World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(RESEARCH ARTICLE)

Ant diversity (Hymenoptera: formicidae) in cocoa orchards following an age gradient in the haut-sassandra region (Côte d'Ivoire)

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World Journal of Advanced Research and Reviews, 2025, 25(02), 2100-2112

Publication history: Received on 31 December 2024; revised on 15 February 2025; accepted on 18 February 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.25.2.0455

Abstract

Cocoa farming is the main cause of deforestation in Côte d'Ivoire, with dramatic side-effects for ecosystems and biodiversity. These consequences also affect ants, which play a crucial role in ecosystems, contributing to soil bioturbation, the regulation of phytophagous insects and the accidental pollination of flowers. In this context, it is very important to understand the effects of cocoa-based cropping systems on ant diversity in the ecosystems of the Haut-Sassandra. Cultural practices have an impact on the ant population present in these environments. The aim of this study was to identify the ant species present in cocoa plantations and to determine the influence of the age gradient of cocoa orchards on ant communities. A total of 79 species were identified. They belonged to 25 genera and 5 sub-families in the plantations in the different localities. The Pitfall method gave the highest abundance in Daloa and Issia. As for Vavoua and Zoukougbeu, the baiting methods gave the highest abundances. The species *Oecophylla longinoda* dominated all the plots.

This approach provides essential information for the sustainable management of cocoa plantations, taking into account the complex ecological interactions that exist between crops, biodiversity and agricultural practices.

Keywords: Cocoa plantation; Ant; Age gradient; Diversity; Ecosystem impact

1. Introduction

Ants (Hymenoptera: Formicidae) are ubiquitous social insects that play a major ecological role in terrestrial ecosystems, particularly in agricultural habitats where they influence pest population dynamics, organic matter degradation and soil structure [1]. They also contribute to the accidental pollination of flowers [2]. Their diversity, both in terms of species composition and community structure, is influenced by a multitude of environmental factors, including the age of agricultural plantations [3]. In agricultural systems, particularly in perennial crops such as cocoa, management practices and plantation maturation can modulate ecological conditions, thus affecting the associated fauna, including ants [4]. Thus, because of ants' sensitivity to environmental disturbances, these insects are used as biological indicators for assessing the integrity of biodiversity [5] [6].

Côte d'Ivoire is the world's leading cocoa producer. Cocoa orchards spread over a wide variety of terrain and climatic conditions, particularly in the Haut-Sassandra region, which is a key production area [7]. Cocoa trees, grown in

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agroforestry or monoculture systems, have a direct impact on the biodiversity of the insect communities that reside there, including ants. The latter are often sensitive to variations in soil conditions, humidity and plant structure, which are modified as the plantation develops [8]. Thus, ant communities in cocoa orchards can be influenced by the age of the plantations which modifies plant density, the structure of the plant cover, as well as the availability of resources and ecological niches. In this context, understanding the relationships between the characteristics of cocoa orchards and ant diversity thereby contributing to better management of biodiversity in cocoa farming systems [9].

The aim of this study is to examine ant diversity in cocoa orchards following an of age gradient in the Haut-Sassandra region. Specifically to (1) identify the ant species present in cocoa plantations and (2) determine the influence of the age gradient of cocoa orchards on ant communities.

2. Materials and methods

2.1. Study site

The study was carried out in the Haut-Sassandra region, in central-western Côte d'Ivoire, in the departments of Daloa, Vavoua, Issia and Zoukougbeu (Figure 1) from March 2021 to November 2021. In each department, nine cocoa plantations were selected. A total of 36 cocoa farms were selected for the entire study. The plots were chosen according to an age gradient in each department. These were young plots (0-10 years), intermediate-age plots (11-20 years) and old plots (21 years and over). These three types of cocoa farm were represented in each department. Haut-Sassandra region covers an area of 15,200 km². The climate is humid tropical, with two rainy seasons and two dry seasons. Annual rainfall varies between 1,300 mm and 1,800 mm. The vegetation consists mainly of dense semi-deciduous rainforests and wooded savannahs. The average annual temperature is around 26°C.

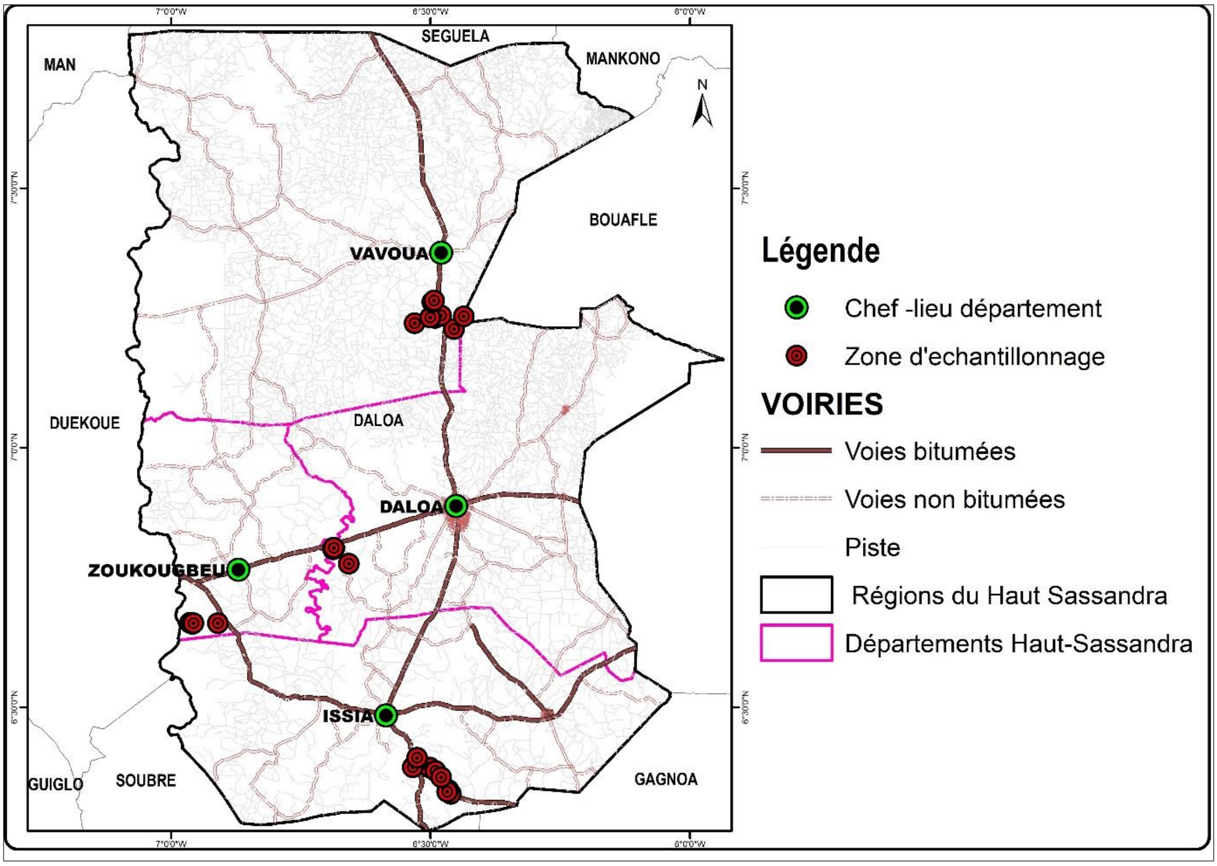

Figure 1 Study site

2.1.1. Sampling and identification

Ants were sampled along a 200 m long transect made up of 20 sections 10 m apart, around which pitfall traps, beating and food bait methods were applied.

The pitfall trap is a trap included in the ALL (Ants of the Leaf Litter) protocol. Containers commonly known as "beakers" of the same capacity (200 ml) were placed in the soil so that their upper rim was level with the soil surface. The cups were then filled to a quarter of their volume with a mixture of ethanol diluted to 70° and glycerin [10]. The beakers in the cups were then protected by tree leaves against any rain that might degrade the nature of the solution included. The Pitfal traps were recovered after 48 hours. The ants were then sorted and preserved in an Eppendoff tube containing 96° alcohol.

Threshing is a white cloth measuring one metre square used to collect fauna present in the canopy [11]. It consisted of tying four (04) rods around the tree to be sampled, so as to place them under its foliage (Figure 5c). The branches of the tree to be sampled were then vigorously shaken with a stick to make the insects fall onto the fabric below. The fallen ants were quickly collected using entomological forceps and preserved in an Eppendoff tube containing 96° alcohol.

Canned tuna (fatty) was chosen as the bait method. Tuna crumbs were placed at each section of the transect (Figure 5d). A total of 20 sampling points were set up. Samples were taken after 15 min, 30 min and 1 hour. The collected ants were preserved in eppendoff tubes containing 96°C alcohol.

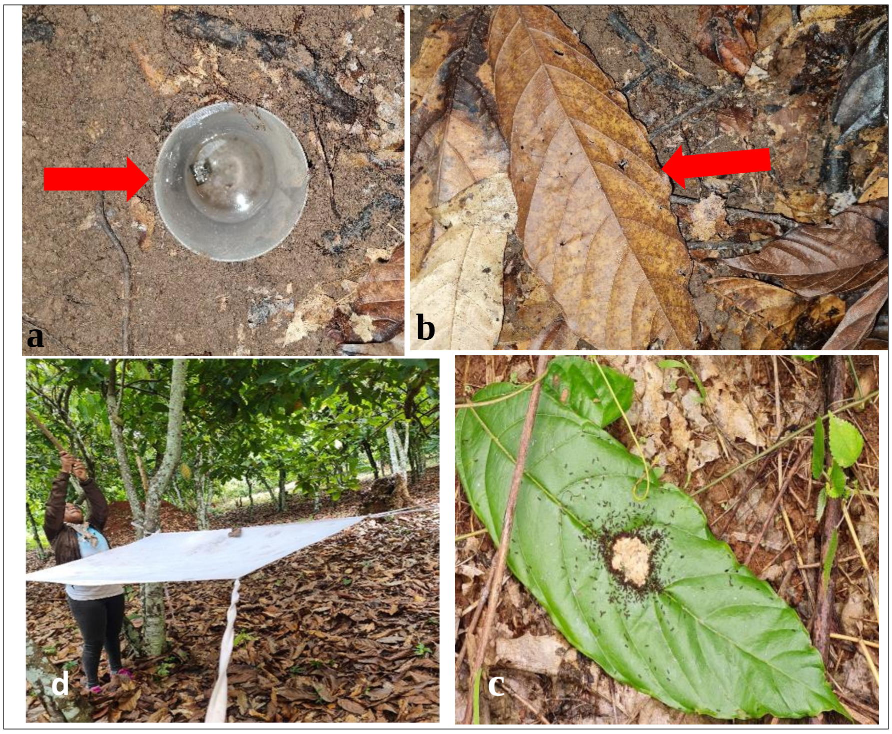

Figure 2 Ant sampling method (a and b: pitfall trap; c: food bait; d: beating)

2.1.2. Data Analysis

Data collected was entered into an EXCEL spreadsheet. The data were then subjected to an analysis of variance (ANOVA) using Statistica version 7.1 software in order to assess the diversity of the different plots. R software was used to plot the abundances and frequencies of occurrence of the plots along the age gradient. Sampling efficiency was then measured using species accumulation curves and sampling coverage rate. These tools make it possible to compare species richness and composition between different habitats. Species accumulation curves represent species richness as a function of harvesting effort, making it possible to compare the methods used in each department using EstimateS 9.1.0 software. Species richness corresponds to the number of species identified in a given environment and is calculated using estimators such as Jackknife 1 and Chao 2. Absolute abundance measures the total number of individuals of a species, while relative abundance assesses the contribution of one species in relation to the others.

The Shannon index allowed to assess diversity by taking into account species richness and abundance. The equitability index measures the distribution of individuals between species, and Simpson's index assesses the probability of choosing two individuals of the same species at random.

Analysis of variance (ANOVA) was used to test the significance of differences between groups (for example, between departments). A post-hoc test is applied to differentiate these groups if necessary. Hierarchical ascending classification (HAC) was used to group similar samples according to species abundance and richness, creating a dendrogram that helps to visualise similarities between environments. These methods offer a detailed approach for assessing and comparing ecological diversity in different areas.

3. The results

3.1. Sampling efficiency

Evaluation of the sampling efficiency revealed that more than 71% of the expected myrmecofauna was collected in the various localities (Table I). The sampling efficiency of ants in all departments varied from 71.61% (Issia) to 80.29% (Daloa) in the type of land cover studied, an average coverage rate of 76.47%. This rate indicates that the sampling method used was very effective in all departments.

The comparison between the accumulation curves with an asymptotic trend obtained from the Chao 2 estimator and the observed species richness shows a good estimate of the species richness of the ants in the different localities (Figure 6). The number of ant species would not change significantly even if additional transects had been sampled, as the curves have an asymptotic trend (Figure 7).

Table 1 Sampling richness and coverage at the various study sites

	Daloa	Issia	Zoukougbeu	Vavoua
Number of samples	540	540	540	540
Observed specific richness (Sobs)	51	51	52	42
Expected specific richness (Chao 2)	63,52	71,22	59,22	52,95
Sample coverage rate (%)	80,29	71,61	78,27	75,7
Number of unique species	6	13	7	2

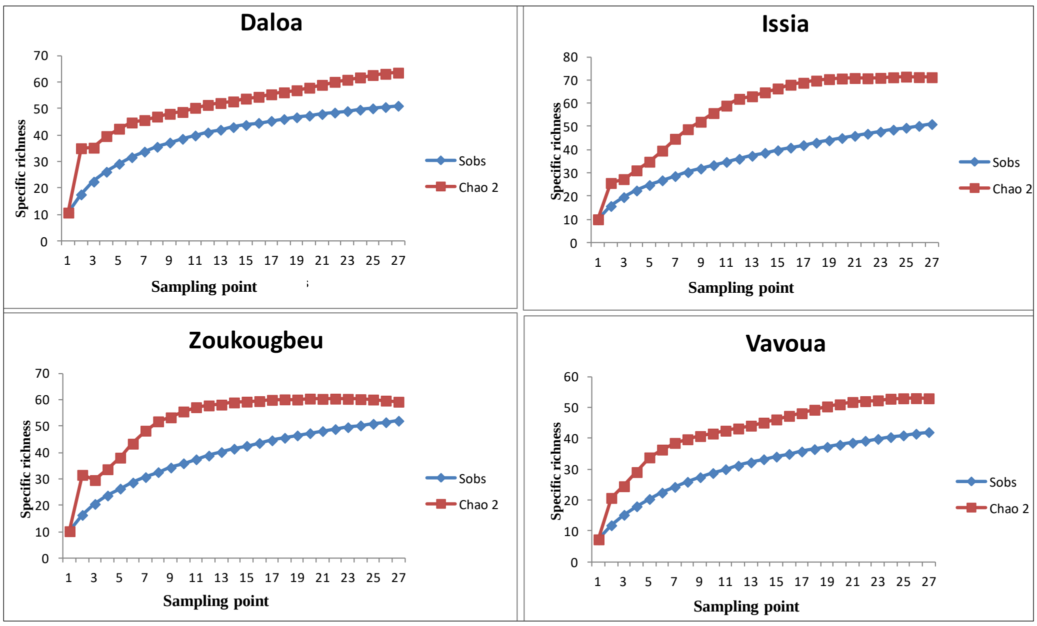

Figure 3 Ant species accumulation curve as a function of sampling effort in the various departments

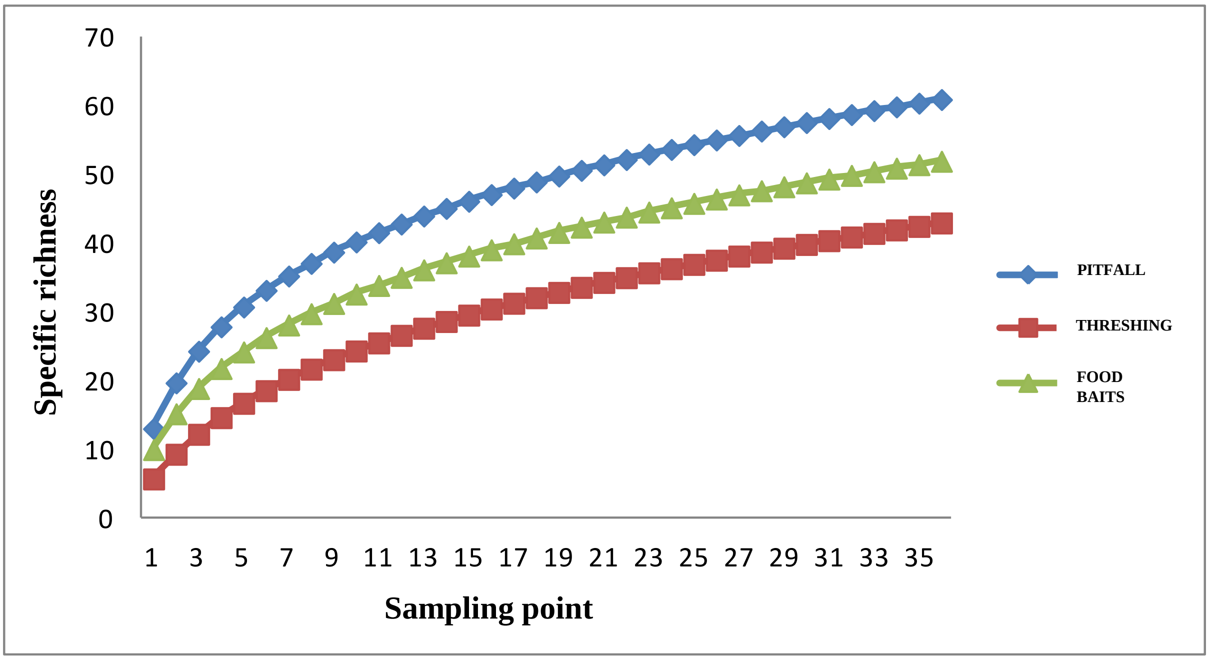

Figure 4 Species accumulation curves as a function of sampling method

3.2. Specific composition of ants

A total of 79 ant species were collected overall the sampling campaign. They belong to 25 genera and 5 sub-families (Dolichodorinae, Dorylinae, Formicinae, Myrmicinae and Ponerinae). (Table II). The department of Zoukougbeu and Issia (52 species) recorded the highest number of species, followed by the department of Daloa, which recorded 51 ant species. The department of Vavoua recorded the lowest number of species with 42 ant species.

Table 2 Specific composition of ant species in the various départements

Subfamilies	Tribe	Species	Daloa	Issia	Zoukougbeu	Vavoua
Dolichoderinae	Tapinomini	*Tapinoma lugubre*	180	68	159	59
	Tapinomini	*Tapinoma luteum*	0	1	0	0
	Tapinomini	*Tapinoma melanocephalum*	11	13	6	1
	Tapinomini	Tapinoma sp.1	0	4	0	0
	Tapinomini	Tapinoma sp.2	10	15	0	0
	Tapinomini	*Technomyrmex andrei*	1	0	1	0
	Tapinomini	Technomyrmex sp.1	0	0	1	0
Dorylinae	Ecitonini	*Dorylus nigricans*	44	63	43	85
	Ecitonini	Dorylus sp.1	51	0	0	3
	Ecitonini	Dorylus sp.2	271	120	65	39
	Ecitonini	Dorylus sp.4	1	0	1	2
	Cerapachyini	Parasyscia sp.1	0	1	0	0
Formicinae	Camponotini	*Camponotus acvapimensis*	36	26	6	11
	Camponotini	*Camponotus cinctellus*	29	69	19	5
	Camponotini	*Camponotus maculatus*	15	7	23	3
	Camponotini	*Camponotus schoutedeni*	0	1	0	0

	Camponotini	*Camponotus vividus*	4	2	3	11
	Formicoxenini	*Lepisiota egregia*	41	6	183	91
	Formicoxenini	Lepisiota sp.1	2	12	10	2
	Formicoxenini	Lepisiota sp.2	1	0	3	0
	Formicoxenini	Lepisiota sp.3	0	1	0	0
	Lasiini	*Nylanderia boltoni*	8	16	3	5
	Lasiini	*Nylanderia lepida*	0	3	0	0
	Lasiini	*Nylanderia scintilla*	1	1	0	1
	Formicini	*Oecophylla longinoda*	1222	865	757	736
	Formicoxenini	Plagiolepis sp.1	1	0	0	0
	Camponotini	*Polyrhachis concava*	0	1	4	1
Myrmicinae	Carebarini	*Carebara distincta*	9	0	2	11
	Carebarini	*Carebara thoraxica*	1	0	0	0
	Carebarini	Carebara sp.1	0	0	1	0
	Cataulacini	*Cataulacus erinaceus*	6	0	2	0
	Cataulacini	*Cataulacus traegaordhi*	0	0	2	0
	Crematogastrini	Crematogaster sp.1	76	86	23	1
	Crematogastrini	Crematogaster sp.2	68	35	38	23
	Crematogastrini	Crematogaster sp.3	146	0	3	1
	Crematogastrini	Crematogaster sp.4	0	0	2	0
	Crematogastrini	Crematogaster sp.5	15	1	1	2
	Crematogastrini	Crematogaster sp.6	0	2	7	0
	Crematogastrini	Crematogster sp.7	0	1	0	7
	Formicoxenini	Leptothorax sp.1	1	0	1	0
	Solenopsidini	*Monomorium afrum*	39	34	9	6
	Solenopsidini	*Monomorium bicolor*	65	3	134	34
	Solenopsidini	*Monomorium exigum*	0	1	0	0
	Solenopsidini	*Monomorium floricola*	76	1	59	120
	Solenopsidini	*Monomorium inquietum*	4	0	0	0
	Solenopsidini	*Monomorium occidentale*	0	3	0	0
	Solenopsidini	*Monomorium pharaonis*	13	4	1	4
	Solenopsidini	Monomorium sp.1	1	0	0	0
	Solenopsidini	Monomorium sp.2	0	1	0	0
	Solenopsidini	Monomorium sp.3	1	0	0	0
	Solenopsidini	Monomorium sp.5	162	0	2	19
	Pheidolini	Pheidole sp.10	21	37	8	44
	Pheidolini	Pheidole sp.12	0	3	19	0
	Pheidolini	Pheidole sp.3	70	153	294	496

	Pheidolini	Pheidole sp.4	78	113	2	0
	Pheidolini	Pheidole sp.6	73	42	41	5
	Pheidolini	Pheidole sp.7	662	238	382	225
	Pheidolini	Pheidole sp.8	948	238	652	553
	Dacetini	Strumigenys sp.1	1	0	0	1
	Tetramoriini	*Tetramorium aculeatum*	19	3	0	0
	Tetramoriini	*Tetramorium anxium*	3	1	3	0
	Tetramoriini	*Tetramorium bicarinatum*	0	0	0	1
	Tetramoriini	*Tetramorium caespitum*	0	0	0	6
	Tetramoriini	*Tetramorium caldarium*	0	0	4	0
	Tetramoriini	*Tetramorium rhetidum*	1	0	5	2
	Tetramoriini	*Tetramorium sericeiveintre*	1	2	1	1
	Tetramoriini	*Tetramorium simillimum*	0	0	8	11
	Tetramoriini	*Tetramorium sepositum*	0	1	0	0
	Tetramoriini	*Tetramorium versiculum*	27	2	6	7
	Tetramoriini	*Tetramorium zambesium*	0	1	0	0
Ponerinae	Ponerini	*Bothroponera sorore*	0	1	0	0
	Ponerini	Hypoponera sp.1	0	1	0	0
	Ponerini	*Leptogenys occidentalis*	1	0	0	0
	Ponerini	Leptogenys sp.1	0	2	1	0
	Ponerini	*Mesoponera caffraria*	16	51	17	10
	Odontomachini	*Odontomachus troglodytes*	111	161	129	150
	Ponerini	*Paltothyreus tarsatus*	65	151	111	55
	Pseudomyrmecini	Tetraponera sp.1	0	0	3	0
	Pseudomyrmecini	Tetraponera sp.2	0	0	1	0
5	14	79				

3.3. Bottom-up classification analysis based on sampling methods

The hierarchical classification of the sampling methods used, based on the species richness of the ants, shows similarities between the methods applied. Two main groups stand out (Figure 8). The first group (I) is the pitfall method. The second group (II) is made up of the beating method and the food bait method. The similarity dendrogram shows that the pitfall trap method is very clearly separated from the beating method and the food bait method. The beating method and the food bait method show a high degree of similarity concenring the ant species collected. The species richness of the ants seems to be related to the type of method used.

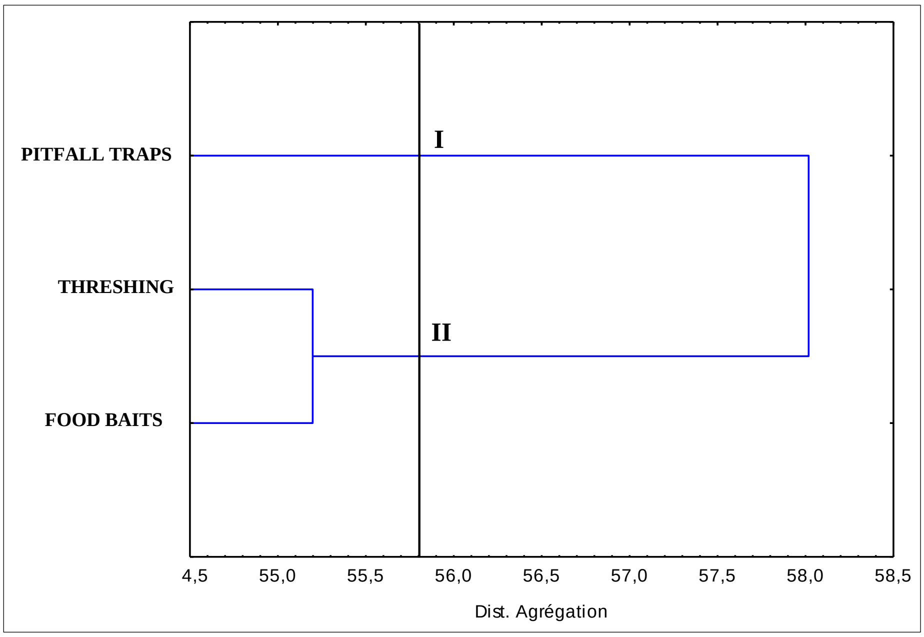

Figure 5 Similarity of environments according to sampling method

3.4. Ant abundance as a function of sampling method and age of cocoa trees

The evaluation of ant abundance according to the sampling method (Figure 9) showed that in the Daloa department, the pit trap method collected the greatest number of ants, followed by the food bait method and finally the beating method. In the department of Issia, the pit trap method also enabled the greatest number of ants to be collected, followed by the beating method and the food bait method. In the department of Zoukougbeu, the food bait method enabled the greatest number of ants to be collected, followed by the pit trap method and the beating method. In the department of Vavoua, the food bait method enabled the greatest number of ants to be sampled, followed by the beating method and finally the pit trap method.

The abundance of ant species as a function of the age gradient of the plot shows that there is no significant difference between age classes (Figure 10). However, the abundance of intermediate-age plots (5231 individuals) was the highest, followed by old (4167 individuals) and young (4086 individuals) plots.

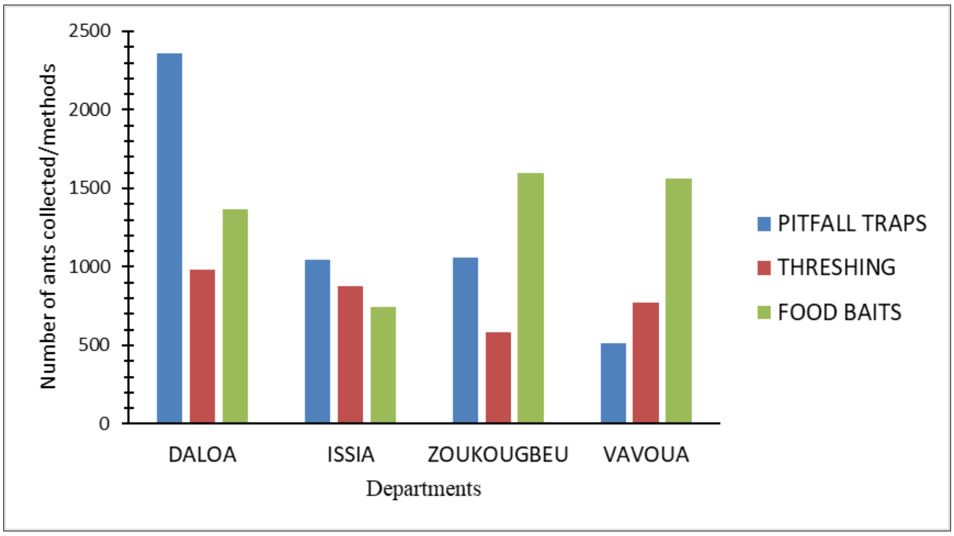

Figure 6 Relative abundance according to sampling method in plantations

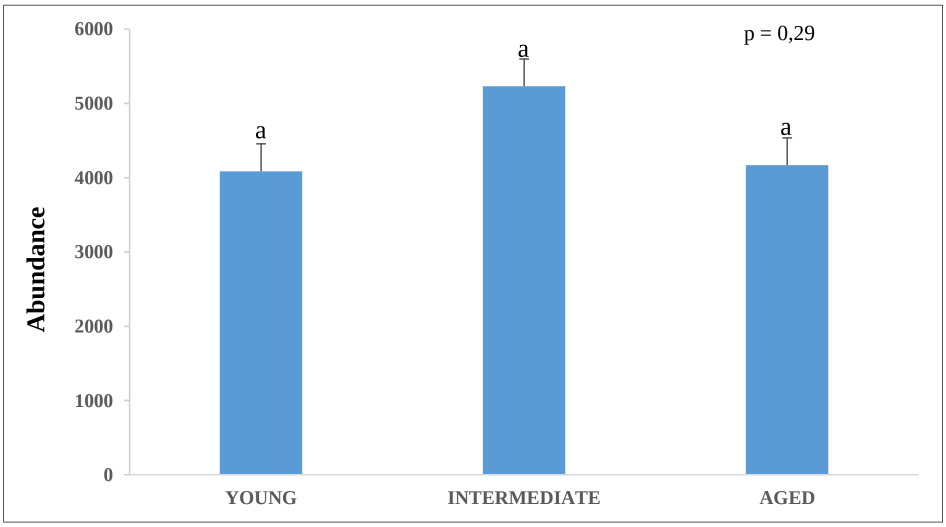

Figure 7 Abundance of ant species as a function of plot age gradient

3.5. Effect of the age gradient of cocoa trees on the diversity index

Analysis of the diversity indices indicates that ant diversity differs according to the age classes of the cocoa farms in the departments (Table III). In the Daloa department, plots with old cocoa trees are more diverse (H'= 2.54), followed by plots with young cocoa trees (H'= 2.38). Plots with intermediate cocoa trees (H'= 2.12) have the lowest Shannon index value. In the same locality, equitability values ranged from 0.62 to 0.71. The highest value was obtained in plots with old cocoa trees (E= 0.71), while the lowest value was obtained in plots with intermediate cocoa trees (E= 0.62). The Simpson indices for these plots ranged from 0.81 (plots with intermediate cocoa trees) to 0.89 (plots with old cocoa trees).

In the department of Issia, plots with young and intermediate cocoa trees are more diversified (H' = 2.40) than plots with old cocoa trees (H' = 2.38). Equitability values are between 0.67 and 0.73 for intermediate and old cocoa plots respectively. Simpson's index varies from 0.82 to 0.86. It is higher in plots with young cocoa trees and lower in plots with intermediate cocoa trees.

The Shannon diversity indices value in the Zoukougbeu department vary according to the plots. The Shannon index is higher in plots with old cocoa trees (H' = 2.50), while it is lower in plots with young cocoa trees (H' = 2.27). The same applies to the equitability and Simpson indices. Equitability is higher in plots with old cocoa trees (E = 0.69) and lower in plots with young cocoa trees (E = 0.64).

Table 3 Diversity of plots sampled according to the three plot age classes

Department	Plots	Shannon (H')	Equitability (E)	Simpson (Dominance)
Daloa	0-10 years	2.38	0.67	0.82
	11-20 years	2.12	0.62	0.81
	>20 years	2.54	0.71	0.89
Issia	0-10 years	2.40	0.69	0.86
	11-20	2.40	0.67	0.82
	>20 years	2.38	0.73	0.85
Zoukougbeu	0-10	2.27	0.64	0.85
	11-20 years	2.34	0.68	0.86
	>20 years	2.50	0.69	0.88
Vavoua	0-10 years	1.90	0.64	0.81

	11-20 years	2.11	0.66	0.82
	>20 years	2.54	0.71	0.85

3.6. Composition and dominance along the age gradient

The results show that 13488 individuals were collected from all the plots in the Haut-Sassandra region. The young and old plots were dominated respectively by the species *Oecophylla longinoda* with 1263 and 1083 individuals, while the intermediate plots were dominated by the species *Pheidole sp8* with 1328 individuals, although the species *Pheidole sp7* and *Pheidole sp3* were very present in the different plots (Table IV). On all the plots, the species *Oecophylla longinoda* had the highest number of individuals, with a total of 3580 individuals recorded (Figure 12).

Table 4 Specific composition as a function of age gradient

SPECIES	YOUNG	INTERMEDIATE	AGED	TOTAL
Oecophylla longinoda	1263	1234	1083	3580
Pheidole sp.3	555	348	110	1013
Pheidole sp.7	236	744	527	1507
Pheidole sp.8	560	1328	503	2391
Tapinoma lugubre	179	147	140	466
TOTAL	**4086**	**5235**	**4167**	**13488**

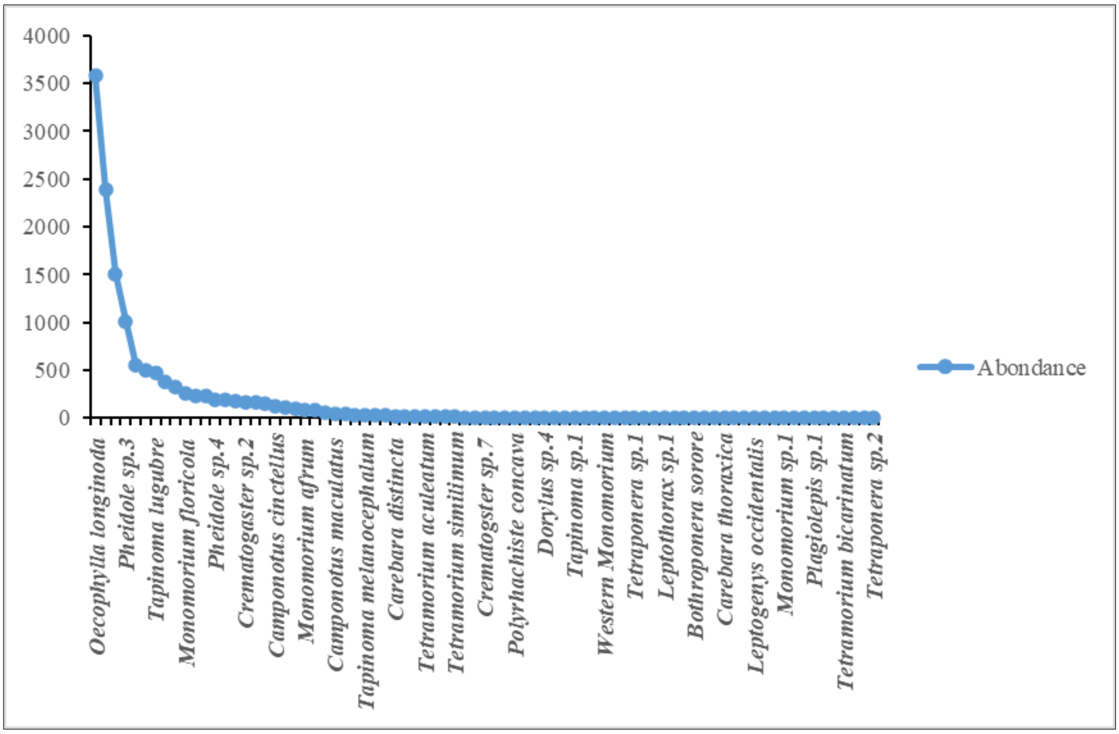

Figure 8 Rank-frequency diagram illustrating the dominance of ant species

4. Discussion

The sampling conducted in cocoa plantations across the departments of Daloa, Issia, Zoukougbeu, and Vavoua allowed for the collection of 76.47% of the expected ant species. This level of representativity suggests that the sampling effectively captured the ant diversity present in these plantations. These results align with other studies showing that proper sampling can capture the majority of insect species diversity in agricultural systems [12] [13] [14].

In total, 79 species were collected, belonging to 25 genera and 5 subfamilies. The departments of Daloa, Issia, and Zoukougbeu exhibited higher species richness (51, 52, and 52 species, respectively), compared to Vavoua (42 species). These variations in species richness may be linked to ecological and environmental factors such as plantation management, vegetation structure, and local agricultural practices [15] [8]. Furthermore, the observed differences could reflect the effect of plantation age on ant community composition, with more diverse communities in older plantations, as seen in other studies on insect diversity in similar agroecosystems [12].

The hierarchical classification of the environments based on the species composition of each plot according to the methods revealed two distinct groups. Samples obtained using beating and baiting methods were significantly similar in their species composition, while they differed from those obtained using pitfall traps. Each sampling method captures different species of ants due to its specific characteristics. The pitfall trap method, for example, is more efficient at capturing ants that live on or in the soil, whereas beating and baiting methods may be more effective at capturing ants living in vegetation or attracted to bait. This aligns with the findings of [16], who demonstrated that different sampling methods can result in biases in species richness and composition estimates. Additionally, the plots studied may show variability in their species composition due to differences in vegetation types, environmental conditions, and other ecological factors. This heterogeneity can lead to the formation of distinct groups in hierarchical classification. Pitfall traps may be more sensitive to species richness in habitats where ants living in the soil or litter are abundant, while beating and baiting methods may be more sensitive in habitats where ants living in vegetation or attracted to bait are more numerous. The differences in sensitivity and efficiency of sampling techniques could lead to different results in the specific composition of the collected samples, which could influence the hierarchical classification of environments. The combination of these factors could explain why samples collected by pitfall traps form a distinct group from those collected by beating and baiting methods. The latter might present similar species compositions due to their shared characteristics and sensitivities. These results are in agreement with [17], who asserts that variability in abundance is related to habitat rather than time.

Shannon and Simpson diversity indices indicated that the sampled habitats are indeed diverse, which is generally an indicator of ecological complexity and ecosystem stability [18]. These results suggest that the cocoa plantations in the region provide suitable environments for ant diversity, reflecting management practices that promote biodiversity in these plantations. According to [19], this may be due to the ecosystems in the region offering a greater variety of habitats and ecological niches for diverse species.

This study showed that the plots in the departments of Daloa, Issia, Zoukougbeu, and Vavoua are all dominated by *Oecophylla longinoda*. The habitats in these departments may be particularly well-suited to the ecological needs of *Oecophylla longinoda*, providing abundant nesting sites and food resources. These results corroborate those of [20], who observed a high abundance of *Oecophylla* ants on Kent mango trees in northern Côte d'Ivoire. According to [21] Allou *et al.* (2006), a significant presence of *Oecophylla* ants has been noted in coconut plots older than 4 years. This species is well known for its ecological role in regulating pest populations [22]. The predominance of *O. longinoda* may indicate ecological stability in these plantations, with this species contributing positively to pest management and local ecosystem structuring. Other studies have shown that this species, due to its social behavior and feeding habits, plays a key role in agroecosystems [23].

5. Conclusion

This study resulted in the collection of 79 species distributed across 25 genera and 5 subfamilies from plantations in various localities. The similarity in species richness based on sampling method indicated that samples collected using food baiting and beating methods were relatively identical in terms of species composition, whereas they differed from those collected using the pitfall trap method. The pitfall method yielded the highest abundances in Daloa and Issia. In contrast, for Vavoua and Zoukougbeu, the baiting methods provided the highest abundances.

The species composition of the environment, in relation to the age gradient of the plots, suggests that both young and old plots are dominated by the species *Oecophylla longinoda*, while intermediate-aged plots are dominated by the species Pheidole sp.8. The results of this study reinforce the idea that ant diversity in cocoa orchards in the Haut-Sassandra region is strongly influenced by the age of the plantations and the sampling techniques used. Sustainable orchard management could take advantage of this diversity by optimising farming practices to favour beneficial ant species while minimising negative impacts on local ecosystems. These results also pave the way for future research into the interactions between ants and other components of agroecosystems, in particular the interactions between ants and other beneficial or harmful insects, as well as their influence on soil health and crop productivity.

Compliance with ethical standards

Acknowledgments

The authors again express their gratitude to the villages and their inhabitants, especially the farmers, for their cooperation during the sampling. They would also like to thank the ECOOKIM group for their technical support.

Disclosure of conflict of interest

The authors declare that they have no conflict of interest with respect to this article.

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