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Traditional Agroforestry Systems and Conservation of Native Plant Diversity of Seasonally Dry Tropical Forests

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Abstract: Traditional agroforestry systems (TAFS), which integrate crops with wildlife, are important reservoirs of human culture and technical experiences with a high capacity for biodiversity conservation. Our study aimed to evaluate the capacity of TAFS to conserve the floristic diversity of tropical dry forests (TDF) in the Tehuacán-Cuicatlán Valley, Mexico. We compared TAFS and TDF by measuring their forest cover, floristic composition, and structure, in addition to documenting the motivations of people to maintain native vegetation in their agricultural fields. We conducted a restricted randomized sampling of perennial plant species, including nine sites of TAFS and nine of TDF to determine the alpha, beta, and gamma diversity. Furthermore, we conducted semi-structured interviews with peasants who managed the agricultural plots we studied. We also performed workshops with people of the communities where surveys were performed. Our findings show that TAFS can maintain, on average, 68% of the species (95% of them native to the region) and 53% of the abundance of individuals occurring in the adjacent TDF. TAFS harbour 30% (39 species) of plants endemic to Mexico. Total species richness of TDF and TAFS were similar, as well as the effective number of species or communities estimated for the alpha, beta, and gamma diversity, but differed in the abundance of individuals. The high species turnover recorded in TDF (72%) and TAFS (74%) has profound implications for conservation, suggesting that it would be necessary to maintain several sites in order to conserve the regional diversity of native vegetation. Material, non-material, and regulatory contributions were reported to be the reason that peasants take into account maintaining natural vegetation. TAFS associated with TDF in the region (also called "Apancles") contain an important richness, diversity, and endemism of components of natural ecosystems, as well as provide multiple socio-ecological contributions. These systems could represent a viable alternative to reconcile biological conservation with social well-being.

Keywords: agroforestry; Apancles; biocultural diversity; biodiversity conservation; traditional plant management; Tehuacán-Cuicatlán Valley; tropical dry forest conservation

1. Introduction

Traditional forms of rural life are commonly able to satisfy basic peasants households' needs by using natural ecosystems and biodiversity while conserving them [1–4]. Among the strategies for such purposes, traditional agroforestry systems (TAFS) are outstanding. These systems deliberately integrate the conservation of forest species with crops and a high diversity of semi-domesticated organisms for the purpose of obtaining ecological, economic, and social benefits [5,6].

TAFS are important reservoirs of human culture, technical experiences, biodiversity, and ecosystems [4]. Agroforestry is probably the earliest form of agricultural management, since the development of agriculture was associated with forest management [7], and the earliest phases of agriculture likely integrated incipient crops within forest landscapes or forest components in agricultural systems. These practices have persisted over millennia [5]. Current TAFS are a result of a long history of silvicultural and agricultural management [8,9], and are of great relevance for facing the challenges in designing sustainable production systems [10,11].

These systems have a high capacity for biodiversity conservation. For instance, reports from Bhagwat et al. [12] suggest that, in the pan-tropical area, TAFS have an arboreal and herbal species richness of 64% occurring in adjacent native forests, whereas Noble and Dirzo [13] found that in Indonesia these systems may conserve 50% to 80% of the plant and bird species diversity of native forests. In Mexico, several studies in the Tehuacán-Cuicatlán Valley region have reported that TAFS contain, on average, 70% of the components of the surrounding forests of temperate and semi-arid areas (not including tropical dry forest) [14]. In addition, these systems maintain a mosaic of vegetation forming biological corridors at the landscape level that provide a favourable habitat for a great variety of associated species [1].

TAFS involve management forms that contribute to biodiversity conservation, among them: (i) tolerance, directed to deliberately maintaining within TAFS wild and weedy plants that occurred in the areas before their transformation; (ii) protection, which consists of providing special care to desirable plants to ensure their permanence in the managed systems—these practices include the removal of competitors, pruning, fertilization, protection against herbivores, procuring light or shade, and protection against other environmental risks; and (iii) promotion, through which people increase the abundance of desirable plants in their natural habitats or TAFS by sowing seeds, planting vegetative structures or entire plants from forests to agricultural fields, managing fire and water, and practicing other strategies that support the abundance of some species. These activities enhance the availability of plant components valued by people, as well as conserving and restoring vegetation [5,13–15].

All these management forms sustain what we call in this study the agroforestry practices, which are interventions in domesticated, weedy, and wild components of TAFS that are deliberately carried out by peasants in these systems to maintain biodiversity and obtain different types of benefits. In the study area and other regions of Mexico, Moreno-Calles et al. [15–17] and Vallejo et al. [18] characterized different types of agroforestry practices for different ecosystems, not including tropical dry forests: (i) vegetation patches, which are areas of forest left inside crop fields (mainly on the edges of the plots and commonly connected with adjacent forest areas) to protect them against landslides, or because they have some valuable forest components, or simply because these areas are stony and difficult to till, or have pronounced slopes or inappropriate soil; (ii) vegetation islands, or small patches of vegetation distributed in the fields (which are small areas combining remnants of native vegetation and other managed plants or deliberately designed sites that are located within the plots); (iii) vegetation fringes that are strips of vegetation forming terraces, barriers, or borders of plants tolerated or promoted inside crop fields to protect soils against erosion and crops against wind, being also effective for maintaining soil and humidity; (iv) isolated trees, which are individuals of arboreal species with special value for people because they provide shade, edible fruits, fodder, firewood, or other benefits; and (v) live fences that include plant components, some of which are from natural vegetation, for delimiting crop fields.

Commonly, people move young plants from inside the fields (or even from forests) to some of the mentioned types of agroforestry practices, most commonly live fences and vegetation fringes. In some crop fields, it is possible to find some or all of these types of agroforestry practices favouring the conservation of a high proportion of biodiversity and ecosystem functions, while satisfying basic human needs.

Seasonally dry tropical forests (or tropical dry forests, TDF) are plant communities formed by tropical species characterized by their loss of leaves during the dry season [19]. TDF represent 41.5% of the areas of the world covered by tropical forests [20,21]. In Mexico, they cover 11.26% of the terrestrial national territory [22] and are mainly distributed on thin, stony soils with good drainage on hill slopes at elevations from 0 to nearly 2000 m [19].

Mexican TDF occur in a wide variety of climatic conditions, but most importantly in those with a marked seasonality, with 6.2 to 10 dry months of the year [23]. Rainfall concentrates in a season generally from May to October, which is determinant in the phenological responses of their components [19]. According to García [24] and Trejo [23], the most representative climate type is the warm sub-humid climate, with summer rains and extreme annual thermic oscillations, in areas where frosts are usually absent and annual averages of temperature are between 18 and 30 °C, and rainfall of 300 to 1500 mm.

TDF are among the tropical ecosystems most threatened by human activities [25–29], and it has been estimated that only 44% of the original surface of these forests remain [30]. Miles et al. [31] identified four regions of the world where TDF are particularly threatened: (i) Indochina, (ii) Chhota-Nagpur (India), (iii) Mexico, and (iv) Chiquitano (Bolivia). The neotropical region is especially relevant since it harbours more than 60% of the remnants of TDF existing on the planet [31,32].

The severe degree of transformation of TDF can be explained because it has suffered chronic anthropogenic disturbance [33] and because it is one of the tropical habitats preferred for the exploitation of natural components and establishing human settlements [26,34]. Neotropical TDF were the setting of great civilizations with a long history of interaction with local ecosystems and where domestication of plants like maize, beans, squashes, cotton, and chili peppers, among others, took place [25,26,35].

The high biological diversity contained in TDF, and even more the high degree of endemism, is remarkable. TDF concentrate the highest endemism in the neotropics; for instance, in Mexico 60%–73% of species of these forests are endemic [25,36], and are therefore a priority for conservation [31,37]. Strategies of use and human subsistence that allow the maintenance of such enormous and unique diversity are of extraordinary importance and, in this task, TAFS may make a valuable contribution.

The main aim of this study is to evaluate the capacity of TAFS for conserving the native vegetation of the seasonally dry tropical forests. For this purpose, we conduct studies in the Tehuacán-Cuicatlán Valley, central Mexico. Based on studies of TAFS [15,16,38–40] conducted in other ecosystems of the region, we expect that these systems have a high capacity for plant diversity conservation, substantially contributing to satisfying human needs, and that these features are intimately linked. For this reason, we document the main motivations of local people to maintain native vegetation and to analyse the potential role of TAFS for designing regional strategies for the conservation of biocultural diversity.

2. Materials and Methods

2.1. Study Area

The Tehuacán-Cuicatlán Valley is one of the main reservoirs of the biocultural richness of Mexico, with a human cultural history of approximately 12,000 years [7], and early archaeological signs of agriculture in association with forest management [7,41–44]. In 1998, the Mexican government decreed the Tehuacán-Cuicatlán Biosphere Reserve, with the purpose to maintain the regional biodiversity shared among the states of Oaxaca and Puebla. More recently, in 2018, the UNESCO inscribed the "Tehuacán-Cuicatlán Valley: originary habitat of Mesoamerica" within the World Heritage List as a Mixed Heritage of Humanity (both cultural and natural), due to the extraordinary value of the regional natural ecosystems and biodiversity, the unique cultural history, and the diversity of traditional Mesoamerican cultures.

This study was conducted in three communities of Mazatec and Cuicatec origin, in the "Cañada Oaxaqueña" region, in the municipality of San Juan Bautista Cuicatlán. This territory has a semi-arid and very dry climate (annual mean temperature and precipitation of 25 °C and 485 mm, respectively), being the confluence zone of several rivers that allow the presence of riparian vegetation, columnar cacti forests, and TDF. Our studies were conducted in the communities of Santiago Quiotepec, San Juan Bautista Cuicatlán, and Santiago Dominguillo, where local people practice primary activities like agriculture, raising goats, and planting fruit trees and gathering of non-timber forest products [45,46].

The Apancle: A Traditional Agroforestry System Associated with Tropical Dry Forest

The term "Apancle" or "Apantle" is the local name for the TAFS associated with the TDF of the Cañada Oaxaqueña region. The name derives from "Apantli", a Náhuatl term referring to the irrigation channels [47] that make agriculture possible in the dry zone studied. It is also the name given to the irrigated agricultural systems found in practically all the communities of the region.

The Apancle is a small-scale traditional agricultural system, carried out in crop fields of 1–3 ha on average (1.66 ± 0.55 ha, min. 0.69, max. 2.38), in areas irrigated by permanent rivers, springs, and seasonal streams. There, people cultivate native varieties of maize ("blanco", "negrito" or "prieto", "pinto", "amarillo"), beans ("delgadito", "mosquito"), and squash ("támala"), mainly destined for direct consumption by households and partly used for barter, presents to friends, and commercialization at local level. Fruit trees cultivated there (lemon, *Citrus aurantifolia*; sapodilla, *Manilkara zapota*; mango, *Mangifera indica*; jobo, *Spondias purpurea*; annona *Annona reticulata*) are directed mainly to regional markets and partly to direct consumption. In the Apancle, the domesticated plants are integrated with remnants of native vegetation, live fences, forest cover patches, vegetation islands, and fringes, as well as isolated trees of the TDF. In these TAFS, people make use of organic fertilizers (dung from goats, cows, and bats, and ash from home stoves) combined with chemical fertilizers (urea and other nitrogen compounds, and diammanic phosphate). This means a relatively low economic investment in external inputs, since people select and store their seeds for the following agricultural cycle, and make use of the labour of family members (except during seed sowing, when they pay two people for two days for sowing 0.5 ha). Land rotation without using fire is undertaken in one- to two-year cycles (in the community of Quiotepec). Mechanization is at a low level, mainly using manual tools like shovels, sticks, "talacho" (a hand tool used for digging), machetes, "chicole" (a long stick with a basket in the tip for fruit harvesting), and ploughs; tractors are most commonly rented and used only for preparing the land. After harvest, people allow cattle and goats to enter the agricultural fields to feed on straw, and therefore the Apancle should be considered an agrosilvopastoral system, according to Nair [48].

2.2. Sampling Design

To evaluate the capacity of TAFS for plant diversity conservation, we compared the vegetation maintained in these systems with areas of TDF. We measured the vegetation cover maintained in the agricultural plots through the different types of agroforestry practices, as well as the floristic composition, structure (abundance, density, frequency), the spatial arrangement of components, and motivations of people to maintain plants and vegetation in their agricultural fields.

We adapted sampling methods developed for analysing TAFS in other vegetation types of the region by Moreno-Calles et al. [15–17], Vallejo et al. [14,38,39] and Campos-Salas et al. [40]. We conducted a restricted randomized sampling of perennial species, including nine sites of TAFS and nine of TDF. For selecting the TAFS plots studied, we firstly identified several plots, numbered these, selected three from each community by randomly choosing numbers, and then asked for permission to sample from the various landowners. TDF sites were selected considering similar topographic, soil, and geomorphological conditions to TAFS. In each site of TDF, we sampled a total area of 500 m^2 by sampling five squares of 10 × 10 m (100 m^2) each, randomly located in an area of 1.5 ha (the average area of agricultural plots studied), separating each 100 m^2 by at least 20 m. In each sampling square, we counted all individuals of the different species of trees and columnar cacti (abundance), registering for each tree its height and diameter at breast height ≥2 cm (DBH, approximately at 1.3 m). Each 100 m^2 square was subdivided into four 5 × 5 m (25 m^2) nested squares, one of which was randomly selected for recording height and two perpendicular diameters of shrubs, lianas (woody climbers), rosetophyllous plants (of the genera *Agave* and *Hechtia*), and globose cacti. Previously, we sampled vegetation in nine sites of TAFS with a total size in each plot the same area sampled in the TDF sites (i.e., 500 m^2). In each site, we also included five 100 m^2 squares (some 10 × 10 m and others 20 × 5 m, according to the form of the vegetation patches), where we measured the growth forms referred to. Each agricultural plot required a specific design of the sampled area, sectorizing and proportionally representing every type of agroforestry practice recorded; for defining such strategies, we mapped the distribution of the vegetation areas inside the plot, with the help of Google Earth Pro® (Figure 1). Sampled TAFS included plots with different levels of management intensity, which was considered to be higher in plots with lower vegetation cover and higher energy invested in management, complexity of tools used, and crop production [49,50].

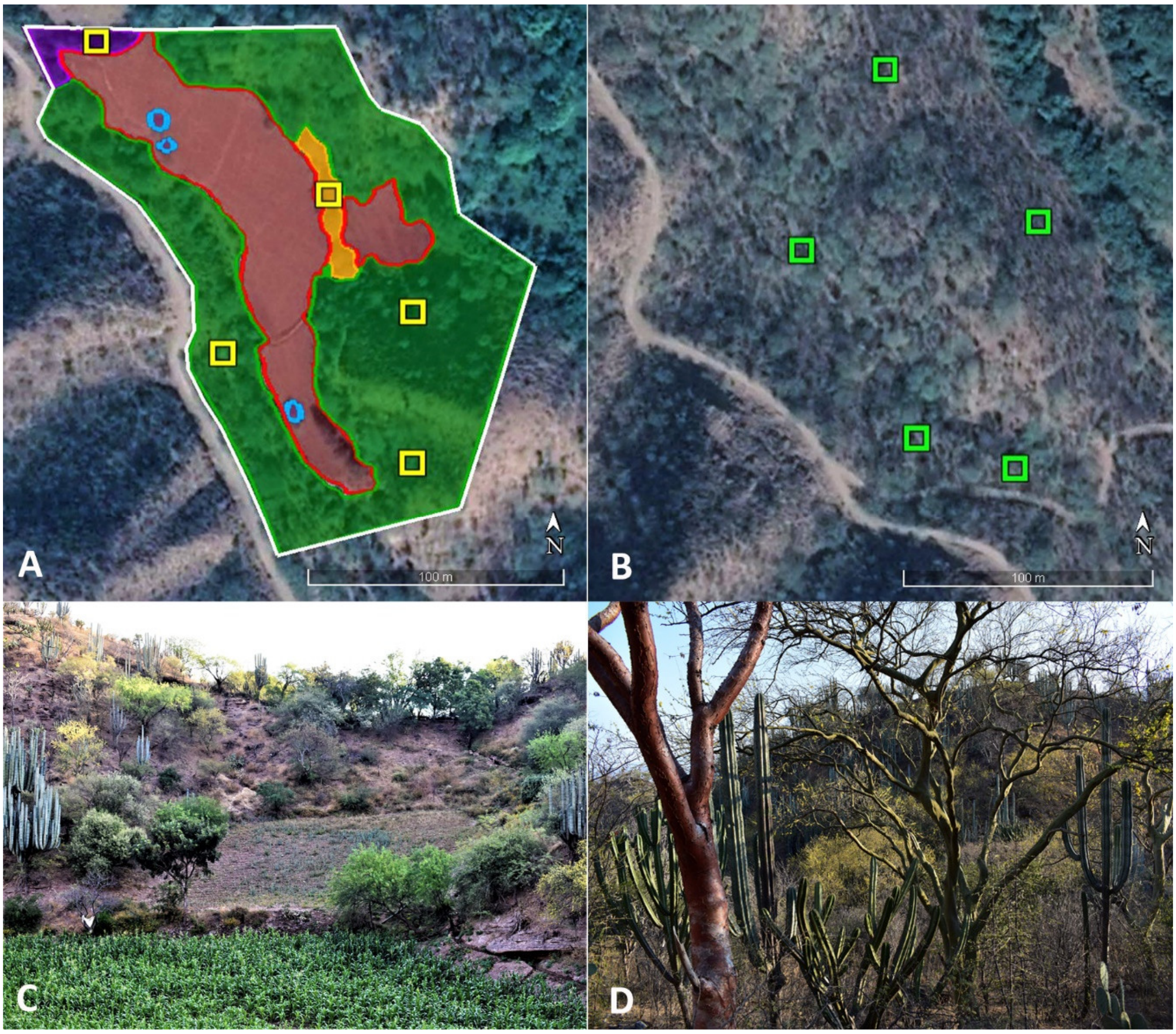

Figure 1. Sampling design. (**A**) Example of a traditional agroforestry system (TAFS) sampling site. Colours indicate different coverages: remnants of native vegetation (green); live fences (purple); isolated trees (blue); vegetation fringes (orange); agricultural cover (red). The yellow squares indicate samples of 10 × 10 m. (**B**) Example of a tropical dry forest (TDF) sampling site. The green squares indicate samples of 10 × 10 m. (**C**) View of a TAFS site. (**D**) View of a TDF site. Credit for (**A**–**B**): Google Earth Pro®; (**C**–**D**): Francisco J. Rendón-Sandoval.

In all sites sampled, we conducted ethnobotanical collection and preparation of herbarium specimens, and took photographs. Based on these materials, we then documented the cultural value of the plants occurring in the studied areas. We identified and processed all samples and the voucher specimens were deposited to the herbaria the National Herbarium of Mexico MEXU and the IBUG from the University of Guadalajara, Mexico (acronyms according to Thiers [51]). The taxonomic identification was carried out rigorously by experts in the field, in addition to the support by specialists in some plant groups. Particularly helpful for identifying plant specimens was the collection of the project "Flora del Valle de Tehuacán-Cuicatlán". For estimating and comparing plant diversity in the different settings, as far as possible, we carried out vegetation sampling under similar environmental conditions to the sites where the TAFS were sampled, particularly elevation and slope inclination. For TAFS, on average, 652 ± 79.73 m (min. 590, max. 770) and 19.33 ± 9.81° (min. 0, max. 30), respectively, while for TDF 771 ± 163.23 m (min. 625, max. 1071) and 19.78 ± 9.93° (min. 5, max. 32).

To document the motivations of local people for conserving native vegetation, we conducted semi-structured interviews with the peasants who managed the agricultural plots studied, as well as workshops with groups of people of the communities where the research was conducted. In the interviews, we asked questions about the history of each crop field, socio-economic aspects of the production units, aspects of agricultural management to characterize the level of intensification, and forms of managing vegetation and criteria for making decisions about the maintenance of wild species in the agricultural plots (Supplementary File S2). We classified the benefits of the vegetation maintained within agricultural plots following the proposal of Díaz et al. [52] into three main topics: (i) material contributions—substances, objects, or other tangible elements of nature that directly sustain the existence of people; (ii) nonmaterial contributions—effects of nature on subjective or psychological aspects that sustain the quality of life of people and that provide opportunities for recreation, inspiration, spiritual experiences, or social cohesion; and (iii) regulating contributions—structural and functional aspects of organisms and ecosystems that modify the environmental conditions experienced by people and that regulate the generation of material and nonmaterial contributions. The study was conducted from September 2017 to August 2019.

2.3. Data Analyses

We estimated the average diversity at the local level of each site (alpha diversity; α), the total diversity at the regional level of the Cañada Oaxaqueña (gamma diversity; γ), and the relationship between both, which reflects the change in species composition (beta diversity; $\beta = \gamma/\alpha$) [53], indicating the number of effective communities, which can range from 1 to N (nine in this case).

For the beta diversity, we estimated the Sørensen pairwise dissimilarity index (β_{sor} = b + c/2a + b + c), where *a* represents the total number of species that occur in both sites, *b* represents the total number of species that occur in the neighbouring site but not in the focal site, and *c* represents the total number of species that occur in the focal site but not in the neighbouring site [54]. We used this index to describe the spatial differentiation and the differences in species richness between communities, as well as to obtain the total beta diversity expressed as a percentage. Furthermore, we explored the partitioning of the spatial turnover and nestedness of species assemblages proposed by Baselga [55]. The spatial turnover (β_{sim} = min (b, c)/a + min (b, c)) estimated the replacement of some species by others, while the nestedness ($\beta_{nes} = \beta_{sor} - \beta_{sim}$) identified which of the biotas of sites with smaller numbers of species were subsets of the biotas at richer sites [55].

We estimated the effective numbers of species (also called Hill numbers) as measures of "true" diversity of order q = 0, 1, and 2 [56] for perennial species, including trees, shrubs, lianas, cacti (columnar and globose), and rosetophyllous plants (of the genera *Agave* and *Hechtia*). The q exponent determines the sensitivity of the index to relative species abundance, that is, the influence that rare, typical, or dominant species may have in the estimation of diversity [56–58]. When $q = 0$ (${}^0D$, diversity of order 0) the abundance of species does not influence the value of q, thus providing disproportionate weight to rare species, and the obtained value is equivalent to the species richness. When $q = 1$ (${}^1D$, diversity of order 1) all species have a weight proportional to their abundance in the community (it is, therefore, one of the best parameters to estimate diversity), and is equivalent to the exponential of Shannon's entropy index calculated with the natural logarithm (${}^1D = exp\ H'$). The Hill number of order 1 can be therefore interpreted as the number of typical species in the community. When $q = 2$ (${}^2D$, diversity of order 2) the abundant species have higher influence and rare species are discounted; hence, this diversity can be interpreted as the number of dominant species in the community, and is equivalent to the inverse value of Simpson's dominance index (^2D = 1/D).

We used *t*-tests to assess statistically significant differences between TDF and TAFS sites in terms of abundance of individuals, richness, and species diversity. In addition, we calculated the evenness factor ($EF = {}^2D/{}^0D$), which indicated how equitably the abundances of species were distributed (the closer to 1, the more the community was equitable) [59]. We also estimated the indexes of Shannon's entropy (*H'*) and Simpson's dominance (*D*; the closer to 1, the community had higher dominance and was less diverse).

The analyses were performed using R statistical software (v. 3.6.3; R Development Core Team) with the package entropart [60].

3. Results

The TAFS studied can maintain on average 71% of the families, 66% of the genera, and 68% of the perennial species (95% of them native to the region), and 53% of the abundance of individuals occurring in the neighbouring TDF. The percentage of species is one of the highest recorded in TAFS of other vegetation types studied in the region, as shown in Figure 2. TAFS also provide multiple benefits to local societies, among which the most outstanding were shade, firewood, edible fruit, medicine, wood for making tools and fences, and ornamental and ritual uses.

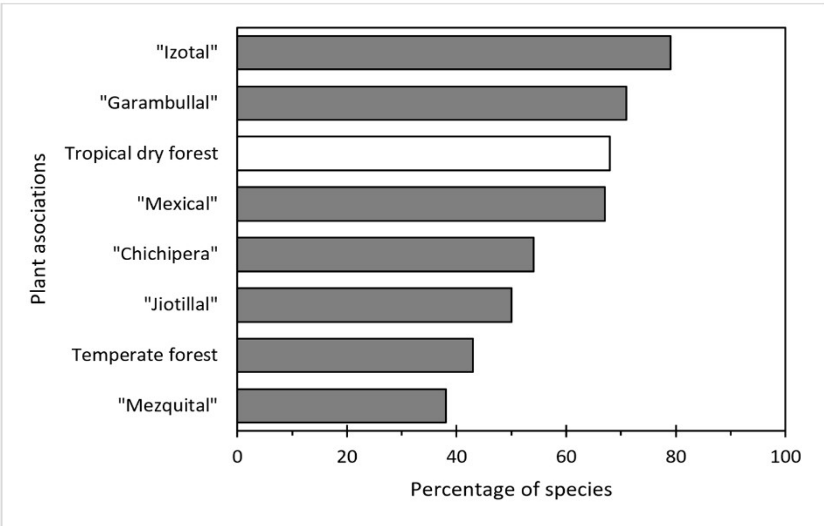

Figure 2. Comparison between the percentage of species maintained within traditional agroforestry systems associated with tropical dry forest (white bars) and different plant associations (grey bars) occurring in the Tehuacán-Cuicatlán Valley.

3.1. Types of Agroforestry Practices

In the study area, we found the following types of agroforestry practices: (i) remnants of native vegetation, that are areas of TDF with different degrees of conservation, from those well conserved and with high ecological integrity (even higher than some adjacent forest areas where the raising of goats and firewood extraction are practiced) to those with highly modified structure (most commonly favouring the abundance of useful plants); (ii) forest cover patches are formed by native species of TDF (i.e., "guajes", *Leucaena* spp. and jobo or "ciruelas", *Spondias purpurea*), wild species from other plant communities (i.e., "coyul", *Acrocomia mexicana* and sapodilla or "chicozapote", *Manilkara zapota* from the tropical moist forest), or exotic species (i.e., lemon and mango), and people promote the abundance of individuals for establishing orchards of useful species with high commercial value. These patches represent forest cover, but no remnants of TDF; (iii) live fences are mainly composed of species with the capacity for rooting and sprouting of branches, like Cactaceae, Burseraceae, Fabaceae, and Rhamnaceae, or other spiny plants used with the purpose of delimiting and protecting crops against livestock. Here, these species are also valued because they provide edible fruit, shade, and organic matter to enrich soils; (iv) isolated trees, which are commonly relatively large and multi-purpose individual trees, especially those providing shade, fruits, fodder, or wood (i.e., "mezquite", *Prosopis laevigata*; "matagallina", *Quadrella incana*; and "cardón", *Pachycereus weberi*); (v) vegetation fringes that we recorded in only one field mainly composed of species of the genus *Agave*, placed perpendicular to the slope inclination, forming terraces that contribute to retaining soil and humidity [61]; and (vi) vegetation islands (recorded in only one field) are a small vegetation patch, which is maintained since it has plants providing shade, microclimate regulation, and edible fruit (Figure 3).

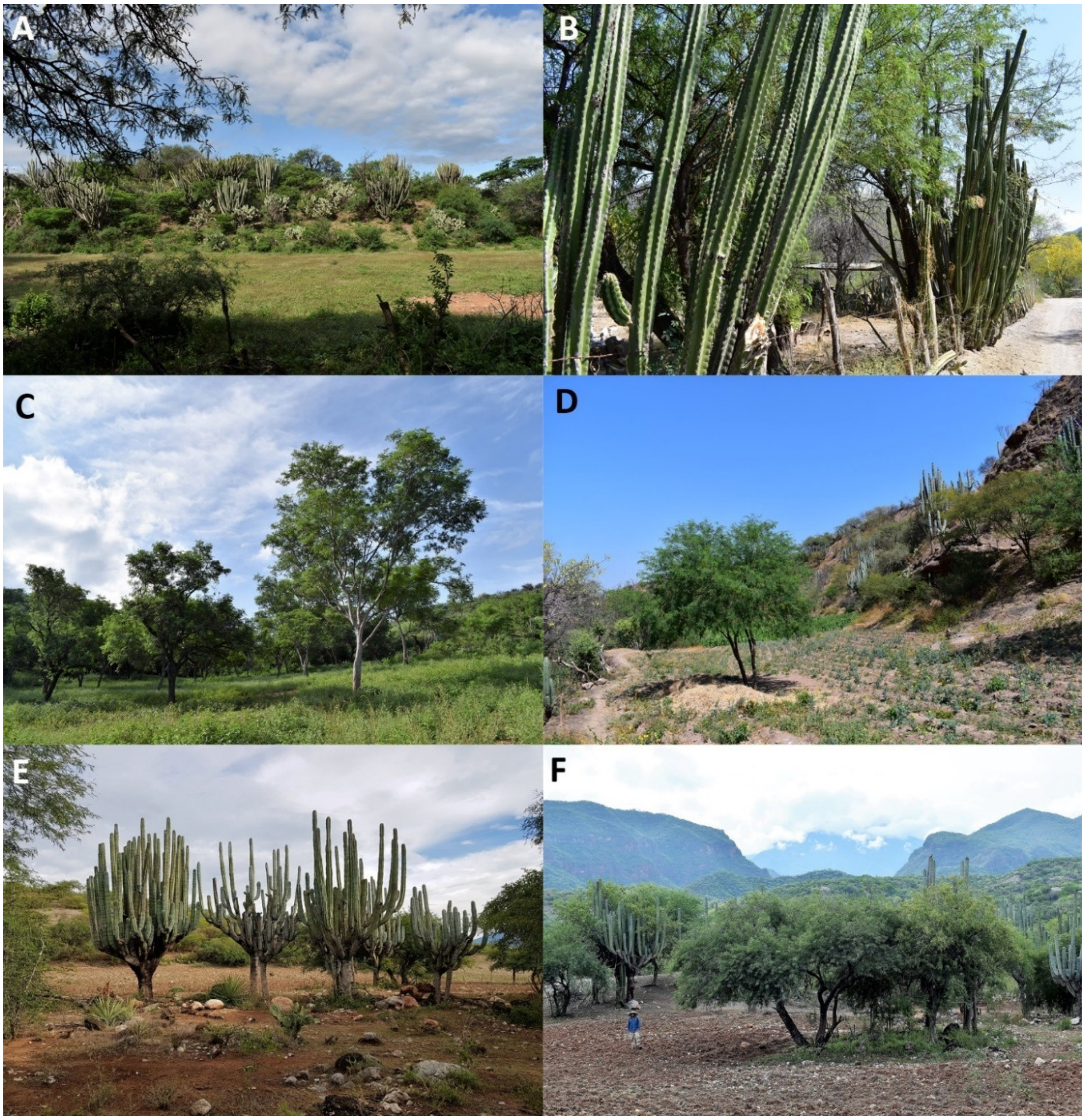

Figure 3. Types of agroforestry practices recorded in traditional agroforestry systems ("Apancles") of the Cañada Oaxaqueña region. (**A**) Remnants of native vegetation. (**B**) Live fences. (**C**) Forest cover patches. (**D**) Isolated trees. (**E**) Vegetation fringes. (**F**) Vegetation islands. Photo credit for (**A–D**) and (**F**): Francisco J. Rendón-Sandoval; (**E**): Ignacio Torres-García.

In the Apancles analysed, we recorded a higher proportion of agricultural area (54.02%) compared to forest cover, considering as forest cover the area occupied by the sum of all types of agroforestry practices. The average percentage of forest cover in Apancles was 45.98%. We documented a gradient of management intensity in the varying percentage of forest cover that TAFS maintain, which ranged from 11.11% (in "Rinconada" Cuicatlán) to 89.29% (in "La Cañadita" Quiotepec) (Table 1). We also documented correspondence between the amount of vegetation cover and the capacity for biodiversity conservation in the Apancles, as shown in Figure 4. The most frequent types of agroforestry practice were live fences and remnants of native vegetation, occurring in 89% of the sampling sites, then isolated trees in 78% of the sites, forest cover patches in 44% of the sites, and finally vegetation islands and fringes, which were recorded in one site each. In general, the forest cover was mainly due to remnants of native vegetation (38.33%), live fences (9.21%), and forest cover patches (4.29%). Isolated trees covered 0.88% of the area, vegetation fringes 0.38%, and vegetation islands 0.11% (Table 1).

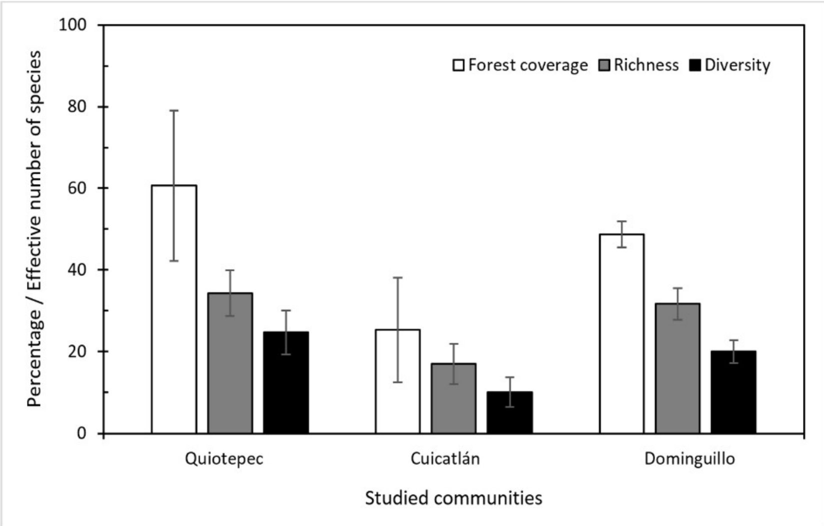

Figure 4. Correspondence between the average percentage of forest coverage (white bars), richness (grey bars), and species diversity (black bars) recorded in traditional agroforestry systems of three communities of the Cañada Oaxaqueña region. Error bars indicate 95% confidence intervals.

3.2. Capacity for Biodiversity Conservation

We documented in total 132 perennial plant species belonging to 101 genera and 39 families of Magnoliophyta (Supplementary File S1). We found significant differences only in the abundance of individuals (t = 3.414; p = 0.001; Figure 5). Total species richness (${}^0D$) recorded in the sampling sites of TDF and TAFS were similar (98 and 101 species, respectively), as well as the effective number of species or communities estimated for the alpha, beta, and gamma diversity of order 1 (${}^1D$) and 2 (${}^2D$) (Figure 6). However, the average alpha diversity was slightly higher in TDF (${}^0D_\alpha = 34.67$, ${}^1D_\alpha = 19.92$, and ${}^2D_\alpha$ =11.12 effective species) than in the Apancles (${}^0D_\alpha = 27.67$, ${}^1D_\alpha = 16.08$, and ${}^2D_\alpha = 9.29$ effective species) (Figure 6A, Table 2).

For beta diversity between sites (Figure 6B), we found higher values of the effective number of communities in TAFS for order 0 (${}^0D_\beta = 3.65$ versus 2.83 in TDF), which indicates that in the Apancles the species turnover is mostly due to the rare species. On the other hand, the typical species in the Apancles and TDF are not being replaced (${}^1D_\beta = 3.10$ and 2.96 effective communities, respectively), while the turnover of dominant species in TDF sites is slightly higher (${}^2D_\beta = 3.73$) than in the Apancles (${}^2D_\beta = 3.41$).

Table 1. Surface occupied by different types of agroforestry practices (forest cover) versus agricultural cover recorded in nine traditional agroforestry systems ("Apancles") analysed in the Cañada Oaxaqueña region. The forest cover corresponds to the area occupied by the sum of all the recorded agroforestry practices. The percentage of each type of cover is indicated in parentheses.

Sites	Agroforestry Practices Cover in m² (%)						Surface in ha (%)		
	Remnants of Native Vegetation	*Live Fences*	*Forest Cover Patches*	*Isolated Trees*	*Vegetation Fringes*	*Vegetation Islands*	**Forest Cover**	**Agricultural Cover**	**Total**
Quiotepec									
Los Chivos	12,676 (56)	380 (2)	1687 (7)	137 (1)			1.49 (66)	0.76 (34)	2.25
La Cañadita	7373 (52)	2541 (18)	2765 (19)				1.27 (89)	0.15 (11)	1.42
El Panteón	588 (9)	299 (4)		329 (5)	572 (8)		0.18 (26)	0.51 (74)	0.69
Cuicatlán									
La Cruz			1459 (12)	285 (2)			0.17 (14)	1.02 (86)	1.20
Hormiga	7901 (46)	482 (3)		262 (2)			0.86 (51)	0.84 (49)	1.70
Rinconada	1812 (8)	575 (3)		80 (0)			0.25 (11)	1.97 (89)	2.22
Dominguillo									
Manantial	7495 (49)	520 (3)		141 (1)		159 (1)	0.83 (54)	0.70 (46)	1.53
Abandonada	5852 (37)	830 (5)		96 (1)			0.68 (43)	0.89 (57)	1.57
El Tablero	9472 (40)	1463 (6)	540 (2)				1.15 (48)	1.24 (52)	2.38
Total	**53,169 (35.54)**	**7090 (4.74)**	**6451 (4.31)**	**1330 (0.89)**	**572 (0.38)**	**159 (0.11)**	**6.88 (45.98)**	**8.08 (54.02)**	**14.96 (100)**

The Apancles had 81% dissimilarity between sites (β_{sor} = 0.8134 ± 0.1451), 74% of it due to the species turnover (β_{sim} = 0.7376) and 7% to the nestedness (β_{nes} = 0.0758), which is according to the number of singletons (24) and doubletons (15) recorded in these TAFS. The TDF sites had 77% dissimilarity (β_{sor} = 0.7697 ± 0.1361), 72% of it due to the species turnover (β_{sim} = 0.7192) and 5% to the nestedness (β_{nes} = 0.0505), with fewer singletons (13) and doubletons (6).

Despite finding no significant differences, the gamma diversity of order 1 (${}^1D_\gamma$) and 2 (${}^2D_\gamma$) in TDF were higher (${}^1D_\gamma$ = 56.03 and ${}^2D_\gamma$ = 41.50 effective species, respectively) than in the Apancles (${}^1D_\gamma$ = 49.89 and ${}^2D_\gamma$ = 31.71 effective species), and the opposite pattern was found for total species richness (Figure 6C, Table 2).

TDF was a more equitable community (evenness factor = 0.423) than Apancles (evenness factor = 0.314) (Table 2), although both system types had similar richness and diversity.

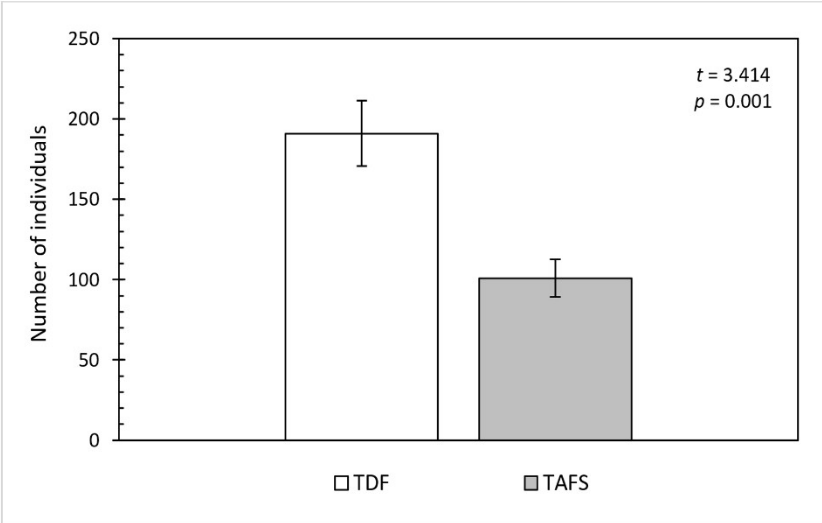

Figure 5. Average abundance of individuals of perennial plants (recorded in 18 sampling sites of 500 m²) of tropical dry forests (TDF) and traditional agroforestry systems (TAFS) in the Cañada Oaxaqueña region. Error bars indicate 95% confidence intervals.

Estimations of Shannon (*H′*) and Simpson (*D*) indexes of Apancles revealed lower entropy (*H′* = 3.94 *nats*) and higher dominance (*D* = 0.024) compared with sites of TDF (*H′* = 4.05 *nats*; *D* = 0.032). Among all sites sampled, a TAFS of Quiotepec ("La Cañadita") had the highest values of alpha diversity (${}^0D$ = 45, ${}^1D$ = 35.23 and ${}^2D$ = 27.76 effective species; *H′* = 3.56 *nats*), while the least alpha-diverse was one Apancle particularly intensified in Cuicatlán ("La Cruz"), with only eight species recorded (${}^0D$ = 8, ${}^1D$ = 6.12, ${}^2D$ = 5.12 effective species; *H′* = 1.81 *nats*) (Table 2).

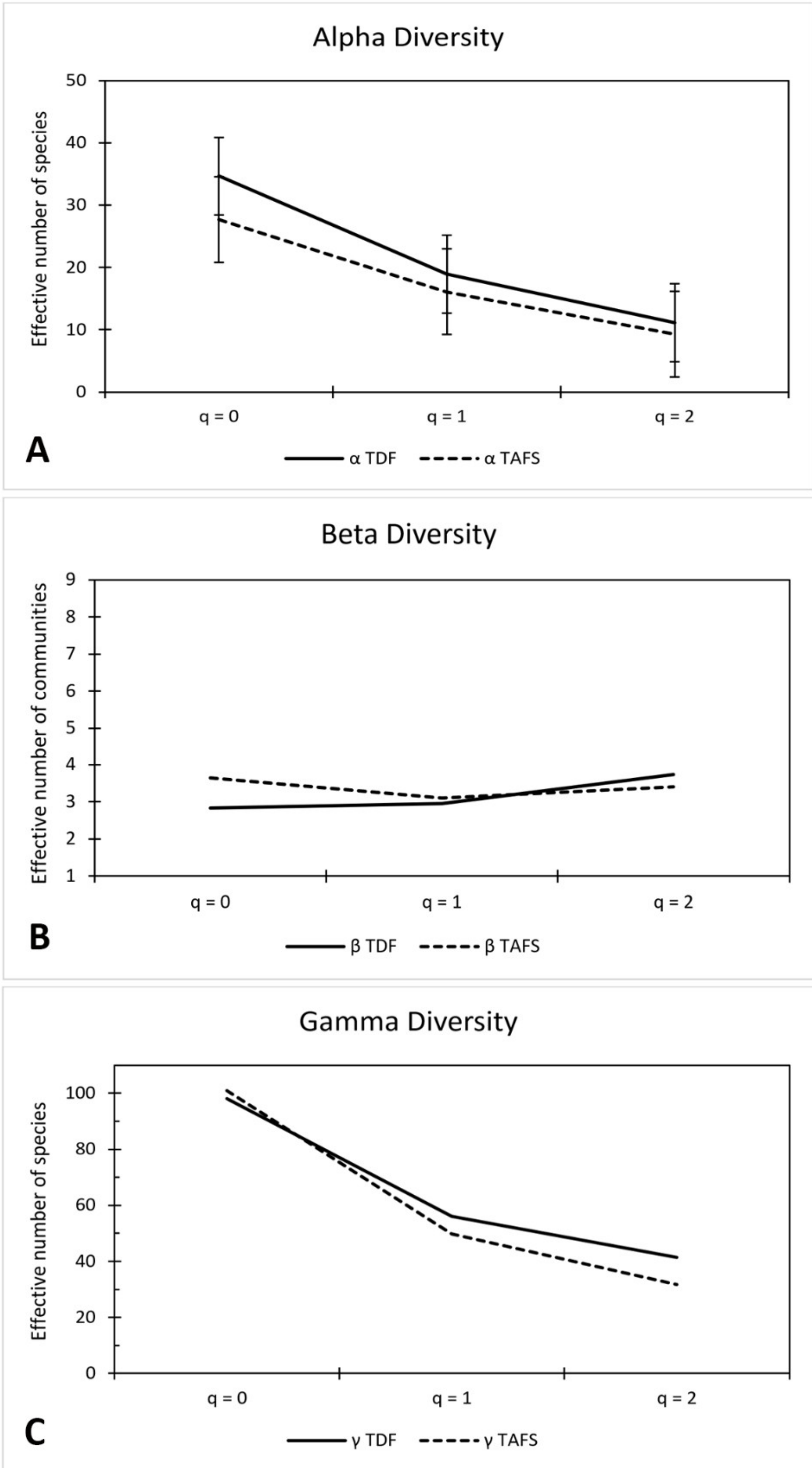

Figure 6. Diversity profiles of perennial species (recorded in 18 sampling sites of 500 m^2) of tropical dry forests (TDF; continuous line) and traditional agroforestry systems (TAFS; dotted line) in the Cañada Oaxaqueña region. (**A**) Average alpha diversity (α) among sites. (**B**) Beta diversity (β) among communities. (**C**) Gamma diversity (γ). Error bars indicate 95% confidence intervals.

Table 2. Diversity values (from 18 sampling sites of 500 m²) of the perennial species of tropical dry forests and traditional agroforestry systems in three communities of the Cañada Oaxaqueña region.

Sites	Abundance of Individuals	⁰D (Species Richness)	¹D (Typical Species)	²D (Dominant Species)	Evenness Factor (²D/⁰D)	Shannon (*H′*)	Simpson (*D*)
Tropical Dry Forests							
Quiotepec							
El Mono	113	38	27.77	22.21	0.584	3.32	0.045
Pitayagrande	168	38	26.33	20.31	0.534	3.29	0.049
La Roseta	203	33	18.71	13.68	0.415	2.93	0.073
Cuicatlán							
Tabuada	244	37	23.20	17.24	0.466	3.14	0.058
Plan dos	182	32	20.85	16.16	0.505	3.04	0.062
Cañada de Marcelino	248	42	22.70	13.73	0.327	3.12	0.073
Dominguillo							
Las Manitas	139	46	31.35	21.40	0.465	3.45	0.047
Tepalcates	166	24	9.02	4.99	0.208	2.20	0.200
La Coyotera	252	22	7.31	4.94	0.225	1.99	0.202
Alpha Diversity (α)	**191 ± 49.93**	**34.67 ± 7.86**	**19.92 ± 8.10**	**11.12 ± 6.44**	**0.321**	**2.95**	**0.090**
Gamma Diversity (γ)	**1715**	**98**	**56.03**	**41.50**	**0.423**	**4.05**	**0.024**
Traditional Agroforestry Systems (“Apancles”)							
Quiotepec							
Los Chivos	87	32	21.81	15.48	0.484	3.08	0.065
La Cañadita	140	45	35.23	27.76	0.617	3.56	0.036
El Panteón	83	26	17.06	12.83	0.493	2.84	0.078
Cuicatlán							
La Cruz	26	8	6.12	5.12	0.640	1.81	0.195
Hormiga	107	25	17.26	13.61	0.544	2.85	0.073
Rinconada	77	18	6.85	3.30	0.183	1.92	0.303
Dominguillo							
Manantial	130	39	25.74	19.56	0.502	3.25	0.051
Abandonada	90	26	17.47	12.70	0.488	2.86	0.079
El Tablero	169	30	16.85	11.20	0.373	2.82	0.089
Alpha Diversity (α)	**101 ± 41.63**	**27.67 ± 10.87**	**16.08 ± 8.94**	**9.29 ± 7.29**	**0.336**	**2.80**	**0.108**
Gamma Diversity (γ)	**909**	**101**	**49.89**	**31.71**	**0.314**	**3.94**	**0.032**

3.3. Floristic Composition

In the sampling sites, the plant families better represented were Fabaceae, Cactaceae, Euphorbiaceae, and Burseraceae, and the genera *Bursera*, *Opuntia*, *Agave*, and *Vachellia* (Table 3). We identified the species *Phaulothamnus spinescens* (Achatocarpaceae), which is a new record for the state of Oaxaca, a scarce species previously reported in arid zones of southwestern US, and the Mexican states of Baja California, Nayarit, Nuevo León, Puebla, Tamaulipas, and Sonora, in xerophytic scrubs at elevations of 900 to 1100 m [62]. This species was recorded only in one site of TDF and one Apancle of the community of Quiotepec at an elevation of 615 m.

Table 3. Distribution of the number of genera and species (recorded in 18 sampling sites of 500 m^2) in the most diverse families and genera of tropical dry forests and traditional agroforestry systems of the Cañada Oaxaqueña region. The percentage with respect to the total number of genera and species is indicated in parentheses.

Families	Genera (%)/Species (%)	Genera	Species (%)
Fabaceae	14 (13.86)/19 (14.39)	*Bursera*	7 (5.30)
Cactaceae	12 (11.88)/18 (13.64)	*Opuntia*	6 (4.55)
Euphorbiaceae	6 (5.94)/9 (6.82)	*Agave*	4 (3.03)
Burseraceae	1 (0.99)/7 (5.30)	*Vachellia*	3 (2.27)
Malvaceae	6 (5.94)/6 (4.55)	*Croton*	3 (2.27)
Rhamnaceae	4 (3.96)/5 (3.79)	*Mimosa*	3 (2.27)
Malpighiaceae	5 (4.95)/5 (3.79)	*Sarcomphalus*	2 (1.52)
Verbenaceae	3 (2.97)/5 (3.79)	*Stenocereus*	2 (1.52)
Others	51 (50.50)/58 (43.94)	Others	101 (77.28)

In TDF we recorded a remarkably higher abundance of individuals (1715; on average 191 ± 49.93 individuals per site (min. 113, max. 252)) and species diversity (35 ± 7.86 species; min. 22, max. 46), than in Apancle systems, where 909 individuals (on average 101 ± 41.63; min. 8, max. 45 per site) and 28 ± 10.87 species (min. 26, max. 169) were recorded (Table 2).

The most frequent species in TDF sites were *Bursera aptera* (occurring in all sampled sites), *Bursera submoniliformis* (in 89% of the sites), *Ceiba parvifolia*, *Pachycereus weberi*, and *Randia thurberi* (in 78% of the sites). In contrast, 27% of species were recorded in one single site, most of them (58%; 15 species) occurred only in the TDF. In the Apancles, the most frequent species were *Prosopis laevigata* and *Quadrella incana* (occurring in 89% of the sites), as well as *Escontria chiotilla*, *Mimosa luisana*, and *Pachycereus weberi* (occurring in 78% of the sites). These species have multiple uses, mainly providing shade, firewood, and wood for tools and fences, as well as edible fruits, mainly cacti, which is highly valued in the region. In the Apancles, 46% of the species were recorded in one single site, 50% of them (23 species) only found in these systems.

Species with the highest relative density (Figure 7) in TDF were *Croton alamosanus* (238 individuals/ha), *Aeschynomene compacta* (193), *Mammillaria carnea* (182), *Echinopterys eglandulosa* (169), and *Bursera aptera* (167). In the Apancles, the species with the highest relative density were *Stenocereus stellatus* (142 individuals/ha), *Prosopis laevigata* (136), *Vachellia campechiana* (107), *Quadrella incana* (102), and *Lippia graveolens* (93).

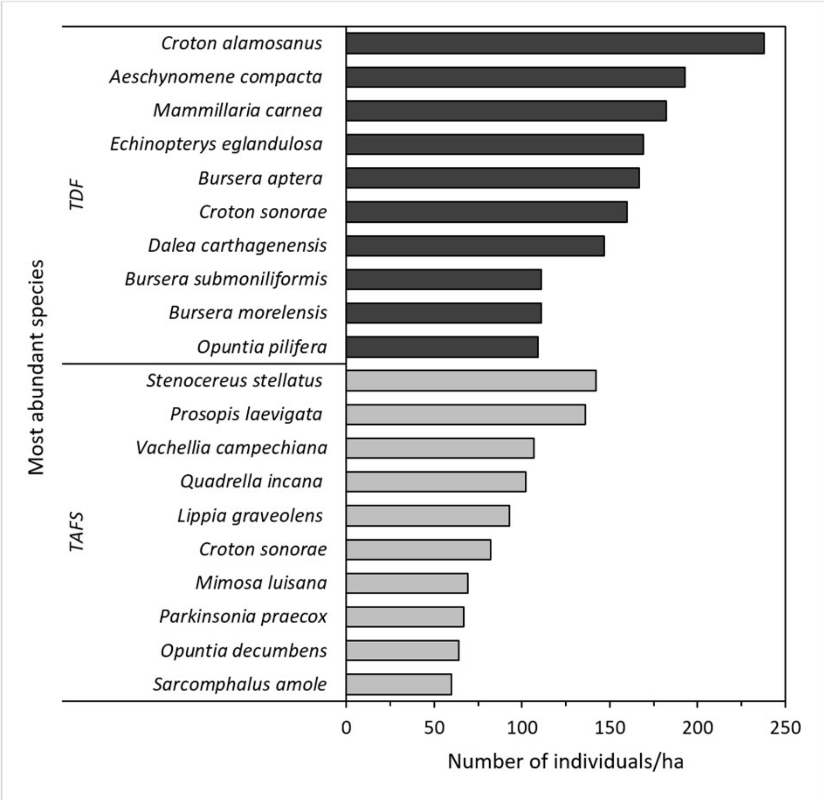

Figure 7. Relative density (extrapolated to 1 ha) of the most abundant perennial species (recorded in 18 sampling sites of 500 m^2) of tropical dry forests (TDF; black bars) and traditional agroforestry systems (TAFS; grey bars) in the Cañada Oaxaqueña region.

3.4. Endemism

We recorded a high degree of endemism in the study area: 58 species (44% of all species recorded) are distributed only in Mexico. Seven species (12%) are restricted to the states of Oaxaca and Puebla, eight species (14%) are only found in the Tehuacán-Cuicatlán Valley, and one species (*Agave quiotepecensis*) is micro-endemic of the Cañada Oaxaqueña region, in slopes of mountains neighbouring the Sabino and Grande rivers [63]. Also relevant is the presence of *Escontria*, a monotypic genus endemic of Mexico, in the states of Guerrero, Michoacán, Oaxaca, and Puebla [64,65], as well as *Hechtia*, which is a genus quasi-endemic to Mexico, with 96% of its species restricted to the national territory [66]. TDF contained 37% (50 species) endemic species, while Apancles had 30% (39 species) of plant species endemic to Mexico (Figure 8, Supplementary File S1).

Some of the species recorded that are restricted to Mexico are within some risk category according to the Red List of Threatened Species of the International Union for Conservation of Nature (IUCN) [67] and Mexican laws (NOM-059- SEMARNAT-2010) [68] (Supplementary File S1). In addition, all species of the Cactaceae family are listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) [69], which includes species that are not necessarily endangered, but whose trade must be controlled to avoid incompatible use with the survival of species.

Figure 8. Some species of perennial plants endemic to Mexico preserved within the traditional agroforestry systems ("Apancles") of the Cañada Oaxaqueña region. (**A**) *Agave quiotepecensis*. (**B**) *Vachellia campechiana*. (**C**) *Mimosa luisana*. (**D**) *Bursera linanoe*. (**E**) *Bursera morelensis*. (**F**) *Bursera aptera*. (**G**) *Mammillaria carnea*. (**H**) *Lophocereus marginatus*. (**I**) *Pachycereus weberi*. (**J**) *Myrtillocactus geometrizans*. (**K**) *Stenocereus stellatus*. (**L**) *Escontria chiotilla*. Photo credit: Francisco J. Rendón-Sandoval.

3.5. Reasons for Conserving the Native Vegetation

Among the native plant species, we recorded 96 (73% of the total) with at least one local use. Many species had more than one local use (i.e., edible, medicine, fodder, wood). We documented that the main motives for maintaining (through tolerance, protection, and promotion) components of TDF within agricultural plots were different benefits that can be classified as contributions: (i) material, (ii) nonmaterial, and (iii) regulating.

The material contributions included plants providing edible roots, stems, flowers, or fruits (specially Cactaceae species), some used for preparing beverages, establishing live fences, or medicines, or used as firewood, fodder, resins, poisons, and wood. Nonmaterial contributions included ornamental plants that form part of ceremonies and rituals, do not cause damage, and have a "right to live", as well as those that "cause well-being". The regulating contributions included plants that provide shade, "attract rain", maintain water, regulate the climate, are the habitat of other useful species, increase soil fertility, control pests, and protect soil against erosion (Figure 9, Table 4, Supplementary File S1).

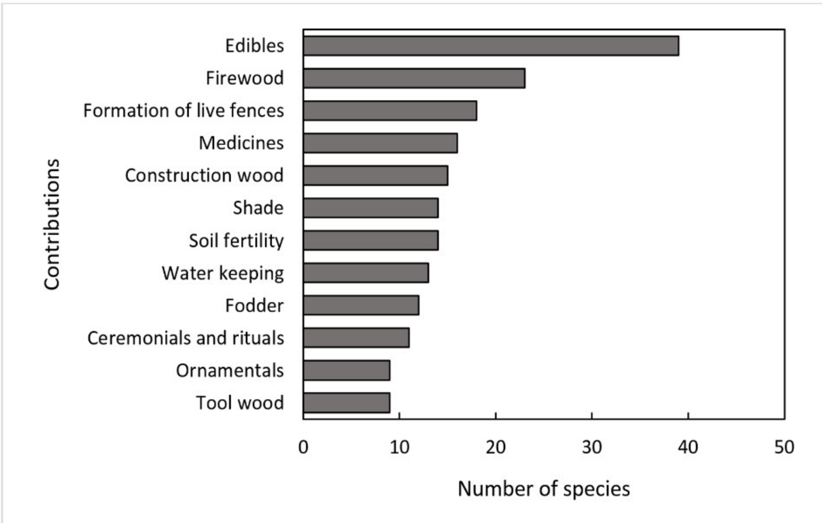

Figure 9. Main contributions of plant species to the satisfaction of human needs in the Cañada Oaxaqueña region.

4. Discussion

4.1. Capacity for Biodiversity Conservation

The findings of this study show that the TAFS analysed can conserve an important proportion of the plant species richness (68%) and abundance of individuals (53%) native to the TDF. At the same time, the Apancle systems contribute to satisfying basic human needs. These systems are sources of food, firewood, medicine, materials for construction, shade, soil fertility, hydric regulation, fodder, and inputs for ornamental and ritual uses, among others (Figure 9).

Analysis of beta diversity showed that the high dissimilarity between sites, which can be explained by the species turnover and that we found in the Apancles (74%) and TDF (72%), has profound implications for conservation, suggesting that it is necessary to maintain several sites in order to conserve the regional diversity of natural ecosystems.

Table 4. Contributions of vegetation to the satisfaction of human needs in the Cañada Oaxaqueña region. Species mentioned in workshops and interviews are included. The contributions are ordered from the highest to lowest number of species recorded in each category.

Contributions	Number of Species	Some Outstanding Examples
Material		
Edible fruits	23	columnar cacti
Edible stems	12	"quelites" (*Crotalaria pumila*, *Porophyllum ruderale*), "nopal de cruz" *Acanthocereus subinermis*
Edible flowers	2	"cacayas" of "rabo de león" *Agave quiotepecensis* and "mano de león" *Agave seemanniana*
Edible roots	1	"jícama de pochote" *Ceiba parvifolia*
Firewood	23	Fabaceae
Formation of live fences	18	Cactaceae, Burseraceae, Fabaceae, Rhamnaceae
Medicines	16	"cuachalalá" *Amphipterygium adstringens* (healing), "oreganillo" *Lippia graveolens* (digestive)
Construction wood	15	"mezquite" *Prosopis laevigata*, "quebracho" *Vachellia pringlei*
Fodder	12	Fabaceae (tender fruits), "caulote" *Guazuma ulmifolia*
Tool wood	9	"agalán" *Karwinskia humboldtiana*, "palo prieto" *Krugiodendron ferreum*, "matagallina" *Quadrella incana*
Beverage preparation	5	"cardón" *Pachycereus weberi* ("pulque rojo"), others columnar cacti, "chupandía" *Cyrtocarpa procera*
Thirst quencher	1	fruit of "biznaga" *Ferocactus latispinus* var. *spiralis*
Resins	1	"linaloe" *Bursera linanoe*
Saponifers	1	"cholulo" *Sarcomphalus pedunculatus*
Poisons	1	"brea" *Bursera aptera*
Regulating		
Shade	14	"mezquite" *Prosopis laevigata*, "guamúchil" *Pithecellobium dulce*
Soil fertility	14	"chimalacate" *Viguiera dentata*, Fabaceae
Water keeping	13	"mezquite" *Prosopis laevigata*, "palo de agua" *Astianthus viminalis*
Protect soil from erosion	6	*Agave* spp., *Hechtia* spp., *Opuntia* spp.
Pest control	1	"venenillo" *Cascabela thevetia* (versus the ant "chicatana" *Atta mexicana*)
Habitat of other useful species	1	"mantecoso" *Parkinsonia praecox* (host of the mushroom "nanacate" *Schizophyllum commune*)
Rainfall attraction		"all the trees on the hill call the water"
Nonmaterial		
Ceremonials and rituals	11	"copales" and "cuajiotes" of genus *Bursera*
Ornamentals	9	"huesito" *Plocosperma buxifolium*, "solterito" *Petrea volubilis*
"They have a right to life"		"all plants"

Comparing this information with that of similar studies in other ecosystems of the region, like columnar cacti forests ("chichipera", "garambullal", "jiotillal") [15,16], temperate forests [39], scrub forests ("mezquital") [38], and rosetophyllous forests ("izotal" and "mexical") [40], the high capacity for biodiversity conservation of the Apancles is clear, since these are among the most effective systems for conserving plant diversity in the Tehuacán-Cuicatlán Valley (Figure 2). In addition, the proportion of perennial species conserved in TAFS recorded in our study (68%) is similar to that documented at a pan-tropical level by Bhagwat et al. [12] (64%), and within the range estimated by Noble and Dirzo [13] for Indonesia (50%–80%).

Considering the effective numbers of species estimated for the alpha and gamma diversity of order 1 (one of the better parameters, since all species are included with a weight proportional to their abundance in the community), the capacities of plant diversity conservation of the Apancles studied are 81% and 96%, respectively. These figures suggest that Apancles can conserve the greater part of the diversity of perennial plant species of the neighbouring TDF. However, despite such remarkable conservation capacity, Apancles maintain only one half of the abundance of individuals (53%; Figure 5) and are "samples of diversity", where half of the representation of individuals has been reduced, and, thereby, part of the ecological interactions and ecosystem functions. Therefore, it is necessary to go beyond the estimation of diversity and to evaluate these effects. It has been documented that although TAFS may be similar to native vegetation in terms of species richness, the floristic composition is not consistent and may represent an excess of pioneer species that spread and establish in the disturbed areas easily [70,71]. It is important to have in mind that pioneers can have a role in creating an ecological succession in highly degraded land.

Based on this aspect, to evaluate the capacity for biodiversity conservation of the TAFS, we considered it pertinent to study which conditions best maintain the diversity inside these systems and to include more detailed approaches to robustly characterize their configuration. In this study, for instance, we documented higher dominance and lower equitability in Apancles than in TDF, even when we recorded that total species richness and diversity were similar in both systems (Table 2, Figure 6).

An outstanding aspect of the Apancles is their capacity for harbouring endemic species, since nearly 30% of species whose distribution is restricted to Mexico are maintained there. This pattern is consistent with the high degree of endemism documented in the Mexican TDF, which are the main reservoir of endemism in the neotropics with nearly 60–73% endemic species [25,36]. Hence, these are considered a priority for conservation on a global scale [31,37].

4.2. Floristic Composition

The most diverse families and genera recorded in the Cañada Oaxaqueña region (Table 3) were also reported by several studies in the neotropical TDF [72–76]. The review by Rzedowski and Calderón de Rzedowski [77] reported the predominance of the family Fabaceae in the Mexican TDF, as confirmed in this study. Also outstanding in the study area were the families Cactaceae, Euphorbiaceae, and Burseraceae, which is consistent with previous studies [73,78].

The genus with a higher number of species in the sampling sites was *Bursera*, represented by trees producing aromatic resins that are locally used in ceremonies and rituals. Some of these species have the capacity for rooting and sprouting of branches, and hence are frequently used for live fences in the Apancles. Such high diversity of *Bursera* has prompted some authors to characterize a type of TDF as "Cuajiotal", where photosynthetic stemless trees of this genus are dominant [79]. Oaxaca is one of the states with more species of *Bursera* (37), only surpassed by Guerrero (47 species) [80]. Other genera well represented in this study were *Croton*, *Euphorbia*, *Lysiloma*, *Mimosa*, *Randia*, and *Vachellia*, which have a wide distribution in TDF of the neotropics [78]. All these genera were mentioned by Rzedowski and Calderón de Rzedowski [77] among those that contain the greatest number of species and that live preferentially or exclusively in the TDF.

We found a marked differentiation in the species more abundantly recorded in the TAFS and TDF (Figure 7). In the Apancles, the most abundant were species of multi-purpose plants like *Stenocereus stellatus* producing edible fruit and live fences (which are relatively easy to propagate from branches, and have rapid growth and production), *Prosopis laevigata* and *Vachellia campechiana* providing wood, shade, and firewood, *Quadrella incana* providing fencing stakes and tool wood, and *Lippia graveolens* with medicinal and condimental uses. Plants more abundant in TDF (*Croton alamosanus, Aeschynomene compacta*, *Mammillaria carnea*, *Echinopterys eglandulosa*, and *Bursera aptera*) were little or not used. Peasant management increases the abundance of useful plants inside agricultural fields, as documented in several studies [5,15,40,81], through the implementation of different types of agroforestry practices.

4.3. Types of Agroforestry Practices Implemented in the Apancles

Peasants of the Cañada Oaxaqueña maintain native varieties of maize, beans, and squashes, some "improved" commercial varieties or hybrid cultivars, and exotic fruit trees coexisting with components of neighbouring TDF through traditional and modern practices, similarly described by Durand [82] for the rural areas of Mexico. This real situation in the Tehuacán-Cuicatlán Valley, as in other regions of Mexico, should discourage oversimplified conclusions about the supposition of functional relationships between knowledge and management, and that traditional societies are in all cases ecologically sustainable [82].

Some types of agroforestry practices are more passive than others, and in some cases it is questionable if they are genuine agroforestry practices; for instance, when a remnant of native vegetation or a vegetation island may be maintained in an agricultural field simply because people do not have machines or sufficient labour to remove the vegetation. In contrast, live fences, one of the most frequent practices and with high capacity for biodiversity conservation [83], actively contribute to maintaining and recovering elements of TDF because they do not interfere with agricultural practices, and are areas continually enriched as new components replace others [5,13,52]. These facts make it necessary to evaluate more specifically which type of agroforestry practices are more efficient for conserving biodiversity and contributing to satisfy people's needs. However, we could see that peasants actively design their plots, where they make management decisions planned and with clearly defined purposes.

In this study, we identified a type of agroforestry practice scarcely described before, i.e., forest cover patches, which are composed of native and exotic species that constitute orchards with high economic importance in the region. This practice contributes to satisfying human needs more than conserving native biodiversity, but through these patches people obtain monetary incomes and maintain other socio-ecological functions.

The forest cover maintained in the Apancles (45.98%) is also remarkable, as it is much higher than that recorded in other ecosystems in the region (on average 25%) [84,85]. We found that the communities with higher vegetation cover (Quiotepec and Dominguillo) conserve higher richness and diversity of TDF species, whereas in Cuicatlán, where intensive agriculture predominates, forest cover, species richness, and diversity are all low in Apancles (Figure 4). In consequence, increasing forest cover in TAFS would increase their capacity for biodiversity conservation.

4.4. Implications of the Apancles for Conservation of Biocultural Diversity

Our study reveals that Apancles are important for biodiversity conservation and satisfying human needs. The main reasons motivating the maintenance of native vegetation inside Apancles are the material contributions (as edibles plants, firewood, formation of live fences, medicines, construction wood, fodder, and tool wood), then the regulating contributions (mainly shade, soil fertility, and protection against erosion), and with a relatively lower weight, the nonmaterial contributions (as plants for ceremonies, rituals, and ornaments). These results are similar to those reported by other studies in the region [15,18,46].

Currently, the need to establish horizontal communication between scientists and people with traditional ecological knowledge is recognized in order to effectively attend to the complex multidimensional environmental and social challenges affecting local people [86–90]. Science possesses a dynamic and effective agenda for producing new knowledge and local people have gathered knowledge and tested experience for millennia [9,91,92]. For this reason, the challenges would be more effectively addressed by the combination of views, methods, and perspectives of both approaches.

It is also necessary to integrate some antagonist perspectives in science about the trade-offs associated with biodiversity conservation and food security of the human population [93,94]. The debate has been around the strategy of land-sparing, which proposes intensifying industrialized agricultural production and locating areas for conservation in different places [95], whereas land-sharing argues that primary productive activities can be compatible with biodiversity conservation [1,96,97], as this study showed. Recent reviews of the topic [98] suggest that none of the strategies are sufficient for finding one single solution to find a balance between producing and conserving, because of the high complexity of socio-ecological systems and their multiple contexts. Instead, they appear more effective in constructing local management alternatives, considering the specific contexts, the local needs, motivations, knowledge, techniques, and customs. In all cases it is important to have in mind that the main aims are that the management of productive systems should be effective and rentable, without risk to human well-being and biodiversity conservation [98]. We consider that the complementarity of both strategies and other multiple options should be analysed contexts, considering local peoples' views and those of other sectors interacting in local contexts.

Summarizing, it is relevant that many peasants maintain strategies to take advantage of the components of nature that allow them to ensure their permanence [29,30,32]. At the same time, the new challenges of a rapidly changing world would be more effectively solved through dialogs between local people, scientists, and other actors (nongovernmental organizations and government, among others), offering accompaniment from a committed science. TAFS, with their advantages and limitations, offer viable opportunities to find solutions to the purposes of satisfying human needs and biodiversity conservation.

4.5. Strategies and Perspectives for Public Policies

Based on the consideration of factors that put the TAFS identified by Moreno-Calles et al. [99] at risk, we have delineated some proposals for strengthening these systems, which, if implemented could support participatory processes with local people: (i) to promote increasing the forest components inside agricultural fields; it would be desirable to increase the forest cover with multipurpose species native to the region, which would favour regional biological conservation and provide benefits for the peasants; (ii) to value and rescue local views, knowledge, and techniques sustaining biocultural diversity; (iii) to enhance programs directed toward favouring the existence and improvement of TAFS from the perspectives of academia, governments, and civil society organizations, among others; (iv) to encourage the involvement of young people in agroforestry management; and (v) to communicate alternative strategies of conservation promoted by the Mexican government, such as payment for environmental services, promoting areas for voluntary conservation, and unities for the conservation of wildlife. However, to include TAFS in public policies at the regional scale, it is necessary to enhance a strategy of communication among different sectors of the area, particularly with those decision-makers and political actors involved in environmental legislation.

Similarly to other protected areas of Mexico with great extents of TDF (i.e., Sierra de Huautla Biosphere Reserve, in the state of Morelos, or Chamela-Cuixmala Biosphere Reserve, in Jalisco), it is also crucial to encourage spaces for social participation where local people make public their opinions and perspectives, and to have access to decision-making and mechanisms for compensating the cost of conservation [100].

5. Conclusions

Biodiversity loss has been shown to threaten the maintenance of human well-being [101]. Moreover, the maintenance of socio-ecological systems is highly dependent on biodiversity [102]. In this context, although conservation supposes contraposition with the satisfaction of social needs, it is possible and necessary to reconstruct and enhance systems where the production and maintenance of ecosystem integrity are possible [100]. TAFS represent an outstanding opportunity to maintain socio-ecological systems for the long term but they need improvements, which scientific and participatory research may identify, to increase their capacities for both purposes.

We recognize that TAFS associated with TDF in the study area harbour an important richness, diversity, and endemism of plant components of natural ecosystems. The Apancles are an expression of traditional and contemporaneous management with features of sustainability and respectful coexistence between societies and ecosystems, so they may be viable options for constructing sustainable agricultural systems. Therefore, these systems should be studied more deeply, revalued in terms of their role in caring for nature, improved in their capacities for conserving and producing, and explored as regional strategies for biodiversity and biocultural diversity conservation at local, regional, national, and global scales.

Supplementary Materials: The following are available online at www.mdpi.com/2071-1050/12/11/4600/s1. Supplementary File S1: Perennial species (recorded in 18 sampling sites of 500 m^2) of seasonally dry tropical forests and traditional agroforestry systems (also called "Apancles") of the Cañada Oaxaqueña region. Supplementary File S2: Guide of semi-structured interviews.

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References

1. Perfecto, I.; Vandermeer, J. Biodiversity Conservation in Tropical Agroecosystems. A New Conservation Paradigm. *Ann. N. Y. Acad. Sci.* **2008**, *1134*, 173–200.
2. Altieri, M.A.; Toledo, V.M. The agroecological revolution in Latin America: Rescuing nature, ensuring food sovereignty and empowering peasants. *J. Peasant Stud.* **2011**, *38*, 587–612.
3. Fischer, J.; Abson, D.J.; Butsic, V.; Chappell, M.J.; Ekroos, J.; Hanspach, J.; Kuemmerle, T.; Smith, H.G.; von Wehrden, H. Land sparing versus land sharing: Moving forward. *Conserv. Lett.* **2014**, *7*, 149–157.
4. Casas, A.; Camou, A.; Otero Arnaiz, A.; Rangel Landa, S.; Cruse-Sanders, J.; Solís, L.; Torres, I.; Delgado, A.; Moreno Calles, A.I.; Vallejo, M.; et al. Manejo tradicional de biodiversidad y ecosistemas en Mesoamérica: El Valle de Tehuacán. *Investig. Ambient.* **2014**, *6*, 23–44.
5. Casas, A.; Caballero, J.; Mapes, C.; Zárate, S. Manejo de la vegetación, domesticación de plantas y origen de la agricultura en Mesoamérica. *Bol. Soc. Bot. México* **1997**, *61*, 31–47.

6. Moreno-Calles, A.I.; Galicia-Luna, V.; Casas, A.; Toledo, V.M.; Vallejo-Ramos, M.; Santos-Fita, D.; Amou-Guerrero, A. La Etnoagroforestería: El estudio de los sistemas agroforestales tradicionales de México. *Etnobiología* **2014**, *12*, 1–16.
7. MacNeish, R.S. A summary of subsistence. In *The Prehistory of the Tehuacán Valley: Enviroment and Subsistence*; Byers, D.S., Ed.; University of Texas Press: Austin, TX, USA, 1967; pp. 209–309.
8. Altieri, M.A.; Toledo, V.M. Natural resource management among small-scale farmers in semi-arid lands: Building on traditional knowledge and agroecology. *Ann. Arid Zone* **2005**, *44*, 365–385.
9. Boege, E. *El Patrimonio Biocultural de los Pueblos Indígenas de México. Hacia la Conservación in Situ de la Biodiversidad y Agrodiversidad en los Territorios Indígenas*, 1st ed.; Instituto Nacional de Antropología e Historia: Comisión Nacional para el Desarrollo de los Pueblos Indígenas: Ciudad de México, Mexico, 2008; ISBN 9789680303854.
10. Casas, A.; Lira, R.; Torres, I.; Delgado-Lemus, A.; Moreno-Calles, A.I.; Rangel-Landa, S.; Blancas, J.; Larios, C.; Solís, L.; Pérez-Negrón, E.; et al. Ethnobotany for Sustainable Ecosystem Management: A Regional Perspective in the Tehuacán Valley. In *Ethnobotany of Mexico. Interactions of People and Plants in Mesoamerica*; Lira, R., Casas, A., Blancas, J., Eds.; Springer: Utrecht, Netherlands, 2016; pp. 179–206; ISBN 9781461466697.
11. Leakey, R.R.B. The Role of Trees in Agroecology and Sustainable Agriculture in the Tropics. *Annu. Rev. Phytopathol.* **2014**, *52*, 113–133.
12. Bhagwat, S.A.; Willis, K.J.; Birks, H.J.B.; Whittaker, R.J. Agroforestry: A refuge for tropical biodiversity? *Trends Ecol. Evol.* **2008**, *23*, 261–267.
13. Noble, I.R.; Dirzo, R. Forests as Human-Dominated Ecosystems. *Science* **1997**, *227*, 522–525.
14. Vallejo, M.; Moreno-Calles, A.I.; Casas, A. TEK and biodiversity management in agroforestry systems of different sociocological contexts of the Tehuacán Valley. *J. Ethnobiol. Ethnomed.* **2016**, *12*, 31.
15. Moreno-Calles, A.I.; Casas, A.; Blancas, J.; Torres, I.; Masera, O.; Caballero, J.; García-Barrios, L.E.; Pérez-Negrón, E.; Rangel-Landa, S. Agroforestry systems and biodiversity conservation in arid zones: The case of the Tehuacán Valley, Central México. *Agrofor. Syst.* **2010**, *80*, 315–331.
16. Moreno-Calles, A.I.; García-Frapolli, E.; Casas, A.; Torres-García, I. Traditional agroforestry systems of multi-crop "milpa" and "chichipera" cactus forest in the arid Tehuacán Valley, Mexico: Their management and role in people's subsistence. *Agrofor. Syst.* **2012**, *84*, 207–226.
17. Moreno-Calles, A.I.; Toledo, V.M.; Casas, A. La importancia biocultural de los sistemas agroforestales tradicionales de México. In *Hacia un Modelo Intercultural de Sociedad del Conocimiento en México*; Olive, L., Lazos-Ramírez, L., Eds.; Universidad Nacional Autónoma de México: Ciudad de México, Mexico, 2014; pp. 35–56, ISBN 9786070263002.
18. Vallejo, M.; Casas, A.; Moreno-Calles, A.I.; Blancas, J. Los sistemas agroforestales del Valle de Tehuacán: Una perspectiva regional. In *Etnoagroforestería en México*; Moreno-Calles, A.I., Casas, A., Toledo, V.M., Vallejo, M., Eds.; Universidad Nacional Autónoma de México: Morelia, Mexico, 2016; pp. 192–216.
19. Rzedowski, J. *Vegetación de México*; Limusa: Ciudad de México, Mexico, 1978; ISBN 9789681800024.
20. Bastin, J.-F.; Berrahmouni, N.; Grainger, A.; Maniatis, D.; Mollicone, D. The extent of forest in dryland biomes. *Science* **2017**, *356*, 635–638.
21. Olson, D.M.; Dinerstein, E.; Wikramanayake, E.D.; Burgess, N.D.; Powell, G.V.N.; Underwood, E.C.; D'amico, J.A.; Itoua, I.; Strand, H.E.; Morrison, J.C.; et al. Terrestrial Ecoregions of the World: A New Map of Life on Earth. *Bioscience* **2001**, *51*, 933–938.
22. Challenger, A.; Soberón, J. 3. Los ecosistemas terrestres. In *Capital Natural de México, Vol. I: Conocimiento Actual de la Biodiversidad*; Sarukhán, J., Ed.; Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, Mexico City, Mexico, 2008; pp. 87–108, ISBN 978-607-7607-02-1.
23. Trejo, I. El clima de la selva baja caducifolia en México. *Investig. Geográficas* **1999**, *39*, 40–52.
24. García, E. *Modificaciones al Sistema de Clasificación Climática de Köppen (Para Adaptarlo a Las Condiciones de la República Mexicana)*, 5th ed.; Instituto de Geografía, Universidad Nacional Autónoma de México: Ciudad de México, Mexico, 2004;
25. DRYFLOR; Banda-R., K.; Delgado-Salinas, A.; Dexter, K.G.; Linares-Palomino, R.; Oliveira-Filho, A.; Prado, D.; Pullan, M.; Quintana, C.; Riina, R.; et al. Plant diversity patterns in neotropical dry forests and their conservation implications. *Science* **2016**, *353*, 1383–1388.
26. Murphy, P.G.; Lugo, A.E. Ecology of Tropical Dry Forest. *Annu. Rev. Ecol. Syst.* **1986**, *17*, 67–88.
27. Búrquez, A.; Martínez-Yrízar, A. Límites geográficos entre selvas secas y matorrales espinosos y xerófilos: ¿qué conservar? In *Diversidad, Amenazas y Áreas Prioritarias Para la Conservación de las Selvas Secas del Pacífico*

de México; Ceballos, G., Martínez, L., García, A., Espinoza, E., Bezaury Creel, J., Dirzo, R., Eds.; Fondo de Cultura Económica y Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, Mexico City, Mexico, 2009; pp. 53–62, ISBN 9709000381.

28. Janzen, D.H. Tropical dry forests: The most endangered major tropical ecosystem. In *Biodiversity*; Wilson, E.O., Peters, F.M., Eds.; National Academy Press: Washington, DC, USA, 1988; pp. 130–137.
29. Trejo, I.; Dirzo, R. Deforestation of seasonally dry tropical forest: A national and local analysis in Mexico. *Biol. Conserv.* **2000**, *94*, 133–142.
30. Sánchez-Azofeifa, G.A.; Quesada, M.; Cuevas-Reyes, P.; Castillo, A.; Sánchez-Montoya, G. Land cover and conservation in the area of influence of the Chamela-Cuixmala Biosphere Reserve, Mexico. *For. Ecol. Manag.* **2009**, *258*, 907–912.
31. Miles, L.; Newton, A.C.; DeFries, R.S.; Ravilious, C.; May, I.; Blyth, S.; Kapos, V.; Gordon, J.E. A global overview of the conservation status of tropical dry forests. *J. Biogeogr.* **2006**, *33*, 491–505.
32. Montes-Londoño, I. Tropical Dry Forests in Multi-functional Landscapes: Agroforestry Systems for Conservation and Livelihoods. In *Integrating Landscapes: Agroforestry for Biodiversity Conservation and Food Sovereignty*; Montagnini, F., Ed.; Springer: Cham, Switzerland, 2017; pp. 47–78.
33. Ribeiro, E.M.S. *Efeitos da Pertubações Antrópicas Crônicas Sobre a Diversidade da Flora Lenhosa da Caatinga*, Universidade Federal de Pernambuco: Recife, Brazil, 2015.
34. Sánchez-Azofeifa, G.A. Research priorities for Neotropical dry forests. *Biotropica* **2005**, *37*, 477–485.
35. 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, Universidad Nacional Autónoma de México y Agrupación Sierra Madre, S.C.: Ciudad de México, Mexico, 1998; ISBN 9789709000023.
36. Rzedowski, J. El endemismo en la flora fanerogámica mexicana: Una apreciación analítica preliminar. *Acta Botánica Mex.* **1991**, *15*, 47–64.
37. Olson, D.M.; Dinerstein, E. The Global 200: Priority Ecoregions for Global Conservation. *Ann. Mo. Bot. Gard.* **2002**, *89*, 199–224.
38. Vallejo, M.; Casas, A.; Pérez-Negrón, E.; Moreno-Calles, A.I.; Hernández-Ordoñez, O.; Tellez, O.; Dávila, P. Agroforestry systems of the lowland alluvial valleys of the Tehuacán-Cuicatlán Biosphere Reserve: An evaluation of their biocultural capacity. *J. Ethnobiol. Ethnomed.* **2015**, *11*, 8.
39. Vallejo, M.; Casas, A.; Blancas, J.; Moreno-Calles, A.I.; Solís, L.; Rangel-Landa, S.; Dávila, P.; Téllez, O. Agroforestry systems in the highlands of the Tehuacán Valley, Mexico: Indigenous cultures and biodiversity conservation. *Agrofor. Syst.* **2014**, *88*, 125–140.
40. Campos-Salas, N.; Casas, A.; Moreno-Calles, A.I.; Vallejo, M. Plant Management in Agroforestry Systems of Rosetophyllous Forests in the Tehuacán Valley, Mexico. *Econ. Bot.* **2016**, *70*, 254–269.
41. Smith, E.C. Plant remains. In *The Prehistory of the Tehuacan Valley*; MacNeish, R., Ed.; The prehistory of the Tehuacan Valley: Austin, TX, USA, 1976; pp. 220–225.
42. Blancas, J.; Casas, A.; Pérez-Salicrup, D.; Caballero, J.; Vega, E. Ecological and socio-cultural factors influencing plant management in Náhuatl communities of the Tehuacán Valley, Mexico. *J. Ethnobiol. Ethnomed.* **2013**, *9*, 39.
43. Smith, E.J. Agriculture, Tehuacan Valley. *Fieldiana Bot.* **1965**, *31*, 53–98.
44. Casas, A.; Otero Arnaiz, A.; Pérez-Negrón, E.; Valiente-Banuet, A. In situ Management and Domestication of Plants in Mesoamerica. *Ann. Bot.* **2007**, *100*, 1101–1115.
45. Brunel, M.C. Poner la conservación al servicio de la producción campesina, reto para la construcción de un nuevo paradigma de desarrollo. *Argumentos* **2008**, *57*, 115–137.
46. Blancas, J.; Casas, A.; Rangel-Landa, S.; Moreno-Calles, A.; Torres, I.; Pérez-Negrón, E.; Solís, L.; Delgado-Lemus, A.; Parra, F.; Arellanes, Y.; et al. Plant Management in the Tehuacán-Cuicatlán Valley, Mexico. *Econ. Bot.* **2010**, *64*, 287–302.
47. Rojas-Rabiela, T.; Martínez-Ruiz, J.L.; Murillo-Licea, D. *Cultura Hidráulica y Simbolismo Mesoamericano del Agua*; Rojas-Rabiela, T., Martínez-Ruiz, J.L., Murillo-Licea, D., Eds.; Instituto Mexicano de Tecnología del Agua (IMTA)/Centro de Investigaciones y Estudios Superiores en Antropología Social (CIESAS): Jiutepec, Mexico, 2009; ISBN 978-697-7563-06-8.
48. Nair, P.K.R. Classification of agroforestry systems. *Agrofor. Syst.* **1985**, *3*, 97–128.
49. Casas, A.; Rangel-Landa, S.; Torres, I.; Peréz-Negrón, E.; Solís, L.; Parra, F.; Delgado, A.; Blancas, J.; Farfán-Heredia, B.; Moreno-Calles, A.I. In situ management and conservation of plant resources in the Tehuacán-Cuicatlán Valley, México: An ethnobotanical and ecological approach. In *Current Topics in Ethnobotany*; De

Albuquerque, U.P., Alves-Ramos, M., Eds.; Research Signpost, Kerala, India, 2008; pp. 1–25, ISBN 9788130802435.

50. Blancas, J.; Casas, A.; Moreno-Calles, A.I.; Caballero, J. Cultural Motives of Plant Management and Domestication. In *Ethnobotany of Mexico. Interactions of People and Plants in Mesoamerica*; Lira, R., Casas, A., Blancas, J., Eds.; Springer: Utrecht, Netherlands, 2016; pp. 233–255; ISBN 978-1-4614-6668-0.
51. Thiers, B. Index Herbariorum: A Global Directory of Public Herbaria and Associated Staff. New York Botanical Garden's Virtual Herbarium. Available online: Sweetgum.nybg.org/ih/ (accessed on 3 December 2019).
52. Díaz, S.; Pascual, U.; Stenseke, M.; Martín-López, B.; Watson, R.T.; Molnár, Z.; Hill, R.; Chan, K.M.A.; Baste, I.A.; Brauman, K.A.; et al. Assessing nature's contributions to people. *Science* **2018**, *359*, 270–272.
53. Whittaker, R.H. Vegetation of the Siskiyou Mountains, Oregon and California. *Ecol. Monogr.* **1960**, *30*, 279–338.
54. Koleff, P.; Gaston, K.J.; Lennon, J.J. Measuring beta diversity for presence-absence data. *J. Anim. Ecol.* **2003**, *72*, 367–382.
55. Baselga, A. Partitioning the turnover and nestedness components of beta diversity. *Glob. Ecol. Biogeogr.* **2010**, *19*, 134–143.
56. Jost, L. Entropy and diversity. *Oikos* **2006**, *113*, 363–375.
57. Jost, L.; González-Oreja, J.A. Midiendo la diversidad biológica: Más allá del índice de Shannon. *Acta Zoológica Lilloana* **2012**, *56*, 3–14.
58. Moreno, C.E.; Barragán, F.; Pineda, E.; Pavón, N.P. Reanálisis de la diversidad alfa: Alternativas para interpretar y comparar información sobre comunidades ecológicas. *Rev. Mex. Biodivers.* **2011**, *82*, 1249–1261.
59. Jost, L. The relation between evenness and diversity. *Diversity* **2010**, *2*, 207–232.
60. Marcon, E.; Hérault, B. entropart: An R Package to Measure and Partition Diversity. *J. Stat. Softw.* **2015**, *67*, 1–26.
61. Torres-García, I.; Rendón-Sandoval, F.J.; Blancas, J.; Casas, A.; Moreno-Calles, I. The genus *Agave* in agroforestry systems of Mexico. *Bot. Sci.* **2019**, *97*, 263–290.
62. Medina-Lemos, R. Achatocarpaceae. In *Flora del Valle de Tehuacán-Cuicatlán*; Medina-Lemos, R., Ed.; Instituto de Biología, Universidad Nacional Autónoma de México: Ciudad de México, Mexico, 2009; pp. 1–5, ISBN 9786070206399.
63. García-Mendoza, A.J.; Franco Martínez, I.S.; Sandoval Gutiérrez, D. Cuatro especies nuevas de *Agave* (Asparagaceae, Agavoideae) del sur de México. *Acta Bot. Mex.* **2019**, e1461, doi:10.21829/abm126.2019.1461.
64. Arias, S.; Gama-López, S.; Guzmán-Cru, L.U.; Vázquez-Benítez, B. Cactaceae. In *Flora del Valle de Tehuacán-Cuicatlán*; Medina-Lemos, R., Ed.; Instituto de Biología, Universidad Nacional Autónoma de México: Ciudad de México, Mexico, 2012; Volumn 95, pp. 1–235, ISBN 9786070230790.
65. Miguel-Talonia, C.; Téllez-Valdés, O.; Murguía-Romero, M. Las cactáceas del Valle de Tehuacán-Cuicatlán, México: Estimación de la calidad del muestreo. *Rev. Mex. Biodivers.* **2014**, *85*, 436–444.
66. Espejo-Serna, A. El endemismo en las Liliopsida mexicanas. *Acta Bot. Mex.* **2012**, *100*, 195–257.
67. International Union for Conservation of Nature (IUCN). The IUCN Red List of Threatened Species. Version 2019-3. Available online: https://www.iucnredlist.org/ (accessed on 20 May 2019).
68. SEMARNAT. *NOM-059-SEMARNAT, Protección Ambiental-Especies Nativas de México de Flora y Fauna Silvestre-Categorías de Riesgo y Especificaciones Para su Inclusión, Exclusión o Cambio-Lista de Especies en Riesgo*; Secretariat of the Interior: Mexico City, Mexico, 2010; p. 77.
69. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Apéndices I, II y III valid from 26 November 2019. Available online: https://www.cites.org (accessed on 17 March 2020).
70. Marjokorpi, A.; Ruokolainen, K. The role of traditional forest gardens in the conservation of tree species in West Kalimantan, Indonesia. *Biodivers. Conserv.* **2003**, *12*, 799–822.
71. McNeely, J.A. Nature vs. nurture: Managing relationships between forests, agroforestry and wild biodiversity. *Agrofor. Syst.* **2014**, *61*, 155–165.
72. Trejo, I.; Dirzo, R. Floristic diversity of Mexican seasonally dry tropical forests. *Biodivers. Conserv.* **2002**, *11*, 2063–2084.
73. Méndez-Toribio, M.; Martínez-Cruz, J.; Cortés-Flores, J.; Rendón-Sandoval, F.J.; Ibarra-Manríquez, G. Composición, estructura y diversidad de la comunidad arbórea del bosque tropical caducifolio en Tziritzícuaro, Depresión del Balsas, Michoacán, México. *Rev. Mex. Biodivers.* **2014**, *85*, 1117–1128.

74. Lott, E.J.; Bullock, S.H.; Solis-Magallanes, A. Floristic Diversity and Structure of Upland and Arroyo Forests of Coastal Jalisco. *Biotropica* **1987**, *19*, 228–235.
75. Gillespie, T.W.; Grijalva, A.; Farris, C.N. Diversity, composition, and structure of tropical dry forests in Central America. *Plant Ecol.* **2000**, *147*, 37–47.
76. Gallardo-Cruz, J.A.; Meave, J.A.; Pérez-García, E.A. Estructura, composición y diversidad de la selva baja caducifolia del Cerro Verde, Nizanda (Oaxaca), México. *Bot. Sci.* **2017**, *35*, 19–35.
77. Rzedowski, J.; Calderón, G. Datos para la apreciación de la flora fanerogámica del bosque tropical caducifolio de méxico. *Acta Bot. Mex.* **2013**, *102*, 1–23.
78. Gentry, A.H. Diversity and floristic composition of neotropical dry forests. In *Seasonally Dry Tropical Forests*; Bullock, S.H., Mooney, H.A., Medina, E., Eds.; Cambridge University Press: Cambridge, UK, 1995; pp. 146–194.
79. Valiente-Banuet, A.; Casas, A.; Alcántara, A.; Dávila, P.; Flores-Hernández, N.; del Coro Arizmendi, M.; Villaseñor, J.L.; Ortega Ramirez, J. La vegetación del valle de Tehuacán-Cuicatlán. *Boletín La Soc. Botánica México* **2000**, *67*, 24–74.
80. Rzedowski, J.; Medina-Lemos, R.; Calderón de Rzedowski, G. Inventario del conocimiento taxonómico, así como de la diversidad y del endemismo regionales de las especies mexicanas de Bursera (Burseraceae). *Acta Bot. Mex.* **2005**, *70*, 85–111.
81. Casas, A.; Parra, F.; Aguirre-Dugua, X.; Rangel-Landa, S.; Blancas, J.; Vallejo, M.; Moreno-Calles, A.I.; Guillén, S.; Torres-García, I.; Delgado-Lemus, A.; et al. Manejo y domesticación de plantas en Mesoamérica. Una estrategia de investigación y estado del conocimiento sobre los recursos genéticos. In *Domesticación en el Continente Americano. Volumen 2. Perspectivas de investigación y manejo sustentable de recursos genéticos en el Nuevo Mundo*; Universidad Nacional Autónoma de México / Universidad Nacional Agraria La Molina / CONACYT: Morelia, Michoacán, México, 2017; pp. 69–102; ISBN 978-607-02-9334-4.
82. Durand, L. La relación ambiente-cultura en antropología: Recuento y perspectivas. *Nueva Antropol.* **2002**, *18*, 169–184.
83. SEMARNAT. *Experiencias de Agroforestería en México*, 1st ed.; Moreno-Calles, A.I., Ed.; Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT): Ciudad de México, Mexico, 2019; ISBN 9786076260562.
84. Moreno-Calles, A.I.; Casas, A. Agroforestry Systems: Restoration of Semiarid Zones in the Tehuacán Valley, Central Mexico. *Ecol. Restor.* **2010**, *28*, 361–368.
85. García-Licona, J.B.; Maldonado-Torres, R.; Moreno-Calles, A.I.; Álvarez-Sánchez, M.E.; García-Chávez, J.; Casas, A. Ethnoagroforestry management and soil fertility in the semiarid Tehuacán Valley, México. *Ethnobiol. Conserv.* **2017**, *6*, 1–8, doi:10.15451/ec2017-06-6.5-1-16.
86. Berkes, F.; Folke, C.; Gadgil, M. Traditional Ecological Knowledge, Biodiversity, Resilience and Sustainability. *Biodivers. Conserv.* **1994**, *4*, 269–287.
87. Berkes, F.; Folke, C. *Linking Social and Ecological Systems. Management Practices and Social Mechanisms for Building Resilience*; Cambridge University Press: Cambridge, UK, 1998; ISBN 9780521591409.
88. Pretty, J.; Adams, B.; Berkes, F.; Ferreira, S.; Athayde, D.; Dudley, N. The Intersections of Biological Diversity and Cultural Diversity: Towards Integration. *Conserv. Soc.* **2009**, *7*, 100–112.
89. Leakey, R.R.B. Converting 'trade-offs' to 'trade-ons' for greatly enhanced food security in Africa: Multiple environmental, economic and social benefits from 'socially modified crops.' *Food Secur.* **2018**, *10*, 505–524.
90. Leakey, R.R.B. From ethnobotany to mainstream agriculture: Socially modified Cinderella species capturing 'trade-ons' for 'land maxing.' *Planta* **2019**, *250*, 949–970.
91. Toledo, V.M.; Barrera-Bassols, N. *La Memoria Biocultural. La Importancia Ecológica de Las Sabidurías Tradicionales*; Icaria Editorial: Barcelona, Spain, 2008; ISBN 9788498880014.
92. Berkes, F.; Colding, J.; Folke, C. Rediscovery of traditional ecological knowledge as adaptive management. *Ecol. Appl.* **2000**, *10*, 1251–1262.
93. Waggoner, P.E. How much land can ten billion people spare for nature? *Daedalus* **1996**, *125*, 73–93.
94. Borlaug, N. Feeding a Hungry world. *Science* **2007**, *318*, 359.
95. Phalan, B.; Onial, M.; Balmford, A.; Green, R.E. Reconciling Food Production and Biodiversity Conservation: Land Sharing and Land Sparing Compared. *Science* **2011**, *333*, 1289–1291.
96. Perfecto, I.; Vandermeer, J. Separación o integración para la conservación de biodiversidad: La ideología detrás del debate "land- sharing" frente a "land-sparing ". *Ecosistemas* **2012**, *21*, 180–191.
97. Vandermeer, J.; Perfecto, I. The Future of Farming and Conservation. *Science* **2005**, *308*, 1257b–1258b.

98. Ortega-Álvarez, R.; Casas, A.; Figueroa, F.; Sánchez-González, L.A. Producir y conservar: Nuevos horizontes en torno a los modelos de integración y separación territorial. *Soc. Y Ambiente* **2018**, *18*, 11–44.
99. Moreno-Calles, A.I.; Toledo, V.M.; Casas, A. Los sistemas agroforestales tradicionales de México: Una aproximación biocultural. *Bot. Sci.* **2013**, *91*, 375–398.
100. Durand, L. Pensar positivo no basta. Actitudes en torno a la conservación en la Reserva de la Biosfera Sierra de Huautla, México. *Interciencia* **2010**, *35*, 430–436.
101. Díaz, S.; Fargione, J.; Iii, F.S.C.; Tilman, D. Biodiversity Loss Threatens Human Well-Being. *PLoS Biol* **2006**, *4*, 1300–1305.
102. Srivastava, D.S.; Vellend, M. Biodiversity-ecosystem function research: Is it relevant to conservation? *Annu. Rev. Ecol. Evol. Syst.* **2005**, *36*, 267–294.