Impact of Human Activities on the Distribution of Termite Communities in Teak Plantations (*Tectona grandis* L. F., Verbenaceae) in the Korhogo Communal Area (North Côte d'Ivoire)

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Authors' contributions

This work was carried out in collaboration among all authors. Author CT designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors FD and EAABK managed the analyses of the study. Author AMAA and KPK managed the literature searches. All authors read and approved the final manuscript.

Article Information

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ABSTRACT

Aims: This study aimed to assess the impact of human activities on termites in teak plantations in the Korhogo communal area.
Methodology: Termites were sampled from October to November 2020 using the transect method recommended by Jones and Eggleton (2000). The study was carried out in three teak plantations undergoing different levels of human activities, with a forest fragment as reference area. Five types of human activity were assessed and the overall proportion of human pressure on each habitat was calculated. The species richness (S), Shannon index (H'), Evenness (E) and the relative abundance

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were calculated of termites for each habitat type. Analyses of variance (ANOVA) were used to compare the species richness and abundance of termites.

Results: The results showed that the village plantation of teak (PVT) had the highest degree of human pressure (50.94%), followed by the teak plantation of the forest of Mount Korhogo (TFMK) (29.24%). The teak plantation of Botanical Garden (TJB) was under low pressure (6.60%). A total of 30 species grouped in 19 genera and 8 sub-families of termites were identified in all plots. Termite diversity was high in the forest fragment (19.67 ± 1.15) and in the teak plantation of Botanical Garden (21.33 ± 2.08), but low in the village teak plantation (11 ± 1). The abundance of termites evolves in the same direction as the species richness.

Conclusion: Anthropogenic activities affect the trophic composition of termites, particularly the humivore group. Reconstruction of the fauna and flora of the teak forests would be beneficial for the conservation of termite species. In this region, teak forests would thus play a role as a refuge for termite communities, which are recognised as the main soil fertilising organisms in the tropics.

1. INTRODUCTION

Biodiversity loss is generally more intense in tropical regions and mainly due to the destruction of natural habitats [1-2]. Globally, the deterioration of natural habitats is mainly due to human activities. Among these human activities, agricultural practices and grazing are major contributors to the alteration of these habitats in many tropical countries [3]. Côte d'Ivoire, a predominantly agricultural country, is no exception to this global reality. Studies on deforestation in tropical countries have concluded that Côte d'Ivoire has experienced one of the highest deforestation rates in the world (6%/year) [4-5]. In the northern region of the Côte d'Ivoire, for example, the cotton area increased from 137 ha in 1960 to almost 230,000 ha in 2002 [6], thus transforming natural landscapes into agricultural land on a very large scale. This has led to a drastic reduction in the diversity of soil fauna, especially termites [7]. SODEFOR (Forest development conpany) has used teak as the leading species in its reforestation policy in Côte d'Ivoire, especially in the north of the country. Thus, around villages and towns, several teak plantations have been established, transforming agricultural areas into plantations [8]. This transformation of land into teak plantations has certainly had an impact on animal biodiversity, particularly soil fauna. Indeed, many studies have shown that some agrosystems can support high levels of species richness, often even resembling that of undisturbed forests [9].

Recently in the Korhogo region, studies showed that mango plantations harbor a diversity of termites close to that of the natural environment [10]. Concerning teak plantations, very little work has been done in Côte d'Ivoire on the contribution of teak agrosystems to the conservation of biodiversity, particularly that of termites. Yet termites are one of the major biotic components of tropical ecosystems where they represent, along with earthworms and ants, the true engineers of the ecosystem [11]. These insects play a role in soil fertilisation through the storage and decomposition of organic matter of plant origin [12-13]. Given the particular influences that termites have in soil fertilisation processes in tropical areas, it is important to understand how certain agrosystems such as teak plantations influence their assemblages. The overall objective of the present study is to contribute to the preservation of termite communities as the main soil fertilising organisms in the tropics.

2. METHODOLOGY

2.1 Study Site

The sampled plots are located in the communal area of Korhogo (Fig. 1) from October to November 2020. The climate is dry Sudanese tropical with two contrasting seasons: the rainy season extends from mid-April to October and the dry season from November to mid-April. The average annual rainfall varies between 1000 and 1600 mm. Rainfall is the most important climatic factor. The four (4) plots differ in the human activities observed. The characteristics of these plots are described as follows:

➢ *Forest fragment of botanical garden (FF)*

Located within the university (PELEFORO GON COULIBALY of Korhogo), the forest covers an area of about 7 ha (9°25'48"N 5°37'58"W). Some

dead wood is present. The litter is moderately thick and consists mainly of dead tree leaves. The garden forest has a sparse canopy (Fig. 1A). In this area, human activities such as the cutting of a few trees by local residents and the passage of fire are rarely recorded.

> ➤ *The teak plantation of botanical garden (TJB)*

Established in 2007, the teak grove of the botanical garden covers an area of about 6 ha (9°25'45"N 5°37'48"W). The litter is very thick and mainly composed of dead teak leaves and humus. This garden is a fallow land of more than 30 years with the presence of several wild species of Poaceae, Mimosaceae, Euphorbiaceae, Rubiaceae, Fabaceae, Cucurbitacea. Anthropogenic activities such as wood cutting, livestock grazing and bushfires are almost never observed in this habitat (Fig. 1B).

> ➤ *The teak plantation of the "Mont Korhogo" forest (TFMK)*

This teak plantation of more than 75 ha is located in the classified forest "Mont Korhogo" (9°29'27"N 5°40'36"W) near the town (Fig. 1C). Due to its geographical location (close to the city of Korhogo), it is subject to strong anthropogenic pressures. Several places are considered to be dumping grounds for household waste. In addition, unauthorised and uncontrolled felling of trees, introduction of livestock and regular passage of fire are regularly practised. In this teak grove, the litter is not very thick.

> ➤ *Village teak plantation (PVT)*

Located in the village of Bafimé (9°28'05"N 5°33'41"W) east of the town of Korhogo, the teak plantation covers an area of about 2 ha. The litter is composed of leaves, dead branches and very little humus (Fig. 1D). This teak plantation is subject to regular felling of teak wood, bushfires during the dry season and regular livestock traffic.

2.2 Termite Sampling

Termite sampling was carried out using the standardised method for termite collection [14]. This consisted of delineating 20 sections of 10 m^2 (5 m x 2 m) in each plot, along a transect 100 m long and 2 m wide. The excavation is carried out in successive sections in two stages. Termites were collected in labelled pillboxes containing 70° ethyl alcohol. Three transects (at least 10 metres apart) were made in each habitat type.

2.3 Identification of Termites

Individuals were first identified to genus and then to species level using a binocular magnifying glass, using the identification keys of [15-22]. After identification, each species was classified into one of the trophic groups (Fungus-growers, Soil feeders, Grass-feeders and Wood-feeders).

2.4 Evaluation of Anthropic Pressure

Anthropogenic pressures on the different habitats were quantified in different ways depending on the type of pressure. Five types of pressure were selected to study the different habitats:

Tree cutting: We counted the number of trees that had been debarked and those whose roots had been removed or whose branches had been cut along a 5 m strip on either side of the termite transect.

Fire passage: The number of bushfires over the last five years was counted. Grazing: The number of livestock intrusions per day over the study period was counted. Household waste: The number of rubbish heaps in the site was counted and recorded.

Termite nests destroyed: Termite nests destroyed for rodent hunting and termite collection for poultry rearing were counted along a 5 m strip on either side of the termite transect. The assessment of the degree of anthropogenic pressures was based on the method of Yeo et al, [23]. The proportions of different anthropogenic pressures on each habitat were calculated. For each type of pressure, the investigations measured a (phi) value in each habitat type i. the (phi) value was obtained by summing the quantities obtained along the sampling transects.

For each type of pressure, the overall proportion of human pressure exerted on each habitat (Phm) was then calculated using the formula:

$$Phm = \frac{phi}{\sum phi}$$

In order to classify habitats according to the respective degrees of pressure experienced, we have arbitrarily established a rating scale for anthropogenic pressures (Table 1).
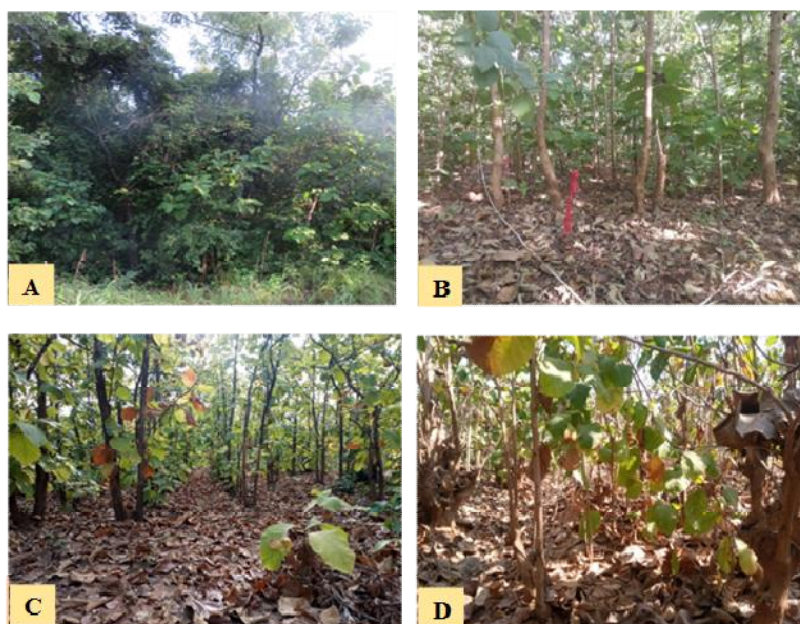
Fig. 1. View of the different habitats sampled
A: Forest Fragment (FF) B: Teak plantation of the Botanical Garden (TJB) C: Teak plantation of the Mount Korhogo Forest (TFMK) D: Village Teak Plantation (PVT).

Table 1. Rating scale for level of anthropogenic pressure

Level of human pressure	Level	Human pressure rating scale
No pressure	0	Phm = 0
Low pressure	1	0 ≤ Phm ≤ 25%
Average pressure	2	25% ≤ Phm ≤ 50%
Strong pressure	3	50% ≤ Phm ≤ 75%
Very strong pressure	4	75% ≤ Phm ≤ 100%

Table 2. Observed and predicted species diversity of termites in the different habitats sampled

	FF	TJB	TFMK	PVT
Observed species	26	24	18	13
Predicted species	30.92	23.98	18.8	13.98
Sampling efficiency	84.09	95.91	94.84	92.99

Forest Fragment (FF). Teak plantation of the Botanical Garden (TJB). Teak plantation of the Mount Korhogo Forest (TFMK). Village Teak Plantation (PVT)

2.5 Data Analysis

Several indices were calculated for each habitat using the PAST software. These were species richness (S), Shannon index (H') and Evenness (E). The relative abundance of termites in the transect, which is the average number of encounters (occurrences) of species i collected in a transect was also calculated for each habitat type. It is based on the incidence (presence = 1 and absence = 0) of the species considered [24]. Analyses of variance (ANOVA, $p<0.05$) using Statistica software (version 7.1) were used to compare the species richness and abundance of termites between the different habitat types. These tests showed the relationship between the level of entropic impact and the total number of termites in the habitats studied

3. RESULTS

3.1 Efficiency of the Sampling Method

The efficiency of the sampling method used for the sampling of litter termites varied between 84.09% and 95.91%. The average coverage rate

of 91.95% indicates a high efficiency of the sampling method for all habitats (Table 2). The lowest coverage rate was obtained with the forest fragment of the botanical garden (FF).

3.2 Classification of Habitats According to Disturbance

Table 3 showed the degree of pressure in each habitat type for the five types of pressure studied, as well as the overall pressure on each habitat. It showed that the village teak plantation (PVT) had the highest degree of overall pressure (50.94%), followed by the teak plantation of the "Mont Korhogo" forest (TFMK). While the teak plantation of botanical garden (TJB) had only low pressure (6.60%) as did the forest fragment of botanical garden (13.20%). But specifically, the village plantation of theca (PVT) and the teak plantation "Mont Korhogo" forest (TFMK) were threatened by tree cutting and nest destruction.

3.3 Impact of Anthropogenic Disturbance on Termite Communities

3.3.1 Impact on the specific composition of termites

A total of 30 termite species were identified in the four (4) habitats sampled. They were grouped into 20 genera, two families (Termitidae and Rhinotermitidae) and 8 subfamilies (Table 4). The termite fauna inventory indicated that the forest fragment of the botanical garden (FF) recorded the highest species richness with a total of 26 termite species collected. It was followed by the teak plantation of the botanical garden (TJB) with 24 species. The village teak plantation appears (PVT) to be the least species rich with 13 species. Statistical analyses showed that the number of species harvested varies significantly from one habitat types to another. The Newman-Keuls test shows a significant difference between TFMK (14 ± 1.73 species) and PVT (11.00 ± 1 species). The FF (19.67 ± 1.15 species) and the TJB (21.33 ± 2.08 species) were statistically different from the TFMK and the PVT. On the other hand, no significant difference was observed between the average richness of the FF and the TJB (P > .05.) (Fig. 2).

Of the 30 species identified, 11 were common to all habitats (36.66%). The FF shared the highest number of termite species with the TJB (22 species). However, some termite species were specific to each habitats. Thus, the FF had 4 specific species. The TJB had one specific species and the PVT recorded one specific species (Fig. 3).

3.3.2 Impact on termite diversity

In all of the habitats surveyed, the Shannon index shows little variability (Table 4). It was low in PVT (2.22), but increased to reach a maximum value in the TJB (2.96). This index varied slightly between FF (2.91) and TJB. In this study. Evenness (E) was highest in the FF (E = 0.94) followed by the TJB (E = 0.93), indicating a good distribution of species in these habitats. The lowest Evenness (E) index was recorded in the PVT (E = 0.86).

3.3.3 Impact on termite abundance

The lowest mean abundances were observed in the PVT and in the teak plantation TFMK with 49.98 ± 7.2 and 69.65 ± 9.73 occurrences respectively. The TJB and the FF recorded the highest abundances of termites identified with 111.66 ± 6.36 and 84.32 ± 8.6 occurrences respectively. The abundances of the trophic groups varied according to the habitat sampled. Fungus-growers group had the highest abundance with 116.65 ± 8.72 or 36.96% of the total termite abundance. The highest abundance of this group was observed in the teak forest of the botanical garden with 41.33 ± 2.60 occurrences. The abundance of fungus-growers varied significantly according to the habitat type (P= .00088). Statistical tests showed that the abundance of wood-feeders and soil-feeders varied significantly by habitat (P= .0132 and P= .000173). They were present in all habitats and had total abundances of 74.65 ± 8.92 and 109.99 ± 10.92 occurrences respectively. The lowest abundance recorded was that of the grass-feeders group, with 14.32 ± 3.33 occurrences or 4.54% of the total abundance. The highest abundance of this group was recorded in the TFMK with 6.33 ± 1.45 occurrences. Grass-feeders were very poorly represented in the FF with 0.33 ± 0.33 occurrences. The abundance of this group varied significantly according to the habitat types (P= .015135) (Table 5).

4. DISCUSSION

A total of 30 species of termites were collected from the 4 plots sampled. This high specific richness would be linked to the fact that 3 of the 4 sampled habitats were relatively conserved plots with the absence of any agricultural activity.

Table 3. Degree of anthropic pressure in the different habitats

	FF	TJB	TFMK	PVT
Trees cut down	8	4	12	25
Passage of fire	2	1	5	5
Entrance of animals	2	1	5	8
Household waste	0	0	3	7
Nests destroyed	2	1	6	9
Overall pressure	14 (13.20%)	7 (6.60%)	31 (29.24%)	54 (50.94%)

Forest Fragment (FF). Teak plantation of the Botanical Garden (TJB). Teak plantation of the Mount Korhogo Forest (TFMK). Village Teak Plantation (PVT)

Fig. 2. Average number of species from different habitats
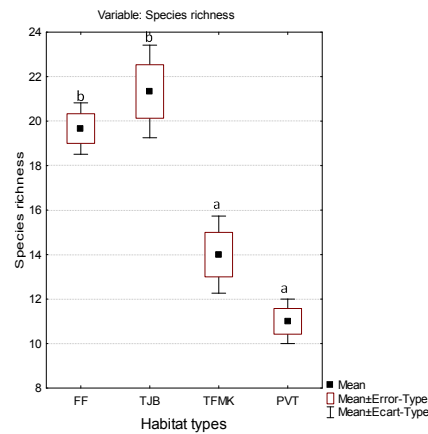*Forest Fragment (FF). Teak plantation of the Botanical Garden (TJB). Teak plantation of the Mount Korhogo Forest (TFMK). Village Teak Plantation (PVT); Mean and standard error followed by the same letter are not significantly different at the 5% level*
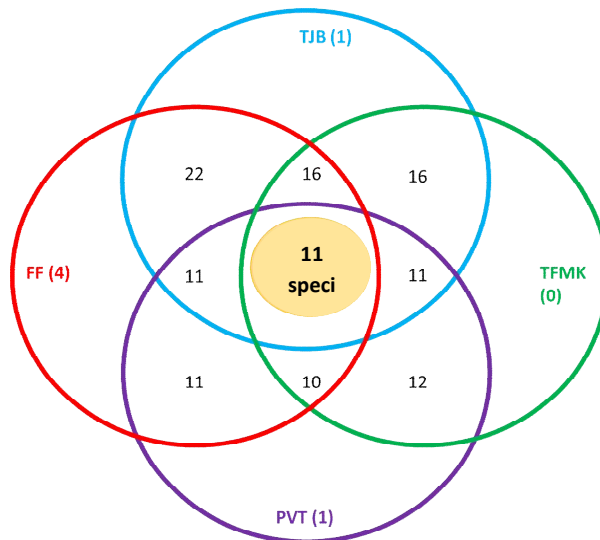

Fig. 3. Distribution of termite species among habitat types
Forest Fragment (FF). Teak plantation of the Botanical Garden (TJB). Teak plantation of the Mount Korhogo Forest (TFMK). Village Teak Plantation (PVT);

Table 4. Termite species identified in the different habitat types

Families	Sub- families	Species	GT	FF	TJB	TFMK	PVT
Termitidae	Termitinae	*Megagnathotermes Silvestri*	s	*	*		
		*Microcerotermes fuscotibialis (*Sjöstedt*)*	w	*	*	*	
		Microcerotermes sp1	w	*	*	*	*
		Microcerotermes sp2	w	*			
		Ophiotermes grandilabius	s	*			
		Pericapritermes socialis	s	*			
		Pericapritermes urgens Silvestri	s		*	*	
		*Procubitermes sjöstedti (*von Rosen*)*	s	*	*	*	*
		Promirotermes holengrni	s	*	*		
	Macrotermitinae	*Ancistrotermes cavitorax (*Sjöstedt*)*	f	*	*	*	*
		Ancistrotermes guineensis Silvestri	f		*		
		Ancistrotermes crucifer Silvestri	f	*	*	*	*
		*Macrotermes bellicosus (*Smeathman*)*	f	*	*	*	*
		*Macrotermes subhyalinus (*Rambur*)*	f	*	*	*	
		Microtermes sp1	f	*	*	*	*
		Microtermes sp2	f				*
		*Odontotermes pauperans (*Silvestri*)*	f	*	*	*	*
		Pseudacanthotermes militaris	f	*	*	*	
	Nasutitermitinae	*Etermeulus acquilinus*	s	*			
		Fulleritermes tenebricus Silvestri	w	*	*	*	*
		*Trinervitermes geminatus (*Wasmann*)*	g			*	*
		*Trinervitermes trinervilus (*Rambur*)*	g	*	*		
	Apicotermitinae	*Astalotermes* sp	s	*	*	*	*
	Amitermitinae	*Amitermes evuncifer* Silvestri	w	*	*	*	*
		Amitermes guineencis	w	*	*		
	Cubitermitinae	*Basidentitermes potens*	s	*	*	*	
		Isognathotermes sp	s	*	*	*	
		Nitiditermes sp	s	*	*	*	*
Rhinotermitidae	Rhinotermitinae	*Shedorhinotermes laminianus (*Sjöstedt*)*	w	*	*		
	Coptotermitinae	*Coptotermes intermedius* Silvestri	w	*	*		
diversity indices	Specific richness (S)	**30**		26	23	18	13
	Shannon (H)			2.90	2.96	2.73	2.21
	Equitability (E)			0.94	0.93	0.89	0.86

Forest Fragment (FF). Teak plantation of the Botanical Garden (TJB). Teak plantation of the Mount Korhogo Forest (TFMK). Village Teak Plantation (PVT); Trophic group; f=Fungus-growers. s=Soil feeders. w=Wood-feeders and g=Grass-feeders

Table 5. Variation of relative abundance of trophic groups in different habitats

Feeding group	FF	TJB	TFMK	PVT	TOTAL	F	P
Fungus-growers	30.33a (2.03)	41.33b (2.60)	23.33a (1.76)	21.66a (2.33)	116.65 (8.72)	16.43	.00088
Soil-feeders	34.33a (4.05)	40.00a (2.52)	29.33a (2.90)	6.33b (1.45)	109.99 (10.92)	26.17	.000173
Wood-feeders	19.33ab (2.19)	27.33b (0.66)	10.66a (4.41)	17.33ab (1.66)	74.65 (8.92)	6.86	.0132
Grass-feeders	0.33a (0.33)	3.00ab (0.58)	6.33b (0.66)	4.66b (1.76)	14.32 (3.33)	6.54	.015
TOTAL	84.32 (8.6)	111.66 (6.36)	69.65 (9.73)	49.98 (7.2)	315.61 (31.89)	-	-

Forest Fragment (FF). Teak plantation of the Botanical Garden (TJB). Teak plantation of the Mount Korhogo Forest (TFMK). Village Teak Plantation (PVT); Numbers in brackets are the standard deviations. Mean and standard deviations followed by the same letter are not significantly different at the 5% level

These results are different from those obtained by 25 Gbenyedji et al [25], who collected 11 species in two teak plantations in Togo using the modified transect method. This difference would be due to the number of plots and transects sampled. Indeed, unlike the work of Gbenyedji et al [25] which took place in only 2 teak plantations with 2 transects of 50 meters, the present study took place in 3 teak groves and a relatively well preserved forest. The sampling effort is therefore higher for the present study. Jones and Eggleton [14] report that the sampling method and the sampling effort influence the number of species harvested. Also, the high number of termite species collected would be linked to the fact that this study took place at the end of the rainy season, thus offering the best conditions for the assembly of termites.

The specific richness and abundances of termites were lower in the village teak plantation and in the teak plantation of the Mount Korhogo forest. The low diversity of termites in these habitats is related to the human activities observed in these plots. Regular passage of livestock, bush fires and tree cutting were factors that negatively influence termite assemblage. Several studies have linked the exploitation of habitats to termite communities. Diahuissié et al., [26], showed that old cashew orchards with low human pressure inhabited a high diversity that even approached that of natural habitats. It should also be noted that in these plots, the destruction of nests by populations in search of rodents and termites to feed poultry could have a negative impact on the assembly of termites.

The low anthropogenic activities observed in the teak plantation of the botanical garden would explain the greater diversity and abundance of termites observed in this habitat. This same reason would explain the high abundance of the group of soil-feeders group. This habitat would be relatively more stable than the others, because of their conservation. The amount of litter and decaying organic plant debris would favor the establishment of termites in these habitats [27-28]. The group of grass-feeders was however less observed in these habitats although we are in a savannah area. Indeed, the plots sampled in this study being covered habitats, they are certainly not favorable to the development of grasses which constitute the basis of the diet of this group of termites [29]. The abundance of wood-feeders was very important in the village teak plantation. Dead wood due to the felling of trees in this area

constitutes an important resource of nutrients [30].

5. CONCLUSION

The results showed that the village plantation of theca (PVT) had the highest degree of human pressure (50.94%). followed by the teak plantation of Mount Korhogo forest (TFMK). This study of termite diversity in teak plantation showed that termite diversity increases when anthropogenic pressure decreases, until it reaches a level comparable to that of the forest fragment (natural reference habitat), in the teak plantation of Botanical Garden, fauna and floristic reconstruction of teak groves would be beneficial for the re-establishment of termite species. In this region, good management of anthropogenic activities in the teak groves would make these habitats areas of refuge for termite communities recognized as the main soil fertilizing organisms in tropical regions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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