

Does Forest Patch Fragmentation Reshape Arboreal Ant Assemblage: Case Study around the Lamto Scientific Reserve, Central Côte d'Ivoire?

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Abstract

Arboreal ants are an essential component of the canopy fauna in tropical forests. However, very little is known about their responses to human-induced disturbances. This study examines the effects of forest habitat fragmentation on arboreal ant communities in a forest-savanna mosaic in central Côte d'Ivoire. Using sampling methods such as funnel traps and vegetation beating, ants were collected from tree trunks and in the lower canopy layer. Sampling was conducted during 2019 in both the dry and rainy seasons. A total of 74 ant species were collected, belonging to 23 genera and 6 subfamilies (Ponerinae, Formicinae, Dorylinae, Myrmicinae, Dolichoderinae, and Pseudomyrmicinae). The largest number of species was collected in the reserve's forest islands (58 species), followed by rural forests (42 species), cocoa plantations (30 species), and rubber plantations (26 species). Furthermore, species compositions differed among habitats. Furthermore, six species were identified as indicator species in the reserve's forest islands, compared to two species in the rural forest remnants. In cocoa and rubber plantations, no species were identified as indicator species. Indeed, human activities affecting rural forest fragments have a negative impact on the diversity and distribution of arboreal ants.

Keywords

Biodiversity, Insects, Canopy, Adaptation, Global Changes

1. Introduction

Arboreal ants are a key component of the canopy fauna in tropical forests. Indeed,

they include a wide variety of species with diverse nesting sites [1]. In the canopy, ants exert significant predation pressure and thus significantly influence the diversity, structure, and dynamics of other arboreal arthropods [2], hence their use as biological control agents [3] [4]. Furthermore, these ants are considered pollinators for certain plants [5]. Despite the key role of arboreal ants, studies conducted on ant diversity and distribution in Côte d'Ivoire have primarily focused on ground-dwelling ants [6]-[8]. Consequently, there is a significant lack of data on the diversity of arboreal ants in Côte d'Ivoire. Indeed, deforestation caused by intensive agriculture, unregulated logging, and population growth and industrialization has led to the loss of natural habitats [9]. Thus, one of the major consequences of this phenomenon is habitat fragmentation. In the long term, this leads to changes in the structure and functioning of the resulting habitat fragments [10].

Central Côte d'Ivoire is home to a unique type of vegetation known as a forest-savanna mosaic, which lies at the intersection of two major biomes (forest and savanna) [11]. Indeed, these habitats are of particular importance for biodiversity conservation [12], and agricultural activity is significant there, as they offer the dual opportunity to grow food crops typical of savanna areas such as yams and export crops like cocoa and coffee, which originally require forest plots [13]. Recently, rubber cultivation has been added to these export crops in this region of the country [14], exacerbating the phenomenon of habitat fragmentation. Evergreen forests or semi-deciduous forests embedded within savannas are often interpreted as remnants of what were originally continuous forests, while the savannas are viewed as forests degraded by human activities [15].

However, studies examining the effects of habitat fragmentation on animal diversity focus on vertebrates. Few studies have examined the impact of habitat fragmentation on the species and functional diversity of invertebrates, particularly insects like ants [16], even though they play a key role in ecological processes such as nutrient cycling, pollination, seed dispersal, and predation [17]. This work aims to understand the impact of habitat changes on arboreal ant populations in the Lamto Scientific Reserve area. Specifically, it consists of 1) assessing the arboreal ant assemblage and their distribution in their natural habitats within the various habitats of the Lamto Reserve and surrounding areas, and 2) assessing those of the habitats in the rural area adjacent to the reserve, namely, the cocoa and rubber plantations, as well as the remnant forests found there.

2. Materials and Methods

2.1. Study Site

This study was conducted in the Taabo Department in central Côte d'Ivoire. The study sites were selected within the Lamto Reserve and in the remnant forests, as well as in the cocoa and rubber plantations of the village of Zougoussi, located at 7 Km at the West of the Lamto Reserve (Figure 1). The annual mean precipitation is 1257 mm, and the mean temperature varies around 28°C annually. The vegetation consists of a forest-savanna mosaic including humid Guinean Savanna (GS),

Forest Islands (FI) and Gallery Forests (GFs). Sampling was focused on Forest Islands (FI) and Gallery Forests (GFs) within Lamto Scientific Reserve and in agroecosystems surrounding the Lamto Reserve.

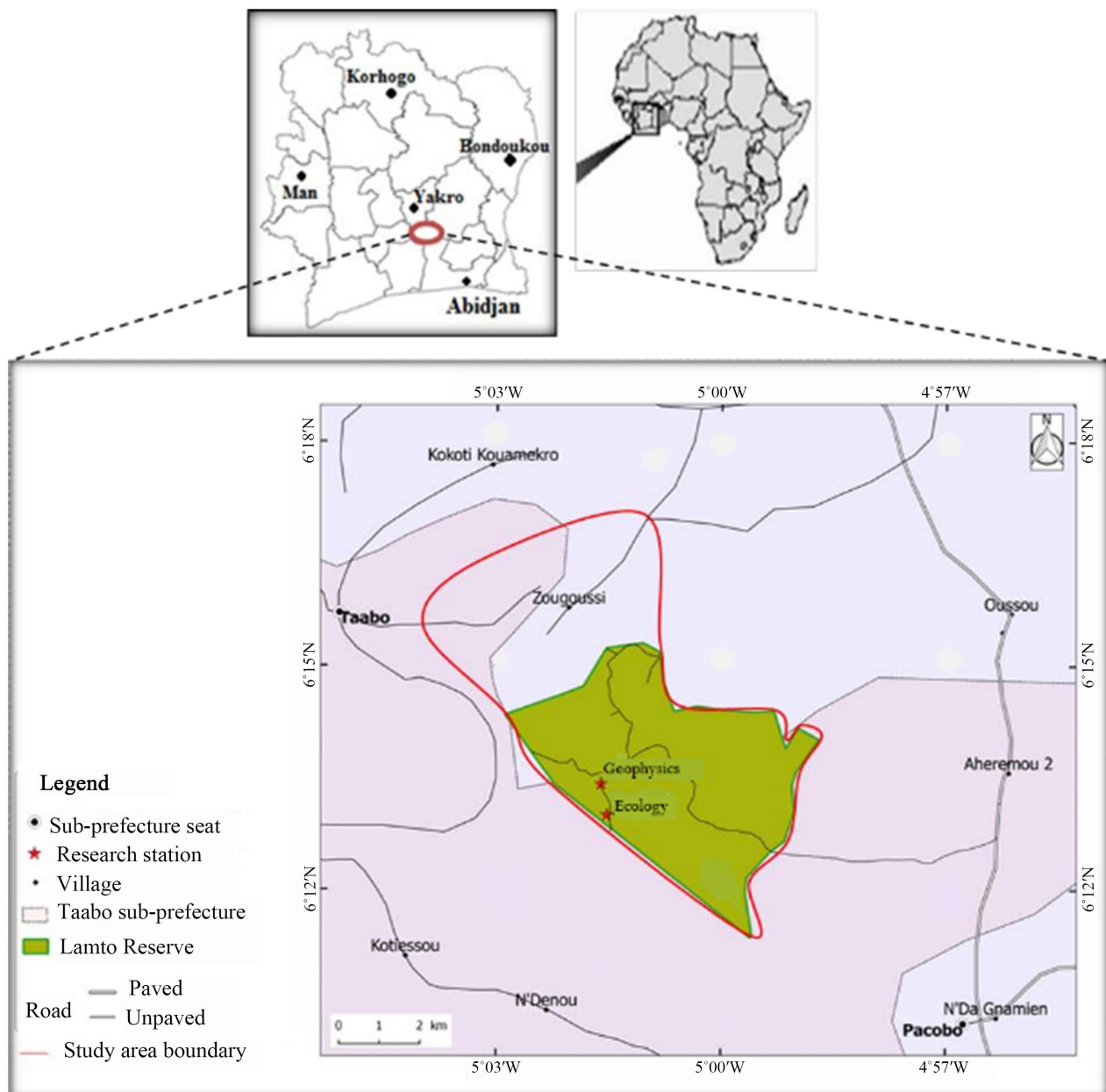


Figure 1. Location of study area.

Forest Islands (FI) are semi-deciduous forest fragments scattered throughout the Lamto Reserve, often surrounded by savannah or connected to gallery forests (GFs) [18]. In this habitat, edaphic variants of the dense and humid semi-deciduous Forest Island with *Celtis* spp. and *Triplochiton scleroxylon* K. Schum. (Malvaceae) can be observed [19] over areas of 0.93 - 27 ha [20]. These less dense forest patches have a discontinuous canopy and an undergrowth dominated by lianas

[19]. Their location in annually burnt savannah sometimes subjects them to the influence of fire [21]. Within the Lamto Reserve, these forests are subject to minimal human pressure, which explains their better state of conservation. However, the forest patches in rural areas, particularly those in the village of Zougoussi, show signs of advanced degradation by fire [20]. The dominant plant species found therein are *Dialium guineense* Willd. (Fabacées), *Olex subscorpioidea* Oliv. (Olacacées), *Trichilia prieureana* A. Juss. (Meliacées), *Pouteria alnifolia* (Baker) Roberty (Sapotacées) and *Lecaniodiscus cupanioides* Planch. (Sapindacées). The canopy is patchy, and the forest floor is covered with a thin layer of litter. These forests are subject to selective logging for the daily needs of local communities, as well as other types of human pressures such as hunting and land clearing. Forest islands are degraded and/or divided into small forest fragments as a result of human activities.

Cocoa plantations (*Theobroma cacao* L., Malvaceae) are between 15 and 20 years old. They are located near the village of Zougoussi. Their canopies are usually dense, and the ground is mainly covered with fallen cacao leaves. In these plantations (Figure 2), one finds a few kapok trees (*Ceiba pentandra* (L.) Gaertn., Bombacaceae), avocado trees (*Persea americana* Mill., Lauraceae), mango trees (*Mangifera indica* L., Anacardiaceae), and citrus trees such as orange trees (*Citrus sinensis* (L.) Osbeck, Rutaceae) and many other tree species [22]. Rubber tree plantations (*Hevea brasiliensis* (Willd. ex A. Juss.) Müll. Arg., Euphorbiaceae) are relatively young (6 to 14 years) and occupy a large area because rubber cultivation is new to the region. These plantations are strictly monocultural, and their areas range from 1 to 10 ha [23]. However, the cocoa and rubber plantations will eventually contribute to increased vegetation cover.

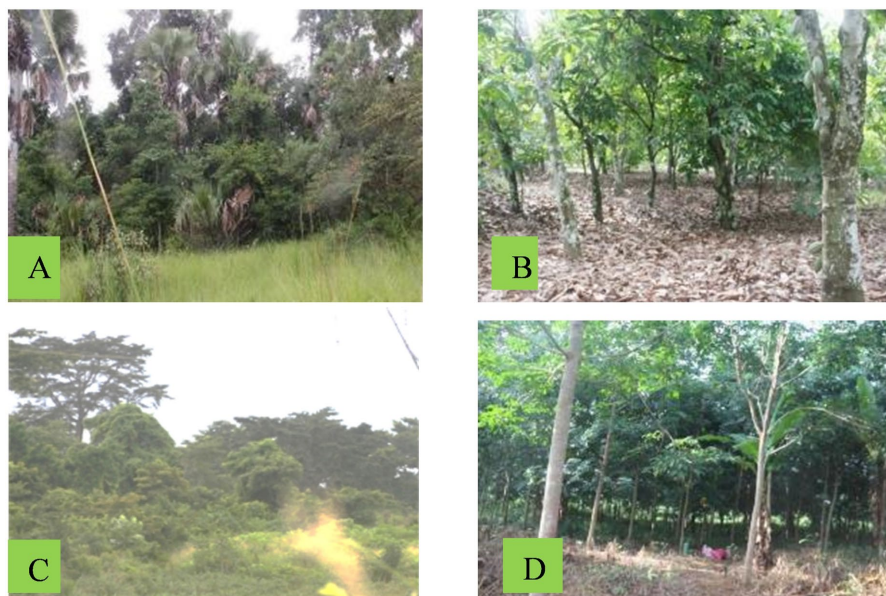


Figure 2. Sampling sites: A: forest island, B: cocoa plantation, C: rural forest, D: rubber plantation.

2.2. Sampling Design

Ants were sampled in January and July 2019 during the dry season and the rainy season. We used two sampling methods: i) baited traps and ii) beating of the vegetation. Baited traps are funnel traps made from a plastic bottle of mineral water (50 or 33 cL) and a 15 m nylon wire. For more details, see [24]. The experimental design was 100 m × 50 m plots installed in forest island (FI) of the reserve, rural forest (RF), cocoa (CO) and rubber (RU) plantations, located at least 100 m from the edge of the sampled habitat. In each sampling plot, ants were collected at 20 sampling stations, with sampling stations separated by at least 10 m, considering trees with a diameter ≥ 10 cm. In the savannah habitat, a sampling station consists of a protein bait and a sugar bait, both located at 5 m height on the same tree. In the forest habitat, a sampling station consists of protein and sugar baits located at 10 m height and protein and sugar baits located at 5 m height, all on the same tree and a beating within 2 m of the tree where the baits were placed. The choice to sample at two different heights in the forest is explained by the fact that, in the forest, at 5 m height, the crown of the trees of the low stratum was not always reached; this is why we also sampled at 10 m to have better representativeness of the ant assembly of the low canopies of the forests. This is not the case in our savannah plots, where tree tops were found at an average height of 8 m, so at 5 m the baits are in the tree canopy (Figure 3). The combination of all samples taken at a sampling station constitutes a sampling unit. Also, the samples from the rainy season and those from the dry season were combined into a single sample. Thus, a total of 20 sampling stations were included at each sampling plot, 60 sampling stations per habitat, so 60 sampling units per habitat, and 240 sampling units in total.

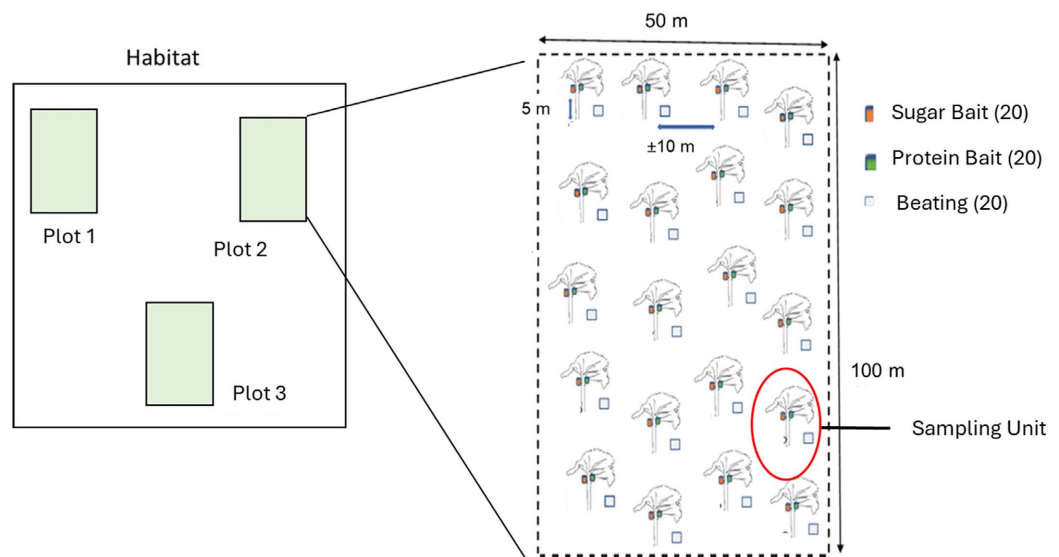


Figure 3. Representation of sampling design.

2.3. Identification

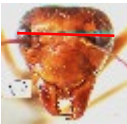
Ants were identified with a Leica MZ6 microscope using Fisher and Bolton's [25]

guide to the ant genera of Africa and Madagascar for identification of ants to the genus level. The keys of Bolton [26]-[28] and other reliable digital keys [29] were used for identification to the species level. When species-level identification was impossible, distinct specimens were sorted into morphospecies. Morphospecies were numbered according to the ant reference collection for Côte d'Ivoire at the Tropical Ecology Station at Lamto Reserve [6]. These identifications were made in the entomology laboratory of the Lamto Ecology Station.

3. Data Analysis

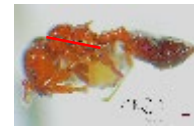
Observed species richness was calculated by adding up the number of species and morphospecies observed across all samples within each habitat type. The Chao2 index species richness estimator was calculated to extrapolate the species richness from our data. Sample coverages were determined to estimate sampling efficiency based on different sampling methods using EstimateS v.9.1.0. Ant species richness across habitats was compared using a one-way ANOVA and Tukey's pairwise comparison test. The ANOSIM test allowed us to compare the ant species composition. The similarity of ant assemblages between habitats was estimated using the Bray-Curtis index and displayed using Non-metric Multidimensional Scaling with PAST 5.03 Software [30]. The rank-frequency plot was used to study community structure by evaluating the relationship between species richness and the number of individuals [31]. Indicator species (IndVal) analysis was also conducted to identify species associated with different habitats, and significance was tested using Monte Carlo permutation in order to verify whether a species' preference for a particular habitat type is significantly higher than would be expected from a random distribution [32] [33]. This analysis was performed using the vegan, permute, and Indic species packages in R [34]. Additionally, we measured morphological traits of two dominant arboreal species to demonstrate the potential effects that a reduction in the size of forest patches or their conversion to plantations might have on the species' functions within their habitat [35]. Thus, six traits were selected [36]: clypeus width, femur length, head width, mandible length, scape length, and alitrunk length (**Table 1**). These various morphological traits are associated with different functions performed by ants in their environment [37]. Past Software v3.09, R Software v4.4.3 and Microsoft Excel were used for statistical analyses, considering the value of $p \leq 0.05$ as an indicator of statistical significance.

Table 1. Characteristics taken into account in the measurement of morphological traits according to Santoandre [36].

Characters	Illustrations
Head Width	

Continued

Alitrunk Length



Mandible Length



Scape Length



Femur Length



Clypeus Width



4. Results

4.1. Species Richness of Ant Communities in Different Habitats

The study yielded 74 species, belonging to 23 genera and 6 subfamilies (Ponerinae, Formicinae, Dorylinae, Myrmicinae, Dolichoderinae, and Pseudomyrmicinae). The richest habitat was forest island (58 species), followed by rural forests (42 species), cocoa plantations (30 species), and rubber plantations (26 species) (**Table 2**).

Table 2. Arboreal ant species list from sampling in Lamto Island Forest, rural forests, cocoa plantations and rubber plantations of Zougoussi village.

Subfamily	Species	IF	FR	Rubber	Cocoa
Formicinae	<i>Camponotus acvapimensis</i> Mayr, 1862	1	1	1	1
	<i>Camponotus compressiscapus</i> André, 1889	1	1	1	1
	<i>Camponotus lateralis</i> Olivier, 1792	1	0	0	1
	<i>Camponotus maculatus</i> Fabricius, 1782	1	1	1	1
	<i>Camponotus puberulus</i> Emery, 1897	1	1	1	1
	<i>Camponotus solon</i> Forel, 1886	1	1	1	1
	<i>Camponotus vividus</i> Smith, 1858	1	1	0	1
	<i>Camponotus schoutedeni</i> Forel, 1911	1	0	1	1

Continued

	<i>Lepisiota</i> sp. 1	1	1	1	1
	<i>Lepisiota</i> sp. 2	1	1	1	0
	<i>Lepisiota</i> sp. 3	1	0	0	0
	<i>Nylanderia boltoni</i>	0	1	0	0
	<i>Oecophylla longinoda</i> Latreille, 1802	1	1	1	1
	<i>Plagiolepis alluaudi</i> Emery, 1894	1	1	0	0
	<i>Plagiolepis</i> sp. 2	1	1	0	0
	<i>Polyrhachis decemdentata</i> André, 1889	0	1	0	0
	<i>Polyrhachis</i> sp. 2	1	0	0	1
	<i>Polyrhachis</i> sp. 3	1	1	0	0
Dorylinae	<i>Dorylus</i> sp. 1	1	0	1	0
	<i>Cardiocondyla neferka</i>	0	1	0	0
	<i>Cataulacus traegaohdi</i> Santschi, 1914	1	1	0	1
	<i>Cataulacus vorticus</i> Bolton, 1974	1	0	0	0
	<i>Crematogaster africana</i> Mayr, 1895	1	1	1	1
	<i>Crematogaster nigronitens</i> Santschi, 1917	1	0	0	0
	<i>Crematogaster solenopsides</i> Emery, 1899	1	1	1	1
	<i>Crematogaster</i> sp. 10	1	0	0	0
	<i>Crematogaster</i> sp. 14	1	1	1	1
	<i>Crematogaster</i> sp. 17	1	1	1	0
	<i>Crematogaster</i> sp. 2	1	0	1	0
	<i>Crematogaster</i> sp. 22	1	1	0	0
	<i>Crematogaster</i> sp. 9	1	0	0	0
	<i>Crematogaster striatula</i> Emery, 1892	0	1	0	0
Myrmicinae	<i>Leptothorax angulus</i>	1	0	0	1
	<i>Leptothorax</i> sp. 1	1	0	1	0
	<i>Monomorium inquietum</i> Santschi, 1926	1	1	0	1
	<i>Monomorium bicolor</i>	0	0	0	1
	<i>Monomorium dolatu</i> Bolton, 1987	1	0	0	0
	<i>Monomorium floricola</i> Jerdon, 1851	1	1	1	1
	<i>Monomorium pharaonis</i> Linnaeus, 1758	1	1	0	1
	<i>Monomorium</i> sp. 2	0	1	0	1
	<i>Monomorium</i> sp. 3	1	0	0	0
	<i>Monomorium</i> sp. 4	1	1	0	0
	<i>Pheidole excellens</i> Mayr, 1862	0	1	1	1
	<i>Pheidole megacephala</i> Fabricius, 1793	1	1	1	0
	<i>Pheidole</i> sp. 12	1	0	0	1

Continued

	<i>Pheidole</i> sp. 3	1	1	0	0
	<i>Pheidole</i> sp. 4	0	0	1	1
	<i>Pheidole</i> sp. 6	0	1	0	1
	<i>Pheidole</i> sp. 8	1	0	0	0
	<i>Terataner</i> sp. 2	0	1	0	0
	<i>Terataner velatus</i> Bolton, 1981	0	1	0	0
	<i>Tetramorium quadridentatum</i> Stitz, 1910	1	1	0	0
	<i>Tetramorium</i> sp. 2	1	0	0	1
	<i>Tetramorium auxium</i>	0	1	0	0
	<i>Tetramorium flavithorax</i> Santschi, 1914	1	0	0	0
	<i>Tetramorium hapale</i>	1	0	0	0
	<i>Tetramorium</i> sp. 3	0	0	1	0
	<i>Tetramorium rheticum</i>	1	1	1	0
	<i>Tetramorium</i> sp. 6	1	0	0	0
	<i>Tetramorium</i> sp. 15	1	0	0	0
	<i>Tetramorium</i> sp. 17	1	1	0	0
	<i>Tetramorium zapyrum</i>	1	0	0	0
Ponerinae	<i>Anochetus</i> sp. 1	0	1	0	0
	<i>Hypoponera</i> sp. 1	0	0	0	1
	<i>Paltothyreus tarsatus</i>	0	1	0	0
	<i>Platythyrea conradti</i>	1	0	0	0
	<i>Platythyrea</i> sp. 2	1	0	0	0
	<i>Psolidomyrmex foveolatus</i> André, 1890	1	0	0	0
Dolichoderinae	<i>Paratrechina longicornis</i>	1	1	1	1
	<i>Tapinoma lugubre</i>	1	1	1	1
	<i>Tapinoma melanocephalum</i> Fabricius, 1793	1	0	0	0
	<i>Tapinoma</i> sp. 3	1	0	0	0
	<i>Tapinoma</i> sp. 4	1	1	1	0
Pseudomyrmicinae	<i>Tetraponera mocquerysi</i> André, 1890	1	0	1	1
	Species Richness Observed	58	42	26	30

Habitat comparisons revealed a significant difference in the average species richness (ANOVA One-Way: $F = 12.47$; $p < 0.05$). Pairwise comparison indicated that the mean ant species richness ($\pm$ SE) of FI (44 ± 2.52) was significantly higher than that of all other habitats (Table 3). Also, the mean rural forest ant species richness ($\pm$ SE) (27 ± 1.53) (Tukey's Pairwise test, $p = 0.029$) was higher than that of the cocoa plantation (Table 4).

Table 3. Specific richness and sampling coverage for different habitats.

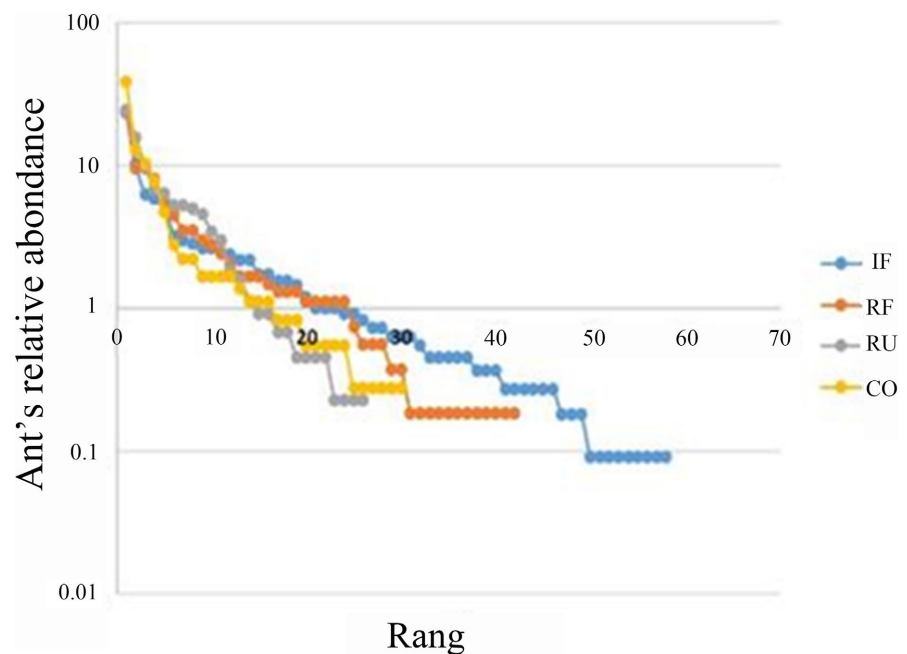
Habitats	S (obs)*	S (est)* (Chao2)	Sampling Coverage	S (obs) Mean	Uniques Species	Doubletons
IF	58	65.99	87.89	44 ± 2,516	10	4
FR	42	63.93	65.7	27 ± 1,527	12	2
Rubber	26	27.2	95.59	17 ± 1,452	4	4
Cocoa	30	32.49	92.34	15 ± 3,511	5	6

Note: *S (obs): Specific Richness observed; *S (est): Specific Richness estimated, or expected.

Table 4. Pairwise comparison of arboreal ant specific richness using Tukey's test: Tukey's Q below the diagonal, p (same) above the diagonal.

	IF	FR	Rubber	Cocoa
IF		0.02948	3.68E-07	1.12E-05
FR	3.93		0.02948	0.1607
Rubber	7.86	3.93		0.8991
Cocoa	6.877	2.947	0.9825	

4.2. Community Structure of Arboreal Ant Species in the Surveyed Habitats

**Figure 4.** Distribution and allocation of specific richness based on ant abundance across different habitats.

Three distinct groups were identified within the communities of rural forests, cacao plantations, and rubber plantations, while four distinct groups were identified in the reserve's forest island (**Figure 4**). The first group includes the most abundant ant species (between 10% and 100%). This group consists of four spe-

cies: *Crematogaster solenopsides*, *Crematogaster* sp. 14, *Camponotus maculatus*, and *Oecophylla longinoda*. The second group includes the less abundant species (between 1 and 10%). Approximately 36 species were represented there across all habitats. It includes species such as *Camponotus acvapimensis*, *Tetraponera mocquersyi*, and *Platythyrea conradti*. The third level grouped rare species (between 1% and 0.1%) and includes a large number of species such as *Leptothorax angulus* and *Terataner velatus*. Finally, the last group consists of very rare species (less than 0.1%) found exclusively in the forest islands of the Lamto Reserve. This group includes 9 species, including *Cataulacus vorticus*, *Tapinoma melanocephalum*, *Platythyrea* sp. 2, *Tetramorium rheidum*, etc.

4.3. Endemic, Common, and Indicator Species of the Studied Habitats

The distribution of ant species across habitats made it possible to distinguish those that are common to all or nearly all habitats from those that were collected in only one habitat type. Thus, 13 ant species were found in all habitats, while 11 other ant species were found in three different habitats, and 17 species were found in two habitats. Finally, the forest patches within the reserve hosted 17 species unique to them, while the rural forests contained 10 species and the cocoa and rubber plantations contained two species each. Furthermore, the IndVal analysis showed that six indicator species were associated with the forest patches in the Lamto Reserve, including two species—*Lepisiota* sp. 3 and *Tetramorium hapale*—with a specificity value of 1. In the rural forests, out of the two associated indicator species, only *Polyrhachis decemdentata* had a specificity value of 1 (Table 5). As for the cocoa and rubber plantations, they showed no specific association with any ant species.

Table 5. Indicator species significantly associated with the reserve's forest island and the rural forest (FI: Forest Islands, RF: Rural Forests, CO: Cocoa Plantations, RU: Rubber Plantations).

Habitats	Number of Indicator Species	Species	Specificity (A)	Fidelity (B)	IndVal	<i>p</i> -Value
FI	6	<i>Crematogaster</i> sp. 9	0.846	0.183	0.394	0.001
		<i>Lepisiota</i> sp. 3	1.000	0.133	0.364	0.001
		<i>Tetramorium zapyrum</i>	0.636	0.116	0.272	0.004
		<i>Tetramorium hapale</i>	1.000	0.067	0.258	0.002
		<i>Tapinoma</i> sp. 3	0.800	0.067	0.231	0.012
		<i>Tetramorium</i> sp. 2	0.625	0.083	0.228	0.014
RF	2	<i>Monomorium</i> sp. 2	0.682	0.250	0.413	0.001
		<i>Polyrhachis decemdentata</i>	1.000	0.050	0.224	0.019
CO		None	-	-	-	-
RU		None	-	-	-	-

4.4. Functional Traits of Several Species of Arboreal Ants

Oecophylla longinoda and *Crematogaster solenopsides* were the most dominant species found in all the habitats surveyed during this study. Their presence in all these habitats, whether protected or human-altered, suggests they have the potential to be dominant species. Functional traits measured in *Oecophylla longinoda* revealed numerous differences among ants from rural forests, cocoa plantations, rubber plantations, and the reserve's forest island. Thus, clypeus width and scape length do not vary among ants from different habitats. However, the femur length of individuals collected from rural forests was found to be shorter than that of ants collected from the reserve's forest islands, rubber plantations, and cacao plantations (Kruskal-Wallis test; $p < 0.05$). As for head width, it was smaller in ants from rural forests than in those found in the reserve's forest islands (Mann-Whitney test; $p < 0.05$) and rubber plantations (Mann-Whitney test; $p < 0.05$). Next, regarding mandible length, the only difference observed was between the reserve's forest patches and rural forests (Mann-Whitney test; $p < 0.05$), with the mandibles of *Oecophylla* ants from rural forests always smaller than those of ants from the forest islands.

Finally, regarding alitrunk length, the results showed that in rural forests, *Oecophylla* ants have shorter alitrunks (Kruskal-Wallis test, $p < 0.05$) than those of ants in the reserve's forest islands (Mann-Whitney test; $p < 0.05$), cocoa plantations (Mann-Whitney test; $p < 0.05$), and rubber plantations (Mann-Whitney test; $p < 0.05$) (Table 4).

Concerning *Crematogaster solenopsides*, the morphological traits measured for individuals of this species do show significant differences between habitats. The exception is scape length, where there is a difference between individuals from forest habitats and those from plantations (Kruskal-Wallis test, $p < 0.05$). In fact, the scape length of the ants does not differ between the two types of forest habitats, but the results show that it is shorter in individuals from cocoa and rubber tree plantations (Table 6).

Table 6. Size (mm) of morphological traits of the species *Oecophylla longinoda* and *Crematogaster solenopsides* in different habitats. (FI: Forest Islands, RF: Rural Forests, CO: Cocoa Plantations, RU: Rubber Plantations).

Species	Habitats	Alitrunk's Length	Femur's Length	Head's Length	Scape's Length	Clypeus's Length	Mandible's Length
<i>O. longinoda</i>	FI	1.11	1.32	0.67	1.08	0.25	0.44
	RF	0.90*	1.05*	0.61*	0.89*	0.22*	0.37*
	CO	1.12	1.05	0.67	1.05	0.26	0.42
	RU	1.08	1.15	0.70	1.09	0.29	0.43
<i>C. solenopsides</i>	FI	0.35	0.26	0.37	0.26	0.09	0.16
	RF	0.37	0.25	0.38	0.25	0.10	0.17
	CO	0.36	0.23	0.38	0.24	0.07	0.18
	RU	0.33	0.20	0.34	0.24	0.06	0.17

Note: *Shows a significant difference between values.

5. Discussion

A greater number of ant species was associated with the forest island in the Lamto Reserve, while few species were associated with forest remnants and monoculture plantations in the rural area. A possible explanation may be that the forest islands in the reserve, being in a protected habitat, are certainly subject to much less human pressure than the forests in the rural area. This likely gives them greater complexity than rural forests, which are constantly subjected to human activities (harvesting of firewood and timber, collection of medicinal plants, hunting, and land clearing for the expansion of neighboring plantations) that further reduce their size. These observations are consistent with [38], who demonstrated that ant species richness is positively correlated with habitat complexity. This fact has also been mentioned by Wilson and MacArthur [39], who supported the habitat heterogeneity hypothesis that greater habitat complexity should provide more nesting and foraging sites, as well as a greater abundance of food. This would therefore explain the high species richness observed in the forest patches within the reserve.

Furthermore, changes in vegetation structure could act as a selective filter for species movements, thereby influencing the distribution of ants [40]. Indeed, another reason could be related to the size of forest fragments, as it has been shown that in other forest types (dry tropical and montane), a reduction in forest size decreases ant species richness [41].

The rank-frequency diagram revealed that in the Lamto Forest, four groups of species can be distinguished based on their abundance. In contrast, three groups were identified in rural forests and in cocoa and rubber plantations. Furthermore, certain species may lose their status as dominant species when moving from one habitat to another. For example, *Crematogaster solenopsides* is more abundant only in the reserve's forest island, whereas *Oecophylla longinoda* is abundant in all habitats. Indeed, for some arboreal ant species, dominance depends on habitat quality [42]. Some species of the genus *Crematogaster* are dominant in one habitat type but not in another. These species are sometimes involved in mutualistic interactions with plants, and their abundance may also depend on the abundance of these plants within the habitat [43].

In contrast, species belonging to the genus *Oecophylla* are highly aggressive and competitive dominant species in both natural habitats and plantations [44] [45]. Furthermore, the absence of very rare species collected in the reserve's forest patches, such as *Tetramorium rhetidum*, *Cataulacus vorticus*, and *Tapinoma* sp. 4, in rural forests and plantations may suggest that these species are the first victims of the ecological disturbances affecting these habitats. This could be related to the dispersal capacity of these species in question, as not all species are capable of dispersing across forest fragments, even if they are close to one another. For example, in the Atlantic forests of Brazil, the species *Dinoponera lucida* Emery cannot disperse from one forest fragment to another, even when the fragments are close to one another [46].

Here, in this study, the species identified as indicator species in each habitat are rare. The number of these indicator species decreases drastically from the forest island within the reserve to rural forests and is obviously missing in monoculture plantations. Indeed, although rural forests share the same origins as the forest islands within the reserve [18], the indicator species of the Forest patches within the reserve do not retain the same status in rural forests. This may be due to the stress caused by human activities or to interactions between species. The study by Alohou [47] also identified different indicator species between native forests and remnant forests that had been converted into sacred forests in Benin. Thus, the plant species found in these sacred forests as indicators became indicators of anthropogenic disturbances in this type of habitat. Consequently, we could classify the ant species *Monomorium* sp. 4 and *Polyrhachis decemdentata* as indicators of disturbed forests. Meanwhile, the changes observed in arboreal ant communities in rural forest fragments do not appear to affect only rare species. Certain changes may also occur in abundant species, particularly in terms of their functional traits. This study shows that individuals of the species *Oecophylla longinoda* in rural forests are smaller than those in the forest islands within the reserve. This result does not corroborate the observations of David & Capy [48], who stated that in an environment with low diversity, reduced competition should lead to an increase in body size. However, this might be entirely accurate when the contested resources are limited to food. Also, in reduced habitats, additional nutritional resources, nesting sites and foraging areas become highly sought-after resources. Thus, Nooten [38] showed that ants in simplified habitats comprised fewer species and exhibited a different set of functional traits compared to those in more complex habitats, which corroborates our results. Similarly, Gibb *et al.* [49] showed that the body size of ants in disturbed habitats was smaller. However, numerous studies have shown that reduced body size in certain ant species is correlated with colony size [50]-[52]. This finding could represent an adaptive strategy for the species *Oecophylla longinoda* in rural forest fragments. However, not all species, despite their dominant nature, respond in the same way to stress caused by environmental conditions. This may explain why, for the species *Crematogaster solenopsides*, no differences were observed between the forest islands within the reserve and rural forests. This species appears to be resistant to changes in its environment.

An analysis of tree-dwelling ant communities, taking vertical stratification into account, showed that between the reserve's forest island and those in the rural area, differences in species richness and abundance occurred within 2-meter strata. This may suggest that most of the species collected are generally found at or above this height. However, a comparison of the strata across the different habitats revealed nearly identical species compositions, suggesting that the differences observed in these various habitat types depend primarily on the higher canopy layers. Indeed, the two vegetation formations differed in terms of canopy structure [53].

6. Conclusion

This work has shown that the large forest island in the Lamto Reserve is home to a greater number of ant species, in contrast to the smaller rural forests, which are more heavily impacted by human activities. Other differences were also observed in community structure, such as the number of rare species and the number of indicator species. For all these parameters, species richness decreases from the forest patches in the Lamto Reserve to the forests in rural areas. This study has demonstrated the importance of protected areas for the conservation of the smallest species, such as ants. Indeed, plans for managing or creating biodiversity conservation areas must necessarily take into account the size of the habitat to be preserved.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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