DOI: 10.29298/rmcf.v15i85.1461

Research article

Estructura arbórea en dos exposiciones de un bosque de pino en Cochoapa El Grande, Guerrero

Tree structure in two exposures of a pine forest in *Cochoapa El Grande*, state of *Guerrero*

Beatriz Calleja-Peláez[1,2]*, Bernardo López-López[1], Eduardo Alanís-Rodriguez[2], Ricardo Telles-Antonio[3], Marco Aurelio González-Tagle[2], Josafat Cano-Abad[1]

Fecha de recepción/Reception date: 24 de enero de 2024.
Fecha de aceptación/Acceptance date: 24 de junio de 2024.

[1]Universidad Intercultural del Estado de Guerrero, México.
[2]Facultad de Ciencias Forestales. Universidad Autónoma de Nuevo León. México.
[3]Universidad Mexiquense del Bicentenario, México.

*Autor para correspondencia; correo-e: beatriz.calleja07@gmail.com
*Corresponding autor; e-mail: beatriz.calleja07@gmail.com

Abstract

The objective of this research was to evaluate the structure, composition and similarity of tree species in two exposures: Northwest (NW) and Southeast (SE) of a temperate forest in the community of *Cochoapa El Grande*, *Guerrero*, Mexico. In each of the exposures, six plots of 500 m^2 each were randomly established. The assessed mensuration variables were total height (m) and normal diameter (m) (*ND*, $d_{1.30m}$, cm); the mensuration distribution, Importance Value Index (*IVI*), Pretzsch Index, and Sørensen's similarity index were determined based on those variables. The average density of the area was 810 ind ha^{-1}, with four *Pinus* species; the SE exposure had the highest abundance (1 040 ind ha^{-1}), with a basimetric area of 25.30 m^2 ha^{-1} and a volume of 225.21 m^3 ha^{-1}. In the NW exposure, three species were recorded, with 580 ind ha^{-1}, 39.80 m^2 ha^{-1}, and a volume of 415.15 m^3 ha^{-1}. The species with the highest *IVI* value was *P. pseudostrobus* (NW=86.86 % and SE=68.65 %). Three strata were defined by means of the Pretzsch Index: The values for the NW exposure were A=1.30, A_{max}=2.20, and A_{rel}=59.08 %; in the SE exposure, the recorded values were A=1.26, A_{max}=2.48, and A_{rel}=50.69 %. The tree composition exhibited a high similarity (86 %) between the two exposures. Exposure and climatic conditions contribute to the distribution and adaptation of various species, as height and basimetric area parameters are modified.

Key words: Basimetric area, Pretzsch Index, Sørensen's Similarity Index, Importance Value Index, *Pinus pseudostrobus* Lindl., volume.

Resumen

El objetivo de la presente investigación fue evaluar la estructura, composición y similitud de especies arbóreas en dos exposiciones: Noroeste (NO) y Sureste (SE) de un bosque templado en la comunidad Cochoapa El Grande, Guerrero, México. En cada una de las exposiciones se establecieron de manera aleatoria seis parcelas de 500 m^2 cada una; las variables dasométricas evaluadas fueron altura total (m) y diámetro normal (*DN*,

$d_{1.30m}$, cm). Con ello se determinó la distribución dasométrica, Índice de Valor de Importancia (*IVI*), el Índice de *Pretzsch* y el Índice de similitud de *Sørensen*. La densidad promedio del área fue de 810 ind ha^{-1}, con cuatro especies del género *Pinus*; en la exposición SE se presentó la mayor abundancia (1 040 ind ha^{-1}), con 25.30 m^2 ha^{-1} en área basal y un volumen de 225.21 m^3 ha^{-1}. En la exposición NO se registraron tres especies, con 580 ind ha^{-1}, 39.80 m^2 ha^{-1} y un volumen de 415.15 m^3 ha^{-1}. La especie con el valor de *IVI* más alto fue *P. pseudostrobus* (NO=86.86 % y SE=68.65 %). A través del Índice de *Pretzsch* se definieron tres estratos: NO tuvo A=1.30, $A_{máx}$=2.20 y A_{rel}=59.08 %; en la exposición SE los registros fueron de A=1.26, $A_{máx}$=2.48 y A_{rel}=50.69 %. La composición arbórea entre exposiciones mostró una similitud alta (86 %). La exposición y las condiciones climáticas contribuyen a la distribución y adaptación de diversas especies, ya que se modifican los parámetros de altura y área basal.

Palabras clave: Área basal, Índice de *Pretzsch*, Índice de Similitud de *Sørensen*, Índice de Valor de Importancia, *Pinus pseudostrobus* Lindl., volumen.

Introduction

The importance of forests worldwide lies in their biodiversity (of flora and fauna). They cover 31 % of the earth's surface; almost half of the forest area is intact, and more than one third corresponds to primary forests (ONUAA y PNUMA, 2020). Another important role of these ecosystems is to reduce the problems of climate variability due to the effect of various anthropogenic activities (ONUAA y PNUMA, 2020), which, in turn, lead to an accelerated decline in the forest cover.

Mexico has a forest area of 137 million hectares, of which more than 94 million are primary vegetation; these areas are in the possession of *ejidos* and indigenous communities, with a high degree of conservation (Conafor, 2020). The main genera that are distributed in these plant communities are *Pinus*, *Abies*, *Pseudotsuga*, *Cupressus*, *Juniperus* and *Quercus*, in addition to certain mixed communities (Challenger and Soberón, 2008).

Knowledge about the structure and composition of forests has been a basic issue for natural resource management personnel (Aguirre-Calderón, 2015; Manzanilla *et al.*, 2020); it is essential for proposing strategies that contribute to their conservation or to sustainable forest harvesting (Pretzsch, 1998; Aguirre *et al.*, 2003).

Several factors such as altitude, slope, and slope exposure have been reported to significantly influence the composition, structure, and richness of plant communities in the northern hemisphere (Silva-García *et al.*, 2022), where the species have certain adaptive characteristics to establish themselves in defined habitats (Hernández-Salas *et al.*, 2013; Delgado *et al.*, 2016); furthermore, López-Gómez *et al.* (2012) indicate that hillside exposure modifies the microclimatic conditions for species establishment, and the NE exposure is the most humid; however, there is little information on their behavior.

Studies on forest structure, diversity, and composition have been carried out in several Mexican states (Graciano-Ávila *et al.*, 2017; Manzanilla *et al.*, 2020; Caballero *et al.*, 2022; García-García *et al.*, 2023); however, they are still scarce in the state of *Guerrero*. The objective of the present study was to evaluate the effect of hillside exposure (NW *vs.* SE) in the tree structure of a *Pinus* forest in *Cochoapa El Grande*. The hypothesis was that the trees with the NW exposure have higher values of normal diameter, total height, basimetric area, and volume.

Materials and Methods

Study area

The work was carried out in *Los Pinos*, located in *Cochoapa El Grande* municipality, in the Southeast of the state of *Guerrero*, in the *Sierra Madre del Sur* physiographic province between 98°28'14.86'' W and 17°11'47.79'' N, at 2 184 masl (Figure 1). The predominant vegetation type is *Pinus* forest (INEGI,2010).

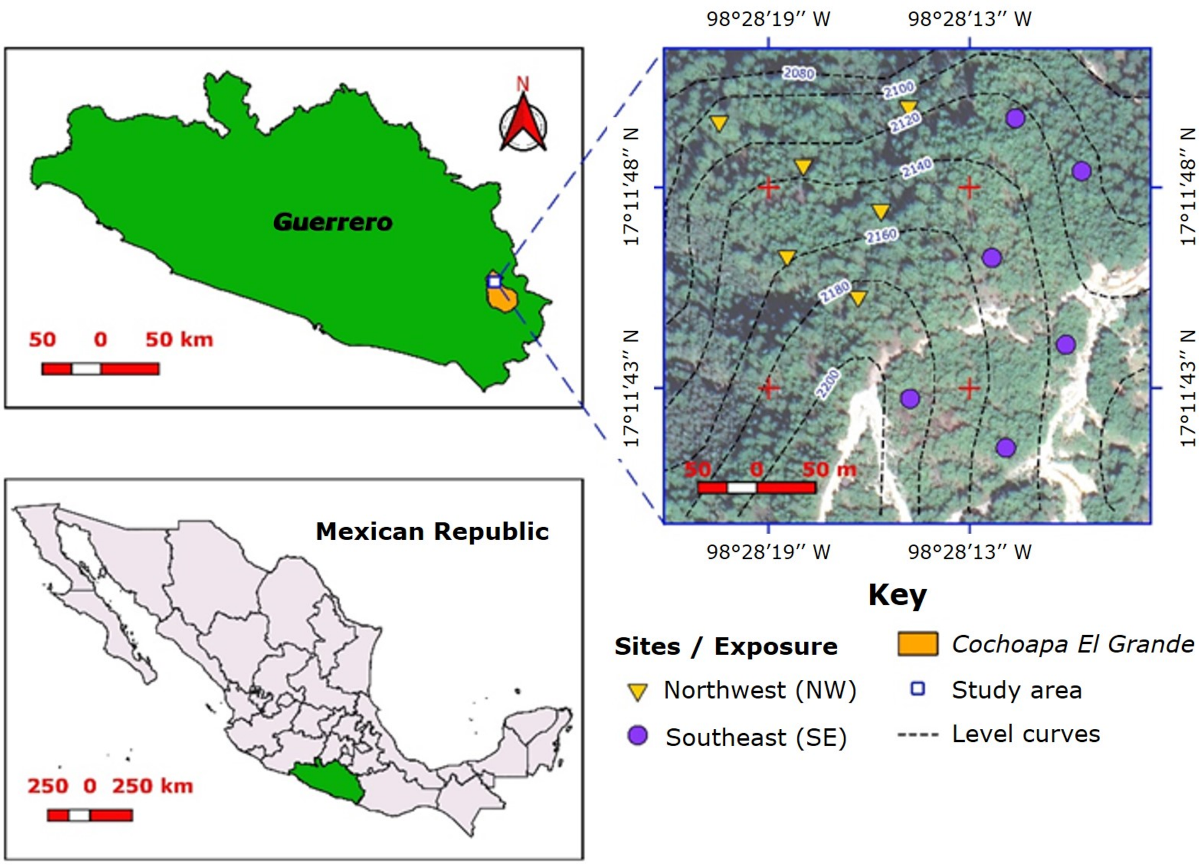


Figure 1. Location of the sampling sites in the study area.

The dominant soils are Leptosol (78.28 %), Regosol (21.35 %), and Phaeozem (0.32 %). The climate type corresponds to the humid temperate C(m)(w), with an average annual temperature of 12-26 °C and precipitation ranging between 110 and 3 000 mm (INEGI, 2008).

Data collection and analysis

Within the *Los Pinos* location, six 500 m^2 sampling sites were established randomly in the Southeast (SE) and Northwest (NW) exposures, based on the parameters of the National Forest and Soil Inventory (*Infys* in Spanish) (Figure 1). The mensuration variables recorded at each sampling unit were normal diameter (*ND*, $d_{1.30m}$, cm) of individuals with a diameter $\geq$7.5 cm, at a height of 1.30 m above ground level, using a model 283D/5M Forestry Suppliers® diametric tape; the height (*h*) was recorded with a model PM5/360PC Suunto® clinometer. The scientific name was corroborated with the Field Guide to the Pines of Mexico and Central America (Farjon *et al.*, 1997).

Based on the variables of each exposure (SE and NW), the ecological Importance Value Index (*IVI*) (Equation 1) was calculated with percentage values of 0 to 100 % per species, which were obtained by adding the values of abundance (density), dominance in the basimetric area (m^2 ha^{-1}), and relative frequency (presence at each site) (Mostacedo and Fredericksen, 2000; Alanís *et al.*, 2020).

$$IVI = \frac{(AR+DR+FR)}{3} \qquad (1)$$

Where:

IVI = Importance Value Index

AR = Relative abundance

DR = Relative dominance

FR = Relative frequency

The vertical structure of the tree population was determined based on the Pretzsch Index (*A*) (Pretzsch, 1998), which classifies a population into three strata: Stratum I (80-100 %), in which the highest individual has an index of 100 %, Stratum II (50-80 %), and Stratum III (0 and 50 %). This index ranges between a value of zero and one maximum value; the value zero (*A*=0) indicates that the population is composed of a single species and a single floor; A_{max} is the maximum value for each species per stratum, reached when all taxa are present in the same proportion in a stratum or stand (Corral *et al.*, 2005; Manzanilla *et al.*, 2020). The following Equation was used for calculating the index:

$$A = -\sum_{i=1}^{s}\sum_{j=1}^{z} P_{ij} \times ln(P_{ij}) \qquad (2)$$

$$A_{max} = ln(S \times Z) \qquad (3)$$

$$A_{rel} = \frac{A}{ln(S\times Z)} \times 100 \qquad (4)$$

Where:

A = Vertical distribution index

P_{ij} = Percentage of species in each zone, estimated using ($ni;\frac{j}{N}$)

ni;j = Number of individuals of species *i* in stratum *j*

A_{max} = Derived from the *A* index, it represents the maximum value of *A*, determined by the number of species and height areas

S = Number of species present

Z = Number of strata in relation to the height

N = Total number of individuals

A_{rel} = Percentage of standardization of the A index

The similarity of the species composition was estimated through the calculation of the similarity of the taxa present using the Sørensen's qualitative similarity index (Sc) (Equation 5) proposed by Magurran (2004).

$$Sc\,\% = \frac{2c}{a+b} \times 100 \qquad (5)$$

Where:

Sc %= Similarity coefficient

a and b = Number of unique species at each site

c = Number of species in common between the two sites

Volume was estimated using the Equation described in the Forest Biometric System for the management of the forests of Mexico (*Sibifor*, in Spanish) in the state of *Guerrero* (Equation 6) and applying the estimators established for each species (Table 1). This system is considered a portfolio of reliable equations for calculating volumetric stocks (Vargas-Larreta *et al.*, 2017).

$$V = a0 \times d^{a1} \times h^{a2} \qquad (6)$$

Where:

V = Total roll volume of tree with bark *a0*, *a1*, and *a2* = Parameters of the model

d = Diameter

h = Height

Table 1. Parameters of the models applied for volume estimation by species.

Parameter	Estimator			
	***Pinus pseudostrobus* Lindl.**	***Pinus douglasiana* Martínez**	***Pinus herrerae* Martínez**	***Pinus teocote* Schltdl. & Cham.**
a0	0.0000594	0.0000333	0.0000531	0.0000822
a1	1.7990181	1.8478799	1.898198	1.9270973
a2	1.0437044	1.1923615	0.972669	0.7849548

The analysis of data collected in the field was processed in an Excel® spreadsheet, and in order to detect differences between variables by exposure, a Student's *t*-test was performed using IBM SPSS Statistics 20.0 software (SPSS, 2011).

Results and Discussion

The pine forest of the community of *Cochoapa El Grande*, *Guerrero* is dominated by four species of the Pinaceae family: *Pinus douglasiana* Martínez, *P. herrerae* Martínez, *P. pseudostrobus* Lindl. y *P. teocote* Schltdl. & Cham. In several studies, the genus *Pinus* has been cited as one of the most widely distributed in the forests of Mexico (López-Hernández *et al.*, 2017; Rendón-Pérez *et al.*, 2021; Caballero *et al.*, 2022; García-García *et al.*, 2023).

The number of *Pinus* species recorded in this research agrees with the results of Caballero *et al.* (2022), who identified five taxa in temperate forests in the center of the country, and with Rendón-Pérez *et al.* (2021) who mention only three species in the Southeastern part of the state of *Hidalgo*.

Horizontal structure

An average density of 810 ind ha^{-1} was estimated in the forest. The SE exposure had 1 040 ind ha^{-1} of four taxa of the genus *Pinus*, while in the NW exposure there were 580 ind ha^{-1} with three species (Table 1). *P. pseudostrobus* was the most abundant in the two exposures with 520 and 830 ind ha^{-1}, respectively; followed by *P. douglasiana* (113 ind ha^{-1}) and *P. herrerae* (57 ind ha^{-1}); these values are higher than those estimated by Silva-García *et al.* (2022), who documented a high density of 600 and 344 ind ha^{-1} for *P. arizonica* Engelm. in two exposures (North and South) in a temperate forest in the state of *Durango*. Barrios-Calderón *et al.* (2022) counted 533 ind ha^{-1} for *P. maximinoi* H. E. Moore in a *Pinus*-*Quercus* forest in *Chiapas*. In the locality of *Pueblo Nuevo*, *Durango*, Silva-García *et al.* (2021) recorded 40, 23, and 22 ind ha^{-1}, respectively, of *P. durangensis* Martínez, *P. herrerae* and *P. douglasiana*; these are low numbers compared to those obtained in the present study.

In terms of the dominance estimated by basimetric area, the Northwest exposure had the highest value (39.80 m^2 ha^{-1}) (Table 2). *P. pseudostrobus* had figures above 38.18 m^2 ha^{-1}, which is higher than those cited in other studies for the same species: Graciano-Ávila *et al.* (2017), for the Southwest of the state of *Durango*, and Ramos *et al.* (2017) and Manzanilla *et al.* (2020), who estimated in pine and pine-oak forests in the *Galeana* municipality, state of *Nuevo León*, 23.54, 4.94, and 10.25 m^2 ha^{-1}, respectively. The Southeast exposure presented 25.30 m^2 ha^{-1} of dominance, with 19.26 m^2 ha^{-1} for *P. pseudostrobus*, the most dominant species for this exposure; while, *P. douglasiana* had 3.98 m^2 ha^{-1}, which is higher than 1.10 m^2 ha^{-1} estimated by Silva-García *et al.* (2021) in Southern *Durango* state.

Table 2. Estimated structural parameters for each species per exposure (NW and SE).

Exp.	Species	Abundance		Dominance		Frequency		*IVI*
		Absolute *N* ha^{-1}	Relative *Ar* %	Absolute m^2 ha^{-1}	Relative *Dr i* %	Absolute sites	Relative %	
NW	*Pinus pseudostrobus* Lindl.	520	89.66	38.18	95.93	6	75	86.86
	Pinus herrerae Martínez	57	9.77	1.25	3.13	1	12.5	8.47
	Pinus teocote Schltdl. & Cham.	3	0.57	0.37	0.94	1	12.5	4.67
	Total	580	100	39.80	100	8	100	100
SE	*Pinus pseudostrobus* Lindl.	830	79.81	19.26	76.13	5	50	68.65
	Pinus douglasiana Martínez	113	10.90	3.98	15.72	2	20	15.54
	Pinus herrerae Martínez	90	8.65	1.27	5.04	2	20	11.23
	Pinus teocote Schltdl. & Cham.	7	0.64	0.79	3.10	1	10	4.58
	Total	1 040	100	25.30	100	10	100	100

Exp. = Exposure.

The species with the lowest dominance was *P. teocote* with 0.37 and 0.79 m^2 ha^{-1} in the two exposures of the present study (Table 2), but higher than that reported by Caballero *et al.* (2022) for pine forest (0.02) and alder-pine forest (0.07) in the state of *Puebla*.

The species with the lowest Importance Value Index (*IVI*) was *P. teocote* with 4.67 to 4.58 %, while the highest *IVI* corresponded to *P. pseudostrobus*, with 86.86 % in the Northwest exposure and 68.65 % in the Southeastern exposure (Table 2); these are values close to those recorded by Ramos *et al.* (2017) of 78 % for the same species in a burned area and by Mora-Donjuán *et al.* (2017) for *Quercus elliptica* Née in an oak forest in *Guerrero*. Manzanilla *et al.* (2020) report an *IVI* of 27.67 and 12.18 % for *P. pseudostrobus* at two sites with Northeastern exposure —figures higher than the 7 % considered for *P. patula* Schltdl. & Cham. forest in *Ixtlán de Juárez*, *Oaxa*ca (Castellanos-Bolaños *et al.*, 2008).

Vertical structure (Pretzsch)

Based on Pretzsch's Vertical Distribution Index, three height strata were defined for the two exposures: Stratum I or upper (>80 % of maximum height), Stratum II or medium (between 50-80 %), and Stratum III or low (up to 50 %).

NW exposure. The maximum height ranged from 26.7 to 33 m, with *P. pseudostrobus* (a species present in all three strata) dominating with 36 individuals; *P. teocote* registered only one individual of 28.5 m in height. The middle Stratum consisted of *P. pseudostrobus* and *P. herrerae*, with heights ranging between 17 and 26.4 m, and the lower Stratum had heights ranging from 11.3 to 16.5 m (Table 3).

Table 3. Values of the Pretzsch vertical index for the study area.

Exposure	Stratum	Species	Ind. No.	*H* (m)		Pretzsch index			
				Max	Min	$\bar{x}$	*A*	A_{max}	A_{rel} %
NW	I	*Pinus pseudostrobus* Lindl.	36	33	26.7	29.9	1.30	2.20	59.08
		Pinus teocote Schltdl. & Cham.	1	28.5	28.5				

	II	*Pinus pseudostrobus* Lindl.	87	26.4	17	21.7			
		Pinus herrerae Martínez	13	25	17	21			
	III	*Pinus pseudostrobus* Lindl.	33	16.5	6	11.3			
		Pinus herrerae Martínez	4	16	11.2	13.6			
	Total		174	145.4	106.4	97.4			
SE	I	*Pinus douglasiana* Martínez	3	29.7	28.4	29.1	1.26	2.48	50.69
		Pinus pseudostrobus Lindl.	3	34	27.5	30.8			
	II	*Pinus douglasiana* Martínez	7	26.3	18.2	22.3			
		Pinus herrerae Martínez	1	18	18	18			
		Pinus pseudostrobus Lindl.	60	27	17.4	22.2			
		Pinus teocote Schltdl. & Cham.	1	23.5		11.8			
	III	*Pinus douglasiana* Martínez	24	16.5	3.6	10.1			
		Pinus herrerae Martínez	26	16	3.7	9.9			
		Pinus pseudostrobus Lindl.	186	17	3	10			
		Pinus teocote Schltdl. & Cham.	1	16.3	16.3	16.3			
	Total		312	224.3	136.1	180.2			

SE exposure. In Stratum I, *P. pseudostrobus* and *P. douglasiana* were recorded with heights ranging between 27.5 and 34 m (six individuals), while the middle Stratum consisted of four taxa —*P. pseudostrobus*, *P. douglasiana*, *P. herrerae* and *P. teocote*—, with a range of 17.4 to 27 m, and the lower Stratum (3 to 17 m), of 237 individuals of the same species (Table 3).

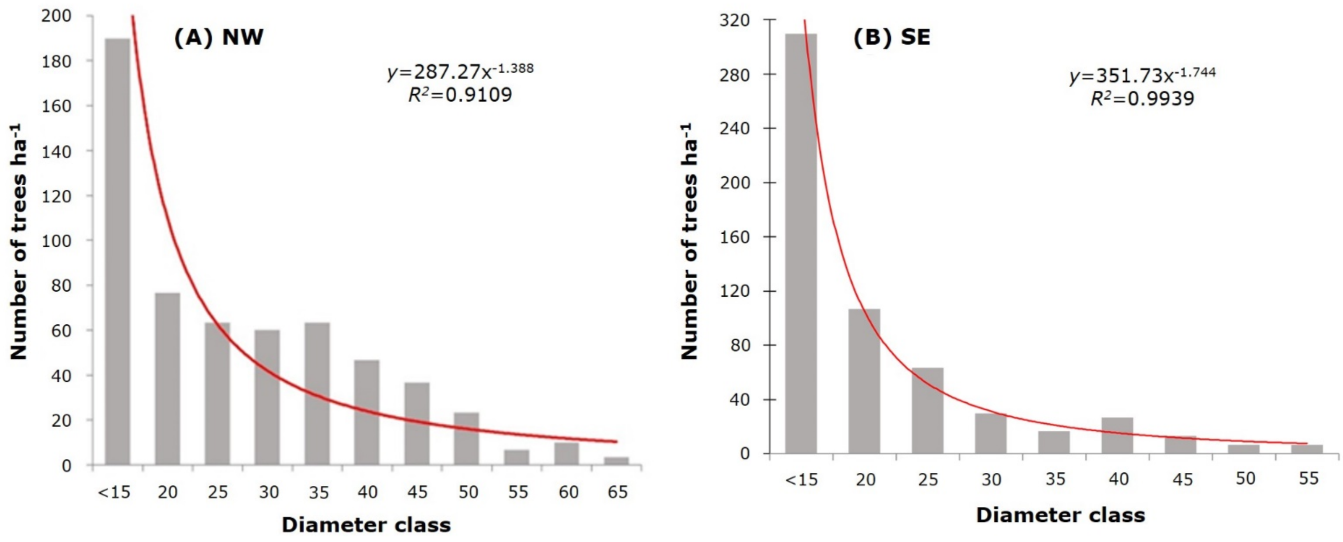
Lamprecht (1990) points out that there are taxa with a behavior of continuous distribution; a clear example is *P. pseudostrobus*, a species with vertical distribution in the three strata for the two exposures studied, and on the SE slope, *P.*

douglasiana showed a continuous behavior. According to results, these taxa are assured of their permanence in the composition and structure, as they are distributed in the three strata of the forest (Acosta *et al.*, 2006).

The NW exposure presented relatively higher values for the Pretzsch index A=1.30, 2.20 A_{max}, and 59.08 % of A_{rel}, with respect to the SE whose recorded values were A=1.26, 2.48 A_{max} and 50.60 % A_{rel} (Table 3). These values are close to those estimated by Mora-Donjuán *et al.* (2017) for an oak forest in the *Sierra Madre del Sur* of the state of *Guerrero* and by Rubio *et al.* (2014), with A=2.01-1.86, A_{max}=3.74-3.30 and A_{rel}=54-56 % at P-1 and P-2, respectively, in pine-oak forest in the Southeast of *Nuevo León*. Therefore, Flores-Morales *et al.* (2022) point out that A_{rel} close to 100 % indicate that all species are equally distributed in the three height strata; this result is similar to that obtained in the present research.

Diameter characterization

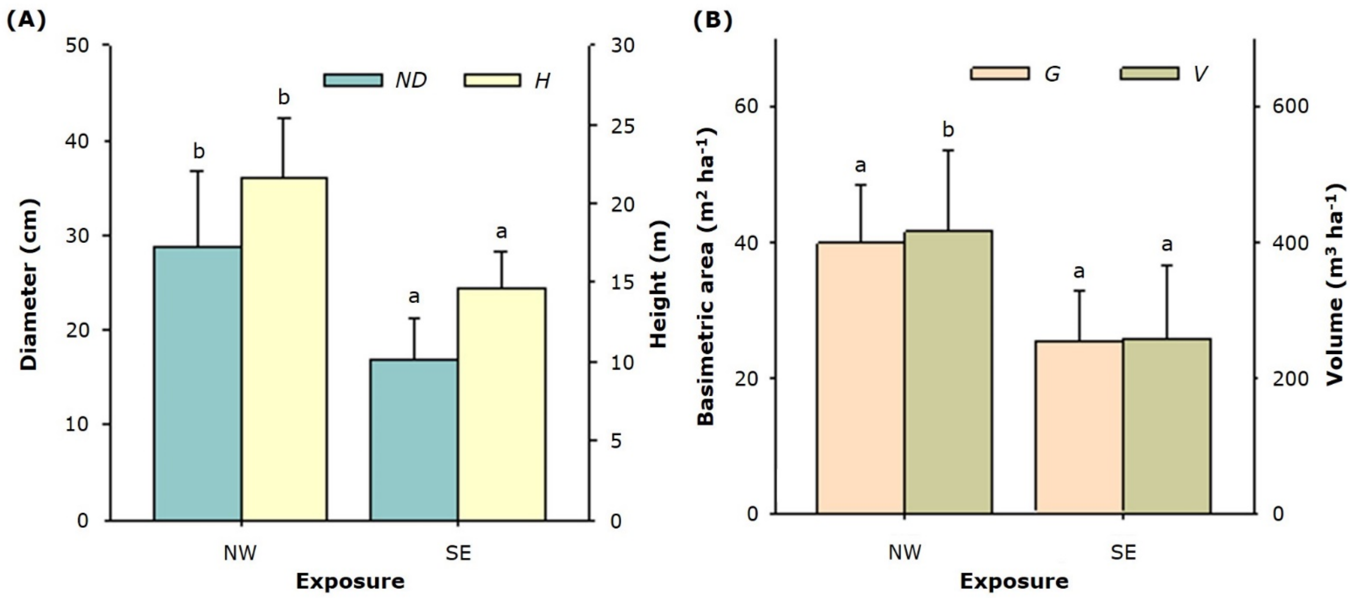
Based on the mensuration characterization (cm) in the two exposures, SE exhibited a high value of R^2=0.99, with 310 ind ha^{-1} for the <15 cm category; for ND<55 cm only seven individuals were observed (Figure 2B). Likewise, in the NW (R^2=0.91), there was a greater number of individuals in the <15 cm diameter class (190 ind ha^{-1}), and only three trees had values of 65 cm (Figure 2A). Based on the data analysis, an asymmetric behavior was observed to the left, resulting in an inverted *J*-shaped structure, with a dominance of young trees and a decrease of large diameter trees (due to anthropic causes); this shows a high regeneration rate of the forest, which will eventually replace the trees with larger diameters. The R^2 value is similar to that recorded by López-Hernández *et al.* (2017) in a forest in the state of *Puebla* (R^2=0.96). Other studies have documented that the behavior of the curve is characteristic of temperate forests in various states of the country (Manzanilla *et al.*, 2020; Caballero *et al.*, 2022; García-García *et al.*, 2023).



A = NW exposure; B = SE exposure.

Figure 2. Distribution of diameter classes by exposure in a pine forest in *Cochoapa El Grande*, *Guerrero*, Mexico.

The mensuration variables were higher in the NW exposure with *ND*=28.76 cm, *H*=21.6 m, *G*=39.8 m^2 ha^{-1}, and *V*=415.15 m^3 ha^{-1}; in the SE exposure, values of *ND*=16.9 cm, *H*=14.7 m, *G*=25.3 m^2 ha^{-1} and *V*=225.21 m^3 ha^{-1} were recorded, with *p* values <0.05 according to Student's *t*-test for comparison of means (Figure 3). The results are consistent with the assumption that the Northeast exposure provides favorable temperature and humidity conditions for species development (Manzanilla *et al.*, 2020), and lower water deficit and plant evapotranspiration (López-Gómez *et al.*, 2012).



A = Diameter and height; B = Basimetric area and volume of two exposures. Mean values±standard deviation. Different letters indicate significant differences.

Figure 3. Comparison of *t*-means for mensuration variables.

Sørensen's qualitative similarity index estimated 85.71 % of shared species in both exposures (NW and SE), indicating 86 % similarity in plant composition. This value resembles that described by Buendía-Rodríguez *et al.* (2019) with >80 % in a Northeast exposure for a pine-oak forest in the state of *Nuevo León*.

Conclusions

The results for the *Pinus* forest in *Cochoapa El Grande*, *Guerrero*, show a better normal diameter, total height, and basimetric area in the Northwest exposure due to the presence of favorable conditions of temperature and humidity, which favor a lower water deficit of the species. *Pinus pseudostrobus* presents the highest Importance Value Index, with 86.86 and 68.85 % in the Northwest and Southeast exposure, respectively. The species composition exhibits very similar values.

The Pretzsch index allows us to visualize the height distribution of the trees in the area. The diameter distribution indicates that the forest is made up of young or regenerating trees, which will eventually replace the long-lived individuals on the site. In order to carry out works focused on the structure and composition of forests, will allow to know the changes through time and will favor the implementation of strategies for the sustainable management of forest resources.

Acknowledgments

The authors are sincerely grateful to the Commissioner and residents of the community of *Cochoapa El Grande* for their access and availability to carry out the field work, as well as to the field brigade.

Conflict of interest

The authors declare that they have no conflict of interest. Eduardo Alanís-Rodríguez declares not to have participated in the editorial process of the manuscript.

Contribution by author

Beatriz Calleja-Peláez: study design, analysis, and drafting of the manuscript; Bernardo López-López: fieldwork planning, statistical analysis, and revision of the manuscript; Eduardo Alanís-Rodríguez: study design and review of the manuscript;

Ricardo Telles-Antonio and Marco Aurelio González-Tagle: revision of the manuscript; Josafat Cano-Abad: field data collection.

References

Acosta, V. H., P. A. Araujo y M. C. Iturre. 2006. Caracteres estructurales de las masas. Facultad de Ciencias Forestales de la Universidad Autónoma de Santiago del Estero. Santiago del Estero, JFB, Argentina. 35 p. https://fcf.unse.edu.ar/archivos/series-didacticas/SD-22-Caracteres-estructurales-ACOSTA.pdf. (15 de noviembre de 2023).

Aguirre, O., G. Hui, K. von Gadow and J. Jiménez. 2003. An analysis of spatial forest structure using neighbourhood-based variables. Forest Ecology and Management 183(1-3):137-145. Doi: 10.1016/S0378-1127(03)00102-6.

Aguirre-Calderón, O. A. 2015. Manejo Forestal en el Siglo XXI. Madera y Bosques 21:17-28. Doi: 10.21829/myb.2015.210423.

Alanís R., E., A. Mora O. y J. S. Marroquín de la F. 2020. Muestreo ecologico de la vegetacion. Universidad Autónoma de Nuevo León. Monterrey, NL, México. 204 p.

Barrios-Calderón, R. de J., J. E. Pérez P., J. R. Torres V. y J. F. Aguirre-Cadena. 2022. Estructura y composición florística de un bosque de *Pinus*-*Quercus* en El Porvenir, Chiapas. Revista Mexicana de Ciencias Forestales 13(73):50-74. Doi: 10.29298/rmcf.v13i73.1252.

Buendía-Rodríguez, E., E. J. Treviño-Garza, E. Alanís-Rodríguez, O. A. Aguirre-Calderón, M. A. González-Tagle y M. Pompa-García. 2019. Estructura de un ecosistema forestal y su relación con el contenido de carbono en el noreste de México. Revista Mexicana de Ciencias Forestales 10(54):4-25. Doi: 10.29298/rmcf.v10i54.149.

Caballero C., P., E. J. Treviño G., J. M. Mata B., E. Alanís R., J. I. Yerena Y. y L. G.

Cuéllar R. 2022. Análisis de la estructura y diversidad arbórea de bosques templados en la ladera oriental del volcan Iztaccihuatl, Mexico. Revista Mexicana de Ciencias Forestales 13(71):76-102. Doi: 10.29298/rmcf.v13i71.1253.

Castellanos-Bolaños, J. F., E. J. Treviño-Garza, Ó. A. Aguirre-Calderón, J. Jiménez-Pérez, M. Musalem-Santiago y R. López-Aguillón. 2008. Estructura de bosques de pino pátula bajo manejo en Ixtlán de Juárez, Oaxaca, México. Madera y Bosques 14(2):51-63. Doi: 10.21829/myb.2008.1421212.

Challenger, A. y J. Soberón. 2008. Los ecosistemas terrestres. *In*: Sarukhán, J. (Comp.). Capital Natural de México, vol. 1. Conocimiento actual de la biodiversidad. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (Conabio). Tlalpan, D. F., México. pp. 87-108.

Comisión Nacional Forestal (Conafor). 2020. *México con alto grado de vegetación nativa*. https://www.gob.mx/conafor/articulos/mexico-con-alto-grado-de-vegetacion-nativa?idiom=es#:~:text=Datos%20del%20Inventario%20Nacional%20Forestal,pertenecen%20a%20la%20vegetaci%C3%B3n%20primaria. (3 de noviembre de 2023).

Corral R., J. J., O. A. Aguirre C., J. Jiménez P. y S. Corral R. 2005. Un análisis del efecto del aprovechamiento forestal sobre la diversidad estructural en el bosque mesófilo de montaña «El Cielo», Tamaulipas, México. Investigación Agraria: Sistemas y Recursos Forestales 14(2):217-228. Doi: 10.5424/srf/2005142-00885.

Delgado Z., D. A., S. A. Heynes S., M. D. Mares Q., N. L. Piedra L., … y L. Ruacho-González. 2016. Diversidad y estructura arbórea de dos rodales en Pueblo Nuevo, Durango. Revista Mexicana de Ciencias Forestales 7(33):94-107. https://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S2007-11322016000100094. (13 de diciembre de 2023).

Farjon, A., J. A. Pérez de la R. and B. T. Styles. 1997. A field guide to the pines of Mexico and Central America. Royal Botanic Gardens. Richmond, LDN, England. 147 p.

Flores-Morales, E. A., O. A. Aguirre-Calderón, E. J. Treviño-Garza, M. A. González-Tagle, ... y F. Huizar-Amezcua. 2022. Diversidad y estructura arbórea de un bosque templado bajo manejo en el municipio de Pueblo Nuevo, Durango, México.

Polibotánica (54):11-26. Doi: 10.18387/polibotanica.54.2.

García-García, S. A., E. Alanís-Rodríguez, Ó. A. Aguirre C., E. J. Treviño-Garza, L. G. Cuéllar-Rodríguez y A. Collantes C. 2023. Composición, estructura y estado de la regeneración arbórea en un gradiente altitudinal en un bosque templado de Guadalupe y Calvo, Chihuahua. Polibotánica (56):81-100. Doi: 10.18387/polibotanica.56.5.

Graciano-Ávila, G., Ó. A. Aguirre-Calderón, E. Alanís-Rodríguez y J. E. Lujan-Soto. 2017. Composición, estructura y diversidad de especies arbóreas en un bosque templado del Noroeste de México. Ecosistemas y Recursos Agropecuarios 4(12):535-542. Doi: 10.19136/era.a4n12.1114.

Hernández-Salas, J., Ó. A. Aguirre-Calderón, E. Alanís-Rodríguez, J. Jiménez-Pérez, … y L. A. Domínguez-Pereda. 2013. Efecto del manejo forestal en la diversidad y composición arbórea de un bosque templado del noroeste de México. Revista Chapingo Serie Ciencias Forestales y del Ambiente 19(2):189-199. Doi: 10.5154/r.rchscfa.2012.08.052.

Instituto Nacional de Estadística y Geografía (INEGI). 2008. Conjunto de datos vectoriales escala 1:1 000 000. Unidades climáticas (2008). https://www.inegi.org.mx/app/biblioteca/ficha.html?upc=702825267568. (28 de noviembre 2023).

Instituto Nacional de Estadística y Geografía (INEGI). 2010. Compendio de información geográfica municipal de los Estados Unidos Mexicanos, Cochoapa el Grande, Guerrero. Clave geoestadística 12078. INEGI. Aguascalientes, Ags., México. 9 p. https://www.inegi.org.mx/contenidos/app/mexicocifras/datos_geograficos/12/12078.pdf. (28 de noviembre de 2023).

Lamprecht, H. 1990*.* Silvicultura en los trópicos. Los ecosistemas forestales en los bosques tropicales y sus especies arbóreas. Posibilidades para un aprovechamiento sostenido*.* Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ). Eschborn, HE, Alemania. 335 p.

López-Gómez, V., P. Zedillo-Avelleyra, S. Anaya-Hong, E. González-Lozada y Z. Cano-Santana. 2012. Efecto de la orientación de la ladera sobre la estructura poblacional y ecomorfología de *Neobuxbaumia tetetzo* (Cactaceae). Botanical Sciences 90(4):453-457. https://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S2007-42982012000400005. (20 de enero de 2024).

López-Hernández, J. A., O. A. Aguirre-Calderón, E. Alanís-Rodríguez, J. C. Monarrez-González, M. A. González-Tagle y J. Jiménez-Pérez. 2017. Composicion y diversidad de especies forestales en bosques templados de Puebla, México. Maderas y Bosques 23(1):39-51. Doi: 10.21829/myb.2017.2311518.

Magurran, A. E. 2004. Measuring biological diversity. Blackwell Publishing Company. Oxford, OX, United Kingdom. 256 p.

Manzanilla Q., G. E., J. M. Mata B., E. J. Treviño G., Ó. A. Aguirre C., E. Alanís R. y J. I. Yerena Y. 2020. Diversidad, estructura y composición florística de bosques templados del sur de Nuevo León. Revista Mexicana de Ciencias Forestales 11(61):94-123. Doi: 10.29298/rmcf.v11i61.703.

Mora-Donjuán, C. A., O. N. Burbano-Vargas, C. Méndez-Osorio y D. F. Castro-Rojas. 2017. Evaluación de la biodiversidad y caracterización estructural de un Bosque de Encino (*Quercus* L.) en la Sierra Madre del Sur, México. Revista Forestal Mesoamericana Kurú 14(35):68-75. https://revistas.tec.ac.cr/index.php/kuru/article/view/3154. (25 de noviembre de 2023).

Mostacedo, B. y T. S. Fredericksen. 2000. Manual de métodos básicos de muestreo y análisis en Ecología Vegetal. El País y Proyecto de Manejo Forestal Sostenible (Bolfor). Santa Cruz de la Sierra, S, Bolivia. 87 p. http://www.bio-nica.info/biblioteca/mostacedo2000ecologiavegetal.pdf. (26 de noviembre de 2023).

Organización de las Naciones Unidas para la Aimentacion y la Agricultura (ONUAA) y Programa de las Naciones Unidas para el Medio Ambiente (PNUMA). 2020. El estado de los bosques del mundo 2020. Los bosques, la biodiversidad y las personas. ONUAA y PNUMA. Roma, RM, Italia. 197 p.

Pretzsch, H. 1998. Structural diversity as a result of silvicultural operations. Lesnictví-Forestry 44(10):429-439. https://www.waldwachstum.wzw.tum.de/fileadmin/publications/457.pdf. (25 de septiembre de 2023).

Ramos R., J. C., E. J. Treviño G., E. Buendía R., O. A. Aguirre C. y J. I. López M. 2017. Productividad y estructura vertical de un bosque templado con incidencia de incendios forestales. Revista Mexicana de Ciencias Forestales 8(43):64-88. https://cienciasforestales.inifap.gob.mx/index.php/forestales/article/view/66. (25 de noviembre de 2023).

Rendón-Pérez, M. A., P. Hernández-de la Rosa, A. Velázquez-Martínez, J. L. Alcántara-Carbajal y V. J. Reyes-Hernández. 2021. Composición, diversidad y estructura de un bosque manejado del centro de México. Madera y Bosques 27(1):1-19. Doi: 10.21829/myb.2021.2712127.

Rubio C., E. A., M. A. González T., J. Jiménez P., E. Alanís R. y D. Y. Ávila F. 2014. Diversidad y distribución vertical de especies vegetales mediante el Índice de Pretzsch. Ciencia UANL 17(65):34-41. https://cienciauanl.uanl.mx/?p=799. (25 de noviembre de 2023).

Silva-García, J. E., O. A. Aguirre-Calderón, E. Alanís-Rodríguez, E. Jurado-Ybarra, J. Jiménez-Pérez y B. Vargas-Larreta. 2021. Estructura y diversidad de especies arbóreas en un bosque templado del Noroeste de México. Polibotánica (52):89-102. Doi: 10.18387/polibotanica.52.7.

Silva-García, J. E., O. A. Aguirre-Calderón, E. Alanís-Rodríguez, E. Jurado-Ybarra, … y J. J. Corral R. 2022. Influencia de la altitud y exposición en la estructura y composición de un bosque templado en Durango. Revista Mexicana de Ciencias Forestales 13(70):64-84. Doi: 10.29298/rmcf.v13i70.1163.

Statistical Package for the Social Science (SPSS). 2011. IBM SPSS Statistics for

Windows. Version 20.0. IBM Corp. New York, NY, United States of America.

Vargas-Larreta, B., J. J. Corral-Rivas, O. A. Aguirre-Calderón, J. O. López-Martínez, … and C. G. Aguirre-Calderón. 2017. SiBiFor: Forest Biometric System for forest management in Mexico. Revista Chapingo Serie Ciencias Forestales y del Ambiente 23(3):437-455. Doi: 10.5154/r.rchscfa.2017.06.040.