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## Diversity and spatial distribution of epigean nest termite communities in semi-deciduous forest areas of Cameroon

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### Abstract

This study aimed to assess diversity and the spatial pattern of some epigeous nesting termites species. Data were collected in the localities of Lobo and Sep1 respectively. At each site, the experimental set-up consisted of a 100 m x 100 m plot in which X and Y Cartesian coordinates were defined. On each coordinate axis, reference points were placed at 10m intervals to easily locate nests. These data enabled us to collect 14 termites' species, including 7 at each sampling site. Cubitermitinae were represented by 72.72% of total species collected. With regard to nest density, on average we observed  $42.5 \pm 12.02$  nests  $\text{ha}^{-1}$  and 49.41% of these were inactive. Predation pressure from *Dorylus* sp. ants is assumed to be the cause of this high percentage of inactive nests. The termite species associated with these nests did not interact, despite the colonies' spatial distribution being aggregated in the plots. This would be caused by the feeding behavior of some soil-feeding termites' species which feed on distinct soil components, as well as by niche filtering, which is the process that allows the species to cohabit.

**Keywords:** Spatial pattern, termites, diversity, epigeous nests, semi-deciduous forest

### 1. Introduction

One of the primary goals in ecology is to understand the processes and mechanisms that govern species distribution, abundance, and coexistence (Ricklefs *et al.*, 1999, Brown *et al.*, 1995) [10, 35]. The principle of competitive exclusion asserts that two species competing for the same resources cannot coexist in a stable environment. However, new research suggests that niche filtering is the mechanism underlying species coexistence in certain soil-dwelling arthropod communities. Soil fauna has a significant impact on tropical ecosystem dynamics. It contributes to the recycling of organic matter, participates in biogeochemical cycles, stimulates fungal and bacterial metabolism, and hence influences soil biological fertility (Abbadie *et al.*, 1992) [2]. Through their activity, these ecosystem engineers regulate the flow of energy and materials across different spatial and temporal scales (Lavelle *et al.*, 2004) [27]. One of the most significant consequences of termites on ecosystems is their role in reducing soil density and moving materials via bioturbation, as well as the eventual destruction of their structures (Jouquet *et al.*, 2011) [25]. After their biogenic structures are destroyed, termite mound material is redistributed by erosion, affecting soil fertility (Sarcinelli *et al.*, 2009; Rückamp *et al.*, 2012) [37, 36]. Estimates based on the diameter and height of epigeous nests suggest that termites may move huge amounts of soil when constructing a termite mound, ranging from 4 to  $11 \text{m}^3 \cdot \text{ha}^{-1}$  (Oliveira *et al.*, 2011) [33].

Epigeous termite mounds are structures formed by combining soil from saliva faecal material with litter, which enhances Ca, K, and Mg ion concentration in comparison to the surrounding soil (McComie and Dhanarajan, 1993; Brauman *et al.*, 2000) [31, 13]. The shape of these biogenic structures varies depending on the species and habitat, ranging from a simple dome capped by one or more caps to a spherical or cylindrical cap (Williams 1966; Boga *et al.* 2015) [41, 9]. Their internal structure consists of compartments separated by thin walls and connected by holes the size of the warriors' heads. This architecture allows gases to diffuse and plays a crucial role in tactical defence against predators while maintaining strong connection (Perna *et al.*, 2008; Wango and Josens, 2011) [34, 39]. Assessing the spatial distribution of these biogenic structures can provide data on the ecology of soil faunal

communities and establish an important basis for maintaining biodiversity at the soil level (Abe and Wakatsuki, 2010)<sup>[3]</sup>. The spatial distribution of soil fauna is dependent on the spatio-temporal scale because different groups of organisms may present different spatial patterns (Ackerman *et al.*, 2007)<sup>[4]</sup>. Under comparable habitat conditions, the variable spatial configuration of social insects is not only attributable to abiotic factors, but spatial variations in density are also caused by biotic interactions due to their mobility (Blanco-Moreno *et al.*, 2014)<sup>[8]</sup>. The aim of this study is to assess the activity, density, diversity and spatial distribution of epigeous nesting termite communities in semi-deciduous forest zones.

## 2. Methods

### 2.1. Description of sampling sites

The data were collected in the localities of Lobo (Lat: 3°53'56.8"N; Long: de 11°12'31.6"E; altitude: 731m ± 7m) and Sep II (Lat: 3°15'46.8"N; Long: 11°39'27.3"E altitude 624±5 m.) from 2 September to 30 October 2019; this period corresponds to the main rainy season. The two localities, locate in the Central Cameroon region, have an equatorial climate type, including two rainy seasons and two dry seasons (figure 1). The main rainy season runs from September to mid-November while the short rainy season lasts from mid-March to June. The long dry season lasts from mid-November to mid-March, while the short dry season extends from July to August. Rainfall averages 1,800-2,000 mm per year, with temperatures ranging from 22 to 29 °C (Kemadjou 2011)<sup>[26]</sup>.

Rainfall is around 1, 200 to 1,600 mm/year and temperatures range from 22 to 26 °C, with the hottest months being December and March (Abada *et al.*, 2016). The permanent humidity, averaging 79.5% over the year, supports the dense forest. This forest marks the transition between the southern evergreen forest and the northern peri-forest savannahs of Cameroon. Within this forest, the imprint of human activity is highly visible and is clearly evident in the way the landscape is shaped. The environment is now characterised by a mosaic of plant cover, hence the term primary semi-deciduous dense rainforest (Kemadjou, 2011)<sup>[26]</sup>. In Lobo, the forest has been severely degraded by the intensification of slash-and-burn agriculture, with only a few 30-year-old fallows remaining. In Sep I, the forest is less disturbed, with a few pockets of primary forest and old secondary forests over 50 years old (Mbenoun and Makon, 2016)<sup>[30]</sup> (Figure 1).

### 2.2. Sampling procedure

At each site, one-hectare plots (100 m x 100 m) were marked out, one in September 2019 (Lobo) and the other in October 2019 (Sep1). On each plot, all epigeous nests were marked, explored, and their Cartesian coordinates *x* and *y* within the plot were recorded the nests were count, follow by the estimation of the volume and surface as described in Soki and Josens (1996)<sup>[38]</sup> and Marins *et al.*, (2016)<sup>[29]</sup>. So, the volume and surface area of termite mounds can be estimated by approximating their shape to that of stacks of cylinders, cones and cone trunks. The total volume of a nest is therefore the sum of the volumes of the different parts of the nest; the same applies to the total surface area, but after deducting the area located at the intersection of the stack of geometric shapes, then the various parameters, such as the large circumference (C), the small circumference (c) and the

thickness (E) for the case of a truncated cone, and ellipsoid or a hemi ellipsoid; the circumference C and the height h for nests in the shape of a spherical cap, a cone or a cylinder, were measured. Thereafter different mound volumes and attributes have appeared in the sampling plot. Nests were classed based on their volume and physical appearance. Nests were divided into three groups based on volume: category 1 (vol ≤12 dm<sup>3</sup>), category 2 (12<vol≤ 30 dm<sup>3</sup>) and category 3 (vol >30 dm<sup>3</sup>) (Mélo and Bandeira, 2004)<sup>[32]</sup>. A record was also produced for each termite mound, taking into account its apparent age, which was recent, degraded, and deteriorated based on the appearance of its surface (Wango and Josens 2011)<sup>[39]</sup>. Once these parameters had been determined, the activity of the nests was assessed by taking samples to determine the species of termite contained in the nest. Termite mounds which were not occupied by their builders or which no termites species were found were considered as inactive and others were occupied by their builders were considered as active (Figure 2). The termite samples collected were preserved in tubes containing 80% ethyl alcohol. The samples were then repackaged in the biochemistry laboratory of the Ecole Normale Supérieure de Yaoundé I and identified in the microbiology laboratory of IRAD using the identification keys of, Williams (1966)<sup>[41]</sup>, Bouillon & Mathot (1965)<sup>[11]</sup> and Josens and Deligne (2019)<sup>[24]</sup>.

### 2.3. Data analysis

The data collected in the field were recorded in an Excel spreadsheet and then analysed using the chi<sup>2</sup> test to assess differences in abundance between nest categories in the sampling sites. Nest volumes (dm<sup>3</sup>) were compared within the different categories, as well as between sampling sites, using a simple analysis of variance (ANOVA) followed by Tukey's HSD method, and Spearman's correlation test was used to assess the influence of volume (dm<sup>3</sup>) on nest activity these analysis were performed using Statistica 8.0 software. Then, we used the pair correlation function to determine the spatial interaction between termite species in different sampling areas. The pair correlation function (PCF, *g*(*r*), also known as neighbourhood density function) defined as:

$$g(r) = K'(r)/2\pi$$

Where *K'*(*r*) is a derivation of Ripley's K function (Ripley 1987). PCF avoids the cumulative characteristic of Ripley's K function, and thus allows the separation of clustering at different, spatial scales (Wiegand & Moloney 2014)<sup>[41]</sup>. Values of *g*(*r*) = 1 suggest a random point process, *g*(*r*) < 1 suggest regularity, and *g*(*r*) > 1 suggest clumping (at the scale defined by a given radius, *r*).

The Ripley's K function was used to explain the spatial arrangement of point patterns, which in this case is the locations of nest within sampling area. The K function take into account the only the presence of nest in sampling area. Ripley's K plots were created and displayed using the *Kest* function in the *spatstat* package in R. Confidence intervals were created using the *Kest* and envelope functions. The envelope command creates confidence envelopes by using Monte Carlo simulations testing the null hypothesis of complete spatial randomness. To assess the distribution of termite nests in the plots, the data were analysed using the *spatstat* package in R.3.4.4 software.

A Moran's index (I) for nest volume was also used to test for spatial autocorrelation of the points in the field. This test explains to what degree the occurrence of an event in space is likely to affect the occurrence of an event in a neighboring or nearby space. The value of this index statistic varies on a scale of -1 to +1, with -1 indicating a high negative spatial autocorrelation, or a highly dispersed pattern, 0 indicating no spatial autocorrelation, or a random pattern, and +1 indicating high positive spatial autocorrelation, or a clustered pattern. This analysis was performed using the ape package in R.3.4.4 software.

### 3. Results

#### 3.1. Termites diversity and composition

The data collected enabled us to collect 14 species belonging to 6 genera, including 7 in Lobo and 7 in Sep 1. These species are divided into three subfamilies, including Cubitermitinae with 8 species, Termitinae with 2 species and macrotermitinae with only one species. Cubitermitinae account for 71.42% of the total species richness.

From a functional groups point of view, all the species collected are classified as the fungus-growing Macrotermitinae (*Protermes prorenpensis*), wood-feeding Termitinae (*Microcerotermes fuscotibialis*), soil feeding Apicotermitinae (Apicotermitinae1), soil-feeding Termitinae (*Pericapritermes minimus*), soil-feeding Cubitermitinae (*Isognathotermes minitabundus*, *Isognathotermes sulcifrons*, *Isognathotermes antennalis*, *Isognathotermes hegghi*, *Isognaothotermes subarquatus*, *Lepidotermes* sp 1, *Lepidotermes* sp 2 *Lepidotermes goliathi*, *Noditermes* sp 1, *Orthotermes depressifrons*)

#### 3.2. Nest activity and categorization

In this study, the number of termite nests ranged from 34 to 51 ha<sup>-1</sup> between Lobo and Sep 1 (42.5± 12.02 nests ha<sup>-1</sup> on average). A total of 85 termite mounds was counted, of which 42 representing 49.41% were not occupied by their builders or which no termites species were found were considered as inactive and others (43) were occupied by their builders were considered as active. Among the active mounds 35 were occupied by *Isognathotermes* sp. representing a total 41.17% of a total nests sampled. In others hands, In lobo 32.35% of the mounds were active, and 62.74% were active in Sep. Spatial variability of vitality was depend of locality and its relationship to mound size. In lobo the vitality of mound was positively correlate to mound size in lobo ( $r=0.40$   $p<0.05$ ); in Sep 1 the mound size was not correlate with activity ( $r=0.17$   $p>0.05$ ). But in general the activity was independent to the mound size ( $r=0.03$   $p>0.05$ ).

Different mound volumes and aspects have emerged in sampling plot. Therefore nests were classified according to their volume and physical aspect. According to their volume, nests were classified in three categories: category 1 (vol<12 dm<sup>3</sup>) (63 mounds), category 2 (12<vol<30 dm<sup>3</sup>) (8 mounds) and category 3 (vol>30 dm<sup>3</sup>) (14 mounds); in each plot, these categories are statistically different considering Godness fit test ( $\chi^2=68.212$   $ddl=2$ ,  $p<0.0001$ ); Considering the volume of the nests measured (dm<sup>3</sup>), it appears that the volume of category 3 (volume > 30dm<sup>3</sup>) is statistically different from the other two categories (2  $ddl$ ,  $F(1,79) = 36.14$ ,  $p=0.00000$ ), but overall, the sampling site has no effect on the volume of the nests (1  $ddl$ ,  $F(1,79) = 1.67$ ,  $p=0.14$ ) (Anova and Tukey's HSD post-hoc test) (table 1).

For each termite mound, a record was also created considering its apparent age which was recent (24 mounds), eroded (41 mounds) or dilapidated (20 mounds) from the appearance of its surface; Godness fit test showed that these classes are not similar ( $\chi^2=8.5647$ ,  $df=2$ ,  $p=0.01$ ).

#### 3.3. Spatial pattern and interactions between communities

Concerning their pattern, the distribution of epigeous nests are represented in figure 3 and figure 4. When considered all together, nests were generally clustered. Although the distribution of nests was aggregated in both sites, the cross PCF analysis did not reveal any interaction between the termite species associated with the epigeous nest explored (Figure 5 and Figure 6).

In our spatial autocorrelation analysis, we focused on Moran's I for nest volume. The Moran's I values for nest volume, were between Lobo and Sep1 were respectively (I= -0.056  $p=0.72$ ) and (I= -0.014  $p=0.88$ ) indicating no clear pattern in the spatial distribution of nest volume.

### 4. Discussion

The goal of this study was to contribute to our understanding of termite ecology in Cameroon's semi-deciduous forest by investigating termite diversity and the spatial distribution of termite mounds within the sampling site. Epigeal nesting termite populations in semi-deciduous forests contained more soil-feeding termites than wood-feeders and fungus-grower termites; several species, such as *Pericapritermes minimus*, *Microcerotermes fuscotibialis*, and Apicotermitinae species, were discovered nesting in abandoned mounds. These findings are comparable to those reported by Wood *et al.*, (1982) [43] in Nigeria. These nests were then classified based on their appearance and volume; in three categories in which eroded nests were more abundant than the other types of nests. Wango *et al.*, (2021) [40] found comparable results in Bongoé (Central African Republic), where 43 of the 70 nests were degraded, 18 were dilapidated, and 9 were recent. Finally, in terms of volume, they noticed that the average volume of *Cubitermes* spp nests varied between 211 and 316 dm<sup>3</sup>, in contrast to our study, where these volumes were between 2.17 to 134.29 dm<sup>3</sup>. In addition to this we observed in our study that 74.11% of the nests had a volume of less than 12 dm<sup>3</sup>.

Average density of 42.5 mounds ha<sup>-1</sup> observed in our study areas appeared to be higher than earlier reports of Boga *et al.*, (2015) [9] and Bandiya *et al.*, (2012) [7] which respectively recorded a density of 8.99 and 10.08 mounds ha<sup>-1</sup> in Ivory coast and in a Semi-arid Zone of Nigeria. Nest density also depends on the quality of the sampling site; in fact, for termites of the gender *Isognathotermes* spp their density at lobo (20 year fallow) is 5 ha<sup>-1</sup> compared to Sep 1 (primary forest) 29 ha<sup>-1</sup>; the high number of nests of these termites at Sep could be explained by the stability of this habitat could explain the recolonization and restoration of *Isognathotermes* spp colonies. This observations corroborated the findings of Lepage and Tano (1988) [28] who showed that only the old secondary forest (30-40 years) regain an important termites' population.

The distribution termite mounds shows Lobo contains the most important rate (67.65%) of inactive nests contrary to Sep 1 (37.26%). The low level of termite activity at this site could be due to human activities, in particular shifting cultivation, which prevents the establishment of a large

proportion of termite colonies (Eggleton *et al.*, 2002) <sup>[18]</sup>. But also the lowest activity of termite mounds in this site, it has been particularly noted the abundant presence of ants on the ground, the presence of a nest of black ants hunters *Dorylus* sp. One might therefore think that these ants hunt decimate populations of termites and so, prevent their abundant installation in this area. This would explain the lowest density of termite mounds and the higher rate of inactive mounds in the site. These observations imply a perpetual struggle between the different colonies of termites and ants. Confirming the observations made by Hauser (1976) <sup>[22]</sup>. In general we obtained 49% of mound were inactive contrary to Boga *et al.* (2015) <sup>[9]</sup> were 18.70% of inactive mound.

Concerning spatial pattern, Collins (1981) <sup>[16]</sup>, Boga *et al.* (2015) <sup>[9]</sup> which reported a random distribution pattern of termites mound respectively in Southern Guinea Savanna of Nigeria and in Ivory Coast. These authors argued that spatial pattern termite mounds was related to the stability of this habitat protected from human activities since 51 years. But also by the result of inter-specific competition as it has been previously noted (Grohmann *et al.*, (2010) <sup>[20]</sup>. Contrary to these authors, the distribution of nests was aggregated in our study, we can attribute this by the fact that new colonies are formed in the vicinity of pre-existing colonies. In other respects, there are a variety of factors that contribute to a clustered distribution, these could include environmental factors such as availability of food resources, canopy cover, and refuge (Dibog *et al.*, 1998; Axelsson and Andersson, 2012; Hahn *et al.*, 2017) <sup>[17, 6, 21]</sup>.

With regard to interactions, no interactions were observed between different termite species. Indeed, the results of this study show that sympatric geophagous termites feed on distinct soil components. This also suggests that some species are more likely to move along this soil organic matter humification gradient than others, in response to general habitat conditions or the presence of competitors. Food niche differentiation may therefore explain the coexistence of geophagous termite species in neotropical tropical forests (Bourguignon *et al.*, 2009) <sup>[12]</sup>.

Furthermore, niche partitioning has often been used to explain the coexistence of species (Camarota *et al.*, 2016) <sup>[14]</sup>. However, the large number of species has led ecologists to question the role of interspecific competition in coexistence, and alternative mechanisms have been proposed (Cerdá *et al.*, 2013) <sup>[15]</sup>. Andersen (2008) <sup>[5]</sup> has proposed alternative explanations for the high diversity of species at local scales, based on sociability and modularity, which protect them from environmental damage (Hölldobler and Wilson, 2009) <sup>[23]</sup>. In addition, competitive interactions between species are highly variable over time and space as a function of environmental variations. Resource dominance leads species to overcome the negative effects of interspecific competition. In this way, recent studies have suggested that niche filtering (similarities in resource use) is the mechanism responsible for species coexistence (Fowler *et al.*, 2013) <sup>[19]</sup>. Given that niche partitioning favours the coexistence of species that differ in the use of limited resources and that niche filtering favours the coexistence of species with similar niches.

## 5. Conclusion

Evaluation of the spatial distribution of epigeous termite nests in semi-deciduous forest zones enabled us to collect 14

termite species associated with these mounds. Although the spatial pattern of these nests was clustered, no interaction was observed between the termite species associated with these nests. Furthermore, the high proportion of inactive nests is attributable to the disturbance level of sampling site and the predation pressure of ants of the genus *Dorylus* sp.

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## 7. Conflict of interest

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

## 8. Authors Contribution

PAD and TZ conceived the idea. PAD and Y devised the methodology and interpreted results. EGS carried out the experiment under supervision by PAD and MMPS All authors contributed to the final manuscript

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