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Bee diversity in agroforestry parklands and fruit orchards dominated by shea, néré, mango and cashew trees

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ABSTRACT

This study analyses the diversity and composition of bee communities across different agroecosystems in northern Côte d'Ivoire, including shea (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) parklands, as well as mango (*Mangifera indica*) and cashew (*Anacardium occidentale*) orchards. The objective was to compare bee species richness, diversity, and similarity across these habitat types. Field surveys identified 30 bee species belonging to 22 genera and four families: Apidae, Halictidae, Megachilidae, and Colletidae. Apidae was the most diverse family across all environments. Parklands exhibited higher species richness (25 species) than orchards (15 species), with a notable dominance in néré parklands (21 species). However, the Shannon diversity index and evenness were higher in orchards (H' = 1.835; E = 0.69) than in parklands (H' = 1.54; E = 0.50), indicating a more homogeneous distribution of individuals in orchards. Species composition analysis revealed low similarity between parklands and orchards (31%), reflecting distinct bee communities. Ten species were common to all habitats, while 15 were specific to parklands and five to orchards, indicating strong ecological specialization. These results are explained by the greater floral diversity and heterogeneous structure of agroforestry parklands, which promote higher species richness compared to homogeneous orchards. Thus, this study highlights the importance of traditional agroforestry systems for bee biodiversity conservation and underscores the potential negative effects of agricultural intensification on pollinator communities.

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INTRODUCTION

Bee diversity is a key component of terrestrial ecosystem functioning and agricultural productivity, due to their fundamental role in the pollination of flowering plants. Globally, pollinators contribute to the reproduction of more than 75% of food crops, thereby ensuring food security and the stability of agricultural systems (Klein *et al.,* 2007). In the Savanes district, located in northern Côte d'Ivoire, agroforestry landscapes are dominated by traditional shea (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) groves, as well as mango (*Mangifera indica*) and cashew (*Anacardium occidentale*) orchards. These systems represent forms of sustainable land use, characterized by the conservation of useful trees within cultivated fields. They offer a diversity of floral resources and microhabitats favorable to a wide variety of bees, including both the honeybee (*Apis mellifera*) and numerous wild species (Kremen *et al.,* 2007; Boffa, 1999).

However, these ecosystems are currently under significant human pressure, including agricultural expansion, deforestation, wildfires, and the use of pesticides. These disturbances lead to habitat fragmentation and a reduction in the resources available to bees, which can affect their diversity and the pollination services they provide (Garibaldi *et al.,* 2013; Potts *et al.,* 2010). In this context, studying bee diversity in parks dominated by shea and néré trees, as well as in mango and cashew orchards in the Savanes district, appears essential. It not only allows for a better understanding of the structure and dynamics of pollinator communities but also enables an assessment of the influence of different land-use types on their distribution.

MATERIALS AND METHODS

Study sites

The study was conducted in the Tchologo and Poro regions (Fig. 1). The Poro region (12,500 km²) is located between 8°26' and 10°27' north latitude and 5°17' and 6°19' west longitude, and the Tchologo region (17,728 km²) between 9°35'50 north latitude and 5°13'30 west longitude. These regions are characterized by a Sudanese-type climate, marked by two seasons: a very distinct dry season and a rainy season. Their vegetation consists mainly of wooded savannas. The most dominant tree species in terms of size is the kapok tree (*Ceiba pentandra*).

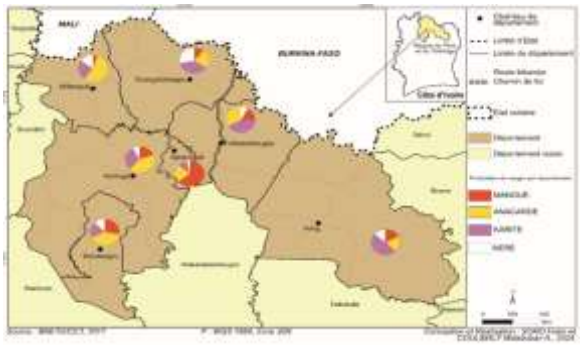

Fig. 1. Map of the Poro and Tchologo regions

Also found are the nere (*Parkia biglobosa*), the shea tree (*Vitellaria paradoxa*), the mango tree (*Mangifera indica*), and the cashew tree (*Anacardium occidentale*), whose fruits are consumed and sold by local communities.

Plant material

The plant material consisted of Néré (*Parkia biglobosa*), Shea (*Vitellaria paradoxa*), Mango (*Mangifera indica* L.), and Cashew (*Anacardium occidentale* L.) trees. The animal material consisted of bees collected from the various study areas.

The equipment consisted of colored cup traps (white, blue, and yellow) for capturing insects; pill bottles and 70% alcohol for preserving the insects; a thermo-hygrometer for measuring temperature and relative humidity; a binocular magnifying glass; and a reference collection of bees from Dr. Tuo Yalamoussa, confirmed by Alain Pauly in 2018.

Bee collection

To assess bee diversity in shea and néré parks, as well as cashew and mango orchards, colored cups (yellow, blue, and white) were used to trap bees (Saunders *et al.,* 2013). These cups were attached to metal stakes at flower height (Tuell *et al.,* 2009).

Three plots were sampled for each plant species, for a total of twelve (12) plots.

In the mango and cashew orchards, a standardized experimental setup organized into three 30-meter-long transects along the planting rows was used. In the shea and néré groves, the traps were positioned per tree at flower height, taking into account the 15-meter (m) distance between trees. At each tree, all three cup colors were represented.

Mounting and identification of bees

The mounting of bees involved sorting them to separate them from other insects captured by the cup traps. Appropriate entomological pins were used to mount the bees. In practice, the pin is inserted vertically into the right half of the scutum. It protrudes about one centimeter above the bee to allow for handling. Furthermore, the insect should not be pinned too low on the pin, as space must be left for labels. The wings are spread slightly apart so that the rear of the body is visible.

The specimens were mounted on a polystyrene backing to better spread out the legs rather than letting them dangle and risk breaking them during handling. The smallest specimens, approximately 5 mm in size, are pinned or glued to the tip of a Bristol board tag. The bee specimens were mounted and identified to the genus or species level.

Analysis of bee diversity

Diversity is defined as the degree of heterogeneity within a population (Blondel *et al.,* 1973). To assess bee diversity, several indices were used. Species richness and diversity indices (α-diversity and β-diversity) were calculated. α-diversity provides information on intra-habitat diversity. β-diversity, on the other hand, involves comparing species diversity across habitats or along environmental gradients.

Species richness (S)

Species richness (S) corresponds to the total number of bee species sampled in a given habitat (Morin and Findlay, 2001). It is very rare to record all insect species in a natural habitat (due to limitations often arising from insufficient sampling effort). However, it is possible to overcome this constraint by using estimation methods, which, based on a sample, allow for the determination of the expected species richness in the case of exhaustive sampling. The biodiversity analysis software EstimateS (Version 7.0) (Colwell, 2004) was thus used to estimate the expected species richness in the studied habitats.

S= Σ species

Diversity - α (alpha)

Shannon Index (H')

Species diversity was assessed using the Shannon diversity index (H′), which considers both species richness and the relative abundance of species within a community. Unlike species richness alone, the Shannon index incorporates differences in the abundance of individual species and is sensitive to both common and relatively rare species (Magurran, 2004).

The Shannon diversity index was calculated as:

$$H' = -\sum_{i=1}^{s} p_i log_2 p_i$$

where:

H′ = Shannon diversity index;

S = total number of species;

$p_i=N_i/N$ = proportion of individuals belonging to species i;

N_i = number of individuals belonging to species i; and

N = total number of individuals of all species.

The value of H′ is zero when only one species is present and increases as both species richness and evenness increase. For a given number of species, the index reaches its maximum value when all species are represented by equal numbers of individuals. The Shannon diversity index was calculated using EstimateS software (Version 7.0).

Equitability Index (E)

Also known as the evenness index, equitability (E) measures the even distribution of species. It allows for the comparison of stands containing different

numbers of taxa (Dajoz, 1982). Its purpose is to assess the balance of the populations present.

E = H '/ H' max
where:
H 'max = Log2 S (Blondel, 1979).
S represents total species richness.
E approaches 0 when a single taxon dominates a population, and equals 1 when all taxa have the same abundance

Diversity - β (Beta)

The Jaccard similarity index, or P-diversity, is a measure of biodiversity that compares species diversity between two ecosystems. This involves comparing the number of taxa that are unique to each ecosystem. It is calculated using the following formula.

$$J = \frac{a}{(a + b + c)}$$

With:
a: number of species common to two sites or habitats.
b: number of species unique to site or habitat 1.
c: number of species unique to site or habitat 2

Statistical analysis of the data

The data collected were analyzed using version 7.1 of the STATISTICA software and version 5.2.1 of the R software. Analysis of variance (ANOVA) and Duncan's test at the 5% significance level were used to analyze and compare bee diversity and abundance. The graphs were created using Microsoft Excel.

RESULTS

Bee species diversity

Across all study areas, 30 bee species were identified. These species belong to 22 genera grouped into 4 families (Apidae, Halictidae, Megachilidae, and Colletidae). The Apidae family is the most diverse, with 17 species. It is followed by the Halictidae (9 species), Megachilidae (3 species), and Colletidae (1 species) (Table 1).

In the shea and nere tree plantations, 25 bee species were identified. They belong to 4 families (Apidae, Halictidae, Megachilidae, and Colletidae) and are grouped into 20 genera. The Apidae family is the most diverse, with 15 species. It is followed by the Halictidae and Megachilidae families, with 7 and 2 species, respectively. The Colletidae family, the least diverse, contains only one species of bee (Table 1).

In mango and cashew orchards, fifteen (15) species of bees were identified. They belong to three families (Apidae, Halictidae, and Megachilidae) and are grouped into 13 genera. The Apidae family is the most diverse, with 8 species. It is followed by the Halictidae (5 species) and the Megachilidae (2 species) (Table 1).

Bee species diversity by habitat

Across all the néré parks, 21 bee species were identified. They belong to 4 families (Apidae, Halictidae, Megachilidae, and Colletidae) and are grouped into 20 genera. The Apidae family is the most diverse, with 12 species. It is followed by the Halictidae and Megachilidae families, with 6 and 2 species, respectively. The Colletidae family, the least diverse, contains only 1 species of bee.

Fourteen (14) bee species were identified in the shea parks. They belong to 3 families (Apidae, Halictidae, and Megachilidae) and are grouped into 12 genera. The Apidae family is the most diverse with 8 species. It is followed by the Halictidae (4 species) and the Megachilidae (2 species).

In mango orchards, eleven (11) bee species were identified. They belong to 3 families (Apidae, Halictidae, and Megachilidae) and are grouped into 10 genera. The Apidae family is the most diverse with 7 species. It is followed by the Halictidae (3 species) and the Megachilidae (1 species).

In cashew orchards, thirteen (13) species of bees were identified. They belong to 3 families (Apidae, Halictidae, and Megachilidae) and are grouped into 11 genera. The Apidae family is the most diverse with 7 species. It is followed by the Halictidae (4 species) and the Megachilidae (2 species).

Species diversity and evenness of bees by habitat type

The Shannon diversity index is higher (H'= 1.835) in orchards (mango and cashew) than in parks (shea and nere) where H'= 1.54 (Table 2). This means that orchards are more diverse, i.e., they contain a greater number of species and/or a better distribution of individuals among these species.

Table 1. List of bee species captured by habitat (A check mark indicates the presence of the species in the habitat)

Families	Species	Orchard	Park
Apidae	*Apis mellifera*	*	*
	Hypotrigona spp	*	*
	Meliponula bocandei	*	*
	Meliponula togoensis	*	*
	Amegilla spp	*	*
	Xylocopa olivacea	*	*
	Lipotriches spp	*	
	Ceratina spp	*	
	Melipona spp		*
	Amegilla nubica		*
	Anthophora spp		*
	Ceratina acantha		*
	Euglossa spp		*
	lipotriches pseudoclavada		*
	Tetralonia obscuriceps		*
	Xylocopa spp		*
	Bombus transversalis		*
Colletidae	*Hylaeus* spp		*
Halictidae	*Halictus* spp	*	*
	Lasioglossum spp	*	*
	Pseudapis spp	*	*
	Sphecodes spp	*	
	Halictus scabiosae	*	
	Halictus tripartitus		*
	Lasioglossum albescens		*
	Nomia spp		*
	Pattelapis spp		*
Megachilidae	*Megachile* spp	*	*
	Coelioxys spp	*	
	Chalicodoma spp		*
4 families	30 species	15 species	25 species

Table 2. Biological diversity of bees by plant species

Indexes	Orchard	Parks	*Anacardium occidentale*	*Mangifera indica*	*Vitellaria paradoxa*	*Parkia biglobosa*
Specific richness(S)	15	25	13	11	14	21
Shannon (H')	1,892	1.678	1,835	1,759	1,543	1,592
Equitability (E)	0,698	0,509	0,715	0,733	0,584	0,522

Regarding evenness, orchards have a higher value (E = 0.69) than parks (E = 0.50), indicating that in orchards, species are relatively well represented relative to one another. In contrast, the lower value observed in parks indicates an uneven distribution of species, with some dominant species and others less represented (Table 3).

Table 3. Jaccard similarity between parklands and orchards

Plant species	Park	Orchard
Orchard	0.312	1
Park	1	

This reflects a more even distribution of individuals across species in orchards, whereas in parks, the distribution is less balanced, with certain species dominating.

Similarity in bee composition between parks and orchards

Similarity coefficients indicate a low degree of similarity between the taxonomic composition of orchards (mango and cashew) and that of parks (shea and nere), with a value of 31% (Table 4). Of a

total of 30 species recorded, 10 species are common to both orchards and parks, representing 33%.

These include: *Apis mellifera*, *Hypotrigona* spp., *Meliponula bocandei*, *Meliponula togoensis*, *Amegilla* spp., *Xylocopa olivacea*, *Halictus* spp., *Lasioglossum* spp., *Pseudapis* spp., and *Megachile* spp. Furthermore, certain bee species are specific to habitat types.

Orchards host 5 specific species, namely: *Lipotriches* spp, *Ceratina* spp, *Sphecodes* spp, *Halictus tripartitus*, and *Coelioxys* spp. Finally, parks host the largest number of specific species, with 15 species, or 50%. These species are: *Melipona* spp., *Amegilla* spp., *Anthophora* spp., *Ceratina acantha*, *Euglossa* spp., *Lipotriches pseudoclavata*, *Tetralonia obscuriceps*, *Xylocopa* spp., *Bombus transversalis*, *Hylaeus* spp., *Halictus tripartitus*, *Lasioglossum albescens*, *Nomia* spp., *Pattelapis* spp., and *Chalicodoma* spp.

Similarity in bee composition by plant species

Similarity coefficients reveal a high degree of similarity in taxonomic composition between certain habitats. In fact, a 60% similarity is observed between mango and cashew orchards. Similarly, mango orchards and shea groves show a 56% similarity, while that between cashew orchards and shea groves is 58% (Table 4). These high values indicate that these habitats share a large number of bee species, reflecting relatively similar communities. In contrast, the similarities between néré groves and other habitats are low. Consequently, these habitats share few species in common, revealing a significant difference in the composition of bee communities.

Table 4. Jaccard similarity among bee habitats

Plant species	Mangue	Anacarde	Karité	Néré
Parkia biglobosa	0.230	0.214	0.296	1
Vitellaria paradoxa	0.562	0.588	1	
Anacardium occidentale	0.60	1		
Mangifera indica	1			

DISCUSSION

The results show that bee species richness is higher in agroforestry parks than in orchards. This difference can be explained primarily by greater floral diversity, the presence of varied natural vegetation, and less intensive agricultural practices in the parks. These observations confirm the findings of Gotlieb *et al.* (2011), Jha and Vandermeer (2010) and Kuhlmann (2009), who emphasize the importance of plant diversity in sustaining bee communities and conserving pollinators.

Parks dominated by néré and shea trees thus constitute favorable habitats thanks to their heterogeneous structure and the availability of numerous ecological niches. According to Garibaldi *et al.* (2013), traditional agroforestry systems represent true reservoirs of biodiversity. In contrast, mango and cashew orchards are characterized by a more homogeneous structure and reduced floral diversity, which limits the niches available to certain bee species. These findings align with those of Stein *et al.* (2017), who demonstrated that the simplification of agroecosystems leads to a decline in pollinator diversity.

The study also reveals that the Apidae family dominates across all the habitats studied. This high prevalence may be linked to their strong ecological adaptability and social behavior.

Species such as Apis mellifera and meliponas form large colonies and exploit a wide variety of floral resources. These results are consistent with those of Soro *et al.* (2024) in Côte d'Ivoire as well as those of Tuo *et al.* (2020) in mango orchards. However, they differ from the observations of Pauly *et al.* (2010), who indicate that the Halictidae constitute the most diverse family in sub-Saharan Africa. This discrepancy could be linked to ecological and methodological differences between the studies.

Furthermore, Colletidae were observed exclusively in néré parks. This pattern could be explained by

the availability of floral resources suited to their particular method of pollen collection, particularly among species of the genus *Hylaeus* (Pauly, 1979). This confirms the importance of plant diversity in sustaining different families of bees.

Analysis of diversity indices shows, however, that orchards exhibit higher species diversity than parks, despite lower species richness. The higher values of the Shannon index and evenness in orchards reflect a more balanced distribution of individuals among species. This situation is likely linked to the abundance of floral resources during periods of mass flowering of mango and cashew trees. Parks, on the other hand, show a strong dominance of certain generalist species such as *Apis mellifera* and *Hypotrigona* spp., thereby reducing overall evenness.

These results are consistent with the work of Ricketts *et al.* (2008); Klein *et al.* (2007) and who show that low-intensity agricultural systems can maintain high pollinator diversity when floral resources remain abundant.

The specific composition of bee communities varies greatly depending on the habitat. The low Jaccard similarity index observed between orchards and parks indicates that these environments harbor distinct communities. Common species, such as *Apis mellifera, Meliponula* spp., *Amegilla* spp., and *Xylocopa olivacea*, are primarily generalist taxa capable of exploiting various types of floral resources. Conversely, certain species observed only in parks, such as *Euglossa* spp. or *Tetralonia obscuriceps*, reflect a high degree of ecological specialization and confirm the role of néré parks as reservoirs of biodiversity.

Finally, the high similarity between mango and cashew orchards reflects the homogeneity of bee communities in these agricultural systems. The low similarity with néré parks, on the other hand, indicates that the latter possess specific ecological characteristics that favor particular assemblages. These observations align with the work of Steffan-Dewenter *et al.* (2002) and Brosi *et al.* (2008), which show that the structure of pollinator communities depends heavily on habitat diversity and the degree of naturalness of the environments.

In short, this study highlights the importance of agroforestry systems in conserving bee biodiversity, while also showing that less intensively managed orchards can also help support pollinators when they maintain sufficient floral resources and keep pesticide use to a minimum.

CONCLUSION

In conclusion, this study highlights the significant diversity of bee communities within the agroecosystems of northern Côte d'Ivoire, recording a total of 30 species across four families.

The results demonstrate that agroforestry parklands-specifically those dominated by shea and néré trees-exhibit higher species richness than mango and cashew orchards, a trend driven by their more diverse and heterogeneous vegetation structure. Conversely, orchards are characterized by greater evenness and a more homogeneous distribution of individuals among species. The ubiquitous dominance of the Apidae family across all habitats reflects their strong ecological plasticity and adaptability to diverse environments. Furthermore, the low similarity observed between parklands and orchards underscores the existence of distinct bee communities that are strongly influenced by land-use types. Parklands, particularly those with néré trees, serve as vital biodiversity reservoirs by harboring a large number of habitat-specific species. Ultimately, this study confirms the essential role of traditional agroforestry systems in conserving pollinator biodiversity and warns against the potential negative impacts of agricultural intensification on the structure and diversity of bee communities.

Consequently, future studies should quantify the direct impact of these distinct bee communities on fruit and nut yields to strengthen the economic arguments for parkland conservation.

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