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Tree diversity indices in the coffee agroecosystems of the Loxicha jungle, Oaxaca

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Abstract

Ten coffee farms located in the jungle of the Municipality of San Bartolome Loxicha, Oaxaca, Mexico, were explored and evaluated, where a great diversity of trees associated to coffee is generally found, which, as agroecosystems are mostly complex, being an example of an agroforestry system. The objective was to register the existing shade trees and to evaluate their importance in the agroecosystem through diversity indices. The methodology proposed by the Smithsonian Migratory Bird Center (SMBC) was applied, delimiting sites of 2000 m^2 at random, taking an emergent tree as the center of each site. One hundred and thirty-six tree species used as shade were counted, mostly native and, in addition to the shade they provide to the coffee tree, the producers obtain wood, firewood, fruits, and medicinal uses. The dominant species was the "cuil" tree (*Inga edulis* Mart.), followed by "aguacatillo" (*Phoebe ehrenbergii* Nees), and "palo mujer" (*Alchornea latifolia* Sw.). The arboreal diversity constitutes a great biological richness along with shrubby plants, epiphytes and the large number of birds that can be seen among the trees.

Keywords: *Inga edulis, Phoebe ehrenbergii, Alchornea latifolia*, biological wealth, emergent tree.

Introduction

In an effort to conserve the coffee agroecosystems of Latin America, the Smithsonian Migratory Bird Center (SMBC) inspects and certifies coffee plantations as organic and bird friendly, considering the most important characteristics, the canopy, height and the number of strata, tree diversity and the presence of epiphytes and vines; a wide diversity promotes greater stability in a natural system and this also applies for coffee plantations, considering that a coffee plantation where shade-grown coffee is produced, must have a structure similar to natural forests, which are formed by trees of different heights and sizes, because having only one stratum or only one level of shade does not resemble a natural forest (Rice y Drenning, 2003 y García et al., 2015).

Vegetation studies in the tropics have faced problems such as identification and knowledge of the numerous species that constitute the forests to determine the patterns of their growth dynamics, in space and through time (Astudillo et al., 2019). The high and medium evergreen forest has been the main ecosystem where coffee plantations have been established since 1795, the year when it was introduced in Mexico, especially the *Coffea arabica* o *Coffea canephora* (robusta) variety, which requires shade for its cultivation. In this regard, 40 % of the surface where coffee is produced corresponds to high and medium jungles, 23 % to pine-oak forests, 21% to tropical deciduous forest and 15 % to cloud forests (Moguel y Toledo, 1996; Sánchez et al., 2017; Reyes et al., 2022).

Work regarding the structure and function of coffee plantations has been carried out, such as those made by Moguel

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and Toledo (1999); Ruelas et al. (2014); Garcia et al. (2015); Espinoza-Guzman et al. (2020); Ramos-Reyes et al. (2020); mainly in the areas of Xalapa, Coatepec and Cordoba, Veracruz, where they describe diverse types of coffee plantations according to the type and use of shade trees, encompassing a complex mosaic of agroecosystems and productive levels where on the one hand, a strong competition for light, nutrients, water and space is presented, and on the other hand there is an ethnic and socioeconomic influence of the coffee plantation areas.

Additionally, as part of the techniques to measure biodiversity in natural ecosystems, different diversity rates have been used, mainly focused on getting to know the richness of the arboreal tree species, where the Margalef, Simpson, Menhinick, Pielou, Berger-Parker, McIntosh and Shannon indices are widely used because they are quantifiable, comparable, representative, controllable, viable, geo-referenceable and predictable to measure alpha diversity (Soler et al., 2012; Valdez et al., 2018; Manzanilla et al., 2020); Montalvo (2006), used the Jaccard similarity coefficient and found a high arboreal diversity in the municipalities of Candelaria Loxicha, Pluma Hidalgo and San Agustin Loxicha located between the altitudinal range of 600 to 1200 m.a.s.l.

Sánchez and Schwentesius (2015) used the Margalef, Simpson and Berger Parker indices and reported medium to high arboreal vegetation diversity in coffee plantations of San Vicente Yogondoy, which belongs to the Loxicha jungle; therefore, considerably surpassing the minimal requirements requested for a coffee plantation to be diverse regarding arboreal species and can be certified as a bird friendly coffee plantation, stating that the trees not only provide shade to the coffee trees, but they also provide diverse benefits to the owners who uses them as a source of food, ornamental, medicinal, for building material and to capture water, among other services.

Rojas et al. (2012), pointed out the changes and the transformation the landscapes have suffered because of the coffee production system in Colombia, determining that the fragility of the jungles has caused a loss in diversity, these are the landscapes that have been transformed to establish coffee plantations with mountain mesophilic forest. In the case of the coffee estates of the jungle of Loxicha in the State of Oaxaca, there is usually found great arboreal diversity, which the producers consider must be preserved (Noriega et al. 2011). Therefore, based on the need to evaluate the arboreal biodiversity in general, for the Loxicha jungle and its importance in the agroecosystem, the objective of this work was to estimate the diversity indices and register the existing shade trees.

Materials and methods

The study area is in the Loxicha region, located at 120 km south from the city of Oaxaca. This region constitutes the upper part of the basin of the Copalita River; it encompasses the border communities of Candelaria Loxicha, located at 450 masl to San Agustìn Loxicha, a community located at 1820 m.a.s.l. The vegetation corresponds to the semi-evergreen tropical forest (Pennington y Sarukhán, 2005) modified by the coffee agroecosystem.

Because of the environmental factors, the climatic types are (A)C(w2), Aw1, Aw0, warm subhumid in the area near the pacific coastline and C(w2), Cb'(W2), subhumid temperate in the upper part of the mountains, characterized by high temperatures most of the year with little oscillation (García, 2004). Due to its closeness to the sea, circulation is formed in the plateau of warm humid winds that collide with the mountain in the exposition of the windward, besides local convection, the air gets cold, causing condensation, which leaves important quantities of humidity. Additionally, tropical cyclones influence the precipitation regimen, causing prolongated rains in the months of July and October, which along with the action of the winds produce physical effects in ecosystems and in crops.

Sampling sites and sample size

To evaluate the diversity of arboreal species and characterize coffee plantations, ten coffee sites were sampled applying the methodology proposed by the Smithsonian Institute to evaluate and certify organic and bird friendly coffee plantations (Rice y Drenning, 2003). Pieces of land or plots were defined randomly, taking as the center of every site an emerging or dominant tree, at a sampling intensity of 20%, which is equal to 1 site ha^{-1} considering a surface of 2000 m^2 $hectare^{-1}$, counting and registering the number of the existing arboreal species and their heights. Additionally, the arboreal stratum and shade coverage were counted, and the plots were georeferenced. For this purpose, we had the accompaniment of the coffee producers and connoisseurs of the shade trees.

The selected coffee plantations were explored with a photographic camera, a field notebook, GPS (GARMIN), clinometer Suunto, densiometer and a machete. Samples of some species were collected for its identification. Several diversity indices were calculated with the registration of the number of trees; the Margalef diversity index, the Menhinick index, the Simpson index, the McIntosh index and the Shannon Weiner index. The Margalef index is expressed through Equation (1), where *S* is the number of species and *N* is the total number of individuals.

$$D_{Mg} = \frac{S-1}{lnN} \tag{1}$$

The expression represents the number of species according to the logarithm of the extension of the sample, which can be used as a diversity index and reflects accurately its attributes, in the total number of species and in the relation between the respective number of individuals

(Margalef, 1995). This index transforms the number of species per sample to a proportion where the species are added by the expansion of the sample. It also implies there is a functional relation between the number of species and the total number of individuals where *k* is constant. If this is not maintained, then the index varies with the size of the sample in an unknown way. Using *S*–1, instead of *S*, gives $D_{Mg} = 0$, when there is only one species (Magurrán, 1989; Moreno et al., 2011).

The Menhinick diversity index is expressed with Equation (2). Like the Margalef index, this index is based on the relation between the number of species and the total number of observed individuals which increases when the size of the sample increases.

$$D_{Mn} = \frac{S}{\sqrt{N}} \tag{2}$$

To understand the dominance of species, the Simpson index was obtained with Equation (3), where *pi* is the proportional abundance of specie *i*, that is, the number of individuals of species *i* divided between the total number of individuals of the sample:

$$\lambda = \sum p_i^2 \tag{3}$$

This dominance index expresses the probability of two individuals being of the same species when randomly sampled. It is strongly influenced by the importance of the most dominant species. Since its value is inverse to equality, the diversity can be calculated as 1 – λ (Magurran, 1989; Medrano et al., 2017; Salmerón et al., 2017).

The McIntosh index is expressed by Equation (4), where *U* is evaluated in the form described by Equation (5) for i=1,2,3, ..., *S*. This dominance index is independent from N which is the total number of individuals registered in the sample (Magurran, 1989).

$$D = \frac{N - U}{N - \sqrt{N}} \tag{4}$$

$$U = \sqrt{\sum n_i^2} \tag{5}$$

Finally, the Shannon-Wiener (*H'*) index of equality was estimated, it defines diversity based on the number of individuals per species and it is evaluated with Equation (6), where *pi* represents the proportional abundance per specie.

$$H' = -\sum pi ln pi \tag{6}$$

This index expresses the uniformity of the values of importance throughout all the species of the sample. Additionally, the value of this index is lower when all the individuals belong to the same species and it is higher when each species corresponds to a different species (Daniel, 1998; Pla, 2006).

Results and discussion

The sampled coffee plantations had the following surfaces: 5, 3, 3, 6, 4, 7, 4, 2, 9 and 2 ha, respectively. Adding them up gave a total of 45 ha, therefore, to cover the 20 % sampling intensity suggested by the Smithsonian Institute, the size of the sample was 9 ha, so 45 sites of 2000 m^2 were sampled. One hundred and thirty-six arboreal species were registered which are the shade trees of the coffee agroecosystem, they are mainly native species, from which timber and firewood are obtained, as well as other local uses. The list of the arboreal species is presented in Table 1, with the number of individuals registered per coffee plantation, organized by level of importance inside the agroecosystem.

According to Campo and Duval (2014), the number of individuals are ordered from the highest to the lowest, where the highest is considered as the most important species inside the ecosystem and organizing them by importance takes into consideration dominance, abundance and frequency of each specie. Therefore, the dominant specie is the “cuil” tree (*Inga edulis* Mart.), followed by “aguacatillo” (*Phoebe ehrenbergii* Nees) and “palo de mujer” (*Alchornea latifolia* Sw.), which constitute the main strata of the coffee plantation agroecosystem, with heights that go from 16 to 20 m. The emerging or dominant trees are higher than 30 m, the trees that stand out are, “guapinol” (*Hymenaea courbaril* L.), “ceiba” (*Ceiba pentandra* (L.) Gaertn.), “palo maría” (*Calophyllum brasiliense* Cambess.), “macuil” (*Tabebuia rosea* (Bertol.) DC.) and “hormiguillo” (*Cordia alliodora* (Ruiz & Pav.) Oken), the same ones in the region of Chatina reported by Castelán (2016), which are the core trees of the coffee plantation agroecosystem. In general, for the Loxicha jungle, beside the ones mentioned above, “palo cobre” (Sommera grandis Standl.), “ocote” (Pinus maximinoi H. E. Moore) and “chalum” (Ficus tecolutensis (Liebm.) Miq.) also stand out.

The estimated parameters to obtain the indices are presented in Table 2. The values obtained from the indices were: Margalef 16.4027, Menhinick 2.2199, Simpson 0.9624, McIntosh 0.8194 and Shannon-Wiener 3.9034. For the Margalef index, values lower than 2.0 refer to areas of lower diversity due to anthropogenic effects, and values above 5.0 indicate high biodiversity, these indices along with the Menhinick express specific richness in a simple form, considering simultaneously the number of species and the number of individuals in the samples (Magurran, 1989; Cué et al., 2019).

The *pi* value goes from 0.10444 for *Inga edulis* to 0.00026 for *Lysiloma* spp., from the most abundant to the scarcest.

Table 1. Registration of the shade trees in the coffee agroecosystem of the Jungle of Loxicha, Oaxaca.

Árbol	Nombre científico	Individuos por cafetal									
		1	2	3	4	5	6	7	8	9	10
1	*Inga edulis* Mart.	43	21	24	56	35	64	39	16	75	19
2	*Phoebe ehrenbergii* Mez	36	23	26	47	26	55	30	20	68	11
3	*Alchornea latifolia* Sw.	22	9	11	31	21	42	18	13	43	8
4	*Cecropia obtusifolia* Bertol.	17	12	16	34	21	37	15	11	36	7
5	*Musa paradisiaca* L.	16	13	11	26	16	33	20	13	48	10
6	*Cupania dentata* Moc. & Sessé ex DC.	20	8	5	16	10	22	15	12	32	11
7	*Tecoma stans* (L.) Juss. Ex Kunth	14	6	7	8	10	17	13	9	21	7
8	*Trema micrantha* (L.) Blume	12	9	10	11	6	20	6	2	28	3
9	*Senna pallida* (Vahl) Irwin & Barneby	7	6	8	10	7	11	5	7	16	5
10	*Tabebuia rosea* (Bertol.) DC.	10	6	4	11	10	12	6	4	15	2
11	*Saurauia serrata* DC.	9	5	7	10	13	8	5	6	13	4
12	*Saurauia scabrida* Hemsl.	6	7	5	12	8	10	3	7	11	6
13	*Sommera guatemalensis* Standl.	8	4	5	10	8	12	5	4	13	2
14	*Guazuma ulmifolia* Lam.	10	6	3	12	7	10	6	2	12	1
15	*Miconia minutiflora* (Bonpl.) DC.	9	7	4	9	6	7	7	4	11	3
16	*Sommera grandis* Standl.	7	4	6	8	5	10	5	4	12	5
17	*Croton draco* Schltdl.	6	5	7	8	2	9	4	6	13	4
18	*Archibaccharis* spp. H.B.K.	4	6	6	9	3	9	5	6	11	3
19	*Eriobotrya japónica* (Thunb.) Lindl.	5	3	3	7	6	8	6	4	9	3
20	*Psidium guajava* L.	5	3	4	6	4	7	5	5	8	3
21	*Citrus sinensis* (L.) Osbeck	4	1	2	5	3	5	4	2	10	2
22	*Sommera* spp. Schltdl.	5	1	0	4	6	7	3	0	7	3
23	*Ficus tecolutensis* (Liebm.) Miq.	3	2	1	5	2	6	2	1	8	3
24	*Mangifera indica* (L.) Blume Wall.	4	1	2	5	3	5	1	1	6	2
25	*Homalium trichostemon* S. F. Blake	3	3	0	4	5	6	0	2	6	1
26	*Leucaena leucocephala* Benth.	2	4	1	2	3	3	2	5	5	2
27	*Heliocarpus donnell-smithii* Rose	1	0	1	5	1	7	2	3	7	1
28	*Quercus* spp. L. (encino rojo)	3	1	3	4	0	5	0	3	6	2
29	*Annona muricata* L.	4	0	1	4	1	4	2	2	7	1
30	*Persea* spp. Mill. (aguacate piedra)	2	1	3	5	3	2	3	0	5	0
31	*Dendropanax* spp. Decne. & Planch.	3	0	2	4	3	2	1	1	7	1
32	*Trophis* spp. L.	1	0	1	5	0	6	0	2	6	3
33	*Rhus striata* (Ruiz & Pav.)	0	1	1	4	1	5	3	0	8	1
34	*Andira* spp. Lam.	3	1	0	0	3	5	4	2	5	0
35	*Yucca* spp. *L.*	2	1	1	5	2	4	2	0	5	1
36	*Miconia* spp. (Ruiz & Pav.)	4	0	0	6	1	0	5	0	7	0
37	*Quercus oleoides* Cham. & Schltdl.	3	1	2	5	2	0	3	0	6	0
38	*Musa* spp. L. (plátano morado)	0	0	0	6	3	1	2	2	6	2
39	*Andira inermis* (W. Wright) DC.	1	0	1	3	3	2	1	4	5	2
40	*Pinus maximinoi* H. E. Moore	2	0	0	3	1	4	4	1	6	0
41	*Dendropanax arboreus* (L.) Planch. & D	1	1	2	1	3	3	2	0	5	3
42	*Inga* spp. Mill. (cuil blanco)	3	0	1	3	2	4	1	1	4	1
43	*Inga* spp. Mill. (cuil de perico)	2	2	1	4	1	5	0	0	5	0
44	*Bursera simaruba* (L.) Sarg.	3	0	2	3	0	5	0	1	6	0
45	*Trichilia havanensis* Jacq.	3	1	1	5	0	3	0	0	7	0

Table 1. Registration of the shade trees in the coffee agroecosystem of the Jungle of Loxicha, Oaxaca. (cont.)

Árbol	Nombre científico	Individuos por cafetal									
		1	2	3	4	5	6	7	8	9	10
46	*Persea americana* Mill.	2	0	0	3	2	5	0	0	6	1
47	*Byrsonima crassifolia* (L.) Kunth	0	1	1	4	2	3	1	1	4	2
48	*Theobroma cacao* L.	1	2	2	3	3	1	1	0	4	1
49	*Ficus carica* L.	2	1	0	4	2	3	0	2	3	1
50	*Siparuna* spp. Aublet	2	0	0	4	1	4	0	0	6	0
51	*Pouteria sapota* (Jacq.) H. E. Moore & Stearn	1	0	1	5	0	5	1	0	4	0
52	*Solanum aff. Chiapasense* K. E. Roe.	0	2	0	3	2	4	2	1	3	0
53	*Coccoloba* spp. P. Browne	1	1	1	2	1	5	1	0	4	0
54	*Gliricidia sepium* (Jacq.) Steud.	0	0	0	4	0	3	2	0	5	1
55	*Hymenaea courbaril* L.	2	0	1	4	1	2	0	0	4	1
56	*Erythrina americana* Mill.	2	1	1	3	0	4	0	0	3	1
57	*Inga* spp. Mill. (cuil de cera)	1	1	2	2	0	3	1	1	2	1
58	*Leucaena* spp. Benth.	2	0	1	2	1	4	2	0	0	2
59	*Inga* spp. Mill. (cuiloch)	2	1	0	3	1	2	0	1	1	1
60	*Inga* spp. Mill. (cuil peludo)	1	3	0	2	1	2	0	2	0	1
61	*Juglans styraciflua* L.	2	0	0	2	0	2	1	0	5	0
62	*Pinus oocarpa* Schiede ex Schltdl.	1	1	0	2	1	2	0	1	3	1
63	*Diospyros digyna* Jacq.	0	0	1	2	0	2	1	1	4	0
64	*Persea* spp. Mill. (aguacate montez)	2	0	0	1	0	3	2	1	0	1
65	*Albizia* spp. Durazz.	0	2	0	2	1	4	1	0	0	0
66	*Rollinia membranácea* Triana & Planch.	1	0	0	1	1	2	1	0	3	0
67	*Cedrela odorata* L.	0	0	0	2	0	1	1	1	3	1
68	*Inga* spp. Mill. (cuil sierra)	1	0	1	1	1	0	2	0	2	1
69	*Lysiloma acapulcensis* (Kunth) Benth.	1	2	1	0	1	1	0	1	1	1
70	*Apeiba tibourbou* Aubl.	1	1	2	0	1	1	0	0	2	0
71	*Persea donell-smith* Mez.	0	1	0	2	0	1	1	1	1	1
72	*Inga* spp. Mill. (cuil delgado)	2	1	1	0	0	1	0	0	2	1
73	*Guarea glabra* Vahl	0	0	1	1	2	3	0	1	0	0
74	*Calophyllum brasiliense* Cambess.	1	0	1	1	1	0	2	0	2	0
75	*Citrus* spp. L.	0	0	0	2	0	1	1	0	1	2
76	*Inga* spp. Mill. (cuil chauixtle)	2	1	1	0	1	0	1	0	0	1
77	*Ficus* spp. L.	1	0	1	1	0	1	2	0	1	0
78	*Brunellia mexicana* Standl.	0	0	0	1	0	2	1	1	2	0
79	*Zanthoxylum melanostictum* Schltdl. & Cham.	1	0	0	2	0	1	1	0	1	1
80	*Oreopanax langlassei* Standl.	1	0	1	0	1	0	2	0	1	0
81	*Coccoloba* spp. P. Browne	2	0	0	1	0	1	1	0	1	0
82	*Poulsenia armata* (Miq.) Standl.	0	2	1	0	1	0	0	1	0	1
83	*Inga* spp. Mill. (cuil rojo)	3	0	0	2	0	0	1	0	0	0
84	*Leucaena* spp. Benth.	2	0	1	0	1	1	0	0	0	1
85	*Chrysophyllum mexicanum* Brandegee	0	1	1	0	1	0	0	1	2	0
86	*Citrus aurantifolia* Swing.	1	1	0	1	0	2	0	1	0	0
87	*Citrus limon* (L.) Burm.	0	1	1	0	2	0	1	0	1	0
88	*Tamarindus indica* L.	1	0	1	1	1	0	2	0	0	0
89	*Trichilia* spp. P. Browne	1	2	0	0	0	1	0	1	1	0
90	*Inga* spp. Mill. (cuil peine)	0	1	1	0	1	2	0	0	0	0

Table 1. Registration of the shade trees in the coffee agroecosystem of the Jungle of Loxicha, Oaxaca. (cont.)

Árbol	Nombre científico	Individuos por cafetal									
		1	2	3	4	5	6	7	8	9	10
91	*Enterolobium ciclocarpum* (Jacq.) Griseb.	1	0	0	1	0	2	0	0	1	0
92	*Crescentia* spp. L.	1	0	1	1	0	0	2	0	0	0
93	*Miconia impetiolaris* (Sw.) D. Don ex DC.	0	0	0	0	2	1	0	0	1	1
94	*Persea* spp. Mill.	1	0	0	1	0	0	1	0	1	0
95	*Inga jinicuil* Schltdl. & Cham. Ex. G. Don	0	0	0	0	1	1	0	1	0	1
96	*Citrus reticulata* Blanco	0	1	1	0	0	0	1	0	1	0
97	*Castilla elástica* Cerv.	0	0	0	1	0	1	0	1	0	1
98	*Genipa americana* L.	1	0	0	2	0	0	1	0	0	0
99	*Spondias mombin* L.	0	0	0	0	1	0	0	2	0	0
100	*Spondias purpurea* L.	0	0	1	0	0	1	0	0	1	0
101	*Ficus cotinifolia* Kunth	0	0	0	1	0	0	1	0	0	1
102	*Trophis racemosa* (L.) Urb.	0	1	0	1	0	0	0	0	1	0
103	*Acrocomia aculeata* (Jacq.) Lodd. ex Mart.	1	0	1	0	1	0	0	0	0	0
104	*Zanthoxylum spp*. L.	0	0	0	0	0	1	1	0	1	0
105	*Persea* spp. Mill. (aguacatillo)	0	0	0	0	0	0	0	0	2	0
106	*Persea* spp. Mill. (aguacatillo rojo)	0	0	0	1	1	0	0	0	0	0
107	*Ceiba pentandra* (L.) Gaertn.	0	1	0	0	0	0	0	0	1	0
108	*Spondias* spp. L.	1	0	1	0	0	0	0	0	0	0
109	*Inga* spp. Mill. (cuil verde)	1	0	0	0	0	0	1	0	0	0
110	*Inga* spp. Mill. (guajinicuil)	0	0	0	0	2	0	0	0	0	0
111	*Inga* spp. Mill. (guajinicuil liso)	0	0	0	0	0	0	0	0	1	1
112	*Sommera* spp. Standl.	0	1	0	0	0	0	0	1	0	0
113	*Ficus* spp. L. (matapalo)	0	0	0	1	0	0	1	0	0	0
114	*Cochlospermun vitifolium* (Willd.) Spreng.	0	0	1	0	1	0	0	0	0	0
115	*Swietenia macrophylla* King	1	0	0	0	0	0	0	0	0	1
116	*Eugenia jambos* (L.) Alston	0	0	0	0	0	0	0	0	2	0
117	*Astronium graveolens* Jacq.	0	0	0	0	0	2	0	0	0	0
118	*Curatella americana* L.	0	1	0	1	0	0	0	0	0	0
119	*Diospyros* spp. L.	1	0	0	0	0	1	0	0	0	0
120	*Persea americana* Mill. (aguacate negro)									1	
121	*Persea* spp. Mill. (aguacate apestoso)									1	
122	*Cornus disciflora* Moc. & Sessé ex DC.										1
123	*Acacia cornígera* (L.) Willd.					1					
124	*Inga* spp. Mill. (cuil de cerro)							1			
125	*Inga* spp. Mill. (cuil montés)									1	
126	*Couepia poliandra* (Kunth) Rose			1							
127	*Licania platypus* (Hemsl.) Fritsch						1				
128	*Rondeletia buddleioides* Benth.								1		
129	*Musa* spp. L. (plátano camote)					1					
130	*Musa* spp. L. (plátano costilla)	1									
131	*Musa* spp. L. (plátano macho)			1							
132	*Musa* spp. L. (plátano perón)									1	
133	*Musa* spp. L. (plátano raután)							1			
134	*Aphanante monoica* (Hemsl.) Leroy									1	
135	*Xylopia frutescens* Aubl.									1	
136	*Lysiloma* spp. Benth.									1	

Table 2. Estimated values to obtain the different diversity indices.

S	N	lnN	Σpi^2	U	Σni^2
136	3753	8.2303	0.03759	727.647	529471

The Simpson and McIntosh indices express the dominance of the species, influenced by the abundance of the most common species; the Simpson index expresses the probability of two individuals being of the same species when randomly sampled; if dominance is large, the probability is low, and higher if the relative abundance of the species is the same. A high probability was obtained with both indices, which indicates that in the coffee plantation agroecosystem, the relative dominance of most of the species is the same.

The Shannon-Weiner index indicates high diversity with normal range that varies from 2 to 3, the closer it gets to 5, the diversity is higher (Medrano et al., 2017), located within the high range of the topical jungles in good preservation state such as Veracruz and Campeche. The 3.9 value obtained for the Loxicha jungle barely exceeds the 3.5 value obtained for the coffee plantations of Veracruz reported by García et. al. (2015). Giménez et. al. (2011) mentioned that the Shannon index is a good indicator of arboreal diversity. Measuring the relative abundance of each species enables the identification of those species that for their scarce representativity in the community are more sensitive to environmental perturbation. Furthermore, it enables the identification of a change in diversity, in number of species, either in the distribution of abundance of species or in dominance, warning about impoverishment processes (Magurran, 1989). Regarding the diversity in the coffee plantation agroecosystem, the scarcest species are *Couepia polyandra* (Kunth) Rose, *Aphananthe monoica* (Hemsl.) Leroy, *Xylopia frutescens* Aubl., *Licania platypus* (Hemsl.) Fritsch, among others that might probably need a special type of environment in addition to its low adaptation to changing environmental conditions.

Magurran (2004) mentioned that diversity is a concept intuitively easy to understand and easy to accept when an ecosystem is more diverse than other, for example, that a tropical jungle is more diverse than a coniferous forest, as it is mentioned by Manzanilla et al. (2020), after obtaining a Shannon index from 1.02 to 1.68 in the temperate forests of Southern Nuevo Leon. Under this consideration, the residents of the Loxicha region know that their coffee plantations have great diversity of vegetable species; however, due to the current promotion of ranching activities and the coffee crisis (Rojas et al., 2012), coffee growers consider the possibility of changing crops or agricultural activity, which is reflected in the loss of biological diversity hosted in the agroecosystem. Therefore, evaluation through sequential studies must be considered to identify the changes related to the alterations of the agroecosystem (Espinoza-Guzmán et al., 2020) and as Daniel (1998) suggests, with a modification of the Shannon-Wiener index, because it is one of the most used indices to evaluate biodiversity.

Another preoccupation is the one pointed out by Reyes et al. (2002) that nowadays, biological diversity of shade trees of the coffee plantations has decreased considerably, due to the generalized recommendation to establish a monospecific shade with taxa from the genus *Indiga*, mainly as it has happened in the coffee regions of Mexico, such as Veracruz, Puebla, and Chiapas. In the later state, in the region of Soconusco, they obtained a Shannon index of 1.2 which is considered as low arboreal richness.

Conclusions

The indices obtained indicate high richness of arboreal species, in general for the coffee plantations associated to the jungle. However, the coffee trees are in average 15 to 30 years old, which indicates that most of the plots have been maintained without management since they were established; additionally, the condition of the coffee trees is inadequate, most of them are old and have not been renewed. As management practice, the shade has not been regulated, so there are more than three arboreal strata with a density or shade coverage of 80 to 90 %. Most of the shade trees are native species, which are of great value for the coffee plantations and in general for the local population, in addition to the shrub, herbaceous and epiphyte plants and of course, the great number of birds that are seen on the trees; they know the importance of the shade trees regarding condensation of humidity and the multiple environmental services that their forests generate.

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