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Research Article

Análisis de la estructura y diversidad arbórea de bosques templados en la ladera oriental del volcán Iztaccíhuatl, México

Analysis of the structure and tree diversity of temperate forests of the eastern side of the Iztaccihuatl volcano, Mexico

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Abstract:

The diversity and tree structure of temperate forests in central Mexico that have been under anthropogenic pressures were analyzed. A forest inventory was carried out in three tree communities: pine forest (BP), alder-pine forest (BHP) and pine-oak forest (BPQ), and 50 sites of 500 m^2 were randomly established in each one. The mensuration variables obtained were total height and normal diameter ≥7.5 cm. The diameter distribution was analyzed for each community, and the Importance Value Index, the Pretzsch Index, and the diversity indexes were estimated. A total of eleven tree species were recorded, with *Pinus hartwegii* dominating in BP, *Alnus jorullensis* in BHP and *Pinus ayacahuite* in BPQ. BPQ showed the highest density (272 N ha^{-1}) and basal area (32.28 m^2 ha^{-1}). The Pretzsch index indicated that BHP and BPQ have a high mean uniformity, and BP has a low mean uniformity in height diversity. The three tree communities showed a positive asymmetric diameter distribution, with more trees in the first diameter classes. The results indicate that anthropogenic interventions in the three tree communities of the forest are evident, and that the area should be properly managed to conserve the structural attributes of this important hydrological and forest reserve. The information generated could serve as a reference to develop conservation or management plans for the species.

Key words: Tree communities, species composition, density, diversity indices, Pretzsch index, *IVI*.

Resumen:

Se analizó la diversidad y la estructura arbórea de bosques templados del centro de México que han estado bajo presión antropogénica. Se realizó un inventario forestal en tres comunidades arbóreas: bosque de pino (BP), bosque de aile-pino (BHP) y bosque de pino-encino (BPQ); en cada una se establecieron, de manera aleatoria, 50 sitios de 500 m^2. Las variables dasométricas obtenidas fueron altura total y diámetro normal. Los parámetros analizados fueron los siguientes: distribución diamétrica, Índice de Valor de Importancia, Índice de *Pretzsch* e índices de diversidad. En total se registraron 11 especies arbóreas; de ellas, *Pinus hartwegii* dominó en BP, *Alnus jorullensis* en BHP y *Pinus ayacahuite* en BPQ. El BPQ presentó la mayor densidad (272 N ha^{-1}) y área basal (32.28 m^2 ha^{-1}). El Índice de *Pretzsch* indicó que los bosques de BHP y BPQ tienen una uniformidad media alta, y el BP una uniformidad media baja en diversidad de alturas. Las tres comunidades arbóreas mostraron una distribución diamétrica asimétrica positiva, con mayor número de árboles en las primeras clases diamétricas. Los resultados evidencian las intervenciones antrópicas en las tres comunidades arbóreas forestales; y ante esto, el área debe gestionarse de manera adecuada para conservar los atributos estructurales de esa importante reserva hidrológica y forestal. La información generada puede utilizarse de referencia para desarrollar planes de conservación o manejo de las especies.

Palabras clave: Comunidad arbórea, composición de especies, densidad, índices de diversidad, Índice de *Pretzsch*, *IVI*.

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Introduction

Temperate forests are important for the functions and services they provide, as well as for the role they play in mitigating climate change (Kay *et al.*, 2021). In particular, those distributed in central Mexico are considered one of the critical points in the conservation of global biodiversity (Myers *et al.*, 2000). However, the forest ecosystems of the Transversal Volcanic Axis region have historically been subjected to great pressure from different events (González *et al*., 2022).

Natural and man-made events such as forest fires, pests and diseases, logging, deforestation, among others, affect the structure, composition and diversity of forests (Mishra *et al.*, 2004; Gao *et al.*, 2020) by degrading them and simplify them (Caviedes and Ibarra, 2017). The destruction and degradation of forest ecosystems are the main effects of the presence of human beings in the region (Conanp, 2013), which is especially evident in the changes in the structure of the tree canopy.

Conservation efforts have led to the establishment of reserve areas such as the *Izta-Popo* National Park (Conanp, 2013). The conservation of this important hydrological and forest reserve must continue through the proper management of neighboring forest areas.

Forests are complex systems, made up of multiple structural attributes that interact with each other at different levels (Messier and Puettmann, 2011). Knowledge of its structure is essential for its management and conservation, especially where natural succession processes and anthropogenic effects are observed (Gadow *et al*., 2012). It has been documented that the structure of the forest is related to the total production of biomass, the conservation of biodiversity and the functions of the habitat (Cortés-Pérez *et al.*, 2021; Vargas-Larreta *et al.*, 2021), so the study of its attributes allows understanding forest dynamics; that is, the current state and its future development (Hui *et al.*, 2019).

Among the variables that are estimated to study the structure of forests in particular, it can be mentioned: tree density, basimetric area and Indexes Importance Value (Xi *et al*., 2021), vertical distribution of species and those of diversity (Treviño *et al.*, 2001; González *et al.*, 2018), as well as the probability density functions for the analysis of the diameter distribution of the trees (Souza *et al.*, 2021). The analysis of these variables shows the changes that have occurred in the tree structure of forest communities in response to human activities.

Materials and Methods

Study area

The study was carried out in temperate forests of central Mexico, in the *Chiautzingo* municipality of the state of *Puebla* (Figure 1). Three arboreal communities corresponding to pine forest (BP), alder-pine forest (BHP) and pine-oak forest (BPQ) were delimited. The work area was located between the coordinates 98°35'42.29" W, 19°10'19.17" N and 98°32'47.21" W, 19°10'36.40" N. The climate is a subhumid semi-cold temperate [Cb'(w_2)] (García, 2004); the average annual temperature is from 5 to 12 °C, that of the warmest month is 22 °C and that of the coldest month ranges between 3 and 18 °C. The precipitation of the driest month is <40 mm; with summer rains and percentage of winter rain from 5 to 10.2 % of the annual total. The altimetric elevation varied between 2 900 and 3 600 m.

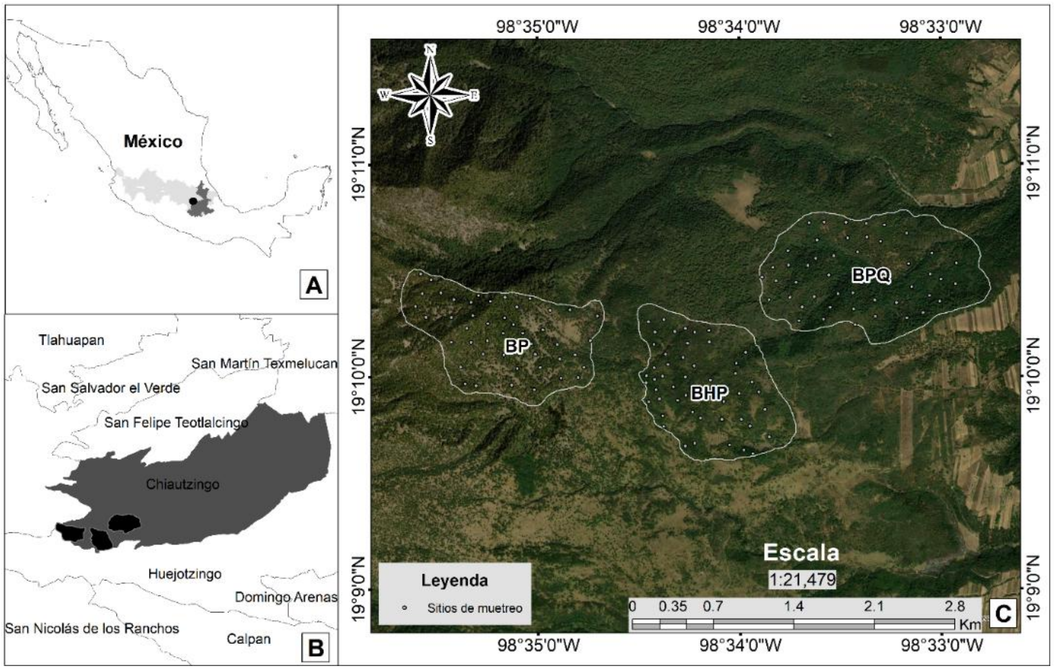

Figure 1. a) Location of the state of *Puebla*, Mexico; b) *Chiautzingo* municipality; c) Tree forest communities studied: pine forest (BP), alder-pine forest (BHP) and pine-oak forest (BPQ).

Sampling design and data collection

50 circular sampling sites of 500 m^2 were randomly established per tree community (Figure 1). At each site, all trees with a normal diameter ≥7.5 cm were measured. The mensuration evaluated variables were normal diameter measured with a

Forestry Supliers Inc.® diametric tape (model 283d/5M) and total height with a Haglöf® model Vertex III hypsometer.

Data analysis

Richness of species was quantified with the Species Richness Index (*S*) and the diversity indexes: Margalef (D_{mg}), Simpson (λ), Shannon-Wiener (*H'*) and Pielou (*J'*) (Table 1) (Magurran, 2004; Moreno, 2001). The calculations were done in R 4.0.3 (R Core Team, 2021) using the Biodiversity package (Kindt and Coe, 2005).

Table 1. Equations to analyze the structure and diversity of forests.

Indexes	Description
Diversity	Species Richness Index: $(S) = \text{Total number of species}$ Margalef Index: $(D_{mg}) = (S-1)/ln\,(N)$ Where: *N* = Total number of individuals Simpson Diversity Index: $(\lambda) = 1 - \Sigma\, p_i^2$ Shannon–Wiener Index:

	$(H') = -\sum p_i * \ln p_i$ Where: p_i = Relative abundance *ln* = Logarithm base 10 Pielou Equity Index: $(J') = H'/\ln(S)$
Importance Value Index (*IVI*) *IVI* = (*AR* + *DR* + *FR*) / 3	Relative abundance: $(AR) = \frac{Absolute\ abundance\ of\ a\ species}{Absolute\ abundance\ \text{of all species}}\ x\ 100$ $Absolute\ abundance = \frac{Density\ of\ a\ species}{Sampled\ area}$ Relative dominance: $(DR) = \frac{Absolute\ dominance\ of\ one\ species}{Absolute\ dominance\ of\ all\ species}\ x\ 100$ $Absolute\ dominance = \frac{Basimetric\ area\ of\ one\ species}{Sampled\ area}$ Relative frecuency: $(FR) = \frac{Absolute\ frecuency\ of\ one\ species}{Absolute\ frecuency\ of\ all\ species}\ x\ 100$ $Absolute\ frecuency = \frac{Number\ of\ sites\ where\ each\ species\ occurs}{Total\ number\ of\ sampled\ sites}$
Pretzsch Index or of verticale distribution of species (*A*)	$A = -\sum_{i=1}^{S}\sum_{j=1}^{Z} p_{ij} *\ ln\ (p_{ij})\ ,\quad A_{max} = ln(S * Z)\ ,\ \ A_{rel} = \frac{A}{ln(S * Z)} * 100$ Where: *S* = Number of present species *Z* = Number of height strata

Pij = Percentages of species in each area, and is estimated using the following expression:

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

where
ni, j = Number of individuals of the same *i* species in *j* zone
N = Total number of individuals.
The value of *A* is standardized with the equation A_{rel}.

To evaluate the floristic structure, its abundance was determined for each species based on the number of trees, its frequency according to its presence in the sampling sites and its dominance based on its basimetric area. The relative results were used to obtain a weighted value at the species level called Importance Value Index (*IVI*), which allows hierarchically ordering the dominance of each taxon in mixed forests, and acquires values from 0 to 100 % (Table 1).

The characterization of the vertical structure was done with the Pretzsch Index (*A*), in which *A* has values between zero and a maximum value (A_{max}); when a value *A*=0 it means that the forest community is constituted by a single species that occurs in a single stratum. A_{max} is reached when all the taxa occur in the same proportion, both in the community and in the different strata (Corral *et al.*, 2005). For the estimation of the vertical distribution of the species, three height zones were defined: zone I (80 to 100 % of the maximum height); zone II (50 to 80 % of the maximum height) and zone III (from zero to 50 % of the maximum height).

The *A* index was estimated with the equation *A* and A_{max} (Table 1). The value of *A* was standardized with the A_{rel} equation. When the A_{rel} values are close to 100 %, it implies that all the species are equally distributed in the three height strata.

The diameter structure of the tree communities was analyzed from the grouping of all the individuals in diameter classes of 5 cm, and histograms of diameter classes were elaborated. The estimation of the diameter distributions was carried out through probability density functions. The most widely used in forest sciences to describe diameter distributions are the distributions Weibull (Gove *et al.*, 2008; Souza *et al.*, 2021), Normal, Johnson SB, Log-normal, Beta and Gamma (Ferreira de Lima *et al*., 2015; Hui *et al.*, 2019). For the typification of the distribution patterns of the diameter classes, the after mentioned functions were used in this study, and the one that best fit the histograms was selected, with the use of the R 4.0.3 software (R Core Team, 2021) and the stats packages stats (R Core Team, 2021), univariateML (Moss, 2019), fitdistrplus (Delignette-Muller and Dutang, 2015), and ggplot2 (Wickham, 2016).

In order to statistically compare the richness of species and the possible differences in density and basal area between the tree forest communities, the R 4.0.3 program (R Core Team, 2021) was used to test the assumptions of normality of the variables; data were subjected to Kolmogorov-Smirnov statistical tests. The results of the test showed that the data of the variables did not meet the assumptions of normality, a condition that supported the performance of a non-parametric analysis of variance with the Kruskal-Wallis test. For both tests, a significance level of 95 % was established.

Results

Richness of species

In general, 11 tree species were recorded, distributed in eight genera and seven families, the most representative was Pinaceae with five taxa; the rest only presented one. Five species were documented in the BP tree community, 10 in BHP and nine in BPQ (Table 2).

Table 2. Tree species registered in BP, BHP and BPQ.

Scientífic name	Family	Common name	Record
Abies religiosa (Kunth) Schltdl. & Cham.	Pinaceae	*Oyamel*	BHP, BPQ, BP
Alnus jorullensis Kunth	Betulaceae	*Aile*	BHP, BPQ, BP
Arbutus xalapensis Kunth	Ericaceae	*Madroño*	BHP, BPQ
Buddleja cordata Kunth	Scrophulariaceae	*Tepozán*	BHP
Cupressus lusitanica Mill.	Cupressaceae	*Ciprés*	BPQ
Pinus ayacahuite Ehrenb. ex Schltdl.	Pinaceae	*Pino crucillo*	BHP, BPQ, BP
Pinus hartwegii Lindl.	Pinaceae	*Pino de altura*	BHP, BP
Pinus montezumae Lamb.	Pinaceae	*Ocote*	BHP, BPQ
Pinus teocote Schied. ex Schltdl. & Cham.	Pinaceae	*Ocote*	BHP, BPQ, BP
Quercus laurina Bonpl.	Fagaceae	*Encino blanco*	BHP, BPQ
Salix paradoxa Kunth	Salicaceae	*Borreguillo*	BHP, BPQ

The value of the Shannon-Wiener index showed that the three tree communities presented a low diversity of species (≤2). The Simpson index and the Margalef index indicated that the BQ and BHP had a low diversity, and the BPQ registered a higher diversity. The values of the Pielou index showed a low uniformity for BP, and a high mean in species for BHP and BPQ (Figure 2a).

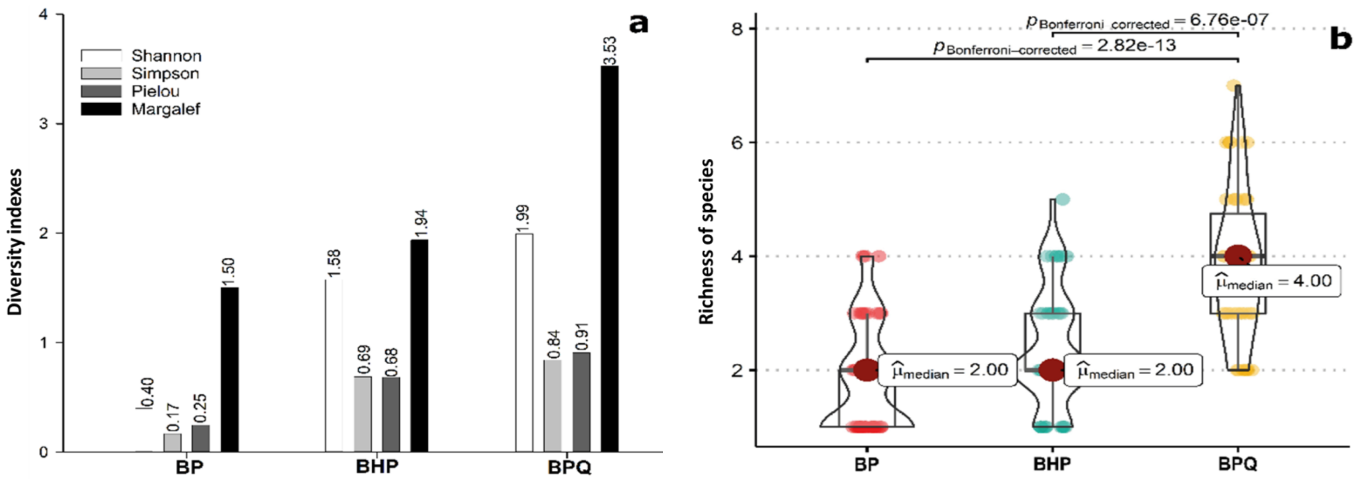

Figure 2. a) Diversity indexes by tree forest community: BP (pine forest), BHP (alder-pine forest) and BPQ (pine-oak forest); b) Kruskal-Wallis test for richness of species.

In BP there was dominance of one taxon, in addition to a reduced number of taxa; while BHP and BPQ recorded a greater number of taxa, with a more equitable distribution of the dominant species, mainly in the BPQ. The number of species per site in BP ranged from one to four, in BHP from one to five, and in BPQ from two to six (Figure 2b). The Kruskall-Wallis test showed statistically significant differences in species richness between BP-BPQ and BHP-BPQ (Figure 2b).

Floristic structure

The average density and basimetric area of the tree communities was 227 trees ha^{-1} and 24.6 m^{2} ha^{-1}. Pinaceae and Betulaceae were the dominant families. The most abundant species were *P. hartwegii* Lindl. and *Alnus jorullensis* Kunth; the first dominated the BP, and the second abounded in BHP and BPQ. For BP, the *Pinus* genus obtained 80.82 % of the *IVI*, and at the taxon level *P. hartwegii* with 73.50 %; in BHP, *Alnus* represented by *A. jorullensis* obtained 50.86 %; and in BPQ, *Pinus* reached 39.43 % in *IVI*, with *P. ayacahuite* Ehrenb. ex Schltdl. as the most important species (Table 3).

Table 3. Importance Value Index (*IVI*) by tree community.

Community	Specie	ABUNDANCE		DOMINANCE		FREQUENCY		*IVI*
		Absolute N ha^{-1}	Relative %	Absolute m^2 ha^{-1}	Relative %	Absolute Sitios	Relative %	
BP	*Pinus hartwegii* Lindl.	242	90.85	16.80	75.60	49	53.85	73.44
	Alnus jorullensis Kunth	12	4.57	4.13	18.59	15	16.48	13.22
	Pinus ayacahuite Ehrenb. ex Schltdl.	6	2.10	0.45	2.03	15	16.48	6.87
	Abies religiosa (Kunth) Schltdl. & Cham.	6	2.10	0.81	3.66	11	12.09	5.95
	Pinus teocote Schied. ex Schltdl. & Cham.	1	0.37	0.02	0.11	1	1.10	0.53
	Total	267	100	22.22	100		100	100
BHP	*Alnus jorullensis* Kunth	74	51.04	12.47	64.61	43	36.44	50.70
	Pinus hartwegii Lindl.	20	13.83	1.74	9.03	7	5.93	9.60
	Pinus montezumae Lamb.	9	5.95	1.16	6.00	19	16.10	9.35
	Abies religiosa (Kunth) Schltdl. & Cham.	11	7.33	1.89	9.79	12	10.17	9.10
	Buddleja cordata Kunth	15	10.51	0.83	4.32	14	11.86	8.90
	Salix paradoxa Kunth	8	5.26	0.32	1.65	9	7.63	4.84
	Pinus ayacahuite Ehrenb. ex Schltdl.	4	2.49	0.66	3.44	10	8.47	4.80
	Arbutus xalapensis Kunth	3	2.21	0.16	0.81	2	1.69	1.57
	Pinus teocote Schied. ex Schltdl. & Cham.	1	0.69	0.07	0.34	1	0.85	0.63
	Quercus laurina Bonpl.	1	0.69	0.002	0.01	1	0.85	0.52
	Total	145	100	19.30	100		100	100
BPQ	*Pinus ayacahuite* Ehrenb. ex Schltdl.	40	14.77	11.95	37.01	34	17.62	23.13
	Alnus jorullensis Kunth	70	25.72	3.96	12.26	38	19.69	19.22
	Quercus laurina Bonpl.	51	18.74	3.56	11.03	33	17.10	15.62
	Arbutus xalapensis Kunth	39	14.40	1.35	4.19	29	15.03	11.21

	Pinus teocote Schied. ex Schltdl. & Cham.	16	6.02	3.78	11.72	14	7.25	8.33
	Abies religiosa (Kunth) Schltdl. & Cham.	19	6.98	3.15	9.76	14	7.25	8.00
	Pinus montezumae Lamb.	10	3.53	3.07	9.50	21	10.88	7.97
	Cupressus lusitanica Mill.	16	5.80	1.19	3.70	4	2.07	3.86
	Salix paradoxa Kunth	11	4.04	0.27	0.83	6	3.11	2.66
	Total	272	100	32.28	100		100	100

The Kruskall-Wallis test showed significant differences in tree density between BP-BHP (p=7.99e-08) and BHP-BPQ (p=7.73e-06) (Figure 3a). At BHP sites, 40 to 430 trees ha^{-1} were recorded; however, the density of most of the sites was less than 250 trees ha^{-1}, something similar occurred with the BP sites. In BPQ, whose tree density varied from 60 to 800 trees ha^{-1}. In basal area, BP-BPQ (p=0.007) and BHP-BPQ (p=2.64e-05) were statistically different (Figure 3b).

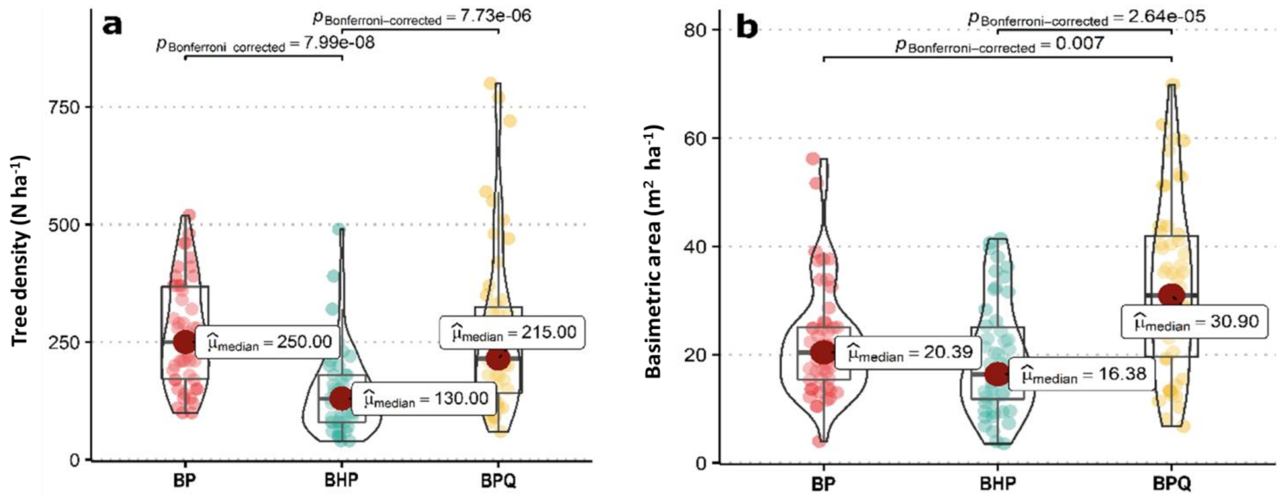

Figure 3. a) Kruskal-Wallis test for tree density; b) Kruskal-Wallis test for basimetric area per tree community.

Vertical structure

The maximum height for the trees in the present study was 28 m (BP), 33 m (BHP) and 36.5 m (BPQ). From these values, stratification was performed to calculate the *A* index, whose values were: BP (A=1.13, A_{max}=2.71 and A_{rel}=41.55), BHP (A=2.26, A_{max}=3.40 and A_{rel}=66.49) and BPQ (A=2.41, A_{max}=3.30 and A_{rel}=73.13); the foregoing indicated that in none of the three communities were the species distributed equally in the height strata; in all cases the largest number of trees was concentrated in the lower stratum (tables 3, 4 and 5).

Table 4. Height strata for the BP tree community.

SPECIES	ABUNDANCE			DOMINANCE		
	N ha^{-1}	**% N ha^{-1} from total**	**% N ha^{-1} from stratum**	**m^2 ha^{-1}**	**% m^2 ha^{-1} from total**	**% m^2 ha^{-1} from stratum**
STRATUM I (22.4–28 m)						
Abies religiosa (Kunth) Schltdl. & Cham.	1	0.22	9.09	0.19	0.84	9.42
Alnus jorullensis Kunth	3	0.97	39.39	1.28	5.75	64.55
Pinus hartwegii Lindl.	3	1.27	51.52	0.52	2.32	26.04
Total	7	2.47	100	1.98	8.91	100
STRATUM II (14-22.39 m)						
Abies religiosa (Kunth) Schltdl. & Cham.	3	1.20	3.13	0.47	2.13	3.52
Alnus jorullensis Kunth	8	3.15	8.22	2.76	12.41	20.54
Pinus ayacahuite Ehrenb. ex Schltdl.	1	0.45	1.17	0.22	1.00	1.65
Pinus hartwegii Lindl.	88	33.13	86.50	9.95	44.79	74.11
Pinus teocote Schied. ex Schltdl. & Cham.	1	0.37	0.98	0.02	0.11	0.18
Total	102	38.31	100	13.43	60.44	100
STRATUM III (<13.99 m)						
Abies religiosa (Kunth) Schltdl. & Cham.	2	0.67	1.14	0.16	0.70	2.28
Alnus jorullensis Kunth	1	0.45	0.76	0.10	0.43	1.39

Pinus ayacahuite Ehrenb. ex Schltdl.	4	1.65	2.78	0.23	1.03	3.38
Pinus hartwegii Lindl.	151	56.45	95.32	6.33	28.49	92.95
Total	158	59.22	100	6.81	30.65	100
General total	267	100	300	22.22	100	300

Table 5. Height strata for the BHP tree community.

SPECIES	ABUNDANCE			DOMINANCE		
	N ha^{-1}	% N ha^{-1} from total	% N ha^{-1} from stratum	m^2 ha^{-1}	% m^2 ha^{-1} from total	% m^2 ha^{-1} from stratum
STRATUM I (26.40-33 m)						
Abies religiosa (Kunth) Schltdl. & Cham.	3	1.92	34.15	0.95	4.94	33.99
Alnus jorullensis Kunth	3	2.19	39.02	1.28	6.66	45.77
Pinus ayacahuite Ehrenb. ex Schltdl.	1	0.69	12.20	0.19	0.98	6.75
Pinus hartwegii Lindl.	1	0.41	7.32	0.19	0.99	6.83
Pinus montezumae Lamb.	1	0.41	7.32	0.19	0.97	6.66
Total	8	5.62	100	2.81	14.54	100
STRATUM II (16.50-26.39 m)						
Abies religiosa (Kunth) Schltdl. & Cham.	5	3.43	10.29	0.78	4.02	7.56
Alnus jorullensis Kunth	33	22.91	68.72	7.75	40.18	75.60
Buddleja cordata Kunth	1	0.69	2.06	0.12	0.61	1.14
Pinus ayacahuite Ehrenb. ex Schltdl.	1	0.96	2.88	0.26	1.34	2.51
Pinus hartwegii Lindl.	4	2.61	7.82	0.57	2.94	5.54
Pinus montezumae Lamb.	3	2.06	6.17	0.72	3.72	6.99
Pinus teocote Schied. ex Schltdl. & Cham.	1	0.69	2.06	0.07	0.34	0.65
Total	49	33.33	100	10.26	53.15	100
STRATUM III (<16.49 m)						
Abies religiosa (Kunth) Schltdl. & Cham.	3	1.92	3.15	0.16	0.83	2.56
Alnus jorullensis Kunth	37	25.51	41.80	3.43	17.77	55.00
Arbutus xalapensis Kunth	3	2.19	3.60	0.16	0.81	2.51
Buddleja cordata Kunth	15	10.15	16.63	0.72	3.71	11.48
Pinus ayacahuite Ehrenb. ex Schltdl.	2	1.23	2.02	0.22	1.13	3.49

Pinus hartwegii Lindl.	16	10.70	17.53	0.98	5.09	15.76
Pinus montezumae Lamb.	5	3.43	5.62	0.25	1.31	4.05
Quercus laurina Bonpl.	1	0.69	1.12	0.00	0.01	0.04
Salix paradoxa Kunth	8	5.21	8.54	0.32	1.65	5.11
Total	89	61.04	100	6.24	32.31	100
General total	146	100	300	19.30	100	300

For BP, the most abundant species in the three strata was *P. hartwegii*. Of the five present, three were recorded in stratum I, which corresponds to 2.47 % of the trees and 8.91 % of the basal area. In stratum II, the five species were present, with 38.31 % of the individuals and a basal area of 60.44 %; in stratum III four were observed, with the largest number of individuals (59.22 %) and 30.65 % of basal area (Table 4).

At BHP, the most abundant species in all three strata was *A. jorullensis*. Of the nine taxa identified in the tree community, five were in stratum I, which corresponded to 5.62 % of the trees, and 14.54 % of the basal area. In stratum II, seven species were recorded, with 33.33 % of the individuals and a basal area of 53.15 %. In stratum III nine species were observed, with the highest number of individuals (61.04 %) and 32.31 % of basal area (Table 5).

In BPQ, the species with the highest abundance in the upper stratum was *P. ayacahuite*, and *A. jorullensis* in the lower stratum. Of the nine taxa present in the tree community, five corresponded to stratum I, which represented 5.64 % of the trees and 21.74 % of the basal area. In stratum II, seven species were recorded, with 16.63 % of the individuals and 42.32 % of the basal area. In stratum III, nine taxa were recorded, with 77.73 % of the individuals and 35.94 % of the basal area (Table 6). It should be noted that the tallest individuals in the three tree communities were specimens of *Abies religiosa* (Kunth) Schltdl. & Cham.

Table 6. Height strata for the BPQ tree community.

SPECIES	ABUNDANCE			DOMINANCE		
	N ha^{-1}	% N ha^{-1} from total	% N ha^{-1} from stratum	m^2 ha^{-1}	% m^2 ha^{-1} from total	% m^2 ha^{-1} from stratum
STRATUM I (29.20-36.50 m)						
Abies religiosa (Kunth) Schltdl. & Cham.	3	1.03	18.18	1.33	4.13	19.00
Pinus ayacahuite Ehrenb. ex Schltdl.	7	2.71	48.05	4.13	12.78	58.80
Pinus montezumae Lamb.	1	0.51	9.09	0.48	1.50	6.90
Pinus teocote Schied. ex Schltdl. & Cham.	4	1.39	24.68	1.07	3.33	15.30
Total	15	5.64	100	7.02	21.74	100
STRATUM II (18.25-29.19 m)						
Abies religiosa (Kunth) Schltdl. & Cham.	6	2.27	13.66	1.53	4.75	11.22
Alnus jorullensis Kunth	2	0.73	4.41	0.41	1.26	2.98
Arbutus xalapensis Kunth	1	0.37	2.20	0.08	0.25	0.60
Pinus ayacahuite Ehrenb. ex Schltdl.	15	5.35	32.16	5.70	17.66	41.73
Pinus montezumae Lamb.	7	2.42	14.54	2.52	7.80	18.42
Pinus teocote Schied. ex Schltdl. & Cham.	9	3.30	19.82	2.48	7.68	18.14
Quercus laurina Bonpl.	6	2.20	13.22	0.94	2.92	6.91
Total	45	16.63	100	13.66	42.32	100
STRATUM III (<18.24 m)						
Abies religiosa (Kunth) Schltdl. & Cham.	10	3.66	4.71	0.28	0.88	2.45
Alnus jorullensis Kunth	68	24.91	32.05	3.55	11.00	30.62
Arbutus xalapensis Kunth	39	14.29	18.38	1.27	3.94	10.96
Cupressus lusitánica Mill.	16	5.79	7.45	1.19	3.70	10.28
Pinus ayacahuite Ehrenb. ex Schltdl.	18	6.67	8.58	2.12	6.57	18.27
Pinus montezumae Lamb.	2	0.59	0.75	0.07	0.21	0.58
Pinus teocote Schied. ex Schltdl. & Cham.	4	1.32	1.70	0.23	0.71	1.99
Quercus laurina Bonpl.	45	16.48	21.21	2.62	8.10	22.54
Salix paradoxa Kunth	11	4.03	5.18	0.27	0.83	2.31
Total	212	77.73	100	11.60	35.94	100
General total	273	100	300	32.28	100	300

Diametric characterization

In the three tree communities, the distributions of the diameter classes were positively skewed; that is, they are biased towards the first classes, which were the most represented in the area; while large diameter individuals (*DBH*>80cm) were scarce, characteristic of a mature irregular forest. The inequality in diameter sizes is an effect associated with competitive processes carried out by the species during the different stages of forest development, but it is also associated with interventions carried out by humans.

The BP community was fitted to the Gamma function ($p<0.005$), BHP to three-parameter Weibull ($p<0.022$), and BPQ to Log-normal ($p<0.005$) (Figure 4).

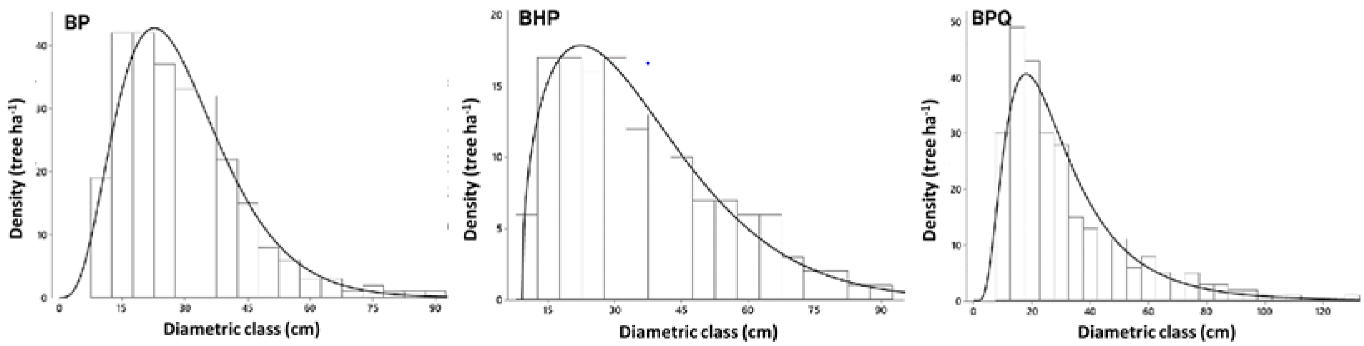

Figure 4. Tree density per diametric class.

Discussion

The composition, diversity and structure of natural forests must be considered in the management and conservation of forest ecosystems (Ćosović *et al.*, 2020). The arboreal communities of temperate forests studied are dominated in the tree layer, generally, by the Pinaceae family, and in the lower parts the *Pinus* forests are mixed with *Quercus* and *Alnus*, among other genera. Likewise, in some places the *Alnus* forests form successional communities, arising as a consequence of the destruction of other types of forests (Rzedowski, 2006).

In the study area, 11 species were recorded, this is similar to that cited by some authors for temperate forests of *Durango* State (Solís *et al.*, 2006; Návar-Cháidez and González-Elizondo, 2009); *Chihuahua* State (Hernández-Salas *et al.*, 2013) and *Puebla* State (López-Hernández *et al.*, 2017). Among the 11 taxa identified, the presence of *Pinus ayacahuite* was observed, which has been used for reforestation in the area.

Tree density values (266, 145 and 272 individuals ha^{-1}) estimated for the region are similar to those reported by Ramos *et al.* (2017) for a temperate forest in the *Sierra Madre Oriental*; however, they are lower than the figures documented for temperate forests by other authors for specimens with a diameter ≥7.5 cm (575, 389 or 576 individuals ha^{-1}) (Graciano-Ávila *et al.*, 2017; López-Hernández *et al.*, 2017; Gonzalez *et al.*, 2018).

The estimated basimetric area (22.21, 19.30 and 32.28 m^2 ha^{-1}) is higher than that reported by Dávila-Lara *et al.* (2019) for a temperate forest in *San Luis Potosí* State and similar to what was recorded for temperate forests in *Nuevo León* State (Ramos *et al.*, 2017) and *Chihuahua* State (Hernández *et al.*, 2018).

The *IVI* obtained for the Pinaceae family in the BPQ community (47.43 %) is close to that documented (40.20 %) by Dávila-Lara *et al*. (2019) in a pine-oak forest in

San Luis Potosí. Also in BP Pinaceae it is of greater importance (86.78 %), similar to that cited by Hernández-Salas *et al.* (2013) and López-Hernández *et al.* (2017).

In the height characterization of the tree communities through the Pretzsch index, it became evident that the three types of forest have strata of similar heights, and that the highest percentage of trees is concentrated in stratum III; trees with a height ≤18 m are grouped in it. The A (1.13, 2.26, 2.41), A_{max} (2.71, 3.40, 3.30) and A_{rel} (41.55, 66.49, 73.13) values for BP, BHP and BPQ, respectively. Of them, the BPQ and BHP are very similar to what they indicate (A=2.19, 2.22; A_{max}=3.4, 3.2; A_{rel}=64.3, 69.8 %) Dávila-Lara *et al.* (2019) and Rubio *et al.* (2014), both for BPQ.

The diameter distributions of patchy forests have been studied using mathematical models or histograms with fitted curves through probability density functions (Pond and Froese, 2015). The diameter distributions of the three tree communities were similar, with a greater number of trees in the first classes, which is characteristic of forests with human intervention, mainly due to the removal of large trees for commercial purposes.

Probability density functions fitted to tree community data have been used in the study of other patchy forests. These were Weibull (Souza *et al.*, 2021), Gamma (Gorgoso-Varela *et al.*, 2020) and Log-normal (Ferreira de Lima *et al*., 2015).

Conclusions

The tree communities of temperate forests studied differ in diversity and structure, are heterogeneous and include communities made up, mainly, by species of the *Pinus*, *Abies*, *Alnus* and *Quercus* genera, among others, that stand out for their dominance or abundance. In addition, the communities have a medium high uniformity (BHP, BPQ) and a medium low uniformity (BP) in height diversity. Diversity values are low for BP, so it shows dominance of one species. Likewise, the distribution of the trees by diameter classes confirms that most individuals are gathered in the first diameter classes, which indicates a population in a recovery phase, after being subjected to pressure factors such as logging.

When applying statistical analysis to determine differences between temperate forest tree communities, there are significant differences in density (BP-BHP, BHP-BPQ), basimetric area (BP-BPQ, BHP-BPQ) and species richness (BP-BPQ, BHP-BPQ). Based on the analysis carried out, the differentiated response of the communities to the effect of the activities carried out in them, particularly in the BPQ communities, is evident.

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Conflict of interest

The authors declare not conflict of interest.

Contribution by author

Prudencia Caballero Cruz: data collection and analysis, witing of the manuscript; Eduardo Javier Treviño Garza, José Manuel Mata Balderas, Eduardo Alanís Rodríguez, Israel Yerena Yamallel y Luis Gerardo Cuéllar Rodríguez: coordination of data analysis, writing and review of the manuscript.

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