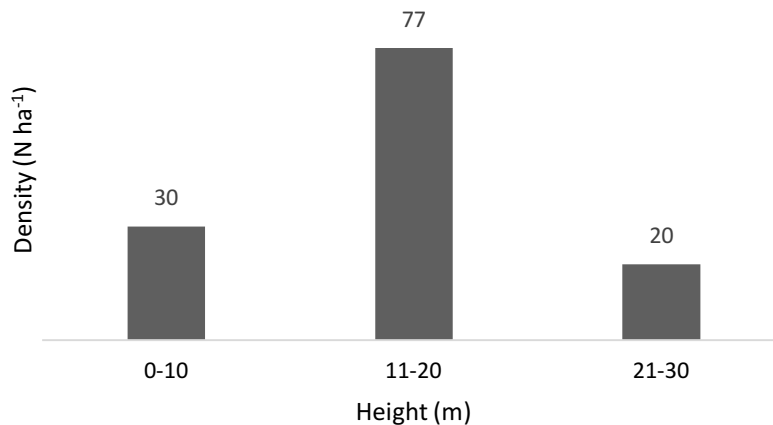


Figure 2. Height class distribution in a *Pinus-Quercus* forest in the la Sierra Madre del Sur, Guerrero, Mexico.

For the vertical structural diversity of the species, three strata were determined: high (III), from 23 to 28 m; medium (II), from 15 to 22 m and low (I), from 5 to 14 m. Of the three strata, the highest species density was found in the low, with 50.4 % of the individuals (127 N ha⁻¹), of which *Pinus oocarpa* contributed 102 N ha⁻¹. In the

middle stratum, 41.7 % of the total individuals were concentrated, represented by *Quercus crassifolia*, *Quercus rugosa*, *Pinus maximinoi* and *Pinus oocarpa* with 86 N ha⁻¹ (81.1 %) (Figure 3).

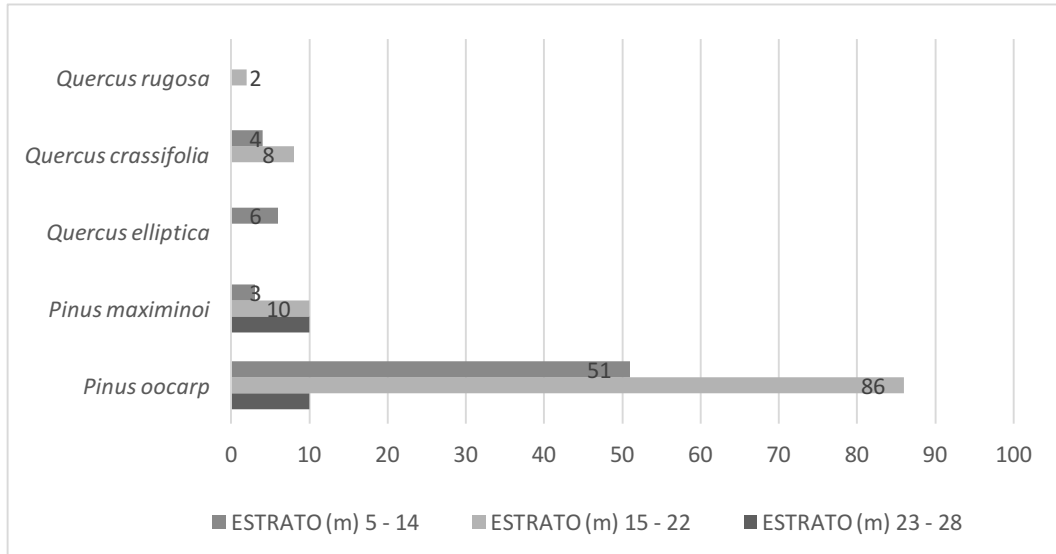


Figure 3. Species vertical distribution in the study area.

The result obtained for the Pretzsch index was $A = 2.07$ with an $A_{max} = 2.70$, which indicates that the distribution of species is highly represented by the low stratum (I) with a higher proportion of trees between 5 and 14 m, which decreases slightly as the height increases in the next stratum (II). The high stratum (III) has a low relative density (7.8 %), and is made up of two species (*Pinus oocarpa* and *Pinus maximinoi*). These results coincide with those of Rubio *et al.* (2014), who also recorded a high presence of trees in the lower stratum and low representativeness of the upper stratum (Table 4).

Table 4. Species vertical distribution in the study area.

Stratum (m)	Max. height /stratum (%)	Density (N ha⁻¹)	Percentage in regard to total number of individuals (%)
I	28 m (100 %)	128	50.4
II	22 m (80 %)	106	41.7
III	14 m (50 %)	20	7.8
Total		254	100

Conclusions

According to the results of the present investigation, it is concluded that the studied plant community gathers few species (5 species) and a low diversity, which is related to the high density of *Pinus* and *Quercus*, which generates a projection of greater than 100 %.

This community presents a state of active regeneration, since of the three vertical strata defined, the best represented is the lower one, which confirms the largest number of individuals of low bearing and in the lower diameter categories (10 to 30 cm) a numerous population and few specimens with diameters above 40 cm.

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Conflict of interests

The authors declare no conflict of interests.

Contribution by author

Cuauhtémoc Méndez Osorio: field work and preparation of the manuscript; Carlos Alberto Mora Donjuán: writing of the manuscript, analysis of results and discussion, design of figures and maps; Eduardo Alanís Rodríguez: writing and general review of the manuscript; Javier Jiménez Pérez: writing and general review of the manuscript; Oscar Alberto Aguirre Calderón: writing and general review of the manuscript; Eduardo Javier Treviño Garza: writing and general review of the manuscript; Miguel Ángel Pequeño Ledezma: writing and general review of the manuscript and application of corrections.

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