Article

Structure, richness and diversity of tree species in a tropical deciduous forest of *Morelos*

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Abstract:

Because of its neighborhood to Mexico City, which is the nucleus with the largest population in the country, the state of *Morelos* has received considerable pressure on its forest resources; the tropical deciduous forest is one of the most impacted vegetation types. In order to know the state of conservation of this association, a study was conducted in which the structure, richness of species and diversity of tree species in the *Tepalcingo* municipality of said entity was described. All trees with a normal diameter ≥ 10 cm were counted in 34 sampling sites of 500 m^2 with a minimum separation between them of 200 m. These sites were located using a georeferenced map, which was confirmed in the field; each of them was identified with stakes and a cross ditch in the center, to facilitate its location and subsequent remeasurement. Results indicate the presence of 883 individuals, belonging to 50 species and 20 families, of which Fabaceae stands out. The Importance Value Index (IVI), *highlights as main species Lysiloma divaricatum* (61.1)*, Amphipterygium adstringens* (28.5), *Conzattia multiflora* (27.1), *Mimosa benthami* (21.5), *Bursera copallifera* (18.03), the index values of diversity indicate trends similar to those described for the number of species.

Introduction

Tropical forests cover only 10 % of the Earth's surface, but they are of great global importance since they capture and process significant amounts of carbon and harbor between half and two thirds of the total species of the planet (Malhi and Grace, 2000). This vegetation located in seasonally dry tropical regions is heterogeneous and is influenced by a complex environmental and biogeographic history (Pérez *et al.,* 2012).

Latin America is the region with the highest species richness in the world with nearly 120 thousand species of flowering plants (Zarco *et al.*, 2010), but the one that has, in turn, the greatest intensity of destruction and from 60 to 65 % of total global deforestation (FAO, 2007).

Mexico, Brazil, Colombia and Indonesia are among the first places of species richness on the planet, which mainly gather in their tropical forests (Martínez and García, 2007); however, between 1976 and 2000 the rate of loss of these forests was 0.76 % year^{-1}.

The state of *Morelos*, due to its nearness to the largest population center in the country, Mexico City, has received considerable pressure on its forest resources. Among the most impacted ecosystems are the deciduous tropical forest (BTC) and the temperate coniferous and broadleaved forest, both ecosystems with a wide territory in the country (Sagarpa, 2001).

In the southern area of the state is located the most important BTC, which includes the *Sierra de Huautla* Biosphere Reserve (REBIOSH), and it gathers the largest concentration of biodiversity of *Morelos*. Its actual condition of protected natural area does not guarantee its conservation, when it comes to areas populated by rural communities. The residents of the reserve have a close relationship with local biodiversity, and in some cases they depend directly on the environment for their survival, such as food, construction materials, medicinal plants, fuels, cultivation

and grazing areas, among others. In the REBIOSH, more than 640 species of plants are used for these purposes (Conanp, 2005).

Therefore, this study aimed to describe the structure, composition and diversity of tree species in the BTC in an *ejido* of *Morelos*, Mexico. This basic information will contribute to a better understanding of the spatial and abundance patterns of vegetation for its management and conservation.

Materials and Methods

Study area

The study was carried out in the *El Limón de Cuauchichinola ejido*, in *Tepalcingo de Hidalgo* municipality, which is located in the southeast of the state of *Morelos*, Mexico, at 18°32' N and 98°56' W, at 1 220 m high. It has 4 236 ha, of which 1 970 ha are forested lands; It is part of the *Sierra de Huautla* Biosphere Reserve (Figure 1).
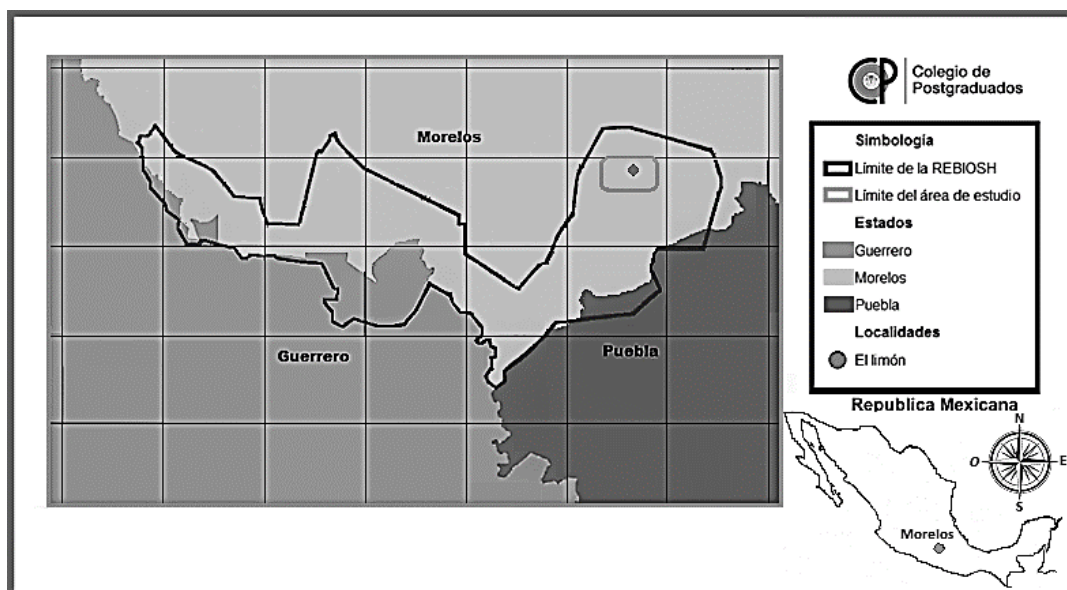

Figure 1. *El Limón ejido*, *Sierra de Huautla* Biosphere Reserve, *Morelos*.

As it belongs to the *Balsas* River basin, the REBIOSH constitutes a rich reservoir of endemic Mexican species. The dominant soil types in the mountains of the reserve are Haplic phaeozem, Eutric regosol and Lithosol (INEGI, 1990). Erosion is moderate, although it tends to be severe in areas with disturbed vegetation and seasonal agriculture or on steep slopes > 15 % (Conanp, 2005).

The climatic formula $Aw_o''(w)$ (i') g describes a subhumid warm climate, the driest of the subhumid, with a rainfall regime in summer, with an oscillation of the average monthly temperatures between 7 and 14 °C, and the highest temperature in May, between 26 and 27 °C (García, 2004), the precipitation of 900 mm per year, the maximum during July and September, with probable reductions or even total absence in August.

The main type of vegetation is the BTC; its main physiognomic characteristics are related to its marked climatic seasonality, which causes that most of the plant species lose their leaves for periods of five to seven months during the dry season of the year. The trees, in general, reach heights of 4 to 10 m and eventually up to 15 m (Dorado, 2001).

Sampling and measurement of variables

In order to include the greater heterogeneity of the arboreal component, 34 circular sites of 500 m^2 were established and with a minimum separation between them of 200 m. These sites were initially located in a geo-referenced map, which was checked in the field through a Garmin eTrex 10 geopositioner. The sites or plots were identified with stakes and a ditch in the shape of a cross in the center, to facilitate its later location.

The trees within each of the sites ≥ 10 cm in diameter at breast height (DBH 1.30 m) were counted. To each individual was assigned a number and marked with an aluminum label, fastened with a nail, and tried to avoid damaging the trees. For

each individual, their taxonomic identity was recorded and their diameter was measured with a Forestry Suppliers tape.

Vertical and horizontal structure

Height was obtained with a 5 m telescopic extension pole GEO-SURV. FGTS-5 (individuals ≤ 8 m) and a Suunto PM5/360PC clinometer (trees> 8 m). The maximum diameter (north and south) of the cup projection was also measured in each individual (Zarco *et al*., 2010) The horizontal structure of the forest was described from the distribution of the number of trees by diametric class; for the vertical structure of each site, frequency histograms by height category were elaborated (Zarco *et al.,* 2010).

Importance Value Index (IVI)

This index allows to determine the dominance of the species and the degree of heterogeneity of the ecosystem. It also provides a global estimate of the importance of a species in a given community.

The IVI consists of the summation of the relative values of density, frequency and dominance. The Importance Value Index (IVI) was developed by Curtis and McIntosh (1951). It is a structural synthetic index, oriented mainly to rank the dominance of each species in mixed stands and is calculated as follows:

$$IVI = \ relative\ dominance + \ relative\ density \ + relative\ frecuency$$

Relative dominance (estimator of the basimetric area) was obtained as follows:

$$relative\ dominance\ = \frac{absolute\ dominance\ by\ species}{absolute\ dominance\ of\ all\ species} \times 100$$

Where:

$$absolute\ dominance = \frac{basimetric\ area\ of\ one\ species}{sampled\ area}$$

The basimetric area (AB) of the trees through the formula:

$$AB = \frac{\pi}{4}DAP^2$$

The relative density was determined as:

$$relative\ density\ = \frac{absolute\ density\ of\ each\ species}{absolute\ density\ of\ all\ species} \times 100$$

Where:

$$absolute\ density = \frac{number\ of\ individuals\ of\ one\ species}{sampled\ area}$$

The relative frequency was the result of:

$$relative\ frequency\ = \frac{absolute\ frecuency\ per\ species}{absolute\ frecuency\ of\ all\ species}\ \times 100$$

Where:

$$absolute\ frecuency = \frac{number\ of\ sites\ en\ in\ which\ each\ species\ is\ present}{total\ number\ of\ sampled\ sites}$$

Diversity

The richness of species (D_α) comes from Margalef's index (1977), which is used to estimate the biodiversity of a community.

$$D_\alpha = \frac{S-1}{\log N}$$

Where:

S = Number of species

N = Total number of individuals

As D_α has a higher value, there is a greater richness of species. Lower values than 2 are taken as zones of low biodiversity and over 5, of high biodiversity.

In order to know how homogeneous or heterogeneous were the plots (sites), the following diversity indexes were calculated (Magurran, 2004).

Shannon-Wiener (H´). This index measures the average degree of uncertainty to predict the species to which an individual taken at random within the plots belongs. This index assumes that individuals are selected at random and that all species are represented in the sample. The values that it produces are close to zero when there is only one species, and to the natural logarithm of S, when all species are represented by the same number of individuals.

$$H' = -\sum_{i=1}^{S} P_i \ln(P_i)$$

Where:

S = Number of species

P_i = Individuals of the i species ratio

At a higher value of H´, higher the diversity of species.

Simpson (S). It measures the probability that two individuals chosen at random in the plots belong to the same species.

$$S = \frac{1}{\sum \frac{n_i(n_i - 1)}{N(N - 1)}}$$

Where:

n_i = Number of individuals in the i^{eth} species

N = Total number of individuals

At a higher value of S, lower the dominance of a species(s).

Diversity of Fisher. The Fisher index (Fisher *et al.,* 1943) attempts to mitigate the problem of undervaluation or overvaluation of the previous indexes, so that one species is the intermediate result of the previous two; it calculates the Geometric Average:

$$S = \alpha(\log e)\left(1 + \frac{N}{\alpha}\right)$$

Where:

S = Number of the species recorded in the sample

N = Total number of individuals in the sample = diversity index

This index could be used to compare this study with others, since it only considers the number of species (S) and the total number of individuals (N) in the samples studied (Berry, 2002); in addition, it does not depend on the size of the sampled area such as the Shannon and Simpson indexes.

Results

Structure

There were 883 individuals registered in the 34 sites (1.7 ha). No species was present in all of them, and the most frequent were *Lysiloma divaricatum* (Jacq.) J.F.Macbr. in 79.4 % of the sites; *Conzattia multiflora* (B. L. Rob.) Standl. in 70.6 %; *Bursera copallifera* (Sessé & Moc. ex DC.) Bullock (47.1 %); *Amphipterygium adstringens* (Schltdl.) Schiede ex Standl. and *Malpighia mexicana* A. Juss. at 44.1 %; these five species represent 10 %. A total of 35 species (70 %) appeared in five or fewer sites and 10 species (20 %) were recorded in only one. The density was 520 individuals ha^{-1}, with 26 per site on average, with a standard deviation (SD) of ± 9, and a range of 13 to 48 (Table 1).

Table 1. Values of the structural and diversity features in 34 sites of the deciduous tropical forest at the *El Limón ejido*, *Morelos* State.

Site	Density (individuals)	Basimetric area (m^2)	DBH (cm)	Height (m)	S	Shannon-Wiener (H)	Simpson D	Fisher α
1	22	0.041	21.5	10.0	10	1.9	5.4	7.1
2	21	0.045	21.1	8.4	7	1.5	3.8	3.7
3	23	0.042	19.7	9.5	9	1.7	4.1	5.4
4	28	0.019	14.8	8.3	11	2.0	6.1	6.7
5	16	0.027	16.9	7.1	6	1.5	4.6	3.5
6	33	0.025	17.3	6.2	7	1.4	3.0	2.7

7	26	0.023	15.8	4.1	6	1.2	2.5	2.4
8	14	0.023	15.5	6.1	9	2.0	10.1	10.9
9	32	0.031	17.9	6.5	12	2.2	8.9	7.0
10	23	0.014	12.9	4.5	2	0.2	1.1	0.5
11	17	0.041	21.4	7.2	4	1.3	3.9	1.6
12	31	0.034	19.6	10.0	10	1.8	4.1	5.1
13	37	0.028	17.8	9.7	11	1.8	4.0	5.3
14	19	0.052	21.7	9.8	8	1.7	4.3	5.2
15	32	0.029	18.5	10.0	11	1.8	3.9	5.9
16	20	0.021	15.9	8.0	7	1.7	6.1	3.8
17	30	0.030	18.6	10.9	9	1.7	4.9	4.4
18	29	0.035	19.2	8.6	11	1.9	5.6	6.5
19	13	0.064	26.6	10.4	4	1.2	3.5	2.0
20	15	0.044	21.8	9.9	4	1.2	3.5	1.8
21	33	0.030	18.4	9.2	14	2.2	7.4	9.2
22	13	0.039	20.9	10.3	8	2.0	11.1	8.9
23	26	0.029	18.1	9.6	7	1.6	4.5	3.1
24	19	0.032	18.9	6.8	7	1.7	5.3	4.0
25	33	0.023	16.5	8.1	8	1.5	3.6	3.4
26	29	0.027	17.8	6.7	6	0.9	1.7	2.3
27	16	0.046	21.0	7.2	8	1.8	6.0	6.4
28	20	0.033	18.9	6.1	3	0.9	2.6	1.0
29	23	0.027	17.9	10.9	5	1.2	3.0	2.0
30	48	0.023	16.4	7.4	13	2.0	5.3	5.9
31	36	0.028	17.6	10.8	8	1.4	2.8	3.2
32	35	0.030	18.3	10.2	11	2.0	6.0	5.5
33	39	0.019	14.9	11.2	7	1.1	2.1	2.5
34	32	0.022	15.9	7.4	8	1.7	5.5	3.4
Total	883	1.075	-	-	50	2.9	9.02	11.5
Mean	26	0.032	18.4	8.4	8.0	1.6	4.7	4.5
DE	9	0.011	2.6	1.9	2.9	0.4	2.2	2.4

CV (%)	32.73	32.89	14.3	22.6	35.7	26.5	46.7	54.3

CV = Coefficient of variation; DN = Normal diameter; DE = Standard deviation; S = Number of species

Floristic composition

In the 34 registered sites, 50 species belonging to 36 genera and 20 families were counted. Fabaceae had the highest values by number of species (15) and individuals (517); Burseraceae occupied the second place with seven species and 88 individuals, Fabaceae together with Burseraceae, Convolvulaceae, Euphorbiaceae and Malpighiaceae, represented 60 % of the total richness obtained and 78.5 % of the number of individuals (Table 2).

Table 2. Five families with the highest values in number of species and individuals.

Families	Species	Individuals
Fabaceae	15	517
Burseraceae	7	88
Convolvulaceae	3	40
Euphorbiaceae	3	19
Malpighiaceae	2	29
Subtotal[*]	30 (60 %)	693 (78.5 %)
Others(15)	20 (40 %)	190 (21.5 %)

[*]Subtotal refers the contribution of these families as well as their percent of the total.

Vertical stratification

The average height in the total of the sites sampled in the *El Limón ejido* was 8.4 ± 1.9 m, with an interval of 4.1 to 11.2 m (Table 1); the species that reached greater height were *Conzattia multiflora* and *Lysiloma acapulcensis* (Kunth) Benth. (16 m), two strata were differentiated: the lower one was constituted by categories from 2 to 9 m (64.9 % of the individuals), and the superior comprised categories of 10 to 15 m (34.9 %); while only 0.2 % exceeded 15 m (Figure 2).
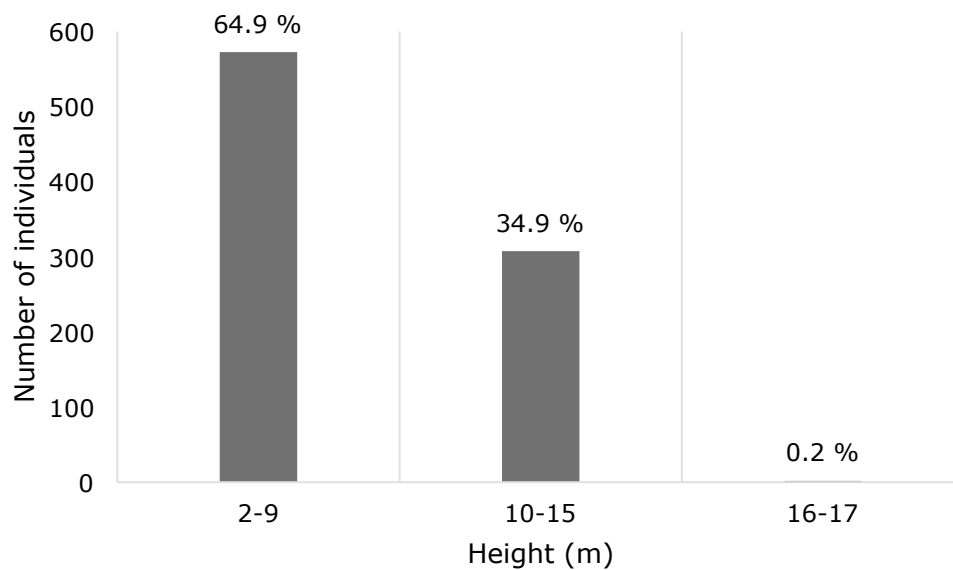

Figure 2. Vertical stratification of the arboreal component in the *El Limón ejido.*

The mean DBH was 18.4 ± 2.6 cm, and the interval ranged between 10 and 74.3 cm (Table 1). The species with the most outstanding average values were *Ficus cotinifolia* Kunth (47.4 cm), *Euphorbia fulva* Stapf (37.2 cm) and *Bursera schlechtendalii* Engl. (29.3 cm). From 883 individuals, 93.6 % belong to the two smaller diameter categories (Figure 3).
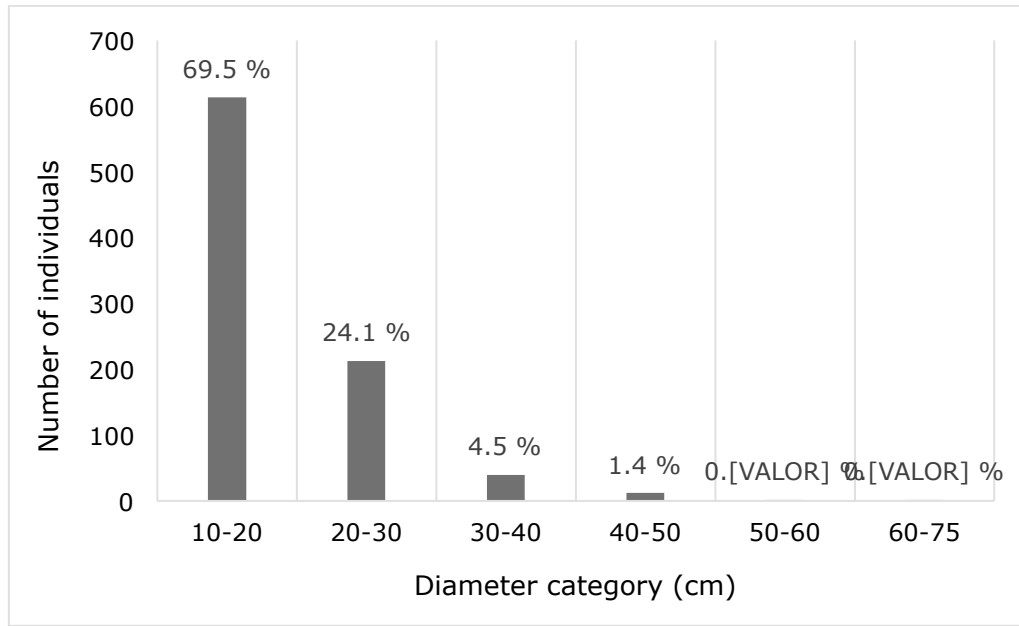
Figure 3. Diameter distribution of the arboreal component in the *El Limón ejido, Morelos* State

Importance Value Index (IVI)

The five species with high IVI present in the 34 sites were, *Lysiloma divaricatum, Amphipterygium adstringens, Conzattia multiflora, Mimosa benthami* J.F.Macbr. and *Bursera copallifera* (Table 3).

Table 3. Species with the highest Importance Value Index (IVI) in the 34 sites of the *El Limón ejido, Morelos* State.

	Species	Dominance		Density		Frequency		IVI
		ABS	REL	ABS	REL	ABS	REL	
1-	*Lysiloma divaricatum* Jacq.) J.F.Macbr.	6.71	23.44	245	27.74	27	9.96	61.16
2-	*Amphipterygium adstringens* (Schltdl.) Schiede ex Standl.	4.15	14.49	75	8.49	15	5.53	28.52
3-	*Conzattia multiflora* (B. L. Rob.) Standl.	2.93	10.21	71	8.04	24	8.85	27.11
4-	*Mimosa benthami* J. F. Macbr.	2.02	7.06	89	10.07	12	4.42	21.57
5-	*Bursera copallifera* (Sessé & Moc. ex DC. Bullock)	1.56	5.44	59	6.68	16	5.90	18.03
	Subtotal	17.37	60.64	539	61.02	94	34.66	156.39
	45 resting species	11.27	39.36	344	38.98	177	65.34	143.61
	Total	28.64	100	883	100	271	100	300

ABS = Absolute; REL = Relative.

Diversity

The average richness in the sampled sites was 8 ± 2.9 with an interval between 2-14 species (Table 1). The Margalef index revealed a species richness of 7.2.

The total value for the Shannon-Wiener index was 2.9, the average of 1.6 ± 0.4, with values from 0.2 to 2.2 and a coefficient of variation of 26.5 %. The value of the Simpson index (9.02) and the average 4.7 ± 2.2, with a coefficient of variation of

47 %. The value obtained for the Fisher α -value was 11.5 and the average of 4.5 ± 2.4, with a variability of 54.3 % (Table 1).

Discussion

Structure

The average density for *El Limón ejido* is 26 individuals, which coincides with other previously documented experiences for this type of vegetation in Mexico (Trejo, 2005).

The comparison of density with other studies is limited, since they were considered other diametric categories, which depend on the objectives. In this particular work the DBH ≥ 10 cm was taken.

Floristic composition

In this study it was found that Fabaceae gathers the greatest number of species and individuals (Table 2), which agrees with descriptions of the dry forests of Mexico, Central and South America (Gillespie *et al.,* 2000; Phillips and Miller, 2002; Trejo and Dirzo, 2002; Gallardo *et al*., 2005; Ruiz *et al.*, 2005; Lott and Atkinson, 2006; Pineda *et al.,* 2007; Pérez *et al*., 2010; Almazán-Núñez *et al*., 2012; Martínez *et al.,* 2013). The review of Rzedowski and Calderón (2013), on the BTC, confirms the predominance of this family.

Also, Burseraceae, Convolvulaceae, Euphorbiaceae and Malpighiaceae occupy important positions for the number of species and individuals, as reported by Phillips and Miller (2002); Gallardo *et al*. (2005), Sousa (2010) and Almazán-Núñez *et al*. (2012).

It is not surprising to find that the Burseraceae family has high values in number of species and individuals (Table 2), since the *Balsas* basin has been recognized as a center of endemism and diversification of this taxon (De-Nova *et al*., 2012). It is postulated that its great diversity is due, in part, to geographic processes such as the uplift of the Western *Sierra Madre* and the Trans-Mexican Neovolcanic Axis, events that occurred during the Tertiary and Quaternary periods (Rzedowski *et al*., 2005) and that allowed its radiation, mainly along the Pacific slope and the *Balsas* basin.

Vertical stratification

The average tree height in the *ejido* was 8.44 m, which, when compared with other studies, is higher than the one obtained by Méndez *et al.* (2014) of 4.6 m and 4.1 m of Gallardo *et al.* (2005) in *Cerro Verde*, *Oaxaca*, but closer to that of 6 and 8 m recorded in different locations of Mexico and the Caribbean islands (Murphy and Lugo, 1986; Martínez *et al.*, 1996; Salas, 2002; Segura *et al.,* 2002; Gallardo *et al*., 2005; McLaren *et al.,* 2005; Durán *et al*., 2006; Álvarez-Yépiz *et al.,* 2008).

As mentioned before, heights have a direct relation with the diametric classes that were taken; Gallardo *et al.* (2005) included trees with diameters ≥ 5 cm and Méndez *et al*. (2014), ≥ 1 cm.

Importance Value Index (IVI)

The results obtained in the present study are consistent with those of Hernández *et al*. (2011) in three *ejidos* of the *Sierra de Huautla, Morelos*, in which *Lysiloma divaricatum* and *Mimosa benthami* registered a high IVI, which places them within the first ten species in this area. However, it is important to point out that they have taken censuses of species without considering the diameter.

Diversity

In the total sampling of the 1.7 ha, 50 species were counted from the ≥ 10 cm OF DBH tree population. The richness of species is similar to that recorded by Hernández *et al.* (2011), which found 54 species. Also, Méndez *et al.* (2014) counted 53 and 47 species, as they included all the individuals ≥ 1 and ≥ 2.5 cm of DBH, respectively; there have been results rather close in several localities of Mexico (Trejo and Dirzo, 2002; Pineda *et al.,* 2007; Martínez *et al.,* 2013). Richness is far from the highest values (> 100 species) documented for BTC in the Neotropics (Gentry, 1995) and worldwide (Phillips and Miller, 2002). In fact, the number of this diversity feature is more similar to those calculated by Pineda *et al.* (2007), Martínez *et al.* (2013) and to the other locations of the country studied by Trejo (2005). When compared to other sites located in America, the values of the diversity indexes (Table 1) follow trends similar to those described for the number of species.

Conclusions

The results from the actual study make it possible to confirm that the structure, richness and diversity of tree species of the deciduous tropical forest in *El Limón ejido* of *Cuauchichinola* are comparable to those described for this type of vegetation in other parts of Mexico.

Acknowledgements

Conflict of interests

The authors declare no conflict of interests

Contribution by author

Miguel Ángel Sánchez Hernández: data collection at the field, data analysis, writing and review of the manuscript; Aurelio M. Fierros González: design and supervision of the project, field work support, review of the manuscript; Alejandro Velázquez Martínez: supervision of the project, review of the manuscript; Héctor Manuel De los Santos Posadas: data analysis support and review of the manuscript; Arnulfo Aldrete: review of the manuscript; Enrique Cortés Díaz: field work support and review of the manuscript.