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Artículo de investigación

The dynamic of shade trees in cocoa agrosystems

La dinámica de los árboles de sombra en los agrosistemas de cacao

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Abstract

The presence of diverse shade trees in cocoa agrosystems allows for the creation of suitable habitats for wildlife species, enabling them to thrive within the plantation environment. The objective of this research is to calculate the similarity indices of shade trees used in cocoa agrosystems in the region of Comalcalco, Tabasco, Mexico. Field sampling was carried out to collect data on breast height diameter, canopy diameter and canopy height, these variables were used to calculate the Sorensen and Morisita-Horn similarity indices. The similarity between the study sites, Sorensen's qualitative index shows that SA 1 - SA 2 are the most similar in species composition, SA 1 - SA 2 with 27.46% similarity, followed by SA 2 - SA 3 with 27.27 %, while SA 1 - SA 3 are the sites with a less similar structure of 26.52%. The role of shade trees in cocoa agrosystems is significant as it can serve as a variable in assessing and predicting the quality of available habitats for wildlife conservation, including birds, reptiles, and arboreal mammals, using ecological niche modeling techniques.

Resumen

La presencia de diversos árboles de sombra en los agrosistemas de cacao permite la creación de hábitats adecuados para las especies de vida silvestre, lo que les permite prosperar en el entorno de la plantación. El objetivo de esta investigación es calcular los índices de similitud de árboles de sombra utilizados en agrosistemas cacaoteros en la región de Comalcalco, Tabasco, México. Se realizó un muestreo de campo para recolectar datos sobre el diámetro de la altura del pecho, el diámetro del dosel y la altura del dosel, estas variables se utilizaron para calcular los índices de similitud de Sorensen y Morisita-Horn. La similitud entre los sitios de estudio, el índice cualitativo de Sorensen muestra que SA 1 - SA 2 son los más similares en composición de especies, SA 1 - SA 2 con 27.46 % de similitud, seguido de SA 2 - SA 3 con 27.27 %, mientras que SA 1 - SA 3 son los sitios con una estructura menos similar del 26,52%. El papel de los árboles de sombra en los agrosistemas de cacao es importante, ya que puede servir como variable para evaluar y predecir la calidad de los hábitats disponibles para la conservación de la vida silvestre, incluidas aves, reptiles y mamíferos arbóreos, utilizando técnicas de modelado de nichos ecológicos.

Keywords:
biodiversity indices, dasometric variables, shade trees.

Palabras clave:
índices de biodiversidad, variables dasométricas, árboles de sombra.

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Contribución

¿Por qué se realizó el estudio?

Esta investigación permite identificar las especies arbóreas presentes en estos sistemas, lo cual es fundamental para conservar las especies nativas. Además, los árboles asociados en estos agrosistemas desempeñan un papel importante al proporcionar sombra, lo que contribuye a la sostenibilidad de la producción de cacao. En lugar de basarse únicamente en el cultivo de cacao, los productores obtienen beneficios económicos a través de los árboles asociados. Por lo tanto, investigar esta estructura y diversidad arbórea proporciona información valiosa para orientar las prácticas agrícolas y fomentar una convivencia armoniosa entre la producción de alimentos y la conservación del medio ambiente.

¿Cuáles fueron los resultados más relevantes?

A través del análisis de los índices de similaridad, se puede apreciar la diversidad presente en los agrosistemas de cacao. La introducción de diferentes especies de árboles en estos sistemas proporciona una serie de ventajas, como una polinización mejorada, un microclima más propicio, la conservación de la biodiversidad y la oportunidad de obtener productos adicionales. Estos beneficios contribuyen a fortalecer la capacidad de recuperación de los agrosistemas de cacao, así como un manejo más sostenible y rentable de los cultivos.

¿Qué aportan estos resultados?

La investigación sobre la estructura y diversidad de los árboles de sombra utilizados en los agrosistemas de cacao contribuye significativamente a la conservación de especies nativas y al manejo sostenible de estos sistemas. Proporciona conocimientos clave para la toma de decisiones informadas en cuanto a la conservación de la biodiversidad, la restauración de paisajes, el manejo adecuado de los agrosistemas y la mejora de la productividad y calidad del cacao.

Graphical Abstract

Introduction

By intentionally managing shade trees alongside crops, agrosystems possess the capacity to create habitats and preserve wildlife species within extensively modified tropical landscapes (1). Coffee and cocoa agrosystems are widely recognized as the most familiar examples, frequently characterized by a diverse array of shade tree species forming a prominent and dense canopy (2). Hence, the significance of these shade trees is profound, and they exhibit considerable variation in their characteristics. They can be categorized into three main types: 1) Polycultural system: In this approach, multiple species of shade trees, including forest species, are intentionally planted alongside the crop trees. The shade trees are interspersed throughout the plantation, creating a diverse and mixed canopy that benefits the cocoa or coffee plants, 2) Monocultural shade: This type of system is characterized by a dominant shade tree species or a few selected species that primarily provide shade for the crops. The shadow cast by these trees dominates the agrosystem, 3) Diversity shade systems: These systems encompass a wide range of shade tree species, typically consisting of around 30 to 40 different plant species. This diversity includes both fruit-bearing and timber species. The spine of these systems typically consists of fast-growing nitrogen-fixing legumes such as Erythrina spp., Gliricidia sepium, Samanea saman, and Inga spp. In all of these approaches, the shade trees play a crucial role in providing the necessary shade and microclimate for the cocoa or coffee plants to thrive, while also contributing to the overall ecological diversity and sustainability of the agrosystem (3).

Shade trees utilized in cocoa agrosystems globally share commonalities with those found in plantations in Mexico. In Ghana, for instance, shade tree species such as Persea americana, Citrus senensis, Gliricidia sepium, Ceiba pentandra, Cedrela odorata, and Spondias mombin are commonly employed in cocoa agrosystems (Abdulai et al., 2018). In Brazil, cocoa agrosystems make use of shade tree species like Spondias mombin, Cedrela odorata, Guazuma ulmifolia, Ceiba pentandra, and Genipa americana. These trees contribute to the shade and overall ecological dynamics of cocoa plantations in the country (4). In Colombia, cocoa agrosystems incorporate shade tree species such as Spondias mombin, Psidium guajava, Swietenia macrophylla, Cordia alliodora, Annona muricata, Guazuma ulmifolia, Artocarpus altilis, Pouteria caimito, Gliricidia sepium, Persea americana, Musa paradisiaca, Cedrela odorata, and Ceiba pentandra. These diverse trees contribute to the shade and ecological composition of cocoa plantations throughout the country (5). Cedrela odorata, Spondias mombin, and Guazuma ulmifolia are among the shade tree species utilized in cocoa agrosystems in Bolivia. These trees play a crucial role in providing shade and contributing to the ecological balance within cocoa plantations in the country (6). In Cameroon, cocoa agrosystems incorporate shade tree species such as Ceiba pentandra, Citrus reticulata, Citrus sinensis, Persea americana, Psidium guajava, Spondias mombin, Mangifera indica, and Musa paradisiaca. These trees are deliberately planted in cocoa plantations to provide shade and contribute to the overall ecological balance within the agrosystems (7). In Costa Rica, shade tree species commonly found in cocoa agrosystems include Carica papaya, Castilla elastica, Cedrela odorata, Cocos nucifera, Genipa americana, Gliricida sepium, Leucaena leucocephala, Spondias mombin, and Samanea saman. These trees are intentionally cultivated alongside cocoa crops to provide shade and contribute to the ecological dynamics of the agrosystems in the región (8). In Nigeria, shade tree species such as Citrus sinensis, Mangifera indica, Psidium guajava, Citrus reticulata, Persea americana, Cocos nucifera, Ceiba pentandra, and Spondias mombin are commonly found in cocoa agrosystems. These trees are deliberately grown alongside cocoa crops to provide shade and contribute to the overall ecological balance within the agrosystems in the country (9). In Indonesia, cocoa agrosystems incorporate shade tree species including Mangifera indica and Swietenia macrophylla. These trees are intentionally planted alongside cocoa crops to provide shade and contribute to the ecological dynamics of the agrosystems in the country (10). In Ecuador, Cedrela odorata is a shade tree species commonly used in cocoa agrosystems. It is intentionally cultivated alongside cocoa crops to provide shade and contribute to the ecological balance within the agrosystems in the country (11). In Peru, cocoa agrosystems incorporate shade tree species such as Cedrela odorata, Persea americana, and Swietenia macrophylla. These trees are deliberately planted alongside cocoa crops to provide shade and contribute to the overall ecological balance within the agrosystems in the country (12).

The presence of diverse shade trees in cocoa plantations (Theobroma cacao) offers valuable habitats for the conservation of wildlife. These trees serve as crucial spaces that support a wide range of organisms, including insects, birds, amphibians, reptiles, and mammals (13). Cocoa is a prominent crop that is often associated with a wide array of shade trees, showcasing substantial diversity (14). Spondias mombin, Cedrela odorata, Persea americana, Mangifera indica, and Citrus sinensis are among the frequently employed shade tree species in cocoa plantations worldwide (15). Guazuma ulmifolia, Ceiba pentandra, Erythrina americana, and Samanea saman are the prevalent shade tree species found in cocoa plantations in Tabasco. These trees are commonly utilized to provide shade for cocoa trees in the region (16; 17). The objective of this research is to calculate the similarity indices of shade trees used in cocoa agrosystems in the region of Comalcalco, Tabasco, Mexico.

Methodology

Characterization of the study área

The research was conducted in three distinct cocoa agrosystems situated in the Comalcalco region of Tabasco, Mexico (Figure 1). For this study, three specific cocoa agrosystems were chosen as the designated research sites.

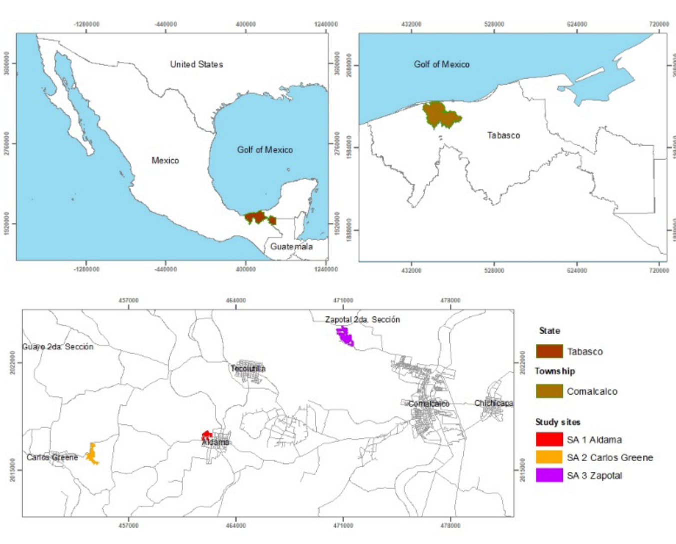

Figure. 1. Cocoa agrosystems were used as study sites

Sampling procedure

To assess the vegetation structure within the cocoa agrosystems, the three study sites (listed in table 1) were utilized. In each of these sites, a total of 10 plots measuring 25 × 10 meters were selected, resulting in a plot area of 250 square meters. This approach followed the recommendations proposed by (18). In total, 30 Temporary Sample Plots (TSPs) were established, and measurements including diameter at breast height (DBH), total height, and crown diameter were recorded for all individuals with a DBH of 1.3 meters or greater.

Table 1. Sites used in this study

Study sites	Location	Coordinates (UTM) X	Coordinates (UTM) Y	Área
SA 1	Aldama	461830	2017193	21.08 ha
SA 2	Carlos Greene	454416	2016030	49.59 ha
SA 3	Zapotal	471172	2023367	57.82 ha

Characterization of the dynamic of shade trees in cocoa agrosystems

The cocoa agrosystems are characterized by their integrated polycultivation approach, where different plant types are strategically arranged in layers and tiers, spanning from the sun-exposed areas to the shaded regions (as depicted in figure 2). This multi-layered system promotes biodiversity and provides varying levels of light and shade for the different plants grown within the agrosystems.

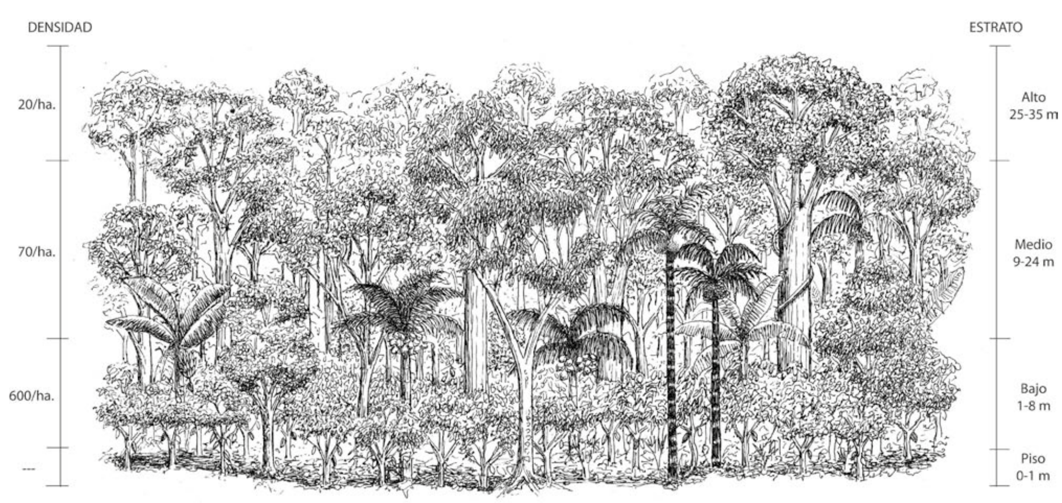

Figure. 2. Dynamic of the cocoa agroecosystem with shade trees. Source: (19)

Dasometric variables

The trees within the cocoa agrosystems were taxonomically identified and marked with GPS coordinates for georeferencing purposes. Various dasometric variables were recorded, including the diameter at breast height (DBH) at 1.3 meters above the ground, crown diameter measured using a tape, and total height (Ht) measured using a clinometer, following the methodology outlined by (20).

Diameter at breast height (DBH)

After establishing the plots, a direct measurement of the diameter at breast height (DBH) was conducted for all trees within each Temporary Sample Plot (TSP). Only one reading of DBH was taken for each tree present in the TSPs, where $DBH = C/\pi DBH = C/\pi$.

Determination of canopy height

To overcome the challenges associated with directly measuring canopy heights, an indirect approach was employed. A clinometer was utilized to measure the angles of the tree base (□), the canopy (□), and the horizontal distance (hd). This method allowed for an estimation of canopy heights in situations where direct measurements were impractical, using the following basic trigonometric formula: $Ht = hd(\tan\rho + \tan\theta)$ $Ht = hd(\tan\rho + \tan\theta)$.

Determination of crown diameter (CD)

To determine the crown diameter within each Temporary Sample Plot (TSP), the projection of the crowns was measured in two directions: primarily North-South and East-West. This approach allowed for the assessment of crown dimensions within the TSPs in multiple orientations, taking as reference the projection of the ends of the same on the ground $CD = (cd1 + cd2)/2CD = (cd1 + cd2)/2$[11].

Using the collected measurement data, a database was created to facilitate the calculation of Basal Area (BA), which represents the cross-sectional area of a tree measured at a height of 1.30 meters. The Basal Area was computed using the following formula: $BA = 0.7854 * DBH^2 BA = 0.7854 * DBH^2$ where BA = Basal area in m^2 and DBH = diameter at breast height in m^2.

Sorensen Similarity Index

In order to assess the floristic similarity among the three study sites included in this investigation, the Sorensen Similarity Index (ISS) was employed. This index allowed for a comparison of the shared plant species between the study sites, providing insights into their floristic resemblance. ISS = [(2C) /(A+B) *100]

Morisite-Horn Index

The Morisita-Horn model is widely utilized as a means to quantify similarity between ecological communities. This model possesses certain attributes that render it valuable, such as its ability to minimize the influence of species richness and sample size. However, it is worth noting that the model is greatly influenced by the abundance of the most common species within the communities being compared. Where, I_{M-H} = 2 □ (an_i bn_i) / [(da + db) (aN) (bN)]. Where, aN = number of individuals of community A, and an_i = number of individuals of the ith species in A. is = □ an^2 /aN^2.

Statistical analysis

The mean values of vegetation height, diameter at breast height, and crown diameter per plot were analyzed using the t-student test for independent samples. This statistical test was employed to compare the means and determine the presence of significant differences in the

dasometric variables among the study sites. By applying this test, we obtained an indicator of the observed significant differences in the dasometric variables between the different study sites.

Results

Average height and diameter

The shade trees associated with cocoa in SA 1 and SA 2 exhibit larger dimensions, with an average height of 16.40 m and 15.47 m, and a crown diameter of 7.55 m and 7.38 m, respectively, as indicated in table 2. In contrast, the trees in SA 3 are comparatively smaller in terms of height and diameter.

Table 2. Average height and diameter of cocoa and associated trees

Sites	Cocoa		shade trees	
	Height (m)	Diameter (m)	Height (m)	Diameter (m)
SA 1	5.16	4.82	16.40	7.55
SA 2	4.87	4.91	15.47	7.38
SA 3	5.53	3.88	11.67	4.72

Basal area

The average basal area of cocoa trees within the 3 to 7-meter stratum is recorded as 21.7 m^2, as presented in table 3. In comparison, the associated plants in the other strata of SA 1 and SA 2 exhibit larger average basal areas of 156 m^2 and 208 m^2, respectively, within the agrosystems. Notably, the basal area of cocoa trees and shade trees in SA 3 is significantly smaller when compared to the other study sites.

Table 3. Total basal area of cocoa agrosystems

Height stratum	SA 1		SA 2		SA 3	
	Basal Area (m^2)	Trees m^2 ha^{-1}	Basal Area (m^2)	Trees m^2 ha-^{1}	Basal Area (m^2)	Trees m^2 ha^{-1}
3-7 m	21.88	3321	23.15	7494	20.25	1254
8-11 m	38.71	565	28.44	2718	28.44	678
12-15 m	79	159	79	656	63.99	267
16-19 m	240	24	255	126	79	141
>20 m	270	12	470	49		11

Field sampling

A total of 16 families were identified within the three cocoa agrosystems selected as study sites, as indicated in table 4. Among these families, Fabaceae displayed the highest number of species, with a total of six species. Sapotaceae was represented by three species, while Malvaceae, Anacardiaceae, Bignoniaceae, Lauraceae, Meliaceae, Moraceae, and Rutaceae each had two species within the agrosystems.

Table 4. Tree species are found in three cocoa agrosystems in Comalcalco, Tabasco

Family	Scientific name	Common name	Height (m)	Agrosystems		
				SA 1	SA 2	SA 3
Anacardiaceae	Mangifera indica	Mango	10-30	X		
	Spondias mombin	Jobo	10-30	X	X	X
	Spondias purpurea	Ciruela	3-8	X		
Annonaceae	Annona muricata	Guanábana	3-8	X		
	Annona reticulata	Annona	6-8			X
Bignoniaceae	Tabebuia rosea	Maculis	10-30	X	X	X
Burseraceae	Bursera simaruba	Palo mulato	20-35		X	
Fabaceae	Erythrina americana	Mote	10-30	X	X	
	Inga jinicuil	Jinicuil	12-15		X	X
	Gliricidia sepium	Cocoite	12-20	X		
	Tamarindus indica	Tamarindo	10-30		X	X
	Samanea saman	Samán	25-50		X	X
	Leucaena leucocephala	Guaje	3-6			X
Lauraceae	Cinnamomum zeylanicum	Canela	10-15		X	
	Persea schiedeana	Chinin	8-25	X		
	Persea americana	Aguacate	10-20		X	X
Malpighiaceae	Byrsonima crassifolia	Nance	3-7			X
Malvaceae	Ceiba pentandra	Ceiba	20-70	X		X
	Guazuma ulmifolia	Guácimo	8-15		X	
Meliaceae	Cedrela odorata	Cedro	10-35	X	X	X
	Swietenia macrophylla	Caoba	35-50			X
Moraceae	Artocarpus altilis	Castaña	12-21	X		
	Castilla elástica	Hule	20-25			X
Myrtaceae	Pimenta dioica	Pimienta	6-8	X		
	Psidium guajava	Guajava	3-10			X
	Syzygium jambos	Pomarrosa	10-16		X	
Rutaceae	Citrus latifolia	Limón	3-6			X
	Citrus sinensis	Naranja	9-10	X		
	Citrus nobilis	Mandarina	2-6		X	
	Citrus aurantium	Naranja agria	3-5			X
Sapindaceae	Talisia olivaeformis	Guaya	15-20			X
	Nephelium lappaceum	Rambutan	12-20	X		
Sapotaceae	Chrysophyllum cainito	Caimito	10-25		X	
	Manilkara sapota		25-30		X	

	Pouteria sapota	Zapote	15-45	X		X
Oxalidaceae	Averrhoa carambola	Carambola	3-5		X	
Bixaceae	Bixa orellana	Achiote	2-5	X		
Boraginaceae	Cordia alliodora	Laurel	7-25		X	
Caricaceae	Carica papaya	Papaya	2-8			X
Musaceae	Musa paradisiaca	Platano	1-3		X	
Muntingiaceae	Muntingia calabura	Capulin	3-8		X	
Rubiaceae	genipa americana	Jagua	15-25	X		

Similarity indices

In terms of the similarity between the study sites (as shown in table 5), Sorensen's qualitative index indicates that SA 1 and SA 2 exhibit the highest similarity in terms of species composition. On the other hand, the Morisita-Horn index suggests that the three study sites have a similar overall structure, considering both species composition and their relative abundance. SA 1 and SA 2 demonstrate a similarity of 27.46%,

followed by SA 2 and SA 3 with 27.27%, while SA 1 and SA 3 exhibit a slightly lower similarity in structure at 26.52%.

Table 5. Pairwise similarity of study sites

Sites	Sorensen (Qualitative)	Morisita-Horn (Quantitative)
SA 1 - SA 2	69	27
SA 2 - SA 3	48	27
SA 1 - SA 3	40	26

Statistical analysis of dasometric variables

Among the dasometric variables examined, the diameter of the tree crown was the only one that exhibited statistically significant differences ($p < 0.05$) when comparing the means between the study sites, as presented in Table 6.

Table 6. Significant differences in the averages of the diameter of the Crown

	Mean	N	TREAT
A	6.1742	10	SA 2
A	5.9353	10	SA 1
B	4.5151	10	SA 3

Based on the calculated values for the sites Aldama-Zapotal, Zapotal-Greene, and Aldama-Greene, the obtained values of TT = ± 2.2622 and FT = 3.18, with □ = 0.05, indicate the presence of statistically significant differences, as indicated in Table 7.

Table 7. Average comparison values for the variables height, diameter at breast height, crown diameter and basal area.

Variables	SA 1 - SA 3		SA 2 - SA 3		SA 1 - SA 2	
	t Value	Value F	t Value	Value r F	t Value	Value F
DHB	2.11	4.52	-1.11	4.76	0.02	7.24
CROWN	4.66	2.09	-5.11	2.19	-0.33	4.58
HEIGHT	1.58	4.40	-0.14	4.36	1.29	4.91
BA	2.54	3.22	-1.03	53.73	-0.32	16.67

Discussion

As a result of habitat fragmentation and loss, certain species including insects, birds, amphibians, reptiles, and mammals have sought refuge in cocoa and coffee agrosystems (21). It is important to acknowledge that these available habitats cannot be compared to pristine rainforests, which offer ideal conditions for many species due to their biotic and abiotic processes. However, for some endangered species, agrosystems represent their only available habitat. These agrosystems possess the potential to provide suitable habitats for wildlife conservation due to their tree diversity and canopy structure across different strata (1). The presence of various strata within cocoa plantations offers numerous benefits and ecosystem services, including water collection and purification, soil conservation, crop pollination, carbon sequestration, decomposition of organic waste, species conservation, protection against ultraviolet rays, partial climate stabilization, and the aesthetic appeal of natural environments (22). Consequently, it is important to consider providing economic incentives or implementing payment programs for environmental services to small-scale producers. This approach would encourage them to conserve and enhance tree cover in their cocoa plantations (23).

The presence and behavior of shade trees in cocoa agrosystems play a significant role in plant-animal interactions, population dynamics, and the evolutionary processes of animals that rely on plants for sustenance (24; 25). Both abiotic and biotic factors influence the structural characteristics of agrosystems, such as canopy height and species distribution, which are crucial for maintaining diverse strata and the abundance of trees (26). The dynamic of shade trees in cocoa agrosystems holds great importance due to their composition, structure, and diversity, as they create favorable conditions to support the conservation of wildlife species (14). The dynamic of shade trees in cocoa agrosystems is commonly classified into five levels, including the emerging layer, canopy, undergrowth, and soil layer (27; 28). Additionally, the dynamic of shade trees in cocoa agrosystems is classified as high, medium, low, and floor, indicating different levels of presence and distribution (29).

Certain tree species found in these study sites serve as fruit trees, including Citrus sinensis, Mangifera indica, Annona muricata, and Persea americana. Other trees present are valued for their use in forestry, such as Tabebuia rosae and Tabebuia guayacan. Notably, species like Cedrela odorata and Swietenia macrophylla, categorized as vulnerable according to the IUCN, are also found in these areas. Promoting the presence of shade trees in cocoa agrosystems is crucial for the conservation of wildlife species, as they create biological corridors that facilitate the movement and shelter of birds, insects, and mammals (30). Diversification in agrosystems has become an important strategy for producers to mitigate economic losses resulting from price fluctuations and low coffee and cocoa production (31). These strategies primarily involve diversifying the range of crops, including staple crops, vegetables, fruits, timber, ornamental plants, and even animals (32).

By incorporating shade trees and enhancing biodiversity within the system, diversification can improve the provision of ecosystem services without compromising coffee production (33).

In this study, the average height of trees was recorded as 11.67 m, with an average basal area of 38.71 m^2 and a tree density of 49 m^2 ha^{-1}. These characteristics are similar to those observed in Mexico, where the average height is 11.28 m, the basal area is 34.1 m^2, and the tree density is 45.75 m^2 ha^{-1} (34). In Cameroon, on the other hand, the mean height is 55.5 m, the basal area is 48.7 m^2, and the density is 51.3 m^2 ha^{-1} (30). In Indonesia, the mean height is reported as 11.56 m, the basal area as 56.87 m^2, and the density as 77.5 m^2 ha^{-1} (10). Ghana shows a mean height of 15.1 m, a basal area of 42.8 m^2, and a density of 49 m^2 ha^{-1} (35). In Ecuador, the mean height is reported as 12.1 m, the basal area as 37.7 m^2, and the density as 54.6 m^2 ha^{-1} (11). Lastly, in Costa Rica, the mean height is 21.1 m, the basal area is 25.5 m^2, and the density is 61 m^2 ha^{-1} (36).

The presence of arboreal fauna at different levels of stratification is closely associated with the structural diversity of trees, making them vital components for biodiversity richness. In our study site, cocoa agrosystems serve as the primary habitat for wildlife, representing the closest resemblance to a natural forest due to the dynamic of shade trees within the cocoa agrosystems. Within these agrosystems, various habitats can be identified: 1) house gardens and cover crops: These areas support a wide range of fauna, including insects, spiders, and some mammals such as anteaters, wild boars, tapirs, and jaguars. The substantial amount of litter that falls to the ground in these areas is rapidly decomposed by termites, worms, and fungi, 2) ornamental shade and fruit trees: These trees provide habitats for snakes and certain bird species. They contribute to the diversity of fauna found within the agrosystems, 3) managed foliage and nitrogen-fixing legumes: These areas attract a variety of birds, including toucans, as well as mammals, reptiles, and amphibians. The presence of foliage and legumes creates suitable conditions for their survival, 4) emergent production palms and trees: These tall trees are particularly important for bird species like the scarlet macaw and other unique species. They serve as essential habitats within the

agrosystems. The dynamic of shade trees in cocoa agrosystems plays a crucial role in providing these diverse habitats for wildlife, compensating for the loss of natural forest habitats.

Conclusion

Field measurements were conducted to determine the dasometric variables of shade trees within cocoa agrosystems. These variables included canopy height, crown diameter, and diameter at breast height. The information obtained from these measurements is crucial for calculating the index of importance and forest value of the shade trees. These attributes are significant as they can serve as input variables or parameters for predicting available habitats using ecological niche models and assessing habitat quality, particularly for birds and arboreal primates. Cocoa plantations, thanks to the presence of shade trees, have the potential to serve as important refuge areas for various species, including insects, birds, amphibians, reptiles, and mammals. This is especially evident when comparing them to more intensive agricultural practices that lack such diverse habitats. To enhance the assessment of shade tree dynamics in cocoa agrosystems, the use of LiDAR technology is recommended. This tool allows for the measurement of parameters related to shade tree dynamics and enables the quantification of species-habitat relationships. Such information is valuable for supporting conservation efforts and promoting the persistence of local populations.

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