

interest in some specific areas (Návar-Cháidez and González-Elizondo, 2009; Aragón-Piña *et al.*, 2010; Hernández-Salas *et al.*, 2013; Graciano-Ávila *et al.*, 2017). However, these investigations have focused mainly on assessing the composition and horizontal structure, so it is necessary to direct attention to species of high conservation and restricted distribution interest to analyze their regeneration and vertical structure. Therefore, the objective of this study was to determine the richness and diversity of species present in the community, as well as its vertical structure to know the behavior of different tree species and their regeneration in a forest of *Pseudotsuga menziesii* in Chihuahua State.

Materials and Methods

Study area

Fieldwork was carried out in a mixed forest consisting mainly of *Pseudotsuga menziesii*, *Pinus arizonica* Engelm. and *Quercus tuberculata* Liebm.; in the place known as *El Triste*, which is located within the *Chinatú ejido*, *Guadalupe* and *Calvo* municipality, southwest of the state of *Chihuahua* between 40°00'00" - 80°00'00" N and 40°00'00" - 160°00'00" W (Figure 1).

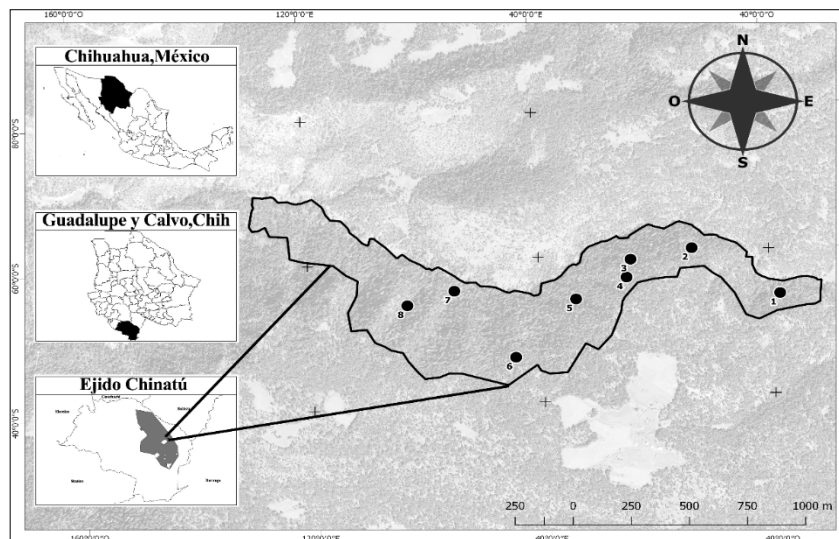


Figure 1. Location of the study area and sampling sites.

Table 1. Pretzsch Index (*A*).

Index/Equation	Description
$A = \sum_{i=1}^S \sum_{j=1}^Z p_{ij} * \ln p_{ij}$	S= Number of present species Z= Number of height strata P_{ij} = Percentage of species in each zone $P_{ij} = n_{ij}/N$
$A_{max} = \ln(S * Z)$	$N_{i,j}$ = Number of individuals of the same species (<i>i</i>) in the zone (<i>j</i>)
$A_{rel} = \frac{A}{\ln(S*Z)} * 100$	N= Total number of individuals

Abundance was determined for each of the strata according to the number of individuals present ($N \text{ ha}^{-1}$), the average, minimum, maximum value and coefficient of variation obtained from the height and diameter variables. The diversity of the plant community was assessed using the Shannon-Weiner index (H') (Shannon, 1948), Margalef index (D_{Mg}) (Magurran, 2004) and true diversity (D), which allows a better comparison of the richness of species (Jost, 2006) (Table 2).

Table 2. Species richness and diversity indexes.

Index	Equation	Description
Margalef (D_{Mg})	$D_{Mg} = \frac{(S - 1)}{\ln(N)}$	S= Number of species N=Total number of individuals
Shannon-Weiner (H')	$H' = \sum_{i=1}^S p_i \times \ln(p_i)$ $p_i = n_i / N$	S= Number of species P_i = Rate of individuals of the <i>i</i> species
True diversity (D)	$D = \exp(H') = \exp \left[\sum_{i=1}^S p_i \ln p_i \right]$	p_i = Relative abundance of the <i>i</i> - ^{eth} species S= Number of species

The above figures are similar to those reported by Méndez *et al.* (2014) who calculated an $A = 2.07$ with $A_{max} = 2.70$, and by Jiménez *et al.* (2001) that recorded an $A = 2.07$ and $A_{max} = 3.50$; both in mixed coniferous and broadleaved forests. This vertical distribution analysis showed that as tree height increases, species diversity decreases. Such authors mentioned that the greatest biological heterogeneity was presented as the zone of the strata decreases.

Regeneration in stratum I has 1.01 % of the individuals, II, 4.02 % and III, 94.97 % (Table 3). According to Lamprecht (1990), the species present in all strata are defined as species with continuous vertical distribution (DVC); *P. arizonica* presented this distribution as it was registered in the three strata (Table 3). The trees behaved in a similar way (Table 3) since stratum I had 2.72 % of the individuals, II with 28.26 % and III with 69.02 %, similar percentages to those reported by Jiménez *et al.* (2001) who evaluated a multicohortal forest of *Pinus - Quercus* in northeastern Mexico. The species with DVC in the tree stratum were *Q. tuberculata*, *P. menziesii* and *Abies durangensis* (Table 4).

Table 3. Number and percentage of individuals present in the stages of regeneration and adult trees.

Stratum	Regeneration		Trees	
	Number of individuals	% of individuals	Number of individuals	% of individuals
I	2	1.01	13	2.72
II	8	4.02	130	28.26
III	189	94.97	318	69.02
Total	199	100.00	461	100.00

Abundance. *Q. tuberculata* and *P. arizonica* shared stratum I of the regeneration with 1 N ha⁻¹ each; in stratum II, *Q. tuberculata* did not appear, *P. menziesii* was present with 5 N ha⁻¹, *P. arizonica* with 4 N ha⁻¹ and *Juniperus deppeana* Steud. 1 N ha⁻¹. In stratum III, eight species were identified, of which the most abundant were *Abies durangensis* with 75 N ha⁻¹, *J. deppeana* with 65 N ha⁻¹, *Q. tuberculata* with 34 N ha⁻¹ and *P. menziesii* with 30 N ha⁻¹ (Table 4). The most abundant species in this forest without disturbance are from the Pinaceae family, which coincides with the results of Méndez (2014), which should be treated with reservation because their data comes from a post-fire evaluation. In this type of forest with disturbance, up to 812 N ha⁻¹ (Alanís *et al.*, 2011), and 3 400 N ha⁻¹ (González-Tagle *et al.*, 2008) are recorded with a higher frequency of Fagaceae.

It was observed that all species in regeneration have a presence in the woodland, in addition *Arbutus xalapensis* Kunth appears with 43 N ha⁻¹ in stratum III. The forest has a greater abundance of *P. menziesii* than in stratum I of the woodland obtained 8 N ha⁻¹, *Q. tuberculata* and *Abies durangensis* 3 N ha⁻¹; stratum II was integrated by nine species of which *P. menziesii* stand out with 58 N ha⁻¹, *P. arizonica* with 28 N ha⁻¹ and *Q. tuberculata* with 13 N ha⁻¹ and in stratum III, 10 species were recorded, the most abundant of which were *P. menziesii* with 89 N ha⁻¹, *P. arizonica* with 55 N ha⁻¹, *Arbutus xalapensis* with 43 N ha⁻¹ and *Q. tuberculata* with 33 N ha⁻¹ (Table 4). This is consistent with Camacho *et al.* (2014) who reported greater biological diversity in stratum III, of a pine-oak forest in *Nuevo León*, Mexico.

Regeneration and tree variables. Regeneration in stratum I showed an average crown diameter (Coverage) of 3.40 m and an average height of 7.5 m; in stratum II, the average cup was 2.27 m, while the height was 4.27 m; and, stratum III averaged a cup diameter of 1.37 m with an average height of 1.32 m. The tallest individuals came from *P. arizonica* with 1.62 m and *Quercus sideroxylla* Humb. & Bonpl with 1.60 m (Table 4).

Table 5. Results of abundance ($N\ ha^{-1}$), normal diameter (cm), canopy cover (m) and height (m) of the species in the different strata considered for the Pretzsch index (A) and index of Shannon (H') and true diversity index (D) of the strata in the mature vegetal community.

Stratum	Species	Abundance			Normal diameter			Canopy cover			Height			H'	D
		$N\ ha^{-1}$	\bar{X}	CV	Min	Max	CV	\bar{X}	Min	Max	CV	Min	Max		
I	<i>PsMe</i>	8	42.92	38	23.20	63.50	8.47	4.35	10.95	43	24.15	23.10	26.30	0.12	1.13
	<i>QuTu</i>	3	53.67	36	34.00	73.00	14.43	10.20	18.65	0	24.00	22.00	26.00		
	<i>AbDu</i>	3	45.15	54	28.00	62.30	10.85	7.95	13.75	57	27.20	25.40	29.00		
	Subtotal	13													
II	<i>PsMe</i>	58	27.89	52	11.30	94.00	5.77	1.93	9.95	41	16.22	13.90	20.50	0.81	2.26
	<i>PiAr</i>	28	29.74	54	14.40	53.00	6.11	2.90	10.85	40	16.10	13.80	20.00		
	<i>QuTu</i>	13	29.80	54	20.50	88.50	7.51	3.60	4.80	39	15.55	13.80	17.80		
	<i>AbDu</i>	16	26.80	45	13.00	39.50	6.61	4.85	9.25	40	15.95	14.00	20.10		
	<i>PiAy</i>	6	29.80	50	16.20	46.00	9.29	5.00	13.20	43	18.28	14.80	21.30		
	<i>PiDu</i>	4	50.83	20	42.50	62.00	7.55	6.65	8.15	28	18.57	14.80	21.60		
	<i>QuSi</i>	3	26.43	47	28.00	38.00	6.98	5.15	8.80	45	14.20	14.10	14.30		
	<i>PiCh</i>	3	35.37	27	25.80	35.70	6.31	5.45	7.18	30	16.60	16.30	16.90		
	<i>JuDe</i>	1	53.50	0	53.50	53.50	8.85	8.85	8.85	0	17.80	17.80	17.80		
Subtotal	130														
III	<i>PsMe</i>	89	16.55	59	7.50	42.00	4.62	2.40	10.20	40	9.20	4.40	13.50	1.64	5.15
	<i>PiAr</i>	55	16.72	59	7.80	34.30	3.46	1.60	8.20	40	8.40	2.30	13.50		
	<i>ArXa</i>	43	18.48	63	7.50	82.40	5.51	2.00	9.10	45	7.54	3.50	12.00		
	<i>QuTu</i>	33	17.16	61	8.00	64.00	5.97	2.00	15.75	41	8.29	3.10	13.50		
	<i>JuDe</i>	36	17.81	60	8.00	31.50	3.83	1.90	6.90	41	5.45	2.00	12.00		
	<i>PiAy</i>	15	16.44	61	7.70	24.10	4.25	2.50	6.10	40	7.57	4.30	11.30		
	<i>AbDu</i>	21	17.10	60	9.60	22.00	5.33	3.45	7.50	41	11.01	7.50	13.50		
	<i>QuSi</i>	14	17.29	62	9.00	22.50	5.24	3.55	7.65	41	8.45	3.50	12.90		
	<i>PiCh</i>	11	16.72	34	8.70	31.60	4.58	2.65	6.30	28	10.16	7.50	13.40		
	<i>PiDu</i>	1	12.50	0	12.50	12.50	3.65	3.65	3.65	0	9.80	9.80	9.80		
	Subtotal	318													
Total	460														

Psme = *Pseudotsuga menziesii* (Mirb.) Franco; *Qutu* = *Quercus tuberculata* Liebm; *AbDu* = *Abies durangensis* Martínez; *Piar* = *Pinus arizonica* Engelm.; *PiAy* = *Pinus ayacahuite* Ehrenb. ex Schltld.; *PiDu* = *Pinus durangensis* Martínez; *QuSi* = *Quercus sideroxyla* Humb. & Bonpl.; *PiCh* = *Picea chihuahuana* Martínez; *Jude* = *Juniperus deppeana* Steud; *ArXa* = *Arbutus xalapensis* Kunth.

The Margalef Index (D_{Mg}) resulted in $D_{Mg} = 1.52$ (Table 5), which indicates a species richness similar to that obtained by Graciano *et al.* (2017) and González *et al.* (2018), who recorded $D_{Mg} = 1.53$ and $D_{Mg} = 1.98$ in temperate forests of the states of *Durango* and *Nuevo León*; otherwise, that of Hernández-Salas *et al.* (2013), because they calculated $D_{Mg} = 1.04$ and $D_{Mg} = 0.90$ in productive pine and oak forests in the state of *Chihuahua*.

Conclusions

The studied community has natural regeneration of most of its species despite having large trees that cause a closed canopy; *Pinus durangensis* and *Arbutus xalapensis* do not show it, which can be attributed to the shortage of mature individuals. Most of them were presented in stratum III, which suggests that the forest has a high capacity for recovery and replacement of mature trees, which leads to ecosystem conservation.

Based on abundance and defined vertical structure strata, the forest studied is a community dominated mainly by *Pseudotsuga menziesii* in all woodland strata, stratum I with less presence of *Abies durangensis* and *Quercus tuberculata*, while in II and III have associations with *P. arizonica*, *Q. tuberculata* and *A. xalapensis*. Three species with continuous vertical distribution (*P. menziesii*, *A. durangensis* and *Q. tuberculata*) were registered, these being the ones that dominate the upper canopy.

The study of new populations of *Pseudotsuga menziesii* such as this one, provides quantitative information for decision-making in favor of conservation, especially if it coexists with endemic and protective species (*Abies durangensis* and *Picea chihuahuana*).

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