
STRUCTURE AND TREE DIVERSITY IN TRADITIONAL POPOLUCA COFFEE AGROECOSYSTEMS IN THE LOS TUXTLAS BIOSPHERE RESERVE, MEXICO

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SUMMARY

The structure and tree diversity of traditional coffee agroecosystems was studied in a Popolucan community within the Biological Reserve of Los Tuxtlas, Veracruz, Mexico, along an altitudinal gradient from 450 to 1000masl. The coffee agroecosystems were established in three physiognomic units: tropical semi-deciduous forest, tropical rain forest and deciduous forest. To understand the structure of the coffee agroecosystems, 30 plots of 400m² were established. Sixty-four tree species and 23 herbs from 44 families were recorded. The most numerous families were Mimosaceae, Asteraceae, Fabaceae and Myrtaceae. The coffee agroecosystems had four layers: herbs, shrubs, lower trees, and upper trees. The shrub layer was dominated by four varieties of *Coffea arabica*. The

species with the highest importance values were *Apeiba tibourbou*, *Cordia alliodora* and *Inga vera*. The species with the highest economic value were *Acosmium panamense*, *Calophyllum brasiliense*, *Terminalia amazonia*, and *Vochysia guatemalensis*. Coffee agroecosystems established in tropical semi-deciduous forest have higher diversity values, which has the lowest floristic similarity and the highest dissimilarity values. The complementarity index indicated a high rate of replacement and confirmed the fundamental role of peasant's knowledge and management in the selection of species and the structure of the agroecosystem, but also in increasing and in some cases improving diversity without reaching the original diversity of the vegetation.

In Mexico, coffee is cultivated on the mountain slopes of the Sierra Madre Oriental facing the Gulf of Mexico, mainly in Hidalgo, Puebla, San Luis Potosí, Veracruz states and some districts in Tabasco; in the Pacific, it is cultivated in Chiapas, Colima, Jalisco, Nayarit and Oaxaca atates (Nolasco, 1985; Regalado-Ortiz, 2006) between 300 and 1,800masl. Coffee is grown on mountain slopes and in locations where northern, tropical and subtropical elements are found (Moguel

and Toledo, 1999). According to Bartra (2003) 280,000 peasants produce coffee at smallholder scale in Mexico; 65% of the coffee peasants are indigenous, 183,000 of which own 2ha or less. In addition, there are 74,000 farms <5ha. Particularly in indigenous areas, 41% of the area occupied by coffee agroecosystems is present in tropical rain forests, 23% in pine and oak forest, 21% in low deciduous forest and 15% in deciduous forest. Traditional coffee agroecosystems are considered to help maintain diversity because they conserve

different forest strata (Miranda and Hernández, 1963; Bartra, 2003). Moreover, the use of shade trees, such as 'solero' or 'xochicoahuil' (*Cordia alliodora*) and different species of 'chalahuite' (*Inga* spp.), allows peasants to exploit several forest products and helps conserve orchids and other vascular epiphytes, along with birds and arthropods (Perfecto *et al.*, 1996; Moguel and Toledo, 1999; Villavicencio and Valdez, 2003; Cruz *et al.*, 2004; Hietz, 2005; Solís-Montero *et al.* 2005; Bandeira *et al.*, 2005;

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Soto-Pinto *et al.*, 2007). Similarly, within different coffee agroecosystems, environmental factors such as soil and water, together with shadow management, diversification of the tree canopy and use of cover legumes can improve coffee yields, while tree density can adversely affect coffee quality (Skovmand Bosselman *et al.*, 2009). Also, as native trees are preserved, the role of natural regeneration could be important for the structure, floristic composition, richness and diversity of tree species (Godínez-Ibarra and López-Mata, 2002; Philpott *et al.*, 2008).

The state of Veracruz is second, after Chiapas, in coffee production in Mexico, by number of peasants and yield. Around 30% of the area dedicated to coffee is located between 300 and 800masl; these areas are considered marginal because they lie outside of the ideal agroecological zone for coffee production and yield, and quality are low (Moguel and Toledo, 1999). In the Sierra of Santa Marta, under the above mentioned conditions, management by the Popoluca peasants is similar to the diversified poly-culture structure (Franco, 2007; Hernández-Martínez, 2008; Williams-Linera and López-Gómez, 2008), which can increase β diversity. However, the prolonged coffee production crisis (Martínez, 1997) has forced these peasants to eliminate many coffee agroecosystems and replace them with cattle farms, which has had a negative impact on the soil, biological diversity, production and productivity, as well as having an impact on processes such as the water, carbon and nitrogen cycles (Sánchez *et al.*, 2003; Bandeira *et al.*, 2005). Due to its ecological importance, the tree structure and diversity in this type of agroecosystem must be studied in greater detail, as has been done for birds and insects (Gould and Guerrero-Rivera, 2006; López-Gómez *et al.*, 2007; Oijen *et al.*, 2010). This knowledge is essential to understand how the system operates to achieve a sustainable use of the natural resources associated with coffee production. This information is particularly relevant given the fast decline of natural resources at the local and global level, because these types of agroecosystems constitute important diversity reserves that have only recently been studied with the level of scientific rigour that they deserve (Vandermeer, 2011). The goal of this study was to analyse the tree

structure and biological diversity of coffee agroecosystems established along an altitudinal gradient between 450 and 1,100masl within the buffer area of Los Tuxtlas Biosphere Reserve, Veracruz.

Materials and Methods

Study area

The study area is located in the Popoluca community of Ocotal Chico, Soteapan, Veracruz, at 18°18'31"N and 94°52'26"W, and covers 1361ha (Graciano, 2004). It is part of the buffer area of Los Tuxtlas Biosphere Reserve in the Sierra of Santa Marta (Siemens, 2004; Figure 1) and has a volcanic origin, with igneous rocks and andesitic or alkaline basaltic lava from the quaternary period. Its physiography includes five morphoedaphological units that were formed by mountains with slopes covered by volcanic cones (Siemens, 2004). The area is located in the sub-basin of the Huazuntlan River, within the Coatzacoalcos river basin. The vegetation includes 1) tropical pine forest, which is dominated by *Pinus oocarpa* and five oak species; 2) tropical semideciduous forest (TSF) dominated by

Brosimum alicastrum, *Cedrela odorata*, *Inga leptoloba* and *Luehea speciosa*, among others; 3) tropical rainforest (TRF) dominated by *Omphalea oleifera*, *Quercus* sp., *Terminalia amazonia* and *Calophyllum brasiliense*; and 4) deciduous forest (DF) dominated by *Alfaroa mexicana*, *Liquidambar styraciflua*, *Quercus* sp. and *Ulmus mexicana* (Castillo-Campos and Laborde, 2004).

Agroecosystem selection and measurements

Based on participatory workshops, a list of 69 peasants was compiled. Their agroecosystems were located in areas previously occupied by 1) TSF (TSF coffee) between 450 and 600masl, with warm humid climate, summer precipitation (García, 1988) and Acrisols; 2) TRF (TRF coffee) between 600 and 800masl, with warm humid climate, rainfall throughout the year and Acrisols; and 3) DF (DF coffee) between 800 and 1000masl, with semi-warm wet climate, rainfall throughout the year and Andosols. All soil types are highly susceptible to erosion (Mariano and García, 2010). All coffee agroecosystems studied are located



Figure 1. Location of the study area within the Los Tuxtlas Biosphere Reserve (after Siemens, 2004).

in slopes that vary between 15 and 60%, and within them some of the trees from the original vegetation were preserved. Using a random number table, 30 agroecosystems were chosen along the altitudinal gradient (Scheaffer and Ott, 1987), 10 from each section of the altitudinal gradient. Farm size varied based on the requests that each farmer made to the PROCEDE (Ejido and Community Right Program) of the National Agricultural Records. On each farm, a 400m² (20×20m) site was marked and divided into four 10×10m (100m²) quadrats that, in turn, were subdivided into eight 5×10m (50m²) quadrats. Four of these rectangles were randomly chosen and the height and cover of shrub and herbaceous strata were measured. For all the trees in the sampling area, the diameter at breast height (DBH) was measured at 1.3m above soil surface, and the total height and trunk height (up to the first branch) were measured using a Haga altimeter. Based on these data, basal area was calculated as $BA = (\pi \times D^2) / 4$, where BA: basal area and D: DBH. The cover was quantified based on perpendicular measurements of the vertical projection of tree crowns, and the corresponding area was calculated as $CC = ((D_1 + D_2 / 4)^2) \pi$ (Müller-Dombois and Ellenberg, 1974). The distance between trees was measured with a measuring tape in order to know the horizontal distribution of species. The vegetation structure was analysed based on the relative density values (RDVs), frequency (FR) and relative dominance (DOR) based upon DBH. All relative values were calculated by dividing the number, frequency and dominance of a species by the total number, frequency and dominance of all species. The importance value was calculated as the sum of the three values ($IV = RDV + DOR + FR$), and this value was divided by three to obtain the relative importance value (RIV) (Müller-Dombois and Ellenberg, 1974; Moreno, 2001). To quantify the floristic similarity, the Sørensen coefficient (Müller-Dombois and Ellenberg, 1974) was calculated with the formula $IS = (2C / (A + B)) \times 100$, where A is the number of species in community A, B is the number of species in community B, and C is the number of species in both communities. Similarly, the complementarity index was calculated (Moreno, 2001). First, the total richness was calculated for all sites with the formula $S_{AB} = a + b - c$, where a: number of species in site A, b: number of species in site B and c: number of species common to both sites. Next, the number of species unique to each site was calculated as $U_{AB} = a + b - 2c$. The complementarity index was calculated based on the values obtained above with

the formula $C_{AB} = U_{AB} / S_{AB}$, where U_{AB} is the species unique to each site and S_{AB} is the total richness of all sites. The value of the index varies between 0 and 1, where 0 represents identical sites, and 1 indicates entirely different sites. By multiplying the value by 100, a percentage was obtained. Species richness and diversity was analysed with the Shannon-Wiener, Simpson and Fisher diversity indexes using the software Estimates 8.2.0 (Colwell, 2009).

Coffee agroecosystems structure

The vegetation structure was graphically represented with vertical and horizontal profile diagrams. To recognize the floristic composition, voucher specimens for all the plant species that were present on the coffee agroecosystems were collected. Species that were not at the sites but had flowers and/or fruit were also collected, although they were not included in the analysis. As the elevation increased, only plants that had not been previously observed were collected. Voucher specimens were deposited in the herbarium at the Instituto de Investigaciones Biológicas, Universidad Veracruzana in Xalapa, Veracruz, Mexico.

Results and Discussion

General structure and floristic composition of coffee agroecosystems

Coffee agroecosystems had four strata: herbaceous, shrub, low trees and tall trees, one layer less than those observed by Soto-Pinto *et al.* (2000). Due to peasant management the herbaceous layer had a low cover, which favoured the presence of some species with economic value and abundant leaf litter; additionally, weed control is carried out mainly by machete (66.6%), only 16.6% with herbicide, while another 16.6% use both (Franco, 2007). In this stratum, the dominant plants were shrub hot pepper (*Capsicum annuum* var. *annuum*), 'barbasco' (*Dioscorea composita*), cucumber (*Cucumis sativus*), 'tomatillo' (*Solanum pimpinellifolium*), bean (*Phaseolus* spp.), hot pepper fruits (*Capsicum annuum*), goosefoot (*Chenopodium* sp.), *Caladium bicolor*, *Colocasia* sp., *Ceratozamia* sp. and 'camedor' palm (*Chamaedorea* spp.), which was introduced through government programs and the Sierra de Santa Marta A. C. project.

In TSF coffee agroecosystems the shrub stratum was dominated by different varieties of *Coffea arabica*, including Mundo Novo (80.7%), Robusta (8.7%), Caturra (6.4%) and Criolla (4.1%). In TRF coffee plantation, Mundo

Novo (79.8%), Caturra (7.5%), Robusta (6.8%) and Criolla (5.9%) were present. Finally, in DF coffee agroecosystems, Caturra (50%), Garnica (28.1%), Mundo Novo (10.7%) and Criolla (11.23%) dominate. Coffee plants were planted in 2.5×2.5m and 2.0×2.0m grids, for a density of 1600-2,500 shrubs/ha, similar to what was found by Soto-Pinto *et al.* (2000) and Peeters *et al.* (2003) in different places of Chiapas, Mexico. However, according to Descroix and Wintgens (2004), density for coffee plantations under shade must be 1250-1600 plants/ha with distances of 2.8×2.8 to 3.0×3.0 for Robusta varieties, and 1100-1600 plants/ha for Arabica; that is to say, 3×3 to 2.5×2.5m. In this stratum, some species, such as Mexican pepper leaf (*Piper sanctum*) and 'platanillo' (*Heliconia curtispatha*) were not eliminated because their economic importance.

The floristic composition at the 30 study sites comprised 51 tree species. The most important were *I. vera* Willd (RIV= 26.42), *Cordia alliodora* (RIV= 10.59), *Cecropia obtusifolia* (7.40), *Heliocarpus appendiculatus* (6.85) and 23 herbaceous species. Forty-four families were identified (Table I); the most numerous were Mimosaceae (seven species), Asteraceae (six species), Fabaceae (six species) and Myrtaceae (four species). *I. vera* had the highest RIV along the altitudinal gradient because peasants consider it to be a tree with multiple uses: it does not lose its foliage in the dry season, produces firewood and provides more cover. Romero-Alvarado *et al.* (2002) found that the presence of *Inga* species does not improve the quality of coffee. Furthermore, using a parameterisation model, VanOijen *et al.* (2010) found that coffee yield tends to decrease with tree density in different coffee plantations in Central America, even in the presence of N-fixing trees, a similar phenomenon as was observed by Skovmand Bosselman *et al.* (2009) in Colombia. Importantly, although all species provide shade, the peasants conserve species like *Vochysia guatemalensis* (it has three different uses), *C. odorata* and *Swietenia macrophylla* because they sell the wood or use them for construction (they cover between 37-45% of the sites). Fruit trees cover 26-31% of the sites, outstanding among them *Annona reticulata*, *Inga jinicuil* and *Byrsonima crassifolia* (this one with three different uses). This Activity is similar to that observed by Rice (2011) in Peruvian and Guatemalan coffee plantations. It is noteworthy that, similar to Peruvian and Guatemalan peasants survival, Popoluca peasant survival depends not only on coffee agroecosystems (22%), but also other incomes such

TABLE I
FLORISTIC COMPOSITION OF THE COFFEE AGROECOSYSTEMS IN OCOTAL CHICO, SOTEAPAN, VER, MEXICO *

Family	Scientific name	Use	Life form	Original vegetation type
Anacardiaceae	<i>Astronium graveolens</i> Jacq.	Timber	Tree	DF
	<i>Mangifera indica</i> L.	Fruit	Tree	TRF
	<i>Spondias mombin</i> L.	Fruit	Tree	TRF-DF
Annonaceae	<i>Annona reticulata</i> L.	Fruit, medicinal *	Tree	DF
	<i>Rollinia mucosa</i> (Jacq.) Baill.	Not documented	Tree	TRF
Asteraceae	<i>Ageratella</i> sp.	Not documented	Herb	DF
	<i>Baltimora recta</i> L.	Not documented	Herb	DF
	<i>Critonia daleoides</i> (DC.)	Medicinal	Shrub	TRF
	<i>Montanoa</i> sp.	Medicinal	Herb	TRF
	<i>Sinclairia discolor</i> Hook. & Arn.	Not documented	Herb	TRF
	<i>Vernonia patens</i> Kunth	Not documented	Shrub	TRF
Bignoniaceae	<i>Spathodea campanulata</i> Beauv.	Shade	Tree**	TRF
Bombacaceae	<i>Pachira aquatica</i> Aubl.	Medicinal	Tree	TSF
Boraginaceae	<i>Cordia alliodora</i> (Ruiz & Pav.) Oken	Timber	Tree	TSF-TRF
Burseraceae	<i>Bursera simaruba</i> (L.) Sarg.	Hedge, shade	Tree	DF
Caricaceae	<i>Carica papaya</i> L.	Fruit	Tree	TSF
Cecropiaceae	<i>Cecropia obtusifolia</i> Bertol.	Shade	Tree	TSF-DF
Chrysobalanaceae	<i>Hirtella triandra</i> Sw	Medicinal	Tree	TRF-DF
Combretaceae	<i>Terminalia amazonia</i> (J. F. Gmel.) Exell	Timber	Tree	DF
Cucurbitaceae	<i>Sechium edule</i> (Jacq.) Sw.	Edible	Herb	TSF-TRF-DF
Euphorbiaceae	<i>Acalypha microstachya</i> Benth.	Medicinal	Tree	TRF
Fabaceae	<i>Acosmium panamense</i> (Benth.) Yakovlev	Timber	Tree	TSF
	<i>Erythrina americana</i> Mill.	Hedge, edible (flowers)	Tree	TSF-TRF
	<i>Gliricidia sepium</i> Stend.	Hedge, firewood	Tree	TSF
	<i>Lonchocarpus guatemalensis</i> Benth.	Shade	Tree	DF
	<i>Tephrosia</i> sp.	Temporal shade	Shrub**	TSF
	<i>Willardia schiedeana</i> (Schltdl.) F. J. Herm	Shade	Tree	TSF-TRF
Guttiferaceae	<i>Calophyllum brasiliense</i> Cambess.	Timber, construction	Tree	TRF
Haemodoraceae	<i>Xiphidium caeruleum</i> Aubl.	Not documented	Herb	TRF
Hamamelidaceae	<i>Liquidambar styraciflua</i> L.	Shade	Tree	DF
Heliconiaceae	<i>Heliconia curtispatha</i> Petersen	Not documented	Herb	TSF
Hypericaceae	<i>Vismia baccifera</i> (L.) Triana & Planch.	Medicinal	Tree	TSF
	<i>Vismia camaguey</i> Sparague & L. Riley	Not documented	Tree	DF
Lamiaceae	<i>Hyptis mutabilis</i> (L. Rich.) Briq.	Not documented	Herb	TRF
Lauraceae	<i>Ocotea verticillata</i> Rohwer	Shade	Tree	DF
Lasistemataceae	<i>Lacistema aggregatum</i> Rusby (P. J. Bergiev)	Not documented	Tree	DF
Malpighiaceae	<i>Byrsonima crassifolia</i> (L.) Kunth	Shade, fruit, medicinal	Tree	TSF
	<i>Malpighia glabra</i> L.	Not documented	Shrub	TSF
	<i>Tetrapterys schiedeana</i> Schltdl. & Cham.	Not documented	Woody vine	DF
Malvaceae	<i>Sida acuta</i> Burm. f.	Medicinal	Shrub	TSF
	<i>Sida cordifolia</i> L.	Not documented	Shrub	TRF
	<i>Sida rhombifolia</i> L.	Medicinal	Shrub	TRF
Maranthaceae	<i>Stromanthe acrochlamys</i> (Woodson & Standley) H. A. Kenn. & Nicolson	Not documented	Herb	TSF
	<i>Adelobotrys adscendens</i> (Sw.) Triana	Not documented	Vine	DF
Melastomataceae	<i>Miconia argentea</i> (Sw.) DC.	Handles for tools, shade	Tree	TRF
	<i>Cedrela odorata</i> L.	Timber, shade	Tree	TSF-DF
Meliaceae	<i>Swietenia macrophylla</i> G. King	Timber, shade	Tree	TRF
	<i>Trichilia havanensis</i> Jacq.	Timber, handles for tools	Tree	TSF
	<i>Zapoteca</i> sp.	Medicinal	Tree	TSF
Mimosaceae	<i>Cojoba arborea</i> (L.) Britton & Rose	Timber, shade	Tree	TSF
	<i>Inga jinicuil</i> Schltdl. & Cham.	Shade, fruit	Tree	TSF-TRF-DF
	<i>Inga punctata</i> Willd.	Shade, firewood	Tree	TSF-TRF
	<i>Inga marginata</i> Willd.	Shade, firewood	Tree	TSF-TRF
	<i>Inga vera</i> Willd.	Shade, firewood	Tree	TSF-TRF-DF
	<i>Leucaena leucocephala</i> (Rose) S. Zárate	Shade, fruit	Tree	TRF
Myrtaceae	<i>Calyptranthes lindeniana</i> O. Berg.	Shade	Tree	DF
	<i>Eugenia acapulcensis</i> Steud.	Shade, fruit, medicinal	Tree	TSF
	<i>Eugenia capuli</i> (Schltdl. & Cham.) O. Berg.	Fruit, shade	Tree	TSF
	<i>Pimenta dioica</i> (L.) Merr.	Spice, shade	Tree	TSF-TRF-DF
Orchidaceae	<i>Catasetum integerrimum</i> Hook.	Ornamental	Epiphyte	DF
	<i>Sacoila lanceolata</i> A. Rich	Ornamental	Herb	TSF
	<i>Vanilla planifolia</i> G. Andrews	Ornamental	Epiphyte	TRF
Palmae	<i>Astrocaryum mexicanum</i> Liebm ex Mart.	Edible	Tree	DF

(It continues in following page)

Continuation Table 1

Family	Scientific name	Use	Life form	Original vegetation type
Primulacaceae	<i>Rapanea</i> sp.	Not documented	Tree	DF
Polygonaceae	<i>Coccoloba uvifera</i> L.	Medicinal	Tree	TRF
Rubiaceae	<i>Alibertia edulis</i> (L. Rich) A. Rich. ex. DC.	Medicinal	Tree	TSF
	<i>Chiococca alba</i> (L.) Hitchc.	Not documented	Tree	TSF
Rutaceae	<i>Citrus aurantifolia</i> Swingle	Fruit, Shade	Tree	TRF
	<i>Citrus sinensis</i> (L.) Osbeck	Fruit, Shade	Tree	TSF-TRF
	<i>Zanthoxylum caribaeum</i> Lam.	Shade	Tree	TSF
Salicaceae	<i>Zuelania guidonia</i> (Sw.) Britton & Millsp.	Not documented	Tree	DF
Sapindaceae	<i>Allophylus cominia</i> (L.) Sw.	Medicinal	Tree	DF
	<i>Cupania glabra</i> Sw.	Firewood	Tree	TSF
Solanaceae	<i>Capsicum annum</i> Var. <i>glabriusculum</i> (Dunal) Heiser & Pickersgill	Edible	Herb	TSF-TRF
	<i>Solanum pimpinellifolium</i> L.	Edible	Herb	TSF
Sapotaceae	<i>Chrysophyllum cainito</i> L.	Fruit	Tree	TSF
	<i>Chrysophyllum mexicanum</i> Brandegee & Standl.	Fruit, handles for tools	Tree	TSF
Surianaceae	<i>Suriana maritima</i> L.	Not documented	Shrub	TRF
Thelypteridaceae	<i>Thelypteris blanda</i> C. F. Reed	Not documented	Herb	DF
Tiliaceae	<i>Apeiba tibourbou</i> Aubl.	Medicinal	Tree	TRF
	<i>Heliocarpus appendiculatus</i> Turcz.	Not documented	Tree	TSF-DF
	<i>Luehea speciosa</i> Wild.	Timber, shade	Tree	TRF
Ulmaceae	<i>Trema micrantha</i> (L.) Blume	Bird feed	Tree	TSF-TRF-DF
Verbenaceae	<i>Tectona grandis</i> L. f.	Timber	Tree**	DF
Vochysiaceae	<i>Vochysia guatemalensis</i> Donn. Sm.	Construction, timber, shade	Tree	TRF-DF

* Medicinal uses were documented based upon Leonti (2002). ** Introduced.

as government programs (52%), off-farm labor (17%) and livestock sales (9%) (Franco, 2007). In San Fernando, near the study area, socioeconomic variables influence ecological ones and modernization might have a negative effect in traditional coffee agroecosystems diversity (Potvin *et al.*, 2005).

The structure: floristic composition, vertical strata, spatial distribution and diversity of the coffee agroecosystems studied followed similar patterns to those observed by Perfecto *et al.* (1996) and Soto-Pinto *et al.* (2000) in Chiapas; Bandeira *et al.* (2005) in the Chinantec region, Oaxaca; and Hernández-Martínez (2008) in Coatepec, Veracruz. Moreover, local management and knowledge of agroecosystems play a fundamental role in the selection of the species that will be part of these systems because each peasant follows a different strategy to structure the coffee agroecosystem, altogether with a vast knowledge of local environmental conditions. We found 51 different tree species (345 individuals) in the studied sites, 60 to 85% fewer than reported in similar agroecosystems and vegetation types studies in Veracruz (Sánchez *et al.*, 2003; Villavicencio and Valdez, 2003; Williams-Linera *et al.*, 2005; López-Gómez *et al.*, 2007). We collected 44 different families of plants in the whole study area, representing 84 different plant species, of which 64 are trees. That is, twice the plant families and 28% more trees than

reported by Peeters *et al.* (2003) in Paredón, Chiapas. Additionally, the coffee agroecosystems studied conserved 25% more species, or at least the same number of species, as compared with some TSFs in Puerto Rico (Bandeira *et al.*, 2005; Gould and Guerrero-Rivera, 2006).

The horizontal structure of all the coffee agroecosystems studied was similar; 80% of the tree species displayed a random distribution, and only 20% displayed a uniform one (Figure 2). Height ranges 5-35m, and it can be deduced that the more or less complex tree structure of the agroecosystems can help as a refuge for a diversity of birds, insects, and microorganisms (Philpott and Bichier, 2012; Jacinto, 2012; Retama *et al.*, 2014). It is also important that the age of coffee plantations is 16-40 years old, the older being located at higher elevations, while coffee agroecosystems closer to villages are the younger ones, generally with a better management.

For TSF coffee agroecosystems (Table II), height was 0.6-26.0m. The tallest species were *Acosmium panamense* ('guayacan', 12m), *Cecropia obtusifolia* (trumpet tree, 26m), *Cedrela odorata* (cedar, 19m), *Cordia alliodora* ('solerillo', 20m), *Gliricidia sepium* (13m), *Heliocarpus appendiculatus* ('jonote', 15m), *Inga jinicuil* (22m), *I. vera* ('chalahuite', 26m) and *Trema micrantha* ('mupi' or 'ixpepe', 26m). Seventeen tree species (97 individuals) were identified on these coffee

agroecosystems. The species with the highest RIVs were *A. panamense*, *C. obtusifolia*, *C. odorata*, *Cojoba arborea* ('cañamazo'), *C. alliodora*, *H. appendiculatus*, *I. vera*, *Pimenta dioica* (allspice) and *T. micrantha*. The importance value for *I. vera* was twice as large as the importance value of *C. alliodora*. The species with the lowest RIVs were *Citrus sinensis*, *Chrysophyllum cainito*, *Carica papaya*, *Pachira aquatica* and *Tephrosia* sp. (introduced). The species with the highest cover were *I. jinicuil*, with 80.3m², greater than that of *I. vera* (69.3m²) despite having a lower density, *B. crassifolia* (68.7m²), *C. alliodora* (64.5), *G. sepium* (63.4) and *A. panamense* (45.6m²). A total of 37 species were identified from the different strata.

In the TRF coffee agroecosystems (Table III), 18 tree species (115 individuals) were identified. The maximum height was 35m, and the minimum 4.5m. The tallest species were *Apeiba tibourbou* (18m), *Calophyllum brasiliense* (35m), *C. alliodora* (32m), *Hirtella triandra* (26), *I. jinicuil* (25m), *I. vera* (26), *Luehea speciosa* (17), *Pimenta dioica* (20) and *V. guatemalensis* (18). The species with the highest RIVs were *Apeiba tibourbou* ('palo gusano' or 'papachote'), *Citrus sinensis* (sour orange), *C. alliodora*, *Inga jinicuil* (pod), *I. vera*, *P. dioica*, *T. micrantha* and *Vochysia guatemalensis* ('corpo'). The species with the lowest importance values were *Coccoloba uvifera* (sea grape), *Citrus aurantifolia* (lime) and *Swietenia macrophylla*

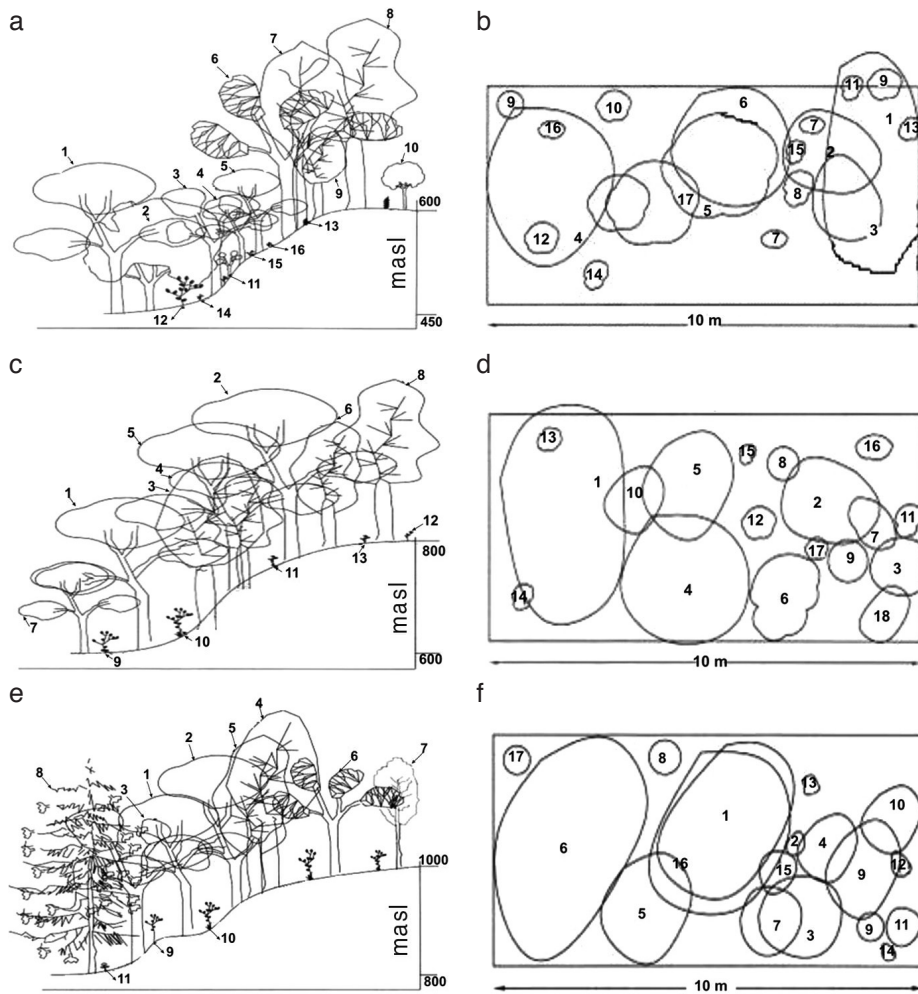


Figure 2. Vertical (a, c and e) and horizontal (b, d and f) profiles of coffee agroecosystems in Ocotal Chico. In a and b the species with greater importance values and highest covers in TSF coffee were, in tree stratum, 1: *Inga vera*, 2: *Acosmium panamense*, 3: *Trema micrantha*, 4: *I. jinicuil*, 5: *Pimenta dioica*, 6: *Cecropia obtusifolia*, 7: *Cedrela odorata*, 8: *Cordia alliodora*, 9: *Heliocarpus appendiculatus*, 10: *Citrus sinensis*, and 11: *Carica papaya*; in shrub stratum, 12: *Coffea arabica* v. Robusta, and 13: *arabica* v. Mundo Novo; in herbaceous stratum, 14: *Dioscorea composita*, 15: *Phaseolus* spp., and 16: *Chenopodium* sp. In b these species were 1: *I. jinicuil*, 2: *Glicicidia sepium*, 3: *C. alliadora*, 4: *I. vera*, 5: *Byrsonima crassifolia*, and 6: *A. panamense*. In c and d the species with greater importance values and highest cover in TRF coffee were, in tree stratum, 1: *I. vera*, 2: *I. jinicuil*, 3: *Apeiba tiburbou*, 4: *T. micrantha*, 4: *P. dioica*, 5: *Vochysia guatemalensis*, 7: *C. sinensis*, and 8: *C. alliadora*; in shrub stratum, 9: *C. arabica* v. Caturra and 10: *C. arabica* v. Mundo Novo; in herbaceous stratum, 11: *Capsicum annum*, 12: *Dioscorea composita* and 13: *Chenopodium* sp. In d these species were 1: *A. tiburbou*, 2: *Luehea speciosa*, 3: *Hirtella triandra*, 4: *Callophyllum brasiliense*, and 5: *I. jinicuil*. In e and f greater importance values and highest cover in DF coffee were, in tree stratum, 1: *I. vera*, 2: *I. jinicuil*, 3: *T. micrantha*, 4: *Terminalia amazonia*, 5: *V. guatemalensis*, 6: *C. obtusifolia*, 7: *Ocotea verticillata*, and 8: *Liquidambar styraciflua*; in shrub stratum, 9: *C. arabica* v. Garnica and 10: *C. arabica* v. Caturra; in herbaceous stratum: 1: *Tetrapterys schiedeana*. In f these species were 1: *I. vera*, 2: *I. jinicuil*, 3: *V. guatemalensis*, 4: *T. amazonia*, and 5: *T. micrantha*.

(mahogany). The species with the greatest cover were *A. tiburbou* (151.66m²), *C. brasiliense* (103.86), *C. alliadora* (51.54), *Hirtella triandra* (55.41), *I. jinicuil* (59.20) and *L. speciosa* (77.47m²). These coffee agroecosystems had a total of 36 species.

In the areas with DF coffee agroecosystems (Table IV) 16 tree species (133 individuals) were observed, with a minimum height of 4.2 and a maximum of 32m. The tallest trees were *A.*

reticulata (20m), *Cecropia obtusifolia* (18), *H. appendiculatus* (18), *H. triandra* Sw (14), *I. jinicuil* (30), *I. vera* (32), *T. amazonia* (31), *T. micrantha* (18) and *V. guatemalensis* (18). The species with the highest RIVs were *I. vera*, *T. micrantha*, *T. amazonia*, *I. jinicuil*, *C. obtusifolia*, *V. guatemalensis*, *C. odorata* and *L. guatemalensis*. The species with the lowest RIVs were *Burseria simaruba* (copper wood), *L. guatemalensis* ('gusanillo' or

'palo blanco'), *Spondias mombin* (yellow mombin) and *Tectona grandis* (introduced). The species with the greatest cover were *A. reticulata* L. (93.3m²), *T. amazonia* (75.9), *T. micrantha* (55.4) and *I. vera* (50.7m²). On these coffee agroecosystems, 31 species were collected from the different strata.

Structurally, the species with the highest importance value along the altitudinal gradient were *I. vera*, *A. tiburbou*, *C. alliadora* and *T. micrantha*. The first two species also dominate coffee agroecosystems in the Chinantec region in Oaxaca (Bandeira *et al.*, 2005). The type II structural pattern of these species suggests the existence of disturbed areas in an advanced phase of tree gap planting (Martínez-Ramos and Álvarez-Buylla, 1995). As observed in the study by López-Gómez and Williams-Linera (2006) on the coffee agroecosystems of Ocotal Chico, no important structural differences existed because the peasants were interested in species composition, not in increasing the height or basal area of the trees. In addition to *I. vera*, other species that were highlighted in López-Gómez and Williams-Linera (2006) are *Citrus* spp., *Mangifera indica*, *Psidium guajava* and *Persea schiedeana*. The first three were found in the present study. However, *B. crassifolia*, *C. alliadora*, *I. jinicuil*, *L. speciosa* and *T. micrantha* displayed greater cover and lower density.

Population structure

Based on the diameter class distribution of species with a higher importance value, some structural patterns (*sensu* Martínez-Ramos and Álvarez-Buylla, 1995) were distinguished. For TSF coffee agroecosystems, *I. vera* and *C. alliadora* displayed a type II pattern, which is characterised by a higher frequency of intermediate size individuals and a lower frequency of older individuals. *T. micrantha* follows a type III pattern, with small, intermediate and large individuals. *C. obtusifolia* and *A. panamense* did not display any defined structural patterns (Figure 3). In TRF coffee agroecosystems, *I. vera* and *C. alliadora* followed a type II pattern, but *V. guatemalensis* was characterised by a type III pattern, with small, intermediate and large individuals. *I. jinicuil* and *A. tiburbou* did not show a defined structural pattern (Figure 4). In DF coffee agroecosystems, *I. vera*, *T. micrantha* and *I. jinicuil* displayed a type II pattern, and *T. amazonia*, and *C. obtusifolia* did not have a defined structural pattern (Figure 5). The horizontal tree distribution was heterogeneous along the gradient as a result of the topological arrangement and

TABLE II
TREE STRUCTURE OF COFFEE AGROECOSYSTEMS LOCATED IN THE TROPICAL SEMIDECIDUOUS RAINFOREST (450-600M) IN OCOTAL CHICO*

Species	Number of individuals	Cover (m ²)	Height (m)	Basal area (m ²)	Absolute frequency	Relative density	Relative frequency	Relative dominance	IV	RIV
<i>Acosmium panamense</i>	3	45.6	10.6	218.16	0.3 (30%)	0.03	0.06	0.08	0.18	6.12
<i>Byrsonima crassifolia</i>	1	68.6	15	283.52	0.1 (10%)	0.01	0.02	0.11	0.14	4.76
<i>Carica papaya</i>	1	6.61	3	19.63	0.1 (10%)	0.01	0.02	0.00	0.04	1.35
<i>Cojoba arborea</i>	2	0.1	0.7	0.12	0.3 (30%)	0.02	0.06	0.00	0.08	2.96
<i>Cecropia obtusifolia</i>	5	23.93	14.1	263.59	0.3 (30%)	0.05	0.06	0.10	0.22	7.40
<i>Cedrela odorata</i>	3	17.7	16.2	245.13	0.2 (20%)	0.03	0.04	0.09	0.17	5.71
<i>Citrus sinensis</i>	3	4.4	4.9	84.94	0.1 (10%)	0.03	0.02	0.03	0.08	2.88
<i>Cordia alliodora</i>	11	64.5	17.3	234.32	0.5 (50%)	0.11	0.11	0.09	0.31	10.59
<i>Chrysophyllum cainito</i>	1	2.14	3	50.26	0.1 (10%)	0.01	0.02	0.02	0.05	1.75
<i>Gliricidia sepium</i>	2	63.4	12.5	188.69	0.2 (20%)	0.02	0.04	0.07	0.13	4.64
<i>Heliocarpus appendiculatus</i>	3	23.9	8.6	333.29	0.2 (20%)	0.03	0.04	0.12	0.20	6.85
<i>Inga vera</i>	45	69.3	16.4	261.74	1 (100%)	0.46	0.22	0.10	0.79	26.42
<i>Inga jinicuil</i>	4	80.4	13.3	176.71	0.2 (20%)	0.04	0.04	0.06	0.15	5.17
<i>Pachira aquatica</i>	1	2.0	2.5	7.06	0.1 (10%)	0.01	0.02	0.003	0.03	1.19
<i>Pimenta dioica</i>	4	11.4	7.1	44.76	0.3 (30%)	0.04	0.06	0.017	0.12	4.22
<i>Tephrosia</i> sp.	1	0.33	2	7.06	0.1 (10%)	0.01	0.02	0.003	0.03	1.19
<i>Trema micrantha</i>	7	30.8	8.7	157.73	0.3 (30%)	0.07	0.06	0.06	0.20	6.71
n=17	97			2576.80	4.4	1.00	1.00	1.00	3.00	100.00

* Reference area 4,000m² (10 sampling sites of 400m²).

TABLE III
TREE STRUCTURE IN COFFEE AGROECOSYSTEMS LOCATED IN THE TROPICAL RAINFOREST (600-800M) IN OCOTAL CHICO

Species	Number of individuals	Cover (m ²)	Height (m)	Basal area (m ²)	Absolute frequency	Relative density	Relative frequency	Relative dominance	IV	RIV
<i>Apeiba tibourbou</i>	2	151.6	18	15614.54	0.1 (10%)	0.02	0.02	0.72	0.76	25.33
<i>Calophyllum brasiliense</i>	1	103.9	35	855.30	0.1 (10%)	0.01	0.02	0.04	0.07	2.33
<i>Citrus aurantifolia</i>	2	12.3	4.5	63.61	0.1 (10%)	0.02	0.03	0.00	0.05	1.78
<i>Citrus sinensis</i>	3	7.7	7.8	263.98	0.3 (30%)	0.03	0.07	0.01	0.11	3.67
<i>Coccoloba uvifera</i>	1	12.3	26	176.71	0.1 (10%)	0.01	0.02	0.01	0.04	1.33
<i>Cordia alliodora</i>	15	51.5	23.9	776.01	0.4 (40%)	0.13	0.09	0.04	0.26	8.67
<i>Hirtella triandra</i>	1	55.4	6	1017.87	0.1 (10%)	0.01	0.02	0.05	0.08	2.67
<i>Inga jinicuil</i>	5	59.2	15.6	589.64	0.4 (40%)	0.04	0.09	0.03	0.16	5.33
<i>Inga vera</i>	59	42.3	14.4	376.10	1 (100%)	0.51	0.23	0.02	0.76	25.33
<i>Leucaena leucocephala</i>	3	6.8	6.2	34.90	0.1 (10%)	0.03	0.02	0.00	0.05	1.73
<i>Luehea speciosa</i>	3	77.5	12.6	732.21	0.2 (20%)	0.03	0.05	0.03	0.11	3.67
<i>Mangifera indica</i>	1	17.3	7.5	295.59	0.1 (10%)	0.01	0.02	0.01	0.04	1.33
<i>Pimenta dioica</i>	4	42.3	10.5	226.98	0.3 (30%)	0.03	0.07	0.01	0.11	3.67
<i>Spathodea campanulata</i>	1	3.9	5	95.03	0.1 (10%)	0.01	0.02	0.00	0.03	1.00
<i>Spondias mombin</i>	2	6.0	5	78.54	0.2 (20%)	0.02	0.05	0.00	0.07	2.34
<i>Swietenia macrophylla</i>	2	11.2	6	116.89	0.1 (10%)	0.02	0.02	0.01	0.05	1.70
<i>Trema micrantha</i>	3	41.6	8.2	143.13	0.3 (30%)	0.03	0.07	0.01	0.11	3.58
<i>Vochysia guatemalensis</i>	7	18.7	9.6	173.36	0.4 (40%)	0.06	0.09	0.01	0.16	5.33
n=18	115			21630.47	4.4	1	1.01	1.00	3.02	100.80

* Reference area 4,000m² (10 sampling sites of 400m²).

management conducted by peasants (Figure 2). The population structure of *C. alliodora* and *V. guatemalensis* is due because their use is centered on diameter classes for home construction and planks, respectively.

Floristic similarity

According to the Sørensen index, the coffee agroecosystems that were established in TSF and DF had 21% similarity and shared seven species: *C.*

obtusifolia, *C. odorata*, *H. appendiculatus*, *I. jinicuil*, *I. vera*, *P. dioica* and *T. micrantha*. The agroecosystems that were located in TRF and DF were 21% similar and had seven species in common: *H. triandra*, *I. jinicuil*, *I. vera*, *P. dioica*, *S. mombin*, *T.*

TABLE IV
VEGETATION STRUCTURE OF COFFEE AGROECOSYSTEMS LOCATED
IN THE DECIDUOUS FORESTS (800-1000M) IN OCOTAL CHICO*

Species	Number of individuals	Cover (m ²)	Height (m)	Basal area (m ²)	Absolute frequency	Relative density	Relative frequency	Relative dominance	IV	RIV
<i>Annona reticulata</i>	1	93.3	20	764.53	0.1 (10%)	0.01	0.03	0.12	0.13	4.33
<i>Astrocarium mexicanun</i>	1	13.5	5	314.16	0.1 (10%)	0.01	0.03	0.05	0.09	3.00
<i>Bursera simaruba</i>	2	1.7	2.8	8.81	0.1 (10%)	0.02	0.03	0.02	0.07	2.33
<i>Cecropia obtusifolia</i>	3	51.6	14.6	481.75	0.2 (20%)	0.02	0.06	0.06	0.14	4.67
<i>Cedrela odorata</i>	4	3.1	4.2	46.86	0.2 (20%)	0.03	0.06	0.02	0.11	3.67
<i>Heliocarpus appendiculatus</i>	2	17.7	6.9	95.03	0.2 (20%)	0.02	0.06	0.03	0.08	2.67
<i>Hirtella triandra</i>	3	48.7	4.5	838.10	0.1 (10%)	0.02	0.03	0.13	0.18	6.00
<i>Inga jinicuil</i>	6	45.4	13.5	373.25	0.2 (20%)	0.05	0.06	0.05	0.16	5.33
<i>Inga vera</i>	86	50.8	11.8	351.52	1 (100%)	0.65	0.28	0.07	1.00	33.33
<i>Lonchocarpus guatemalensis</i>	3	0.3	12	73.39	0.1 (10%)	0.02	0.03	0.02	0.07	2.33
<i>Pimenta dioica</i>	2	7.6	6	94.17	0.2 (20%)	0.02	0.06	0.02	0.10	3.33
<i>Spondias mombin</i>	1	4.5	5.8	314.16	0.1 (10%)	0.01	0.03	0.03	0.07	2.33
<i>Tectona grandis</i>	1	49.1	6	415.47	0.1 (10%)	0.01	0.03	0.06	0.11	3.67
<i>Terminalia amazonia</i>	2	75.9	31	1541.34	0.1 (10%)	0.02	0.03	0.23	0.28	9.33
<i>Trema micrantha</i>	11	55.4	12.4	341.87	0.6 (60%)	0.08	0.17	0.04	0.29	9.67
<i>Vochysia guatemalensis</i>	5	20.9	14.3	264.75	0.2 (20%)	0.04	0.06	0.03	0.13	4.33
n=16	133			6319.22	3.6	1	1	0.98	3.01	100.33

* Reference area 4000m² (10 sampling sites of 400m²).

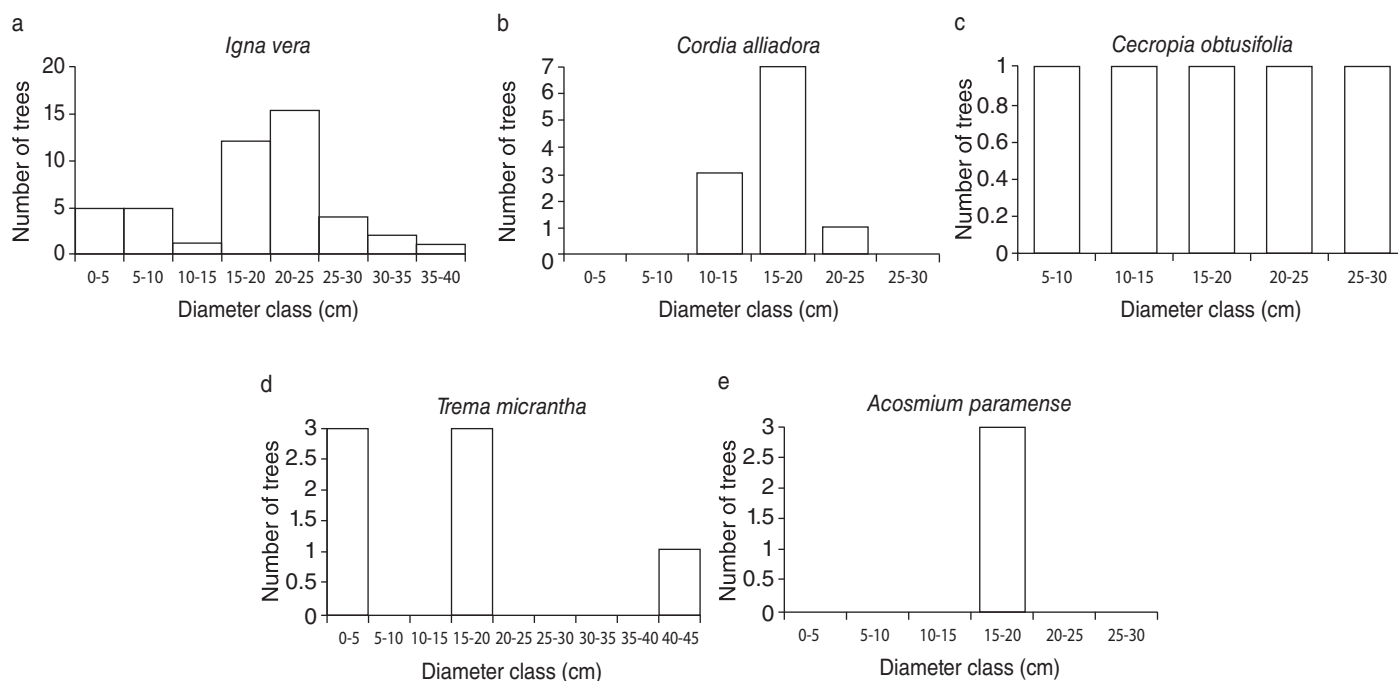


Figure 3. Population structure patterns, based on diameter classes, for species with greater importance values for coffee agroecosystems established in the tropical semideciduous forest. a: *I. vera* and b: *C. alliodora* display a type II pattern; c: *C. obtusifolia* and e: *A. panamense* do not have a defined structural pattern; and d: *T. micrantha* displays a type III pattern.

micrantha and *V. guatemalensis*. Coffee agroecosystems located in TSF and TRF displayed 30% similarity and had 11 common species: *C. annum* var. *glabriusculum*, *C. sinensis*, *C. alliodora*, *Erythrina americana*, *I. jinicuil*, *Inga punctata*, *Inga marginata*, *I. vera*, *P. dioica*, *T. micrantha* and *Willardia schiedeana*. The indexes of floristic similarity were low; that is to say, the

different coffee agroecosystems have high replacement rates due to the decisions peasants made about plants they used in each section of the altitudinal gradient, a phenomenon also reported by Williams-Linera and López-Gómez (2008) and by Rice (2011) for fruit species. This observation is remarkable for the case of TSFs, which are located closest to dwellings. In other areas

of Veracruz, the values were even lower (Williams-Linera and López-Gómez, 2008). The mean floristic similarity was 12%, more than twice that found by Guiracochoa *et al.* (2001) in cacao agroforestry systems in Costa Rica. Likewise, Godínez-Ibarra and López-Mata (2002) reported an intermediate similarity, with a low number of shared species, for three TSF samples.

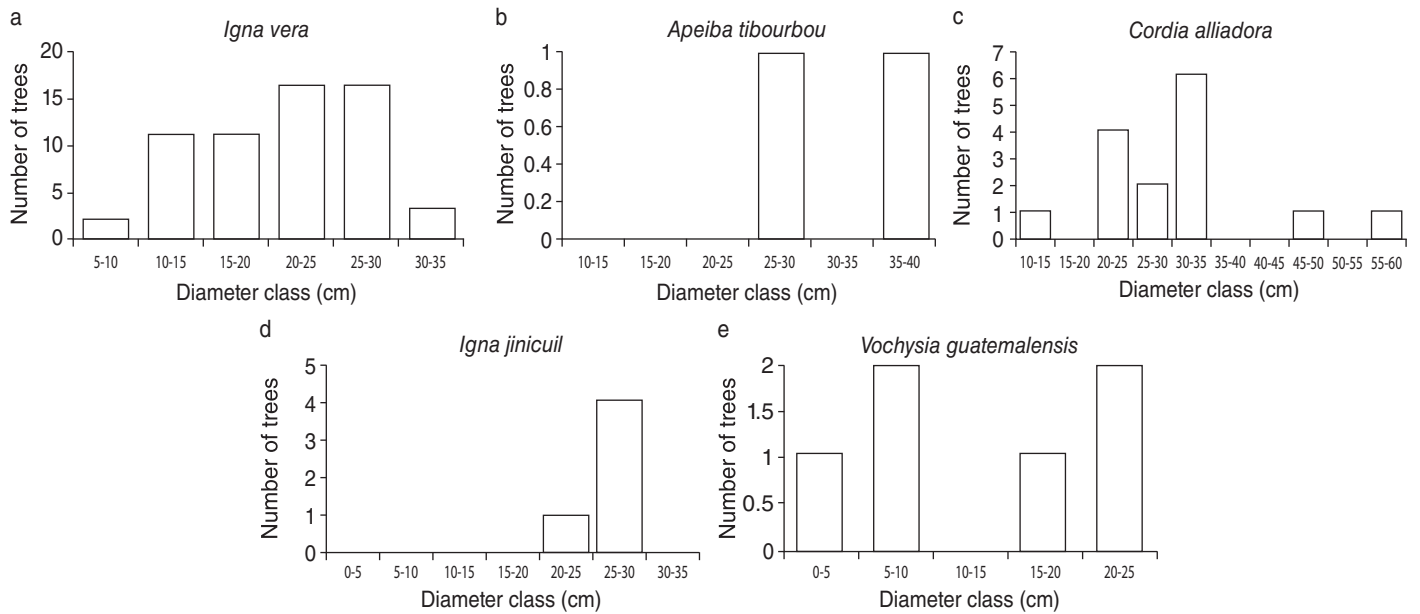


Figure 4. Population structure patterns, based on diameter classes, for species with greater importance values for coffee agroecosystems established in tropical rainforests. a: *I. vera* and c: *C. alliodora* display a type II pattern; b: *A. tibourbou* and d: *I. jinicuil* do not have defined structural patterns; and e: *V. guatemalensis* displays a type III pattern.

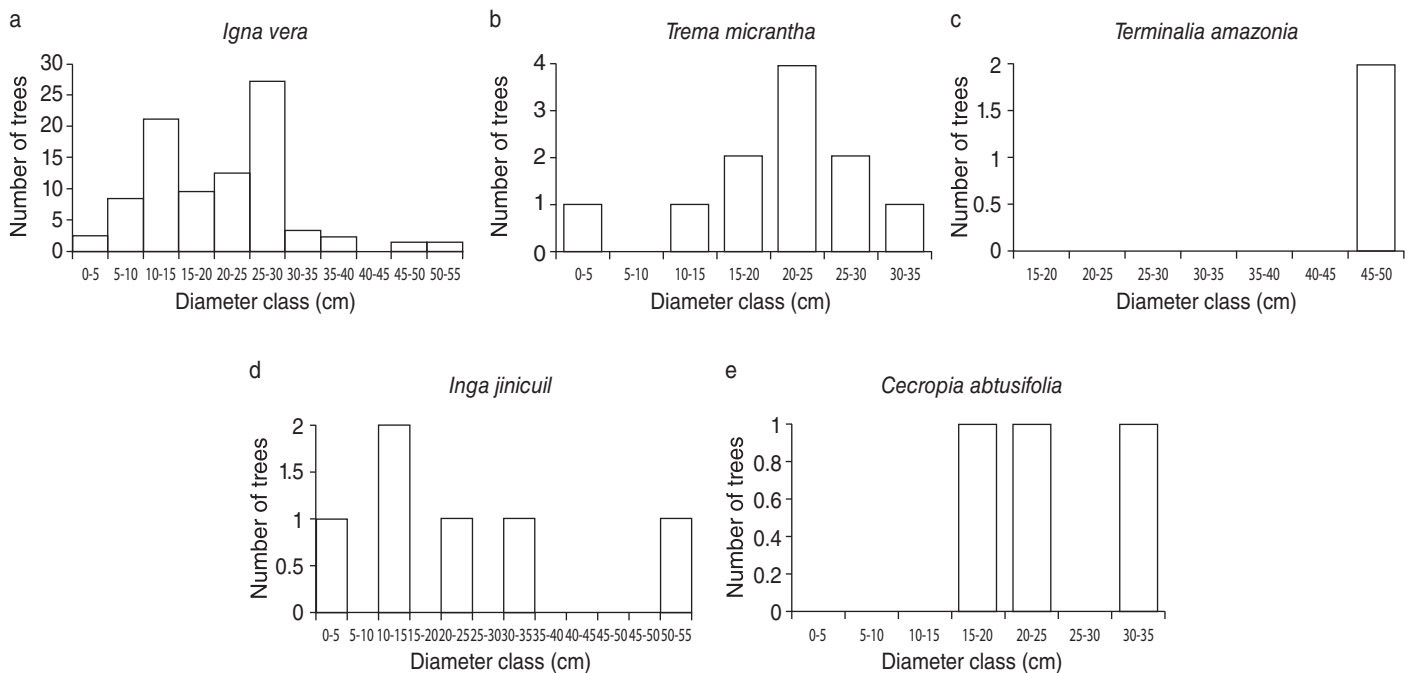


Figure 5. Population structure patterns, based on diameter classes, for species with greater importance values in coffee agroecosystems established in deciduous forest. a: *I. vera*, b: *T. micrantha* and d: *I. jinicuil* display a type II pattern, characterised by higher frequency of medium-sized individuals and lower frequency of older individuals; c: *T. amazonia* and e: *C. obtusifolia* do not have defined structural patterns.

Species richness, diversity and complementarity index

Along the altitudinal gradient, 345 individuals were recorded (60 tree and 23 herbaceous species) within 12000m². The greatest tree richness

(44.5%) occurred on coffee agroecosystems that were located in TSFs. For these agroecosystems, the Shannon-Wiener diversity index varied between 3.39 and 1.89, the Simpson index ranged between 61.95 and 31.1 and Fisher's alpha varied between 57.8 and 27.35. The coffee agroecosystems

that presents higher diversity values are those located near dwellings. These values confirm the greater biological diversity of these systems (Table V).

The complementarity in species composition for the coffee agroecosystems that were located in TSFs and DFs

TABLE V
BIOLOGICAL DIVERSITY INDEX FOR COFFEE
AGROECOSYSTEMS IN OCOTAL, CHICO

Site	Type of agroecosystem	Fisher's alpha	Shannon's index	Simpson's index
1	TSF coffee	43.4	1.89	1
2	TSF coffee	57.8	2.42	61.95
3	TSF coffee	44	2.73	42.71
4	TSF coffee	40	2.9	37.13
5	TSF coffee	39.35	3.04	34.95
6	TSF coffee	37.72	3.15	33.62
7	TSF coffee	37	3.23	32.65
8	TSF coffee	34.83	3.28	31.42
9	TSF coffee	34.71	3.35	31.45
10	TSF coffee	34.17	3.39	31.15
11	TRF coffee	34.12	3.44	31.14
12	TRF coffee	33.19	3.47	30.75
13	TRF coffee	33.02	3.51	30.85
14	TRF coffee	32.7	3.53	30.77
15	TRF coffee	32.4	3.56	30.62
16	TRF coffee	31.9	3.58	30.51
17	TRF coffee	31.83	3.6	30.57
18	TRF coffee	30.48	3.62	30.58
19	TRF coffee	30.61	3.63	30.36
20	TRF coffee	30.3	3.64	30.3
21	DF coffee	29.67	3.65	30.38
22	DF coffee	29.32	3.66	30.35
23	DF coffee	29	3.67	30.23
24	DF coffee	28.54	3.68	30.35
25	DF coffee	28.26	3.69	30.28
26	DF coffee	28.07	3.7	30.22
27	DF coffee	27.91	3.7	30.11
28	DF coffee	27.78	3.71	30.21
29	DF coffee	27.65	3.72	30.25
30	DF coffee	27.35	3.73	30.21

TSF coffee: tropical semi deciduous forest coffee agroecosystems, TRF coffee: tropical rain forest coffee agroecosystems, DF coffee: deciduous forest coffee agroecosystems. Calculation made with Estimates Version 8.2.0 (<http://viceroy.eeb.uconn.edu/estimates>)

was 88%; those located in TRFs and DFs had the same value. For agroecosystems located in TSFs and TRFs, complementarity was 82%, similar to those obtained by Williams-Linera *et al.* (2005) and López-Gómez *et al.* (2007) in deciduous forest and coffee agroecosystems of central Veracruz. Similarly, Villavicencio and Valdez (2003) found a 58% floristic similarity and 42% different species for coffee agroecosystems established in TSFs and TRFs in San Miguel, near Cordoba, Veracruz. In this same area, these authors observed greater evenness in the tree structure of rustic coffee agroecosystems established in TSF. Our results indicate a high replacement rate and, therefore, a high β diversity, which confirms that moderate disturbances resulting from human management, may have increased the species richness, although the original vegetation diversity was not reached (Williams-Linera *et al.*, 2005; Philpott *et al.*, 2008a).

Furthermore, the exclusive species found in each coffee agroecosystem studied herein also indicate a high diversity (Table VI) and confirm the influential role of traditional peasants in preserving and even increasing diversity. Their

management practices seem to be fundamental for conservation of natural resources in the area. It should be noted that, contrary to what was found by Philpott *et al.* (2008b) in Sumatra, Popoluca peasants conserve more native species along the altitudinal gradient (of those mandatory to be certified by programs like the Smithsonian Migratory Bird Center or 'Bird Friendly'). This diversity could be the basis for local programs aimed to conserve trees, but also birds, insects, microorganisms, biogeochemical cycles and give more resilience to the agricultural matrix (*sensu* Perfecto and Vandermeer, 2008). For instance, tree species such as *A. panamense*, *C. brasiliense*, *T. amazonia*, *T. micrantha* and *V. guatemalensis* in the lower and upper tree strata can diversify the productivity of coffee agroecosystems, giving emphasis to the use of evergreen species. This diversity contributes to soil structural stability because of the high susceptibility to erosion (Juárez, 2008; Cruz, 2009). In the lower tree stratum, *C. alliodora*, *B. crassifolia*, *C. papaya*, *C. sinensis*, *C. cainito*, *I. jinicuil*, *P. dioica* and *S. mombin* are important species. In the herbaceous stratum, some species, such *C. annuum var. annuum*, *Chenopodium* sp., *C. sativus* and *S. pimpinellifolium*, could be used as garden produce, and species such as *Colocasia bicolor*, *Colocasia* sp., *Chamaedorea* sp. and *Ceratozamia* sp. could be used as ornamentals.

TABLE VI
EXCLUSIVE SPECIES FOUND IN THE DIFFERENT COFFEE
AGROECOSYSTEMS, ACCORDINGLY WITH ORIGINAL
VEGETATION TYPE, IN OCOTAL CHICO, SOTEAPAN, VERACRUZ

TSF coffee (23)	TRF coffee (23)	DF coffee (21)
<i>Acosmium panamense</i>	<i>Acalypha microstachya</i>	<i>Adelobotrys adscendens</i>
<i>Alibertia edulis</i>	<i>Apeiba tibourbou</i>	<i>Agerantia</i> sp.
<i>Byrsonima crassifolia</i>	<i>Calophyllum brasiliense</i>	<i>Allophylus cominia</i>
<i>Calathea macrochlamys</i>	<i>Citrus aurantifolia</i>	<i>Annona reticulata</i>
<i>Carica papaya</i>	<i>Coccoloba uvifera</i>	<i>Astrocarium mexicanum</i>
<i>Chiococca Alba</i>	<i>Eupatorium daleoides</i>	<i>Astronium graveolens</i>
<i>Chrysophyllum cainito</i>	<i>Hyptis mutabilis</i>	<i>Baltimorea recta</i>
<i>Chrysophyllum mexicanum</i>	<i>Leucaena leucocephala</i>	<i>Bursera simaruba</i>
<i>Cajoba arborea</i>	<i>Luehea speciosa</i>	<i>Calyptanthus lindeniana</i>
<i>Cupania glabra</i>	<i>Mangifera indica</i> **	<i>Catsetum integerrimum</i>
<i>Eugenia acapulcensis</i>	<i>Miconia argentea</i>	<i>Lacistema aggregatum</i>
<i>Eugenia capulli</i>	<i>Montana</i> sp.	<i>Liquidambar styraciflua</i>
<i>Gliricidia sepium</i>	<i>Rollinia mucosa</i>	<i>Lonchocarpus guatemalensis</i>
<i>Heliconia curtispatha</i>	<i>Sida cordifolia</i>	<i>Ocotea verticillata</i>
<i>Malpighia glabra</i>	<i>Sida rhombifolia</i>	<i>Rapanea</i> sp.
<i>Sacoila lanceolata</i>	<i>Sinclairia discolor</i>	<i>Tectona grandis</i> **
<i>Sida acuta</i>	<i>Spathodea campanulata</i> **	<i>Terminalia amazonia</i>
<i>Pachira aquatica</i>	<i>Suriana maritima</i>	<i>Tetrapteryx schiedeana</i>
<i>Tephrosia</i> sp.**	<i>Swietenia macrophylla</i>	<i>Thelypteris blanda</i>
<i>Trichilia havanensis</i>	<i>Vanilla planifolia</i>	<i>Vismia baccifera</i>
<i>Vismia camaguey</i>	<i>Vernonia patens</i>	<i>Zuelania guidonia</i>
<i>Zanthoxylum caribaeum</i>	<i>Vochysia guatemalensis</i>	
<i>Zapoteca</i> sp.	<i>Xiphidium caeruleum</i>	

TSF coffee: tropical semi deciduous forest coffee agroecosystems, TRF coffee: tropical rain forest coffee agroecosystems, DF coffee: deciduous forest coffee agroecosystems. ** Introduced.

Conclusions

Four strata were found in the 30 coffee agroecosystems studied. *Inga vera* had the highest importance value; however, we found 84 different plants, 64 of which are trees. Of those whose uses could be documented, we found one to three different uses, timber, fruits and medicinal being remarkable. Coffee agroecosystems located near dwellings (TSD coffee) have higher diversity values; however, its tree density is lower (97 individuals) than in TRF coffee (115 individuals) and in DF coffee (133 individuals). Tree height ranges 5-35m. Results show high diversity indices, even higher than in other areas of Chiapas, which is confirmed by the few species that all the coffee agroecosystems share, by the high replacement rate, and by the great number of exclusive species found at each coffee agroecosystem. All these confirm the fundamental role of peasant's knowledge and management in the selection of species and the structure of the agroecosystem, but also in increasing and in some cases improving diversity. Popoluca peasants conserve native species instead of exotics, of which only three species were found. With the information obtained, diversification and restoration programs could be organized based upon native tree richness and the participation of the Popoluca people. This will allow to structure agroecological matrices to improve production and productivity of agroecosystems, but also conserve birds, mammals, insects, microorganisms and the essential biogeochemical cycles.

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REFERENCES

- Bandeira FP, Martorell C, Meave JA, Caballero J (2005) The role of rustic coffee agroecosystems in the conservation of wild tree diversity in the Chinantec region of Mexico. *Biodiv. Cons.* 14: 1225-1240.
- Bartra A (2003). *Cosechas de Ira. Economía Política de la Contrarreforma Agraria*. 1st ed. Itaca. Mexico. 131 pp.
- Castillo-Campos G, Laborde DJ (2004) Vegetación. In Guevara S, Laborde J, Sánchez-Ríos G (Eds.) *Los Tuxtlas. El Paisaje de la Sierra*. Instituto de Ecología, A.C./Unión Europea. Xalapa, Mexico. pp. 231-269.
- Colwell K (2009) *Estimates 8.2.0. Statistical Estimation of Species Richness and Shared Species from Samples*. <http://viceroy.eeb.uconn.edu/estimates>
- Cruz L, Lorenzo C, Naranjo E, Ramírez N (2004) Diversidad de mamíferos en cafetales de las cañadas de la selva lacandona, Chiapas, México. *Acta Zool. Mex.* 20: 63-81.
- Cruz V (2009) *Comparación de Métodos para la Medición de Erosión en la Sub-Cuenca del río Huazuntlán, Veracruz*. Thesis. Universidad Veracruzana. México. 71 pp.
- Descroix F, Wintgens JN (2004) Establishing a coffee plantation. In Wintgens JN (Ed.) *Coffee: Growing, Processing, Sustainable Production. A Guidebook for Growers, Processors, Traders and Researchers*. Wiley. Dramstadt, Germany. pp. 178-245.
- Franco S (2007) *Los Agroecosistemas Cafetaleros de Ocotlán Chico, Municipio de Sotapan, Veracruz*. Thesis. Universidad Veracruzana. México. 61 pp.
- García E (1988) *Modificaciones al Sistema de Clasificación Climática de Köppen (Para Adaptarlo a las Condiciones de la República Mexicana)*. 4th ed. Laríos. México. 217 pp.
- Godínez-Ibarra O, López-Mata L (2002) Estructura, composición, riqueza y diversidad de árboles en tres muestras de selva mediana subperennifolia. *An. Inst. Biol. Mex. Ser. Bot.* 73: 283-314.
- Gould A, González G, Guerrero-Rivera G (2006) Structure and composition of vegetation along an altitudinal gradient in Puerto Rico. *J. Veg. Sci.* 17: 653-664.
- Graciano O (2004) Situación social de la comunidad. In González F (Ed.) *Proc. Workshop for Community Planning and Natural Resource Management*. Proyecto Sierra de Santa Marta, A. C. Mexico. pp. 13-31.
- Guiracochoa G, Harvey C, Somarriba E, Krauss U, Carrillo E (2001) Conservación de la biodiversidad en sistemas agroforestales con cacao y banano en Talamanca, Costa Rica. *Agroforest. Amer.* 8(30): 7-11.
- Hernández-Martínez G (2008) Clasificación agroecológica. In Manson RH, Hernández-Ortiz V, Gallina S, Mehlreter K (Eds.) *Agroecosistemas Cafetaleros de Veracruz. Biodiversidad, Manejo y Conservación*. Instituto de Ecología A.C./Instituto Nacional de Ecología/SEMARNAT. México. pp. 15-34.
- Hietz P (2005) Conservation of vascular epiphyte diversity in Mexican coffee agroecosystems. *Cons. Biol.* 19: 391-399.
- Jacinto J (2012) Coleopterofauna en cafetales de San Fernando, Sotapan, Veracruz. Thesis. Universidad Veracruzana. México. 66 pp.
- Juárez A (2008) *Medición de la Erosión de Suelos en la Sub-Cuenca del río Huazuntlán, Ver.* Thesis. Universidad Veracruzana. México. 65 pp.
- Leonti M (2002) *Moko/La Rosa Negra. Ethnobotany of the Popoluca Veracruz, México*. Thesis. Swiss Federal Institute of Technology. Zurich, Switzerland. 285 pp.
- López-Gómez AM, Williams-Linera G, Manson RH (2007) Tree species diversity and vegetation structure in shade coffee farms in Veracruz, México. *Agr. Ecosyst. Environ.* 124: 160-172.
- López-Gómez AM, Williams-Linera G (2006) Evaluación de métodos no paramétricos para la estimación de riqueza de especies de plantas leñosas en cafetales. *Bol. Soc. Bot. Mex* 78: 7-15.
- Mariano MI, García AL (2010) Tipos de suelos y su uso potencial en la sub-cuenca del río Huazuntlán, Ver. Thesis. Universidad Veracruzana. México. 77 pp.
- Martínez AC (1997) *El Proceso Cafetalero Mexicano*. Instituto de Investigaciones Económicas. Universidad Nacional Autónoma de México. 190 pp.
- Martínez-Ramos M, Álvarez-Buylla E (1995) Ecología de poblaciones de plantas en una selva húmeda de México. *Bol. Soc. Bot. Mex.* 56: 121-153.
- Miranda F, Hernández XE (1963) Los tipos de vegetación de México y su clasificación. In *Xolocotzia. Vol. I. Revista de Geografía Agrícola*. Chapingo, México pp. 41-162.
- Moguel P, Toledo VM (1999) Diversity conservation in traditional coffee systems of Mexico. *Cons. Biol.* 13(4): 11-21.
- Moreno E (2001) *Manual de Métodos para Medir la Biodiversidad*. University Textbooks. Universidad Veracruzana. México. 49 pp.
- Mueller-Dombois D, Ellenberg H (1974) *Aims and Methods of Vegetation Ecology*. Wiley. NewYork, USA. 547 pp.
- Nolasco M (1985) *Café y Sociedad en México*. Centro de Ecodesarrollo. México. 454 pp.
- Oijen van M, Dauzat J, Harmand JM, Lawson G, Vaast P (2010) Coffee agroforestry systems in Central America: I. A review of quantitative information on physiological and ecological processes. *Agroforest. Syst.* 80: 341-359.
- Peeters LYK, Soto-Pinto L, Perales H, Montoya G, Ishiki M (2003) Coffee production, timber and firewood in traditional and *Inga*-shaded plantations in Southern Mexico. *Agr. Ecosyst. Environ.* 95: 481-493.
- Perfecto I, Vandermeer JH (2008) Diversity conservation in tropical agroecosystems: a new conservation paradigm. *Ann. New York Acad. Sci.* 1134: 173-200.
- Perfecto I, Rice R, Greenberg R, Van der Voort M (1996) Shade coffee: a disappearing refuge for diversity. *BioScience* 46: 598-608.
- Philpott SM, Bichier P (2012) Effects of shade tree removal on birds in coffee agroecosystems in Chiapas, Mexico. *Agr. Ecosyst. Environ.* 149: 171-180.
- Philpott SM, Arendt WJ, Armbricht I, Bichier P, Diestch TV, Gordon C, Greenberg R, Perfecto I, Reynoso-Santos R, Soto-Pinto L, Tejeda-Cruz C, Williams-Linera G, Valenzuela J, Zolotoff JM (2008a) Diversity loss in Latin America coffee landscapes: review of evidence on ants, birds and trees. *Cons. Biol.* 22: 1093-1105.
- Philpott SM, Bichier P, Rice RA, Greenberg R (2008b) Diversity conservation, yield, and alternative products in coffee agroecosystems in Sumatra, Indonesia. *Biodivers. Cons.* 17: 1805-1820.
- Potvin C, Owen CT, Melzi S, Beaucage P (2005) Diversity and modernization in four coffee-producing Villages of Mexico. *Ecol. Soc.* 18. www.ecologyandsociety.org/10/iss1/art18/
- Regalado-Ortiz A (2006) *¿Qué es la Calidad en el Café?* Universidad Autónoma Chapingo. México. 309 pp.
- Retama Y, Ávila-Bello CH, Alarcón A, Ferrera-Cerrato R (2014) Hongos micorrízicos arbusculares nativos asociados a *Liquidambar styraciflua* en la sierra de Santa Marta, Veracruz, México. Submitted.

- Rice RA (2011) Fruits from shade trees in coffee: how important are they? *Agroforest. Syst.* 83: 41-49.
- Romero-Alvarado Y, Soto-Pinto L, García-Barrios L, Barrera-Gaytán JF (2002) Coffee yields and soil nutrients under shades of *Inga* sp. vs. multiple species in Chiapas, Mexico. *Agroforest. Syst.* 54: 215-224.
- Sánchez EV, López-Mata L, García-Moya E, Cuevas Guzmán R (2003) Estructura, composición florística y diversidad de especies leñosas de un bosque mesófilo de montaña en la sierra de Manantlán Jalisco. *Bol. Soc. Bot. Mex.* 73: 17-34.
- Scheaffer RL, Mendenhall W, Ott L (1987) *Elementos de Muestreo*. Iberoamérica. México. 321 pp.
- Siemens AH (2004) Los paisajes. In Guevara S, Laborde J, Sánchez-Ríos G (Eds.) *Los Tuxtlas. El Paisaje de la Sierra*. Instituto de Ecología, A.C./European Union. Xalapa, México. pp. 41-59.
- Skovmand Bosselmann A, Dons K, Oberthur T, Smith Olsen C, Rødbild A, Usma H (2009) The influence of shade trees on coffee quality in smallholder coffee agroforestry systems in Southern Colombia. *Agr. Ecosyst. Environ.* 129: 253-260.
- Solis-Montero L, Flores-Palacios A, Cruz-Angón A (2005) Shade coffee agroecosystems as refuges for tropical wild orchids in Central Veracruz, Mexico. *Cons. Biol.* 19: 908-916.
- Soto-Pinto L, Perfecto I, Castillo-Hernández J, Caballero-Nieto J (2000) Shade effect on coffee production at the Northern Tzeltal zone of the state of Chiapas, Mexico. *Agr. Ecosyst. Environ.* 80: 61-69.
- Soto-Pinto L, Villalvazo-López V, Jiménez-Ferrer G, Ramírez-Marcial N, Montoya G, Sinclair FL (2007) The role of local knowledge in determining shade composition of multistrata coffee systems in Chiapas, México. *Biodivers. Cons.* 16: 419-436.
- Van Oijen M, Dautzat J, Harmand JM, Lawson G, Vaast P (2010) Coffee agroforestry systems in Central America: II. Development of a simple process-based model and preliminary results. *Agroforest. Syst.* 80: 361-378.
- Vandermeer JH (2011) *The Ecology of Agroecosystems*. Jones & Bartlett. Sudbury, MA, USA. 387 pp.
- Villavicencio EL, Valdez HJ (2003) Análisis de la estructura arbórea del sistema agroforestal rusticano de café en San Miguel, Veracruz, México. *Agrociencia* 37: 413-423.
- Williams-Linera G, López-Gómez AN, Muñoz-Castro M (2005) Complementariedad y patrones de anidamiento de especies de árboles en el paisaje de bosque de niebla del centro de Veracruz (México). In: Halffter G, Soberón J, Koleff P, Melic A (Eds.) *Sobre Diversidad Biológica: El Significado de las Diversidades Alfa, Beta y Gamma*. Sociedad Entomológica Aragonesa/CONABIO/Grupo Diversitas-México/CONACYT. Zaragoza, España. pp. 153-164.
- Williams-Linera G, López-Gómez A (2008). Estructura y diversidad de la vegetación leñosa. In Manson RH, Hernández-Ortiz V, Gallina S, Mehlreter K (Eds.) *Agroecosistemas Cafetaleros de Veracruz. Biodiversidad, Manejo y Conservación*. Instituto de Ecología A.C./Instituto Nacional de Ecología-SEMARNAT. México. pp. 55-68.

ESTRUCTURA Y DIVERSIDAD DE ÁRBOLES EN AGROSISTEMAS CAFETALEROS POPOLUCA, RESERVA DE BIOFERA DE LAS TUXTLAS, MÉXICO

Guadalupe Castillo Capitán, Carlos H. Ávila-Bello, Lauro López-Mata y Fernando de León González

RESUMEN

La estructura y diversidad arbórea de agroecosistemas cafetaleros tradicionales fue estudiada en una comunidad popoluca dentro de la Reserva de la Biosfera de Los Tuxtlas, Veracruz, México, a lo largo de un gradiente altitudinal entre los 450 y 1000msnm. Los agroecosistemas cafetaleros se encuentran establecidos en tres unidades fisionómicas: selva mediana subperennifolia, selva alta perennifolia y bosque caducifolio. Para entender la estructura de estos agroecosistemas se establecieron 30 parcelas de 400m². Se registraron 64 especies de árboles y 23 hierbas pertenecientes a 44 familias. Las familias más numerosas fueron Mimosaceae, Asteraceae, Fabaceae y Myrtaceae. Los agroecosistemas cafetaleros presentan cuatro estratos: herbáceo, arbustivo, arbóreo inferior y arbóreo superior. El estrato arbustivo está dominado por cuatro

variedades de *Coffea arabica*. Las especies con los mayores valores de importancia fueron *Apeiba tibourbou*, *Cordia alliodora* e *Inga vera*, y las especies con mayor valor económico son *Acosmium panamense*, *Calophyllum brasiliense*, *Terminalia amazonia* y *Vochysia guatemalensis*. Los agroecosistemas cafetaleros establecidos en selva mediana subperennifolia tienen valores más altos de diversidad, similitud florística más baja y los valores más altos de disimilitud. El índice de complementariedad indica una alta tasa de reemplazo y confirma el papel fundamental del conocimiento y manejo de los campesinos en la selección de especies y la estructura del agroecosistema, así como en el aumento y en algunos casos la mejora de la diversidad, sin alcanzar los valores originales de la vegetación.

ESTRUTURA E DIVERSIDADE DE ÁRVORES EM AGROECOSSISTEMAS CAFEIROS POPOLUCA NA RESERVA DE BIOFERA DAS TUXTLAS, MÉXICO

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RESUMO

A estrutura e diversidade arbóreas de agroecosistemas cafeeiros tradicionais foi estudada em uma comunidade Popoluca dentro da Reserva da Biosfera de "Los Tuxtlas", Veracruz, México, ao longo de gradiente altitudinal entre os 450 e 1.000 msnm. Os agroecosistemas cafeeiros se encontram estabelecidos em três unidades fisionômicas: selva mediana subperennifolia, selva alta perennifolia e bosque caducifolia. Para entender a estrutura de estes agroecosistemas se estabeleceram 30 lotes de 400m². Registraram-se 64 espécies de árvores e 23 ervas pertencentes a 44 famílias. As famílias mais numerosas foram Mimosaceae, Asteraceae, Fabaceae e Myrtaceae. Os agroecosistemas cafeeiros apresentam quatro extratos: herbáceo, arbustivo, arbóreo inferior e arbóreo superior. O extrato arbustivo está dominado por

quatro variedades de *Coffea arábica*. As espécies com os maiores valores de importância foram *Apeiba tibourbou*, *Cordia alliodora* e *Inga vera*, e as espécies com maior valor econômico são *Acosmium panamense*, *Calophyllum brasiliense*, *Terminalia amazonia* e *Vochysia guatemalensis*. Os agroecosistemas cafeeiros estabelecidos em selva mediana subperennifolia têm valores mais altos de diversidade, similitude florística mais baixa e os valores mais altos de dissimilitude. O índice de complementariedade indica uma alta taxa de substituição e reforça o papel fundamental dos camponeses no conhecimento e manejo da seleção de espécies e a estrutura do agroecosistema, assim como no aumento e em alguns casos na melhora da diversidade, sem alcançar os valores originais da vegetação.