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Tree structure and diversity of a Humid Mountain Forest in the protected natural area La Martinica, Veracruz, Mexico

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ABSTRACT

Introduction: The Humid Mountain Forest (HMF) has the highest number of plants per unit of surface, whose vegetation grows under heterogeneous environmental conditions and possess a high floristic variation. HMF conservation is important due to the biodiversity it harbors and the environmental services it provides.
Objective: This work evaluated the effect of the terrain aspect and density of the forest canopy on the structure and tree diversity in La Martinica Protected Natural Area, Mexico.
Methods: Stratified sampling was performed in four terrain aspects and two canopy density conditions. Twenty five sampling units of 20 x 25 m were considered, in which the normal diameter (ND), total height and the largest and smallest diameters of the crown of the individuals with a ND ≥ 10 cm were registered. The diversity was estimated by rarefaction curves and the structure was analyzed through the importance value index (IVI) and the forest value index (FVI).
Results: 37 species belonging to 30 genera and 24 families were recorded. Greater diversity was observed in the north terrain aspect and in the closed canopy. Tree species with the highest structural values were different between terrain aspect and canopy types; *Carpinus tropicalis* presented the highest values in the zenithal terrain aspect, *Lippia myriocephala* in the east and south terrain aspect, and *Liquidambar styraciflua* in the north. In both canopy types *Lippia myriocephala* obtained the highest IVI values and FVI in the open canopy; *Carpinus tropicalis* reached a higher FVI in the closed canopy.
Conclusions: Tree structure was different in the four terrain aspects and two canopy conditions studied. The greatest difference in species composition and diversity was observed between the north and east terrain aspects; the north presented the highest richness values, frequent and dominant species.

Key words: canopy opening; effective number of species; NMDS; terrain aspect; tree vegetation.

The Humid Mountain Forest (HMF) is one of the most important biomes in Mexico, has a great richness of flora and endemic species, due to the great variety of habitats and the restricted to a small geographical area (Cruz-Cárdenas et al., 2012; González-Espinosa et al., 2011); its vegetation harbors the largest number of species per unit area (Gual-Díaz & Rendón-Correa, 2014; Gual-Díaz & Rendón-Correa, 2017; Villaseñor, 2010). At the national level,

the humid mountain forest is one of the most threatened ecosystems (González-Espinosa et al., 2012; Toledo-Aceves et al., 2011), due to its scarce distribution and the alterations caused by global climate change, deforestation, the expansion of human communities to mountainous areas where this forest persists, and changes in land use due to conversion to crop systems (Cayuela et al. 2006; González-Espinosa, et al., 2011; Gual-Díaz & Rendón-Correa, 2017).

The Humid Mountain Forest has also been described as cloud forest and mountain cloud forest (Rzedowski, 2006). It develops between 800 and 3 000 m above sea level, in the mountainous regions of Mexico, on the slopes where the humid winds that come from the sea affect, and generally between 1 000 and 3 000 m of altitude (Villaseñor, 2010) to the windward of mountain massifs, where moisture condenses and fogs form, as well as in ravines and humid slopes (Challenger & Soberón, 2008; Rzedowski, 2006; Villaseñor, 2010). The HMF is characterized by having a very dense tree canopy, which limits the passage of light to the lower strata (Challenger & Soberón, 2008; CONAFOR & COLPOS, 2014). Its vegetation develops in very heterogeneous climatic, altitudinal and edaphic conditions and the orographic and local humidity conditions that characterize it, originate a wide structural variability in the form of various associations that differ from each other in height, phenology and dominant species (Gual-Díaz & Rendón-Correa, 2014; Rzedowski, 2006). In addition, HMF contains floristic elements of different biogeographic affinity whose presence creates a great opportunity to evaluate the relationships among factors as climate, microenvironment, changes in vegetation structure, and its floristic composition (González-Espinosa et al., 2011; Guerrero-Hernández et al., 2019).

Slopes facing north, in the northern hemisphere, tend to be more humid, which benefits different plant species; unlike south-facing slopes which receive more solar radiation and tend to be drier and warmer (Holland & Steyn 1975; Mata-González et al., 2002; Renaud et

al., 2011), thus the aspect is a factor that can modify, at a local level, essential variables of plant functions, such as the quantity and quality of incident radiation, temperature or frost frequency (Torres et al., 2012). The foregoing affected, for example, the presences of HMF patches studied by Luna-Vega et al. (2007), one oriented to the north and the other to the southwest, in which these authors found differences in ecological attributes as the number of individuals per ha, basal area (m²/ha), species richness, crown cover and normal diameter. It is important to mention that these ecological attributes have a differential impact on the structure and diversity of the HMF in different environments. Williams-Linera et al. (2013) in a study of the HMF (which they call Cloud Forest) of central Veracruz, they mention that these types of forests located at low altitudes are less diverse, and more similar in composition, unlike forests located at higher elevations, but not found differences in the structure of vegetation in forests located at different altitudes.

Santana et al. (2014), analyzed the biodiversity and structure in fragments of the HMF (described as *Bosque Mesófilo de Montaña*) of Michoacán, México; the authors mention that diversity, similarity, and structure demonstrate significant heterogeneity in HMF fragments. García-De la Cruz et al. (2013) mention, that the alpha diversity of one of the studied sites for a mountain cloud forest of Veracruz, México, was significantly higher than the other two sites; similarly, the plant structure between sites was different, which was attributed to the management history and natural disturbances that favor the establishment and development of different species. Luna-Vega et al. (2007) carried out a structural analysis of two fragments of mountain cloud forest of the Trans-Mexican Volcanic Belt; the authors refer that the two sites have densities of 740-1 720 individuals per hectare, differ in basal area, and foliage coverage. García-Franco et al. (2008) analyzed the vegetation of the Mountain Cloud Forest in three sites in the center of Veracruz, Mexico; the authors mentioned that there were no significant differences for basal area between

sites; in addition, the greatest floristic differences were found between sites further away from each other. Based on the aforementioned, the close relationship that exists between the ecological attributes mentioned above with the structural characteristics and diversity of the HMF can be observed. In the case of the HMF located at west of Xalapa, Veracruz, Williams-Linera et al. (2002) pointed out that the best conserved forests are on very steep slopes, facing north, while the disturbed forests they are located mainly to the south facing slopes.

The conservation of the HMF is important for the biodiversity it encloses and for its contribution to the maintenance of environmental regulation services (CONAFOR & COLPOS, 2014; Manson, 2017; Williams-Linera, 2007). Nevertheless, in the central region of Veracruz this biome is fragmented. The edges of the remnants experience changes in physical conditions, such as variations in the microclimate and, they are under pressure from the expansion of urban settlements (Williams-Linera et al., 2002; Williams-Linera, 2007).

Williams-Linera et al. (2002), report that the Humid Mountain Forest of the central Veracruz, Mexico, has been considerably reduced since the 1960s due to the transformation of the forest for pastures and crops, along with urban growth. Deforestation processes continue in this area (Williams-Linera et al., 2007), so the HMF is at risk. The PNA La Martinica is located within the aforementioned area, so it is subject to the same problems already mentioned. Among the various actions to reduce the deterioration of the HMF, it has been proposed to register the conditions and changes in the environment necessary to prevent negative impacts on the forest conservation; also, enrich the knowledge of the identity and distribution of the region's biodiversity (Williams-Linera et al., 2007). The HMF of the central region of Veracruz is highly fragmented, La Martinica is one of the few remnants that are under protection in order to be preserved, its importance lies in its value as a reserve of biological diversity and it is of great significance to maintain environmental services such as the regulation of water resources (Williams-Linera et al., 2007).

We consider that our study contributes to the knowledge of the current state of the tree vegetation in this important area of HMF in the center of Veracruz state, with which we can generate proposals for the conservation of the tree diversity of this region. Based on the above, the aim of this work was to evaluate the influence of terrain aspect and canopy density on the structure and diversity of tree vegetation in the Humid Mountain Forest at the natural protected area La Martinica, Banderilla, Veracruz. We asked the following questions: (i) do terrain aspect influence structure, diversity and tree species composition? (ii) do canopy density influence structure, diversity and tree species composition? As hypotheses, we assumed that: (i) structure, diversity and tree species composition is different between terrain aspects and particularly north aspect has a positive influence on them (ii) closed canopies have a positive influence on structure, diversity and tree species composition.

MATERIALS AND METHODS

Study Area: The study area is located in the Natural Protected Area (NPA) La Martinica, Banderilla, Veracruz, Mexico (Fig. 1), between 19°35'01.3''-19°35'27.9'' N & 96°56'52.7''-96°57'30.4'' W. The site was a private property where extensive cattle ranching was developed and was decreed as a state-owned protected area in 2010. It has an area of 52.36 ha, of which near to 30.5 ha are covered by forest vegetation (hillsides), and the rest are remnants of induced grasslands which is partially in restoration process (non-sloping area) (Herrera-Beltrán, 2010; SEDESMA, 2006).

La Martinica has plateaus and slopes with angles from 2 to 45°, the area belongs to the Neovolcanic province and is distributed in an altitudinal range between 1 570 and 1 620 m.a.s.l., andosol is the predominant soil type, the average temperature is 18 °C with an oscillation of 5 to 7 °C and the total annual precipitation fluctuates between 1 500 and 2 000 mm
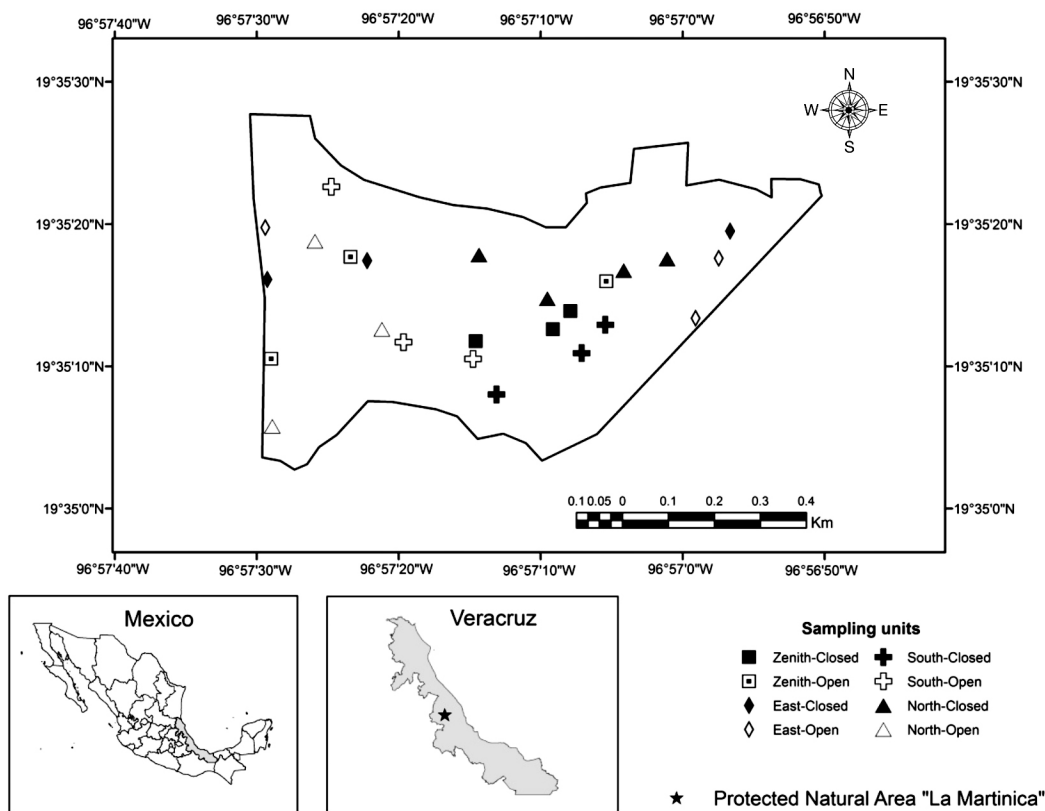
Fig. 1. Location of the study area and distribution of the sampling units in the Protected Natural Area "La Martinica", in the municipality of Banderilla, Veracruz, Mexico.

(SEDESMA, 2006). The climate corresponds to temperate C (fm) b (i') with an ample cool summer, abundant rain all year round and little thermal oscillation (García, 2004). The vegetation corresponds to a humid mountain forest and the most typical characteristic species, we can find *Liquidambar styraciflua* L., *Clethra mexicana* DC, *Carpinus tropicalis* (Donn. Sm.) Lundell, *Ostrya virginiana* (Mill.) Koch, and *Quercus* spp. L (Villaseñor, 2010).

Sampling and measuring variables: A stratified sampling was carried out in four terrain aspects (sampling unit): zenithal (Z), east (E), north (N) and south (S). The forest was classified based on canopy densities in: closed canopy (C), areas with a smaller opening (21.8 ± 0.79), and open canopy (O), where

the opening percentage was bigger (26.23 ± 0.82), a generalized linear model for a Gaussian distribution was used to determine whether canopy opening varied significantly between sites, the test showed that there is a significant difference $P < 0.0001$. The estimation of the gaps in each sampling subunit was made through photographs taken at 1.6 m from the ground (250 in total) at approximately 10:00 in the morning, with a Nikon COOLPIX B500 camera. Images were analyzed with CobCal software version 1.0 (Ferrari et al., 2006), to estimate the opening percentage. This method is based on colorimetry, and the coverage percentage is calculated. Positive colors (represent the vegetative surface to be calculated) and negative colors (representative of the surface to be discarded from calculation) were assigned to

the photograph. The West aspect was not considered because the open canopy condition was poorly represented in that aspect.

The sampling method of Endara-Agramont et al. (2012) was adapted to each terrain aspect and canopy type. Six sampling units (SU) of 20 x 25 (500) were arranged in each aspect. Three SUs were located in each canopy type (3 in Z-C and 3 in Z-O), with the exception of north aspect with closed canopy condition where four SUs were installed, because it was the most extensive area, for a total of 25 SUs, equivalent to 1.25 ha. Each SU was divided into 10 subunits 10 x 5 m (50 m^2) in which the trees were numerated to facilitate counting. Normal diameter (ND) was recorded at 1.3 m height from the ground. Total height was estimated, and also upper and lower crown diameters of every individual with a ND ≥ 10 cm were measured.

Some species were collected, and photographs taken for later taxonomic identification with specific available literature, *i.e.* Barcena (1981), Fernández-Nava (1986), Ludlow-Wiechers (1978), Nash & Nee (1984), Nee (1981), and Pacheco (1983). The Angiosperm Phylogeny Group classification was followed (APG IV, 2016; Stevens, 2017). The nomenclature was verified by consulting the Missouri Botanical Garden database (TROPICOS, 2018). Collected specimens were deposited in the CHAPA herbarium of Colegio de Postgraduados, Mexico.

Structure and diversity: The structure analysis of tree species on each terrain aspect and canopy type was based on the estimation of the importance value index (IVI = relative dominance + relative density + relative frequency) (Curtis & McIntosh, 1951; Sánchez-Gutiérrez et al., 2017) and the forest value index (FVI = relative ND + relative height + relative cover) (Corella-Justavino et al., 2001; Ortega-Baranda et al., 2017).

The diversity between terrain aspects and forest canopy types was compared in units of effective number of tree species. The procedure proposed by Chao & Jost (2012) and

Chao et al. (2014) was used, by interpolation and extrapolation of estimates from diversity rarefaction curves ^qD (y-axis) as a function of sampling coverage

$$\hat{C}n = 1 - \frac{f_1}{n}\left[\frac{(n-1)f_1}{(n-1)*f_1+2f_2}\right]$$

(x-axis), where species richness ($q = 0$), exponential of Shannon entropy ($q = 1$), and inverse of the Simpson concentration ($q = 2$). Therefore, ^0D = number of species, ^1D = effective number of equally frequent species, and ^2D = effective number of dominant species. f_1 is the number of species of which only one individual was registered during the sampling, f_2 is the number of species with two individuals, and n is the total number of registered individuals (Cultid-Medina & Escobar, 2019). Estimations were done in R software using "iNEXT" package (Hsieh et al., 2020; R Core Team, 2019).

Statistical analyses: The effect of the aspects and types of canopies over plant composition were evaluated by a permutational multivariate analysis of variance (PERMANOVA) for a factorial arrangement 4 x 2. Also, the similarity in species composition among aspects and type of canopy was evaluated through non-metric multidimensional scaling (NMDS), which produces a ranking based on a dissimilarity matrix. The analyses were based on 999 permutations using the Bray-Curtis distance as a measure of similarity, with the transformation of the data to square root. These analyses were conducted with R software using "Vegan" package (Oksanen et al., 2019; R Core Team, 2019).

The association among tree species and terrain aspects was based on a correspondence analysis. A frequency matrix of individuals from each species in their respective aspect was elaborated. This analysis was carried out in R software using "CA" package (Nenadic & Greenacre, 2007; R Core Team, 2019).

The effect of the aspect and type of canopy, on the basal area m^2 and tree density (ind. x 500 m^2), was determined using a generalized linear model (Crawley, 2012) with a 4 x 2 factorial

arrangement for a Gaussian error distribution in the case of basal area and *quasi*-Poisson for density. When significant differences were found, they were contrasted in pairs by the Holm adjustment method, analysis were done with the program R using the 'Phia' package (R Core Team, 2019; Rosario-Martinez, 2015).

RESULTS

Individuals of 779 trees were recorded which belong to 37 species, distributed in 30 genera and 24 families. The tree species with the highest structural values in La Martinica were the same for both indices (IVI and FVI). The five species being remarkable abundant were: *Lippia myriocephala* (IVI = 17.2 %, FVI = 16.9 %), *Carpinus tropicalis* (IVI = 12 %, FVI = 12.3 %), *Myrsine coriacea* (IVI = 11.27

%, FVI = 10.74 %), *Liquidambar styraciflua* (IVI = 9.14 %, FVI = 9.69 %), and *Trema micrantha* (IVI = 8.24 %, 9.63 % FVI) (Appendix 1). The most important species were different among terrain aspects. *C. tropicalis* had the highest values on Z aspect (IVI = 17.75 %, FVI = 18.2 %), *L. myriocephala* on E (IVI = 25.36 %, FVI = 25 %) and S aspects (IVI = 21.11 %, FVI = 19.4 %), and *L. styraciflua* on N aspect (IVI = 18.37 %, 20.2 % = FVI) (Appendix 2). By contrast, in both types of canopy *L. myriocephala* had the highest IVI values: at O (22.9 %) and at C (11.84 %), and only FVI in the O canopy type (22.9 %), due to the fact that *C. tropicalis* had a highest FVI in C canopy areas (12.1 %) (Appendix 3).

All the diversity expressions (^0D, ^1D and ^2D) were significantly higher in the N aspect. In fact, no significant differences were observed
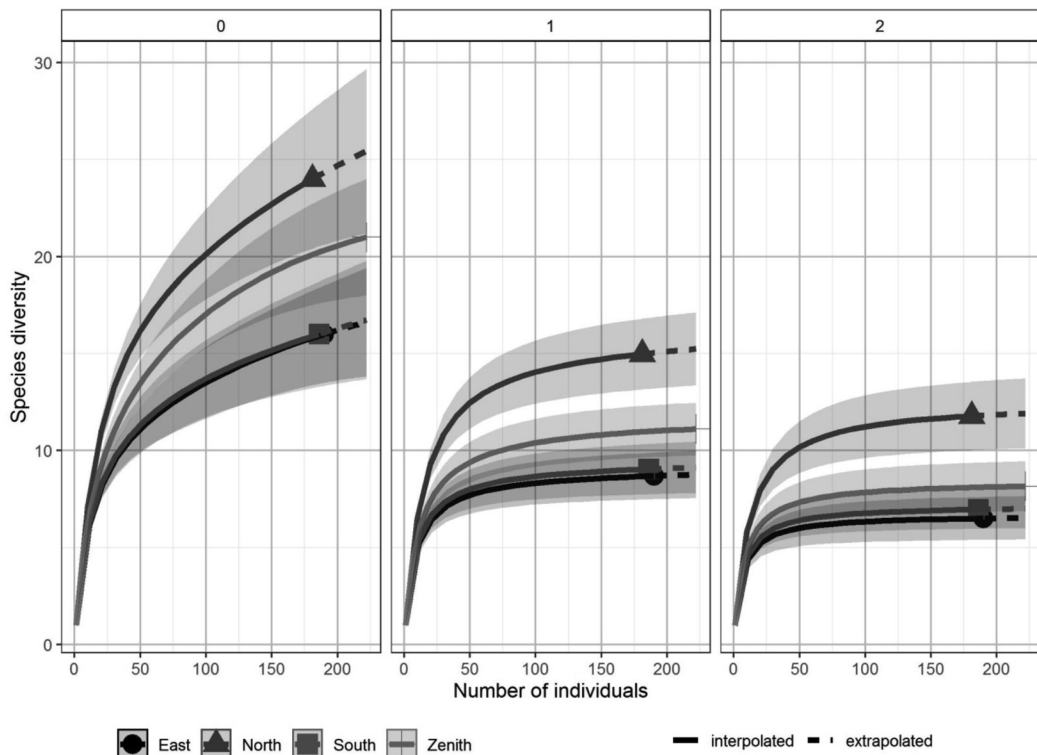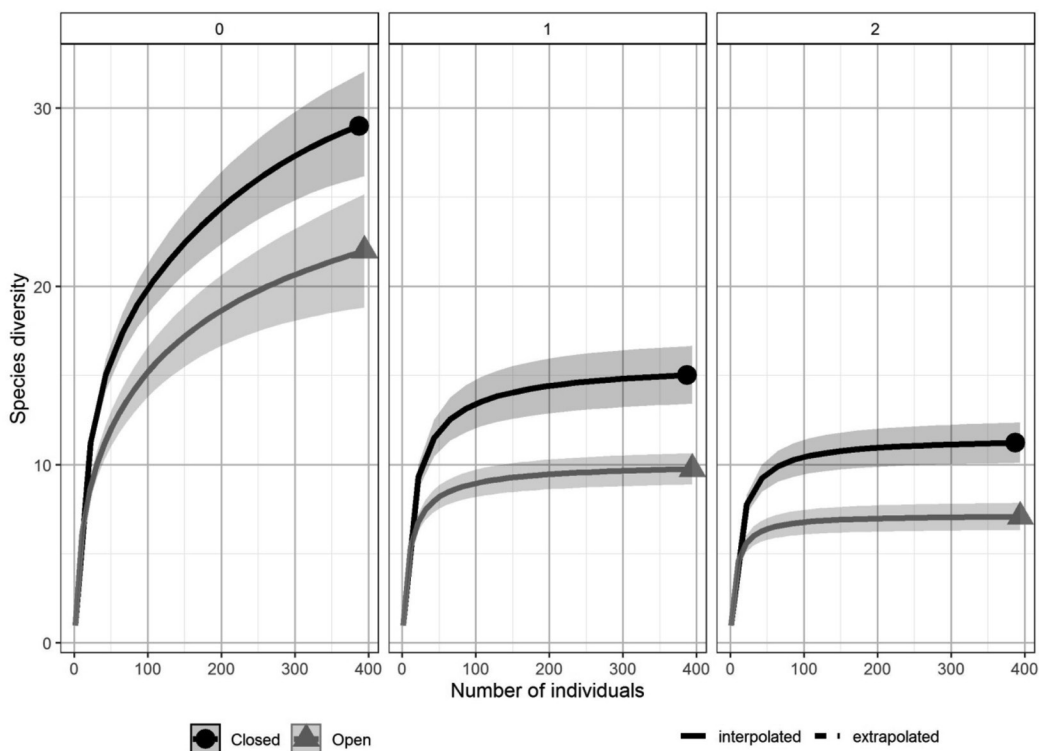

Fig. 2. Rarefaction curves with 95 % CI, constructed based on the coverage of the trees registered according to terrain aspect. In the upper part, the order of diversity is shown: ^0D = number of species, ^1D = effective number of equally frequent species, and ^2D = effective number of dominant species. Curves were extrapolated to the total abundance observed in the zenithal exposure (N = 222 individuals).

in relation to the effective number of common species and abundant species between Z, E and S aspects. Nevertheless, when sampling areas above 50 % coverage, richness in Z aspect was significantly higher than in E and S exposures (Fig. 2). According to canopy types, the same trend was observed for all diversity expressions (^0D, ^1D and ^2D), since they were significantly higher in C canopy (Fig. 3).

Tree structure in terms of composition and density showed significant differences between terrain aspects, the *post-hoc* test indicates that the main difference was found between the E and N aspects (Table 1), as it is depicted by the NMDS (Fig. 4) with a good fit represented in two dimensions (stress = 0.17). According to canopy types, no significant differences were found.

Correspondence analysis explained about 87 % of the total variance of the species in two dimensions. Species such as *O. virginiana*, *Quercus germana* Schltdl. & Cham., and *L. styraciflua* tended to be more frequently associated with the N aspect; *C. tropicalis* and *Rhamnus capreifolia* Schltdl. with Z aspect; *Lippia myriocephala* Schltdl. *et* Cham., *Myrsine coriacea* (Sw.) R. Br. ex Roem. & Schult., *Quercus xalapensis* Bonpl. and *Trema micrantha* (L.) Blume, with E and S terrain aspects (Fig. 5).

Basal area of the individuals varied significantly between terrain aspects. However, it was not significantly different between canopy types, and a significant interaction of factors was not observed either. Afterwards comparisons show that N aspect is the one that differs from other aspects, obtaining record of the largest basal area (Table 2).


Fig. 3. Rarefaction curves with 95 % CI, constructed based on the coverage of the trees recorded by canopy condition. In the upper part, the order of diversity is shown: ^0D = number of species, ^1D = effective number of equally frequent species, and ^2D = effective number of dominant species. Curves were extrapolated to the total abundance observed in the open canopy (N = 394 individuals).

TABLE 1
PERMANOVA results for the composition of tree species

Source	df		Pseudo-F	P	Post-hoc comparisons	
Canopy	1	0.0821	2.1754	0.026**	Exposure	P
Exposure	3	0.1788	1.5797	0.062*	Z-E	0.2
Canopy:Exposure	3	0.0975	0.8612	0.651	Z-N	0.236
Residual	17	0.6415			Z-S	0.842
Total	24	1			E-N	0.017
					E-S	0.548
					N-S	0.355
					Canopy	P
					O-C	0.448

**Significance at 0.05, *significance at 0.1. the design was factorial 4 x 2 considering the condition of the canopy and the exposure of the terrain. Z = zenithal, E = east, N = north, S = south, O = open, C = closed.
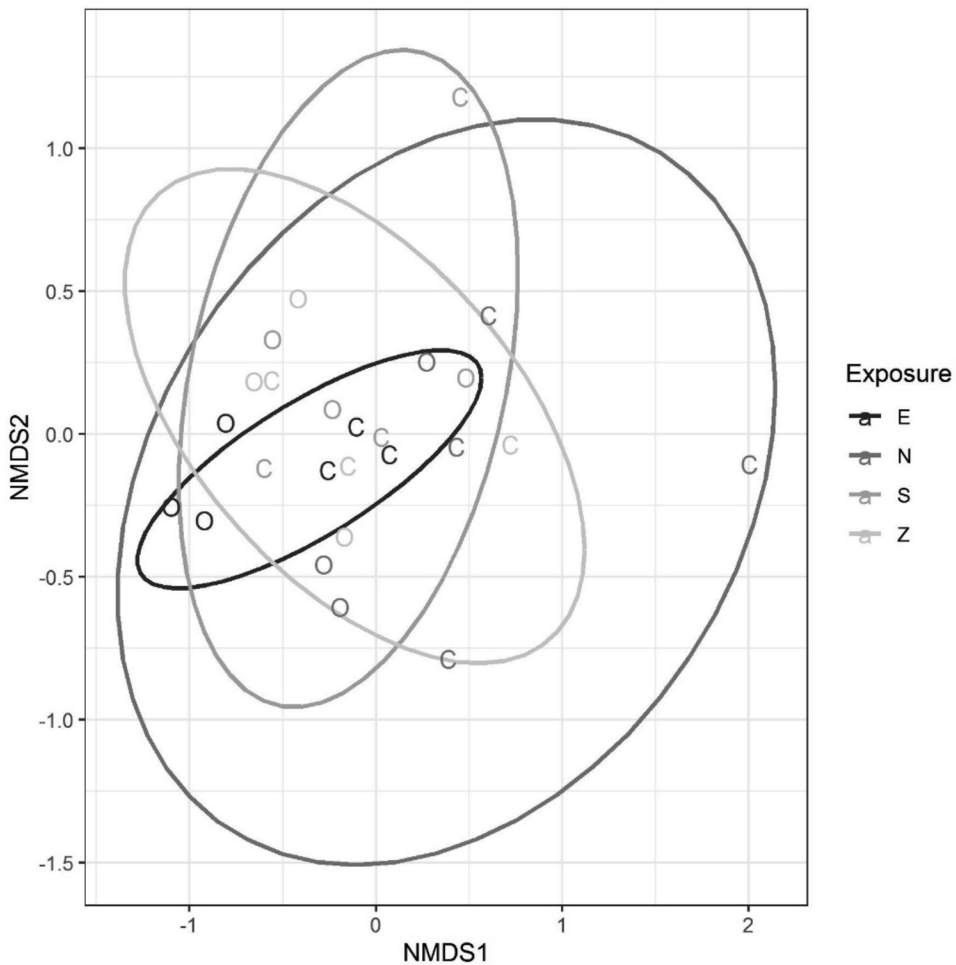
Fig. 4. Non-metric multidimensional scaling of the tree communities recorded in four exposures (Z = zenithal, E = east, N = north, S = south), and two canopy conditions (O = open and C = closed), in the protected natural area La Martinica, municipality of Banderilla, Veracruz, Mexico (good fit = 0.17, Bray-Curtis distance index).

TABLE 2

Statistical results of the generalized linear model on basal area of trees, in a 4 x 2 factorial arrangement considering the canopy opening condition and the direction of sun exposure of the terrain (aspect), and *post-hoc* comparisons

Condition		P		Condition			P
E Exposure	-0.164	0.8694	Post-hoc comparisons	Canopy	O-C	3.469	0.0625*
					Z-E	0.226	1
N Exposure	2.790	0.0054**			Z-N	16.663	0.00022***
					Z-S	0.012	1
S Exposure	0.080	0.9361		Exposure	E-N	19.259	0.00006***
					E-S	0.316	1
C Canopy	1.028	0.3044			N-S	14.510	0.00055***
E Exposure/C Canopy	-0.243	0.8084	Mean basal area ± EE (m^2)	Canopy	O	0.0309 ± 0.00324	
					C	**0.0390 ± 0.00326**	
N Exposure/C Canopy	0.156	0.8757		Exposure	Z	0.0292 ± 0.0043	
					E	0.0262 ± 0.0046	
S Exposure/C Canopy	0.002	0.9987			**N**	**0.0554 ± 0.0047**	
					S	0.0299 ± 0.0047	

*significance at 0.1 **significance at 0.01***significance at 0.001. The highest mean basal area is highlighted.

Tree density did not differ significantly among terrain aspects; nor between canopy types, there was no significant interaction between factors either (Appendix 4).

DISCUSSION

The composition of tree species in the Natural Protected Area La Martinica is similar to that found by García-Franco et al. (2008), Muñiz-Castro et al. (2006), Ruiz-Montiel et al. (2014), Williams-Linera (2002) in other fragments of humid mountain forests in the region. The species richness (37 species) registered was higher than that indicated by García-de la Cruz et al. (2013) and Williams-Linera et al. (2005), who recorded 14 species and a ranging from three to 23 taxa in mature forest, and from nine to 31 in second-growth forest condition (acahual), respectively. However, there were less than those 58 species recorded by Ruiz-Montiel et al. (2014) and also than those registered in the forests studied by Williams-Linera and López-Gómez et al. (2008) with a little more than 50 species. A plausible explanation is that, in our sampling, trees with ND < 10 cm were not included, as it was the case

in those cited studies. Forest regrowth species were excluded, in addition to the eventual differences in sampling.

The second species with a high importance value was *C. tropicalis*, which coincides with the analysis of Ruiz-Jiménez et al. (2012). Those authors state that, for the HMFs of the Gulf of Mexico, it is common for *C. tropicalis* to be one of the dominant species. Several species that have high importance values, match results with García-de la Cruz et al. (2013) and Williams-Linera (2002). Both studies identified *Clethra mexicana, Liquidambar styraciflua, Quercus germana and Quercus xalapensis* as dominant species in the HMFs of the central region of Veracruz. However, in our study *Lippia myriocephala* had higher structural values, which indicates that it is a secondary forest, which has been formerly subject to disturbances (González-Zamora et al., 2016).

The structural patterns observed in the north aspect would be related to the resilient responses that have been observed in this terrain aspect after disturbances, since these lands appear to conserve more species, compared to the south aspect. Such a resilient process facilitates the regeneration of plant communities
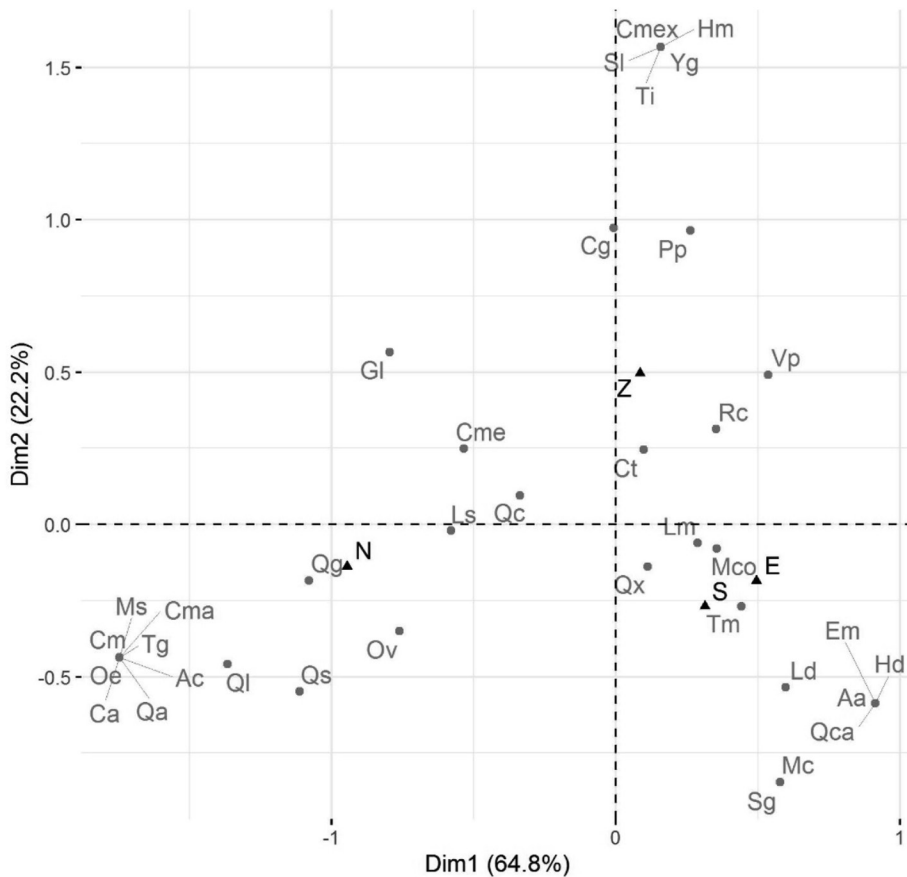
Fig. 5. Association of tree species and terrain aspect (Z = zenithal, E = east, N = north, S = south); (χ^2 = 352.4, P < 0.0001), based on the correspondence analysis. Aa = *Alnus acuminata,* Ac = *Ardisia compressa,* Ct = *Carpinus tropicalis,* Cm = *Citharexylum mocinnoi,* Cme = *Clethra mexicana,* Cma = *Clethra macrophylla,* Ca = *Conostegia arborea,* Cg = *Cornutia grandifolia,* Cmex = *Clethra mexicana,* Em = *Erythrina macrophylla,* Gl = *Gymnanthes longipes,* Hm = *Hedyosmum mexicanum,* Hd = *Heliocarpus donnellsmithii,* Ld = *Leucaena diversifolia,* Lm = *Lippia myriocephala,* Ls = *Liquidambar styraciflua,* Ms = *Magnolia schiedeana,* Mc = *Morella cerifera,* Mco = *Myrsine coriacea,* Oe = *Ocotea effusa,* Ov = *Ostrya virginiana,* Pp = *Pinus pseudostrobus,* Qc = *Quercus corrugata,* Qg = *Quercus germana,* Ql = *Quercus leiophylla,* Qx = *Quercus xalapensis,* Qa = *Quercus acutifolia,* Qca = *Quercus candicans,* Qs = *Quercus salicifolia,* Rc = *Rhamnus capreifolia,* Sg = *Styrax glabrescens,* Sl = *Symplocos limoncillo,* Tg = *Telanthophora grandifolia,* Tm = *Trema micrantha,* Ti = *Turpinia insignis,* Vp = *Vachellia pennatula,* Yg = *Yucca guatemalensis.*

(Åström et al., 2007). This coincides with Williams-Linera et al. (2002) who pointed out that in the case of the HMF located at west of Xalapa, Veracruz, the best conserved forests are on very steep slopes, facing further north; while the disturbed forests are in greater measure to the south facing slopes and also Williams-Linera (2007) indicated that those rarest tree species in the HMFs of Veracruz are restricted to high altitudes and slopes facing north.

The highest species richness in this study was found in north-facing sites, which coincides with that recorded by Bale et al. (1998) who found higher species richness in the Polar aspect compared to the Equatorial one in Australian forests. Santiago-Pérez et al. (2009) in a study of a HMF (mountain cloud forest) in western Mexico, they report, in a general way, a lower richness of arboreal species in a site with western exposure in relation to others

located to the north and northwest. However, it should be mentioned that there are results contrary to ours, as mentioned by Luna-Vega et al. (2007) who report 12 and 18 tree species in two mountain cloud forest sites oriented to the north and southwest, respectively. From the above, it can be concluded that there is variation in the richness and plant diversity in the HMF depending on the aspect. It is pertinent to indicate that other researchers have mentioned that fragments of undisturbed forest in Veracruz have an orientation of slopes further north (Williams-Linera et al., 2002); also, López-Pérez et al. (2011) indicate that the HMF, in a region of the State of Mexico, thrives mainly on north-facing slopes, which is probably an indication of a greater richness and diversity in such areas. A plausible explanation is that mentioned by Holland and Steyn (1975), Mata-González et al. (2002) and Renaud et al. (2011), referring that slope facing north in the northern hemisphere, tend to be more humid which benefits different plant species; unlike south-facing slopes which receive more solar radiation and tend to be drier and warmer.

Tree diversity also differed between canopy types, it was greater in the closed canopy. In accordance with the above, Santiago-Pérez et al. (2009) compared different sites of the HMF through a gradient in which the HMF is associated with the Pine-oak Forest (POF) and secondary scrub (SS), the authors found that the richness and diversity were similar in HMF-POF, but the replacement of species was higher in SS, in addition to the density, diameters, basal area and canopy coverage were higher in HMF-POF than SS. González-Zamora et al. (2016), analyzed the tree diversity and species richness between two HMF sites (conserved and disturbed) and a coffee plantation located in this type of vegetation; the authors found a higher species richness in the conserved forest when comparing it with the disturbed site and the coffee plantation. Furthermore, the highest species diversity corresponded to the conserved site and the lowest to the disturbed site, and the greatest floristic dissimilarity occurred between both types of forest.

Basal area and tree density are similar to the forests studied by Williams-Linera and López-Gómez et al. (2008). However, the range of ND of the trees recorded by those authors was greater than that of our records, because they considered individuals with ND $\geq$ 5 cm. The average ND of tree individuals in La Martinica (17.8 cm) was smaller than that reported by García-De la Cruz et al. (2013) who recorded 23.5 cm. This fact indicates that Humid Mountain Forest in our research is a young secondary forest. Also, wider trees than 1 m ND were not found, which coincides with those observations by Williams-Linera (2007), who noted that those trees with larger diameters in Veracruz are scarce, and found in forests located at higher altitudes, farther away from large human settlements.

Tree density in north aspect was no greater than those in other terrain aspects as it was recorded by Måren et al. (2015). Nevertheless, individuals with a larger basal area were found, which coincides with what was observed by Luna-Vega et al. (2007) when they compared two HMF sites in central Mexico; the authors found a greater basal area, canopy coverage and a general difference in the maximum values of the stem of the trees of the site with north aspect in relation to the trees of the southwest site. These results probably indicate a higher biomass production in the north aspect, as it was verified in the studies of Gong et al. (2008) and Sternberg and Shoshany (2001) who found greater productivity and species diversity on slopes facing north compared to those facing south.

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RESUMEN

Estructura y diversidad arbórea de un bosque húmedo de montaña en el Área Natural Protegida La Martinica, Veracruz, México

Introducción: El Bosque Húmedo de Montaña (BHM) posee el mayor número de especies vegetales por unidad de superficie, cuya vegetación se desarrolla en condiciones ambientales muy heterogéneas y presenta una alta variación florística. La conservación del BHM es importante debido a la biodiversidad que alberga y los servicios ambientales que proporciona.
Objetivo: Este trabajo evaluó el efecto de la orientación del terreno y la densidad del dosel del bosque sobre la estructura y diversidad arbórea en el Área Natural Protegida La Martinica, México.
Métodos: Se efectuó un muestreo estratificado en cuatro orientaciones del terreno y dos condiciones de densidad del dosel; se consideraron 25 unidades de muestreo de 20 x 25 m, en las que se registró: el diámetro normal (DN), la altura total y los diámetros mayor y menor de la copa de los individuos con un DN ≥10 cm. La diversidad se estimó por medio de curvas de rarefacción y la estructura se analizó con el índice de valor de importancia (IVI) y el índice de valor forestal (IVF).
Resultados: Se registraron 37 especies pertenecientes a 30 géneros y 24 familias. Se observó una mayor diversidad en la orientación norte y en el dosel cerrado. Las especies arbóreas con valores estructurales más altos fueron diferentes entre orientaciones y tipos de dosel; *Carpinus tropicalis* presentó los valores más elevados en la orientación cenital, *Lippia myriocephala* en las orientaciones este y sur, y *Liquidambar styraciflua* en la norte. En ambos tipos de dosel *Lippia myriocephala* obtuvo los valores más altos del IVI e IVF en el dosel abierto; *Carpinus tropicalis* alcanzó un IVF más elevado en el dosel cerrado.
Conclusiones: La estructura arbórea fue diferente en las cuatro orientaciones estudiadas y en las dos condiciones del dosel. La mayor diferencia en composición de especies y diversidad se observó entre las orientaciones norte y este, de ellas, la norte presentó los valores más altos de riqueza, especies frecuentes y dominantes.

Palabras clave: apertura del dosel; número efectivo de especies; NMDS; orientación del terreno; vegetación arbórea.

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