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Article

Influencia de la altitud y exposición en la estructura y composición de un bosque templado en Durango

Influence of altitude and exposure on the structure and composition of a temperate forest in the state of *Durango*

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Resumen

Las variables geográficas determinan en gran medida la estructura y diversidad de especies. El objetivo del estudio fue conocer si existen diferencias entre los componentes que conforman la estructura, diversidad y composición florística con relación a la exposición y altitud en bosques templados del estado de Durango. Los datos dasométricos se obtuvieron de 30 sitios permanentes (2 500 m^2), se consideraron: diámetro normal (*Dn*)>7.5 cm (1.30 m), altura total, y el registro por especie. Se definieron seis áreas distribuidas en tres intervalos altitudinales (500 m) con exposición sur y norte. Se caracterizó la estructura por medio del Índice de Valor de Importancia (*IVI*), diversidad alfa (*α*), riqueza de especies (*S*) y el Índice de Diversidad Verdadera de *Shannon* (^1D), así como la diversidad beta (*β*) por medio del análisis de similitud de *Bray-Curtis*. Se realizó una prueba estadística de ANOVA de dos factores para determinar diferencias significativas entre intervalos de altitud en las áreas; las de mayor altitud tuvieron más densidad y área basal en ambas exposiciones, con excepción del área 5 (1 500 a 1 800 m sur) que mostró valores similares en área basal. Los géneros *Pinus* y *Quercus* presentaron un *IVI* superior en todas las áreas. Los sitios en exposición sur registraron una mayor riqueza de especies, sobre todo los que se ubicaron en el intervalo de menor altitud. La similitud entre áreas comprendió las zonas con más altitud y exposición norte, y se aislaron las tierras bajas con intervalos altitudinales diferentes.

Palabras clave: ANOVA, densidad, diversidad, intervalo, riqueza de especies, similitud.

Abstract

Geographic variables can largely determine species structure and diversity. The objective of the study was to determine whether there are differences between the components that make up the structure, diversity, and floristic composition in relation to exposure and altitude in temperate forests of the state of *Durango*. The mensuration data were obtained from 30 permanent sites (2 500 m^2), considering a normal diameter (*Nd*)> 7.5 cm (at 1.30 m), total height, and the record by species. 6 areas distributed at three altitudinal intervals (500 m) with South and North exposure were defined. The structure was characterized based on the Importance Value Index (*IVI*), alpha diversity (*α*) with richness of species (*S*), and the Shannon true diversity index (^1D), as well as beta diversity (*β*) determined by means of a Bray-Curtis similarity analysis. A two-factor ANOVA statistical test was performed to find significant differences between altitude intervals in the different areas. The areas with a higher altitude had higher density and basimetric area in both exposures, except for area 5 (1 500 to 1 800 m south), which showed similar values in basal area. The *Pinus* and *Quercus* genera showed a higher *IVI* in all areas. The sites with a southern exposure had a greater richness of species, especially those located at the lowest altitude interval. The similarity between areas comprised the zones with the highest altitude and northern exposure, isolating the lowlands with different altitude ranges.

Keywords: ANOVA, density, diversity, interval, richness of species, similarity.

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Introduction

Forests and tropical rainforest provide important environmental goods and services, which can contribute to the improvement of the local economy (Méndez *et al.,* 2018). Temperate forests are ecosystems with great diversity in the American continent; they extend from the United States of America to Honduras (Mora-Donjuán y Alanís-Rodríguez, 2016).

Knowledge of the structure and composition of plant communities is fundamental, as it allows the creation of strategies that promote the growth and development of forest stands, ensuring rational use without compromising the original scenarios (Aguirre-Calderón, 2015; Manzanilla *et al*., 2020). In addition, it is necessary to know the richness, composition and degree of similarity of the communities (Domínguez *et al*., 2018), as well as the components that influence diversity and richness, the most prominent of which are the environmental factors and the physical land characteristics (Saldaña, 2013).

Species diversity may decrease towards higher latitudes and altitudes (Malizia *et al*., 2020). García-Aguilar *et al.* (2017) confirm that the development capacity of forests is closely linked to the physical conditions of the terrain. Likewise, McIntire *et al*. (2016) confirm that exposure is a limiting factor for the establishment of shade-intolerant species.

At present, several studies have been carried out on the floristic structure and composition in forest ecosystems, which focus on changes in the altitudinal gradient (Alves *et al*., 2010; Rascón *et al*., 2018). However, the influence of geographic exposure has not been considered, resulting in insufficient information about Mexico.

Therefore, the objective of this research was to determine differences in the structure, richness, composition and degree of similarity of plant communities, with regard to exposure and altitude range in a temperate forest in the state of *Durango*. The following hypotheses are analyzed: (i) the northern exposure will record higher values of basal area; (ii) as altitude increases, the richness and diversity of species will decrease, and (iii) the degree of similarity in the species composition will be defined by exposure.

Materials and Methods

The study area was located in the mountain system called Western *Sierra Madre* in the state of *Durango*, between the geographic coordinates 26°26'25.7" N, and 106°03'57.5" W, and 23°10'29.5" N and 105°22'09.2" W (Figure 1).

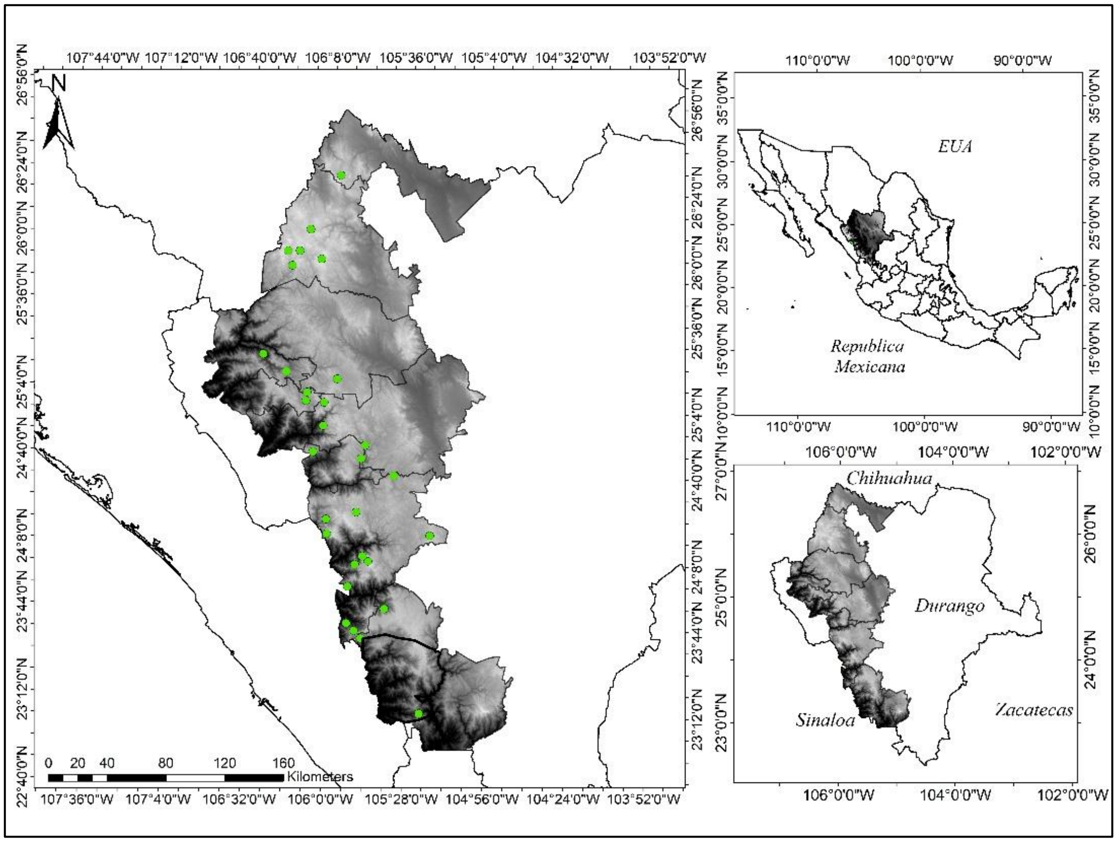

Figure 1. Location of the sampling sites (green dots) in the study area.

According to the Köppen classification modified by García (1988), the predominant climate types in the area are temperate sub-humid, with four subdivisions: (A)c(w_2), (A)c(w_1), C(E)(w_2), and C(E)(w_2)(x'). Temperature variation ranges from 12 to 18 °C, with the exception of some areas with values of 10 to 12 °C; rains usually occur in summer and droughts in winter (Quiñones *et al*., 2012). The soil types form associations between Regosol, Lithosol, Cambisol, and Phaeozem (INEGI, 2007). The existing vegetation types are pine forest, oak forest, pine-oak forest, oak-pine forest, and shrub secondary vegetation in all plant communities (González *et al*., 2012).

Data collection and analysis

The mensuration information was obtained from 30 permanent forest monitoring plots of 2 500 m^2 each, randomly located in six areas, three altitudinal intervals (between 1 500 and 3 000 m), with five plots per exposure (north and south). The normal diameter (*Nd*> 7.5 cm) was considered, which was measured with a Ben Meadows 122450 diametric tape; total height (*H*), measured with a Suunto Pm5/360pc clinometer, and the record by species. The scientific names were corroborated in the website The Plant List (http://www.theplantlist.org/).

The Ecological Importance Value Index (*EVI*) was calculated for each area; percentage values in the range of 0 to 100 were obtained (Alanís-Rodríguez *et al*., 2020) by species, based on the sum of the relative structural parameters of abundance (density), frequency and basal area (Whittaker, 1972; Moreno, 2001). Species richness was determined using the Margalef Index and alpha diversity was estimated using the Shannon True Diversity Index (Jost, 2006). Each of the parameters was calculated using the equations in Table 1.

Table 1. Equations to calculate structure and diversity parameters.

Parameter	Equation	Description
Abundance	$A_i = {N_i}/{S}$ $RA_i = \left[{A_i}/{\sum A_i}\right] * 100$ $i = 1 \dots n$	A_i = Absolute abundance RA_i = Relative abundance of species *i* with respect to the total abundance N_i = Number of individuals of species *i* S = *S*ampling area (ha)
Frequency	$F_i = {P_i}/{NS}$ $RF_i = \left[{F_i}/{\sum F_i}\right] * 100$ $i = 1 \dots n$	F_i = Absolute frequency RF_i = Relative frequency of species *i* with respect to the total frequency P_i = Number of sites where species *i* is present NS = Total number of sampling sites
Basal area	$D_i = {B_a}/{S}$ $RD_i = \left[{D_i}/{\sum D_i}\right] * 100$ $i = 1 \dots n$	D_i = *A*bsolute dominance RD_i = Relative dominance of species *i* with respect to the total dominance B_a = Basal area of species *i* S = Surface area (ha)

EVI	$EVI = \frac{(RA_i + RF_i + RD_i)}{3}$	RA_i = Relative abundance RF_i = Relative frequency RD_i = Relative dominance
Margalef Index	$D_{mg} = \frac{(S-1)}{\ln(N)}$	S = Number of species present N = Total number of individuals n = Number of individuals of species i
Shannon true diversity index	$H = \sum_{i=1}^{s} Pi * \ln(P_i)$ $P_i = {n_i}/{N}$ ${}^{1}D = exp(H´)$	pi= Proportional abundance of the i^{th} species n_i = Number of individuals per species N = Total number of individuals present ${}^{1}D$ = Shannon true diversity index *exp* = Exponential $H´$ = Shannon diversity index

The verification of compliance with the assumptions of normality of the residuals was based on the Shapiro-Wilk statistical test; in addition, the homogeneity of variances was checked by means of the Levene's test. A two-factor analysis of variance (ANOVA) was applied (exposure and altitude interval) in order to determine the differences between areas. Tukey's multiple comparisons test was used to determine differences at the significance level of p<0.05. Statistical analyses were performed using IBM© SPSS© Statistic software version 19 (Zar, 2010).

In order to calculate the beta diversity, defined as the replacement of species in communities with different environmental scenarios (Whittaker, 1972), a classification model was developed using sample similarity algorithms; the percentage of similarity between the samples (0 % to 100 %) was estimated by means of the Bray-Curtis similarity dendrogram, which is suitable for the analysis of the behavior of plant species (Rascón *et al.*, 2018). The analysis was carried out with the Past 4.01 software (Hammer, 2001), using the abundance parameter in the different altitude intervals by area as a grouping matrix.

Results

Forty-eight species were registered (Table 2), distributed into eight families; of these, Fagaceae had the highest number of taxa and comprised 39.58 % of the total, followed by Pinaceae, with 31.25 %. Convolvulaceae and Betulaceae had the lowest values.

Table 2. List of tree species present in the study area.

Family	Species
Betulaceae	*Alnus jorullensis* Kunth
Convolvulaceae	*Ipomoea arborescens* Humb. *et* Bonpl.
Cupressaceae	*Juniperus deppeana* Steud.
Cupressaceae	*Cupressus lusitanica* Mill.
Ericaceae	*Arbutus arizonica* (A. Gray) Sarg.
Ericaceae	*Arbutus bicolor* S. González, M. González & P.D. Sorensen
Ericaceae	*Arbutus madrensis* S. González
Ericaceae	*Arbutus tesselata* P.D. Sorensen
Ericaceae	*Arbutus xalapensis* Kunth
Ericaceae	*Comarostaphylis polifolia* Kunth
Fabaceae	*Lysiloma acapulcense* Benth.
Fabaceae	*Acacia pennatula* Benth.
Fagaceae	*Quercus albocincta* Trel.
Fagaceae	*Quercus castanea* Née
Fagaceae	*Quercus coccolobifolia* Trel.
Fagaceae	*Quercus crassifolia* Humb. & Bonpl.
Fagaceae	*Quercus depressipes* Trel.
Fagaceae	*Quercus durifolia* Seemen ex Loes.
Fagaceae	*Quercus elliptica* Née
Fagaceae	*Quercus fulva* Liebm.
Fagaceae	*Quercus gentryi* C. H. Mull.

Fagaceae	*Quercus jonesii* Trel.
Fagaceae	*Quercus laeta* Liebm.
Fagaceae	*Quercus obtusata* Humb. & Bonpl.
Fagaceae	*Quercus resinosa* Liebm.
Fagaceae	*Quercus rugosa* Née
Fagaceae	*Quercus salicifolia* Benth.
Fagaceae	*Quercus scytophylla* Liebm.
Fagaceae	*Quercus sideroxyla* Bonpl.
Fagaceae	*Quercus urbanii* Trel.
Fagaceae	*Quercus viminea* Trel.
Pinaceae	*Pinus arizonica* Engelm.
Pinaceae	*Pinus cembroides* Zucc.
Pinaceae	*Pinus chihuahuana* Martínez
Pinaceae	*Pinus cooperi* C.E. Blanco
Pinaceae	*Pinus douglasiana* Martínez
Pinaceae	*Pinus durangensis* Martínez
Pinaceae	*Pinus engelmannii* Carrière
Pinaceae	*Pinus herrerae* Martínez
Pinaceae	*Pinus leiophylla* Schiede ex Schltdl. *et* Cham.
Pinaceae	*Pinus lumholtzii* B. L. Rob *et* Fernald
Pinaceae	*Pinus luzmariae* Pérez de la Rosa
Pinaceae	*Pinus oocarpa* Schiede ex Schltdl.
Pinaceae	*Pinus strobiformis* Engelm.
Pinaceae	*Pinus teocote* Schiede ex Schltdl. *et* Cham.
Pinaceae	*Pseudotsuga menziesii* (Mirb.) Franco
Rosaceae	*Crataegus mexicana* DC.
Rosaceae	*Prunus serotina* Ehrh.

Abundance (density). Areas 1 and 2 exhibited higher values. On the southern exposure, the species with the highest abundance were: *P. arizonica* Engelm., with 600 ind ha^{-1}, and *J. deppeana* Steud., with 66 ind ha^{-1}. On the northern exposure, *P. arizonica* had 344 ind ha^{-1}, and *Q. sideroxyla* Bonpl., 111 ind ha^{-1}. Areas 3 and 5 showed similarity in the total number of individuals per hectare. The most abundant taxa in area 3 were *Q. laeta* Liebm., with 122 ind ha^{-1}, and *P. leiophylla* Schiede ex

Schltdl. *et* Cham., with 68 ind ha^{-1}. In area 5, *P. durangensis* and *P. oocarpa* Schiede ex Schltdl. had a greater presence (Table 3). Areas 4 and 6 recorded a difference compared to the higher altitude intervals (p<0.05). In area 4, the species with the highest density were *Q. crassifolia* Humb. & Bonpl., with 121 ind ha^{-1} and *P. leiophylla*, with 83 ind ha^{-1}. In area 6, the most abundant taxa were *P. durangensis*, with 77 ind ha^{-1}, and *Q. resinosa* Liebm., with 47 ind ha^{-1}.

Basimetric area. The southern exposure exhibited the largest basal area in the three altitude intervals. In interval 1 (2 700-3 000 m), the average was 56.42 m^2 ha^{-1}; *P. arizonica* stood out with 21.26 m^2 ha^{-1} in area 1 (Table 3). The ANOVA test showed no significant differences for areas 4 and 6; however, the average was lower, of 15.70 m^2 ha^{-1} and 15.94 m^2 ha^{-1}, respectively. The species with the largest basimetric area were *P. leiophylla*, with 2.94 m, and *P. durangensis*, with 3.36 m^2 ha^{-1} (Figure 2B).

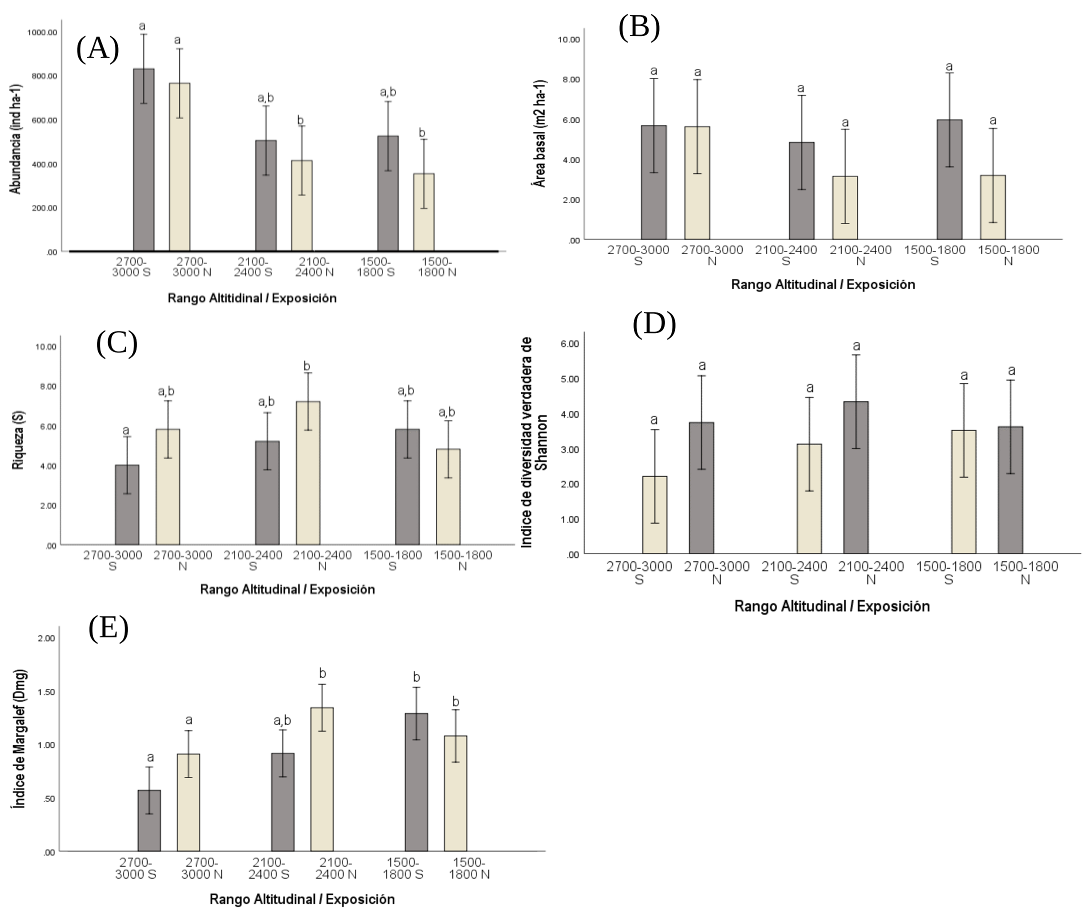

Figure 2. Means and standard error of (A) Abundance (ind ha^{-1}), (B) Basimetric area (m^2 ha^{-1}), (C) Richness of species (*S*), (D) Shannon True Diversity Index (^1D), (E), Margalef Index (D_{mg}). Means with different letters (a, b) indicate differences ($p<0.05$).

Ecological importance value index (*EVI*). The *Pinus* and *Quercus* genera exhibited the highest percentages of IVI; *P. arizonica* reached the highest percentage in the interval 1, north and south; *Q. laeta* Liebm., on the southern exposure, and *Q. crassifolia*, on the northern exposure, dominated the mean altitude interval. In the lowest height interval, the highest IVI was obtained by *P. durangensis*; Table 3 shows the three most important species by area.

Table 3. Estimated structural parameters by area and altitude range (IVI ordered from highest to lowest percentage value, only the three species with the highest value are included).

Exposure/Altitude	**Species**	**Density**		**Frequency**		**Dominance (Basal area)**		**IVI**
		Absolute (N ha^{-1})	**Relative (%)**	**Absolute**	**Relative (%)**	**Absolute (m^2 ha^{-1})**	**Relative (%)**	
South 2 700-3 000 masl (Area 1)	*P. arizonica*	600	75.6	5	25	21.26	74.98	58.53
	J. deppeana	66	8.27	5	25	0.15	5.32	12.86
	P. strobiformis	32	4.03	4	20	1.51	4.02	9.35
North 2 700-3 000 masl (Area 2)	*P. arizonica*	344	45.03	4	13.33	8.9	31.71	30.02
	Q. sideroxyla	111	14.55	5	16.67	8.81	31.38	20.87
	A. xalapensis	73	9.53	3	10	2.02	7.2	8.91
South 2 100-2 400 masl (Area 3)	*Q. laeta*	122	24.21	3	10.71	4.65	19.28	18.04
	P. leiophylla	68	13.49	2	7.14	4.22	17.5	12.71
	Q. sideroxyla	58	11.51	1	3.57	4	16.6	10.53
North 2 100-2 400 masl (Area 4)	*Q. crassifolia*	121	29.38	2	5.56	2.25	14.32	16.42
	P. teocote	50	12.26	4	11.11	2.72	17.29	13.55
	P. leiophylla	66	16.15	2	5.56	2.94	18.75	13.49
South 1 500-1 800 masl	*P. durangensis*	206	39.24	2	7.14	14.29	47.97	31.47

(Area 5)	*P. oocarpa*	177	33.74	3	10.71	5.99	20.12	21.53
	Q. viminea	8	1.53	3	10.71	0.62	2.08	4.78
North 1 500-1 800 masl (Area 6)	*P. durangensis*	76.8	21.92	2	8.33	3.36	21.06	17.1
	Q. gentryi	25.6	7.31	2	8.33	1.49	9.35	8.33
	P. oocarpa	26.4	7.53	2	8.33	1.41	8.88	8.25

The dendrogram of plant communities by altitude intervals showed that there is 65 % similarity between areas 1 and 2, with 65 %, and 46 % between areas 4 and 6 (Figure 3). This indicates a similar floristic composition in these areas, where the dominant species tend to be the same as in other areas. Likewise, the southern exposure of area 5 exhibited lower similarity values compared to the rest of the areas; as a rule, the exposure is precisely what defines the degree of similarity between sites located at lower altitudes. The generalist species found in both exposures and within the three altitudinal intervals were *P. durangensis*, *Q. sideroxyla* Bonpl., *J. deppeana*, and *A. xalapensis* Kunth. At sites with lower altitudes, the species varied by type of exposure: *Q. coccolobifolia* Trel. occurred on the northern exposure, and *A. pennatula* Benth., *L. acapulcense* Benth., *P. serotina* Ehrh., and *I. arborescens* Humb. *et* Bonpl., on the southern exposure.

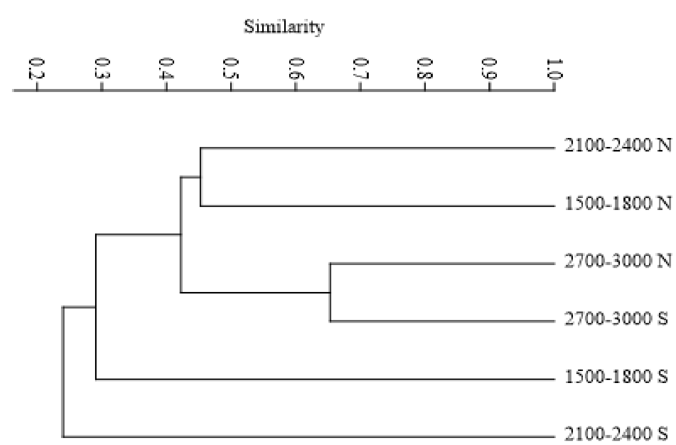

Figure 3. Dendrogram of similarity based on a Bray-Curtis analysis between areas with different altitudinal ranges.

Richness. Differences ($p<0.05$) were found between areas 1 and 4, with a lesser number of species at sites with a higher altitude; the number of species within area 4 was observed to be around twice as high as in area 1. In the remaining areas, the average interval was five taxa per site (Figure 2C).

Diversity indexes. Shannon's true diversity showed no differences ($p<0.05$) between areas, with an average of 2.94 ± 1.58 on the southern exposure and 3.89 on the northern exposure (Figure 2D). Regarding the Margalef index, differences ($p<0.05$) were observed in the areas located at a higher altitude with respect to lower areas. The average values were 0.73 for both exposures in interval 1, and 0.98, in interval 3 (Figure 2E).

Discussion

The results obtained for density agree with those cited by Delgado *et al.* (2016), who estimated 565 ind ha^{-1} and 16 taxa in temperate forests of *Durango*, within an altitudinal range of 2 400 to 2 500 m. On the other hand, López-Hernández *et al.* (2017) registered lower values, 389 ind ha^{-1} and 11 species in forests in the state of *Puebla*; this can be attributed to the fact that the evaluated forests exhibit more intensive harvesting activities than those of the present study.

The basimetric area was found to increase as altitude does, as confirmed by Muñoz *et al.* (2020); exposure and slope can also influence the productivity of different areas. Results of the study show that the basimetric area is larger at sites with higher altitudes, with values up to twice as high. Results are similar to those obtained by Graciano-Ávila *et al*. (2017), who estimated a similar basimetric area in temperate forests of *Durango*, Mexico.

In most temperate forests of Mexico, *Pinus* and *Quercus* tend to be the most prevalent genera, as they include a greater number of species which have more dominant mensuration variables and, therefore, tend to have a higher value of ecological importance (Domínguez *et al*., 2018). In this case, there were variations in the species with a higher IVI value; thus, areas located at both higher and lower altitudes registered higher *EVI*s in *Pinus*, a result that agrees with those obtained by Hernández-Salas *et al.* (2013) and Graciano-Ávila *et al.* (2019), who report *P. durangensis* as the most ecologically important species in the forests of *Chihuahua* and *Durango*. Paredes *et al.* (2019) coincide with the results obtained in the present study and cite *Q. crassifolia as the most ecologically important taxon in a temperate rainforest in Hidalgo.*

Altitude, slope and exposure have a great influence on the floristic composition and species richness of plant communities. Siles *et al.* (2017) recorded 27 taxa over an altitudinal gradient of 1 300 to 1 500 m; these data are similar to those documented in the present study, in which 18 to 23 species were found to occur within the lower altitudinal range. Likewise, authors such as Castellanos-Bolaños *et al.* (2019) agree that the higher the altitude, the lower the number of taxa.

Regarding diversity, Domínguez *et al.* (2018) indicate similar records at similar altitudes for a temperate forest in the *Ruiz Cortinez ejido*, in the region of *El Salto, Durango*, where the values obtained for diversity are similar to those of the present study.

In order to assess the diversity and wealth of species among communities, it is necessary to know the biological characteristics and their proportional distribution

(Moreno, 2001). The value of the Margalef index was lower at higher altitudes, as shown by Báez *et al.* (2015), who indicate that low temperatures and topographical features contribute to the decline of species. Likewise, the high number of taxa at lower altitudes is similar to that estimated by Clark *et al.* (2015), who report a large wealth of species in plots located at low altitudes.

According to Zarco *et al.* (2010), exposure influences the development of different species, particularly at medium and low altitudes; this information is in agreement with that recorded in the present study, where the number of taxa was found to be higher on the southern exposure.

The similarity between communities is linked to altitude and exposure, among other factors (Chust *et al.*, 2006) that determine which species can adapt to different plant communities. Accordingly, it is possible to observe both generalist and specialist species adapted to different areas with particular conditions.

Hernández *et al.* (2013) indicate that the grouping depends, to a large extent, on the degree of adaptation of the taxa, so that different species of conifers and oaks may occur in sites with different characteristics. The above confirms the data obtained for different species of *Pinus* and *Quercus*, which are present in all the areas studied. Likewise, we agree with Delgado *et al.* (2016), who point out the occurrence of particular species established in very clearly defined microhabitats, given that in this study certain taxa were observed only in low altitude intervals and on the southern exposure.

Conclusions

The basal area does not exhibit significant differences between the different areas and altitudinal ranges. However, the density is higher at sites with a higher altitude, contradicting the hypothesis put forward at the beginning of the study.

Regarding the wealth and diversity of species, the hypothesis is fulfilled, since these are greater in areas with a southern exposure. Similarly, sites at lower altitudes have the highest number of species, and both generalist and specialist species are identified in specific areas.

The results indicate that, within the areas evaluated in the different altitudinal intervals, the structure, floristic composition, and wealth of species are strongly influenced by the topographic characteristics of the terrain. It is possible to identify that the degree of similarity of plant communities varies according to the altitudinal range and slope exposure, where temperature can support or hinder the development of species.

Conflict of interest

The authors declare that they have no conflicts of interest.

Contribution by author

Jesús Eduardo Silva-García: manuscript development and statistical analysis; Oscar Alberto Aguirre-Calderón: research approach and coordination; Eduardo Alanís-Rodríguez: data analysis and interpretation; Enrique Jurado-Ybarra: data analysis and interpretation of results; Javier Jiménez-Pérez: statement of objectives and revision of the manuscript; Benedicto Vargas-Larreta: data analysis and revision of the manuscript; José Javier Corral Rivas: statistical analysis.

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