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BIODIVERSITY AND SPECIES USE IN AGROFORESTRY SYSTEMS MANAGED BY TRADITIONAL COMMUNITIES IN THE CENTRAL AMAZON

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ABSTRACT

Climate change represents today's great environmental challenge, and ecological restoration of tropical forests is one of the main coordinated actions on a global scale as a measure to mitigate its impacts. In this way, agroforestry systems (AFSs) are increasingly recommended as a restoration strategy. This study aimed to analyze the diversity of uses and functions of tree species of AFSs managed by traditional populations in the Uatumã Sustainable Development Reserve, Amazonas, and to evaluate how different production objectives influence biodiversity. A total of 22 AFSs were sampled, totaling 4,006 individuals, belonging to 61 species. Based on the intended purpose of planting within the system, species were classified into five categories: food, medicinal, timber, non-timber forest products, and soil restoration. 120 attributes of use of the species were identified. The composition of AFSs according to use categories was analyzed through hierarchical grouping (UPGMA), resulting in four distinct groups: (i) food; (ii) timber; (iii) non-timber forest products and medicinal use; and (iv) soil restoration. The diversity of these groups was evaluated using the Shannon and Simpson indices, species richness, and Pielou's evenness. The groups with AFSs whose main uses were for food and timber production showed greater diversity and species richness, while the group focused on soil restoration obtained the lowest values for these indices. Species evenness, on the other hand, did not differ significantly among the groups. The results show that the different use objectives shape the composition and structure of AFSs, directly influencing their contribution to biodiversity.

Keywords: Agrobiodiversity; Traditional ecological knowledge; Management

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BIODIVERSIDADE E USO DAS ESPÉCIES DOS SISTEMAS AGROFLORESTAIS DESENVOLVIDOS POR COMUNIDADES TRADICIONAIS NA AMAZÔNIA CENTRAL

RESUMO As mudanças climáticas representam o grande desafio ambiental da atualidade, e a restauração ecológica de florestas tropicais é uma das principais ações coordenadas em escala global como medida para mitigar seus impactos. Neste caminho, os sistemas agroflorestais (SAFs) são cada vez mais recomendados como uma estratégia de restauração. Este estudo teve como objetivo analisar a diversidade de usos e funções das espécies arbóreas dos SAFs manejados por populações tradicionais na Reserva de Desenvolvimento Sustentável do Uatumã, Amazonas, e avaliar como diferentes objetivos de produção influenciam a biodiversidade. Foram amostrados 22 SAFs, totalizando 4.006 indivíduos, pertencentes a 61 espécies. Com base na finalidade de plantio no sistema, as espécies foram classificadas segundo cinco categorias: uso na alimentação, uso medicinal, produção de madeira, produtos florestais não madeireiros e com finalidade de restauração do solo. Foram identificados 120 atributos de uso das espécies. A composição dos SAFs conforme categorias de uso foi analisada por meio de agrupamento hierárquico (UPGMA), resultando em quatro grupos distintos: (i) alimentar; (ii) madeireiro; (iii) produtos florestais não madeireiros e uso medicinal; e (iv) restauração do solo. A diversidade desses grupos foi avaliada com os índices de Shannon, Simpson, riqueza de espécies e equabilidade de Pielou. Os grupos com SAFs cujos principais usos foram para alimentação e produção madeireira apresentaram maior diversidade e riqueza de espécies, enquanto o grupo voltado à restauração do solo obteve os menores valores para esses índices. A equabilidade, por outro lado, não diferiu significativamente entre os grupos. Os resultados evidenciam que os diferentes objetivos de uso moldam a composição e estrutura dos SAFs, influenciando diretamente sua contribuição para a biodiversidade.

Palavras-Chave: Agrobiodiversidade; Conhecimento ecológico tradicional; Manejo

1. INTRODUCTION

Climate change represents one of the greatest environmental challenges of the 21st century, requiring coordinated actions on a global scale to mitigate its effects and promote the adaptation of socio-ecological systems (Artaxo, 2023). The global food system, in particular, is one of the main vectors of biodiversity and ecosystem service loss, making the transition from conventional agriculture to more sustainable practices urgent (Mathieu et al., 2025; Klimke et al., 2024). In this scenario, the Paris Agreement established ambitious goals to contain global warming, and Brazil, as a signatory, committed to the recovery of 12 million hectares of native vegetation by 2030, recognizing ecological restoration as a key strategy to achieve its climate commitments (Brasil, 2024; Souza & Corazza, 2017).

In this context, agroforestry systems (AFSs) have been recommended as a socio-environmentally sound forest landscape management practice (FAO, 2017). Defined as land use systems characterized by the deliberate permanence of perennial crops in association with annual and/or animal crops, AFSs are considered a productive and sustainable alternative for different contexts, characterized by a dynamic and ecological management of natural resources (Silva et al., 2023; Brandão et al., 2021). These systems represent a practical application of the principles of agroecology, which aim to redesign food systems to make them more sustainable, resilient, and socially just (Isaac et al., 2024).

Implemented for millennia by traditional and indigenous populations throughout the humid tropics, Agroforestry Systems (AFSs) are the manifestation of a deep Traditional Ecological Knowledge (TEK), knowledge that can be defined as the ancestral knowledge accumulated by local communities over generations, based on direct coexistence with ecosystems, and often more accurate than conventional approaches to environmental management (Silva et al., 2024).

AFSs vary greatly in their structure and species composition, reflecting the different management objectives, cultural contexts, and socioeconomic needs of the communities that develop them (Villa et al., 2021). Examples of this diversity are found worldwide, from subsistence and semi-commercial systems in Indonesia, which ensure food security and income for smallholder farmers (Sudomo et al., 2023), to complex milpa and solar systems managed by Mixtec and Afro-Mexican communities in Mexico for the conservation of edible and timber species (Pérez-Nicolás et al., 2024). In the Amazon, as in these other regions, AFSs are fundamental for the subsistence and in situ conservation of agrobiodiversity.

Despite widely recognized benefits, not all AFSs deliver the same ecological outcomes. Recent studies show that the term "agroforestry" covers a wide range of management intensities, and that only the most diverse systems, which seek to mimic the structure of native forests, have significantly lower biodiversity losses than monocultures (Wynter et al., 2025). Given the wide diversity of AFS models and the distinct effects that each configuration can have on biodiversity, it is plausible to consider that the TEK molds agroforestry according to the implementation objectives of these areas, and that this promotes different impacts on biodiversity.

In this sense, the present study aimed to analyze the impact of the purpose of using the tree species of AFSs managed by populations on the biodiversity of the Sustainable Development Reserve (SDR) of Uatumã, Amazonas, Brazil.

2. MATERIAL AND METHODS

2.1 Characterization of the study area

The study was carried out in 22 AFSs located in eight communities of the SDR of Uatumã, state of Amazonas (Figure 1). The SDR of Uatumã is a state conservation unit, created in 2004, which is part of the Central Corridor of the Amazon, one of the most important instruments for the protection of biodiversity on a large scale in the Brazilian Amazon. It is located approximately 200 km in a straight line from Manaus, the state capital, and houses about 400 families distributed in 21 communities (Amazonas, 2017).

The climate of the region is tropical equatorial (Köppen, 1936), with an average temperature of 27ºC and average rainfall of 2,300 mm per year. The rainy season in the region runs from December to May, with the peak of the rainy season in March and April, averaging 418.0 and 334.8 mm. The dry period runs from June to November, with August and September being the driest months, with an average of 74.0 and 72.6 mm (INMET, 2025).

The upland soils of the region are classified as Latosols and Argisols (Santos et al., 2018). Despite the soils being of low fertility for agricultural production and considered to have limited suitability for crops (EMBRAPA, 2025), traditional agriculture and extractivism represent the main productive activity of the residents, as shown in the Management Plan of this protected area (Amazonas, 2017).

2.2 Data collection

The sample consisted of 22 biodiverse AFSs developed by the residents of the SDR of Uatumã, selected from the snowball methodology (Bailey, 1994), which consists of the indication of new areas by the farmers themselves considered as a reference, following a pre-established criterion. This participatory approach is suitable for the context in which local knowledge is essential to identify the relevant sampling units (Pérez-Nicolás et al., 2024). The inclusion criteria were: systems with at least three years since establishment, containing at least 20 individual trees of five different species. Sample sufficiency was analyzed based on the species rarefaction curve (Gotelli & Colwell, 2001).

The areas of the Agroforestry Systems (AFSs) were delimited with the aid of a GPS receiver configured for the SIRGAS 2000 coordinate system, with a margin of error of ±5 meters. In each area, a census of tree species with a diameter equal to or greater than 2 cm was conducted, measured at 1.30 m above the ground — the standard height for Diameter at Breast Height (DBH). The identification of species and the purpose of use were conducted based on the TEK of local farmers, recognized as traditional peoples with deep mastery of regional flora. To ensure the reliability of the information, a

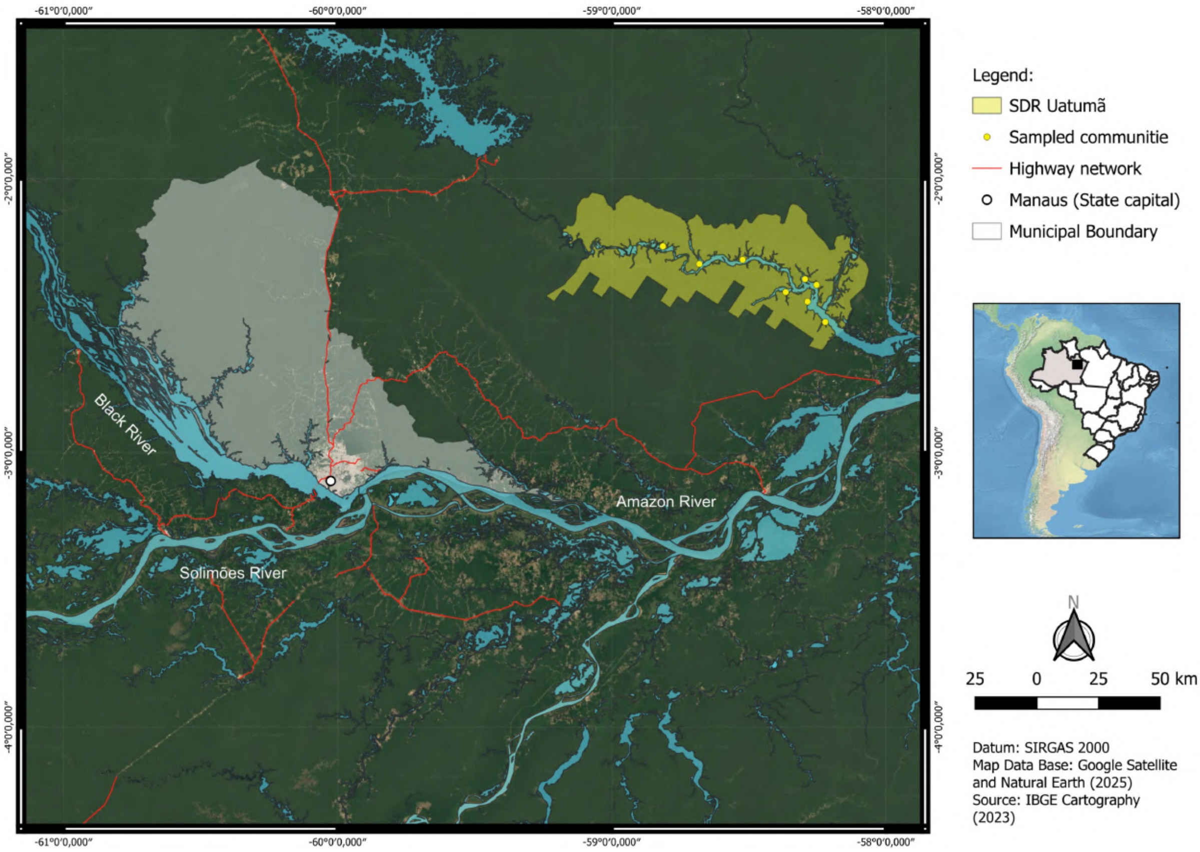

Figure 1. Location of the Uatumã Sustainable Development Reserve and the communities sampled
Figura 1. Localização da Reserva de Desenvolvimento Sustentável do Uatumã e das comunidades amostradas

cross-validation methodology was applied, which consisted of triangulating the vernacular names among different farmers and comparing them with photographic records and a specialized bibliographic review. Species names were standardized according to the International Plant Names Index (IPNI, 2025), and the botanical classification followed the criteria established by the Angiosperm Phylogeny Group system (APG IV, The Angiosperm Phylogeny Group, 2016). The species were classified according to the Importance Value Index (IVI), as described by Mori et al. (1983).

2.3 Hierarchical grouping – Usage Functions

The inventoried species were classified according to their use functions, considering the categories food (FOOD), non-timber forest product (NTFP), timber production (TIM), medicinal use (MED), and contribution to system restoration (REST). The REST category included species deliberately planted to promote environmental improvement, especially soil quality, such as plants used for biomass production, green manure, or soil decompaction. For each species, an attribute matrix was constructed with binary values (0 or 1) indicating the presence or absence of each category of use.

The composition of the use functions for each AFS was determined by multiplying the species presence/absence matrix per AFS by the species use matrix. The resulting usage profile was normalized and used to generate a dissimilarity matrix based on the standardized Euclidean distance.

From this matrix, the hierarchical grouping of the functions for the use of AFSs was carried out, using the UPGMA (Unweighted Pair Group Method with Arithmetic Mean) method. The ideal number of groups in the dendrogram was defined using the Mojena criterion (k = 1.25). The quality of the cluster obtained by the dendrogram was evaluated by means of the cophenetic correlation, which measured the degree of correspondence between the original dissimilarity matrix and the distance matrix represented in the dendrogram.

For the visual representation of the main uses of each grouping, a heatmap graph was built based on the matrix of use profiles, facilitating the visualization of patterns and similarities between the groups.

2.4 Biodiversity Analysis

The biodiversity of each use profile grouping was compared using the Shannon (H′) and Simpson (D) diversity indices, as proposed by Whittaker (1972), the Pielou (J) evenness index (Brower & Zar, 1977) and species richness. To verify significant differences between the use profiles, an analysis of variance (ANOVA) was performed, followed by the Scott-Knott grouping test to distinguish between means ($p < 0.05$). The normality of the data was tested by the Shapiro-Wilk test, the homogeneity of the variances was evaluated by the Bartlett test and the independence of the errors by the Durbin-Watson test.

3. RESULTS

The 22 AFSs analyzed cover a total area of 19.11 hectares, with an average planting age of 5.13 ± 2.36 years. The average diameter of the inventoried trees was 10.5±6.0 cm, and 56.3% of the individuals are in the diameter range between 5 and 10 cm. The average size of each AFS is 0.86 ± 0.64 hectares, with the largest having an area of 2.97 ha and the smallest of 0.11 ha. Each AFS contained an average of 170.08 ± 109.51 individuals.

In all, 4,006 tree individuals were inventoried, distributed in 27 families, 54 genera, and 61 species (Table 1). The total diversity of AFSs presented values of 2.84 for the Shannon Index, 0.88 for Simpson, and 0.69 for Pielou. The species accumulation curve indicated sample sufficiency for species richness from the 14th sampled AFS, with an increment of less than 1% of species from this. Considering IVI, ten species stood out, with values above 50%: *Inga edulis* Mart., *Carapa guianensis* Aubl., *Anacardium occidentale* L., *Schizolobium amazonicum* Huber ex Ducke, *Mangifera indica* Wall., *Dipteryx odorata* (Aubl.) Willd., *Theobroma grandiflorum* (Willd. ex Spreng.) K. Schum., *Persea Americana* Mill., *Bertholletia excelsa* O. Berg and *Handroanthus serratifolius* (Vahl) S. O. Grose.

The 61 species identified in the AFSs of the SDR of Uatumã exhibited a total of 120 use functions: 32 for food, 11 for non-timber forest products, 31 for timber, 29 for medicinal purposes, and 17 for soil restoration. The functional attributes dendrogram divided the AFSs of the SDR of Uatumã into four clusters, with the Mojena cut-off line passing at the height of 2.997 (Figure 2A).

Table 1. Botanical families and importance value index (IVI) of the species of AFSs of the SDR of Uatumã. DR = Relative Density; DivR = Relative Diversity; DoR = Relative Dominance; IVI = Importance Value Index

Tabela 1. Famílias botânicas e índice de valor de importância (IVI) das espécies dos SAFs da RDS do Uatumã. DR = Densidade Relativa; DivR = Diversidade Relativa; DoR = Dominância Relativa; IVI = Índice de Valor de Importância

Botanical family / Species	DR (%)	FR (%)	DoR (%)	IVI (%)
Anacardiaceae				
Anacardium occidentale L.	4,69	81,82	4,43	88,23
Mangifera indica Wall.	2,22	81,82	2,93	80,11
Spondias mombin Jacq.	1,32	18,18	2,63	20,59
Annonaceae				
Annona mucosa Jacq.	0,80	27,27	1,10	26,88
Annona muricata L.	1,57	13,64	1,02	15,07
Apocynaceae				
Couma utilis Müll. Arg.	0,52	13,64	0,55	13,56

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Revista ÁRVORE
ISSN 1806 – 9088

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Botanical family / Species	DR (%)	FR (%)	DoR (%)	IVI (%)
Apocynaceae				
Himatanthus sucuuba (Spruce) Woodson	0,40	9,09	0,40	9,13
Bignoniaceae				
Handroanthus serratifolius (Vahl) S. O. Grose	3,49	50,00	2,75	56,21
Jacaranda copaia (Aubl.) D.Don	0,07	4,55	0,13	4,37
Bixaceae				
Bixa orellana L.	0,62	27,27	0,39	26,00
Burseraceae				
Protium heptaphyllum Marchand	0,15	13,64	0,29	12,94
Trattinnickia burserifolia Mart.	0,25	4,55	0,31	4,72
Caryocaraceae				
Caryocar villosum Pers.	1,05	45,45	1,41	48,33
Clusiaceae				
Vismia guianensis (Aubl.) Choisy	0,12	13,64	0,19	12,81
Euphorbiaceae				
Hevea brasiliensis (Willd. Ex A. Juss.) Müll. Arg.	0,07	9,09	0,07	12,70
Fabaceae				
Adenanthera pavonina L.	0,07	4,55	0,11	4,35
Copaifera multijuga Hayne	0,05	4,55	0,03	4,25
Dipteryx odorata (Aubl.) Willd.	4,42	68,18	4,07	75,15
Enterolobium contortisiliquum (Vell.) Morong	1,25	9,09	2,69	16,44
Hymenaea courbaril L.	1,00	22,73	1,48	27,51
Inga edulis Mart.	27,16	100,00	25,94	153,05
Inga laurina (Sw.) Willd.	0,02	4,55	0,04	4,23
Parkia multijuga Benth.	0,02	4,55	0,01	4,21
Parkia paraenses Ducke	0,20	4,55	0,21	4,57
Schizolobium amazonicum Huber ex Ducke	7,71	59,09	9,86	80,12
Swartzia corrugata Benth.	0,20	13,64	0,26	12,96
Goupiaceae				
Goupia glabra Aubl.	0,72	13,64	0,96	14,17
Icacinaceae				
Poraqueiba sericea Tul.	0,05	4,55	0,04	4,25
Lauraceae				
Aniba rosaeodora Ducke	1,82	9,09	1,51	11,63
Laurus nobilis Cav.	0,07	4,55	0,07	4,31
Mezilaurus itauba (Meisn.) Taub.	0,17	13,64	0,12	12,80
Persea americana Mill.	1,85	68,18	1,63	65,94
Lecythidaceae				
Bertholletia excelsa O. Berg	2,75	54,55	4,57	57,27
Couratari oblongifolia Ducke & R. Knuth	1,55	22,73	1,43	23,78
Lecythis pisonis Cambess.	0,15	4,55	0,23	4,55
Malpighiaceae				
Malpighia crassifolia L.	2,27	31,82	3,34	34,74
Malvaceae				
Pachira aquatica Aubl.	0,05	4,55	0,08	4,29
Theobroma cacao L.	1,62	45,45	1,04	44,30
Theobroma grandiflorum (Willd. ex Spreng.) K. Schum.	4,77	59,09	3,21	66,25
Theobroma microcarpum Mart.	0,72	27,27	0,42	26,13
Melastomataceae				
Bellucia grossularioides (L.) Triana	0,62	22,73	1,03	22,47
Meliaceae				
Carapa guianensis Aubl.	15,23	90,91	12,13	119,48
Cedrela odorata L.	1,45	4,55	0,94	10,72
Swietenia macrophylla King in Hook.	0,05	4,55	0,03	4,25
Moraceae				
Artocarpus heterophyllus Lam.	0,55	27,27	0,42	25,96

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Botanical family / Species	DR (%)	FR (%)	DoR (%)	IVI (%)
Moraceae				
Maquira sclerophylla (Ducke) C. C. Berg	0,02	4,55	0,03	4,22
Myrtaceae				
Eugenia stipitata Mc Vaugh	0,02	4,55	0,01	4,20
Myrciaria dubia (Kunth)Mc Vaugh	0,20	4,55	0,22	4,58
Psidium guajava L.	1,32	31,82	0,90	35,65
Syzygium cumini (Duthie) R. R. Stewart	0,40	22,73	0,39	21,62
Syzygium malaccense (L.) Merr. & L. M. Perry	0,10	13,64	0,11	12,71
Quiinaceae				
Lacunaria jenmanii (Oliv.) Ducke	0,12	4,55	0,17	4,46
Rubiaceae				
Genipa americana L.	0,20	9,09	0,17	8,70
Morinda citrifolia L.	0,05	4,55	0,03	4,25
Rutaceae				
Citrus limonum Risso	0,17	9,09	0,11	8,62
Citrus reticulata Blanco	0,07	4,55	0,04	4,28
Citrus sinensis Pers.	0,32	22,73	0,23	21,38
Sapindaceae				
Nephelium lappaceum L.	0,12	18,18	0,07	16,86
Sapotaceae				
Pouteria caimito Radlk.	0,37	18,18	0,35	17,39
Simaroubaceae				
Simarouba amara Aubl.	0,50	31,82	0,57	30,23
Urticaceae				
Pourouma cecropiifolia Mart.	0,02	4,55	0,05	4,24

The cophenetic correlation observed was 0.679, with statistical significance by the Mantel test (p=0.001), indicating that the hierarchical clustering showed a moderate but consistent fit to the original data. The heatmap (Figure 2B) enabled the identification of the use patterns that best characterize the clusters suggested by the dendrogram (Table 2). Thus, we obtained four groups of AFSs: food (FOOD), timber (TIM), soil restoration (REST), and non-timber and medicinal production (NTFP_MED). The NTFP_MED group was formed because the analysis indicated a high similarity between AFSs intended for non-timber forest production and those with a medicinal profile, justifying the grouping into a single group.

The use groups of the agroforestry systems (AFSs) were compared according to four diversity indicators (Figure 3). Significant variation was observed between the groups regarding Shannon diversity (p=0.015), Simpson diversity (p=0.005), and species richness (p=0.008). There was no significant difference in the evenness of the species.

The Shannon diversity index (Figure 3A) presented the highest values in the TIM (2.16) and FOOD (2.15) groups, differing significantly from the NTFP_MED (1.65) and REST (1.32) groups. The Simpson Index (Figure 3B) found no significant difference between the TIM (0.86), FOOD (0.83), and NTFP_MED (0.74) groups, remaining in the significantly lower group only REST (0.61).

Species richness (Figure 3C) was also statistically higher in the TIM (19.00) and FOOD (17.62) groups, compared to the NTFP_MED (10.25) and REST (7.60) groups. Finally, the equability measured by the Pielou Index (Figure 3D) did not show significant differences between the groups, with values ranging from 0.65 to 0.80.

4. DISCUSSION

The results of this study demonstrate that the biodiversity and structure of AFSs in the SDR of Uatumã are directly influenced by the purposes of use desired by traditional communities, shaped according to their intended use. The diversity indices recorded, such as the Shannon Index (H' = 2.84) and the Simpson Index (D = 0.88), indicate a

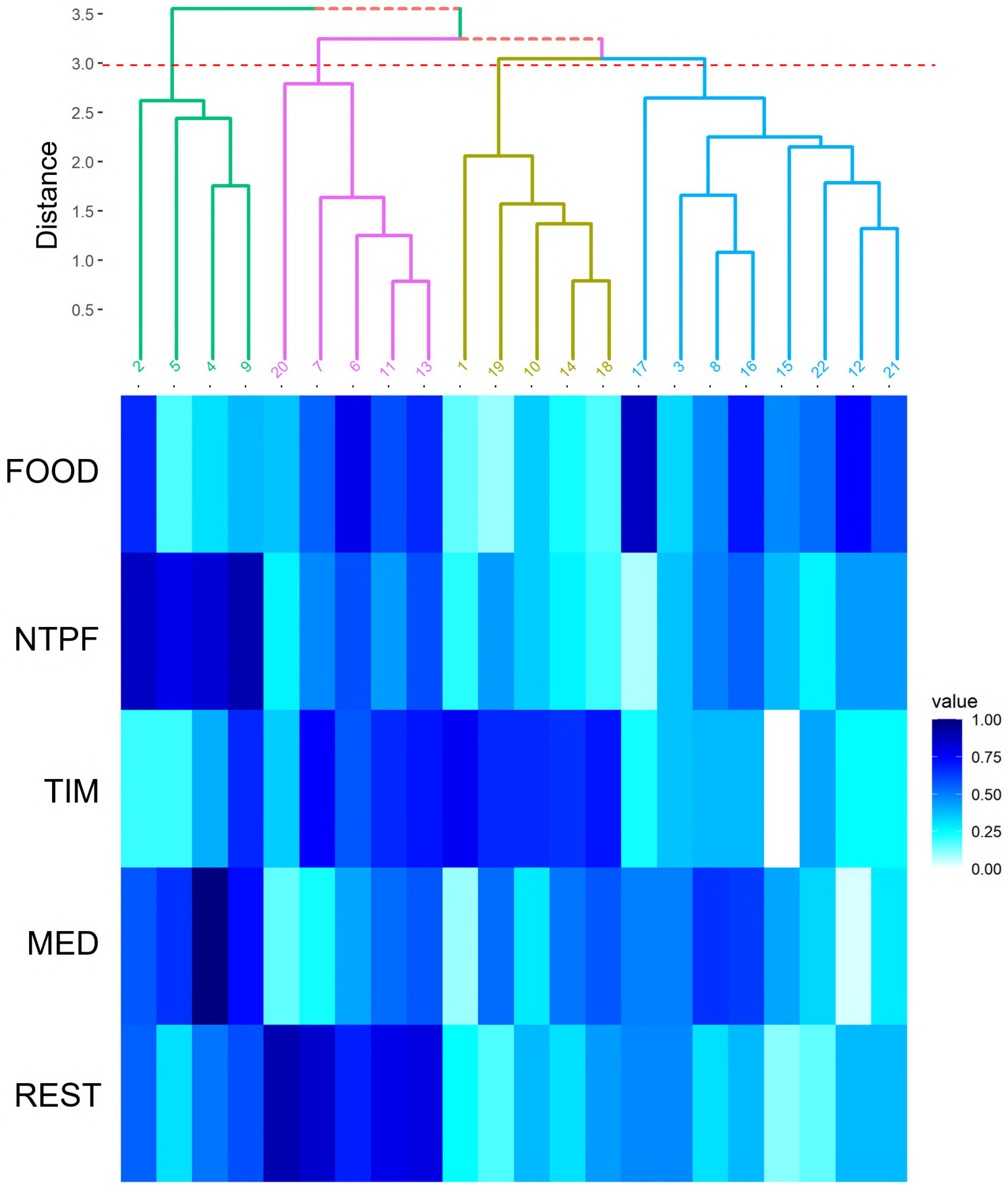

Figure 2. Hierarchical grouping analysis and patterns of use of AFSs. (A) Dendrogram resulting from hierarchical clustering analysis, identifying four distinct groups of AFSs based on the Mojena cut-off criterion (α = 2.98). The robustness of the cluster was evaluated by cophenetic correlation (r = 0.68; p < 0.001, Mantel test with 10,000 permutations). (B) Heatmap associated with the dendrogram, built from the use matrix of the AFSs

Figura 2. Análise de agrupamento hierárquico e padrões de uso dos SAFs. (A) Dendrograma resultante da análise de agrupamento hierárquico, identificando quatro grupos distintos de SAFs com base no critério de corte de Mojena (α = 2,98). A robustez do agrupamento foi avaliada pela correlação cofenética (r = 0,68; p < 0,001, teste de Mantel com 10.000 permutações). (B) Gráfico de calor (heatmap) associado ao dendrograma, construído a partir da matriz de uso dos SAFs

Table 2. Grouping of AFSs according to use patterns
Tabela 2. Agrupamento dos SAFs conforme os padrões de uso

Group	Main attribute	Complementary characteristics	Member AFSs
NTFP_MED	Non-timber and medicinal production	Smaller group (4 AFSs). Intermediate values in soil restoration; low for food and timber production	2, 4, 5, 9
REST	Soil restoration	More balanced functional values. Low expression in timber production	6, 7, 11, 13, 20
TIM	Timber production	Intermediate values in medical use; low for food, NTFP and restoration	1, 10, 14, 18, 19
FOOD	Food Production	Largest group (8 AFSs). Focus on food, with intermediate values in medicinal and NTFP	3, 8, 12, 15, 16, 17, 21, 22

moderate to high diversity, being values comparable to those of other agroforestry systems in tropical regions (Boadi et al., 2024; Tebkew et al., 2023; Loreau et al., 2001). These results reinforce the importance of AFSs for biodiversity conservation in modified Amazonian landscapes, as Santos et al. (2018) report. The Pielou Evenness Index (J = 0.69) indicated a relatively balanced distribution of species among the AFSs. This result is consistent with the patterns observed in managed agroforestry systems, in which the selection of species by the farmer can influence their relative distribution (Tebkew et al., 2023).

Although the average area of the sampled AFSs is less than one hectare, their value for conservation transcends the scale of the individual plot. In the landscape of the SDR of Uatumã, these systems form a heterogeneous matrix, given that over 400 families currently reside in the region, functioning as habitat islands, which increase ecological connectivity, especially of species with use value recognized by local communities. Vagge et al. (2024) report that these islands are key elements of the landscape, as they act as intermediate points of ecological connectivity, allowing the flow of species between fragments and contributing to biodiversity conservation at multiple scales. This role is particularly important in protected areas of sustainable use such as the SDR of Uatumã, where community management becomes an important strategy to harmonize biodiversity conservation with sustainable development (Fang et al., 2025).

The analysis of the use groups revealed that AFSs primarily focused on food production (FOOD) and timber production (TIM) exhibited the highest species diversity and richness indices (Figure 3). This result challenges the perception that food production systems are necessarily less biodiverse than those focused on purely forest plantations. Instead, it indicates a 'win-win' scenario, in which diversification to meet multiple subsistence and income needs promotes structural complexity and, consequently, higher biodiversity. This pattern is consistent with studies in coffee AFSs, where biodiverse systems not only provide use and environmental co-benefits, such as pollination and pest control, but can also maintain productivity without significant trade-offs (Wright et al., 2024). The REST group presented the lowest diversity values. This can be explained by the fact that management aimed at recovering degraded soils, such as the oxisols in the region, tends to prioritize a limited set of pioneer species that are fast-growing and nutritionally undemanding, often legumes, resulting in a simpler initial structure.

Hierarchical clustering analysis and the heatmap (Figure 2) not only separate AFSs into four distinct groups but also reveal the management strategies and underlying socioecological logics of traditional SDR communities in Uatumã. The clear distinction between the groups based on their use profiles confirms that these systems are intentionally designed to meet different needs, a characteristic of traditional agroecosystems (Isaac et al., 2024).

Figure 2B (heatmap) exposes the complexity behind each group. The FOOD group, although focused on food production, exhibits significant intermediate values for

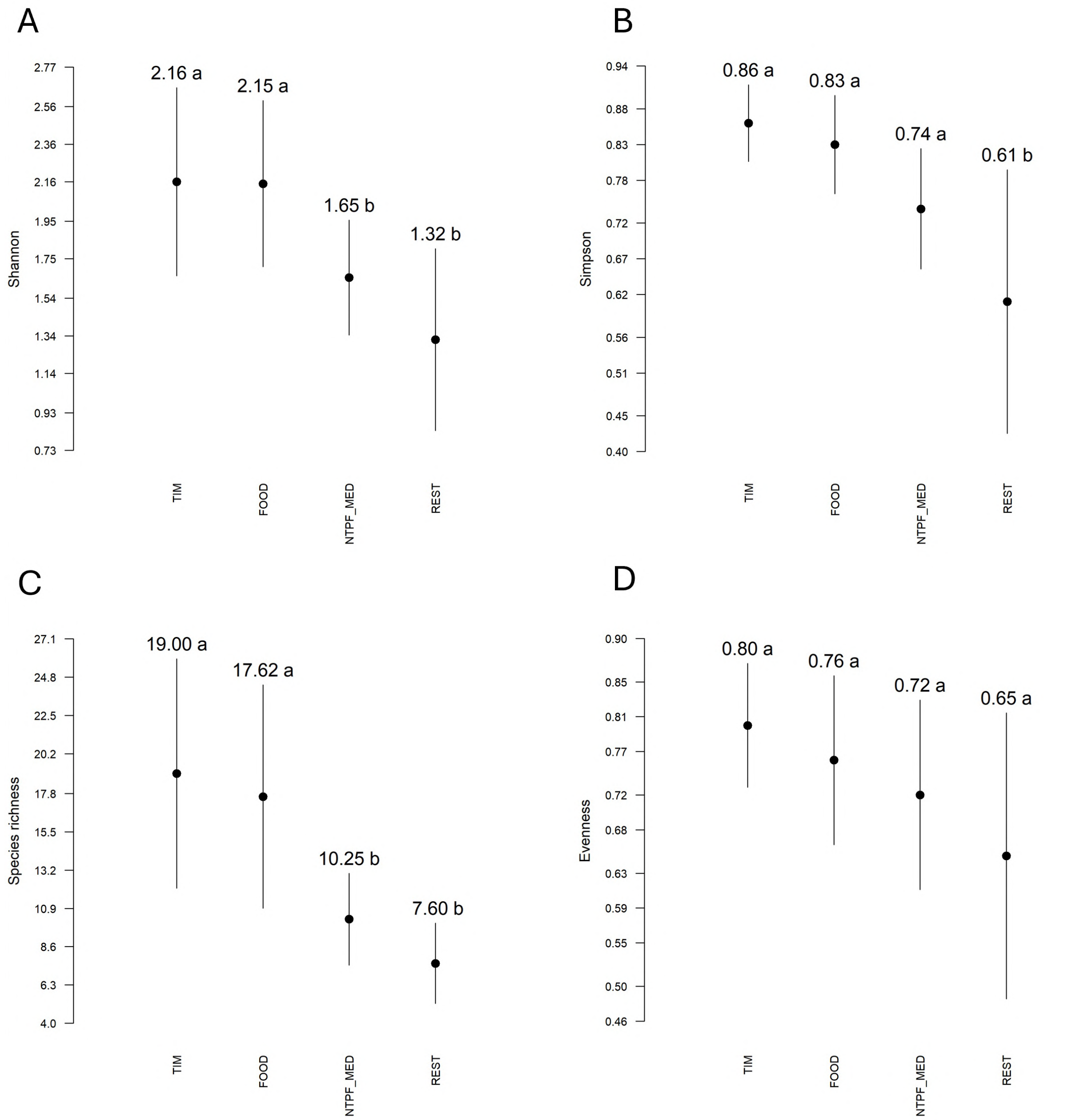

Figure 3. Comparison of diversity indices between four categories of AFS use (TIM = timber; FOOD = food; NTFP_MED = non-timber forest product and medicinal use; REST = system restoration). A. Shannon Index; B. Simpson Index; C. Species Richness; D. Evenness. The points represent the means, and the lines the standard deviation. Means followed by the same letter do not differ statistically ($p < 0.05$) by the Scott-Knott test

Figura 3. Comparação dos índices de diversidade entre quatro categorias de uso de SAFs (TIM = madeireiro; FOOD = alimentação; NTPF_MED = produto florestal não madeireiro e uso medicinal; REST = restauração do sistema). A. Índice de Shannon; B. Índice de Simpson; C. Riqueza de espécies; D. Equabilidade. Os pontos representam as médias, e as linhas o desvio-padrão. Médias seguidas de mesma letra não diferem entre si estatisticamente ($p < 0,05$) pelo teste de Scott-Knott

the medicinal categories and non-timber forest products. This shows a diversification strategy for livelihood security, where food production is integrated with other functions that guarantee the health and well-being of the family, a multipurpose management pattern documented in traditional AFSs in Mexico and Indonesia (Pérez-Nicolás et al., 2024; Sudomo et al., 2023). This diversity of intrinsic uses, which generates co-benefits without necessarily compromising the primary function, is one of the main arguments for the superiority of AFSs over monocultures (Wright et al., 2024).

In contrast, the TIM and NTFP_MED groups show greater specialization, as indicated by the darker, concentrated colors in their respective categories on the heatmap. This specialization indicates an orientation to local or regional markets, where production focused on a few products with higher added value (wood, oils, resins) becomes a viable economic strategy (Sudomo et al., 2023). However, it is notable that even these more specialized systems still maintain a certain level of diversity of uses, avoiding the complete simplification observed in conventional agricultural systems.

The REST group presents a distinct usage profile. As the heatmap shows, it does not have a single dominant category, but rather low to intermediate values distributed more evenly among all categories of use. This, combined with their lower species richness (Figure 3), suggests that these AFSs may represent early successional stages or areas in the process of recovering degraded soils. In these cases, farmers select pioneer and rustic species, but the main focus is not yet maximized production, but the reconstruction of the natural capital of the agroecosystem.

The relationship between each group's use profile and its biodiversity outcomes is particularly revealing. The FOOD and TIM groups, which proved to be the richest in species, validate the hypothesis that the diversification of use attributes by management can be a driver for taxonomic diversity (Mathieu et al., 2025). By selecting species for multiple purposes, farmers create AFSs with greater structural complexity (different strata, life forms), which, in turn, generates more ecological niches for the associated biodiversity. This result challenges the notion of an inevitable trade-off between production and conservation, aligning with studies that show that diversified agroforestry systems can sustain high biodiversity without compromising production (Wright et al., 2024; Callo-Concha & Denich, 2014). The lower diversity in the REST group, on the other hand, is in line with the findings of Wynter et al. (2025), who demonstrate that not all AFSs are equally beneficial for biodiversity; simpler or early-stage systems may have more modest results, but they are also important within their developmental stage.

According to the IVI values, Fabaceae was the most prominent family, both in wealth and abundance of individuals, showing its importance in the management of agroecosystems. It has multiple potential functions, ranging from biological nitrogen fixation to the supply of food, medicinal, and wood resources (Alanis Rodriguez et al., 2018; Haggar et al., 2015). The genus *Inga* reinforces the importance of species that perform multiple functions in an agroforestry system. In addition to their central role in soil improvement through biological nitrogen fixation — a pillar for the sustainability of tropical agroecosystems (Isaac et al., 2024) —, species of this genus provide food, shade and organic matter, agreeing with findings in other neotropical agroforestry systems (Villanueva-González et al., 2023).

Other families of great structural importance in the AFSs studied, such as Meliaceae and Lecythidaceae, exemplify these multiple functions, with species playing ecological roles beyond their primary use for the farmer. Species such as andiroba (*Carapa guianensis*) and brazil nut (*Bertholletia excelsa*), in addition to oil and brazil nut production (Tscharntke et al., 2012; Nakakaawa et al., 2010), respectively, are important for the maintenance of local trophic networks. The brazil nut tree, for example, depends on large bees for pollination and the agouti (*Dasyprocta leporina*) for the dispersal of its seeds, which is one of the main examples of mutualistic interaction in the Amazon (Peres & Baider, 1997). Families such as Anacardiaceae and Myrtaceae, abundant in AFSs, provide a continuous source of fleshy fruits, supporting a wide range of frugivorous animals, from birds to primates (Pizo & Galetti, 2010). By providing food resources and habitat, these species transform AFSs into biodiversity refuges, strengthening the resilience of the landscape (Sambuichi et al., 2012).

It is important to note that the diversity recorded in the AFSs of the SDR of Uatumã is composed of a mosaic of native and exotic species, and this practice is a common

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characteristic of traditional AFSs in the Amazon (D'Souza et al., 2021). However, this raises questions about the effects on the conservation of native biodiversity. Although these species provide abundant resources for generalist fauna, they can alter interaction networks, such as seed dispersal, potentially competing with native species for dispersers (Pizo, 2007). In addition, some species, such as *Artocarpus heterophyllus*, have known invasive potential in forest remnants in Brazil, which can suppress the regeneration of native plants (Togeiro et al., 2020). Thus, it is important to consider the monitoring of these plantations in the management programs of the Conservation Unit.

The divergence between the results of the Shannon and Simpson indices (Figure 3) offers a view of the structure of the tree community. While the Simpson index suggests a relatively similar species dominance among the FOOD, TIM, and NTFP_MED groups, the Shannon index, more sensitive to rare species (Melo, 2008), reveals significant differences. This indicates that, although farmers maintain a similar set of dominant and functional species, the different management objectives promote the coexistence of a varied set of less abundant species. This structure, even if carried out unintentionally, can be a signature of managed systems based on a deep knowledge of ecological interactions, aiming at long-term resilience. The absence of significant differences in equability (Pielou index) between the groups indicates that, regardless of use, the AFSs studied present a relatively similar distribution of the species.

The results of this study have direct implications for conservation and development policies in Amazon. The analysis of the use of AFSs points out that there is no single model of "sustainable agroforestry", even within a population that inhabits the same region and that must share similar practices and customs.

Public policies that do not recognize this diversity of management and objectives are at risk of being ineffective or even counterproductive (Klimke et al., 2024). To be successful, conservation, restoration strategies, and agricultural development programs must be flexible, valuing and supporting the different systems developed by traditional communities. Supporting AFSs with a food focus, for example, generates direct co-benefits for food security and local public health (Roy et al., 2025), while promoting timber AFSs can reduce pressure on primary forests, contributing to climate change mitigation.

5. CONCLUSION

This study reveals that AFSs in the Central Amazon are a mosaic of complex agroecosystems, whose structure and biodiversity are intentionally shaped by the use objectives of the traditional communities that manage them. The analysis of use profiles showed that management strategies, guided by traditional ecological knowledge, result in four distinct use groups, each with a signature in terms of species diversity.

Our results challenge the premise of an inherent conflict between production and conservation. We have demonstrated that AFSs with a focus on food and timber not only meet subsistence and income needs but also sustain high levels of tree species richness and diversity. This finding corroborates global evidence that diversified agricultural systems can generate multiple co-benefits without compromising productivity, representing a "win-win" scenario for farmers and biodiversity (Wright et al., 2024; Mathieu et al., 2025). In contrast, the lower diversity found in soil improvement AFSs should not be interpreted as a failure, but rather as an initial and strategic successional stage, in which the recovery of the productive capacity of degraded lands occurs in parallel with the process of restoring biological diversity over time.

The identification of these different configurations offers a basis for the planning of more effective public policies. It is evident that standardized approaches to the promotion of AFSs in the Amazon are inadequate and may fail to recognize and value the diversity of local productive logics (Klimke et al., 2024). Instead, restoration and rural development programs must be flexible, supporting the different models of AFSs according to their contexts and potential: encouraging food systems to strengthen food security and community health (Roy et al., 2025); integrating timber systems into sustainable value chains to reduce pressure on primary forests; and using soil improvement systems as a low-cost social technology for landscape recovery.

Ultimately, this work reinforces the irreplaceable role of traditional communities as architects of biodiverse landscapes. Understanding and supporting the logic behind its management systems is not only fundamental for biodiversity conservation in the SDR of Uatumã but is also a way to build a more sustainable and equitable future for the Amazon.

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AUTHOR CONTRIBUTIONS

Guimarães, E. R.: Conception of the study, development of methodology, data analysis and interpretation, writing of the manuscript, review and editing. Vargas, V. H. S.: Methodology development, data analysis and interpretation, writing of the manuscript, review and editing. Vianna, A. L. M.: Data collection, review and editing. Castro, A. P.: Review and editing. Cruz, J. F.: Review and editing.

DATA AVAILABILITY

The entire dataset supporting the findings of this study has been published within the article.

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