diversity

MDPI

Article

Importance of Local Studies of Vascular Plant Communities in Conservation and Management: A Case Study in Susticacán, Zacatecas, Mexico

Leopoldo Hurtado-Reveles [1], Mireya Burgos-Hernández [1,*], Juan Carlos López-Acosta [2] and Monserrat Vázquez-Sánchez [1]

[1] Programa de Posgrado en Botánica, Colegio de Postgraduados, km 36.5 Carretera México-Texcoco, Montecillo, Texcoco 56230, Mexico; leohr@outlook.com (L.H.-R.); vazquez.monserrat@colpos.mx (M.V.-S.)

[2] Centro de Investigaciones Tropicales, Universidad Veracruzana, José María Morelos 44, Zona Centro, Xalapa de Enríquez 91000, Mexico; carlolopez@uv.mx

* Correspondence: burgos.mireya@colpos.mx

Abstract: Some parts of the globe have a deficient vegetation coverage survey causing localized plant community qualities generalized from larger scales, hindering their particular configuration. This process is emphasized in megadiverse countries such as Mexico by transformation and loss of land cover. This can be reflected in the municipality of Susticacán, Zacatecas, settled in a mountainous, scarcely explored area, the Sierra de los Cardos. This study aimed to characterize its plant communities, produce a fine-scale map and compare them to other descriptions. Oak forests, pine forests, grasslands, nopaleras, chaparral, and rock outcrop vegetation were detected through satellite image analysis, sampled, statistically evaluated, and their descriptions supported by the literature. The first two presented a high diversity and endemism, despite a small surface. The chaparral occupied the largest area, and its structure and composition suggest its secondary vegetation in expansion. The presence of exotic–invasive species and human activities threaten the native flora. This study is the first to provide detailed information on the plant communities in Susticacán and is a model for the study of local-scale regions. It highlights the importance of describing and mapping them as a contribution to delineate conservation and management efforts.

Keywords: anthropogenic impact; conservation; plant resource management; Sierra de los Cardos; temperate ecosystems; vascular flora

Citation: Hurtado-Reveles, L.; Burgos-Hernández, M.; López-Acosta, J.C.; Vázquez-Sánchez, M. Importance of Local Studies of Vascular Plant Communities in Conservation and Management: A Case Study in Susticacán, Zacatecas, Mexico. *Diversity* **2021**, *13*, 492. https://doi.org/10.3390/d13100492

Academic Editors: Adriano Stinca and Miguel Ferrer

Received: 15 September 2021
Accepted: 7 October 2021
Published: 9 October 2021

1. Introduction

Vegetation in many parts of the world has poor coverage surveys, which produce insufficient data, making proper characterization and classification difficult. In recent years, the study of vegetation has advanced considerably [1]; however, most of the work is concentrated on accessible regions, with a long tradition of vegetation studies, excluding particular areas that require detailed research [2]. In addition to the above, there is an issue of generalizing the qualities of plant communities at a local level, from studies performed at larger geographical scales, which results in an excessive simplification, since it has been shown that it is necessary to obtain information at a fine-grained level as environmental processes at the local scale have the largest influence on the assembly of plant communities [3], and unfortunately, these small remnant fragments are the common landscapes worldwide. Fine-scale contingencies are more significant in plant communities where individuals are sessile, and interactions are local [4]. The non-equilibrium ecological paradigm now offers a conceptual framework for exploring and understanding the role of various community patterns, integrating structural and functional aspects at multiple scales [5].

The first step to understanding systems with vegetation is to obtain information on their characteristics and distribution, which together allow their correct classification and location [6,7]. In this sense, vegetation classification is important, as it provides a common language for scientific communication, allows the comparison of communities between regions, and constitutes a baseline for decision making in the use and conservation of plant resources [8]. Vegetation has been classified mainly based on physiognomic criteria, abiotic and floristic characteristics (species composition) [9]. In Mexico and most neotropical countries, physiognomic features have been the most used, since they take into account elements of the landscape that not only define the types of vegetation [10,11] but also influence how plants interact with other organisms and with the environment [1].

The heterogeneity of the Mexican territory, a product of its complex evolutionary history, geographical location, and rugged orography, makes it the possessor of a great diversity of plant communities [11,12]. At the same time, Mexico holds one of the first spots in the world in terms of deforestation and fragmentation rates. It is estimated that in 2020 alone, 300 thousand hectares of natural forests were lost in the country, while so far this century, this value has been calculated at 4.49 million hectares [13]. To these effects of degradation, the results of climate change are added, which in mountainous areas cause an altitudinal migration of species [14–16]. Focusing efforts on generating greater knowledge about the vegetation present in mountain areas in the country at all spatial scales is necessary.

The Sierra Madre Occidental (SMOc) constitutes one of the most important physiographic provinces in the country in terms of plant diversity [17,18]. The Sierra de los Cardos is a spur of this important mountainous system and breaks the continuum of semi-arid vegetation typical of the surrounding area with altitudes below 2000 m since the mountain range reaches 2931 m asl and presents varied climatic conditions that favor the development of plant communities different from those around it [19–23]. In addition to its biological importance, it has great cultural value, since it constitutes part of the pilgrimage route of the Wixárika people, who consider it a sacred landscape [24], highlighting the link between spirituality and nature, in such a way that its inclusion in The World Heritage List has been proposed [25], which makes this region even more relevant from a biocultural perspective.

Despite the biological and cultural importance of the Sierra, agricultural and livestock activities have gained ground in recent years, registering high levels of anthropogenic impact [26]. Added to this is the documented effect of global climate change on vegetation in temperate climates [27–31], which together, puts the permanence of the ecosystems present in the region at great risk.

We suggest that local studies of plant communities can reveal important information for understanding the structural complexity of vegetation, as well as for future conservation and management plans. In this context, we used as a study model the Sierra de los Cardos in the municipality of Susticacán, Zacatecas, Mexico, to understand the importance of conducting fine-scale vegetation studies versus generalizing it from large-scale work. Therefore, the objectives were (a) to characterize the vascular plant communities present in the region based on their physiognomy and floristic composition, (b) to provide information on their distribution and correct location by generating a fine-scale map, and finally (c) to compare the characteristics of these plant communities with those recognized so far for the study area. This study is the first to provide detailed information on the composition, structure, and distribution of the vascular plant communities present in Susticacán, Zacatecas, Mexico, and highlights the importance of the description and mapping of vegetation at local scales as a contribution to delineate essential habitats and to manage human activities in these areas.

2. Materials and Methods

2.1. Study Site

The Sierra de los Cardos is a spur of the SMOc mountainous system that consists of a region of abrupt topography that reaches 2931 m asl. This mountain range is isolated from the mountainous continuum by hills, valleys, and plateaus of lower altitude, generally below 2000 m asl [32,33]. It is part of the SMOc physiographic province, Sierras and Valles Zacatecanos subprovince, with an area of just over 800 km^2, among the municipalities of Jerez, Monte Escobedo, Susticacán, Tepetongo and Valparaíso in the state of Zacatecas [19–23]. Susticacán is the only municipality where the Sierra covers little more than 70% of its surface since, of its 201 km^2 of territorial extension [21], this spur occupies 156 km^2. This part of the mountain range has an altitudinal variation that ranges from 2070 to 2931 m, and is located between the extreme coordinates 22°41′48′′ and 22°33′45′′ N and 103°19′22′′ and 103°04′47′′ W (Figure 1). The climate varies from temperate subhumid with rains in summer and medium humidity in its western part (Cw1), to semi-dry temperate with rains in summer (Bs) towards the southwest [34]. The precipitation ranges from 600 mm for the lower parts to the east to 700 mm for the north-western portion. The main type of soil in the area is leptosol, and the main rock type is extrusive igneous [21].

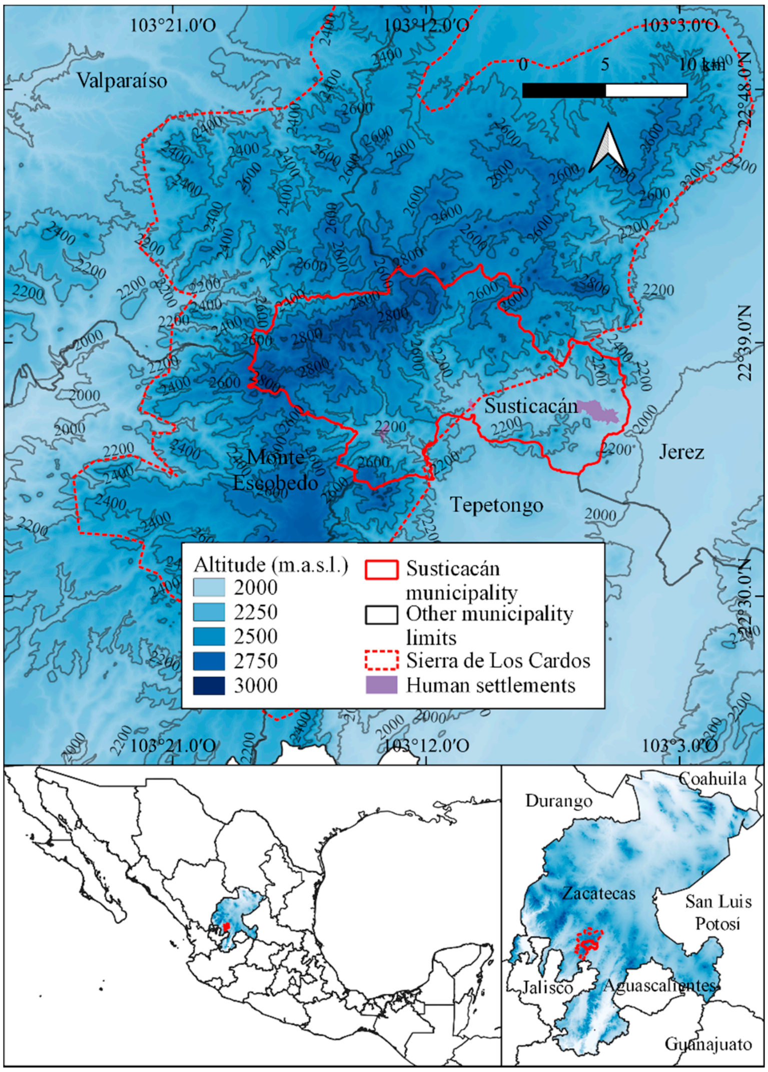

Figure 1. Geographic location of the Sierra de los Cardos in the municipality of Susticacán, Zacatecas, Mexico.

2.2. Identification of Vascular Plant Communities

An unverified preliminary delineation of the vegetation cover was made from the observation of Landsat 8 satellite images (United States Geological Survey; USGS), in which surfaces were differentiated according to color and texture [35]. This preliminary identification allowed the detection of six different types of vegetation cover present in the Sierra de los Cardos, Susticacán.

We verified the information obtained and generate a classified image with supervision; field trips were carried out in each of the different types of coverage identified. Ten sampling points were randomly established (60 in total), in which an inventory of the vascular flora was carried out by the plot method (10 × 10 m) [36]. From each botanical specimen collected, its coverage–abundance was recorded using the Braun–Blanquet scale modified by van der Maarel [37].

To corroborate if the plant communities were different entities, a nonmetric multidimensional scaling analysis (N-DMS) and an analysis of similarities (ANOSIM) were carried out [38,39]. Both methods are commonly used to discriminate how valid an a priori group delimitation is in statistical terms.

To identify which species contribute the most to the dissimilarity between communities, a SIMPER analysis was performed using the Bray–Curtis coefficient [40]. In parallel, the IndVal index was calculated to identify the indicator species of each plant community [41]. All statistical analyses were carried out in PAST 4 software [42].

2.3. Characterization and Distribution of Vascular Plant Communities

To determine the types of vegetation and their characterization, the proposal of Miranda and Hernández-X [43] was taken as a reference, with adjustments based on the characteristics of the communities at the local level. For the above, different physical and environmental variables were considered for each sampling plot, such as altitude, degree of inclination and orientation of the slope, and percentage of woody and herbaceous cover, as well as litter, bare soil, and stony ground. Floristic–structural criteria were also considered, such as the composition and frequency of the registered species, their coverage–abundance, habit, and direct observation of the vertical structure in the sampling sites. These results were also used as a comparison to the most cited and commonly known structural species for each of the different plant communities according to the works of Guzmán and Vela-Gálvez [44], Miranda and Hernández-X [43], Enríquez-Enríquez et al. [45], Rzedowski [11] and González-Elizondo et al. [46].

The percentage of endemic species was determined following COTECOCA [47], Rzedowski [11], Herrera-Arrieta and Pámanes-García [48], and Villaseñor [49], as well as the presence of introduced elements [50,51]. The ecological importance of each species by plant community was also considered by estimating an index of adjusted ecological importance value (AEIV) [52].

With the information generated, a distribution map of the different plant communities presents in the Sierra de los Cardos of the municipality of Susticacán was produced, using Landsat 8 (USGS) images and with the support of the Idrisi Terrset software [53] and QGIS 3.16 [54]. The scenes were atmospheric and topographically corrected, then the spectral signatures were calculated for each putative plant community using the sampling points of the vascular flora as training sites [36]. The bands used were 2, 3, 4, and 8, as well as an additional one with the Normalized Difference Vegetation Index (NDVI) values. The classification was carried out using the Fisher LDAC (Linear Discriminant Analysis Classification) method [55], since it was the most accurate supervised classification algorithm observed during the samplings [53]. To solve some inconsistencies that arose after the classification based only on spectral values, the results were refined considering altitudinal limits and rock types of the study area, for which the descriptions of the Susticacán municipal record were provided by the Instituto Nacional de Estadística y Geografía (INEGI) [21].

3. Results

3.1. Identification of Vascular Plant Communities

According to the different statistical analyses, a clear difference is shown between the six plant communities studied. The N-MDS analysis (Figure 2) shows the six communities as separate entities with a high-stress value (0.3). According to ANOSIM, all communities showed high dissimilarity among themselves (R > 0.8; Table 1), and according to SIMPER results, six species (*Quercus rugosa* Née, *Pinus cembroides* Zucc., *Arctostaphylos pungens* Kunth, *Opuntia leucotricha* DC, *Cyperus seslerioides* Kunth, and *Agave schidigera* Lem.) contribute 41.9% of the total dissimilarity between communities. These same species are indicative of a particular plant community, according to the findings of IndVal (Table 2).

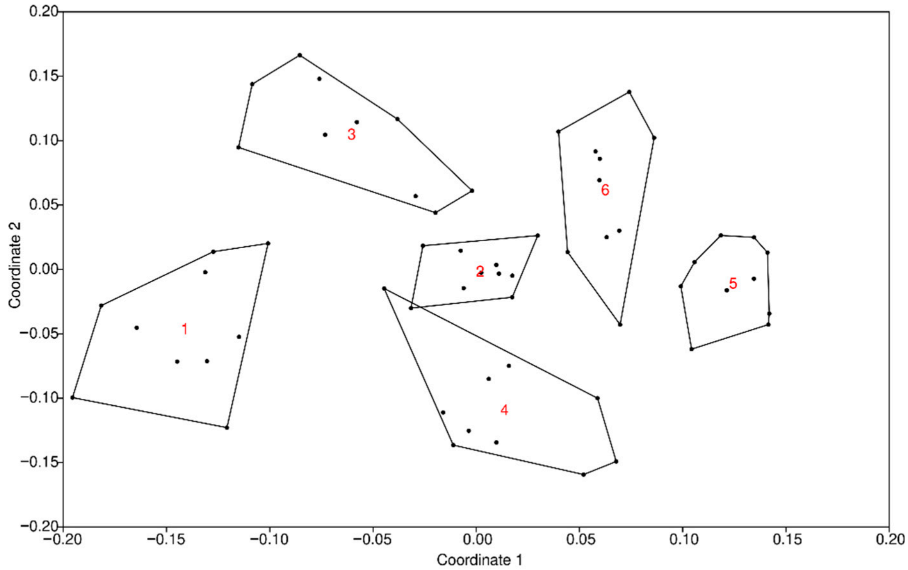

Figure 2. Nonmetric multidimensional scaling analysis (N-MDS) calculated with the Bray–Curtis similarity index (Stress of 0.3). 1 = oak forests; 2 = pine forests; 3 = chaparral; 4 = nopaleras; 5 = grasslands; 6 = rock outcrop vegetation. Each point represents a sampling site, and the distance between them represents dissimilarity.

Table 1. Analysis of similarities (ANOSIM) between the main plant communities present in the Sierra de los Cardos, Susticacán, Zacatecas, Mexico. Green cells indicate R values, blue cells indicate the associated *p*-value, and white cells indicate the total number of species per plant community.

	Oak Forests	**Pine Forests**	**Chaparral**	**Nopaleras**	**Grasslands**	**Rock Outcrop Vegetation**
Oak forests	93	0.0001	0.0001	0.0003	0.0001	0.0001
Pine forests	0.8224	107	0.0001	0.0001	0.0001	0.0001
Chaparral	0.8841	0.9938	73	0.0001	0.0001	0.0001
Nopaleras	0.8716	0.9244	0.9653	99	0.0001	0.0002
Grasslands	0.962	0.9262	0.9689	0.9733	74	0.0001
Rock outcrop vegetation	0.9191	0.8702	0.9462	0.8626	0.808	95

Table 2. Species with the highest IndVal value per plant community and its contribution to the total dissimilarity between communities according to the SIMPER analysis with Bray–Curtis distance measurement.

Plant Communities	**Indicator Species**	**IndVal**	**Contribution to Total Dissimilarity (%)**
Oak forests	*Quercus rugosa* Née	69.93	14.41
Pine forests	*Pinus cembroides* Zucc.	99.01	11.63
Chaparral	*Arctostaphylos pungens* Kunth	99.18	8.93
Nopaleras	*Opuntia leucotricha* DC	78.85	3.62
Grasslands	*Cyperus seslerioides* Kunth	85.20	2.66
Rock outcrop vegetation	*Agave schidigera* Lem.	92.00	0.66
			Total: 41.90

3.2. *Characterization and Distribution of Vascular Plant Communities*

Based on the proposal of Miranda and Hernández-X [43] and the species considered to be structural for each plant community (Table 3), as well as the information generated in this study, six plant communities (Figure 3) are characterized below.

Table 3. Main structural species by plant community reported by Guzmán and Vela-Gálvez [44], Miranda and Hernández-X [43], Enriquez-Enriquez et al. [45], Rzedowski [11] and González-Elizondo et al. [46], and registered in the Sierra de los Cardos, Susticacán, Zacatecas. H = habit (A = tree; H = herb; Ar = shrub); MH = maximum height of the species in meters per community; C/A = coverage–abundance according to the Braun–Blanquet values modified by van der Marel [37]. 1 = isolated individuals <5%; 2 = occasional <5%; 3 = abundant <5%; 4 very abundant <5%; 5 = 5–12.5%; 6 = 12.5–25%; 7 = 25–50%; 8 = 50–75%; 9 = 75–100%; F =% frequency; AEIV = index of adjusted ecological importance value.

Plant Communities	Family	Species	H	MH	C/A	F	AEIV
Oak forests	Fagaceae	*Quercus potosina* Trel.	A	7	7	20	8.24
Oak forests	Fagaceae	*Quercus eduardi* Trel.	A	8	7	20	7.18
Oak forests	Pinaceae	*Pinus cembroides* Zucc.	A	3	2	30	1.87
Pine forests	Asparagaceae	*Dasylirion acrotrichum* (Schiede) Zucc.	Ar	0.9	2	10	0.43
Pine forests	Asteraceae	*Schkuhria pinnata* (Lam,) Kuntze ex Tgell.	H	0.6	2	30	1.27
Pine forests	Asteraceae	*Tagetes micrantha* Cav.	H	0.2	2	30	1.35
Pine forests	Cactaceae	*Opuntia leucotricha* DC.	Ar	0.6	1	20	0.85
Pine forests	Cupressaceae	*Juniperus deppeana* Steud.	A	9	2	20	0.9
Pine forests	Cupressaceae	*Juniperus flaccida* Schltdl.	A	8	4	80	9.82
Pine forests	Fagaceae	*Quercus potosina* Trel.	A	7	2	10	0.86
Pine forests	Fagaceae	*Quercus grisea* Liebm.	A	5	3	20	1.29
Pine forests	Pinaceae	*Pinus cembroides* Zucc.	A	11	8	100	60.5
Chaparral	Ericaceae	*Arctostaphylos pungens* Kunth	Ar	4	8	100	82.7
Chaparral	Ericaceae	*Comarostaphylis polifolia* (Kunth) Zucc. Ex Klotzsch	Ar	1.5	4	30	4.99
Chaparral	Fagaceae	*Quercus potosina* Trel.	A	4.5	7	10	4.9
Nopaleras	Amaranthaceae	*Gomphrena serrata* L.	H	0.1	2	20	0.98
Nopaleras	Asparagaceae	*Yucca decipiens* Trel.	A	6	2	10	0.49
Nopaleras	Asteraceae	*Brickellia secundiflora* var. *nepetifolia* (Kunth) B. L. Rob.	Ar	1.5	2	40	2.03
Nopaleras	Asteraceae	*Heterosperma pinnatum* Cav.	H	0.05	2	10	0.77
Nopaleras	Cactaceae	*Mammillaria heyderi* Muehlenpf.	H	0.2	3	60	3.01
Nopaleras	Cactaceae	*Opuntia leucotricha* DC	Ar	4	6	80	22.5
Nopaleras	Convolvulaceae	*Dichondra argéntea* Humb, and Bonpl. Ex Willd.	H	0.05	2	10	0.44
Nopaleras	Fabaceae	*Dalea bicolor* Humb. and Bonpl. Ex Willd.	Ar	2	4	50	4.47
Nopaleras	Fabaceae	*Mimosa monancistra* Benth.	Ar	1.0	3	60	8.57
Nopaleras	Fabaceae	*Vachellia schaffneri* (S. Watson) Seigler and Ebinger	Ar	3.5	5	40	6.06
Grasslands	Asteraceae	*Schkuhria pinnata* (Lam.) Kuntze	H	0.15	3	40	3.72
Grasslands	Poaceae	*Aristida schiedeana* Trin. and Rupr.	H	0.4	3	10	0.78
Grasslands	Poaceae	*Bouteloua repens* (Kunth) Scribn. and Merr.	H	0.16	3	60	3.94
Grasslands	Poaceae	*Eragrostis intermedia* Hitchc.	H	0.2	3	10	0.78
Grasslands	Poaceae	*Muhlenbergia phleoides* (Kunth) Columbus	H	0.35	6	60	13.5
Grasslands	Poaceae	*Muhlenbergia rigida* (Kunth) Kunth	H	0.8	7	60	11.87
Rock outcrop vegetation	Asparagaceae	*Agave schidigera* Lem.	H	0.5	6	100	11.65

Table 3. *Cont.*

Plant Communities	Family	Species	H	MH	C/A	F	AEIV
Rock outcrop vegetation	Asteraceae	*Schkuhria pinnata* (Lam.) Kuntze	H	0.2	1	20	1.08
Rock outcrop vegetation	Asteraceae	*Stevia salicifolia* Cav.	H	0.5	2	30	1.64
Rock outcrop vegetation	Asteraceae	*Tagetes lunulata* Ortega	H	0.35	2	30	1.85
Rock outcrop vegetation	Asteraceae	*Tagetes micrantha* Cav.	H	0.15	5	70	5.22
Rock outcrop vegetation	Asteraceae	*Tridax palmeri* A. Gray	H	0.9	3	10	0.77
Rock outcrop vegetation	Cactaceae	*Echinocereus acifer* (Otto ex Salm-Dyck) J.N.Haage	H	0.22	3	50	4.45
Rock outcrop vegetation	Cactaceae	*Mammillaria moelleriana* Boed.	H	0.12	3	40	2.46
Rock outcrop vegetation	Cactaceae	*Stenocactus ochoterenianus* Tiegel	H	0.2	5	90	8.74
Rock outcrop vegetation	Cistaceae	*Crocanthemum glomeratum* (Lag.) Janch.	H	0.22	3	40	2.87
Rock outcrop vegetation	Cyperaceae	*Cyperus seslerioides* Kunth	H	0.12	6	40	5.72
Rock outcrop vegetation	Ericaceae	*Arctostaphylos pungens* Kunth	Ar	2	1	10	0.62
Rock outcrop vegetation	Fagaceae	*Quercus potosina* Trel.	Ar	1.5	1	10	0.62
Rock outcrop vegetation	Pinaceae	*Pinus cembroides* Zucc.	A	2	2	60	3.69
Rock outcrop vegetation	Poaceae	*Muhlenbergia emersleyi* Vasey	H	0.45	9	10	26.9

3.2.1. Oak Forests

This community (Figure 3A) covers an approximate area of 25.2 km^2. It is located mainly towards the western half of the mountain range, between 2150 and 2800 m of altitude, concentrating its highest density in the north-western portion (Figure 4). This area is the most humid and temperate, and it receives between 700 and 800 mm of precipitation, with an average annual temperature of 14 °C. It generally develops on slopes of around 35° of inclination, facing north, as well as in ravines.

A total of 96 species, 73 genera, and 38 families were registered in this community. Of the latter, the most representatives were Asteraceae (20 species), Fabaceae (9), Pteridaceae (6), and Ranunculaceae (5), while at the genus level, they were *Quercus* L. (4 species), *Salvia* L. (3), *Verbesina* L. (3), and *Juniperus* L. (3). Woody coverage was 77%, while herbaceous coverage was 63%. The substrate presents a high prevalence of litter, with a scarce presence of bare soil (3%). Stoniness (21%) is limited to isolated rocky outcrops within forests, which do not usually rise above the height of the canopy.

Three well-defined strata can be distinguished. The tree stratum is the dominant one, with a representation of 10% of the species inventoried for this community. It is represented by the Fagaceae, Cupressaceae, and Pinaceae families, and among the most common elements are *Quercus potosina* Trel., *Q. eduardi* Trel., *Q. obtusata* Bonpl., *Juniperus flaccida* Schltdl., and *Q. rugosa*; the latter is the dominant species and has the highest value of ecological importance (AEIV = 52.3). These species register heights of up to 13 m. In the shrub stratum, 20% of the species registered for this community were represented, with Asteraceae being the family with the greatest richness and *Stevia lucida* Lag., the dominant element, with the highest value of AEIV = 11.4, followed by *Montanoa leucantha* (Lag.) SF Blake (3.71), *Rhus allophyloides* Standl. (3.51) and *Verbesina angustifolia* S.F.Blake (3.11). The shrub elements reach heights of up to 3 m. The herb stratum was represented by 70% of the species, dominating Fabaceae, Asteraceae, Poaceae, Pteridaceae, and Ranunculaceae. Here, *Dichondra sericea* Sw. (AEIV = 4.5), *Piptochaetium fimbriatum* (Kunth) Hitchc (3.5), *Phaseolus polymorphus* S. Watson (3.4), and *Penstemon roseus* G. Don (2.9) stand out, with heights of up to 1.5 m.

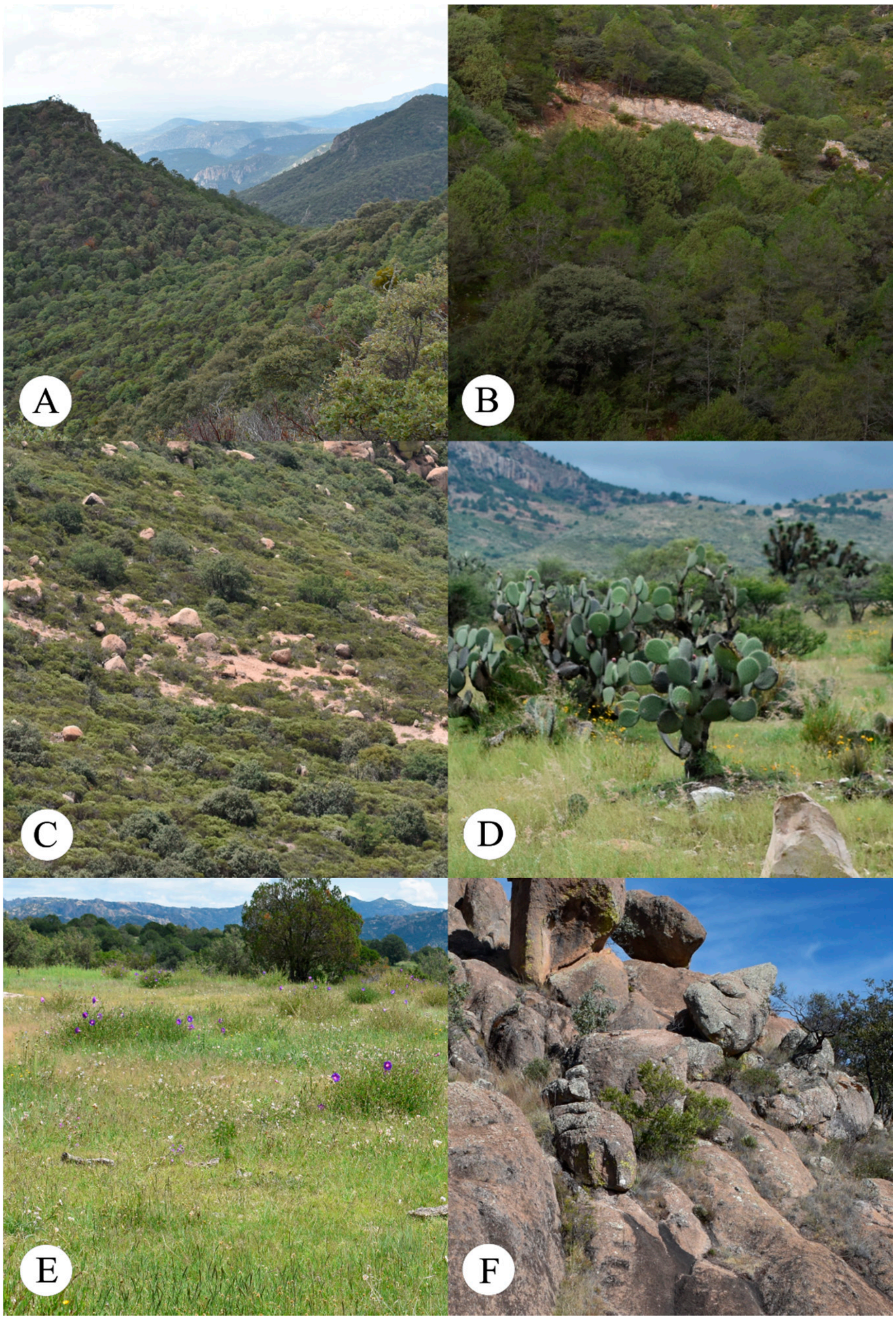

Figure 3. Vascular plant communities of the Sierra de los Cardos, Susticacán, Zacatecas, Mexico. (**A**) = oak forests; (**B**) = pine forests; (**C**) = chaparral; (**D**) = nopaleras; (**E**) = grasslands; (**F**) = rock outcrop vegetation.

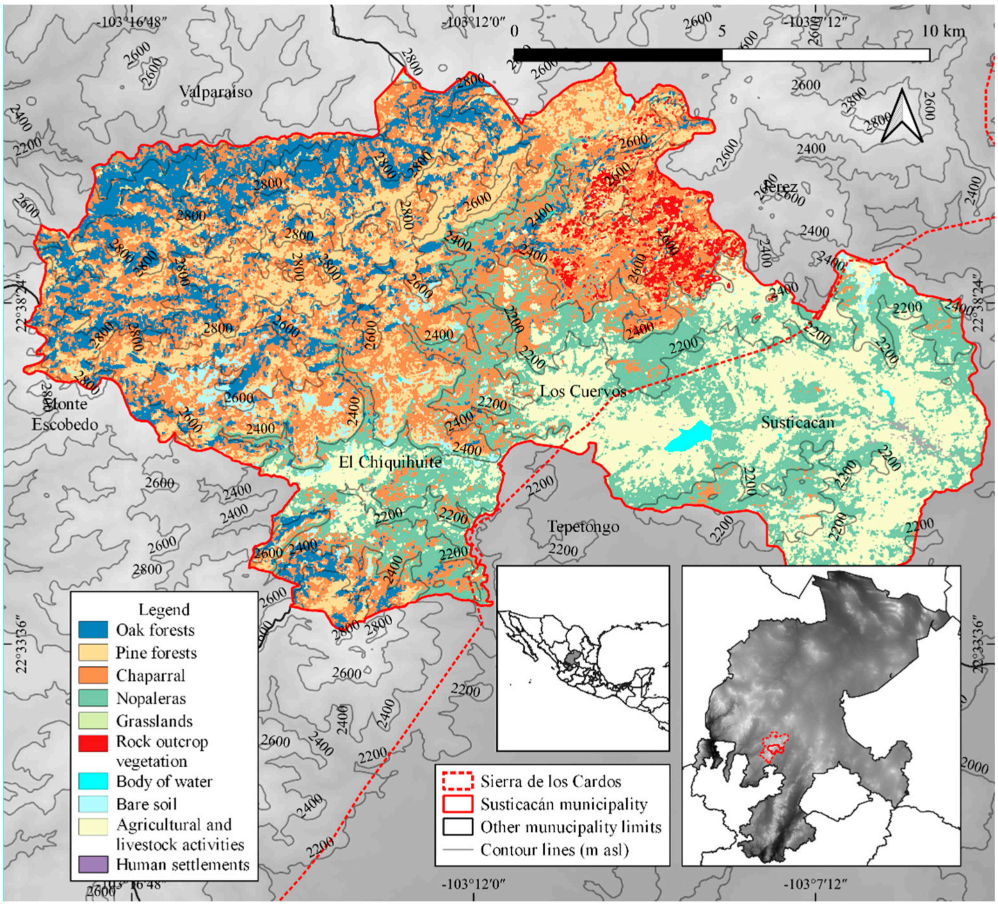

Figure 4. Distribution map of the vascular plant communities present in the Sierra de los Cardos, Susticacán, Zacatecas, Mexico.

3.2.2. Pine Forests

This type of vegetation (Figure 3B) covers an area of approximately 30 km^2, ranking third in terms of surface area. Its distribution in the study area forms a band that runs in a west–northeast direction, presenting its highest density in the western half of the mountain range (Figure 4), between altitudes that oscillate between 2250 and 2900 m. This area presents an average rainfall of between 600 and 700 mm, with an average annual temperature of 15 °C. The vegetation is established both in places with steep slopes and in those relatively flat (between 5° and 40° of inclination), mostly with a slope orientation towards the east.

A total of 107 species, 76 genera, and 42 families were recorded for this community. Asteraceae (21 species) and Poaceae (11) were the most diverse families. The most representative genera were *Stevia* Cav. (7 species), *Muhlenbergia* Schreb. (5), *Ipomoea* L. (4), and *Commelina* L. (3). Woody coverage was 87%, and herbaceous, 65%. The areas occupied by this vegetation have little bare soil (2.6%), an extensive leaf litter cover, and average stoniness of 17.4%, represented by conspicuous rocky outcrops.

Three clearly defined strata can be distinguished. The tree stratum is represented by 6% of the species, mainly from the Pinaceae, Cupressaceae, and Fagaceae families. This stratum has a height of up to 11 m, dominating *Pinus cembroides* (AEIV = 60.5) and *Juníperus flaccida* (9.8). The shrub stratum reaches a height of 1.3 m and is represented by 14% of the species, with Asteraceae as the richest family. *Juniperus deppeana* Steud. (AEIV = 0.9), *Opuntia leucotricha* (0.85), *Dasylirion acrotrichum* (Schiede) Zucc. (0.4), and *Dodonaea viscosa* (L.) Jacq. (0.4) are the most frequent and ecologically important species. In this regard, the herb stratum includes 80% of the species inventoried for this community; it is dominated by grasses and gramineoids, with the families Asteraceae, Poaceae, and Pteridaceae as the most representative. *Piptochaetium fimbriatum* (Kunth) Hitchc (AEIV = 6.9), *Ipomoea stans* Cav. (4.5), *Aristida laxa* Cav. (4.2), *Cyperus seslerioides* (4.1), *Hypoxis mexicana* Schult. and Schult. F. (4.0), and *Aristida schideana* Trin. and Rupr. (3.7) were the most ecologically important species, reaching heights of up to 1 m.

3.2.3. Chaparral

This community (Figure 3C) occupies the largest extension in the study area, with a total of 53.3 km^2. It predominates towards the western half and the northeast part of the study area (Figure 4), between 2350 and 2900 m asl. In this area, there is an average rainfall of 600 to 700 mm, with an average annual temperature of 15 °C. It is found established on flat stony slopes as well as on steep areas with inclinations up to 45°, without a predominant slope orientation.

A total of 73 species, 52 genera, and 29 families were recorded for this plant community. The richest families are Asteraceae (18 species), Poaceae (7), Fabaceae (5), and Cactaceae (5). The most diverse genera were *Muhlenbergia* (4 species), *Quercus* (3), *Mammillaria* Haw. (3), and *Ageratina* Spach (3). Woody coverage was 86%, while herbaceous coverage was 24%. Some sites presented abundant litter (40%), but it was not a generalized characteristic.

Two well-defined strata are distinguished. The shrub is represented by 22% of the species, mostly belonging to Asteraceae. The dominant species was *Arctostaphylos pungens* (AEIV = 82.7), whose elements reach a height of up to 4 m. The herb stratum is represented by 70% of the species, including *Piptochaetium fimbriatum* (AEIV = 6.8), *Crocanthemum glomeratum* (Lag.) Janch (6.0), *Roldana sessilifolia* (Hook. and Arn.) H. Rob. and Brettell (5.6), and *Muhlenbergia peruviana* (P. Beauv.) Steud. (4.4), which together with the rest of the herbaceous species reached heights of up to 1.3 m. Tree stratum is practically absent; however, it is possible to find isolated juvenile individuals of *Quercus potosina*, *Q. crassifolia* Bonpl., *Q. laeta* Liebm., and *Pinus cembroides*, with maximum heights of 4 m.

3.2.4. Nopaleras

This vegetation (Figure 3D) occupies second place in a covered area, with a surface of 42.6 km^2. It is common to find this community in the lower parts of the Sierra, between 2000 and 2400 m asl, towards the eastern half of the study area (Figure 4). Here, the conditions are more xeric, as the climate tends to be notably drier and warmer, with rainfall between 400 and 600 mm and an average temperature of 16°C. It is established mainly on south-facing slopes, both on steep slopes (55° of inclination) as flat terrain.

A total of 99 species, 81 genera, and 34 families were registered. Asteraceae (24 species), Poaceae (11), Fabaceae (10), and Convolvulaceae (7) stand out for the species number, while at the genus level, *Ipomoea* (5 species), *Stevia* (3), *Salvia* (3), and *Bouteloua* Lag. (3) were the most representative. Woody coverage was 61%, while that of herbaceous was 55%. The sites presented stoniness of 40% and 18% of bare soil.

As in the chaparral, two clearly differentiated strata are distinguished. The shrub was the dominant one, with Asteraceae and Fabaceae as the representative families and *Opuntia leucotricha* (AEIV = 22.75), *Dodonaea viscosa* (13.6), *Montanoa leucantha* (Lag.) S.F. Blake (11.4), *Mimosa monancistra* Benth. (8.6), and *Eysenhardtia polystachya* (Ortega) Sarg. (7.0) as the outstanding species, reaching a height of 3.5 m. Although *Urochloa meziana* (Hitchc.) Morrone and Zuloaga (AEIV = 7.2), *Myriopteris aurea* (Poir.) Grusz and Windham (5.9), *Ipomoea stans* (5.5), *Bouteloua curtipendula* (Michx.) Torr. (4.7), *Dyschoriste schiedeana* (Nees) Kuntze (4.1), and *Bouteloua repens* (Kunth) Scribn. and Merr. (3.9) dominated the herbaceous stratum, reaching a height of 1.2 m, represented by the families Asteraceae and Poaceae. Although the tree stratum was absent, it was possible to detect isolated individuals of *Prosopis laevigata* (Humb. and Bonpl. Ex Willd.) M.C. Johnst. and *Yucca decipiens* Trel., with heights of up to 6 m.

3.2.5. Grasslands

Grasslands (Figure 3E) occupy the smallest surface in the study area, with only 1 km^2 of the area covered. They are in small and isolated patches, towards the western half of the mountain range (Figure 4), where the precipitation ranges from 700 to 800 mm and the average temperature is around 14 °C. They generally develop on flat sites, with altitudes ranging from 2340 to 2800 m.

A total of 74 species, 54 genera, and 30 families were recorded in this plant community. Asteraceae (19 species) and Poaceae (13) were the most diverse families. The richest genera were *Muhlenbergia* (5 species), *Stevia* (4), and *Laennecia* Cass. (3). Herbaceous coverage was 95% and 1% woody, with 4% of stony soil.

Both the tree and shrub strata are absent; the few elements that stand out from the herbaceous cover are usually young individuals of *P. cembroides* or *J. flaccida*, which rarely exceed 1.5 m in height. The herb stratum is dominant, represented by 94% of the species, standing out the grasses and graminoids. *Cyperus seslerioides* (AEIV = 22.7), *Muhlenbergia phleoides* (Kunth) Columbus (13.5), *M. rigida* (Kunth) Kunth (11.9), and *Hypoxis mexicana* Schult and Schult. F. (10.4) are the most common, with heights of up to 1 m.

3.2.6. Rock Outcrops Vegetation

This community (Figure 3F) covers an area of 3.9 km^2 and is located between 2300 and 2800 m asl. It is restricted to the northeast part of the mountain range (Figure 4), where the annual precipitation ranges between 600 and 700 mm, with an average annual temperature of 15 °C. It is characterized for being distributed in areas with steep and irregular topography, on an area of rocky outcrops of the extrusive igneous type with slopes of 38° of inclination.

This vegetation registered 95 species, 79 genera, and 42 families. Asteraceae (21 species) and Poaceae (13) stand out here, as well as *Muhlenbergia* (5 species) and *Stevia* (3) among the genera. The sites presented on average a stoniness of 77%, with 6% and 35% of woody and herbaceous cover, respectively. Bare soil occupied 8.7%, while the stony soil occupied 80%.

As with the chaparral and grasslands, the rock outcrop vegetation does not present a tree stratum, except for isolated juvenile individuals of *P. cembroides* with maximum heights of 2 m. For its part, the shrub stratum registers 16% of the species, represented by Asteraceae and dominating *D. viscosa* (AEIV = 5.9), and *Dasylirion acrotrichum* (Schiede) Zucc. (4.2), which reach heights of 2 m.

The stratum herb was dominant, with 86% of the species represented and the grasses and graminoids standing out, with Asteraceae and Poaceae as the most diverse families. The most ecologically important species were *Muhlenbergia emersleyi* Vasey (AEIV = 14.3), *Agave schidigera* (11.7), *Trachypogon spicatus* (L. f.) Kuntze (10.3), *Bulbostylis juncoides* (Vahl) Kük. ex Osten (9.6), *Stenocactus ochoterenianus* Tiegel (8.7), and *Muhlenbergia pubescens* (Kunth) Hitchc. (7.1), which reach a height of up to 1.2 m.

Of the recorded species, *Tradescantia crassifolia* Cav. was the only one shared among all vascular plant communities, while 11 species were found in five of the six communities. *Bouvardia ternifolia* (Cav.) Schltdl. was recorded in all communities except grasslands. *Echeandia flavescens* (Schult. and Schult.f.) Cruden, *Gaga kaulfussii* (Kunze) F.W. Li and Windham, *J. deppeana*, *J. flaccida*, *Pellaea ternifolia* (Cav.) Link., and *P. cembroides* were absent only in nopaleras. *Muhlenbergia phleoides*, *Ipomoea capillaceae* (Kunth) G. Don, *Oxalis decaphylla* Kunth, and *Stevia serrata* Cav. were not recorded in oak forests.

Oak forests and nopaleras were the communities with the highest number of exclusive species, i.e., not shared, with 60% and 40% of them, respectively. Pine forests and oak forests were the plant communities that harbored the largest number of endemic species in Mexico (33 species each). Of the six introduced species known to the area, two are distributed in the grasslands and two more in the nopaleras (Table 4).

Table 4. Summary of the number of species, family, and genus richness, as well as introduced, endemic and exclusive species by plant community in the Sierra de los Cardos, Susticacán, Zacatecas, Mexico.

Plant Communities	Families	Genera	Species	Endemic Species	Exclusive Species	Exotic Species
Oak forests	38	74	96	33	58	1
Pine forest	42	76	107	33	20	1
Chaparral	29	52	73	29	17	0
Nopaleras	34	81	99	24	40	2
Grasslands	30	54	74	22	16	2
Rock outcrops vegetation	42	74	95	31	25	0

4. Discussion

Of the plant communities identified and evaluated, the pine forests and oak forests stand out, which have been reported among the most diverse types of vegetation in Mexico. According to Rzedowski [56] and Koleff et al. [57], these communities occupy between 25% and 34% of the flora estimated for the country and present a high proportion of endemism. The above was corroborated in the present work since it was precisely these two communities that together concentrated the greatest taxonomic and endemic richness in the study area. Their high diversity and heterogeneity contrast with the small area they occupy compared to the rest of the plant communities present in the mountains. It is likely that its establishment in inaccessible areas, mainly in the mountainous area or isolated peaks of the Sierra, is one of the factors that has allowed the safeguarding of this important richness and the preservation of its most representative structural elements, such as *Pinus cembroides*, *Quercus rugosa*, *Q. eduardii*, and *Q. potosina*. These species have been reported as the most conspicuous elements for each of these types of vegetation [11,43–46,58]. It is also highlighted that of the two species in a risk category for Los Cardos reported by Hurtado-Reveles et al. [36], *Mammillaria jaliscana* (Britton and Rose) Boed. is distributed only in oak forests, thus highlighting the biological importance of this vegetation in the area.

Specifically, for the Susticacán oak forests, their structure and composition, as well as their establishment on slopes with less solar exposure and a notably less arid climate, are consistent with those reported for this type of vegetation in the SMOc by Granados-Sánchez et al. [59] and González-Elizondo et al. [46], as well as for the oak forests of the state of Zacatecas by Sabas-Rosales [58]. Regarding pine forests, Barrera-Zubiaga et al. [60] reported this type of vegetation occurring in the central (Fresnillo), northeastern (Concepción del Oro), and north-western (Sombrerete) parts of Zacatecas; however, there was no formal record for Susticacán, located in the central–western part of the state. In this last plant community, the presence, albeit in low frequency, of *Dodonaea viscosa*, constitutes a potential threat to the native flora, since it has been reported to replace the oak and pine–oak forests of the SMOc [61]. In nopaleras, *D. viscosa* was a dominant species, and various studies have recognized it as an indicator of disturbance [62–64]. This may result from the fact that this community, together with the grasslands, are the types of vegetation that are most accessible and close to human settlements, and therefore, are the most affected. For example, of the six species introduced in Los Cardos reported by Hurtado-Reveles et al. [36], it was precisely these last two communities that, together, harbored the largest number (four species). Meanwhile, the predominance of *O. leucotricha* in nopaleras is not unusual, since for the states of Durango and Zacatecas, it has been reported that this species replaces other *Opuntias* due to its ability to withstand strong frosts [65]. However, nopaleras also contribute to an important richness of species and endemism, which could be threatened in the short term due to the presence of exotic species. *Melinis repens* is one of the species that generates the greatest concern, as it is considered an exotic–invasive with a high impact, causing alterations to and the displacement of native species, as well as structural changes in the habitat where it is established [66–68].

The low number of introduced species throughout the different plant communities is not surprising. In the national level review of alien flowering plants, Villaseñor and

Espinosa-García [50] recognize that Mexico has a relatively low proportion of exotic species when compared to its native plant diversity, and among their relevant findings is that Mexico has a very high percentage of weed autochthonous species, contrasted with other countries [56,69]. This would mean that when it comes to populating disturbed sites, introduced species face more competition from native weeds. At the state level, Zacatecas has the second lowest density of alien species [50]. Furthermore, this state is considered one of the least densely populated of the country [70], with Susticacán being the least populated municipality of a total of 58 in Zacatecas [71], and the prevalence of anthropogenic impact derived from urban areas is low. Despite the above, a slightly higher number of non-native species is recorded in Los Cardos than the four registered on the summit of the Mesa Alta in the municipality of Jerez in the central region of Zacatecas by Ramirez-Prieto et al. [72], an area adjacent to our study site. It is likely that the recent increase in the presence of livestock is promoting the maintenance and dispersal of introduced grass species that can potentially become invasive [73].

Rock outcrops vegetation is another interesting community since the combination of abiotic and floristic components reported for this community is specific to the state of Zacatecas [45]. For example, despite the predominance of tufted grasses, this vegetation develops at an altitude of 2300 to 2800 m, i.e., under environmental conditions that are very different from those of the alpine flora of Mexico [16,25,74], a community with which it could be confused. This vegetation type of rock outcrops was first described by Enríquez-Enríquez et al. [45] for the Sierra de Órganos, Zacatecas. According to these authors, this community is established on stony hills of rhyolitic origin, whose rocks are presented in column, wall, and mound formations, with *Agave schidigera*, *Tagetes micrantha* Cav., *Mammillaria moelleriana*, *Selaginella* P. Beauv., *Echinocereus* Engelm, and *Stenocactus* (K. Schum.) A. Berger ex A.W. Hill. as the structural elements, as well as isolated individuals of the *Pinus* and *Quercus* genera, as recorded in the Sierra de los Cardos. The particularities of the floristic composition of this plant community are determined by a high rupicolous specialization of its elements, which had only been observed in the Sierra de Órganos, and now, in the Sierra de los Cardos. It is also evident that the protected and Mexican endemic species *Mammillaria moelleriana* Boed. was found exclusively in this plant community [36].

In this regard, the chaparral occupies the greatest extension of the Sierra in Susticacán, covering practically a third of its surface. The dominance of *Arctostaphylos pungens* in this plant community is not rare, since this species tends to replace and spread at higher altitudes to the pine forests or alternate between them [75,76]. According to Márquez-Linares et al. [77], fires favor *A. pungens*, as it presents a series of adaptations that allow it to germinate, as well as to develop in disturbed environments [78]. The chaparral in the Cardos breaks the continuum of pine forests and oak forests, and they register juvenile specimens of *Q. potosina* and *P. cembroides*. The presence of these elements could suggest that they are secondary communities, since according to González-Elizondo et al. [46], secondary type chaparral occurs in the SMOc massif, between 2300 and 3000 m asl., where the forests have been eliminated or reduced, leaving relict individuals of the vegetation that was replaced, generally pine trees. This is worrying as it could mean that in the medium term, the temperate forests of the area will be replaced by chaparral, so it is necessary to carry out studies of the historical dynamics of and potential changes in the vegetation of the Sierra.

It is important to highlight that the forests of the high regions of Mexico are disappearing rapidly [79], mainly due to the development of agriculture and livestock [80], as well as the introduction of non-native grass species as feed for livestock. This is corroborated in Los Cardos, as according to the Comisión Nacional para el conocimiento y uso de la Biodiversidad (CONABIO) [26], the municipality of Susticacán registers a high index of anthropic impact, with an evident expansion of agricultural and livestock areas that undoubtedly threaten the persistence of plant communities, and with this, native species, especially those with restricted distribution and small and/or isolated populations [81], thus making it necessary to promote their protection so as not to accelerate their local extinction.

Knowing the vegetation of a specific geographic area is a relevant and key requirement for ecological research and environmental assessments. At the same time, it makes it possible to recognize species at risk or potentially vulnerable and generate baselines to establish conservation strategies. Having a clear basic knowledge of the plant species and communities of any area is essential to be able to make adequate use of natural resources without detriment to the biodiversity that resides there. When this type of information is generalized, without considering the local or regional plant community's particularities, it hampers our ability to make realistic projections in time for the next century. Thus, in the Canada Centre for Remote Sensing (CCRS) [82], it is indicated that in Susticacán there is only coniferous forest, mixed forest, temperate scrub, and temperate grasslands, without providing further details in this regard. In the municipal geographic information record [21], tropical rainforests are included among the types of vegetation of Susticacán. However, during the present investigation, this type of plant community was not recorded. Only in the lowest and warmest parts of Zacatecas has the presence of deciduous forest been documented [83]. It is added to the types of vegetation reported by INEGI [21], to the forests and grasslands, omitting the scrub, and again, without further details. These errors and omissions in the vegetation maps, which, until recently, were the only ones available for the municipality, continue to be perpetuated in recent studies [84,85], and it is only an artifice of the generalizations that are made at the regional level, omitting its wide heterogeneity. This has profound consequences for biodiversity, as the mapping of vegetation at local and regional scales contributes to delineating essential habitats and managing human activities in these areas. This mapping of natural resources is highly needed for the monitoring and management of species, habitats, and landscapes.

This study is the first to generate detailed information on the composition and structure of the plant communities present in the Sierra de los Cardos in the municipality of Susticacán in the state of Zacatecas, as well as to provide a map of their distribution on a fine scale. Finally, the status and distribution of plant species and communities could also help to interpret past climatic variations and will be crucial in predicting ongoing changes. Our analyses support the view that it is of great importance to conduct diversity studies at the local level in poorly explored areas, particularly in mountainous areas, as it has implications for the conservation and proper management of natural resources.

Author Contributions: Conceptualization, L.H.-R. and M.B.-H.; methodology, M.B.-H. and L.H.-R.; software, L.H.-R. and J.C.L.-A.; validation, M.B.-H., J.C.L.-A. and L.H.-R.; formal analysis, L.H.-R., M.B.-H. and J.C.L.-A.; investigation, L.H.-R. and M.B.-H.; resources, L.H.-R., M.B.-H., M.V.-S. and J.C.L.-A.; data curation, L.H.-R., M.B.-H. and M.V.-S.; writing—original draft preparation, L.H.-R. and M.B.-H.; writing—review and editing, J.C.L.-A. and M.V.-S.; visualization, M.B.-H. and L.H.-R.; supervision, M.B.-H.; project administration, M.B.-H.; funding acquisition, M.B.-H. and M.V.-S. All authors have read and agreed to the published version of the manuscript.

Funding: National Council of Science and Technology (student grant L.H.-R.-CONACYT-906573).

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors thank to the two anonymous reviewers for their valuable suggestions that undoubtedly allowed us to improve the manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Chytrý, M.; Chiarucci, A.; Pärtel, M.; Pillar, V.D.; Bakker, J.P.; Mucina, L.; Peet, R.K.; White, P.S. Progress in vegetation science: Trends over the past three decades and new horizons. *J. Veg. Sci.* **2019**, *30*, 1–4. [CrossRef]
2. Pärtel, M.; Chiarucci, A.; Chytrý, M.; Pillar, V.D. Mapping plant community ecology. *J. Veg. Sci.* **2017**, *28*, 1–3. [CrossRef]
3. Damschen, E.I. Decoding plant communities across scales. *Ecol. Evol.* **2018**, *2*, 1844–1845. [CrossRef]

4. Czaran, T.; Bartha, S. Spatiotemporal dynamic models of plant populations and communities. *Trends Ecol. Evol.* **1992**, *7*, 38–42. [CrossRef]
5. Mori, A.S. Ecosystem management based on natural disturbances: Hierarchical context and non-equilibrium paradigm. *J. Appl. Ecol.* **2011**, *48*, 280–292. [CrossRef]
6. Franklin, S.B.; Hunter, J.T.; De Cáceres, M.; Dengler, J.; Landucci, F.; Krestov, P. Introducing the IAVS Vegetation Classification Working Group. *Phytocoenologia* **2016**, *46*, 5–8. [CrossRef]
7. Jensen, F.; Bergmeier, E.; Dengler, J.; Janišová, M.; Krestov, P.; Willner, W. Vegetation classification: A task for our time. *Phytocoenologia* **2016**, *46*, 1–4. [CrossRef]
8. European Space Agency. Vegetation Classification Panel. Available online: https://www.esa.org/vegpanel/usnvc/ (accessed on 13 January 2021).
9. Goodall, W.D. Numerical methods of classification. In *Classification of Plant Communities*; Whittaker, R.H., Ed.; Dr. W. Junk Publishers: Hague, The Netherlands, 1978; pp. 247–286.
10. Whittaker, R.H. *Communities and Ecosystems*; Macmillan: New York, NY, USA, 1970; pp. 60–105, ISBN 978-002-4273-90-1.
11. Rzedowski, J. *Vegetación de México*; Comisión Nacional para el Conocimiento y Uso de la Biodiversidad: Ciudad de México, México, 2006; pp. 12–168.
12. Sosa, V.; Loera, I. Influence of current climate, historical climate stability and topography on species richness and endemism in Mesoamerican geophyte plants. *PeerJ* **2017**, *5*, 1–20. [CrossRef] [PubMed]
13. Global Forest Watch. Mexico. Available online: https://www.globalforestwatch.org/dashboards/country/MEX/ (accessed on 4 December 2020).
14. Grabherr, G.; Gottfried, M.; Pauli, H. Climate effects on mountain plants. *Nature* **1994**, *369*, 448. [CrossRef] [PubMed]
15. Alexander, J.M.; Diez, J.M.; Levine, J.M. Novel competitors shape species' responses to climate change. *Nature* **2015**, *525*, 515–518. [CrossRef]
16. Steinmann, V.W.; Arredondo-Amezcua, L.; Hernández-Cárdenas, R.A.; Ramírez-Amezcua, Y. Diversity and origin of the central mexican alpine flora. *Diversity* **2021**, *13*, 31. [CrossRef]
17. Descroix, L.; González Barrios, J.L.; Estrada Ávalos, J. *La Sierra Madre Occidental, una Fuente de Agua Amenazada*; Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias: Gómez Palacio, Mexico, 2004; pp. 25–85.
18. González-Elizondo, M.S.; González-Elizondo, M.; Ruacho González, L.; Lopez Enriquez, L.L.; Retana Rentería, F.I.; Tena Flores, J.A. Ecosystems and Diversity of the Sierra Madre Occidental. In *Merging Science and Management in a Rapidly Changing World: Biodiversity and Management of the Madrean Archipelago*, 3rd ed.; Gottfried, G.J., Ffolliott, P.F., Gebow, B.S., Eskew, L.G., Collins, L.C., Eds.; U.S. Department of Agriculture: Fort Collins, CO, USA, 2013; pp. 204–211.
19. Instituto Nacional de Estadística y Geografía. Prontuario de información Geográfica Municipal de los Estados Unidos Mexicanos, Zacatecas, Jerez, 32020. Available online: http://www3.inegi.org.mx/contenidos/app/mexicocifras/datos_geograficos/32/32020.pdf (accessed on 21 May 2021).
20. Instituto Nacional de Estadística y Geografía. Prontuario de Información Geográfica Municipal de los Estados Unidos Mexicanos, Zacatecas, Monte Escobedo, 32031. Available online: http://www3.inegi.org.mx/contenidos/app/mexicocifras/datos_geograficos/32/32031.pdf (accessed on 21 May 2021).
21. Instituto Nacional de Estadística y Geografía. Prontuario de Información Geográfica Municipal de los Estados Unidos Mexicanos, Zacatecas, Susticacán, 32043. Available online: http://www3.inegi.org.mx/contenidos/app/mexicocifras/datos_geograficos/32/32043.pdf (accessed on 21 May 2021).
22. Instituto Nacional de Estadística y Geografía. Prontuario de Información Geográfica Municipal de los Estados Unidos Mexicanos, Zacatecas, Tepetongo, 32046. Available online: http://www3.inegi.org.mx/contenidos/app/mexicocifras/datos_geograficos/32/32046.pdf (accessed on 21 May 2021).
23. Instituto Nacional de Estadística y Geografía. Prontuario de Información Geográfica Municipal de los Estados Unidos Mexicanos, Zacatecas, Valparaíso, 32049. Available online: http://www3.inegi.org.mx/contenidos/app/mexicocifras/datos_geograficos/32/32049.pdf (accessed on 21 May 2021).
24. Fernández-Borja, H.; Giménez-de Azcárate, J. Ruta Histórico Cultural del Pueblo Huichol. Available online: https://cartocritica.org.mx/2014/ruta-a-wirikuta/ (accessed on 17 May 2021).
25. Giménez-de Azcárate, J.; Escamilla, M. Las comunidades edafoxerófilas (enebrales y zacatonales) en las montañas del centro de México. *Phytocoenologia* **1999**, *29*, 449–468.
26. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. Índice de Impacto Humano en la Biodiversidad Terrestre. Available online: http://geoportal.conabio.gob.mx/metadatos/doc/html/indihum14gw.html (accessed on 4 April 2021).
27. Parmesan, C. Ecological and evolutionary responses to recent climate change. *Annu. Rev. Ecol. Evol. Syst.* **2006**, *37*, 637–669. [CrossRef]
28. Wilson, R.J.; Gutierrez, D.; Gutierrez, J.; Monserrat, V.J. An elevational shift in butterfly species richness and composition accompanying recent climate change. *Glob. Change Biol.* **2007**, *13*, 1873–1887. [CrossRef]
29. Lenoir, J.; Gégout, J.C.; Marquet, P.A.; De Ruffray, P.; Brisse, H. A significant upward shift in plant species optimum elevation during the 20th century. *Science* **2008**, *320*, 1768–1771. [CrossRef] [PubMed]
30. Parolo, G.; Rossi, G. Upward migration of vascular plants following a climate warming trend in the Alps. *Basic Appl. Ecol.* **2008**, *9*, 100–107. [CrossRef]

31. Jump, A.S.; Huang, T.J.; Chou, C.H. Rapid altitudinal migration of mountain plants in Taiwan and its implications for high altitude biodiversity. *Ecography* **2012**, *35*, 204–210. [CrossRef]
32. Instituto Nacional de Estadística y Geografía. Conjunto de Datos Vectoriales Fisiográficos, Continuo Nacional Serie I, Sistema Topoformas. Available online: https://datos.gob.mx/busca/dataset/conjunto-de-datos-vectoriales-fisiograficos-continuo-nacional-escala-1-1-000-000-serie-i/resource/d82b7280-5680-4968-95ec-6755590ae0a2. (accessed on 21 May 2021).
33. Instituto Nacional de Estadística y Geografía. Condensado Estatal Zacatecas. Available online: https://portalanterior.ine.mx/archivos1/Cartografia/2014/CED/32_ZAC/CED32_CARTA_110614.pdf (accessed on 21 May 2021).
34. García, E. *Modificaciones al Sistema de Clasificación Climatológica de Köppen*; Instituto de Geografía: Ciudad de México, Mexico, 1981; pp. 3–34.
35. United States Geological Survey. Earth Explorer. Available online: https://earthexplorer.usgs.gov/ (accessed on 10 November 2020).
36. Hurtado-Reveles, L.; Burgos-Hernández, M.; Vázquez-Sánchez, M.; López-Acosta, J.C. Contribución al conocimiento florístico de la Sierra de los Cardos, Zacatecas, México. *Bot Sci.* in press. 1–45. [CrossRef]
37. Van der Maarel, E. Transformation of cover-abundance values in phytosociology and its effects on community similarity. *Vegetatio* **1979**, *39*, 97–114.
38. Kruskal, J.B. Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. *Psychometrika* **1964**, *29*, 1–27. [CrossRef]
39. Clarke, K.R.; Warwick, R.M. Similarity-based testing for community pattern: The two-way layout with no replication. *Mar. Biol.* **1994**, *118*, 167–176. [CrossRef]
40. Clarke, K.R.; Warwick, R.M. A further biodiversity index applicable to species lists: Variation in taxonomic distinctness. *Mar. Ecol-Prog Ser.* **2001**, *216*, 265–278. [CrossRef]
41. Dufrêne, M.; Legendre, P. Species assemblages and indicator species: The need for a flexible asymmetrical approach. *Ecol. Monogr.* **1997**, *67*, 345–366. [CrossRef]
42. Hammer, Ø.; Harper, D.A.; Ryan, P.D. PAST: Paleontological statistics software package for education and data analysis. *Palaeontol. Electron.* **2001**, *4*, 1–9.
43. Miranda, F.; Hernández-Xolocotzi, E. Los tipos de vegetación de México y su clasificación. *Bot. Sci.* **1963**, *28*, 29–179. [CrossRef]
44. Guzmán, G.; Vela-Gálvez, L. Contribución al conocimiento de la vegetación del suroeste del estado de Zacatecas (República Mexicana). *Bot. Sci.* **1960**, *25*, 46–61. [CrossRef]
45. Enríquez-Enríquez, D.E.; Koch, S.D.; González-Elizondo, M.S. Flora y vegetación de la Sierra de Órganos, municipio de Sombrerete, Zacatecas, México. *Acta Bot. Mex.* **2003**, *64*, 45–89. [CrossRef]
46. González-Elizondo, M.S.; González-Elizondo, M.; Tena-Flores, J.A.; Ruacho-González, L.; López-Enríquez, I.L. Vegetación de la Sierra Madre Occidental, México: Una síntesis. *Acta Bot. Mex.* **2012**, *100*, 351–403. [CrossRef]
47. Comisión Técnico Consultiva para la Determinación Regional de los Coeficientes de Agostadero. *Coeficientes de Agostadero de la República Mexicana, estados Aguascalientes y Zacatecas*; Secretaría de Agricultura y Recursos Hidráulicos: Ciudad de México, Mexico, 1980; pp. 22–30.
48. Herrera-Arrieta, Y.; Pámanes-García, D.S. *Guía de los pastos de Zacatecas*; Instituto Politécnico Nacional: Zacatecas, Mexico, 2010; pp. 19–149.
49. Villaseñor, J.L. Checklist of the native vascular plants of Mexico. *Rev. Mex Biodivers.* **2016**, *87*, 559–902. [CrossRef]
50. Villaseñor, J.L.; Espinosa-García, J.F. The alien flowering plants of Mexico. *Divers. Distrib.* **2004**, *10*, 113–123. [CrossRef]
51. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. Malezas de México. Available online: http://www.conabio.gob.mx/malezasdemexico/2inicio/paginas/lista-plantas-abr2006.htm (accessed on 8 June 2021).
52. Burgos-Hernández, M.; Castillo-Campos, G.; Vergara Tenorio, M.D.C. Potentially useful flora from the tropical rainforest in central Veracruz, Mexico: Considerations for their conservation. *Acta Bot Mex.* **2014**, *109*, 55–77. [CrossRef]
53. Clark Labs. TerrSet. Available online: https://clarklabs.org/ (accessed on 13 January 2021).
54. QGIS Association. QGIS Geographic Information System. Available online: http://www.qgis.org (accessed on 13 January 2021).
55. Yang, J.; Jin, Z.; Yang, J.Y.; Zhang, D.; Frangi, A.F. Essence of kernel Fisher discriminant: KPCA plus LDA. *Comm. Com. Inf. Sc.* **2004**, *37*, 2097–2100. [CrossRef]
56. Rzedowski, J. Diversidad y orígenes de la flora fanerogámica de México. *Acta Bot. Mex.* **1991**, *14*, 3–21. [CrossRef]
57. Koleff, P.; Soberón, J.; Smith, A. Madrean Pine-Oax Woodlands. In *Hotspots Revisited*; Mittermeier, R.A., Robles Gil, P., Hoffman, M., Pilgrim, J., Brooks, T., Goettsch Mittermeier, C., Lamoreux, J., da Fonseca, G.A.B., Eds.; CEMEX: Ciudad de México, Mexico, 2004; pp. 103–112.
58. Sabas-Rosales, J.L. Encinos (*Quercus*: Fagaceae) de Zacatecas: Taxonomía, Diversidad y Distribución. Ph.D. Thesis, Universidad Autónoma de Aguascalientes, Aguascalientes, Mexico, 2016.
59. Granados-Sánchez, D.; Sánchez-González, A.; Granados Victorino, R.L.; Borja de la Rosa, A. Ecología de la vegetación del desierto chihuahuense. *Rev. Chapingo Ser. Cie.* **2011**, *17*, 111–130. [CrossRef]
60. Barrera-Zubiaga, E.J.; Granados-Sánchez, D.; Granados-Victorino, R.L.; Luna-Cavazos, M. Characterization of four pinyon pine forests in the state of Zacatecas, Mexico. *Rev. Chapingo Ser. Cie.* **2018**, *24*, 275–296. [CrossRef]
61. González-Elizondo, M.S.; González-Elizondo, M.; Márquez-Linares, M.A. *Vegetación y Ecorregiones de Durango*; Instituto Politécnico Nacional: Durango, Mexico, 2007; pp. 71–109.

62. Acosta-Hernández, A.C. Papel Sucesional de *Dodonea viscosa* en la Cuenca alta del Río San Pedro Mezquital. Master's Thesis, Instituto Politécnico Nacional, Durango, Mexico, 2016.
63. Rivas, G.R. Disturbios y Variables Ambientales Asociados a la Presencia de *Dodonaea viscosa* en los Municipios de Durango y Mezquital, Durango. Master's Thesis, Instituto Politécnico Nacional, Durango, Mexico, 2019.
64. Márquez-Linares, M.A.; Escobar-Flores, J.G.; Sandoval, S.; Pérez-Verdín, G. Multitemporal distribution analysis of *Dodonaea viscosa* (L.) Jacq. by remote sensing in Durango, Mexico. *AGROProductividad* **2020**, *13*, 61–67. [CrossRef]
65. Reyes-Agüero, J.A.; Vallejo, M. Matorral crasicaule. In *San Luis Potosí, Estudio de Estado*, 2nd ed.; Comisión Nacional para el Conocimiento y Uso de la Biodiversidad La Biodiversidad: Mexico, Mexico, 2019; pp. 47–54.
66. Possley, J.; Maschinski, J. Competitive effects of the invasive grass *Rhynchelytrum repens* (Willd.) C.E. Hubb. on pine rockland vegetation. *Nat. Area J.* **2006**, *26*, 391–395. [CrossRef]
67. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. *Rynchelyctrum repens* (Willd.) C. E. Hubb. Available online: http://www.conabio.gob.mx/malezasdemexico/poaceae/rhynchelytrum (accessed on 7 June 2021).
68. Trevizo, H.E. Impacto Ecológico del Zacate Rosado (*Melinis repens* (Willd.)) con Diferentes Años de Invasión en Pastizales de Chihuahua, México. Master's Thesis, Universidad Autónoma de Chihuahua, Chihuahua, Mexico, 2018.
69. Rapoport, E.H. Remarks on the biogeography of land invasions. *Rev. Chil. Hist. Nat.* **2000**, *73*, 367–380. [CrossRef]
70. Instituto Nacional de Estadística y Geografía. Densidad de Población. Available online: http://cuentame.inegi.org.mx/poblacion/densidad.aspx?tema=P (accessed on 28 September 2021).
71. Instituto Nacional de Estadística y Geografía. División Municipal. Available online: http://cuentame.inegi.org.mx/monografias/informacion/zac/territorio/div_municipal.aspx?tema=me&e=32 (accessed on 28 September 2021).
72. Ramírez-Prieto, J.; Koch, S.D.; Balleza-Cadengo, J.D.J.; Adame-González, M.; Romero-Nápoles, J. Flora de la cima de la Mesa Alta, Jerez, Zacatecas, México. *Bot. Sci.* **2016**, *94*, 357–375. [CrossRef]
73. Kerns, B.K.; Tortorelli, C.; Day, M.A.; Nietupski, T.; Barros, A.M.; Kim, J.B.; Krawchuk, M.A. Invasive grasses: A new perfect storm for forested ecosystems? *Forest Ecol. Manag.* **2020**, *463*, 1–15. [CrossRef]
74. McDonald, J.A.; Martinez, J.; Nesom, G.L. Alpine flora of Cerro Mohinora, Chihuahua, Mexico. *J. Bot. Res. Inst. Texas* **2011**, *5*, 701–705.
75. Rzedowski, J. *Vegetación de México*; Editorial Limusa: Ciudad de México, Mexico, 1978; pp. 247–327.
76. Granados-Sánchez, D.; Sánchez-González, A. Clasificación fisonómica de la vegetación de la Sierra de Catorce, San Luis Potosí, a lo largo de un gradiente altitudinal. *Terra Latinoamericana* **2003**, *21*, 321–332.
77. Márquez-Linares, M.A.; Jurado Ybarra, E.; González-Elizondo, M.S. Algunos aspectos de la biología de la manzanita (*Arctostaphylos pungens* HBK) y su papel en el desplazamiento de bosques templados por chaparrales. *Ciencia UANL* **2006**, *9*, 57–64.
78. Casas, S.R.; González-Elizondo, S.; Tena-Flores, J.A. Estructura y tendencias sucesionales en vegetación de clima templado semi-seco en Durango, México. *Madroño* **1995**, *42*, 501–515.
79. Challenger, A. *Utilización y Conservación de los Ecosistemas Terrestres de México: Pasado Presente y Futuro*; Comisión Nacional para el Conocimiento y Uso de la Biodiversidad: Ciudad de México, Mexico, 1998; pp. 727–795.
80. Meave, J.A.; Rincón, A.; Romero-Romero, M.A. Oak forests of the hyper-humid region of La Chinantla, Northern Oaxaca Range, Mexico. In *Ecology and Conservation of Neotropical Montane Oak Forests*; Kappelle, M., Ed.; Springer: Berlin, Germany, 2006; pp. 113–125.
81. Oldfield, S.; Eastwood, A. *The Red List of Oaks*; Fauna & Flora International: Cambridge, UK, 2007; pp. 5–7.
82. Canada Centre for Remote Sensing. Cobertura del Suelo de México, 2011, a 250 Metros. Available online: http://www.conabio.gob.mx/informacion/gis/ (accessed on 7 June 2021).
83. Trejo-Vázquez, I. El clima de la selva baja caducifolia en México. *Investigaciones Geográficas* **1999**, *39*, 40–52. [CrossRef]
84. Secretaría de Medio Ambiente y Recursos Naturales. *Inventario Estatal Forestal y de Suelos—Zacatecas 2014*; Secretaría de Medio Ambiente y Recursos Naturales: Ciudad de México, Mexico, 2015; pp. 65–165.
85. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. Selvas Secas. Available online: https://www.biodiversidad.gob.mx/ecosistemas/selvaSeca (accessed on 14 June 2021).