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ORIGINAL RESEARCH ARTICLE

Analysis of the composition, structure and diversity of tree species in a temperate forest in northwestern Mexico

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ABSTRACT

The structure and diversity of tree species in a temperate forest in northwestern Mexico was characterized. Nine sampling sites of 50 × 50 m (2,500 m^2) were established, and a census of all tree species was carried out. Each individual was measured for total height and diameter at breast height. The importance value index (*IVI*) was obtained, calculated from the variable abundance, dominance and frequency. The diversity and richness indices were also calculated. A total of 12 species, four genera and four families were recorded. The forest has a density of 575.11 individuals and a basal area of 23.54/m^2. The species of *Pinus cooperi* had the highest *IVI* (79.05%), and the Shannon index of 1.74.

Keywords: Temperate Forest; Durango; Diversity Indices; *Pinus*; *Quercus*

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1. Introduction

The Sierra Madre Occidental is a mountainous complex that extends from near the border with the United States to the north of Jalisco, covering more than 1,500 km from north to south, representing 30% of Mexico's territory[1]. In this region, there are extensive areas covered by conifer and oak forests, resulting in a flora rich in a diversity of pine, oak and arbutus associations[2]. 52 pine species exist in the country, and 20 are found in the state of Durango[3]. The importance of this type of vegetation is not only because of its high diversity, but also because pine and oak species are the trees of greatest economic interest[4].

Structural characterization is important to understand the functioning of ecosystems, which can provide decision elements to contribute to the adequate management of forests[5,6]. Structural indices and measure variables are taken into account[7]. Vertical and horizontal structure is considered a good forest management practice for biodiversity conservation in temperate ecosystems[8]. Structure, diversity and density are the main characteristics of forest stands; diversity is a concept that allows different interpretations, although in general, it is used as a synonym for species diversity[9]. On the other hand, tree structure is a key element to evaluate forest stability[10], which can be modified through the application of silvicultural treatments, changing the structure of forest stands and consequently the forest[11,6]. In Mexico, several studies have been conducted on the diversity of tree species in temperate climates[12,13]. Therefore, the composition, structure and diversity of

tree species in a temperate forest in northwestern Mexico.

2. Materials and methods

The study was conducted in Victoria, located in the city of New Pueblo, located in southwestern Durango State. Geographically framed between 23°40'0'' and 23°47'54''N, and 105°21'31'' and 105°29'52''W (**Figure 1**). Orographically, the ejido Victoria is located in the physiographic province of the Sierra Madre Occidental. According to the INEGI (1988)[14] edaphological chart, the soils of the study area are cambisol, regosol and lithosol with coarse to medium texture. The vegetation consists of pine-oak forests, with different productivity conditions.

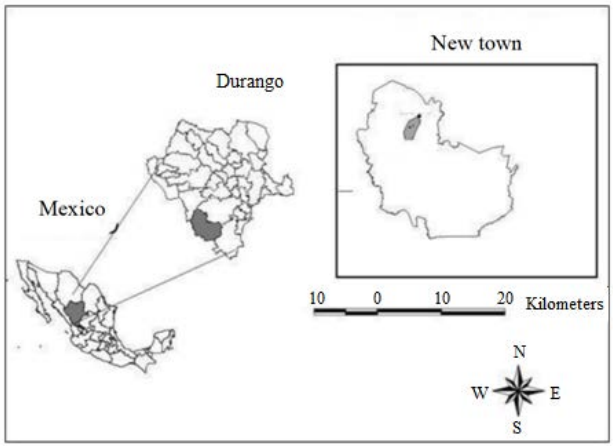

Figure 1. Location of the study area.

The measure data for the study were taken in nine permanent sample plots, quadrangular plots of 2,500 m^2 established in 2007. The database consisted of 1,294 trees whose normal diameter and total height were measured, and the species to which each individual belongs was recorded. To characterize the horizontal structure, abundance was determined according to the number of trees, dominance based on basal area, and frequency based on presence at the sampling sites. The relativized variables were used to obtain the importance value index (*IVI*), which acquires percentage values on a scale from zero to 300[15], the formula is:

$$A_i = \frac{N_i}{E} \quad , \quad AR_i = \left(\frac{A_i}{\sum_{i=1...n} A_i} \right) \times 100$$

Where: A_i is the absolute abundance, AR_i is the relative abundance of species *i* with respect to the total abundance, N_i is the number of individuals of species *i*, and *E* is the sampling area (ha).

Relative coverage was obtained with the formula:

$$D_i = \frac{Ab_i}{E(ha)} \quad , \quad DR_i = \left(\frac{D_i}{\sum_{i=1...n} D_i} \right) \times 100$$

Where: D_i is the absolute cover, DR_i is relative cover of species *i* with respect to the cover, *Ab* is the basal area of species *i* and *E* is the area (ha).

The relative frequency was obtained with the formula:

$$F_i = \frac{P_i}{NS} \quad , \quad FR_i = \left(\frac{F_i}{\sum_{i=1...n} F_i} \right) \times 100$$

Where: F_i is the absolute frequency, FR_i is the relative frequency of species *i* with respect to the sum of the frequencies, P_i is the number of sites where species *i* is present and *NS* is the total number of sampling sites.

The importance value index (*IVI*) is defined as[16,17]:

$$IVI = AR_i + DR_i + FR_i$$

To estimate species richness we used the Margalef index (D_{mg}) and for alpha diversity the Shannon-Weaver index (H) using the formulas[18,19]:

$$D_{mg} = \frac{(S-1)}{ln(N)} \; , \; H' = -\sum_{i=1}^{S} p_i \times ln(p_i) \; , \; P_i = \frac{n_i}{N}$$

Where: *S* is the number of species present, *N* is the total number of individuals, n_i is the number of individuals of species *i* and p_i is the proportion of individuals of species *i* with respect to the total number of individuals. For the characterization of the vertical structure of the species, the vertical distribution index of species (A) was used[11]. Where A has values between zero and a maximum value (A_{max}); when value A = 0 means that the stand is constituted by a single species occurring in a single stratum. A_{max} is reached when all species occur in the same proportion both in the stand and in the

different strata[20]. For the estimation of vertical distribution of species, height zones were defined[21]: zone I: 80 to 100% of the maximum height of the area; zone II: 50 to 80% of the maximum height, and zone III: zero to 50% of the maximum height. The index was estimated with the following formula:

$$A = -\sum_{i=1}^{S}\sum_{j=1}^{Z} p_{ij} * ln(p_{ij}) \ , \ Amax = ln(S * Z)$$

Where: S = number of species present; Z = number of height strata; $p_{i,j}$ = percentage of species in each zone, and is estimated by the following equation $p_{i,j} = n_{i,j}/N$; where $n_{i,j}$ = number of individuals of the same species (i) in zone (j) and N = total number of individuals. The value of A is standardized as follows:

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

3. Results

A total of 12 tree species were recorded, distributed in four genera and four families (**Table 1**). The most representative family was Pinaceae with five species, followed by the families Fagaceae and Ericaceae with three species each. These three families included three genera and 11 species, which constitutes 91.7% of the vegetation recorded in the nine sampling sites.

Table 1. Scientific name and family of tree species recorded in the study area

Scientific name	Family
Arbutus bicolor S. González	Ericaceae
Arbutus madrensis S. González	Ericaceae
Arbutus xalapensis Kunth	Ericaceae
Juniperus deppeana Steud.	Cupressaceae
Pinus ayacahuite Ehrenb. ex Schltdl.	Pinaceae
Pinus cooperí C.E.Blanco	Pinaceae
Pinus durangensis Martinez	Pinaceae
Pinus leiophylla Schiede ex Schltdl. & Cham.	Pinaceae
Pinus teocote Schied. ex Schltdl. & Cham.	Pinaceae
Quercus crassifolia Bonpl.	Fagaceae
Quercus rugosa Née	Fagaceae
Quercus sideroxyla Bonpl.	Fagaceae

The plant community density in the study area was 575.11. The genus Pinus was the most abundant with a density of 369.89 trees, representing 69.01% of the total, followed by the genus Quercus with a density of 108 trees with 18.78% of the total (**Table 2**). The species with the highest density were *Pinus cooperi* (188.89 trees) with 32.84% of the total, *P. durangensis* (143.56 trees) with 24.94% of the total, *Quercus sideroxyla* (104.44 trees) with 18.16% of the total and *Junipers deppeana* (52.89 trees) with 9.2% of the total, which is equivalent to

Table 2. Abundance, dominance and frequency by genus of species recorded in the study area

Genre	Abundance		Dominance		Frequency	
	Absolute (number)	Relative (%)	Absolute (number/m^2)	Relative (%)	Absolute -	Relative (%)
Pinus	396.89	69.01	16.71	70.98	100.00	30.00
Quercus	108.00	18.78	5.58	23.71	77.78	23.33
Juniperus	52.89	9.20	0.74	3.15	88.89	26.67
Arbutus	17.33	3.01	0.51	2.16	66.67	20.00
Total	575.11	100.00	23.54	100.00	333.33	100.00

Table 3. Estimated structural parameters for the species recorded in the study area

Genre	Abundance		Dominance		Frequency		*IVI*
	Absolute (number)	Relative (%)	Absolute (number/m^2)	Relative (%)	Absolute -	Relative (%)	
Pinus cooperi	188.89	32.84	6.96	29.55	100.00	16.67	79.05
Pinus durangensis	143.56	24.96	7.76	32.97	77.78	12.96	70.89
Quercus sideroxyla	104.44	18.16	3.62	15.40	77.78	12.96	46.53
Juniperus deppeana	52.89	9.20	0.74	3.15	88.89	14.81	27.18
Pinus ayacahuite	32.00	5.56	1.05	4.44	77.78	12.96	22.98
Pinus teocote	27.11	4.71	0.85	3.60	66.67	11.11	19.41
Arbutus bicolor	14.22	2.47	0.32	1.38	44.44	7.41	11.25
Quercus crassifolia	3.11	0.54	1.95	8.29	11.11	1.85	10.68
Pinus leiophylla	5.33	0.93	0.10	0.42	22.22	3.70	5.04
Arbutus xalapensis	2.22	0.39	0.16	0.70	11.11	1.85	2.94
Arbutus madrensis	0.89	0.15	0.02	0.08	11.11	1.85	2.1
Quercus rugosa	0.44	0.08	0.00	0.01	11.11	1.85	1.95
Total	575.11	100.00	23.54	100.00	600.00	100.00	

Notice: *IVI* = Importance value index. Species are ordered in descending order according to their *IVI*.

85.16% of the total species. While the least abundant species was *Quercus rugosa* (1 tree) with 0.08% of the total species (**Table 3**).

There was a basal area dominance of 23.54/m^2. The genus *Pinus* had the highest relative dominance (16.71/m^2) with 70.98% of the total, followed by the genus *Quercus* which had a relative dominance of 5.58/m^2, equivalent to 23.71% of the total (**Table 2**). The species with the largest basal area were *P. durangensis* (7.76/m^2) with 32.97%, *P. cooperi* (6.96/m^2) with 29.55%, *Q. sideroxyla* (3.63/m^2) with 15.40% and *Q. crassifolia* (1.95/m^2) with 8.29%, which together account for 86.22% of the total species.

The genus *Pinus* was present in all sampling sites, followed by the genus *Juniperus* which was found in eight of the nine sampling sites (**Table 2**). At the species level, *P. cooperi* was found in all nine sampling sites (100% absolute frequency) with 16.67% relative frequency, followed by *J. deppeana* which was found in eight sampling sites with an absolute frequency of 88%, representing 14.81% relative frequency. The species *Arbutus xalapensis*, *A. madrensis*, *Q. rugosa* and *Q. crassifolia* only occurred in one sampling site (**Table 3**).

The importance value index indicates that *P. cooperi* (79.05%), *P. durangensis* (70.89%), *Q. sideroxyla* (46.53%) and *J. deppeana* (27.18%) were the most outstanding species, having the highest *IVI* values. The rarest species were *A. xalapensis*, *A. madrensis* and *Q. rugosa* which had values less than three percent.

The specific richness of the plant community studied was 12 species, with a Margalef index of -1.53. In relation to the species diversity value, the Shannon index value was 1.74. By the vertical distribution index of the species, three height strata were defined, high (31.04–38.80 m), medium (19.40–31.03 m) and low (< 19–40 m). The high stratum is composed of *P. cooperi*, *P. durangensis* and *P. teocote* with 4.44 trees, equivalent to 0.77% of the zone, and the medium stratum is composed of *P. ayacahuite*, *P. cooperi*, *P. durangensis*, *P. teocote*, *Q. crassifolia* and *Q. sideroxyla* with 87.56 trees representing 15.22% of the zone. In the lower stratum, all the species of the study area were recorded with 483.11 trees, representing 84% of the area. The most abundant species was *P. cooperi* with 172.89 trees followed by *P. durangensis* with 104.89 trees and *Q. sideroxyla* with 100.44 trees (**Table 4**). The *A* index value was 2.07 with an A_{max} value of 3.58 and A_{rel} of 57%, which indicates that the evaluated area has average uniformity in height diversity. A_{rel} values close to 100% indicate that all species are equally distributed in the three height strata.

Table 4. Pretzch vertical index values for the study area

	Proportion (%)			
High stratum (38.80–31.04)	N	N/m^2	Total	In the area
Pinus cooperi	3.00	1.33	30.00	0.23
Pinus durangensis	6.00	2.67	60.00	0.46
Pinus teocote	1.00	0.44	10.00	0.08
Sum	10.00	4.44	100.00	0.77
Middle stratum (31.04–19.40)				
Pinus ayacahuite	67.00	29.78	34.01	5.18
Pinus cooperi	33.00	14.67	16.75	2.55
Pinus durangensis	81.00	36.00	41.12	6.26
Pinus teocote	4.00	1.78	2.03	0.31
Quercus crassifolia	3.00	1.33	1.52	0.23
Quercus sideroxyla	9.00	4.00	4.57	0.70
Sum	197.00	87.56	100.00	15.22
Low stratum (2.50–19.4)				
Arbutus bicolor	32.00	14.22	2.94	2.47
Arbutus madrensis	2.00	0.89	0.18	0.15
Arbutus xalapensis	5.00	2.22	0.46	0.39
Juniperus deppeana	119.00	52.89	10.95	9.20
Pinus ayacahuite	5.00	2.22	0.46	0.39
Pinus cooperi	389.00	172.89	35.79	30.06
Pinus durangensis	236.00	104.89	21.71	18.24
Pinus leiophylla	12.00	5.33	1.10	0.93
Pinus teocote	56.00	24.89	5.15	4.33
Quercus crassifolia	4.00	1.78	0.37	0.31
Quercus sideroxyla	226.00	100.44	20.79	17.47
Quercus rugosa	1.00	0.44	0.09	0.08
Sum	1087.00	483.11	100.00	84.00
Total	1294.00	575.11	300.00	100.00

4. Discussion

Due to its structure and composition, the study area evaluated corresponds to a typical forest of the Sierra Madre Occidental mountain massif[9]. The same dominant families reported for the Sierra Madre Occidental of the state of Durango were found, which are Pinaceae and Fagaceae[22]. The Pinaceae family was the most abundant, recording five species of the genus *Pinus*, which coincides with García and González[23], who point out that the distribution of the Pinaceae family and the genus *Pinus* is wide in all the mountain ranges of the country. These results coincide with those recorded for the state of Chihuahua, where species of the genus *Pinus* are reported to be dominant[24]. While López *et al.*[25] found that the genus *Pinus* also has higher

abundance in temperate forests. Twelve species were recorded, a lower number than the 27 species recorded by Linares *et al*. (1999). The species *P. cooperi* was the most abundant, which is one of the species reported as the most abundant in temperate forests[12,26]. The species with the greatest importance for basal area occupying 86.22% were *P. durangensis*, *P. cooperi*, *Q. sideroxyla* and *Q. crassifolia*; these same species have been reported as those with the greatest basal area in oak-pine forests in the state of Durango with values greater than 65%[26]. The two species with the highest importance value index were *P. cooperi* and *P. durangensis* with 26.35 and 23.63%, respectively; in this regard *P. durangensis* has been reported as the species with the highest ecological value (57.05%) in temperate forests[24] report that the species *P. cooperi* has the highest value of ecological importance (19.92%); while Valenzuela and Granados[26] report *P. durangensis* and *P. cooperi* as the species with the highest value of ecological importance with 33.44 and 10.0%, respectively. In this regard, Margalef[27] mentions that the Shannon index normally varies from 1 to 5, with values lower than 2 being interpreted as low diversity, from 2 to 3.5 as medium diversity, and higher than 3.5 as high diversity. Therefore, the forest community studied has a low diversity (H' = 1.74). However, this value is higher than that recorded by Návar-Cháidez and González-Elizondo[12] for the temperate forests of the state of Durango. The value of the Margalef index (D_{Mg} = 1.53) is higher than those reported by Hernández-Salas *et al.*[24], who recorded values of D_{Mg} = 1.04 and D_{Mg} = 0.90 respectively. Which means that the study site presents higher diversity of tree species if compared to areas of the same region, however, this value is low if compared to values reported for other ecosystems[28,29]. The *A* index had values of 2.07 with A_{max} value of 3.58 and A_{rel} of 57%, indicating that the evaluated area presents average uniformity, in height diversity. Values of A_{rel} close to 100% indicate that all species are equally distributed in the three height strata. This coincides with that reported by Camacho *et al.*[30].

5. Conclusions

The temperate forest studied has a low specific richness and diversity of tree species. The most important families for their structural contribution to this forest are Pinaceae and Fabaceae, with the genera *Pinus* and *Quercus* being the most important. The most important species are *P. cooperi*, *P. durangensis* and *Q. sideroxyla*. For the vertical structure, the diversity of heights is medium, so the stage of development is latizal.

Conflict of interest

The authors declare no conflict of interest.

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