Agroforest Syst (2014) 88:125–140
DOI 10.1007/s10457-013-9660-7

Agroforestry systems in the highlands of the Tehuacán Valley, Mexico: indigenous cultures and biodiversity conservation

Mariana Vallejo · Alejandro Casas · José Blancas · Ana I. Moreno-Calles · Leonor Solís · Selene Rangel-Landa · Patricia Dávila · Oswaldo Téllez

Received: 29 July 2013 / Accepted: 26 November 2013 / Published online: 3 December 2013

Abstract In this study we analysed: (1) the biodiversity conservation capacity of Agroforestry Systems (AFS) in temperate highlands of the Tehuacán–Cuicatlán Valley, Central Mexico, (2) human cultural motives and actions for conserving such diversity and (3) problems endangering that capacity. We evaluated the richness and diversity of perennial plant species maintained in AFS through vegetation sampling of 14 agricultural plots and compared their composition with that of natural forests (14 plots of 500 m^2 each). We examined the situations among communities of Náhuatl, Ixcatec and Cuicatec people, documenting through interviews the management practices of plant species and the whole system, reasons why people maintain vegetation cover within AFS, and factors influencing changes in decisions favouring agriculture intensification. In the AFS studied we recorded a total of 79 species of trees and shrubs, 86 % of them being native species and representing 43 % of all species of trees and shrubs recorded in the sampling of the natural forests the AFS derive from. People leave standing on average a total of 40 individual trees and shrubs per agricultural plot. Reasons for leave plant species standing were more frequently associated with their use as fruit trees, firewood, shade, beauty, respect to nature and other environmental benefits. Water availability for irrigation, land tenure, and dependence on agriculture and forest for peasant's subsistence were main decision factors influencing AFS variation in their composition. AFS in temperate zones are important reservoirs of biodiversity and biocultural heritage and should be keystones for conservation policies in the Tehuacán–Cuicatlán Valley.

Keywords Agroforestry systems · Biodiversity conservation · Forest management · Traditional plant management · Tehuacán–Cuicatlán Valley

M. Vallejo · A. Casas (✉) · J. Blancas · L. Solís · S. Rangel-Landa
Centro de Investigaciones en Ecosistemas, Universidad Nacional Autónoma de México (UNAM), Santa María Guido, Apartado Postal 27-3, 58190 Morelia, Michoacán, Mexico
e-mail: acasas@oikos.unam.mx; acasas@cieco.unam.mx

A. I. Moreno-Calles
Escuela Nacional de Estudios Superiores Unidad Morelia, Universidad Nacional Autónoma de México (UNAM), Santa María Guido, Apartado Postal 27-3, 58190 Morelia, Michoacán, Mexico

P. Dávila · O. Téllez
Facultad de Estudios Superiores Iztacala, UNAM, Los Reyes Iztacala, Apartado Postal, 54090 Tlalnepantla, Estado de México, Mexico

Introduction

Forests of temperate areas in Mexico include a variety of vegetation types dominated by conifers and oaks that cover nearly 18 % of the total vegetation of this country (Ricker et al. 2007). These forests are of particular value in the context of global biodiversity conservation, since they constitute important reservoirs of species richness and endemism of plant genera representative of these ecosystems, such as *Pinus* and *Quercus,* which have their main centres of diversification in Mexico (Valencia 2004; Sánchez-González 2008). Temperate forests of Mexico have been inhabited by humans for thousands of years (MacNeish 1967; Bye 1993; Toledo and Ordóñez 1993) and currently 28 of the 57 main groups of indigenous cultures of México (Toledo et al. 2001) are users and managers of these forests. Human history in these and other areas of Mexico have determined their progressive transformation. In Mexico, some of the most important pre-Columbian cultures, the Aztec, the P'urhepecha, the Tlaxcaltec, the Mazahua, the Matlatzinca, among others, constructed their main cities in these areas (Caballero and Mapes 1985; Boege 2008). The Spanish Conquest and the Colonial period developed particular European influence on these zones because of their similarity with European ecosystems. The Spanish Haciendas in temperate forests zones determined particularly high impacts on both ecosystems and human cultures. However, it was during the last century when human impact on Mexican temperate forests has been really dramatic, associated to modern mechanized agriculture, the establishment of new human settlements, the high extraction of wood by industry, and other practices such as raising of cattle and sheep (Melville 1999), all of which have determined significant degradation of these ecosystems (Toledo and Ordóñez 1993; MEA 2005; Sarukhán and Soberón 2009).

Nowadays, conservation of the Mexican temperate areas as well as maintaining their crucial role of satisfying human needs, require developing sustainable ways of appropriation of goods and services provided by local ecosystems, guaranteeing the maintenance of both diversity of their components and functions (Sarukhán and Soberón 2009). In the context of attending such a challenge, agroecologists and ethnoecologists have identified agroforestry systems (AFS) as interesting technical options for harmonizing the purposes of biodiversity conservation and ecosystems integrity while satisfying human needs and biocultural recreation (Gordon and Newman 1997; Quinkenstein et al. 2009). This goal is possible since AFS combine agricultural practices with the maintenance of a significant number of trees, shrubs and herbs of natural vegetation inside and surrounding the crop fields, allowing biodiversity conservation and utilization of several ecosystem services that benefit agricultural practices (Krishnamurthy and Ávila 1999; Altieri and Toledo 2005; McNeely and Schroth 2006).

Transformed managed areas have particular interest in ecological science since most of the terrestrial ecosystems of the world are already in this condition (MEA 2005) and actions for managing this situation requires stronger theoretical tools. Processes occurring in the AFS have been documented to have repercussions on ecological processes that influence whole landscapes (Wallace et al. 2005; Vandermeer and Perfecto 2007). Therefore, AFS may play significant roles in regulating important ecosystem processes such as biodiversity conservation and maintenance of biotic interactions, carbon sequestration, soil conservation, and regulation of water and nutrient flows, among others (Daily 1997; Soto-Pinto et al. 2002; Schroth et al. 2004; Shibu 2009; Nair 2011; Tscharntke et al. 2011).

It has been widely documented that AFS may host high levels of local and regional biodiversity (Schroth et al. 2004; McNeely and Schroth 2006); at regional scale, these systems may favour connectivity and gene flow between conserved and fragmented areas (Bhagwat et al. 2008; Harvey et al. 2008; Perfecto and Vandermeer 2008; Scales and Marsden 2008; DeClerck et al. 2010); at local scale these systems conform a complex floristic mosaic of useful managed species through a variety of agricultural and silvicultural practices (Altieri 1991; Swift et al. 1998; Schroth et al. 2004; Casas et al. 2007; Moreno-Calles et al. 2010, Moreno-Calles et al. 2013). High levels of biodiversity and connectivity allow species interactions, significantly contributing to the system resilience and long term use, which is crucial for the purposes of stopping land clearing and improving conditions of sustainable production systems (Altieri and Nicholls 2000; Donald 2004; Perfecto et al. 2007; Perfecto and Vandermeer 2008). Biodiversity conservation capacity of AFS is directly determined by the system of people's management decisions, which is in turn influenced by social, cultural and economic factors of households, as well as by ecological conditions of the agricultural system and the surrounding landscape (Moreno-Calles et al. 2012). Therefore, developing strategies for maintaining and increasing such capacity requires integral understanding and attention of these issues.

Temperate forests have particular features necessary to be considered for understanding the associated AFS; for instance, these forests are resistant to frosts, drought, recurrent fire, cattle and sheep raising, and other disturbance types (Challenger 1998; Sánchez-González 2008). In addition, they are systems with a relatively fast regeneration compared with tropical or dry forests (Rzedowski 1978; Quintana et al. 1993). AFS of temperate zones maintain ancient traditional management forms that are on-going processes in numerous areas and have demonstrated to be important reservoirs of indigenous knowledge and techniques of great value for designing sustainable forms of agriculture (Gordon and Newman 1997). Historical records of pre-Columbian systems combining maize cultivation with remains of pine and oak forests were recovered by Budowski (1994). It is recognized that at present AFS of these areas commonly combine cultivation of annual crops with native or introduced species destined to make use of their fruits or wood, but that at the same time are a useful barrier for protecting crops against wind, preventing soil erosion, and benefiting with their shade, firewood, and fodder (Gordon and Newman 1997).

Studies of AFS and biodiversity conservation have centred their attention on tropical regions (Bhagwat et al. 2008; Scales and Marsden 2008; Harvey et al. 2008; Tscharntke et al. 2011). In temperate areas of the New World, the available studies are focused on topics related to their practices and production (Kort et al. 2009; Puckett et al. 2009; Quinkenstein et al. 2009), but there is relatively fewer information on their capacity for conserving biodiversity than in tropical areas. Therefore, contributing information related to biodiversity conservation capacity of AFS of temperate areas is one main issue of our study; we documented plant diversity in these systems and studied the reasons why local people belonging to different indigenous cultures let woody plants standing in their agricultural systems. Studies throughout the world have documented that one main problem of AFS are processes degrading their capacity for maintaining plant cover (Moreno-Calles et al. 2010); we therefore consider that understanding of such processes is crucial for designing policies for conservation of AFS.

Our study was conducted in the Tehuacán–Cuicatlán Valley, Central Mexico. It is an arid and semi-arid zone with high biological and human cultural diversity (Casas et al. 2001; Dávila et al. 2002). Its aridity is caused by the rain shade determined by the surrounding mountains that are part of the Sierra Madre Oriental. Highlands of these mountains host important areas of pine and oak forests (Valiente-Banuet et al. 2009) that significantly contribute to the regional biodiversity. This area has been inhabited by Cuicatec, Mazatec, Ixcatec, Mixtec, Popoloca, Chinantec and Náhuatl people that for long time (human presence has been recorded to be there for more than 10,000 years, according to MacNeish 1967) have managed both forest and agricultural systems and whose technical experience is now of high value for designing conservation of culture and biodiversity in the region.

Highlands and lowlands of the Tehuacán–Cuicatlán Valley host an exceptionally important biocultural heritage. There, the most ancient remains of agriculture in Mexico were found by archaeologists and the greatest inventory of plant resources in any region of Mexico has been documented by ethnobotanists (more than 1,600 plant species used by local peoples, according to Casas et al. 2001, and Lira et al. 2009), nearly 120 native plant species of them have been recorded occurring and managed within AFS, but the inventory of these species and the management techniques is still far to be completed (Blancas et al. 2010).

Moreno-Calles et al. (2010, 2012) conducted studies of the AFS of the arid zone of the region, finding that these systems maintain on average 59 % of plant species belonging to the surrounding natural ecosystems, from which nearly 94 % are native species. Other studies found that AFS in the arid zones of the region maintain on average 94 % of genetic variation of populations of arboreal species dominant in natural vegetation (Otero-Arnaiz et al. 2005; Casas et al. 2006; Parra et al. 2010; Cruse-Sanders et al. 2013).

However, such a kind of studies in highlands is to be documented yet. This zone is in elevations oscillating between 1,800 and 2,400 m, with a variety of pine and oak forests. Indigenous villages have pre-Columbian origin, practicing the traditional agriculture called "milpa", for cultivating maize, beans, and squashes in 1–3 ha plots. Our study aimed to explore the following questions: what capacity do the AFS of highlands have to conserve the biodiversity? is this capacity endangered?, which socio-cultural and ecological factors influence such a capacity? Based on our studies of other AFS of the region (Moreno-Calles et al. 2010) we expected that traditional AFS of the highlands would maintain a high proportion of native biodiversity. We hypothesized that such a capacity is higher in

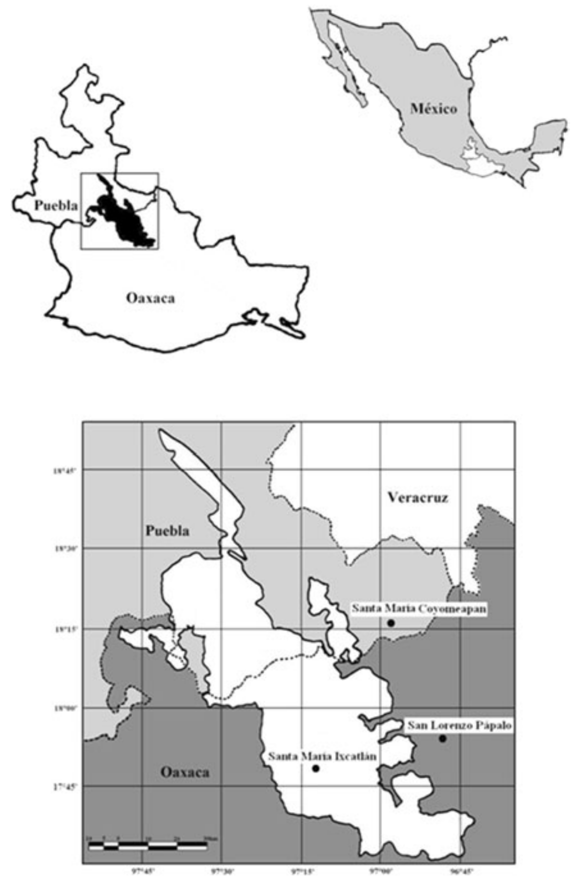

Fig. 1 Study area. The Tehuacán–Cuicatlán Valley and the communities in whose territories the forests and AFS analyzed were sampled

association with the patterns of indigenous peasant way of life and cultural values and therefore, their degradation would be caused mainly by social processes influencing cultural change. We aspire that our study may help to develop policies directed to include traditional knowledge and techniques in biodiversity conservation and recovering and preserving valuable autochthon technology, which is useful for this and other regions of Mexico.

Methods

Study area

The Tehuacán–Cuicatlán Valley is located at the south eastern area of the state of Puebla and the north western portion of the state of Oaxaca (Dávila et al. 2002, Fig 1); it comprises 10,000 km^2 with a high environmental heterogeneity (Valiente-Banuet et al. 2009; Dávila et al. 2002). It is a biodiverse region, with 36 types of plant associations (Valiente-Banuet et al. 2009) and nearly 3,000 plant species recorded.

Our study was conducted in the temperate highlands of the region, where vegetation includes different association types of pine, oak, and pine-oak forests. Particularly, we studied forests and AFS in the territory of the communities of Coyomeapan in the state of Puebla, and San Lorenzo Pápalo and Santa María Ixcatlán in the state of Oaxaca, which are inhabited by Náhuatl, Cuicatec and Ixcatec people, respectively.

The traditional multi-crop system called milpa (commonly combining maize, beans and squashes with other crops) is the main agricultural system and we studied AFS practicing it. The milpas are cultivated in plots no more than 2 ha extent. We evaluated their capacity of conserve native biodiversity through analysing vegetation richness, composition and diversity, by sampling vegetation in AFS and natural forests and comparing these parameters among them. Sampling of vegetation of natural forests was conducted in rectangles of 50 m × 10 m (500 m^2), subdivided in five squares of 10 m × 10 m (100 m^2) (Table 1). In total we sampled 3 sites of forest and 5 AFS in Coyomeapan, nine forest sites and four AFS I San Lorenzo Pápalo, and 6 forest sites and 5 AFS in Santa María Ixcatán. In each sampling plot we recorded all individuals of woody plant species measuring their height, two perpendicular diameters of their canopies and, in the breast height diameter (BHD) of trees. Voucher specimens of all plant species recorded were collected for identification and supporting our research. The nomenclature of the plant species was verified in the database TROPICS. Vegetation sampling in AFS was conducted by mapping the spatial components of each agricultural plot in order to estimate the percentage of vegetation cover, and all the species, number, height and biomass of individual plants of each species occurring within the system were listed in order to complement our records of plant species richness within the sampling plots. In each agricultural plot we identified the agroforestry practices and interviewed people managing them in order to document in detail the agricultural and agroforestry practices, as well as the plant composition of patches forming agroforestry practices. Also, we carried out

Table 1 General characteristics of the farming systems evaluated in the communities studied

Community	Crops	Variety of crops	Introduced trees	Fallow	Irrigation	Machinery	Agrochemicals	Livestock
Coyomeapan	Corn, beans, squashes, pumpkins, peas	Corn: white thick, white thin, blue, yellow gourd pumpkin beans: black bushy, black vine, brown	7 spp.	1 year	No	Mattock	No	Yes
S. L. Pápalo	Corn, bean, gourd, fava beans, peas	One variety per crop	3 spp.	1–3 years	No	Plough and mattock	Yes	Yes
S.M. Ixcatlán	Corn, beans and squashes	Corn: white, blue squash: gourd beans: black thin, frijol de milpa	0	6 months	No	Tractor and mattock	No	Yes

interviews with managers of each agricultural plot in order to record indicators of intensification degree of the system, productivity, and the reasons why local people decided to let woody plant species stand. In addition, we documented the communitarian rules in relation to these decisions and about the utilization of the plant species recorded, governmental programs influencing their decisions, and land tenure, following the method developed by Moreno-Calles et al. (2010).

Ecological parameters

Vegetation sampling allowed calculate the species richness, diversity and composition, as well as the ecological importance value (EIV) relating density, frequency and biomass of each species in the sampling areas in both forests and AFS. Plant composition was evaluated through the number of plant families, genera and species, considering all species and only native plant species. Richness was estimated by the rarefaction method developed by Colwell using the program estimates, particularly the non-parametric estimate Chao (Colwell and Coddington 1994; Gotelli and Colwell 2001; Colwell 2013). Curves of abundance-rank were performed, in order to describe the numeric relations among the ranks of species (order) and their abundances (Magurran 1988). Because values of abundance were markedly different we transformed them to a logarithmic scale, obtaining log-abundance curves as response variable of ranks. Differences among curves slopes were tested through ANCOVA. Diversity was calculated through the *Simpson* (Magurran 1988) and *Shannon* indexes (Shannon and Weaver 1949), which allow analysing homogeneity-heterogeneity of the plant community. Statistical differences of diversity (according to *Shannon* indexes) among populations were tested through *T* student tests. Richness and diversity parameters were calculated for the territories of the communities that were studied and for the whole temperate zone of the region. In addition, we analysed separately trees and shrubs because the parameters studied were markedly different among plants of these life forms. Average height and biomass of plants composing forests and AFS were compared through ANOVA and Bonferroni multiple range tests.

Management types

Interviews and field observations focused on identifying the reasons behind the people's decision to leave woody plants standing on their agricultural plots. In addition, we identified and documented those species managed by tolerance, those especially protected, transplanted and cultivated by sexual and asexual propagules, sensu Blancas et al. (2010). Finally, we documented in detail all agroforestry practices, as well as their purpose and techniques.

Agriculture intensification

Information from interviews was used for constructing an index of use intensification of each agricultural plot studied, in order to compare these indicators among the indigenous communities studied. We included both, qualitative and quantitative indicators related to agricultural practices, animal raising (animal type raised and frequency of grazing) within AFS plots and amount and frequency of use of forest products from AFS. We considered the number of years the AFS have been managed, the surface that has been managed, the annual frequency of the activities, the use of inputs (organic or agrochemical), the tools and machines used, crops used, the duration of agricultural cycles, as well as, the weeding and tilling regimes. We assigned numerical standardized values of all indicators referred to above in order to use them for calculating the *intensification index* developed by Trilleras (2008). Particular attention was dedicated to document the amount of harvested products per agricultural plot, per agricultural cycle in relationship to the plot area, in order to evaluate and compare the plots' production.

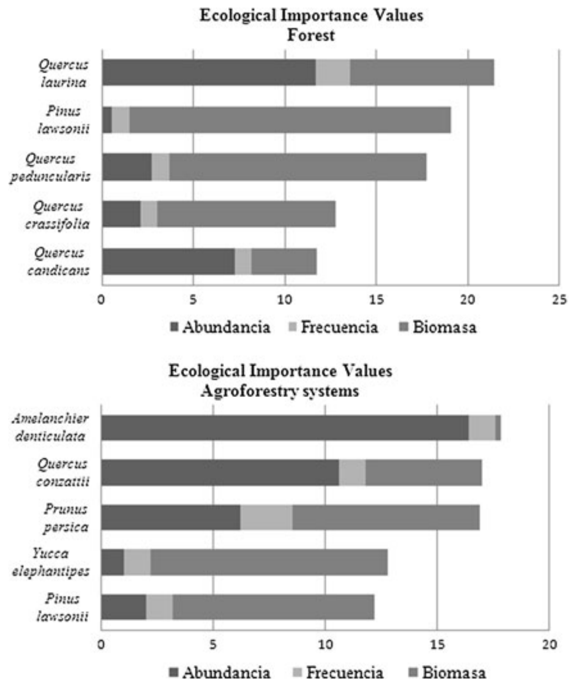

Fig. 2 Ecological importance values (EIV) calculated through vegetation sampling based on density, frequency and biomass of plant species in all the sites studied

Results

In the whole sample of AFS studied we recorded a total of 79 species of trees and shrubs belonging to 27 plant families (Appendix 1 see Table 5). Nearly 49 % of the plant families recorded in the studied area is present in both forests and AFS, 34 % is only distributed in natural forests, and 17 % is only found in AFS. The main plant families recorded are Fagaceae, Asteraceae, Fabaceae, Rosaceae and Pinaceae. Nearly 86 % of the plant species recorded in AFS are native to the Tehuacán Valley based on Dávila et al. (1993); the AFS maintain on average 43 % of the perennial native plant species and 65 % of the native tree species found in sampling sites of temperate natural forests of the region.

According to the EIV, the most important species in AFS were *Amelanchier denticulata, Quercus conzattii, Prunus persica, Yucca elephantipes* and *Pinus lawsonii* (Fig 2). The AFS from Coyomeapan had 19 tree species and 20 species of shrubs, whereas in Santa María Ixcatlán there were 11 tree species and 18 shrub species, and in San Lorenzo Pápalo we recorded 15 tree species and three shrub species.

Plant richness and diversity

AFS had similar species richness than natural forests. The rarefaction curves (Fig 3) indicate that although forest host a higher number of species, the differences are not significant. It is possible to appreciate that AFS of Coyomeapan maintain higher richness than those of other communities, even higher than the local natural forests. In Santa María Ixcatlán and San Lorenzo Pápalo the species richness decreases significantly compared with natural forests (Fig 4). Plant species diversity decreases significantly in AFS compared with natural forests (Fig 5), particularly in San Lorenzo Pápalo and Santa María Ixcatlán; however, in Coyomeapan the diversity of AFS was higher than in natural forests.

Curves of abundance rank (Fig 6) show that species dominance in AFS is generally higher than in natural forests; also, that rare plant species in AFS are lost more rapidly than in the forests, and that AFS have significantly less individual plants than forests, which was expected due to the vegetation clearing for setting up crops. In the AFS of San Lorenzo Pápalo, rare

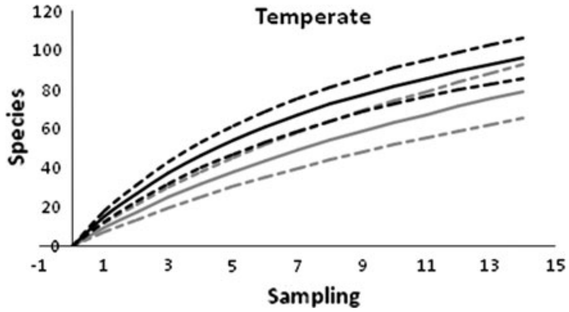

Fig. 3 Sampling rarefaction curves comparing the species richness of the forests and AFS involved in the study. FS Forest system (*black line*), AFS agroforestry systems (*gray line*), confidence limits (95 %, dashed line)

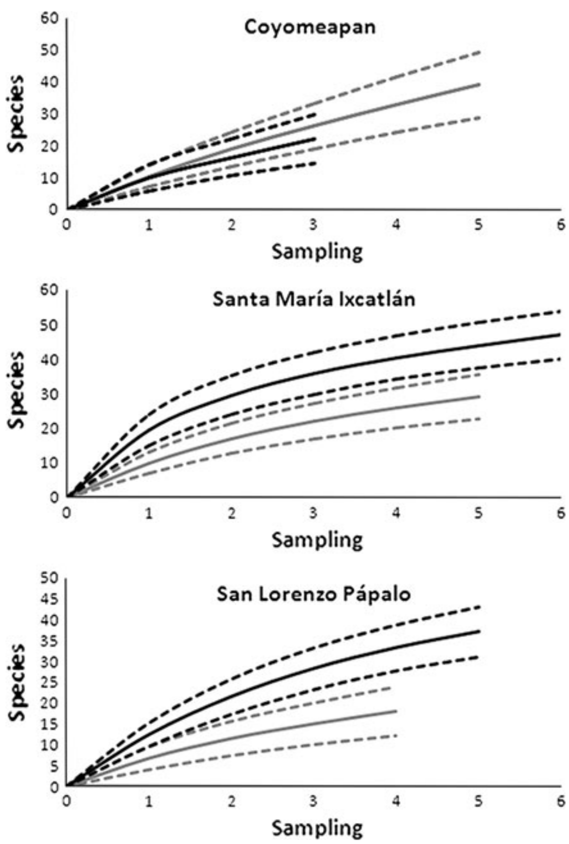

Fig. 4 Sampling rarefaction curves comparing the species richness of the natural forests and AFS in the different communities studied. FS Forest system (*black line*), AFS agroforestry systems (*gray line*), confidence limits (95 %, *dashed line*)

species are lost faster than in Coyomeapan where natural forests are dominated by fewer species and AFS maintain more species with restricted distribution range.

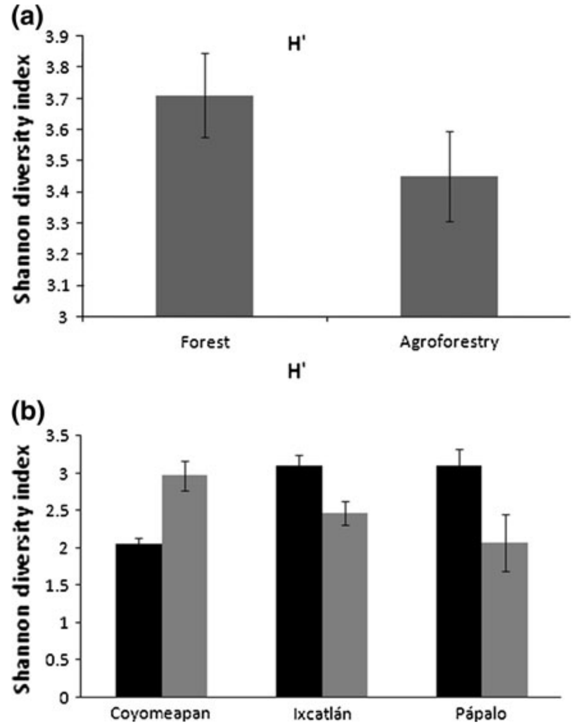

Fig. 5 Comparison of the Shannon diversity indexes among the forest (*black bars*) and the AFS (*gray bars*) studied. Shannon indexes were standardized by rarefaction curves. **a** For the whole sampled sites, **b** in each community studied

Vegetation structure

Agricultural plots conserving higher number of individuals of perennial plants are those from San Lorenzo Pápalo (50 ± 6.08 individual plants per plot, average ± SE); Santa María Ixcatlán and Coyomeapan maintain on average 30–40 ± 11.23 individual plants per plot. However, in AFS of Coyomeapan height of individual plants is significantly higher (2.5 ± 0.35 m in height on average ± SE), than in San Lorenzo Pápalo and Santa María Ixcatlán (1 ± 0.30 m and 1.5 ± 0.14 m, respectively; F = 85,032; $P = 0.0059$). Similarly, agroforestry plots of Coyomeapan and San Lorenzo Pápalo maintain significantly higher plant biomass (800 ± 255 and 500 ± 94 m^3 on average ± SE, respectively than in Santa María Ixcatlán (225 ± 72 m^3; F = 76,531; $P = 0.0091$).

Agricultural and silvicultural management in agroforestry systems

In all communities studied we found as a general management pattern the particularly high importance of

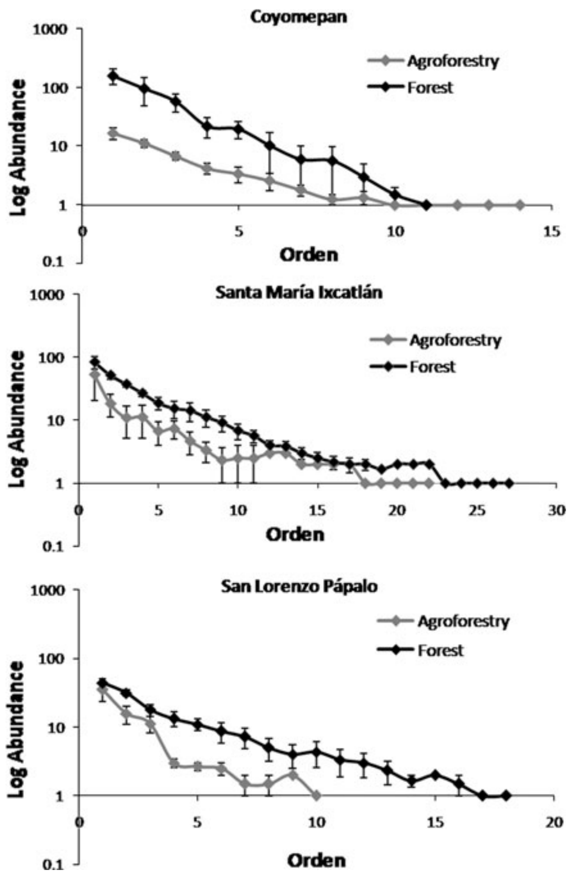

Fig. 6 Dominance/diversity curves of Coyomeapan, Ixcatlán and San Lorenzo Pápalo forests (*black line*) and AFS (*gray line*). Species are plotted from highest to lowest abundance along the *x axis*, and their abundance is displayed in $\log_{10}$ in the *y axis*

the surrounding areas of the AFS plots maintaining vegetation cover; in these areas people keep the higher number of species and individual plants which are generally larger than those in other areas of the plots. However, each community had particular agricultural practices that confer specific features to AFS of their territories (Table 1). For instance, the spatial arrangement of trees and shrubs within the AFS plots are different in each community. In Coyomeapan the standing trees are sparsely distributed scattered in the plot, sometimes in small groups forming short lines but without forming real strips of vegetation, keeping distance among them to make room to crops. The trees that are present in these plots are generally non-native fruit trees but along with them, it is common to find some native shrubs. The native tree species that are commonly found within AFS plots are *Pinus* spp., *Quercus* spp. and *Alnus acuminata*, which are considered valuable trees for their wood, firewood and leaves. Particularly relevant to mention are leaves of *Alnus* trees, which are considered a good fertilizer, as well as leaves of *Quercus* trees used for preparing food. In contrast, in San Lorenzo Pápalo, people keep fruit trees as small islands within the AFS plots, although, other native species are tolerated. The AFS plots studied are close to oak forests and numerous young plants of *Quercus* spp. grow within them and people let them grow. Commonly, adult oaks are pruned, fact that enables a faster recovering of forest when an agricultural plot is left. In Santa María Ixcatlán trees are not let standing inside the AFS plots, except for those highly valued, as it is the case of palms used for making handcrafts. In this village AFS plots are relatively larger than in the others, which commonly favours that people leave part of them as natural vegetation that is used as shade, and for obtaining firewood and medicinal plants (Fig 7).

Agroforestry systems of the highlands in the region maintain trees and shrubs through different management practices. Nearly 61 % are tolerated, 24 % protected, 10 % cultivated, and 5 % transplanted. In other words, most perennial plants survive in the AFS plots because people let them grow and they invest relatively low effort in enriching or maintaining them (Table 2). People let trees to grow within the agricultural plots mostly to produce edible fruits to obtain firewood, timber and shade as well as for aesthetic motives, or environmental benefits. In Coyomeapan the main reasons to leave the trees is to have fruits and firewood or even as support of climbing crop plants such as passion fruit (*Passiflora edulis*). In Ixcatlán people decide to maintain woody plants mainly for shade and others like the palms *Brahea* spp. whose leaves are used for weaving handcrafts, whereas in San Lorenzo Pápalo because trees provide shade, fruits and firewood (Table 3). These reasons were mentioned by

Table 2 Plant management of trees and shrub in the agroforestry systems in the whole sample and in the different communities studied

Community	Management type			
	Tolerated (%)	Protected (%)	Cultivated (%)	Transplanted (%)
Coyomeapan	56	21	20	3
S. M. Ixcatlán	69	24	0	7
S. L. Pápalo	50	28	16	6
Whole Sample	61	24	10	5

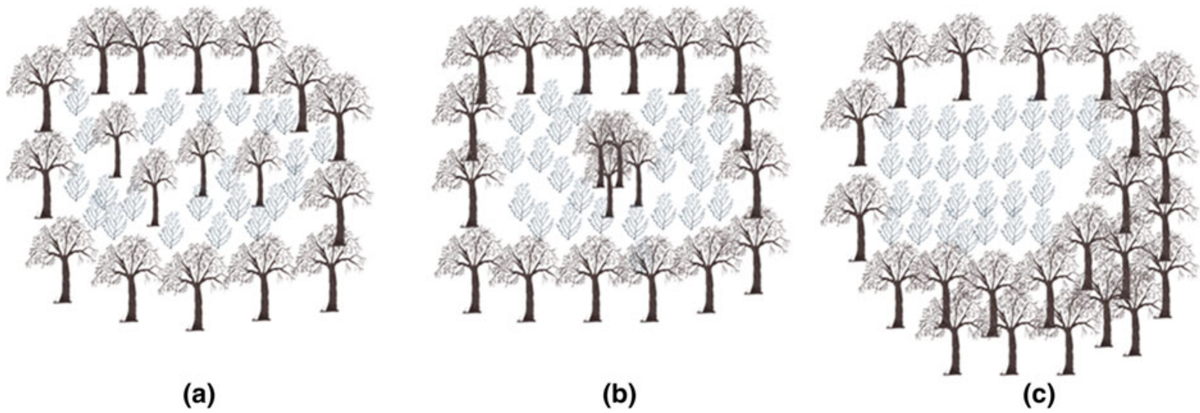

Fig. 7 Schematic spatial arrangement of AFS in the communities studied. The figure indicates that in Coyomeapan **a** the trees and shrubs are tolerated along the whole surface of the agricultural plots including the boundaries. In San Lorenzo Pápalo **b** the trees and shrubs are maintained in the boundary and in small islands inside, whereas, in Santa María Ixcatlán **c** trees and shrubs are in the boundary and in the adjacent crops

Table 3 Percentage of people interviewed that gave explicit reasons for maintaining trees and shrubs in AFS

Reasons	Whole sample (%)	Coyomeapan (%)	S.M. Ixcatlán (%)	S.L. Pápalo (%)
Shade	20	11	27	25
Edible fruit	13	26	9	0
Firewood	13	16	18	6
Does not affect	9	0	27	6
Other edible product	7	16	0	0
Boundary	7	5	0	13
Handcraft manufacturing	7	0	0	20
Medicine	4	11	0	0
Timber	4	10	0	0
Suppor to climbing crops	4	0	10	6
Windbreaks	2	5	0	0
Regulation	2	0	9	0
Ornamental	2	0	0	6
Attractor of rain	2	0	0	6
Part of nature	2	0	0	6
Fodder	2	0	0	6

The second column indicates the results of the whole sample and the rest indicate the responses in each of the communities studied

the people for those species intentionally maintained, but additionally there is a high proportion of plants that are tolerated because people consider that they do not interfere with the agricultural purposes, or because they are pretty or part of nature.

Agricultural intensification

In all AFS plots studied, people feed goats and sheep after harvesting maize and other crops. They also extract plant resources, mainly firewood. The intensification index, with values ranging from 0 to 1, indicates that in Coyomeapan, AFS plots are less intensified (0.1 ± 0.04, average $\pm$ SE), where there is not any agrochemical inputs or machines used. The highest intensification index was found in AFS plots of Santa María Ixcatlán (0.6 ± 0.14), where there is not any agrochemical input, but where the agricultural land is flat terrain, which allows utilization of machines (e.g. tractors) and consequently the removal of vegetation. Intensification index in San Lorenzo Pápalo was on average 0.5 ± 0.12, since use of agrochemical inputs is high, particularly favoured by governmental programs (e. g. the program Procampo), which promote the use of pesticides, herbicides and fertilizers. The average productivity in Coyomeapan was 174.16 ± 20.93 kg/ha on average ± SE, whereas San Lorenzo Pápalo it was 106.25 ± 6.25 kg/ha and in Santa María Ixcatlán 136.66 ± 16.79 kg/ha.

Land tenure

We recorded three types of land tenure, which clearly influenced the management of the AFS. In Coyomeapan, 44 % of land is private, 29 % ejido and 27 % communal (ejido and communal are two forms of collective land tenure in Mexico). In San Lorenzo Pápalo, 70 % is communal and 30 % is private, whereas in Ixcatlán 100 % is communal. Land tenure influences several aspects but especially the AFS plots size. In Ixcatlán, where land tenure is entirely communal, people have an integrated use of landscape, where agriculture is developed almost exclusively in flat terrains of larger size than in other communities. In contrast, in Coyomeapan where nearly half of the land tenure is private, the use of the natural resources and the space is mainly organized by AFS plots.

Communitarian regulations and governmental programs

In the three communities studied we recorded regulations for managing trees. Pines are tree species mainly protected by regulations; consequently people need to obtain a permit with the local authorities for using logging them. In Santa María Ixcatlán there is a specific norm for regulating any tree cutting. In Coyomeapan, where private property is dominant people think that owners have the right to decide whether the trees are cut or not, but local authorities express that cutting trees requires authorization. In general, local authorities allow local people to cut trees for wood and firewood when it is used for domestic consumption, but when trees are used for other purposes such as construction they need to issue a permit. The most penalized action is cutting trees for commercialization of wood. In fact, any use of trees for people external to the community is forbidden. Two persons of the community said that cutting trees is prohibited because they are part of a Biosphere Reserve.

People mentioned a governmental program enhancing maintenance of trees in agricultural systems (the program Proarbol, supported by the Mexican National Forestry Commission, CONAFOR), which pays $1.00 (nearly 8 cents of US dollars) per planted tree. The program provides young pine trees that are non-native species; however, people plant them for receiving the monetary incentive, but they do not monitor for their survival rate.

Discussion

Before the current dual need of producing food and conserving biodiversity and ecosystems, AFS represent an attractive option to be maintained and developed. The results of our study show that nearly 43 % of native species of perennial plants are maintained in the AFS, which is close to the range of conservation levels reported by Noble and Dirzo (1997), who identified that between 50 and 80 % of the local vegetation may be maintained in these systems. Our study focused on woody perennial plant species (not herbaceous plant species), but our data may also be comparable with those reported by Bhagwat et al. (2008), who proposed that the AFS of tropical areas, may maintain on average 60 % of the local biodiversity. Also, our results are comparable with those obtained in the semi-arid areas of the lowlands of the same region where Moreno-Calles et al. (2010) found that these systems may maintain on average 59 % of the plant species of the surrounding natural vegetation.

AFS maintain similar species richness than the natural forests, however, its diversity is generally lower than in forests because of the dominance of some particular species deliberately tolerated or promoted by people, which is a common pattern of silvicultural management associated to AFS in the region (Casas et al. 1997, 2007). However, the AFS of Coyomeapan show that diversity, in these systems, may be even higher than in natural forests, which may be considered as a model of what it is technically possible to achieve. We recorded absence or scarcity of rare species in agroforestry systems of these areas, similarly to that pattern documented for the semiarid areas of the Tehuacán Valley by Moreno-Calles et al. (2010).

One important criticism to AFS is that they are propitious for including exotic potentially invasive plant species. We found that in the highlands of the Tehuacán–Cuicatlán Valley, nearly 82 % of species recorded on average are native, but in Santa María Ixcatlán all species recorded are native, whereas in the semi-arid area Moreno-Calles et al. (2010) reported that 76 % of species are native. Although this information suggests low risk related to invasive species, it should not be discarded since we did not evaluate herbs, which include exotic species more commonly than perennial plants.

Vegetation cover and the number of individual plants remaining in AFS are crucial for vegetation recovering and restoration (Chazdon 2003; Harvey et al. 2006; Harvey et al. 2008). We found in the studied areas that there is on average 40 woody individual plants per AFS plot. However, in some plots we recorded nearly 250 individual plants, mainly young plants, which identify AFS as effective receptive areas of propagules for recovering vegetation. In addition, abundance of individual plants are indicators of other ecological benefits such as connectivity among fragments, soil and water retention and available products for people managing the system.

We found that in the systems studied those plants managed by tolerance are dominant, whereas in other local AFS such as homegardens cultivated plants are dominant (Blanckaert et al. 2004; Larios et al. 2013). The main reasons for not cutting the tree species are their use as shade, food, firewood, and fodder (Table 4) which are similar to those reasons documented in the semiarid zone of the lowlands Tehuacán Valley by Moreno-Calles et al. (2010). In contrast, in local homegardens trees and shrubs are tolerated or enhanced mainly because they are used for ornamental, food and medicinal purposes (Larios et al. 2013).

The AFS that were studied derived from similar pine and pine-oak forests but they differ markedly in social and cultural aspects, which seems to determine important differences in their management and, in composition, richness and diversity. In Coyomeapan, the Náhuatl community land tenure is nearly half private and half communal. It has pronounced slopes that do not make possible the utilization of machines. Consequently these conditions enable the produce of scattered fruit trees inside the AFS plots are not in conflict with modern technology management

Table 4 Biophysical and sociocultural characteristics of the communities studied

Community	Biophysical						Sociocultural				
	Vegetation type	Representative species	Elevation (m)	Slope range	Annual rainfall	Annual temperature	Surface (ha)	People number	Land tenure	Ethnicity	Speakers of indigenous language
Coyomeapan	Pine-oak forest	*Pinus teocote*, *Quercus laurina*, *Q. candicans*, *Ternstroemia pringlei*	1,950–2,400	30°–40°	1,650 mm	15.3 °C	22,881 ha	14,205	Private (44 %) Ejidal (29 %) Comunal (27 %)	Náhuatl	12,079
Santa Maria Ixcatlán	Oak forest and Juniperus forest	*Juniperus flaccida*, *Quercus peduncularis*, *Q. urbanii*, *Brahea dulcis*	1,890–2,100	10°–15°	647.0 mm	16.3 °C	18,993 ha	516	Comunal (100 %)	Ixcatecos	33
San Lorenzo Pápalo	Pine-oak forest	*Quercus conzatii*, *Q. crassifolia*, *Pinus devoniana*, *P. lawsonii*	1,800–2,400	20°–25°	812 mm	15 °C	3,900 ha	583	Comunal (70 %) Private (30 %)	Cuicatecos	233

practices. AFS plots are also delimited by living fences and people make efforts to maintain such resources, since they depend more from their plots, than people of the other communities. This situation reflects in its higher rates of plant richness, diversity and cover, tree size and biomass than in AFS plots of the other communities.

In contrast, in Santa María Ixcatlán, where the whole territory is communal and more extended, the agricultural plots are placed in flat terrains where it is viable to use machines for cultivation. Plots are mainly dedicated to agriculture, whereas forest areas are large enough for providing other goods and services. In these conditions, AFS had lower plant richness and diversity rates than in Coyomeapan, but it is constituted mainly by native species. This fact may also be explained since Ixcatlán is drier than Coyomeapan (Table 4).

In San Lorenzo Pápalo the vegetation islands are more important than in the rest of the communities. This pattern of agroforestry practices allowed the utilization of machines for cultivation. People tolerate young plants of the adjacent natural forests within the isles. For this reason these were the AFS plots with higher number of individual plants, but with the smaller size and biomass. In this site, we found only three species of shrubs and 15 of trees, which indicates a strong selection on those species allowed to remain in the AFS plots.

Management of AFS may be influenced by the degree of access to forest and to landscape resources that are allowed by the collective tenure, as in Santa María Ixcatlán. In contrast, people may be forced to optimize the use of AFS plots increasing diversity of resources in the systems, as for instance in Coyomeapan and San Lorenzo Pápalo. Accordingly, land tenure, land size and resources availability and environmental aspects, such as topography and rainfall regime may all be significantly influencing the management patterns of the AFS.

Conclusions

AFS are reservoirs of both diversity and living strategies with high actual and potential contribution for conserving native biodiversity. This attribute at least in theory allows the connectivity of fragmented and conserved areas, and may favour the maintenance of soils and water, and providing products to households that manage them.

All communities studied are inhabited by indigenous people. Human culture in each community is different and preservation of indigenous features is variable. In general, indigenous patterns of life are more favourable for biodiversity conservation in relation to the multiple use of ecosystems and resources. However land use history, agricultural intensification, land tenure, and ecological aspects influencing agricultural techniques and access to forest resources are all aspects significantly influencing management patterns and capacity of AFS to maintain plant species diversity.

People enhance the presence of natural plant resources in their agricultural plots using different criteria, which are influenced by both culture and ecological contexts, as well as economic motives.

Conservation of biodiversity in the Tehuacán–Cuicatlán Valley needs to include policies for conserving and improving native AFS. Local experience is highly variable according to the socio-cultural and ecological contexts, but interchange of local experiences would be a way of promoting the recovery and improvement of these systems in areas where they are being lost.

Studying ecological, social, economic and cultural aspects motivating construction of AFS, as well as those determining their loss may significantly contribute to develop technology and criteria for public policies enhancing these valuable systems.

Acknowledgments The authors thank the Posgrado en Ciencias Biológicas of the National Autonomous University of Mexico (UNAM) and the National Council of Science and Technology (CONACYT), Mexico for supporting postgraduate studies and a grant for the first author, respectively. We also thank financial support from CONACYT (Research Project CB-2008-01-103551), and the UNAM-DGAPA-PAPIIT (Research projects IN205111-3, IN2092014 and IA203213), as well as Edgar Pérez-Negrón for fieldwork assistance and Ignacio Torres for the illustration of Fig 7. We emphatically thank people of San Lorenzo Pápalo, Santa María Ixcatlán and Coyomeapan for their hospitality and friendship.

Appendix 1

See Table 5.

Table 5 List of species recorded in the sampling of forests and agroforestry systems studied

Families	Species	Forest	AFS
Adoxaceae	*Sambucus nigra* L.		X
Anacardiaceae	*Rhus chondroloma* Standl.		X
	Rhus standleyi F.A. Barkley	X	X
	Rhus virens Lindh. ex A. Gray	X	X
Annonaceae	*Annona cherimola* Mill.		X
Araliaceae	*Oreopanax* sp.	X	
Arecaceae	*Brahea dulcis* (Kunth) Mart.	X	X
Asparagaceae	*Agave potatorum* Zucc.	X	X
	Agave salmiana Otto ex Salm-Dyck	X	X
	Yucca guatemalensis Baker		X
Asteraceae	*Ageratina collodes* (B.L. Rob. and Greenm.) R.M. King and H. Rob.	X	
	Ageratina espinosarum (A. Gray) R.M. King and H. Rob.	X	
	Ageratina hebes (B.L. Rob.) R.M. King and H. Rob.	X	
	*Ageratina mairetiana (*DC.) R.M. King and H. Rob.	X	
	Ageratina sp.	X	X
	Artemisia vulgaris L.		X
	Baccharis conferta Kunth		X
	Baccharis serrifolia DC.	X	
	Barkleyanthus salicifolius (Kunth) H. Rob. and Brettell		X
	Bidens sp.	X	
	Brickelia veronicifolia (Kunth) A. Gray	X	
	Compuesta 1	X	
	Compuesta 2	X	
	Compuesta 3	X	
	Compuesta 4		X
	Eupatorium sp.	X	
	Gymnosperma glutinosum (Spreng.) Less.	X	X
	Montanoa sp.	X	
	Perymenium discolor Schrad.	X	
	Porophyllum ruderale (Jacq.) Cass.	X	
	Psacalium amplifolium (DC.) H. Rob. and Brettell	X	
	Stevia lucida Lag.	X	X
	Stevia sp.	X	
	Verbesina sp.	X	
	Vernonia sp.	X	
	Viguiera sp.	X	
	Zaluzania montagnifolia (Sch. Bip.) Sch. Bip.		X
Berberidaceae	*Berberis* sp.	X	
Betulaceae	*Alnus acuminata* Kunth	X	X
Bignoniaceae	*Tecoma stans* (L.) Juss. ex Kunth	X	
Buddlejaceae	*Buddleja cordata* Kunth	X	
	Buddleja parviflora Kunth	X	
	Buddleja sp.		X

Table 5 continued

Families	Species	Forest	AFS
Cactaceae	*Ferocactus recurvus* (Mill.) Borg		X
	Mammillaria sp.		X
	Opuntia lasiacantha Pfeiff.	X	
	Opuntia sp.		X
Campanulaceae	*Lobelia laxiflora* Kunth	X	
Caricaceae	*Carica papaya* L.		X
Clethraceae	*Clethra* sp.	X	
Cupressaceae	*Juniperus communis* L.		X
	Juniperus flaccida Schltdl.	X	X
Ericaceae	*Arbutus xalapensis* Kunth	X	X
	Arctostaphylos sp.	X	
	Comarostaphylis polifolia (Kunth) Zucc. ex Klotzsch	X	
	Comarostaphylis spinulosa (M. Martens and Galeotti) Diggs		X
	Gaultheria hirtiflora Benth.	X	
	Vaccinium leucanthum Schltdl.	X	
Euphorbiaceae	*Euphorbia sp.*	X	X
	Sebastiania sp.	X	
Fabaceae	*Acacia farnesiana* (L.) Willd.	X	X
	Acacia pennatula (Schltdl. and Cham.) Benth.	X	X
	Acacia sp.		X
	Calliandra sp.	X	
	Desmodium conzattii Greenm.	X	
	Erythrina americana Mill.		X
	Erythrina leptorhiza Moc. and Sessé ex DC.		X
	Hybosema ehrenbergii (Schltdl.) Harms	X	
	Lysiloma sp.		X
	Mimosa sp.		X
	Quercus candicans Née	X	X
	Quercus castanea Née	X	X
	Quercus conspersa Benth.		X
	Quercus conzattii Trel.	X	X
	Quercus crassifolia Humb. and Bonpl.	X	X
	Quercus crassipes Humb. and Bonpl.	X	X
	Quercus glaucoides M. Martens and Galeotti		X
	Quercus laurina Humb. and Bonpl.	X	X
	Quercus magnoliifolia Née	X	X
	Quercus obtusata Humb. and Bonpl.	X	
	Quercus peduncularis Née	X	X
	Quercus rugosa Née	X	
	Quercus salicifolia Née		X
	Quercus scytophylla Liebm.		X
	Quercus urbanii Trel.	X	X
Garryaceae	*Garrya ovata* Benth.		X
Lamiaceae	*Salvia purpurea* Cav.	X	
Lauraceae	*Litsea glaucescens* Kunth	X	X
	Persea americana Mill.		X
Malvaceae	*Sida* sp.		X

Table 5 continued

Families	Species	Forest	AFS
Melastomataceae	*Clidemia* sp.	X	
	Melastomatoceae 1	X	
	Tibouchina scabriuscula (Schltdl.) Cogn.	X	
Myricaceae	*Morella cerifera* (L.) Small	X	X
Oleaceae	*Forestiera rotundifolia* (Brandegee) Standl.		X
Pentaphylacaceae	*Ternstroemia pringlei* (Rose) Standl.	X	X
Pinaceae	*Pinus lawsonii* Roezl ex Gordon	X	X
	Pinus devoniana Lindl.	X	
	Pinus pseudostrobus Lindl.	X	X
	Pinus patula Schiede ex Schltdl. and Cham.	X	X
	Pinus teocote Schiede ex Schltdl. and Cham.	X	X
	Pinus 1	X	X
Plantaginaceae	*Russelia obtusata* S.F. Blake	X	
Polygalaceae	*Monnina xalapensis* Kunth	X	
Pterostemonaceae	*Pterostemon rotundifolius* Ramírez	X	
Myrsinaceae	*Rapanea juergensenii* Mez	X	
Rosaceae	*Amelanchier denticulata* (Kunth) K. Koch	X	X
	Cydonia oblonga Mill.		X
	Prunus americana Marshall		X
	Prunus persica (L.) Batsch		X
	Prunus serotina Ehrh.	X	X
	Pyrus malus L.		X
	Rubus liebmannii Focke	X	
	Rubus sp.	X	X
Rubiaceae	*Bouvardia ternifolia* (Cav.) Schltdl.	X	
	Rubiaceae 1	X	
Rutaceae	*Ptelea trifoliata* L.	X	
	Rutacea 1	X	
	Rutacea 2	X	
Sapindaceae	*Dodonaea viscosa* Jacq.	X	X
Solanaceae	*Cestrum laxum* Benth.	X	
	Solanum cardiophyllum Lindl.	X	
	Solanum hamatile Brandegee		X
	Solanum lanceolatum Cav.	X	
Styracaceae	*Styrax argenteus* C. Presl	X	
Verbenaceae	*Citharexylum affine* D. Don		X
	Lantana velutina M. Martens and Galeotti	X	
	Sp 1	X	

References

Altieri MA (1991) How best can we use biodiversity in agroecosystems. Outlook Agric 20:15–23

Altieri M, Nicholls C (2000) Teoría y práctica para una agricultura sostenible. Serie de Textos Básicos para la Formación Ambiental. Programa de las Naciones Unidas para el Medio Ambiente. Red de Formación ambiental para América Latina y el Caribe, México

Altieri M, Toledo VM (2005) Natural resources management among small-scale farmers in semiaridlands: building on traditional knowledge and agroecology. Ann Arid Zone 44:365–385

Bhagwat SH, Willis KJ, Birks J, Whittaker R (2008) Agroforestry: a refuge for tropical biodiversity? Trends Ecol Evol 23:261–267

Blancas J, Casas A, Rangel-Landa S, Moreno-Calles A, Torres I, Pérez-Negrón E, Solís L, Delgado-Lemus A, Parra F, Arellanes Y, Caballero J, Cortés L, Lira R, Dávila P (2010) Plant management in the Tehuacán–Cuicatlán Valley, Mexico. Econ Bot 64:287–302

Blanckaert I, Swennen RL, Paredes M, Rosas R, Lira R (2004) Floristic composition, plant uses and management practices in homegardens of San Rafael Coxcatlán, Valle de Tehuacán–Cuicatlán, México. J Arid Environ 57:39–62

Boege E (2008) El patrimonio biocultural de los pueblos indígenas de México. INAH, México

Budowski G (1994) El alcance y el potencial de la agroforestería con énfasis en Centroamérica. In: Krishnamurthy L, Leos J (eds) Agroforestería en Desarrollo: Educación. Centro de Agroforestería para el desarrollo sostenible, Universidad Autónoma de Chapingo, México, Investigación y Extensión, pp 1–16

Bye R (1993) The role of humans in the diversification of plants in Mexico. In: Ramamoortthy TP, Bye R, Lot A, Fa J (eds) Biological diversity of Mexico: Origins and distribution. Oxford University Press, New York, pp 707–731

Caballero J, Mapes C (1985) Gathering and subsistence patterns among the Purépecha Indians of Mexico. Journal of Ethnobiology 5(1):31–47

Casas A, Caballero J, Mapes C, Zárate S (1997) Manejo de la vegetación, domesticación de plantas y origen de la agricultura en Mesoamérica. Bol Soc Bot Mex 61:31–47

Casas A, Valiente-Banuet A, Viveros JL, Caballero J (2001) Plant resources of the Tehuacán Valley, México. Econ Bot 55:129–166

Casas A, Cruse J, Morales E, Otero-Arnaiz A, Valiente-Banuet A (2006) Maintenance of phenotypic and genotypic diversity of *Stenocereus stellatus* (Cactaceae) by indigenous peoples in Central México. Biodivers Conserv 15:879–898

Casas A, Otero-Arnaiz A, Peréz-Negrón E, Valiente-Banuet A (2007) In situ management and domestication of plants in Mesoamerica. Ann Bot 100:1101–1115

Challenger A (1998) Utilización y Conservación de los Ecosistemas Terrestres de México: Pasado, Presente y Futuro. Instituto de Biología, Universidad Nacional Autónoma de México. CONABIO—Agrupación Sierra Madre, S. C. México

Chazdon RL (2003) Tropical forest recovery: legacies of human impact and natural disturbances. Perspect Plant Ecol 6:51–71

Colwell RK (2013) Estimates: statistical estimation of species richness and shared species from samples. Version 8. Persistent. http://viceroy.eeb.uconn.edu/estimates

Colwell RK, Coddington JA (1994) Estimating terrestrial biodiversity through extrapolation. Philos Trans R Soc B 345:101–118

Cruse-Sanders J, Parker K, Friar E, Huang D, Mashayekhi S, Prince L, Otero-Arnaiz A, Casas A (2013) Managing diversity: domestication and gene flow in *Stenocereus stellatus Riccob*. (Cactaceae) in Mexico. Ecol Evol 3(5):1340–1355

Daily GC (ed) (1997) Nature's services: societal dependence on natural ecosystems. Island Press, Washington

Dávila P, Villaseñor JL, Medina RL et al (1993) Listados florísticos de México. X. Flora del Valle de Tehuacán–Cuicatlán. Instituto de Biología, UNAM, Mexico

Dávila P, Arizmendi MC, Valiente-Banuet A, Villaseñor JL, Casas A, Lira R (2002) Biological diversity in the Tehuacán–Cuicatlán Valley, Mexico. Biodivers Conserv 11:421–441

DeClerck FAJ, Chazdon RL, Holl KD, Milder JC, Finegan B, Martinez-Salinas A, Imbach P, Canet L, Zayra R (2010) Biodiversity conservation in human-modified landscapes of Mesoamerica: past, present, and future. Biodivers Conserv 143:2301–2313

Donald PF (2004) Biodiversity impacts of some agricultural commodity production systems. Conserv Biol 18:17–37

Gordon AG, Newman S (1997) Temperate agroforestry systems. CABI Internacional, London

Gotelli NJ, Colwell RK (2001) Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. Ecol Lett 4:379–391

Harvey CA, Medina A, Sánchez-Merlo D, Vílchez S, Hernández B, Saenz J, Maes J, Casanovas F, Sinclair FL (2006) Patterns of animal diversity associated with different forms of tree cover retained in agricultural landscapes. Ecol Appl 16:1986–1999

Harvey CA, Komar O, Robin C, Ferguson BG, Finegan B, Griffith DM, Martínez-Ramos M, Morales H, Nigh R, Soto-Pinto L, Van Breugel M, Wishnie M (2008) Integrating agricultural landscapes with biodiversity conservation in the Mesomerican hotspot. Conserv Biol 22:8–15

Kort J, Poppy L, Gordon AM, Caron L (2009) Temperate agroforestry: when trees and crops get together. Agric Ecosyst Environ 131:1–3

Krishnamurthy L, Ávila M (1999) Agroforestería básica. Programa de las Naciones Unidas para el Medio Ambiente. Serie Textos Básicos para la Formación Ambiental N 3, México

Larios C, Casas A, Vallejo M, Moreno-Calles AI, Blancas J (2013) Plant management and biodiversity conservation in Náhuatl homegardens of the Tehuacán Valley, Mexico. J Ethnobiol Ethnomed 9:74

Lira R, Casas A, Rosas-López R, Paredes-Flores M, Rangel-Landa S, Solís L, Torres I, Dávila P (2009) Traditional knowledge and useful plant richness in the Tehuacán–Cuicatlán, México. Econ Bot 63:271–287

MacNeish RS (1967) A summary of subsistence. In: Byers DS (ed) Prehistory of the Tehuacán Valley: enviroment and subsistence, vol 1. University of Texas Press, Austin, pp 290–309

Magurran AE (1988) Ecological diversity and its measurement. Princeton University Press, Princeton

McNeely JA, Schroth G (2006) Agroforestry and biodiversity conservation-traditional practices, present dynamics, and lessons for the future. Biodivers Conserv 15:549–554

Melville EGK (1999) Plaga de ovejas: consecuencias ambientales de la conquista de México. Fondo de Cultura Económica, México

Millennium Ecosystem Assessment (2005) Ecosystems and human well-being: synthesis. Island Press, Washington

Moreno-Calles A, Casas A, Blancas J, Torres I, Rangel-Landa S, Pérez-Negrón E, Caballero J, Masera O, García-Barrios L (2010) Agroforestry systems and biodiversity conservation in arid zones: the case of the Tehuacán–Cuicatlán Valley, Central México. Agrofor Syst 80:315–331

Moreno-Calles A, Casas A, García-Frapolli E, Torres-García I (2012) 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 84(2):207–226

Moreno-Calles AI, Toledo VM, Casas A (2013) Los sistemas agroforestales tradicionales de México: unaaproximación biocultural. Bot Sci 91(4):1–24

Nair PKR (2011) Agroforestry Systems and Environmental Quality: introduction. J Environ Qual 40:784–790

Noble I, Dirzo R (1997) Forests as human-dominated ecosystems. Science 277:522–525

Otero-Arnaiz A, Casas A, Hamrick JL, Cruse-Sanders J (2005) Genetic variation and evolution of *Polaskia chichipe* (Cactaceae) under domestication in the Tehuacán Valley, central Mexico. Mol Ecol 14(6):1603–1611

Parra F, Casas A, Peñaloza-Ramírez JM, Cortés Palomec AC, Rocha Ramírez V, González-Rodríguez A (2010) Evolution under domestication: ongoing artificial selection and divergence of wild and managed *Stenocereus pruinosus* (Cactaceae) populations in the Tehuacán Valley, Mexico. Ann Bot 106:483–496

Perfecto I, Vandermeer J (2008) Biodiversity conservation in tropical agroecosystems. Ann NY Acad Sci 1134:173–200

Perfecto I, Armbrecht I, Philpott SM, Soto-Pinto L, Dietsch TM (2007) Shaded coffee and the stability of rainforest margins in northern Latin America. In: Tscharntke T, Leuschner C, Zeller M et al (eds) The stability of tropical rainforest margins, linking ecological, economic and social constraints of land use and conservation, environmental science series. Springer, Verlag, pp 227–264

Puckett HL, Brandle J, Johnson J, Blankenship E (2009) Avian foraging patterns in crop field edges adjacent to woody habitat. Agric Ecosyst Environ 131:9–15

Quinkenstein A, Wöllecke J, Böhm C, Grunewald H, Freese D, Schneider BU, Huttl RF (2009) Ecological benefits of the alley cropping agroforestry system in sensitive regions of Europe. Environ Sci Policy 12(8):1112–1121

Quintana-Ascencio P, Onzalez-espinosa M (1993) Afinidad fitogeográfica y papel sucesional de la flora leñosa de los bosques de pino-encino de los Altos de Chiapas, México. Acta Bot Mex 21:43–57

Ricker M, Ramírez-Krauss I, Ibarra-Manríquez G, Martínez E, Ramos C, Gonzalez-Medellín G, Gómez-Rodríguez G, Palacio-Prieto L, Hernández H (2007) Optimizing conservation of forest diversity: a country-wide approach in Mexico. Biodivers Conserv 16:1927–1957

Rzedowski J (1978) Vegetación de México. Editorial Limusa, México

Sánchez-González A (2008) Una visión actual de la diversidad y distribución de los pinos en México. Madera y Bosques 14(1):107–120

Sarukhán J, Soberón J (2009) Capital natural de México. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, Mexico

Scales BR, Marsden SJ (2008) Biodiversity in small-scale tropical agroforests: a review of species richness and abundance shifts and the factors influencing them. Environ Conserv 35:160–172

Schroth G, da Fonseca GAB, Harvey CA, Gascon C, Vasconcelos HL, Izac AMN (2004) Agroforestry and biodiversity conservation in tropical landscapes. Island Press, Washington

Shannon CE, Weaver W (1949) The mathematical theory of information. University of Illinois Press, Urbana

Shibu J (2009) Agroforestry for ecosystem services and environmental benefits: an overview. Agrofor Syst 76:1–10

Soto-Pinto L, Perfecto I, Caballero-Nieto J (2002) Shade over coffee: its effects on berry borer, leaf rust and spontaneous herbs in Chiapas, Mexico. Agrofor Syst 55:37–45

Swift MJ, Vandermeer J, Ramakrishnan PS et al (1998) Biodiversity and agroecosystem function. In: Mooney HA, Cushman JH, Medina E et al (eds) Functional roles of biodiversity: a global perspective. Wiley, New York, pp 262–294

Toledo VM, Ordóñez MJ (1993) The biodiversity scenario of México: A review of terrestrial habitats. In: Ramamoortthy TP, Bye R, Lot A, Fa J (eds) Biological diversity of Mexico: origins and distribution. Oxford University Press, New York, pp 707–731

Toledo VM, Alarcón-Chaires P, Moguel P et al (2001) El Atlas Etnoecológico de México y Centroamérica: fundamentos, Métodos y Resultados. Etnoecológica 6(8):7–41

Trilleras J (2008) Análisis socio-ecológico del manejo, degradación y restauración del bosque tropical seco de la región de Chamela–Cuixmala, México. Disertación, Universidad Nacional Autónoma de México, México

Tscharntke T, Clough Y, Bhagwat SA et al (2011) Multi-functional shade-tree management in tropical agroforestry landscapes—a review. J Appl Ecol 48:619–629

Valencia S (2004) Diversidad del género *Quercus* (Fagaceae) en México. Bol Soc Bot Mex 75:33–53

Valiente-Banuet A, Solís L, Dávila P et al (2009) Guía de la vegetación del Valle de Tehuacán–Cuicatlán, Fundación Cuicatlán. UNAM, Impresora Transcontinental, Mexico

Vandermeer J, Perfecto I (2007) The agricultural matrix and the future paradigm for conservation. Conserv Biol 21:274–277

Wallace GN, Barborak J, MacFarland CG (2005) Land-use planning and regulation in and around protected areas: a study of best practices and capacity building needs in Mexico and Central America. Naturaleza y Conservación 3:147–167