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FORÊTS, ARBRES ET BAMBOUS DANS LES EXPLOITATIONS DE CAFÉ / RECHERCHE

Forest, bamboo, and agroforestry systems for climate change adaptation in coffee farms of Colombia

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Photo 1.
Bamboo, *Guada angustifolia* Kunth: typical bamboo stand in the coffee region of Colombia.
Photo J. C. Villalba Malaver.

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RÉSUMÉ

Forêt, bambou et systèmes agroforestiers pour l'adaptation au changement climatique dans les exploitations de café en Colombie

En Colombie, c'est dans la région des Andes que l'on trouve le plus grand nombre de forêts secondaires, une région où la culture du café est également très répandue. Une analyse a été réalisée pour évaluer la forêt, le bambou et l'agroforesterie dans les fermes des familles productrices de café en tant que stratégie pour la transition agroécologique. La recherche a été menée dans trois municipalités du plateau de Popayán, dans le département de Cauca, au sud-ouest de la Colombie. La présence de forêts, de bambous et de systèmes agroforestiers a été examinée à l'aide d'outils qualitatifs et quantitatifs, et en utilisant la méthodologie Shade Tree Advice pour déterminer la fourniture de services écosystémiques. Les résultats ont confirmé que les fermes évaluées sont des lieux habités par des familles paysannes avec une utilisation diversifiée de la terre qui remplit à la fois des fonctions écologiques et économiques. La majorité de ces exploitations gèrent des forêts de succession, des bambous et des systèmes agroforestiers qui servent de stratégie d'adaptation aux risques liés au changement climatique. Grâce aux connaissances des familles d'agriculteurs, il a été identifié que les espèces d'arbres utilisées pour fournir des services de soutien, de régulation et d'approvisionnement de l'écosystème dans la culture du café sont principalement des légumineuses et des arbres fruitiers. D'autres espèces indigènes sont également utilisées pour l'ombrage et les haies vives. Ces résultats sont précieux pour la sélection des espèces d'arbres à propager dans les pépinières et à planter ultérieurement, et pour fournir de l'ombre à la culture du café. De même, ils renforcent les processus de transition agroécologique, soutiennent la certification des exploitations et contribuent à l'amélioration des revenus des familles et des organisations productrices de café.

Mots-clés : arbres d'ombrage, culture de *Coffea arabica* L., utilisation diversifiée des terres, forêt de succession, Guadua angustifolia Kunth, connaissances locales, petits agriculteurs, services écosystémiques, Colombie.

ABSTRACT

Forest, bamboo, and agroforestry systems for climate change adaptation in coffee farms of Colombia

The Andes region of Colombia, known for its extensive coffee cultivation, also holds the country's largest areas of successional forest. This analysis evaluated the use of forest, bamboo, and agroforestry systems in coffee farms as part of an agroecological transition strategy. The research was carried out in three municipalities on the Popayán plateau, located in the Department of Cauca in southwestern Colombia. Using a combination of qualitative and quantitative methods – including the Shade Tree Advice tool to assess ecosystem service provision – the study examined how these systems are integrated into the livelihoods of coffee-growing families. The results confirmed that these farms, managed by peasant families, use a diversified approach to land use that balances ecological sustainability with economic needs. Most farms incorporate successional forests, bamboo groves, and agroforestry systems as part of their adaptation strategies to the growing risks posed by climate change. Local knowledge played a key role in identifying the tree species that support ecosystem services essential to coffee farming. Leguminous and fruit trees are most commonly used to provide ecosystem support, including regulation and supply functions. Other native species are additionally used for shade and live fences. These results are valuable for selecting tree species for propagation in nurseries, planting on farms, and providing shade for coffee crops. Likewise, they strengthen the agroecological transition processes, support the certification of farms and contribute to improving the income of coffee-growing families and organisations.

Keywords: shade trees, *Coffea arabica* L. crop, diversified land use, successional forest, Guadua angustifolia Kunth, local knowledge, small farmers, ecosystem services, Colombia.

RESUMEN

Selva, bambú y sistemas agroforestales para la adaptación al cambio climático en fincas cafeteras de Colombia

La mayor presencia de bosque sucesional en Colombia se encuentra en la región de los Andes, región en la que también existe un cultivo extensivo de café. Se realizó un análisis para evaluar el bosque, la guadua y la agroforestería en fincas de familias cafeteras como estrategia para la transición agroecológica. La investigación se llevó a cabo en tres municipios de la meseta de Popayán, en el departamento del Cauca, al suroeste de Colombia. Se examinó la presencia de sistemas forestales, guaduales y agroforestales utilizando herramientas cualitativas y cuantitativas, y empleando la metodología Shade Tree Advice para determinar la oferta de servicios ecosistémicos. Los resultados confirmaron que las fincas evaluadas son lugares habitados por familias campesinas con un uso diversificado de la tierra que cumple funciones tanto ecológicas como económicas. La mayoría de estas fincas manejan bosques sucesionales, bambú y sistemas agroforestales que sirven como estrategia de adaptación a los riesgos derivados del cambio climático. A través del conocimiento de las familias campesinas, se identificó que las especies arbóreas utilizadas para brindar servicios de soporte, regulación y abastecimiento ecosistémico en el cultivo de café son principalmente leguminosas y frutales. Otras especies nativas son utilizadas adicionalmente para sombra y cercas vivas. Estos resultados son valiosos para la selección de especies arbóreas para su propagación en viveros y posterior plantación, y para proporcionar sombra al cultivo de café. Asimismo, fortalecen los procesos de transición agroecológica, apoyan la certificación de fincas y contribuyen a mejorar los ingresos de las familias y organizaciones cafetaleras.

Palabras clave: árboles de sombra, cultivo de *Coffea arabica* L., uso diversificado de la tierra, bosque sucesional, Guadua angustifolia Kunth, conocimiento local, pequeños agricultores, servicios ecosistémicos, Colombia.

Introduction

In Colombia, farmers cultivate coffee (*Coffea arabica* L.) in the upper part of the Andes mountain range. In 2012, 11% of the national coverage corresponded to successional forests, the majority located in the upper part of the Andes (Hurtado-M. et al. 2022). By 2022, Colombia produced coffee on a total area of 842,400 hectares. The country has more than 500,000 coffee-growing families (Ceballos-Sierra and Dall'Erba 2021). The sustainability of coffee farming is confronted with considerable challenges due to the repercussions of environmental factors and elevated climate variability, which exert a deleterious effect on coffee cultivation. A true threat is observed in the Andean region of the country, especially on critical aspects such as biodiversity conservation, food security and water resource availability, which present considerable risk values (República de Colombia 2016). Moreover, the Andean region of Colombia has suffered high deforestation rates (Escobar-Lasso et al. 2013; Galeano-Rendón and Mancera 2018).

Mainly in the Andean phytogeographic region, the department of Cauca was the fourth largest producer nationwide with 94,460 hectares. It increased its cultivated area by 26,460 hectares since 2007 (Federación Nacional de Cafeteros 2023). With more than 93,000 coffee-growing families, the department of Cauca is the first department in the country (Federación Nacional de Cafeteros 2023).

Traditionally, coffee grows under the tree shade, favouring production and providing a large amount of ecosystem services such as pollination, pest control, climate regulation and nutrient sequestration (Jha et al. 2014). These agroforestry systems also represent an important source of food and contribute to biodiversity conservation. Jamnadass et al. (2015) argue that trees in natural forests and agroforestry systems provide a variety of healthy foods, including fruits, leafy vegetables, nuts, seeds, and edible oils, helping to diversify diets and address nutritional and seasonal food gaps. Forests also supply a wider range of edible plants and fungi, as well as wild meat, fish, and insects.

In the agroecosystems of southwestern Ethiopia, Tadesse et al. (2014a) evaluated how land-use changes affect ecosystem services in forest fragments, smallholder semi-forest/garden coffee and state-owned coffee plantations. State-owned coffee plantations are part of the semi-mechanised and large-scale shade coffee systems in the region. Smallholder farms are coffee agroforests of less than 3 ha (Tadesse et al. 2014a). Coffee systems are diverse in production (wild, semi-wild, garden), management, tree choices and intensification levels. Generally, they have higher shade tree species diversity than state-owned farms (Tadesse et al. 2014b). The results also indicate that both coffee systems can store 50-62% of the above-ground carbon biomass found in forests. Coffee farms and forest remnants therefore need to be integrated into climate change mitigation and adaptation programmes.

Guadua angustifolia Kunth, a bamboo species native to the tropical regions in Central and South America, is widely distributed in the Colombian coffee-growing regions. It grows in natural stands, predominantly along rivers, either as pure stands or mixed with trees (Kleinn and Morales-Hidalgo 2006). Bamboo stems have traditionally been used for many purposes, such as construction and handicraft. The utilisation of *G. angustifolia*, as a natural renewable raw material, could enhance and eventually turn into an economic alternative for farmers, particularly in the Coffee Region of Colombia (Kleinn and Morales-Hidalgo 2006). The presence of forest, agroforestry systems, and bamboo contributes to the sustainability of coffee farms, helps reduce biodiversity loss, and supports climate change adaptation.

In recent years, both qualitative and quantitative methodologies helped to select tree-crop associations in agroforestry systems – especially coffee and cocoa – often grounded in local knowledge and focused on the provision of ecosystem services. Sinclair and Walker (1998) proposed a methodology to explore and represent qualitative knowledge about the ecology of agroecosystems to improve the traditional agroforestry practices. Valencia et al. (2015) also showed the importance of farmers' knowledge to manage coffee agroforests and its consequences for the conservation of tree biodiversity and composition of surrounding forests. The first part of the methodology was qualitative, with structured interviews to classify tree species as "preferred", "non-preferred" or "neutral", and farmers' knowledge and perceptions of management. In the second part, floristic inventories were carried out in the coffee farms of the farmers interviewed. Finally, the results were cross-checked to understand farmers' tree preferences and farm management practices.

Van Der Wolf et al. (2019) developed and intended a standardised methodology to document farmers' knowledge on shade tree species and their provision of ecosystem services: the Shade Tree Advice (STA) methodology. The methodology goes all the way to practical recommendations through an online decision-support tool[1]. Results are uploaded to the online tool and translated into applicable information for farmers and extension agents, guiding the selection of shade tree species tailored to local contexts and individual's preferences (Rigal et al. 2022). Evaluating several studies using STA methodology between the years 2016 and 2020 in Africa, Asia, and Central America, Rigal et al. (2022) demonstrated the validity of this method for establishing links between local ecological knowledge and socioeconomic groups or environmental factors. These authors also saw that there were some ways in which the different areas used the same types of trees, especially leguminous and fruit trees.

Coffee farms in the Cauca department are overwhelmingly managed by peasant families who are keeping

[1] www.shadetreeadvice.org

their crops the same way they always have. They combine forest, bamboo, and agroforestry systems. In this case, the families are linked to the Solidarity Alliance Network of Organisations for Dignified Life and Sustainable Agriculture (ASOVIDAS). Despite this, coffee growers lack information about the forests, the bamboo and the trees associated with coffee cultivation. This limits their ability to strengthen both their organisational and productive processes.

It is important to point out that trees have been shown to have a positive effect on coffee production. Because of this, coffee companies at the national and regional levels are encouraging farmers to plant more shade trees in coffee plantations. The National Federation of Coffee Growers of Colombia has launched the campaign "One Million Reasons to Plant Trees" (Federación Nacional de Cafeteros 2022), while the Committee of Coffee Growers of Cauca has promoted the Strategy "Not a hectare more without shade" (Comité de Cafeteros del Cauca 2022). However, at local level, there is a lack of detailed information on the most appropriate tree species to accompany coffee cultivation. Nor is there information on the ecosystem services provided by these species, according to the traditional knowledge of coffee-growing families.

Therefore, neither the ASOVIDAS Network nor the institutions have data to prioritise certain tree species for nursery production and future plantations. This lack of information can result in the introduction of species that are of no interest to coffee growers or in the inclusion of exotic species.

In this context, the objective of the research was to evaluate the forest, bamboo, and ecosystem services of agroforestry systems in coffee farms of small producers in the department of Cauca in Colombia, as a strategy to strengthen the agroecological transition process.

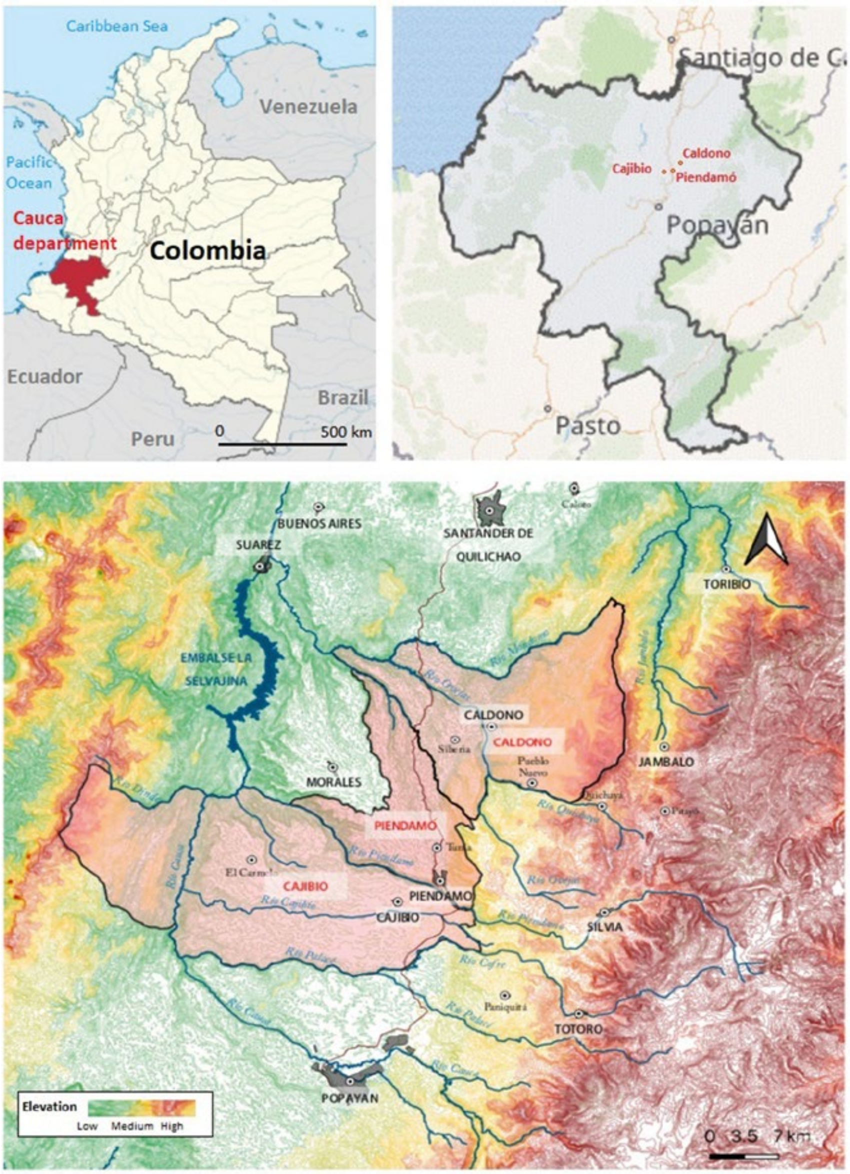

Figure 1.
Maps of the three studied municipalities (Piendamó, Cajibío and Caldono) of the departement of Cauca, located on the Popayan Plateau, south-west of Colombia.

Material and methods

Study area

The study was carried out in three municipalities of the department of Cauca (figure 1), Piendamó, Cajibío and Caldono, south-west of Colombia. The altitude range of the evaluated farms was between 1,400 m and 1,750 m, above mean sea level. The municipalities are located on the Popayán Plateau, where 44,500 hectares of coffee are cultivated in full sun and semi-shade (Comité de Cafeteros del Cauca 2022). The soils are derived from volcanic ash, and the pH ranges from 4.0 to 8.0 in the surface layers (Martinez Mamián 2014).

Farmer selection and field process

The Solidarity Alliance Network of Organisations for Dignified Life and Sustainable Agriculture (ASOVIDAS) was worked with as the organisation and the families were selected based on two criteria: a) member of the organisation: a family that participates in the organisation's activities on a permanent basis and with time available, and b) production system: being in the process of agroecological transition or being certified as organic. The information for the families' selection was provided by the Fundación Colombia Nuestra and the management team of the ASOVIDAS Network[2].

The field process for data collection took place between November 2020 and March 2021, and was divided into two phases that covered both qualitative and quantitative information:

[2] https://colombianuestra.org/Equipo/

- Such division allowed approaching the organisations that are part of the ASOVIDAS Network and the families interested in the study, to analyse the farms' structure and operation. Informative meetings were held with producer organisations in the three municipalities, using a visual tool (poster) that contained project objectives, concepts, and methodology.
- Subsequently, tours and visits were scheduled in 30 farms. During the tours, Participatory Rural Diagnosis tools (Geilfus 2009) were used, including detailed farm maps, a survey, and a tree inventory of the agroforestry system. The observed variables were related to the size of the areas, land use, crop management and specific characteristics of family representatives, such as gender and age. From this information, it was possible to identify the coffee lots in the agroforestry systems that were subsequently evaluated to carry out the evaluation of the trees in the agroforestry system.

For the analysis of the information collected, a matrix was used, facilitating the interrelation of the identified variables. The survey questions were coded so that the responses could be analysed using descriptive statistics, supported by the Microsoft 365 Excel program. From this, the farms were classified according to their size and percentage of area dedicated to coffee in relation to the total farm area. The percentage of producers who had other crops, pastures and/or forestry areas on their farms was evaluated. All these data were analysed with the objective to get a comprehensive view of the type of farms.

During the tours, plots marked as forests, bamboo stands, and living fences on farm maps were visited. The access, uses and management given to each one were recorded, for which specific field formats were used (Villalba and Lasso 2020). The collection and analysis of data for the characterisation of the coffee agroforestry system was carried out to determine the richness, frequency, and density of tree species (Curtis and McIntosh 1950). This data was used to calculate the simplified Importance Value Index (IVI) (Mostacedo and Fredericksen 2000), the species accumulation curve, and the density of trees associated with coffee cultivation. The evaluation of the coffee agroforestry system was carried out in 30 sample units of 20 x 50 m (0.1 ha; 30 sampling units of 0.1 ha x 30 = 3 ha as sampling area) (Louman et al. 2001); that is, in each of the farms, a sample unit was established in the coffee lot with trees. The inventoried trees had a minimum diameter of 10 cm at breast height (DBH). Calculations were performed using Microsoft Excel 365. The IVI was calculated using the richness, density, and frequency of the species (Mostacedo and Fredericksen 2000) identified in the 20 x 50 m sampling units. The species accumulation curve (Schilling and Ferreira 2008) was made with the sampling units (n = 30) for the tree species present in coffee cultivation, including the Jackknife estimate and the confidence intervals (95%), with the Estimates program version 9.1.0. (Colwell et al. 2022).

The same farmers involved in the first survey were invited for the second set of surveys. The second survey

Photo 2.
Agroforestry: a coffee agroforestry system in the Popayán plateau, Department of Cauca, southwestern Colombia.
Photo J. C. Villalba Malaver.

focused on classification exercises based on the process carried out by Wagner et al. (2019) in Tanzania. Based on the information from the first survey, the ecosystem services of shade trees perceived by the respondents were ranked from highest to lowest values. This was done with the average of the assigned values. This consisted of scoring from 0 (the lowest value) to 5 (the highest value), prioritising the first ten services. Based on the list of tree species obtained from the evaluation, the 30 most important ones were selected based on the IVI. And subsequently, the interviewees were asked to select 10 preferred tree species to grow with coffee. The tree species had to be known by the farmers. Images of the species and ecosystem services were printed on cards. The farmers used the cards to classify the effect of the selected trees, for each of the ten services (indicating whether their effect was positive or negative). Ecosystem services were represented with letters and forest species were represented with numbers. During this exercise, farmers also provided explanations for their rankings. The results were recorded and then transferred to a spreadsheet in CSV format to be analysed.

Following the classification of the second survey, an analysis was performed using the Bradley-Terry model (Rigal 2023). The model was run for ten tree services. Species classified less than 10 times were excluded from the results. Scores of each species reflect a comparison of performance rather than absolute values. Scores were normalised to values between 0 and 1, where 1 is the maximum value for the best tree species. Classification data were uploaded to the online database[3].

Finally, a socialisation was held with the farmers in December 2021, at the main office of the Colombia Nuestra Foundation, to provide feedback on the study results.

Table I.
Distribution by sex and age ranges of the coffee farmers surveyed.

Sex	Age ranges (years)		
	15 to 34	35 to 49	> 50
Women	0	5	4
Men	2	8	11
Total	**2**	**13**	**15**
Percentage	7%	43%	50%

Table II.
Size of the farm (ha) and distribution in the municipalities of Cajibío, Piendamó, and Caldono.

Farm size (ha)	Municipalities		
	Cajibío	Piendamó	Caldono
0 to 1	1	3	2
1 to 2	5	2	7
2 to 5	2	3	1
> to 5	2	2	0
Total	**10**	**10**	**10**

Table III.
Land use on the evaluated farms.

Coffee area (ha)	Other crops (ha)	Stubble and pasture (ha)	Forests (ha)	Total area (ha)
27.43	15.85	16.13	13.93	73.34
37%	22%	22%	19%	100%

Results

Families and farms characteristics

The global characterisation of the 30 producers, carried out through the application of a survey, has considered age, sex, size of the properties, land uses and location by municipality. The study participants are affiliated with eight organisations distributed in the municipalities of Caldono, Piendamó, and Cajibío, Department of Cauca (Colombia). These organisations are part of the ASOVIDAS Network, which has comprised 16 associations since its establishment in 2016. The producers share common interests aimed at strengthening their family economies and promoting a link with their local environment.

Of the total producers, 30% were women and 70% were men. As shown in table I, individuals aged 15 to 34 and 35 to 49 together represented 50% of the population, while those over 50 made up the remaining 50%. The first were producers who sought personal, family and work stability, facing the challenge of maintaining over time the combination between production and conservation that defined their properties. Those over 50 years old, in some cases, were the sole managers of their farms. Although still active in farm work, the greatest contribution of this group is related to the transmission of essential knowledge for the development of productive and conservation activities. They are often those who appreciate agrodiversity and recognise the ecosystem services associated with the provision of water, seeds, and shade.

Almost half (47%) of the properties were in the range of 1 to 2 ha (table II). An analysis of property size by municipality revealed that the smallest properties were concentrated in Caldono, with dimensions ranging between 0 and 1 ha. The municipality of Cajibío is characterised by having 50% of the properties in the range of 1 to 2 ha, and Piendamó is distinguished by having more than 50% of its properties located in the range of 2 to 5 ha. According to the information collected from the respondents and field visits, it appeared clearly that these producers and their families need to sell their labour force outside their properties, in agricultural work or outside the sector. This need arises with the fundamental aim of supporting their families financially.

Table III shows that the analysed surface covers 73.34 ha, reflecting a diversity in land use. Over a third of the total area (37%) is used for coffee production, about one-fifth (22%) is allocated both to other crops and to stubble areas and pastures (rest areas and/or pastures), and roughly another fifth (19%) of the total area is reserved for forests.

In the agricultural field, coffee production is mainly orientated towards the export market, while the fundamental purpose of the extension dedicated to other crops is to satisfy the nutritional needs of families, with occasional sales of the production in local markets. The uses of forest and stubble/pasture areas were reported in two-thirds

[3] www.shadetreeadvice.org

(67%) of the studied farms. The first interest that stands out is their contribution to the conservation of biodiversity, water availability and ecological balance. Meanwhile stubble areas and/or paddocks perform dual functions by offering potential for agricultural activities and supporting micro-scale livestock farming. These practices not only complement agricultural systems but also generate additional income and supply raw materials to produce organic fertilisers at specific times.

Additionally, 80% of the producers have initiated a process of agroecological transition and, in some cases, have a certification for organic coffee production. These choices towards a more sustainable agriculture respond to shared objectives of improving their income, conserving soils, preserving human health, and strengthening their family economies.

Forest, bamboo, and agroforestry systems

Of the 30 farms evaluated, two-thirds (67%) had natural successional forest, two-thirds (67%) had bamboo, and four-fifths (80%) had live fences used as a fence or boundary to delimit their farms. One of the main species used as a fence is *Ladenbergia oblongifolia* (Humb. ex Mutis) L. Andersson (Rubiaceae). The families obtained foods such as mushrooms and wild fruits from the natural forest, as well as harvesting firewood for cooking food. The bamboo (*G. angustifolia* Kunth) has a protection-production use; two-thirds (67%) had bamboo near water sources. It is important to highlight that over two-thirds (70%) of the families had wetlands on their farms. The bamboo is also used to produce stems for domestic construction: fences, coffee drying, housing or crafts. Despite its widespread use by coffee-growing families, bamboo was not managed following basic or adapted silvicultural practices (i.e., nursery cultivation, fertilisation, transplantation and spacing of plants in the field, thinning, and rotation cycles), as it is already done in other regions of Colombia (Camargo-García et al. 2007).

In the evaluation carried out in agroforestry systems with coffee, 60 tree species were found, belonging to 29 families and 51 genera. The families and genera with the greatest richness were Fabaceae with eight genera and twelve species and Rutaceae with three genera and six species (table IV).

Photo 3.
Forest: canopy of successional forest in a coffee farm in the tropical mountains of the Andes, Colombia.
Photo J. C. Villalba Malaver.

Table IV.
Richness of tree species recorded in the agroforestry coffee system assessment.

No.	Scientific name	Common Spanish name	Botanical family	Native (N)/ Exotic(E)*
1	*Acacia retinodes* Schltdl.	San Martín – Acacia amarilla	Fabaceae	E
2	*Alchornea latifolia* Sw.	Chachamate – Gargantillo	Euphorbiaceae	N
3	*Annona muricata* L.	Guanabano	Annonaceae	N
4	*Annona squamosa* L.	Anon	Annonaceae	N
5	*Bactris gasipaes* Kunth	Palma de chontaduro	Arecaceae	N
6	*Calliandra pittieri* Standl.	Carbonero	Fabaceae	N
7	*Calliandra trinervia* Benth.	Carbonero rojo	Fabaceae	N
8	*Casimiroa edulis* La Llave	Zapote	Rutaceae	E
9	*Cecropia* sp.	Yarumo	Urticaceae	N
10	*Cedrela odorata* L.	Cedro rosado	Meliaceae	N
11	*Cinnamomun triplinerve* (Ruiz and Pav.) Kosterm.	Canelo	Lauraceae	N
12	*Citrus aurantifolia* (Christm.)	Limón pajarito	Rutaceae	E
13	*Citrus limon* (L.) Burm.fil.	Limón mandarino	Rutaceae	E
14	*Citrus reticulata* Blanco	Mandarino	Rutaceae	E
15	*Citrus* sp.	Naranjo	Rutaceae	E
16	*Cordia alliodora* (Ruiz and Pav.) Cham. Ex A.DC.	Nogal cafetero	Cordiaceae	N
17	*Croton gossypiifolius* Vahl.	Sangre drago	Euphorbiaceae	N
18	*Eriobotrya japonica* (Thunb.) Lindl	Níspero	Rosaceae	E
19	*Erythrina edulis* Triana ex Sprague	Chachafruto	Fabaceae	N
20	*Erythrina poeppigiana* O.F. Cook	Cachimbo	Fabaceae	N
21	*Eucalyptus globulus* Labill.	Eucalipto	Myrtaceae	E
22	*Ficus luschnathiana* (Miq.) Miq.	Uvo, Higueron	Moraceae	E
23	*Fraxinus chinensis* Roxb.	Urupán	Oleaceae	E
24	*Gliricidia sepium* (Jacq.) Kunth	Mataratón	Fabaceae	N
25	*Guadua angustifolia* Kunth	Bamboo - guadua	Poaceae	N
26	*Handroanthus chrysanthus* (Jacq.) S.O. Grose	Guayacán amarillo	Bignoniaceae	N
27	*Heliocarpus popayanensis* Kunth.	Palo bobo - balso	Malvaceae	N
28	*Inga densiflora* Benth.	Guamo machete	Fabaceae	N
29	*Inga edulis* Mart.	Guamo mono	Fabaceae	N
30	*Inga punctata* Willd.	Guamo churimbo	Fabaceae	N
31	*Jacaranda caucana* Pittier.	Gualanday	Bignoniaceae	N
32	*Ladenbergia oblongifolia* (Humb. ex Mutis) L. Andersson	Cascarillo	Rubiaceae	N
33	*Lafoensia acuminata* (Ruiz and Pav.) DC.	Guayacán de Manizales	Lythraceae	N
34	*Leucaena leucocephala* (Lam.) de Wit	Leucaena	Fabaceae	E
35	*Licania tomentosa* Fritsch.	Cucuta	Chrysobalanaceae	E
36	*Mangifera* sp.	Mango	Anacardiaceae	E
37	*Meriania speciosa* (Bonpl.) Naudin	Mayo	Melastomataceae	N
38	*Miconia notabilis* Triana	Mortiño blanco	Melastomataceae	N
39	*Myrcia popayanensis* Hieron.	Arrayán	Myrtaceae	N
40	*Myroxylon balsamum* Harms.	Tache o Balsamo	Fabaceae	N
41	*Myrsine guianensis* Kuntze	Cucharo	Primulaceae	N
42	*Nectandra reticulata* (Ruiz and Pav.) Mez.	Jigua	Lauraceae	N
43	*Oreopanax discolor* (Kunth) Decne. and Planch.	Mano de oso	Araliaceae	N
44	*Persea americana* Mil	Aguacate común	Lauraceae	E
45	*Persea schiedeana* Nees	Aguacatillo	Lauraceae	N
46	*Piper aduncum* L.	Cordoncillo	Piperaceae	N
47	*Pouteria caimito* Radlk	Caimito	Sapotaceae	N
48	*Psidium guajava* L.	Guayabo	Myrtaceae	N
49	*Quercus humboldtii* Bonpl.	Roble	Fagaceae	N
50	*Roystonea regia* O.F. Cook	Palma real	Arecaceae	E
51	*Sambucus nigra* L..	Sauco	Viburnaceae	E
52	*Senna spectabilis* (DC.) H.S. Irwin and Barneby	Vainillo	Fabaceae	N
53	*Syzygium jambos* (L.) Alston	Pomorroso	Myrtaceae	E
54	*Tabebuia rosea* (Bertol.) DC.	Guayacán rosado	Bignoniaceae	N
55	*Tecoma stans* (L.) Juss. Ex Kunth	Fresno	Bignoniaceae	N
56	*Theobroma cacao* L.	Cacao	Malvaceae	N
57	*Trichanthera gigantea* H and B.	Nacedero	Acanthaceae	N
58	*Urtica* L.	Ortiga	Urticaceae	N
59	*Vismia baccifera* (L.) Triana and Planch.	Mandur - morochillo negro	Hypericaceae	N
60	*Zanthoxylum rhoifolium* Lam.	Tachuelo	Rutaceae	N

* At level country, source: Plants of the World Online of Royal Botanical Gardens: https://powo.science.kew.org/

Of the sixty species found, three indigenous species are under some degree of threat: the species *Cedrela odorata* L. and *Quercus humboldtii* Bonpl. are both within the vulnerable category[4], and *Myroxylon balsamum* (L.) Harms is within the near threatened category.

Regarding the density of trees associated with coffee cultivation, it was possible to determine that, on average, in the sampling area (3 ha), the coffee cultivation tree density was 15.3 individuals per 1,000 m^2 sample unit (sd ±7.72, max = 44, min = 5), which is equivalent to 153 individuals/ha. The average number of species for the sampling area was 9 (sd ±4.23, max = 18, min = 2).

Based on the species accumulation curve (figure 2), which represents the relationship between the number of accumulated species and the series of sampling units (Schilling and Ferreira 2008), it was possible to determine that of the thirty 20 x 50 m transects evaluated in lots of coffee with trees, 60 species were found on the Popayán plateau. However, these do not represent the total number of species present in coffee agroforestry systems according to the estimate obtained with the Jackknife index corresponding to the total number of species expected that reached 95 (figure 2). This means that the sampled area was not sufficient to identify the total number of tree species present in agroforestry systems.

Using the IVI, the thirty most important species were selected based on richness, density, and frequency on the farms. These species were used to develop information cards for the second survey (figure 3). The three most important species were *Inga edulis* Mart., *I. densiflora* Benth, and *Persea americana* Mill., and the least important were *Tabebuia rosea* (Bertol.) Bertero ex A.DC., *Sambucus nigra* L., and *Croton gossypiifolius* Vahl.

[4] Global Biodiversity Information Facility (GBIF): https://www.gbif.org

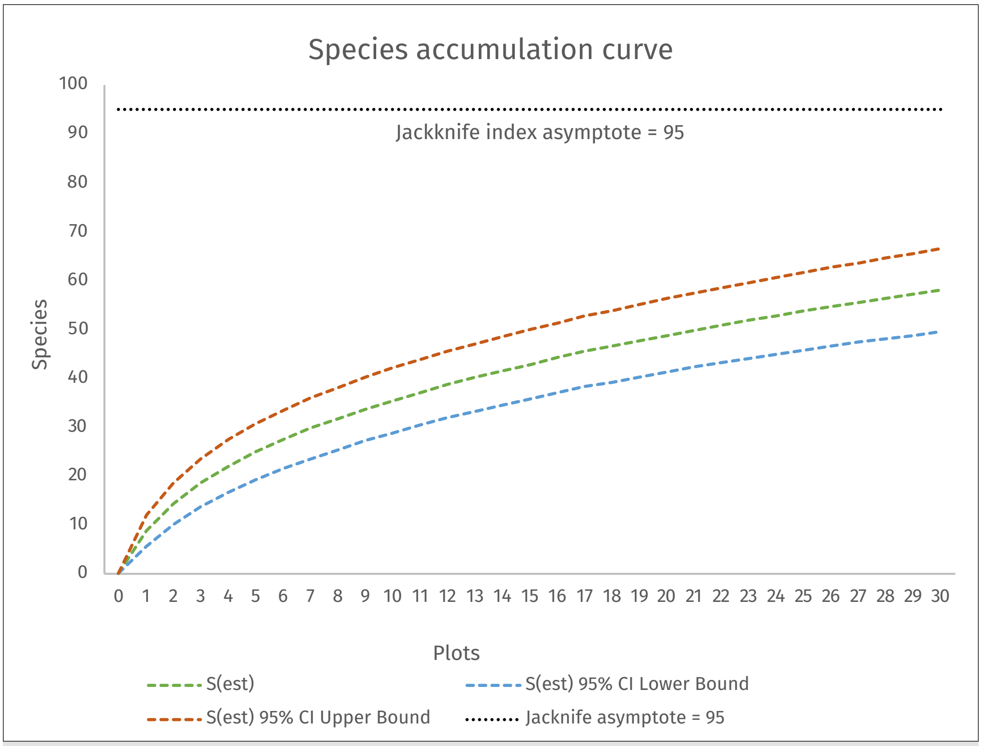

Figure 2.
Species accumulation curve for n = 30, plots of 20 m x 50 m (0.1 ha x 30 = 3 ha of sampled area). Number of inventoried species = 60, number of expected species = 95 (Jackknife index).

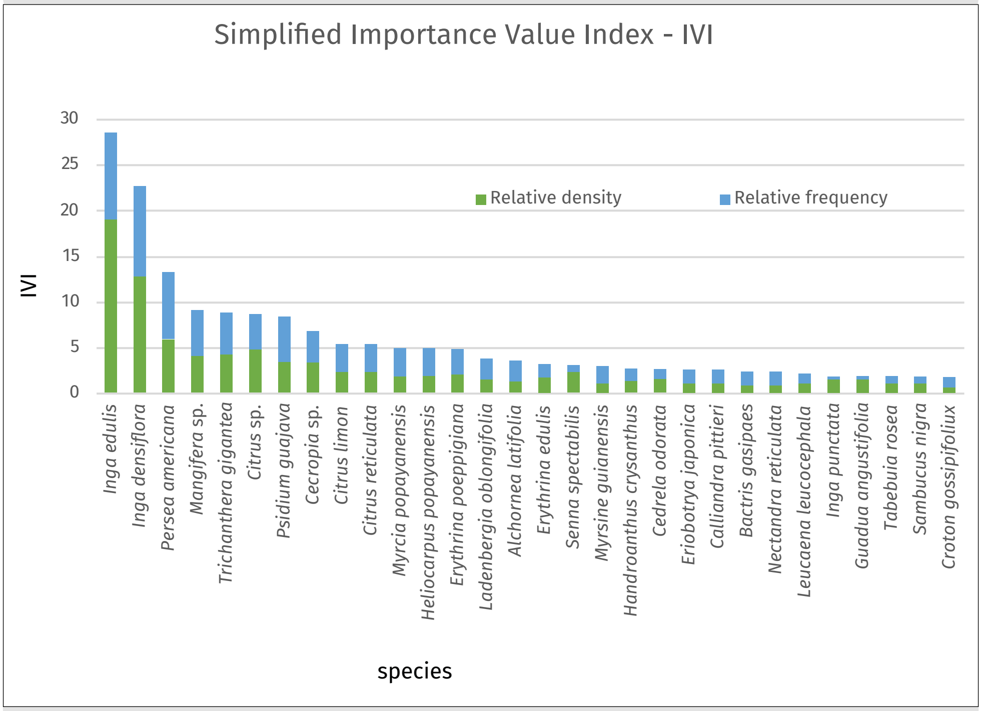

Figure 3.
Importance Value Index (IVI) for the 30 most important species from an ecological point of view. Green bars: relative density measures the abundance of a species relative to the total number of individuals of all species in the sampling area; Blue bars: relative frequency measures the spatial distribution of a species, i.e. the frequency of occurrence of the species in the sampling area.

Based on their traditional knowledge, farmers in the evaluated municipalities selected ten key ecosystem services that trees provide in the coffee production process. They chose the following: biodiversity, protection against wind, protection against hail, climate regulation, improvement in soil fertility, life expectancy of coffee, fruit production, biological control of pests and diseases, coffee production and weed control (table V).

Of the 60-tree species identified, the 30 most important ecosystem services obtained from the IVI were selected, based on the knowledge of coffee farmer families (figure 4). The species *I. densiflora* was the best evaluated by farmers as a provider of ecosystem services for coffee production, followed in order by *I. edulis* and *P. americana*. The first two species belong to the *Inga* genus and are leguminous trees belonging to the Fabaceae family that fix atmospheric nitrogen. The fourth species on the list, *Erythrina poeppigiana*, belongs to this same family. The species ranked in third position, *Persea americana*, is a commercial fruit tree, as is the fifth on the list, a fruit tree of the *Citrus* genus.

Table V.
Ecosystem services prioritised by farmers. The classification was based on a total of 17 services, based on Wagner et al. (2019).

Code	Type of Ecosystem service	Average	Classification
A	Biodiversity	4.6	Support
B	Protection against wind	4.5	Regulation
C	Protection against hail	4.5	Regulation
D	Climate regulation	4.5	Regulation
E	Soil fertility	4.6	Regulation
F	Life expectancy of coffee	4.1	Regulation
G	Fruit production	3.4	Supply
H	Pest control	3.2	Regulation
I	Coffee production	3.5	Supply
J	Weed control	2.6	Regulation

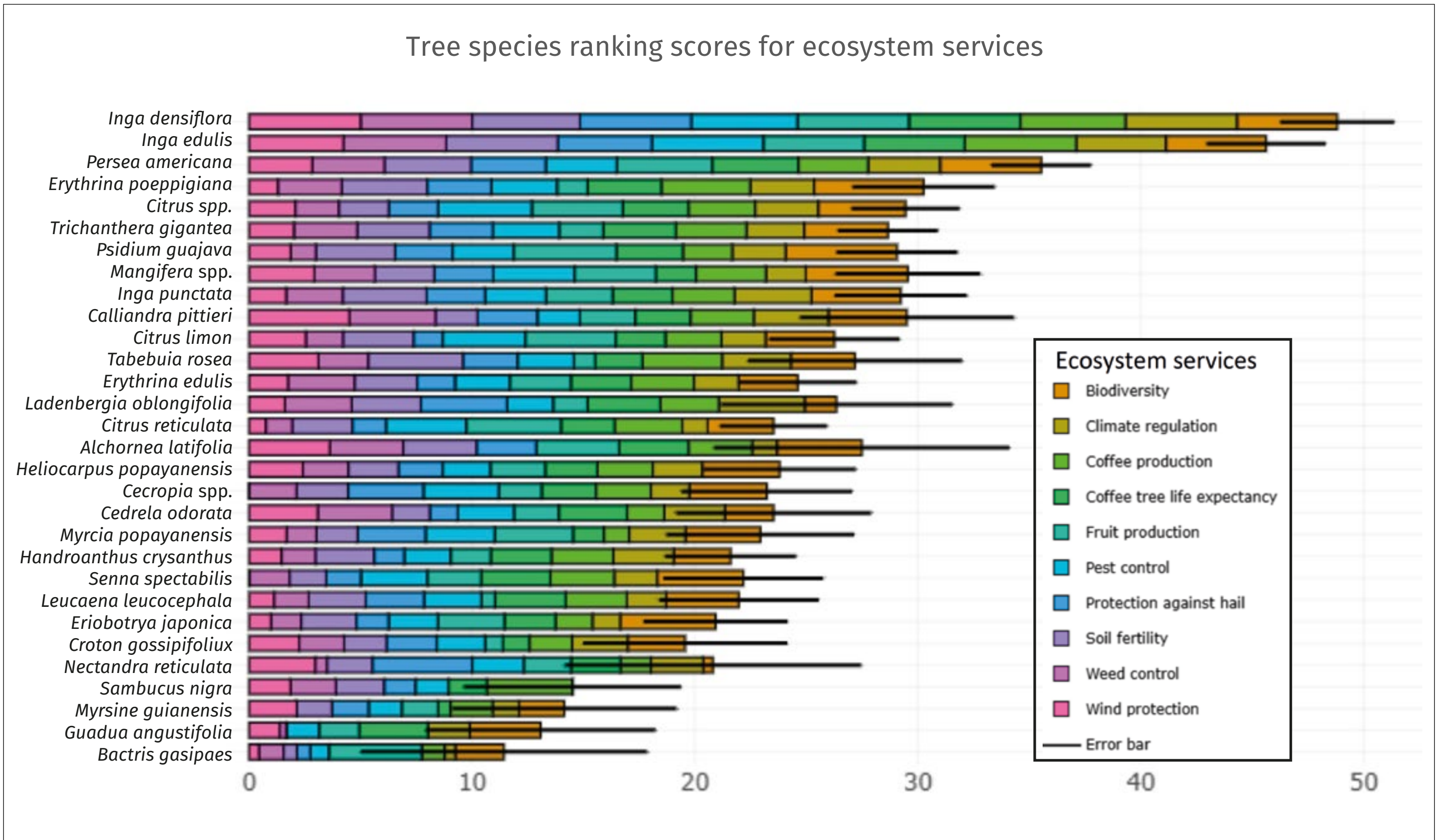

Figure 4.
Tree species ranking scores for ecosystem services based on the group of interviewed farmers in the municipalities of Cajibio, Caldono, and Piendamo, southwestern Colombia.

Discussion

Socioeconomic and ecological functions of land use on farms

The detailed producers' characterisation reveals a clear peasant orientation, manifested in the diverse land uses management, thus fulfilling both economic and ecological functions (Isbell et al. 2017). Their various strategies focus on steering their activities towards a coffee production that aligns with agroecological transition programmes and is eligible for organic certification, but they also seek the production of foods that allow them to be articulated to a local environment. This approach recognises the incorporation of agroecological principles, expressed by different researchers (Dumont et al. 2021; Côte et al. 2022), and is recommended for the adoption of an agriculture based on the management of agrodiversity, landscape structures, and considering ecosystem services, as indicated by Duru et al. (2015).

In relation to age distribution, it was notable that half (50%) of the producers were in the range of 15-49 years old, which indicates a demographic group with significant potential to consolidate farms with the intention of remaining in agriculture. However, the consolidation of the farms and their viability raise questions and face major challenges since half of the properties have areas of less than 1 ha. In this regard, Santana et al. (2021) highlighted the importance of addressing farm size and progressing towards intermediate-sized farms in the Colombian context, exploring the opportunities associated with community management models.

Successional forest at farm scale

We found that 67% of the farms had successional forest, equivalent to 19.8% of the total area evaluated, information to be considered for future studies in coffee farms in the department of Cauca because there is an interesting relationship between the coffee region and the presence of this type of forest. In 2012, there were seven million hectares of successional forest in the Colombian Andes lands (Hurtado-M. et al. 2022). These forests provide food and energy for cooking, supporting the food sovereignty of coffee-growing families (Jamnadass et al. 2013; Hernández and De León 2018; Coral-Mora 2019); but there are gaps in research topics – particularly regarding the ecosystem services they provide, as well as their operation and ecological value (Hurtado-M. et al. 2022). One aspect that merits attention is the study of the functional traits of agroforestry tree species. These are traits that indirectly affect biological success (fitness) through their effects on growth, reproduction, and survival at the organism level (Violle et al. 2007; Calderón and Barreto 2020). Furthermore, these traits should be scaled to the ecosystem level (Salgado-Negret et al. 2015). This will reveal other aspects of diversity, the morphophysiology of the species, as well as the ecological mechanisms and strategies of the forest in the succession process (Hurtado-M. et al. 2022).

In the context of climate change, the provision of ecosystem services, such as biomass accumulation and carbon storage by trees associated with crops and in secondary forests (Beer et al. 2003; Poorter et al. 2016), are issues of broad interest and great impact for the environmental sustainability of coffee cultivation.

Biological and cultural importance of bamboo (*Guadua angustifolia* Kunth)

In the context of climate change, the benefits of trees associated with coffee cultivation (agroforestry systems), access to food, improved income, and health are well documented (Duffy et al. 2021), and important advances are being made regarding the relationship between canopy trees and coffee plants (Holwerda et al. 2021). However, it is imperative to acknowledge the significance of other vegetation components on farms, which have been demonstrated to play a pivotal role at both the local and landscape scale (Zignol et al., 2023). These components also contribute to the provision of ecosystem services. *Guadua angustifolia* is endemic to the Andes mountain range and is frequently observed in coffee farms located in the southern region of Colombia, as evidenced by the findings of this study. The importance of biological and cultural diversity during the field trips was evident, and this has been documented in other regions of the country. For example, Ospina and Finegan (2004), who evaluated 140 plots of 20 m x 20 m (5.6 ha) of bamboo forests, inventoried 63 plant species belonging to 26 botanical families.

At a socio-economical level, families use bamboo for the construction of infrastructures for coffee processing, housing, fences, among others. *Guada angustifolia* is not only important in the southwest of Colombia but more broadly in all the coffee regions of Colombia where this type of use is documented (Rincón et al. 2023). Therefore, there is a need to include it in the evaluation of ecosystem services in coffee farms, including evaluation at the stand (López-Hoyos 2023) and landscape levels. However, according to farmer knowledge and although is important for us, *G. angustifolia* is not advisable for direct association with coffee cultivation.

Tree local knowledge at coffee crop scale

The most important tree species from the ecological point of view were identified based on the simplified IVI, which accounts for richness, frequency and density. The top three were *I. edulis*, *I. densiflora* and *P. americana*, according to the STA tool, which is a standardised methodology for documenting farmer knowledge about shade trees and their provision of ecosystem services (Van Der Wolf et al. 2016). The farmers prioritised the same three species in order. The presence of these species is attributed to the benefits they offer for coffee cultivation, family food supply, and, in the case of *P. americana*, income generation. Other researchers, who used the Shade Tree Advice to evaluate shade trees associated with the cultivation of *C. arabica*, found that leguminous trees of the Fabaceae family and fruit trees always appear as the most important ones (Rigal et al. 2022). This aligns with the present study, where five of the ten top-ranked species are tree legumes and four are commercial fruit trees (figure 4). Rigal et al. (2022) posit that a crucial parameter that merits examination in forthcoming studies pertains to the functional traits of shade tree species selected by farmers. These traits include, but are not limited to, those exhibited by legume tree species, which possess nitrogen-fixing capabilities and generate a uniform shade through their compound leaves. These characteristics appear to be advantageous for their incorporation into coffee agroforestry systems. Evaluating the functional traits of the species would help us to find out additional reasons why farmers select certain shade trees.

In the region of the present study, the use of *I. densiflora* is very common. Although it has compound leaves, its dense foliage creates excessive shade for coffee plants. Farmers' preference for its use is likely due to its ability to fix nitrogen, provide fruit for domestic consumption, and contribute leaf litter to the soil, which serves as habitat for ants that help control pests such as the coffee borer (Mera-Velasco et al. 2010). In the future, it is thus necessary to incorporate the study of functional traits to understand the preference for use of tree species associated with coffee. Species of the *Inga* genus, such as *densiflora* and *edulis*, have been widely evaluated and recommended by the National Coffee Research Center (Cenicafé), including the department of Cauca. *Inga densiflora* is an important tree for producing fruits and firewood. The recommended planting density in the central region of Colombia is 70 trees/ha (12 x 12 m), as optimal shade for low-growing coffee varieties such as Castillo (Farfán-Valencia and Baute-Balcázar 2010). It is important to highlight that bamboo (*G. angustifolia*) is the penultimate species on the list. According to the local knowledge of the coffee farmers, although it is present in two-thirds (67%) of the farms, this means that it is not a species that generates ecosystem services in coffee production.

In Vietnam, based on the local knowledge of farmers and based on the STA, Nguyen et al. (2020) reported that the species that offered the most ecosystem services to produce *C. arabica* crops was the exotic species *Leucaena leucocephala* (Lam.) de Wit. Contrary to the present study, it is not one of those preferred by farmers, occupying position twenty-three out of thirty. More important to farmers were natives of the genus *Inga*, including other native trees such as *Myrcia popayanensis* Hieron., *Alchornea latifolia* Sw., and *Ladenbergia oblongifolia* (Humb. ex Mutis) L. In the coffee agroforestry systems of Kodagu (southern India), native trees were found to provide substantial provisioning services (fruits, timber, fodder, firewood, and medicinal uses), contrary to the popular perception that such species are beneficial only for regulatory services or habitat. The study showed that native trees in coffee agroforestry systems provided many more benefits than exotic trees, with up to four different uses documented for the same species, while for exotic species, at most two or three uses could be documented (Dhanya et al. 2014). Considering that one of the problems of climate change is the loss of biodiversity, a strength of the coffee farms of the ASOVIDAS Network members is the presence of native species, which must be maintained because the intensification of cultivation has led in other regions to homogenise the shade trees, especially with the introduction of exotic species (Guillemot et al. 2018; Nesper et al. 2017), as shown below.

In agroforestry systems in the Western Ghats of India, the introduction of exotic species using *Grevillea robusta* A.Cunn. ex R.Br. could threaten both climate change mitigation and tree diversity conservation: it negatively affects carbon storage and tree diversity, especially in *C. robusta* L. Linden systems (Guillemot et al. 2018). Likewise, Nesper et al. (2017) show that the decrease in shade diversity due to the intensification of production reduces diversity indices. It also affected both coffee production and quality (bean size) and increased incidences of coffee berry borer attacks (*Hypothenemus hampei*).

Rigal et al. (2022) used the STA tool to assess the ecosystem services of trees associated with coffee cultivation with the *C. arabica* variety, based on results obtained in various coffee-growing regions of the world, including Uganda (Gram et al. 2018), Tanzania (Wagner et al. 2019), Nicaragua (Carpente 2020) and Vietnam (Nguyen et al. 2020). In these studies, the impact of trees on pest and disease incidence has always been considered less important than other issues such as their impact on soil and climate regulation, crop production, and economic benefits (Rigal et al. 2022). Improving the STA tool to evaluate the impact of trees on pest incidence will be important for subsequent application in Colombia, especially in the department of Cauca, where ant-insect interactions directly and indirectly affect the coffee plantations and their production. In shaded coffee plantations more precisely, direct predation on the coffee borer *Hypothenemus hampei*[5] was observed, primarily by ants of two *Temnothorax* species, and to a lesser extent by *Wasmannia auropunctata* and *Crematogaster* spp. (Mera-Velasco et al. 2010). It will be thus interesting to assess these interactions based on the local knowledge of farmers in the department of Cauca in the south-west of Colombia.

Conclusion

In summary, it can be concluded that the farms managed by ASOVIDAS coffee growers, which represent a sample of coffee cultivation on the Popayán Plateau, are inhabited by farming families. These farms are distinguished by a diversified use of land that fulfils both ecological and socio-economic functions. A part of the farm that fulfils ecological functions is characterised by the presence of the forest component, including natural forests in a state of succession, bamboo, and agroforestry systems for coffee production. These places are a peasant strategy for diversifying land use, production and landscape thereby ensuring the provision of ecosystem services such as the absorption and storage of carbon and obtaining food or energy in the

[5] GBIF (Global Biodiversity Information Facility). (2024). Hypothenemus hampei. Retrieved 27 February 2024 (https://www.gbif.org/search?q=Hypothenemus%20hampei).

context of climate change. Likewise, the production of coffee associated with trees offers ecosystem support, regulation, and supply services. Subsequent research endeavours may concentrate on the implementation of functional ecology in the context of forestry, bamboo cultivation, and agroforestry systems. These efforts could enhance the analytical scope to encompass the landscape level.

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Access to data
The data is available on Google Drive, in the institutional account of the corresponding author at the following link: https://drive.google.com/drive/u/0/folders/1qT__egxJLsP-50vu5ouffvcEfXWmc5_jj

References

Beer, J., Harvey, C. A., Ibrahim, M. A., Harmand, J. M., Somarriba, E., et al. (2003). Servicios ambientales de los sistemas agroforestales. *Agroforestería en las Américas*, 10(37-38), 80-87. https://repositorio.catie.ac.cr/handle/11554/6806

Camargo-García, J. C., García, J., & Morales, T. (2007). Bases Para La Planificación y Manejo Silvicultural de Bosques de *Guadua*: Una Aplicación a Nivel de Finca En La Zona Cafetera de Colombia. COLCIENCIAS. https://acervo.rotas.ufg.br/espacobambu/acervo-bibliografico/bases-para-la-planificacion-y-manejo-silvicultural-de-bosques-de-guadua-una-aplicacion-a-nivel-de-finca-en-la-zona-cafetera-de-colombia/

Carpente, A. (2020). Optimizing shade tree species recommendation through the mobilization of local ecological knowledge. Experience from the small-scale coffee agroforestry systems in Matagalpa Department, Nicaragua. University of Copenhagen, 166 p. https://hal.science/tel-02613885v1/file/Online%20version%20-%20Anai%CC%88s%20Carpente.pdf

Cauca (Colombia). (2024). In Wikipedia, la enciclopedia libre. https://es.wikipedia.org/w/index.php?title=Cauca_(Colombia)andoldid=157820611

Ceballos-Sierra, F., & Dall'Erba, S. (2021). The effect of climate variability on Colombian coffee productivity: A dynamic panel model approach. *Agricultural Systems*, 190, 103126. https://doi.org/10.1016/j.agsy.2021.103126

Colwell, R. K., Daniel, M., Málaga-Téllez, B. A., Romero, V., Paz-Soldan, L., et al. (2022). EstimateS_9.1_Windows. OSF Home. https://osf.io/su57f/

Comité de Cafeteros del Cauca. (2022). Pur Projet ratifica su compromiso con el Cauca. Federación Nacional de Cafeteros Cauca. https://cauca.federaciondecafeteros.org/listado-noticias/pur-projet-ratifica-su-compromiso-con-el-cauca/

Coral-Mora, E. M. (2019). Acompañamiento en la inclusión del componente forestal a las actividades asociadas a la soberanía alimentaria en el municipio de Caldono – Cauca. Ingeniería Forestal, Universidad del Cauca, Colombia. http://repositorio.unicauca.edu.co:8080/xmlui/handle/123456789/1482

Côte, F. X., Rapidel, B., Sourisseau, J. M., Affholder, F., Andrieu, N., et al. (2022). Levers for the Agroecological Transition of Tropical Agriculture. *Agronomy for Sustainable Development*, 42(4), 67. https://doi.org/10.1007/s13593-022-00799-z

Curtis, J. T., & McIntosh, R. P. (1950). The Interrelations of Certain Analytic and Synthetic Phytosociological Characters. *Ecology*, 31(3), 434-455. https://doi.org/10.2307/1931497

Dhanya, B., Sathish, B. N., Viswanath, S., & Purushothaman, S. (2014). Ecosystem services of native trees: experiences from two traditional agroforestry systems in Karnataka, Southern India. *International Journal of Biodiversity Science Ecosystems Services & Management*, 10(2), 101-111. https://doi.org/10.1080/21513732.2014.918057

Duffy, C., Toth, G. G., Hagan, R. P. O., McKeown, P. C., Rahman, S. A., et al. (2021). Agroforestry contributions to smallholder farmer food security in Indonesia. *Agroforestry Systems*, 95(6), 1109-1124. https://doi.org/10.1007/s10457-021-00632-8

Dumont, A. M., Wartenberg, A. C., & Baret, P. V. (2021). Bridging the gap between the agroecological ideal and its implementation into practice. A review. *Agronomy for Sustainable Development*, 41(3). https://doi.org/10.1007/s13593-021-00666-3

Duru, M., Therond, O., & Fares, M. (2015). Designing agroecological transitions – A review. *Agronomy for Sustainable Development*, 35(4), 1237-1257. https://doi.org/10.1007/s13593-015-0318-x

Escobar-Lasso, S., Cerón-Cardona, J., & Castaño-Salazar, J. H. (2013). Los mamíferos de la cuenca del río Chinchiná, en la región andina de Colombia. *Therya*, 4(1), 139-155. https://doi.org/10.12933/therya-13-111

Farfán-Valencia, F., & Baute Balcázar, J. E. (2010). Efecto del sombrío con especies leguminosas a diferentes densidades de siembra sobre la producción de café. *Cenicafé*, 61(1), 35-45. https://biblioteca.cenicafe.org/handle/10778/44

Federación Nacional de Cafeteros. (2022). 1 millón de razones para sembrar árboles. Federación Nacional de Cafeteros. https://federaciondecafeteros.org/wp/sostenibilidad/eje-ambiental/

Federación Nacional de Cafeteros. (2023). Estadísticas Cafeteras. Federación Nacional de Cafeteros. https://federaciondecafeteros.org/wp/estadisticas-cafeteras/

Galeano-Rendón, E., & Mancera-Rodríguez, N. J. (2018). Efectos de la deforestación sobre la diversidad y la estructura del ensamblaje de macroinvertebrados en cuatro quebradas Andinas en Colombia. *Revista de Biología Tropical*, 66(4). https://doi.org/10.15517/rbt.v66i4.31397

Geilfus, F. (2009). 80 herramientas para el desarrollo participativo: diagnóstico, planificación, monitoreo evaluación. Instituto Interamericano de Cooperación para la Agricultura (IICA). https://evalparticipativa.net/wp-content/uploads/2019/05/02.-80-herramientas-para-el-desarrollo-participativo.pdf

Gram, G., Vaast, P., Van Der Wolf, J., & Jassogne, L. (2017). Local tree knowledge can fast-track agroforestry recommendations for coffee smallholders along a climate gradient in Mount Elgon, Uganda. *Agroforestry Systems*, 92(6), 1625-1638. https://doi.org/10.1007/s10457-017-0111-8

Guillemot, J., Maire, G. L., Munishamappa, M., Charbonnier, F., & Vaast, P. (2018). Native coffee agroforestry in the Western Ghats of India maintains higher carbon storage and tree diversity compared to exotic agroforestry. *Agriculture Ecosystems & Environment*, 265, 461-469. https://doi.org/10.1016/j.agee.2018.06.002

Holwerda, F., Guerrero-Medina, O., & Meesters, A. G. (2021). Evaluating surface renewal models for estimating sensible heat flux above and within a coffee agroforestry system. *Agricultural And Forest Meteorology*, 308-309, 108598. https://doi.org/10.1016/j.agrformet.2021.108598

Hurtado-M., A. B., Muñoz, J. C., Echeverry-Galvis, M. Á., & Norden, N. (2022). Bosques sucesionales en Colombia: una oportunidad para la recuperación de paisajes transformados. *Caldasia*, 44(2), 332-344. https://doi.org/10.15446/caldasia.v44n2.82255

Isbell, F., Adler, P. R., Eisenhauer, N., Fornara, D., Kimmel, K., et al. (2017). Benefits of increasing plant diversity in sustainable agroecosystems. *Journal Of Ecology*, 105(4), 871-879. https://doi.org/10.1111/1365-2745.12789

Jamnadass, R., Place, F., Torquebiau, E., Malézieux, E., Iiyama, M., et al. (2013). La agrosilvicultura en pro de la seguridad alimentaria y nutricional. *Unasylva*, 241(64). https://www.fao.org/3/i3482s/i3482s03.pdf

Jamnadass, R. H., McMullin, S., Iiyama, M., Dawson, I. K., Powell, B., et al. (2015). Understanding the Roles of Forests and Tree-Based Systems in Food Provision. Chapter 2. In: Forests, trees and landscapes for food security and nutrition, B. Vira, C. Wildburger, S. Mansourian (Eds). A Global Assessment Report. IUFRO World Series, 25-49. https://www.cifor-icraf.org/knowledge/publication/5594/

Jha, S., Bacon, C. M., Philpott, S. M., Méndez, V. E., Läderach, P., & Rice, R. A. (2014). Shade Coffee: Update on a Disappearing Refuge for Biodiversity. *BioScience*, 64(5), 416-428. https://doi.org/10.1093/biosci/biu038

Kleinn, C., & Morales-Hidalgo, D. (2006). An inventory of Guadua (*Guadua angustifolia*) bamboo in the Coffee Region of Colombia. *European Journal of Forest Research*, 125(4), 361-368. https://doi.org/10.1007/s10342-006-0129-3

Hernández, L. L., & De León, E. E. S. (2018). Food sovereignty and environmental risk in the social construction of rural territory in San Juan Ixtenco, Tlaxcala. *Textual*, 72, 67-101. https://doi.org/10.5154/r.textual.2017.72.006

López-Hoyos, J. L. (2023). Modelos alométricos para la estimación de atributos de guadua (*Guadua angustifolia* Kunth) en el centro de estudios vegetales y biodiversidad asociada (CEVBA) vereda La Rejoya, Popayán, Cauca. Universidad del Cauca, Colombia, 81 p. http://repositorio.unicauca.edu.co:8080/xmlui/handle/123456789/7873

Louman, B., Quirós, D., & Nilsson, M. (2001). Silvicultura de bosques latifoliados húmedos con énfasis en América Central. Serie técnica. Manual técnico. CATIE, 46, 265 p. https://portals.iucn.org/library/node/26652

Martinez Mamián, C. A. (2014). Evaluación agronómica de 23 accesiones de *Leucaena diversifolia*, en el peniplano de Popayán. Universidad Nacional De Colombia, 87 p. https://repositorio.unal.edu.co/handle/unal/23226

Mera-Velasco, Y. A., Gallego-Ropero, M. C., & Armbrecht, I. (2010). Interacciones entre hormigas e insectos en follaje de cafetales de sol y sombra, Cauca-Colombia. *Revista Colombiana de Entomología*, 36(1), 116-126. https://doi.org/10.25100/socolen.v36i1.9131

Calderón, K. D. R., & Barreto, J. E. M. (2020). Efecto del método de emplazamiento en la respuesta funcional de seis especies arbóreas de Bogotá. *Colombia Forestal*, 23(2), 5-19. https://doi.org/10.14483/2256201x.15811

Mostacedo, B., & Fredericksen, T. S. (2000). Manual de métodos básicos de muestreo y análisis en ecología vegetal. (Vol. 87). Proyecto de Manejo Forestal Sostenible (BOLFOR), 92 p. http://www.bio-nica.info/Biblioteca/Mostacedo2000EcologiaVegetal.pdf

Nesper, M., Kueffer, C., Krishnan, S., Kushalappa, C. G., & Ghazoul, J. (2017). Shade tree diversity enhances coffee production and quality in agroforestry systems in the Western Ghats. *Agriculture Ecosystems & Environment*, 247, 172-181. https://doi.org/10.1016/j.agee.2017.06.024

Nguyen, M. P., Vaast, P., Pagella, T., & Sinclair, F. (2020). Local Knowledge about Ecosystem Services Provided by Trees in Coffee Agroforestry Practices in Northwest Vietnam. *Land*, 9(12), 486. https://doi.org/10.3390/land9120486

Ospina, R., & Finegan, B. (2004). Variabilidad florística y estructural de los bosques dominados por *Guadua angustifolia* en el eje cafetero colombiano. CATIE. https://repositorio.catie.ac.cr/handle/11554/6913

Poorter, L., Bongers, F., Aide, T. M., Zambrano, A. M. A., Balvanera, P., et al. (2016). Biomass resilience of Neotropical secondary forests. *Nature*, *530*, 211-214. https://doi.org/10.1038/nature16512

República de Colombia. (2016). Plan Integral de Gestión Del Cambio Climático Territorial del Departamento de Cauca 2040. Ministerio de Ambiente y Desarrollo Sostenible, 220 p. https://accionclimatica.minambiente.gov.co/download/plan-integral-de-gestion-de-cambio-climatico-territorial-del-cauca-2040/

Rigal, C., Wagner, S., Nguyen, M. P., Jassogne, L., & Vaast, P. (2022). ShadeTreeAdvice methodology: Guiding tree-species selection using local knowledge. *People And Nature*, 4(5), 1233-1248. https://doi.org/10.1002/pan3.10374

Rigal, C. (2023). Bradley Terry Analysis.https://shadetreeadvice.shinyapps.io/BradleyTerryAnalysis/

Rincón, C. E., Montoya, J. A., & Archila, H. F. (2023). Bamboo Construction Inspired by Vernacular Techniques for Reducing Carbon Footprint: A Life Cycle Assessment (LCA). *Sustainability*, 15(24), 16893. https://doi.org/10.3390/su152416893

Salgado-Negret, B., Horacio, P., Pulido Rodríguez, E. N., Cabrera, M., Ruíz Osorio, C., et al (2015). La Ecología Funcional Como Aproximación al Estudio, Manejo y Conservación de La Biodiversidad: Protocolos y Aplicaciones. Instituto de Investigación de Recursos Biológicos Alexander von Humboldt, 236 p. https://tiendahumboldt.org/producto/libro-la-ecologia-funcional-como-aproximacion-al-estudio-manejo-y-conservacion-de-la-biodiversidad-protocolos-y-aplicaciones/?srsltid=AfmBOorYkDGewUdWVaWMfJyqOIEsc87A3UCdL47DlzozP5dXmuz5hajl

Santana, P., Machado, A., Fajardo, D., Garay, L., Salamanca, H., et al. (2021). Hacia un contrato social en torno a la economía campesina. La alimentación de los y las colombianas es con los campesinos o no es. Corporación Latinoamericana Sur, Centro de Estudios e Investigaciones Rurales (CEIR). Universidad de La Salle, 82 p. https://co.boell.org/sites/default/files/2022-03/hb_publicacion_agraria%20OK%20DFINITIVO%202%20demarzo.pdf

Schilling, A. C., & Ferreira Batista, J. L. (2008). Curva de acumulação de espécies e suficiência amostral em florestas tropicais. *Brazilian Journal of Botany*, March, 179-87. https://doi.org/10.1590/S0100-84042008000100016

Sinclair, F., & Walker, D. (1998). Acquiring qualitative knowledge about complex agroecosystems. Part 1: Representation as natural language. *Agricultural Systems*, 56(3), 341-363. https://doi.org/10.1016/s0308-521x(97)00048-6

Tadesse, G., Zavaleta, E., & Shennan, C. (2014a). Effects of land-use changes on woody species distribution and above-ground carbon storage of forest-coffee systems. *Agriculture Ecosystems & Environment*, 197, 21-30. https://doi.org/10.1016/j.agee.2014.07.008

Tadesse, G., Zavaleta, E., & Shennan, C. (2014b). Coffee landscapes as refugia for native woody biodiversity as forest loss continues in southwest Ethiopia. *Biological Conservation*, 169, 384-391. https://doi.org/10.1016/j.biocon.2013.11.034

Valencia, V., West, P., Sterling, E. J., García-Barrios, L., & Naeem, S. (2015). The use of farmers' knowledge in coffee agroforestry management: implications for the conservation of tree biodiversity. *Ecosphere*, 6(7), 1-17. https://doi.org/10.1890/es14-00428.1

Van Der Wolf, J., Jassogne, L., Gram, G., & Vaast, P. (2016). Turning Local Knowledge on Agroforestry into an Online Decision-Support Tool for Tree Selection in Smallholders' Farms. *Experimental Agriculture*, 55(S1), 50-66. https://doi.org/10.1017/s001447971600017x

Villalba, J., & Lasso, A. (2020). Guía para la Caracterización del Componente Forestal en Sistemas Cafeteros. Editorial Universidad del Cauca, 44 p. https://www.researchgate.net/publication/350311903_Guia_para_la_caracterizacion_del_componente_forestal_en_sistemas_cafeteros

Violle, C., Navas, M., Vile, D., Kazakou, E., & Fortunel, C. (2007). Let the concept of trait be functional! *Oikos*, 116(5), 882-892. https://doi.org/10.1111/j.0030-1299.2007.15559.x

Wagner, S., Rigal, C., Liebig, T., Mremi, R., Hemp, A., et al. (2019). Ecosystem Services and Importance of Common Tree Species in Coffee-Agroforestry Systems: Local Knowledge of Small-Scale Farmers at Mt. Kilimanjaro, Tanzania. *Forests*, 10(11), 963. https://doi.org/10.3390/f10110963

Zignol, F., Kjellström, E., Hylander, K., Ayalew, B., Zewdie, B., et al. (2023). The understory microclimate in agroforestry now and in the future – a case study of Arabica coffee in its native range. *Agricultural And Forest Meteorology*, 340, 109586. https://doi.org/10.1016/j.agrformet.2023.109586

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