Chapter

Ecology of Plant Communities in Central Mexico

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Abstract

In Central Mexico converge three biogeographic provinces: Altiplano sur, Sierra Madre Occidental and Costa del Pacífico. Each one of them is composed by different plant communities: Thorn Forest, Temperate Mountain Forest and Dry Tropical Forest respectively. Our objective is to show, through phytoecological analysis, the species richness, diversity and the structure of the plant communities from the Temperate Mountain Forest and from the Tropical Dry Forest. In the Temperate Mountain Forest, 50 forest species were recorded, with a Shannon Wiener diversity index H´ = 1.63 on altitudes from 2400 to 2600 m. The Whittaker β index is B_w = 7.22. In the tropical dry forest, we identified 79 plants species with a mean diversity index H´ = 3.49 on altitudes from 1951 to 2100 m. In this ecosystem the B_w index is 8.12. This study offers important information for the establishment of management practices, considering the protection status from the areas in which this vegetation type is distributed.

Keywords: Aguascalientes, Sierra Fria, Temperate Mountain Forest, Tropical Dry Forest, biogeographic provinces

1. Introduction

Mexico is one of the five countries with the greatest biological diversity in the world, due, in part to the confluence of the Neartic (North America) and Neotropical biogeographic zones (Mexico, Central and south America). As well as, the species evolutionary processes in its territory [1]. The Mexican territory represent only 1% of the earth's surface; nevertheless, Mexico belongs to the select group of the five countries considered megadiverse, along with Brazil, Colombia, China and Indonesia [2, 3]. Due to its geographic locations and its multiple landscapes, a large number and diversity of ecosystems converge in the national territory. For that reason, Mexico is ranked 12th in terms of global forest area [4]. Even though, multiple efforts have been made for the forest conservation during the last decade of the XXI century, on a global scale, forest have been transformed to other uses at a rate of $1.3x10^6$ million ha/yr. or they have been affected by natural disturbances that have partially or totally changed their structure. This amount represents a 19% decrease in comparison to the exchange rate registered in the last decade of the 20th century ($1.6X10^6$ million ha/yr) [5]. Temperate forests in Mexico are found mostly, although not exclusively, in the mountainous areas along the Sierra Madre Occidental (the area with the highest concentration of forest ecosystems in the country), the mountains of Sierra Madre Oriental, the Sierra Norte de Oaxaca and the Altos de Chiapas, as well as in different mountain ranges and isolated mountains in the Altiplano and intermingled in the tropical plains [6]. The conifer and oak forest in Mexico represent the most extensive vegetation cover in terms of vegetation types dominated by woody species, this species covers 16.4% of the total surface of the country, being only surpassed by the xeric shrubland which is the vegetation type which has the largest extension [5]. These ecosystems are important both economically and ecologically, since they support productive activities, harbor great biological diversity and serves as a refuge for wildlife. Likewise, forest provide essential environmental goods and services for the human society subsistence [7, 8].

The State of Aguascalientes has a total extension of 555, 867.4 hectares, of which 291,792.4 hectares equivalent to 52.5% present some forest type [9]. According to the classifications issued by different sources [10, 11], the State of Aguascalientes is made up by three large ecoregions (biogeographic regions), the Temperate Mountain Forest, the Tropical Dry Forest (also known as lowland deciduous forest) and the thorn forest (including crasicaule shrubland and xeric shrubland). The first ecosystem type is mainly distributed in la Sierra Fria, Sierra del Laurel, Sierra de Tepezalá and Cerro de Juan el Grande in El Llano municipality (**Figure 1**). The largest area covered by Temperate Mountain Forest vegetation in Aguascalientes is located in an area locally known as Sierra Fria, this site is a Protected Natural Area by state and federal decree which covers close to 107,000 ha [12]. In the Temperate Mountain Forest, the plant communities the most common vegetation types are oak forests (*Quercus* spp.), pine trees (*Pinus* spp.), oak-pine, pine-oak, juniper (*Juniperus* spp.), manzanita shrubland (*Arcostaphyllos pungens*) and different associations of these genera. The vegetation that has mainly colonized the sites that had been disturbed are *Juniperus deppeana* and *A. pungens*, although there has also been an increase in conifer populations [13]. The second largest formation where this ecosystem is found is located in la Sierra del Laurel in the Southwest corner of the State occupying close to 17,000 ha. This area presents similar plant communities

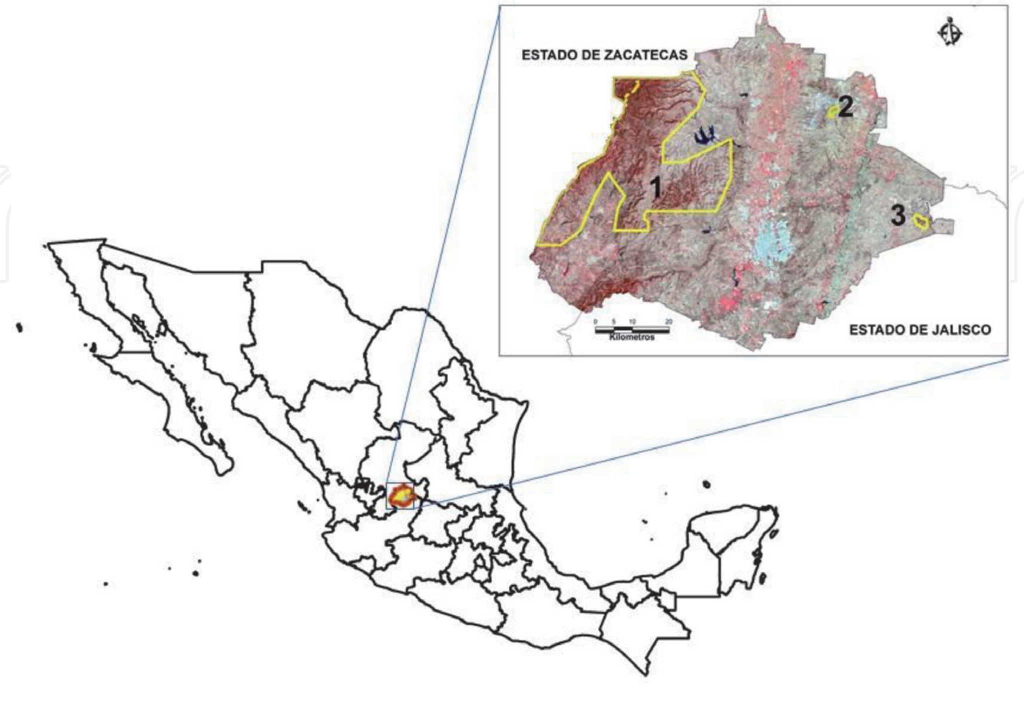

Figure 1.
Distribution areas of the Temperate Mountain Forest in Aguascalientes state. (1) sierra Fria protected natural area (San José de Gracia, Pabellón de Arteaga, Rincón de Romos and Calvillo municipalities); (2) Mountain Hill of Tepezalá, and (3) Juan el Grande Mountain (El llano municipality).

but with a greater dominance of oak populations (*Quercus* spp.) and lower density of manzanita (*A. pungens*).

The largest area occupied by the tropical dry forest is mainly located in the Calvillo municipality, although, there are relics of vegetation indicative of this ecosystem in the Jesus Maria, San Jose de Gracia and Aguascalientes municipalities, which suggests a larger presence of this vegetation type in the past. In the tropical dry forest, forest structures made up of shrubs and trees between 2 and 8 m high and some relics of medium tropical forest. In Aguascalientes, this is one of the ecosystems with the highest species richness [14]. The most representative vegetation in this ecoregion corresponds mainly to the *Lysiloma*, *Bursera*, *Ipomoea*, *Acacia*, *Eysenhardthia*, *Opuntia*, *Mimosa* and *Agave* genera.

Our objective was to provide an overview of some ecological aspects (species richness, diversity and distribution) of woody species natural communities in the most representative ecosystems of the State of Aguascalientes, assuming that there would be a high similarity degree with the vegetation of neighboring sites, considering both the environmental and physiographic characteristics from this State.

2. Materials and methods

Three studies were conducted individually. During 2008–2015, the natural communities of the temperate mountain forest in the area commonly known as Sierra Fria, in the northwest of the State of Aguascalientes, as well as the main disturbances that have affected them in the past and present were analyzed [10, 13]. Likewise, during the period 2011–2015 a study was carried out to determine the diversity, dynamics and functioning of the tropical dry forest in the Calvillo municipality [14, 15].

2.1 Temperate Mountain Forests

2.1.1 Study area and sampling design

This study was carried out in to the Sierra Fria Protected Natural Area (SF-PNA) which is 106,114.6 hectares in size and is located in the northwest of the Aguascalientes State. This area has an altitude ranging between 2,100 and 3,050 masl. The study area comprised 25 thousand hectares, in a polygon located between the coordinates 102°31′31″ to 102°37′44″ west longitude and 22°05′47″ at 22°14′03″ north latitude, assuming that the conditions both geographic, ecological and climatic are representative of the entire ANP (See **Figure 2**).

A stratified sampling strategy was developed [16]. The sampling strata were delimited based on the altitude, solar exposure, and geoform of the site (flat, concave and convex terrain). The first stratum was defined using a Digital Elevation Model (DEM) of the ANP SF, elaborating a spatial grid according to five altitudinal categories: i) 2,000-2,200, ii) 2,200-2,400, iii) 2,400-2,600, iv) 2,600-2,800, and v) >2 800 masl.

To stablish the altitudinal strata, the level curves from study site were defined using the DEM. The solar exposure was approached using an exposure map made with a SPOT 2010® imagine on which the DEM of the site was superimposed. Subsequently, a mesh map was prepared using the ArcGis 10.2. The geoform was obtained based on the slope, where flat terrain = sites with a slope ≤ 10%, concave t. = slope ≥ 10 and ≤ 25% and convex t. = slope ≥ 25%.

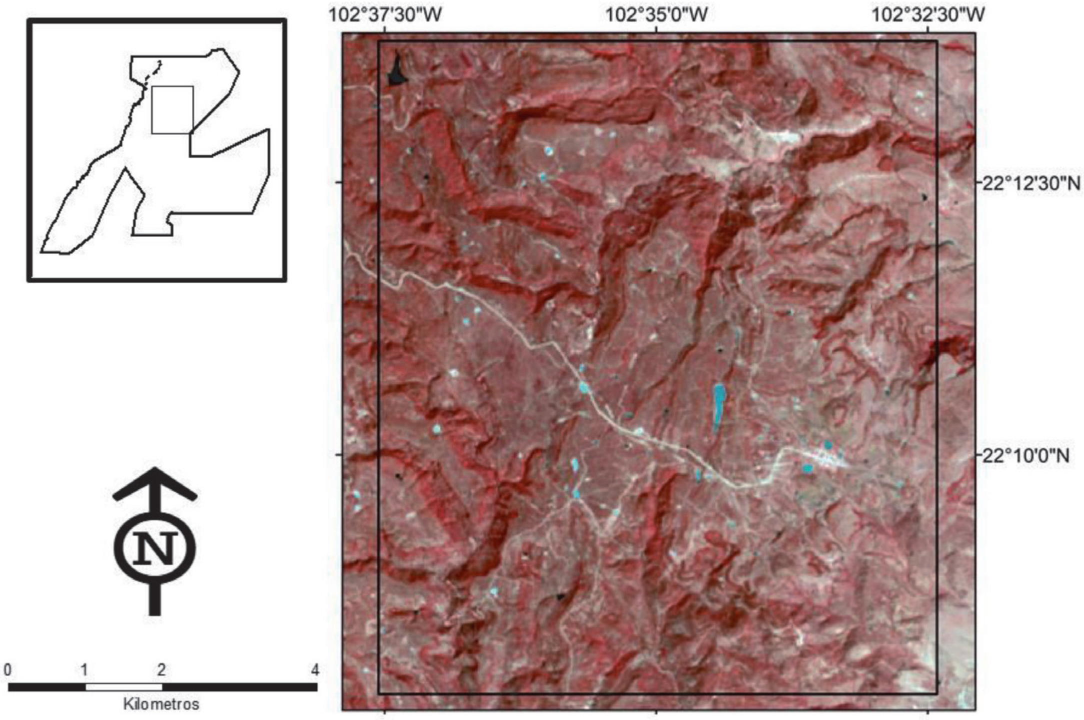

Figure 2.
Location of the protected natural area sierra Fria, the study area of the Temperate Mountain Forest.

2.1.2 Identification, distribution and abundance of forest species

To identify the tree and shrub diversity in the study area, we conducted 60 phytoecological inventories in 60 different sites distributed randomly using the sampling scheme already described (**Table 1**).

The field samplings were performed in rectangular plots of 600 m^2, with a central line 100 m in length and two lateral lines with three m of separation. In each inventory, the frequency of the tree and shrub species present were determined, as well as the site environmental variables. Individuals with DBH ≥ 5 cm and height ≥ 1.50 m were considered as trees. Individuals below these categories were

Altitude levels	**Topographic position**									
	Concave				**Convexe**				**Flat**	**Total**
	N	**S**	**E**	**W**	**N**	**S**	**E**	**W**		
2000–2200	0	0	0	0	1	1	0	0	1	3
2200–2400	0	1	0	0	3	2	0	0	0	6
2400–2600	8	4	1	1	8	3	0	0	3	28
2600–2800	2	0	0	1	4	3	0	0	11	21
> 2800	2	0	0	0	0	0	0	0	0	2
Total	**12**	**5**	**1**	**2**	**16**	**9**	**0**	**0**	**15**	**60**
Total inventories					**60**					

The intersections between lines and columns whose value is zero, indicate areas with little representativeness in the landscape and consequently an absence of samplings.

Table 1.
Number of samplings performed at different altitudinal levels, topographic positions and solar exposures, derived from the sampling system.

considered as juveniles and shrubs. The variables recorded in the site were: altitude, slope (in %), solar exposure (N, S, E, W), physiography (flat land, hillock, plateau, middle slope, high slope, ravine bottom, creek), coverage (c1 = ≤10%; c2 = 11–30%; c3 = 31–50%; c4 = 51–70% y c5 = ≥70%) and geoform. Management variables related to land use (no use, forest exploitation, wildlife management, grazing, agriculture and conservation) were considered as well as intensity of use (null, moderate, over-exploited and not determinable). Each one of the sampling points were geographically located by Transverse Mercator Units (UTM).

In order to identify the oak and conifer species in the field, keys generated by De la Cerda [17] and Siqueiros [18], respectively, were used. The unknown species were collected in botanical presses and identified at the Autonomous University of Aguascalientes herbarium (HUAA). To leave evidence of the new species records in the ANP SF, specimens were deposited in the HUAA.

2.1.3 Distribution and abundance of species

To estimate the distribution of tree and shrub forest species, the presence of each of the species found in each of the 60 sampling sites was quantified. In the case of species considered as restricted distribution (eg. *Quercus cocolobifolia, Pinus chihuahuana*, and *P. duranguensis* var. *quinquefoliata*), samples were taken at specific sites (n = 4), according to the information provided by De la Cerda [17] and Siquéiros [18]. Species with a wide distribution were those that occurred in the greatest number of sites.

The frequency of the species found was determined on 100 m transect at ground level, observing 100 separate points every meter. The species found at each point were recorded (when there was more than one vegetation layer), counting the number of times that each species appeared (absolute frequency) [16] over the whole transect. Relative frequency was calculated using the Equation [19]:

$$\text{Relative frequency} = \left(\frac{\text{Species frequency}}{\sum \text{Frequency values of all} \quad \text{species}}\right) \tag{1}$$

Where:

Frequency of the species x = absolute frequency obtained from each site sampling.

Subsequently, an abundance index was calculated using the equation:

$$\text{Spp.ai} = \frac{\sum_{\text{relative frequencies}}}{\text{Number of sampled sites}} \tag{2}$$

Where:

Spp.ai = Identified Species abundance index.

With this data, distribution and abundance graphs of the main arboreal-shrub forest species were created. The phytoecological analysis was used to calculate the species richness and the Shannon index diversity (*H´*) and the beta Whittaker's (ßw) index respectively, the first were calculated as a function of the altitudinal level, the second also incorporating the geoform using the Species Diversity and Richness® (Pisces Conservation LTD) software. Pear calculate the indexes we used the equation:

$$H' = -\sum_{i=1}^{S} p_i \log_2 p_i \tag{3}$$

Where

S = species richness; Pi = proportion of the individuals of species i with respect to the total number of individuals; ni = number of individuals of species i

$$ß_w = \frac{S}{\bar{\bar{S}}} \tag{4}$$

Where:

S = Species richness and S = mean richness of the site.

2.2 Dry Tropical Forest (DTF)

2.2.1 Study area

Although there are some studies that suggest the existence of relics of Dry Tropical Forest (DTF) vegetation in some municipalities of the Aguascalientes State [15, 20], this ecosystem has a greater representation both in surface area and in its conservation status in Calvillo municipality. The study was conducted in 26 sites with DTF vegetation cover in Terrero de la Labor ejido, located within the Sierra Fria Protected Natural Area, in the Municipality of Calvillo, State of Aguascalientes, in Central Mexico. The ejido polygon comprises an area of 5,861 ha. [21], of which, the DTF occupies 45% of its total area (**Figure 3**). It is located within the extreme coordinates: 102°43′58.88“ West Longitude and 22°6’4.78” North Latitude and at the Southeast end 102°41′24.95“ West Longitude and 21°44’27.61” North Latitude.

2.2.2 Selection of the study sites and sampling design

We used a stratified sampling design system [16]. Sampling strata were delimited based on geoforms, slope, exposure and altitude. To characterize geoforms, three criteria were used: concave, convex and flat terrain. A concave geoform was defined when the slope ranged between 10 and 25%, which usually corresponded to ravines and small depressions. When the sites had a slope between 25 and 60% they were characterized as convex sites. Flat terrains had slopes <10%.

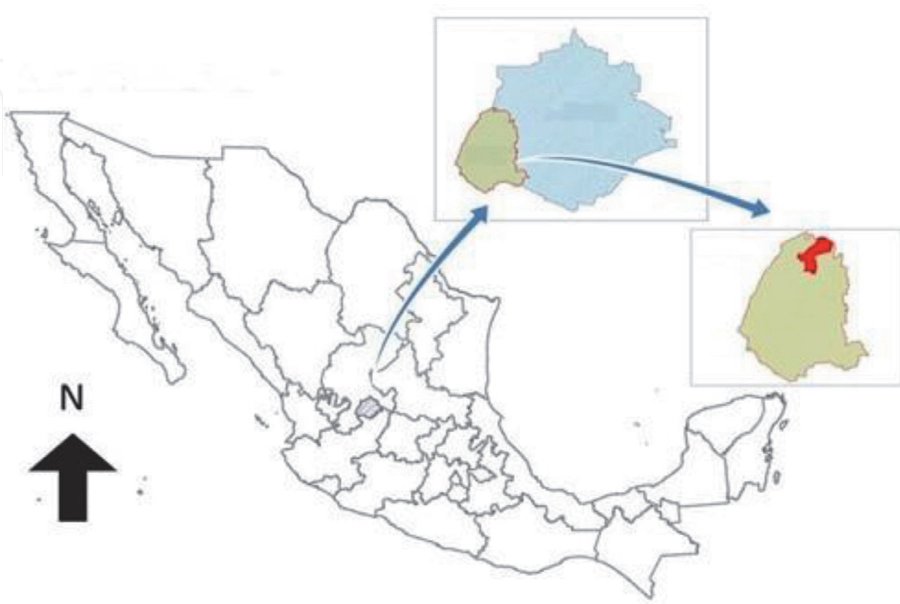

Figure 3.
Location of the study area. (A) Mexico, (B) state of Aguascalientes, (C) municipality of Calvillo and (D) Terrero de la labor Ejido.

Solar exposure was defined using an exposure map made with a Geographic Information System from a 2008 Spot® satellite image and a digital elevation model (MDE). Only the main cardinal points (North, South, East and West) were considered. To locate the altitudinal strata, the contours of the zone defined from the MDE were used. Subsequently, a grid map was developed for the identification of the sampling areas (See **Figure 4**).

2.2.3 Selection and characterization of sites to quantify of the composition and abundance of woody species

We established 26 sites to quantify phytoecological inventories, distributed in the landscape according to the above mentioned sampling system. At each point, the projected coordinates of the site were taken with GPS Garmin 48 XL line in UTM format, zone 13 North and with reference Datum WGS84 and with accuracies of 5 to 12 m with differential kinematic adjustment (WAAS). Subsequently, the points were placed on a SPOT 2010 satellite image (**Figure 5**). Site variables considered were the slope (%), solar exposure, physiography of the terrain, intensity and type of use and canopy coverage.

Slope at each sampling site was obtained by direct field measurement with a Bruntton clinometer with a precision of +/− 2° of variation for each 100 meters of length. This data in turn was contrasted with the data obtained from the digital elevation model with precision of 1 to 2 meters in the Z value. Five classes were used to define the slope: i) <10%, ii) 11–30, iii) 31–50, iv) 51–70 and v) > 70. Exposure to solar radiation was estimated considering the cardinal points North (N), South (S), East (E) and West (O), as well as their combinations.

The altitude of each site was obtained directly in the field with the support of a GPS with barometric adjustment to reduce the effect of mathematical variation of the Geoid model and with precision of 1 to 3 meters. This was compared with the data obtained from the prospecting of points against elevation level curves obtained

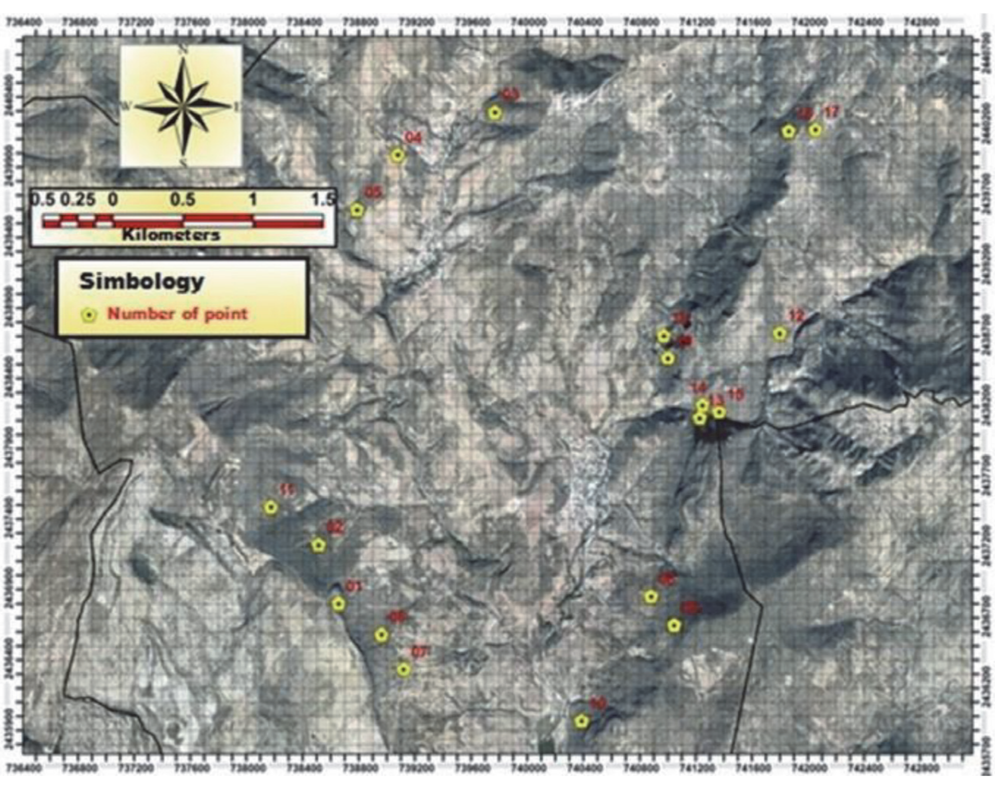

Figure 4.
Geographic representation of dry tropical Forest and the sampling points in Terrero de la labor Ejido, in the municipality of Calvillo, Aguascalientes.

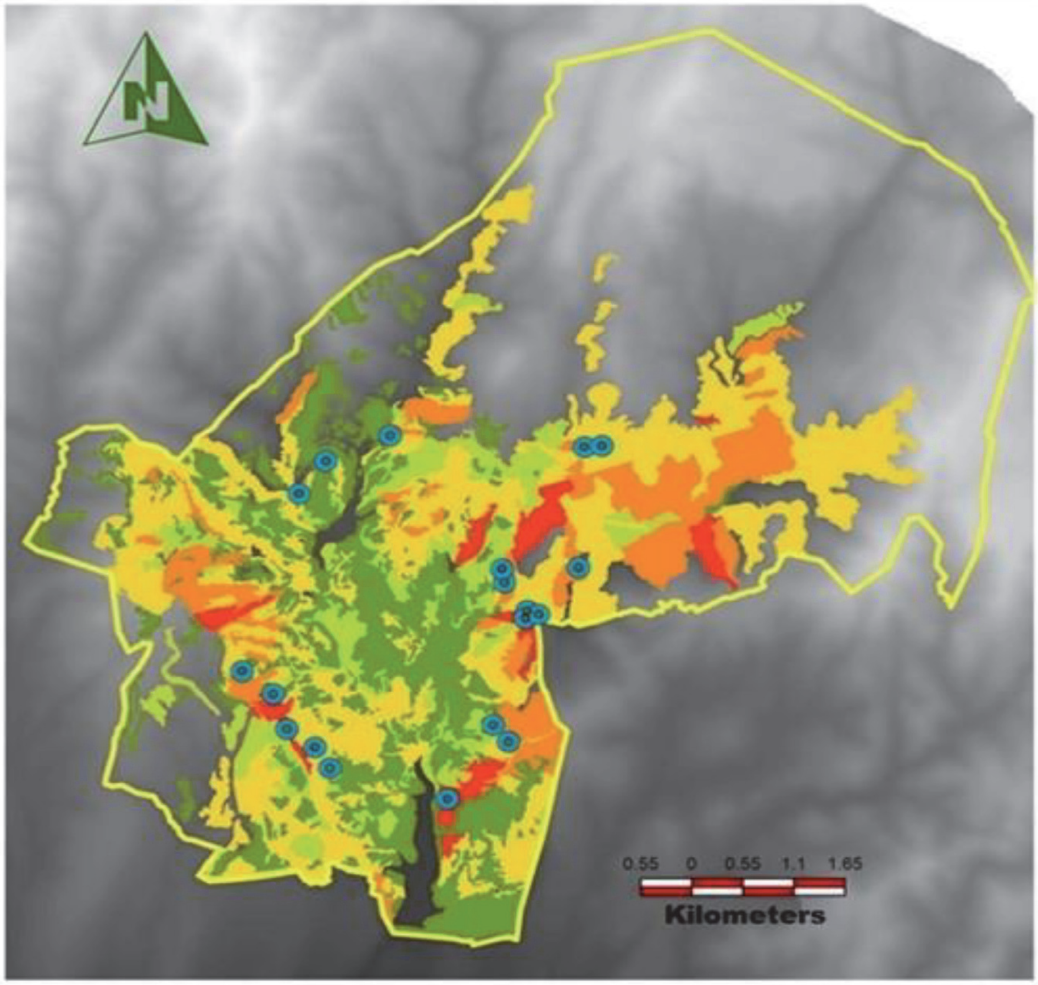

Figure 5.
Ipsographic model of Ejido Terrero de la labor Ejido polygon, and distribution of the sampling points in the DTF.

from the digital elevation model to reduce the potential errors of direct measurements.

The physiography of the terrain was characterized considering flat terrain (slope < 10%), steep (without slope), medium slope (10–25%) and high slope (>60%). The exposure of the sites was quantified with a compass and the magnetic north was taken as reference for its definition in the previously defined ranges. Exposure for each stand of the sampling site was also analyzed along with the digital model of exposures generated from the digital elevation model. The **Table 2** shown the sample points distributed in the landscape of the Dry Tropical Forest.

Other characteristics considered in the description of the sites were the degree of modification (i.e. transformation of geographical space, introduction of species), its intensity (light, medium and overexploited), as well as the type of use by local inhabitants (hunting, grazing, gathering, etc.).

2.2.4 Species richness

To describe species composition, we used a sampling design based on nested plots in an area of 1024 m^2 in each inventory, using the criteria of the minimum area [16]. We started with a plot of 1 x 1 m in a direction perpendicular to the slope in which all present species were recorded, and subsequently, the plot. Subsequently, the plot was increased in size to 2 X 1, 2 X 2, 2 X 4, 4 X 4 m etc. registering the new species for each increment in the area of the squares until reaching the maximum

Meters above sea level (masl)	Topographic position										Total
	Concave coverage (%)					Convex coverage (%)					
	<10	11–30	31–50	51–70	>71	<10	11–30	31–50	51–70	>71	
1800–1900	0	0	0	0	1	0	1	0	3	0	5
1901–2000	0	0	0	0	0	1	1	3	5	1	11
2001–2100	0	0	0	0	0	1	1	2	2	0	6
>2100	0	0	0	0	0	1	1	0	4	0	4
Total inventories	0	0	0	0	1	0	0	5	14	1	26

Table 2.
Distribution of samplings sites according to the proposed design.

extension (i.e.: 32 x 32 m = 1024 m2), to obtain an area/species curve. We then identified the area in which the present species stabilized. This sampling method increased the probability of finding rare species as the area increased, an effect known as Rarefaction [22].

Identification of species was estimated in the field by morphological characters described in previous studies. Specimens that could not be identified in the field were collected and later identified in the Herbarium of the Autonomous University of Aguascalientes (HUAA).

We used the linear intercept survey method (Canfield line). A 100 m long line was perpendicular to the slope, starting at the GPS coordinates of the sampling site, then intersection lines were defined were individuals of DTF species were counted at constant intervals of 1 meter. Shrub and tree individuals were categorized into five heights classes 0–1 m, 1.1–2 m, 2.1–4 m, 4–8 m, 8–15 m and > 16 m. For each class we measured canopy cover of each species by measuring the perpendicular projection of the crown and the frequency of species. To estimate crown, cover the following formula was used:

$$\text{Cover (C)} = \Sigma \text{ length of individuals of species i/total length of intersections X 100.}$$

To estimate frequencies, we used the formula:

$$\text{Frequency (F)} = \Sigma \text{ of number of times that individuals of the species intercepted by the line}/\Sigma \text{ total species intercepted X 100.}$$

2.2.5 Data analysis

Species composition was estimated through the identification of the species found in each of the sampling plots. To find a limit on the number of samples and to reduce the possibility of under- or over-sampling, we conducted a rarefaction analysis. The Shannon-Wienner alpha diversity (H') was calculated for each of the sites and for each altitudinal level using the Richness and diversity species® software, considering that there could be variation in diversity according to the change in environmental conditions in temperature and precipitation as mentioned in the Standard Atmospheric Index (decrease of 0.6°C/100 m altitude).

The formula of the Shannon index is:

$$H' = -\sum_{i=1}^{S} p_i \log_2 p_i \tag{5}$$

where:

- S– Total number of species (species richness)
- p_i– Proportion of individuals of species i in respect to total of individuals (i.e.: relative abundance of species i): $\frac{n_i}{N}$
- n_i– number of individuals of species i
- N– Total number of individuals of all species

The index considers the number of species present in the study area (species richness), and the relative number of individuals of each of those species (abundance).

To estimate replacement rates of species Whitakker's β diversity was computed, using the diversity found for each altitudinal level analyzed as reference.

$$\beta = \frac{S}{\alpha - 1} \tag{6}$$

Where: β = Whitakker's β diversity.
S = Total number of species in samples.
α = Mean number of species in samples.

3. Results

3.1 Temperate Mountain Forest

3.1.1 Richness and diversity species

In the 60 sites, 50 species were recorded, corresponding to 20 families and 27 genera (**Table 3**), of which, due to their structure, 47% (n = 24) were considered trees (height ≥ 3.5 m) and 53% (n = 27) shrubs and juveniles. The best represented families were *Fagaceae* (11 species), *Pinaceae* (8 species) and *Ericaceae* (5 species). The species *Q. obtusata* Bonpl., *J. duranguensis* Martínez and *Crataegus* sp. are new reports in the Sierra Fria.

On average, the highest *H´* diversity index is found in sites whose altitude ranges between 2400 and 2600 and 2600–2800 mamsl (*H´* = 1.48 y 1.63, respectively), the former associated with ravines and difficult access places; the second index corresponds to places with higher moisture content and without use. The lowest indexes (H = 1.22 y 1.36) were found in altitudinal ranges of 2200–2400 and 2000–2200 m, respectively, located on flat lands with intensive management and high resource use rates. According to the geoform, the diversity Wittaker's *ß* was greater on the convex sites (*ßw* = 5.80), followed by the concave sites (*ßw* = 4.27) and flat lands (*ßw* = 4.04). According to the altitudinal level, the highest diversity was found in the sites whose altitude ranges between 2,400 and 2,600 m (*ßw* = 7.22), mainly in ravines and places hard to access. In contrast, the lowest indexes were found on site with an altitude lower than 2, 400 m (*ßw* = 4.52), located on flat lands, under intensive management and easy access.

In the **Figure 6**, we shown an example of dominant vegetation in Temperate Mountain Forest (in conifers, *Pinus leiophylla* and *P. teocote* in order) in the Sierra Fria Protected Natural Area.

Species	Key	Common name*	Family	Forest classification**	Use¥	Report***
Acacia farnesiana	*Acafar*	Huizache	*Leguminosae*	Tr	Nu	Y
Asclepias linearis	*Aline*	Romerillo	*Apocynaceae*	Sh	Nu	Y
Arbutus arizonica	*Aariz*	Madroño	*Ericaceae*	Sh	Fe	Y
Arbutus xalapensis	*Axala*	Madroño rojo	*Ericaceae*	Sh	Fe	Y
Arbutus glandulosa	*Aglan*	Madroño blanco	*Ericaceae*	Sh	Fe	Y
Arctostaphylos pungens	*Apun*	Manzanita	*Ericaceae*	Sh	Fe	Y
Budleia scordioides	*Bsco*	Vara blanca	*Compositae*	Sh	Fr	Y
Budleia cordata	*Bcor*	Tepozan	*Compositae*	Tr	Fr	Y
Bursera fagaroides	*Burfaga*	Venadilla	*Burseraceae*	Sh	Nu	Y
Comerostaphyllis spp.	*Comesp*	Pacuato	*Ericaceae*	Sh	Med	Y
Dalea bicolor	*Dabic*	Engordacabra	*Fabaceae*	Sh	Fr	Y
Dasylirion acotriche	*Dasaco*	Sotol	*Agavaceae*	Sh	Nu	Y
Dodonaea viscosa	*Dovisc*	Jarilla	*Sapindaceae*	Sh	Med	Y
Eucaliptus camaldulensis	*Eucamal*	Eucalipto	*Myrtaceae*	Tr	Nu	Y
Fraxinus uhdei	*Frauhd*	Fresno	*Oleaceae*	Tr	Nu	Y
Garria ovata	*Garova*	planta peluda	*Garryaceae*	Sh	Nu	Y
Pinus chihuahuana	*Pinchi*	Pino Prieto	*Pinaceae*	Tr	Nu	Y
Pinus duranguensis Mart.	*PiduM*	Pino verde	*Pinaceae*	Tr	Ew	Y
Pinus duranguensis f. quinquefoliata	*PiduQ*	Pino verde	*Pinaceae*	Tr	Nu	Y
Pinus leiophylla	*Pile*	Pino Prieto	*Pinaceae*	Tr	Nu	Y
Pinus lumholtzii	*Pilum*	Pino llorón	*Pinaceae*	Tr	Nu	Y
Pinus michoacana	*Pimich*	Pino barbón	*Pinaceae*	Tr	Nu	Y
Pinus cembroides	*Picem*	Pino chaparro	*Pinaceae*	Tr	Nu	Y
Prosopis laevigata	*Prolae*	Mesquite	*Pinaceae*	Sh	Nu	Y
Pinus teocote	*Pinteo*	Pino	*Pinaceae*	Tr	Ew	Y
Jatropha dioica	*Jadio*	Sangre de grado	*Euphorbiaceae*	Sh	Nu	Y
Juniperus flacida	*Jufla*	Olmo triste	*Cupresaceae*	Sh	Nu	Y
Juniperus deppeana	*Judep*	Táscate	*Cupresaceae*	Tr	Fe-Tu	Y
Juniperus duranguensis	*Judur*	Cedro chino	*Cupresaceae*	Sh	Nu	New
Opuntia leucotricha	*Opuleu*	Nopal duraznillo	*Cactaceae*	Sh	Nu	Y
Opuntia streptacantha	*Opust*	Nopal cardón	*Cactaceae*	Sh	Nu	Y
Prunus serotina	*Pruser*	Cerezo negro	*Rosaceae*	Sh	Ft	Y
Quercus cocolobifolia	*Queco*	Palo manzano	*Fagaceae*	Tr	Fe	Y
Quercus chihuahuensis	*Quechih*	Palo blanco	*Fagaceae*	Tr	Fe	Y

Species	Key	Common name*	Family	Forest classification**	Use¥	Report***
Quercus laeta	*Quela*	Palo blanco	*Fagaceae*	Tr	Fe	Y
Quercus grisea	*Quegri*	Palo chino	*Fagaceae*	Tr	Fe	Y
Quercus potosina	*Quepo*	Palo chaparro	*Fagaceae*	Tr	Fe	Y
Quercus microphylla	*Quemic*	Chaparrito	*Fagaceae*	Sh	Nu	Y
Quercus resinosa	*Queres*	Encino hojudo	*Fagaceae*	Tr	Le	Y
Quercus rugosa	*Querug*	Palo blanco	*Fagaceae*	Tr	To	Y
Quercus sideroxyla	*Quersid*	Palo rojo	*Fagaceae*	Tr	Fe-le	Y
Quercus eduardii	*Queredu*	Palo rojo	*Fagaceae*	Tr	Fe-le	Y
Quercus sp.	*Encino 1*	Encino	*Fagaceae*	Sh	Fe	Y
Quercus obtusata	*Querobt*	Encino	*Fagaceae*	Sh	Fe	New
Yucca filifera	*Yufi*	Palma	*Agavaceae*	Sh	Nu	Y
Odontotrichum amplum	*Adoamp*	Vaquerilla	*Asteraceae*	Sh	Nu	Y
Phytecellobium leptophyllum	*Phylep*	Gatuño de la sierra	*Leguminosae*	Sh	Nu	Y
Eisenhardtia polystachya	*Eipol*	Varaduz	*Fabaceae*	Sh	Nu	Y
Crataegus spp.	*Crasp*	Tejocote	*Rosaceae*	Tr	Nu	New
Quercus sp-2	*Encino 2*	Encino	*Fagaceae*	Sh	Nu	Y
Ipomoea stans	*Ipost*	Galuza	*Convolvulaceae*	Sh	Nu	Y

**The common names were provided by the habitants of "La Congoja" community and do not necessarily correspond to the common name in other localities where these species could be found.*
***Within the forest classification, Tr = Tree and Sh = Shrub.*
****The reports correspond to the flora identified previously, the new reports correspond to the individuals identified in this study.*
¥The use of the forest species recorded, depends on the forest managers experience, in this way, Nu = no use; Fe = firewood extraction; Fr = use as forage plant; Med = Medicinal use; Pt = Timber use; for extraction as fence pole; Ew = extraction as wood stripe from P. teocote*; le = leave extraction for ornamentals; To = tools.*

Table 3.
Forest species identified in an area of the SF-natural protected area, Aguascalientes.

3.1.2 Distribution and abundance of species

The most widely distributed species belong to the genus *Juniperus* (locally known as cedros or táscates), *Quercus* (oaks) and *Arbutus* (locally known as madrone). *J. deppeana* is the most widely distributed species followed by *Quercus potosina* and by *Arctostaphyllos pungens.* The madrones (*Arbutus xalapensis* and *A. glandulosa*) appear in fourth and fifth place, respectively (**Figure 7**).

Out of 50 recorded species, 6 are the ones with the highest abundance indexes. *Q. potosina*, the species best represented in the landscape. This species presents the highest abundance index (ia = 0.1585), followed by *J. deppeana* (ia =0.1102) which also presents the widest distribution. Inside the genus *Pinus*, *P. leiophylla* is the most abundant, even above manzanita (*Arctostaphyllos pungens*) and red oaks (*Q. sideroxyla* y *Q. eduardii*; **Figure 8**).

There are species such as *Pinus chihuahuana*, *Pinus lumholtzii* and *Pinus duranguensis* that present restricted distribution, but are abundant in very specific

Figure 6.
Typical vegetation of the Temperate Mountain Forest. (a) Landscape dominates by conifers in the sierra Fria, in this case, by Pinus leiophylla*; (b) wild ash twig (*Fraxinus uhdei*); (c) Manzanita (*Arctostaphyllos pungens*) specimen in a plateau of the sierra Fria; (d) oak specimen locally known as Palo chino (*Quercus grisea*).*

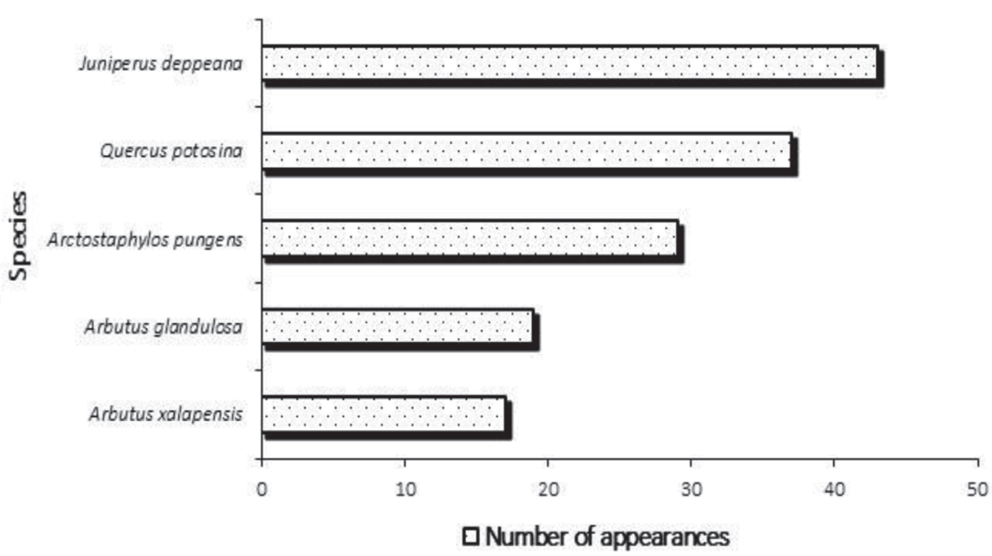

Figure 7.
Forest species with wide distribution in the study area inside the SF-natural protected area.

sites. The distribution analysis based on the altitudinal gradients and geoform suggests that the altitudinal stratum between 2 000 and 2 200 m is the one with the lowest tree and shrub species richness. The best represented species in this range belong to the xeric shrubland being three of them such as *Dodonaea viscosa*, *Phytecellobium leptophyllum*, and *Odontotrichum amplum*, considered as overgrazing indicator species [22]. From the second stratum (2 200 to 2 400 mamsl) *Pinu*s and

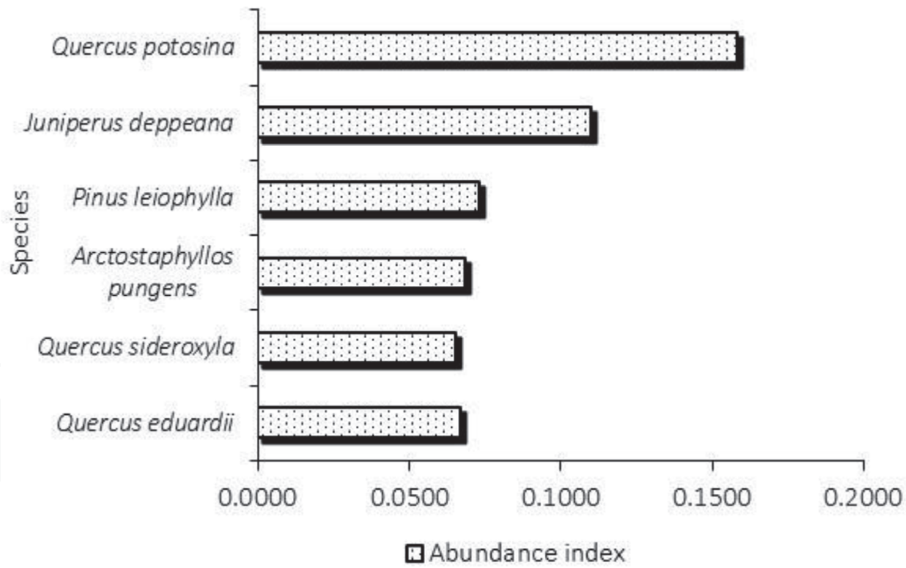

Figure 8.
*Abundancy indexes from the species best represented in the SF-natural protected area, the most representative ecosystem of Temperate Mountain Forest in Ags. The X axis represents the abundancy index which ranges between 0.0670 (*Quercus eduardii*) and 0.1585 (*Q. potosina*). The maximum value of the abundancy index could be 1.*

Quercus species begin to appear, although isolated *Quercus resinosa* individuals can be found at higher altitudes (**Table 4**).

Out of the dominant conifer species at the SF-Natural Protected Area, *Pinus leiophylla* and *P. teocote* are distributed at altitudes ranging from 2 400 to 2 600 masl. Between 2 600 and 2 800 mamsl these two species are more dispersed and located mainly in ravines. *P. leiophylla* is also located on plateaus at 2 700 m (e.g. Mesa del Águila and Mesa del Aserradero). Red oaks (*Q. eduardii* and *Q. sideroxyla*) are distributed at altitudes from 2 400 to 2 600 m, mainly along the ravines (**Table 3**).

In **Figure 9** we shown some species of *Pinus* genera dominants in the intermediate altitudinal strata of SF-Protected Natural Area.

3.2 Dry Tropical Forest

3.2.1 Richness and diversity woody species

We identified 79 species of trees and shrubs, within 45 genera and 14 families (see **Table 5**). The best represented families were Fabaceae (13 genera), Asteraceae (11 genera) and Cactaceae (9 genera). The genera better represented were *Opuntia* (n = 4 spp.), *Acacia* (n = 4 spp.) and *Bursera* (n = 3 spp.). The genero *Salvia* is also important.

The H' diversity found in the DTF of the ejido Terrero de la Labor ejido is constant. The highest diversity index found was 3.49 in two of the 26 analyzed sites, which apparently are well conserved sites. On the contrary, three sites had the lowest H' diversity index with 2.77 (**Table 6**). Although there are apparently no differences, the highest diversity indexes are located mainly in ravines and north facing exposures, and in locations with difficult access (see **Table 7**).

3.2.2 Distribution and abundance of woody species in the DTF

Of the 79 species identified, eight are distributed in more than 70% of the plots of Terrero de la Labor ejido. The species with the greater distribution are the

	ALTITUDE (MASL)±														
Species	**A1**			**A2**			**A3**			**A4**			**A5**		
	2	2.1	2.19	2.2	2.3	2.39	2.4	2.5	2.59	2.6	2.7	2.79	2.8	2.9	3
Arctostaphylos pungens															
Dodonaea viscosa															
Juniperus deppeana															
Quercus potosina															
Bursera fagaroides															
Eisenhardtia polystachya															
Juniperus flacida															
Acacia farnesiana															
Prosopis laevigata															
Arbutus glandulosa															
Quercus resinosa															
Yucca filifera															
Phytecellobium leptophyllum															
Asclepias linearis															
Quercus eduardii															
Odontotrichum amplum															
Pinus leiophylla															
Pinus teocote															
Quercus rugosa															
Quercus chihuahuensis															
Quercus sideroxyla															
Arbutus xalapensis															
Pinus lumholtzii															
Juniperus duranguensis															
Quercus cocolobifolia															
Quercus grisea															
Quercus laeta															

¥The species distribution in different altitudinal gradients was as a function of the 10 dominant species (obtained from the frequency/site) at each altitudinal stratum.
±Altitudes (A1-A5) are calculated in m 1000.*
‡The bars with gray shades indicates that this species is abundant at the altitudinal gradient where it was found. In contrast, the black shades indicate that although this species is not abundant, it was found in.

Table 4.
Dominant species distribution by altitudinal strata.

Myrtillocactus geometrizans (garambullo), *Ipomoea murucoides* (palo bobo), *Eysenhardtia polystachya* (varaduz), *Bursera fagaroides* (venadilla), and *Forestiera phillyreoides* (palo blanco) (**Figure 10**), which were located in 96, 92, 90, 88 and 86% of the plots respectively, assuming that the sampling sites are representative of the entire landscape.

On the other extreme, the rarest species were *Plumeria rubra*, *Ficus petiolaris* and *Fraxinus purpurea*. The first species was only located in one site, while the last two

Figure 9.
Populations of Pinus *(*Pinus *spp) at the SF-natural protected area. The photograph on the left side shows a* Pinus leiophylla *population at the Barranca de Piletas. The pothogragh in the right side shows an image of* Pinus duranguensis. *Photographs as courtesy of Clemente Villalobos llamas and Vicente Díaz Núñez.*

Species	Family	Common name
Acacia berlandieri Benth.	Fabaceae	Carbonera
Acacia farnesiana (L.) Willd.	Fabaceae	Tepame
Acacia pennatula (Schltdl. & Cham.) Benth.	Fabaceae	Huizache o Cascalote
Agave angustifolia Haw.	Asparagaceae	Lechuguilla
Albizia plurijuga (Standl.) Britton & Rose	Fabaceae	Tepeguaje blanco
Alnus acuminata Kunth	Betulaceae	Aile
Amelanchier denticulata (Kunth) K. Koch	Rosaceae	Duraznillo
Amphipterygium molle (Hemsl.) Hemsl. & Rose	Anacardiaceae	Cuachalalate
Asclepias linaria Cav.	Apocynaceae	Algodoncillo
Ayenia mexicana Turcz.	Sterculioideae	
Baccharis heterophylla Kunth	Asteraceae	Escobilla
Bouvardia multiflora (Cav.) Schult. & Schult. f.	Rubiaceae	Clavelito
Brickellia veronicifolia (Kunth) A. Gray	Asteraceae	Orégano de monte
Buddleja cordata Kunth	Buddlejaceae	Tepozán blanco
Buddleja sessiliflora Kunth	Buddlejaceae	Tepozán verde
Bursera bipinnata Donn. Sm.	Burseraceae	Lantrisco
Bursera fagaroides (Kunth) Engl.	Burseraceae	Venadilla
Bursera penicillata (DC.) Engl.	Burseraceae	Arbol de chicle
Calliandra eriophylla Benth.	Fabaceae	Calandria
Castilleja tenuifolia M. Martens & Galeotti	Scrophulariaceae	Hierba del cancer
Cedrela dugesii S. Watson	Meliaceae	Cedro

Species	Family	Common name
Ceiba aesculifolia (Kunth) Britten & Baker f.	Malvaceae	Pochote
Celtis caudata Planch.	Ulmaceae	Capulincillo
Celtis pallida Torr.	Ulmaceae	Vara en cruz
Chusquea sp	Poaceae	Camalote
Colubrina triflora Brongn. Ex G. Don	Rhamnaceae	Algodoncillo
Cordia sonorae Rose	Boraginaceae	Amapa o Vara prieta
Croton ciliatoglandulifer Ortega	Euphorbiaceae	Algodoncillo
Dasylirion acrotrichum (Schiede) Zucc.	Asparagaceae	Sotol
Dodonaea viscosa Jacq.	Sapindaceae	Jarilla
Erythrina flabelliformis Kearney	Fabaceae	Colorín
Eupatorium sp	Asteraceae	Copalillo
Eysenhardtia polystachya (Ortega) Sarg.	Fabaceae	Palo azulo o Varaduz
Eysenhardtia punctata Pennell	Fabaceae	Palo cuate
Ferocactus histrix Lindsay	Cactaceae	Biznaga costillona
Ficus petiolaris Kunth	Moraceae	Ficus silvestre
Forestiera phillyreoides (Benth.) Torr.	Oleaceae	Palo blanco
Fraxinus purpusii Brandegee	Oleaceae	Saucillo
Gymnosperma glutinosum (Spreng.) Less.	Asteraceae	Cola de zorra
Heliocarpus terebinthinaceus (DC.) Hochr.	Meliaceae	Cicuito o Cuero de indio
Ipomoea murucoides Roem. & Schult.	Convolvulaceae	Palo bobo
Iresine sp.	Amaranthaceae	Cola de zorra
Jatropha dioica Sessé	Euphorbiaceae	Sangregrado
Koanophyllon solidaginifolium (A. Gray) R. M. King & H. Rob.	Asteraceae	Caballito
Karwinskia humboldtiana (Schult.) Zucc.	Rhamnaceae	Coyotillo
Leucaena esculenta (Moc. & Sessé ex DC.) Benth.	Fabaceae	Guaje rojo
Lippia inopinata Moldenke	Verbenaceae	Palo oloroso
Lysiloma acapulcense (Kunth) Benth.	Fabaceae	Ébano o Palo fierro Tepeguaje
Lysiloma microphyllum Benth.	Fabaceae	Tepeguaje
Mammillaria bombycina Quehl	Cactaceae	Biznaga de seda
Mammillaria sp.	Cactaceae	Biznaga
Manihot caudata Greenm.	Euphorbiaceae	Pata de gallo
Mimosa monancistra Benth.	Fabaceae	Gatuño o Uña de gato
Mimosa sp.	Fabaceae	Huizache
Myrtillocactus geometrizans (Mart. ex Pfeiff.) Console	Cactaceae	Garambullo
Montanoa leucantha (Lag.) S.F. Blake	Asteraceae	Talacao o Vara blanca
Opuntia leucotricha DC.	Cactaceae	Nopal chaveño o duraznillo
Opuntia robusta J.C. Wendl.	Cactaceae	Tuna tapona
Opuntia sp.	Cactaceae	Nopal
Opuntia streptacantha Lem.	Cactaceae	Nopal cardón

Species	Family	Common name
Perymenium mendezii DC.	Asteraceae	
Pistacia mexicana Kunth	Anacardiaceae	Lantrisco
Pittocaulon filare (McVaugh) H. Rob. & Brettell	Asteraceae	Palo loco
Plumbago pulchella Boiss	Plumbaginaceae	Chilillo medicinal
Plumeria rubra L.	Apocynaceae	Flor de mayo
Prosopis laevigata (Humb. & Bonpl. ex Willd.) M.C. Johnst.	Fabaceae	Mezquite
Ptelea trifoliata L.	Rutaceae	Naranjo agrio o Zorrillo
Quercus laeta Liebm.	Fagaceae	Roble blanco
Salvia mexicana L.	Labiatae	Tlacote
Salvia sp.	Labiatae	Salvias
Stachys coccínea Ortega	Labiatae	Mirto
Stenocereus queretaroensis (F. A. C. Weber) Buxb.	Cactaceae	Pitahaya
Tecoma stans (L.) Juss. ex Kunth	Bignoniaceae	Tronadora
Trixis angustifolia DC.	Asteraceae	Vara verde
Verbesina serrata Cav.	Asteraceae	Vara blanca
Viguiera quinqueradiata (Cav.) A. Gray ex S. Watson	Asteraceae	Vara amarilla
Wimmeria confusa Hemsl.	Celastraceae	Algodoncillo
Yucca filifera Chabaud	Asparagaceae	Palma
Zanthoxylum fagara (L.) Sarg.	Rutaceae	Rabo lagarto

Table 5.
List of species identified in the dry tropical Forest of Terrero de la labor Ejido, Calvillo, Ags.

Altitud level (masl)	Sampled sites	*H´*
1851–1900	7	3.08
101–1950	5	2.57
1951–2000	7	3.60
2001–2100	5	3.14
>2100	2	3.25

Table 6.
Average H′ diversity indices associated to different altitudinal ranges in the DTF of Terrero de la labor Ejido.

were only found in two and three sampling sites, respectively. Their low frequency could be associated to their presence in mid statured forests. The most abundant species are those that, even though they are not those with a wide distribution in the landscape, in the places where they are located their frequency is higher than the rest of the identified species. In the DTF of the Terrero de la Labor, the most abundant species belonged to five different genera, of which the most important are *Lysiloma microphylla* (tepeguaje), *Ipomoea murucoides* (palo bobo), and *Bursera fagaroides* (locally known as venadilla) (**Figure 7**). In the case of *Ipomoea murucoides*, it occupies the second place in both distribution and abundance (see **Figure 11**).

Slope range (%)	Sampled sites	*H´*
0–9	6	2.94
9–25	3	2.88
26–37	5	2.92
37–49	4	3.26
49–64	5	3.34
>65	3	3.39

Table 7.
Diversity indexes associated to different slopes of the sites.

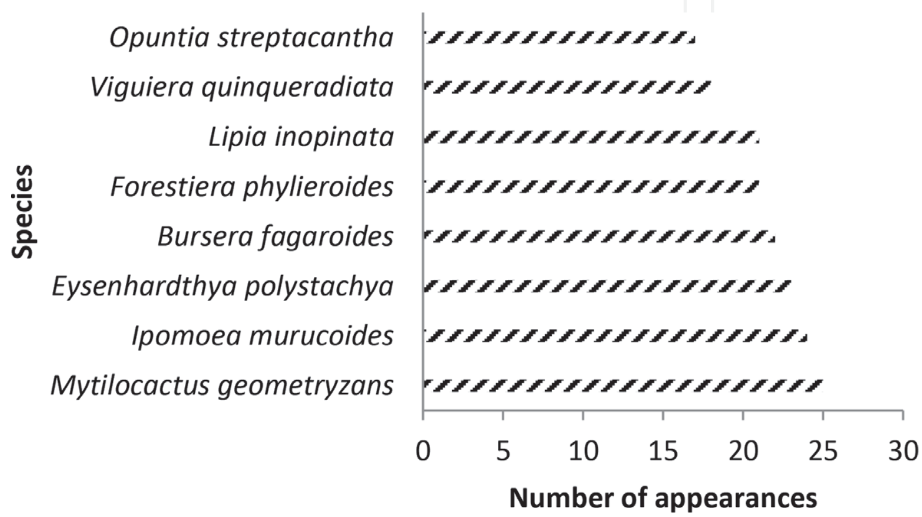

Figure 10.
Species best represented in the DTF Terrero de la labor Ejido.

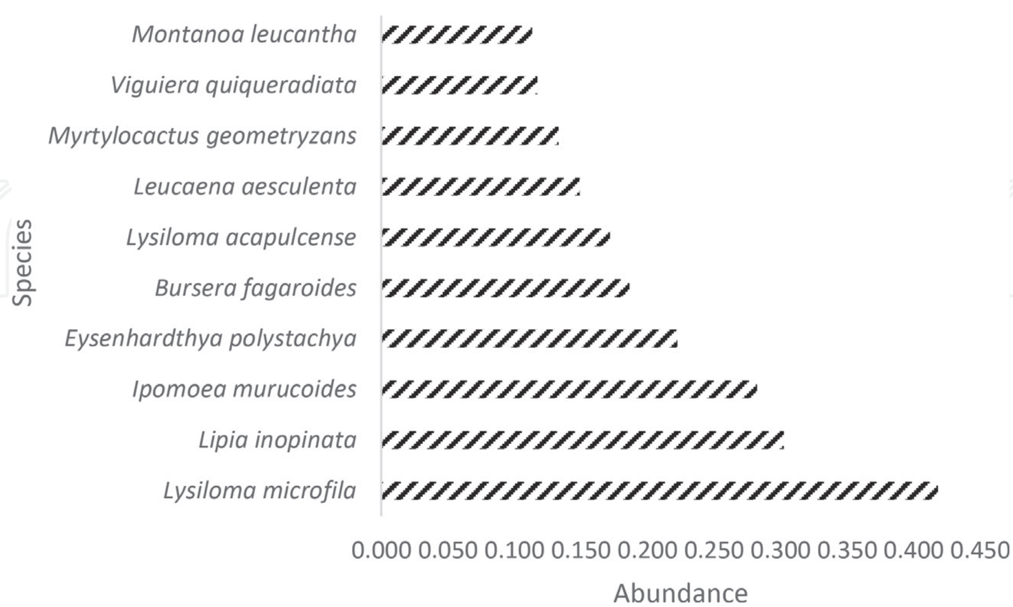

Figure 11.
List of species with the highest abundance in Terrero de la labor Ejido.

The **Figure 12** shown some species of the dominant vegetation in tropical dry forest, in this case, of the Terrero de la labor and las Moras ejidos in the Municipality of Calvillo, Aguascalientes State.

4. Discussion

The loss of biodiversity is one of the environmental problems that has managed to arouse broad global interest in the last two decades [4, 23]. Some of the main

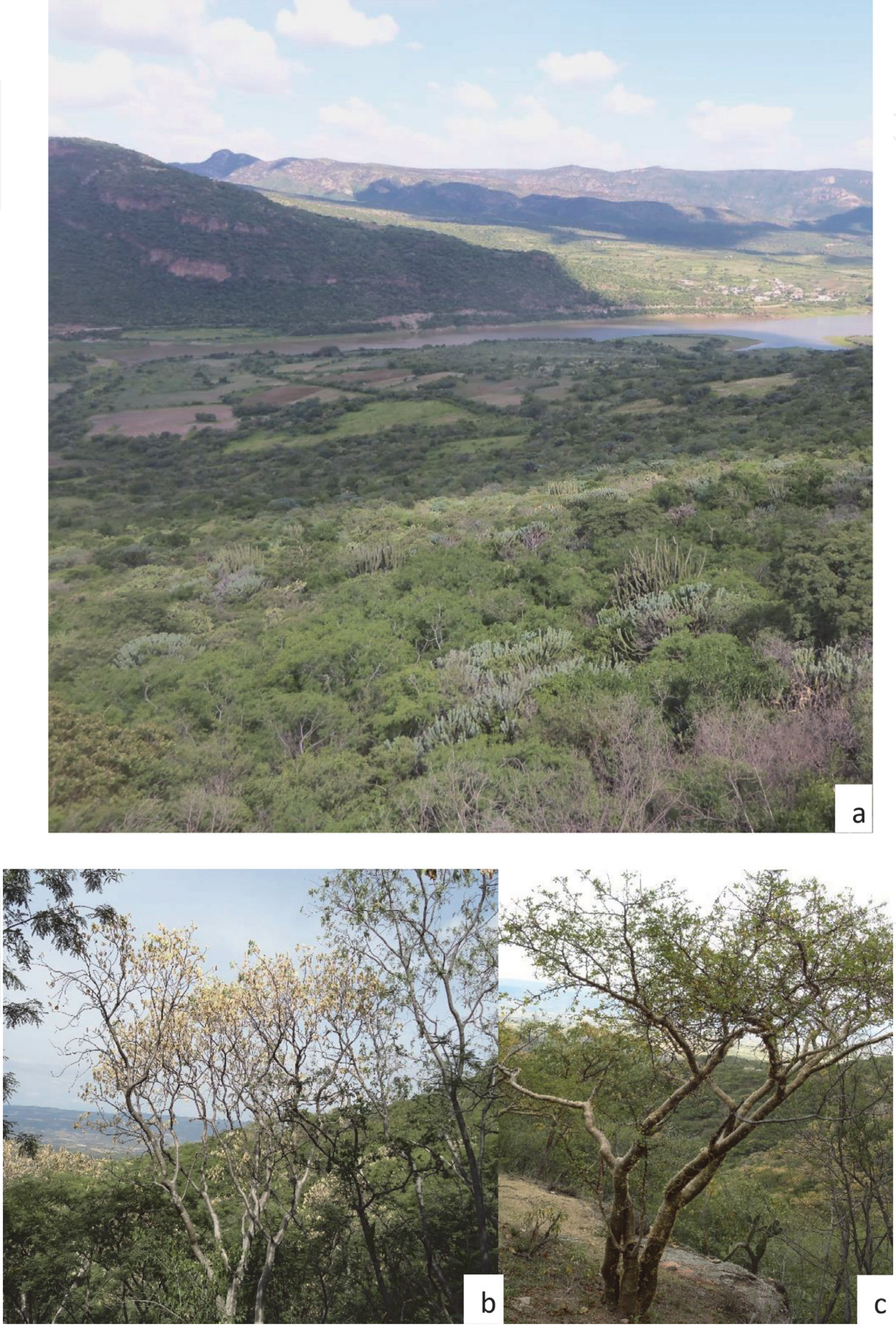

Figure 12.
Diversity of forest species in the tropical dry Forest. (a) Landscape of the tropical dry Forest in the Terrero de la labor and las Moras Ejido; (b) an example of Manihot caudata, *locally known as jaboncillo; (c) specimen of* Bursera fagaroides *(locally known as venadilla or papelillo). Photographs courtesy of Vicente Díaz Núñez, Joaquín Sosa-Ramírez and Jesús Argumedo-Espinoza.*

causes are related to human activities, either directly (overexploitation) or indirectly (habitat alteration), although there is generally an interaction between them. The communication systems have impacted in such a way that both the government and the private sector, as well as society in general, consider a priority to direct greater efforts towards conservation programs. The basis for an objective analysis of biodiversity and its change lies in its correct evaluation and monitoring.

In the Temperate Mountain Forest, the 50 woody species identified show a high species richness in comparison with other mountain regions. The best represented genera correspond to oak trees (*Quercus spp.*) and pines (*Pinus spp*.). The studied area harbors a small portion (6.8%) of the oak species that inhabit Mexico (161 species) [24]; although, this percentage is lower than those reported in areas with a greater territorial surface and higher rainfall, such as the case of San Luis Potosi and Jalisco States, which has identified 45 and 51 oak species respectively, that represent 27.95 and 36.9% of the total oak species registered in Mexico [25], the SF-NPA represent less 5% of the territorial surface in the mentioned states. In relation to pines, the studied area has about 17% of the species identified in Mexico [26]. This proportion is similar to that reported by Márquez-Linares et al., [27] in an area of pine-oak forest, in Durango, Mexico, where they recorded 8 pine species. In relation to "Las Joyas" scientific station, in the Sierra de Manantlán Biosphere Reserve, the *Quercus* diversity (16 spp.) is similar to the one in the Sierra Fria, although the area of las Joyas is smaller (Ca. 3600 ha.).

In the Sierra Fría, the most widely distributed and abundant species are the potosine oak (*Q. potosina*) and alligator juniper (*J. deppeana*). In the case of *Q. potosina*, its distribution and abundance may be related to the dominant physiography in this area, as well as to the mean annual precipitation (650 mm). The appearance of *J. deppeana* is possibly related to the disturbances that occurred in the Sierra Fria during the period between 1920 and 1940 [28]. This species has probably been a pioneer in the recovery of the vegetation cover, although the presence of manzanita (*A. pungens*) has also been documented colonizing sites where disturbances occurred, either natural, as in the case of fires or, anthropogenic, such as forest clearance and harvesting. Pines population is restricted to the Sierra Fría and the Sierra del Laurel. In the Sierra Fria, *Pinus teocote* (locally known as pino ocote) and *Pinus leiophylla* (locally known as pino prieto) are the two most abundant pine species. Its population is abundant in humid places and altitudes higher than 2,500 masl. *P. leiophylla* isolated specimens have been found on flat lands, which suggests that in the past this species had a greater distribution. In the Sierra del Laurel only two pine species have been identified, the pino triste (*Pinus lumholtzii*) and the pino piñonero (*Pinus cembroides var. cembroides*) in isolated populations, which suggests that in the past they were more abundant; however, the existing information is incipient.

The *H*'diversity indexes for each altitudinal stratum suggest that, between 2,400 and 2,600 mamsl, the plant richness of the SF-Natural Protected Area is similar to temperate forests, similar to what the β Whitakker index showed.

The distribution of species such as *J. deppeana* and *Q. potosina*, the most abundant and widely distributed, are influenced by flat sites and canopy covers that vary between 30 and 50%. One explanation is that *Q. potosina* tolerates high drought rates and *J. deppeana* is a pioneer species in disturbed sites, as suggested by Minnich et al. (1994) [28]. On the other hand, the presence or absence of the species may also be dictated due to their dispersal capacity or to the presence or absence of dispersers [19]. The results obtained contribute to describe the habitat of the species, which is an essential factor in programs aiming the restoration and management of temperate climate forests [8, 29], actions that, at least in the case of Mexico, have shown few results.

The species richness in BTS is generally lower than in humid tropical forests [30], although higher than in Temperate Mountain Forests [25]. The BTS is dominated by relatively short trees, most of which lose all their foliage during the dry season. In this community, herbaceous life form, thin woody species, and vines are common, but epiphytes and thick lianas are less abundant and diverse than in humid forests [31]. Diversity is generally higher without a clear dominance of any species, to the point that many of them are rare [32]. In this type of ecosystem, it is common to identify some genera such as *Bursera, Lonchocarpus, Lysiloma* and *Jatropha*, as well as emerging columnar cacti [33].

The species richness found at the Terrero de la labor Ejido BTS (N = 79) is similar to that reported by Trejo (2005) [33], where he points out that on average the tropical dry forest in Mexico harbors around 74 species with a DBH ≥ 1 cm in 0.1 ha. However, in the study site, some species considered "rare" which are indicators of medium forest (e.g *Amphipterygium molle*) were found in ravines and better preserved sites, suggesting that at some point this ecosystem had a greater presence in the landscape.

The analysis of the diversity, distribution and abundance associated with the Tropical Dry Forest in Aguascalientes has been little addressed, so the study conducted in the BTS of the Municipality of Calvillo represents one of the first efforts to understand this ecosystem natural heritage [14]. Previously, partial floristic studies had been carried out, studies which mainly referred to the dominant vegetation types and some important species, however on these studies there were gaps in relation to the ecology of the plant communities [20]. On the other hand, other studies mention some factors related to the mortality of these natural communities [15], but there is no information on vegetation diversity which reflects the real tropical dry forest importance.

This work contributes directly to the management of the ecosystems analyzed. Knowledge about species richness and their distribution provides an overview of the territory's conservation state, considering that both the Temperate Mountain Forest and the Tropical Dry Forest studied are part of the Sierra Fria Protected Natural Area, which is the protected area with the biggest extension in the State. On the other hand, the bases are established for the restoration of degraded ecosystems, either through active restoration or through mechanisms of ecological succession (passive restoration) [29].

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