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# Leaf litter-dwelling ant (Formicidae) diversity in a tropical rainforest and agro-forestry system, South Region of Cameroon: Implications for conservation management

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**Abstract**

The future of tropical rain forests has never been more uncertain, as many of these forests are being rapidly destroyed and degraded through various forms of human impact, such as infrastructure development and agricultural expansion. Ant species were sampled at five habitat types to determine the effect of land-use on their diversity and composition. Four methods were used to sample ant specimens bi-monthly from November 2015 to June 2017. A total of 306 ant species, belonging to 11 subfamilies were recorded. Shannon-Wiener's index indicated that the highest diversity occurred in the forest habitat 209 with Shannon index equal to 4.4. Significant differences value were observed between the banana farm and old cocoa farm, forest and young cocoa farm but not between the banana farm and palm grove; suggesting that ant diversity varied distinctly with land. Environmental management for conservation measures in the study area aimed to preserve sufficient vegetation that varies in diversity, physiognomy and complexity, as well as an herbaceous layer that allows the accumulation of litter favorable to the development of myrmecofauna.

**Keywords:** anthropogenic, ants, disturbances, diversity, land-use, species

## 1. Introduction

Tropical rainforests support at least two-thirds of all terrestrial plant and animal species on earth and also provide significant economic, environmental, and social benefits to humans. However, the future of tropical forests has never been more uncertain, as many rainforests in the tropics are being rapidly destroyed and degraded through various forms of human impact, such as infrastructure development, agricultural expansion, and timber extraction (Wilson, 1990 [57]; Gardner *et al.*, 2009 [25]; Koh and Wilcove, 2008 [32]; Miettinen *et al.*, 2011) [43]. Human population pressure and increasing demand for food, combined with the shift from small-scale independent producers to large-scale agribusiness, have promoted conversion from traditional low intensity agricultural practices (Bhagwat *et al*., 2008) [6] (i.e. use of a small quantity of chemical pesticides and fertilizers, and a small quantity of supplementary livestock) to highly intensive agricultural (Attwood *et al*., 2008) [5]. With continuing land use intensification, there is increasing international concern about ecosystem resilience and loss of biodiversity (Bos *et al*., 2007 [9]; Bhagwat *et al.*, 2008 [6]; Gibbs *et al.*, 2010) [26]. Many studies have documented the negative impact of tropical deforestation and intensification of land use on invertebrate communities, including a collapse in termite species richness and abundance along a land-use management gradient (Jones *et al.*, 2003) [29] and a change in species richness and composition of different animal groups with increasing habitat modification (Lawton *et al*., 1998) [32]. Others have shown that habitat modification and land use can negatively affect ant communities (Roth *et al*., 1994 [50]; Watt *et al*., 2002) [56].

Cameroon is one of the Central African countries (next to Gabon, Equatorial Guinea and Democratic Republic of Congo) on which biodiversity conservation in Africa should focus first (Doumenge, 1998 [19]; Foahom, 2001 [23]; Kamdem-Toham *et al*., 2006) [30]. It has one of the highest species densities of mammals (280 species) and vascular plants (9000 species) in Africa, and shelter more than 40 globally threatened animals (Alpert, 1993) [2]. Cameroon remains a critically important biodiversity hotspot for insects in tropical Africa, even though few studies have been undertaken to support this statement (Eggleton *et al.*, 1996 [20]; Deblauwe and Dominick, 2007 [16]). Only about 17 % of the total forest area in Cameroon (22.000.000 ha) is protected and about 1220.000 ha per year are cleared due to logging and farming (Foahom, 2001) [23]. Ants are a highly valuable taxon as bio indicators for many reasons: they are a diverse group, sensitive to environmental change, easily collected and serve important ecological functions (Majer, 1983 [41]; Alonso and Agosti, 2000 [1]; Anderson, 2000 [4]; Ottonetti *et al*., 2006 [46]). One quantitative inventory has been conducted at Mt Doudou, located in the south western region of Gabon in the Congo Basin (Fisher, 2004) [21]. Up to 151 ant species were found in Cubitermes mounds, which is the highest diversity of ants ever recorded in Cameroon (Dejean *et al*., 1996) [18]. Watt *et al.* (2002) [56] collected 111 species from leaf litter in the Mbalmayo forest reserve in south-central Cameroon during a study on the impact of forest disturbance on ant diversity and abundance. However, no extensive studies of land use management on ground-dwelling ant assemblages in the tropical rainforest of south Cameroon have been published. We hypothesise here that ant diversity was influence by land use in and around Dja forest reserve. The study aimed to assess the impact of land use management on the leaf-litter ant community of Minko'o in the northern periphery of the Dja biosphere reserve, South Region of Cameroon.

## 2. Materials And Methods

### 2.1 Study location

The study was conducted in Minko'o, located at 12 km from Meyomesala and 7 km from Dja Biosphere Reserve in the South Region of Cameroon (Figure 1). The Dja reserve forest is part of the transition zone of the Atlantic coastal rainforests of southern Nigeria and south-east Cameroon, and the evergreen forests of Equatorial Guinea and the Congo Basin (Letouzey, 1985) [37]. The climate is humid equatorial, with bimodal pluviometry and seasons comprise of wet conditions from March to June with heavy precipitation from August to November, interspersed by a high dry season and a short dry season that extend from November to March and from June to July respectively (Suchel, 1988) [51]. Annual rainfall averages vary between 1600 mm and 1700 mm.

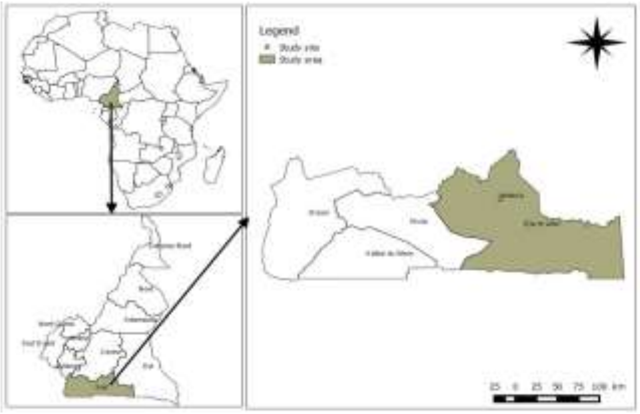


**Fig 1:** Map indicating the location of study site

### 2.2. Description of study sites

Five sites in Minko'o locality were mapped out for the study as follows i) Forest: This biosphere reserve (according to IRAD categorization) covers 50 hectares. ii) Old cocoa farm: It was created over 70 years ago, and covers an area of one hectare. iii) Young cocoa farm: This plantation was created in 2000, and has an area of one hectare. iv) Palm grove: This site covered an area of 6900 $m^2$ and v) Banana farm: This farm measured 7090 $m^2$.

### 2.3. Sampling methods

To provide an adequate representation of species and community structure in the rainforest and associated agroforestry systems, ants were surveyed using four complementary methods: baits, pitfall traps, litter extraction (Berlese) and hand capture.

*Honey-protein baiting trap*: Baits were used to estimate the composition and richness of diurnally active ant foragers (Bestelmeyer *et al*., 2000) [7]. Small pieces of canned sardine, mixed with honey were put on a Marantaceae leaf and placed on the ground. Twenty (20) bait stations were mapped out along 100 m of transect at five (5) meters apart between stations. Ants present on baits were collected after 20 minutes using forceps during one day.

*Hand collecting:* At each site, twenty (20) sections along a 100 m line transect at intervals of five (5) meters apart were mapped out. At each section, ants were collected manually over a fifteen-minute period using forceps and an aspirator for lower vegetation, to the left and right of the line transect.

*Pitfall trapping:* It was used to estimate the abundance and composition of ground active ants (Bestelmeyer *et al*., 2000) [7]. Twenty-one (21) pitfall traps were spaced out along the 100 m line transect, with an interval of (5) meters between each trap. Traps consisted of plastic drinking cups (diameter 18cm; depth 23cm) filled with water and detergent to about one third of the cup volume, and placed in the ground with the cup lip flushed with the surface of soil or leaf litter. Traps were left in place for 24- hours, after which all arthropods were removed.

*Berlese Funnel:* Litter extraction was used to measure the abundance and composition of ants inhabiting soil and leaf litter (Bestelmeyer *et al*., 2000) [7]. Five plots (30 cm×30 cm) were randomly selected along the transect. Leaf litter samples collected were placed in a zip-plot bag to be processed using the Berlese extraction technique. A quantity of leaf litter sample was poured into a PolyVinyl Chloride (PVC) container of diameter 20 cm and depth 35cm. The whole was placed under a lamp for 48-hours. Ants moved out of the litter and fell into a plastic cup (70 mm internal diameter) filed with 70% ethanol as a receptacle. In each habitat, 66 samples were collected, which gave a total of 330 samples for the five habitats per visit on the field. Surveys at each site were conducted every two months from 2015 to 2017 and 10 descents on field were carried out and the overall number of samples was 3300.

### 2.4. Ant identification

All ant specimens were preserved in vials with 70% alcohol and taken to the lab for identification to the lowest taxonomic level possible, using field guides (Hölldobler and Wilson, 1990 [28]; Fisher and Bolton, 2016 [22]) and reference collections housed at the Zoology Laboratory of the University of Yaoundé 1.

### 2.5. Statistical analyses

#### Evaluation of sampling success

In order to evaluate strength of the Sampling Effort (SE), the Theoretical Species Richness (TSR) was calculated using two non-parametric estimators: $S._{ICE}$(Incidence-Based Coverage estimator species richness score) and Chao2 (Chao, 1987) [12], using Vegan package (Oksanen *et al*., 2011) [44] for R software (Version 2.13.0) (R Core Team, 2011) [48].

#### Ant diversity index

In order to assess the effect of land use on ant species diversity and composition, the species richness, Shannon Wiener diversity and Evenness indexes were calculated for each habitat using the Vegan package (Oksanen *et al*., 2011) [44] for R software (Version 2.13.0). These parameters were then compared between habitat using the Kruskal-Wallis ($\chi^2$) test, with associated when necessary with Wilcoxon test for pairwise comparisons corrected with sequential Bonfferoni procedure for *p*-values adjustment (R software version 2.13.0).

Finally, Analysis of Similarity (ANOSIM) was used to evaluate the degree of dissimilarity between ant communities of the studied habitat. We used Bray-Curtis index to perform an analysis of similarities (ANOSIM). This analysis provides an *R* statistic which is a measure of the dissimilarity between habitats. The ANOSIM statistic R is based on the difference of mean ranks between groups ($r_B$) and within groups ($r_W$): $R= (r_{B-} r_W) /(N(N-1)/4)$. R will be in the interval -1…1, value 0 indicating completely random grouping. Value of R close to -1 indicated low dissimilarities while value closer to 1 indicated high dissimilarities (Clarke, 1993) [13]. The results were appreciated at 5 % confidence interval.

### Distribution model of ant species at sites

The rank-frequency diagram allows studying ant community structure through an assessment of the relationship between species richness and their occurrence. The species rank is on the abscissa of the figure and their occurrence on the y-axis (Magurran and McGill, 2011) [39]. The observed distribution models were fitted into theoretical models using the Vegan software package in R Version 2.13.0 (Oksanen *et al*., 2011) [44]. The proposed theoretical adjustment models are: the Log normal model or Preston model (community structured by strong interspecific competition between species), the Zipf-Mandelbrot model (strong ability of some species to increasingly monopolize space as the ecosystem ages-the ecosystem structure will be very close to the pioneer stage) and the Preemption model (communities where frequent species retain their status by limiting the availability of resources for rare species that become scarcer over time).

The Bayesian Information Criteria (BCI) and the Akaike's (AIC) Criteria were used to determine the best theoretical adjustment model, which is the one with the lowest BIC and AIC values. The adjustment in the BIC estimate is given as k = log (S), where S represents species richness, while in the AIC estimate, the value k = 2 (Oksanen *et al.,* 2011) [44].

### Influence of habitat structure on ant occurrence

Since a comparison of sampling methods based on the number of samples makes little sense (each method does not have the same probability of capture) and the number of individuals is not a reliable value in the case of ant studies (data easily distorted if harvest is near a nest or track), it is better to consider only species occurrences. Numerically dominant species were selected on the basis of their membership at the interval 50-100% of the occurrences (Majer, 1972) [40]. Then, effect of site on variation of species occurrences was tested.

## 3. Results

### 3.1. Evaluation of the sampling success

### Use of nonparametric estimators

Sampling effort success varied between 81 and 89%, for all non-parametric estimators. The largest success of the sampling effort was recorded in the young cocoa farm with a rate of 89.86 % using the Chao2 estimator and lower in the old cocoa farm with 81.30% (ICE) of the species sampled. The average capture success achieved with all estimators were 82.88%, 84.21%, 84.80%, 85.33% and 88.06% of the species collected in the old cocoa farm, banana farm, palm grove, forest and young cocoa farm respectively (Table 1).

**Table 1:** Variation of sampling success base on Chao2 and ICE non parametric estimators

| **Habitats** | **Non parametric estimators** | | | | | |
|---|---|---|---|---|---|---|
| | **S** | **Chao2** | **SD. Chao2** | **ICE** | **SD.ICE** | **Mean** |
| Banana farm | 134 | 162(83.95) | 13 | 161(84.47) | 6 | (84.21) |
| Old cocoa farm | 173 | 206(84.46) | 14 | 214(81.30) | 7 | (82.88) |
| Young cocoa farm | 132 | 148(89.86) | 9 | 153(86.27) | 6 | (88.06) |
| Forest | 209 | 250(84.00) | 16 | 250(86.66) | 8 | (85.33) |
| Palm grove | 119 | 142(84. 50) | 12 | 141(85.10) | 6 | (84.80) |

The success percentage is given into a bracket, S is species richness, ICE: Incidence Based Coverage Estimators and SD: Standard deviation. Maximum and minimum success values are indicated by bold numbers.

### Use of rarefaction curves

The rarefaction curves (Figure 2) allow to estimate if the study areas have been globally sampled in a suitable manner or not. The curve that characterizes the forest is more above all the other curves, followed by that of the old cocoa farm, the young cocoa farm, the banana plantation and finally that of the palm grove. In view of these curves, these habitats have been sampled in an acceptable manner because the growth of the curves tends to slow down, meaning that the number of new species decreases with the increase in the number of samples. However, the curve of the young cocoa farm seems to be the one that comes closest to the horizontal asymptote meaning that the vast majority of species in this habitat has been collected and this is confirmed with the data recorded in Table 1. The inflection points beyond which the various curves tend to describe horizontal asymptotes are reached in all cases at the value of 1000 sampling units (Figure 2). In view of these curves, it can be estimated that the majority of the species that make up the community of ground ants in the different environments studied have been collected. But a higher sampling effort would have been necessary in order to get closer to the horizontal asymptote (corresponding to the total number of species estimated for each land use).

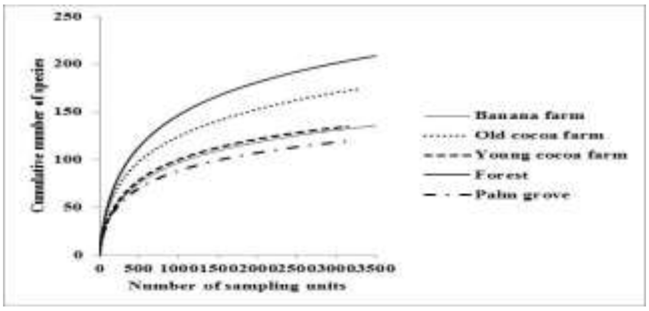


**Fig 2:** Rarefaction curves based on the progression of species richness at sampling sites

### 3.2. Ant diversity and distribution

A total of 306 species from 57 genera and 11 subfamilies were collected in 3300 sampling units representing. The highest species richness was recorded in the forest with 209 species and average of 3.05±1.88 ant species, followed by the old cocoa with 173 species (2.4±1.24 species), the banana farm and young cocoa farm, with richness of 134

(2.2±1.21) and 132 (2.2±1.04) respectively. The palm grove harbored the least count with 119 species (average 2.09± 0.98). The mean variation of species richness per sample was significant between habitats ($\chi^2$ = 30.77, df = 4, P <0.0001) (Table 2). Wilcoxon pairwise comparisons test revealed significant differences (P <0.05) between the old cocoa and young cocoa farm, forest and young cocoa farm, palm grove and old cocoa and forest and palm grove. In contrast, the pair old cocoa and banana farm, forest and banana farm, palm grove and Banana farm, palm grove and young cocoa farm, Banana and Young cocoa and forest and old cocoa did not differ significantly (P> 0.05).

Based on the Shannon index, the most diverse myrmecofauna was obtained in the forest (H'= 4.4 (3.14 ± 0.51); Hmax=5.34(3.35±0.57); E = 0.83 (0.94 ± 0.03)). While, the palm grove was the least diversified (H'= 3.53 (2.64 ± 0.54); Hmax=4.78(2.91±0.62); E = 0.74 (0.91 ± 0.04)). A comparison of the mean values of the Shannon index between habitats showed a significant effect of habitat on ant diversity ($\chi^2$ = 42.06; df= 4; P <0.0001) (Table 2). A pairwise comparison showed that the indices of diversity differed significantly (P <0.05) between the old cocoa and banana farm, old cocoa and young cocoa, forest and banana farm, forest and young cocoa farm, palm grove and old cocoa and forest and palm grove. Banana farm and old cocoa, palm and banana farm, forest and old cocoa and palm grove and young cocoa however, did not differ significantly (P> 0.05). Although these indices are high, the palm grove had the smallest value. For all five habitats studied, the values of the equitability index (E) were greater than 50% (E> 0.5) (Table 2).

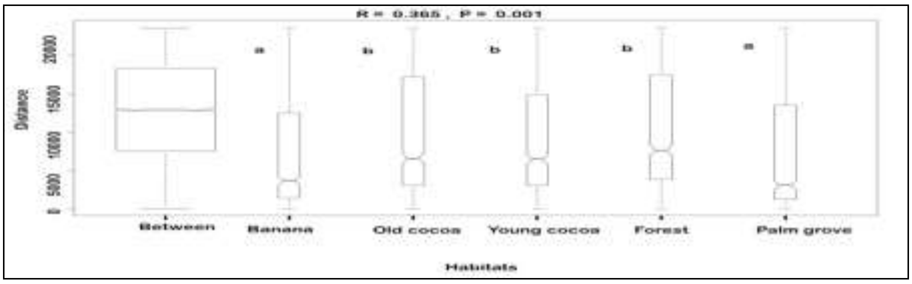
**Table 2**: Variation of richness and specific diversity of myrmecofauna in the agroforestry systems and forest of Minko'o

| | | **Differents habitats** | | | | |
|---|---|---|---|---|---|---|
| **Diversities index** | | | | | | **kruskal. test (χ2)** |
| | Banana farm | Old cocoa farm | Young cocoa farm | Forest | Palm oil farm | |
| Richness specific | 134(22.64±9.24) a | 173(28.07±11,36) b | 132(22.12±7.44) a | 209(32,5±14,22) a | 119(20.91±8,09) a. | χ2=30.77;df=4; P< 0.001*** |
| shannon (H') | 3.62(2.73±0.37) a | 4.22(3±0.48) b. | 3.55(2.66±0.33) a. | 4.4(3.14±0,51) c | 3.53(2.64±0,54) a. | χ2=42.06;df=4; P< 0.001*** |
| Hmax | 4.91(3.03±0.45) a | 5.15(3.22±0.55) ac | 4.89(3.03±0.4) ab | 5.34(3.35±0.57) bc | 4.78(2.91±0.62) ad | χ2=29.64;df=4; P< 0.0001*** |
| Equitability(E) | 0.74(0.91±0.05) a | 0.82(0.93±0.03) bc | 0.73(0.88±0.06) a. | 0.83(0.94±0.03) bc. | 0.74(0.91±0.04) a. | χ2=47.91;df=4; P< 0.0001*** |
| Index of dominance | 0.95(0.91±0.03) a | 0.98(0.93±0.03) bc | 0.93(0.9±0.04) ad | 0.98(0.94±0.03) b. | 0.95(0.9±0.09) ad. | χ2=52.87;df=4; P< 0.0001*** |
| N | 660 | 660 | 660 | 660 | 660 | |

χ2: Kruskall-Wallis test; d.f. = 4, ***: high significant at 5 % confidence interval; different letters are statistically significant different according to pairwise comparisons; Mean ± Standard deviation, N= sampling unit

### 3.3. Similarity between habitats

Considering the whole ant community together, ant species composition differed among habitats (general ANOSIM: R = 0. 365, P=0. 001: Figure 3).



Legend: Different letters a,b indicate the significant differences following the pairwise comparison (P>0.05).

**Fig 3:** Pairwise comparisons based on degree of similarity between ant communities at sampling sites.

Species composition in Old cocoa farm was more similar to forest and young cocoa farm, while ant species composition in palm grove was similar to that of the banana farm (Table 3).

**Table 3:** Differences in species composition of ant from the five habitat of Minko'o tested by means of pairwise ANOSIM comparisons.

| **Pairwise test** | **R** | **P** |
|---|---|---|
| Banana vs Old cocoa | 0.48 | 0.001 |
| Banana vs Young cocoa | 0.28 | 0.001 |
| Banana vs Forest | 0.56 | 0.001 |
| Banana vs Palm grove | 0.11 | 0.001 |
| Old cocoa vs Young cocoa | 0.32 | 0.001 |
| Old cocoa vs Forest | 0.12 | 0.001 |
| Old cocoa vs Palm grove | 0.49 | 0.001 |
| Young cocoa vs Forest | 0.45 | 0.001 |
| Young cocoa vs Palm grove | 0.30 | 0.001 |
| Forest vs Palm grove | 0.57 | 0.001 |

*R* close to zero indicate low dissimilarities while *R* close to 1 indicate high dissimilarities

### 3.4. Ant distribution models at study sites

#### Distribution Model of occurrences

The rank frequency diagram highlights an irregular distribution of species occurrences between communities. Three groups of unequal importance are distinguished within communities as follows: A first group with frequent species (more than 50% of relative occurrence) and species richness of about 8 for each habitat (Figure 4). The second group includes less frequent species (between 25 to 50%) with a richness of 8 species in banana farm and young cocoa, 11 in old cocoa and forest, and 7 species in palm grove while the third group consisted of rare species (less than 25%).

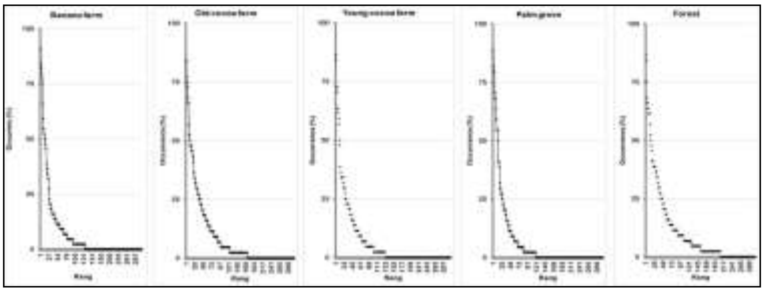


**Fig 4:** Rank-frequency diagrams adjusted according to theoretical models used in the study that depict the relationship between species richness and occurrence at study sites.

The adjusted distribution (using theoretical models) showed that communities of soil-dwelling ants in the banana plantation, (AIC = 582.228), palm grove (AIC = 511.405), young cocoa farmer and aged cocoa farmer (AIC = 730.602) were distributed according to the Mandelbrot theoretical model (Table 4).

**Table 4:** Adjustment to theoretical models of distributions of rank-frequency diagrams of the communities of soil-dwelling ants collected in the different habitats in the locality of Minko'o South region (2015-2017).

| **Parameters** | | **Banana farm** | | | **Palm grove** | | **Old cocoa** | |
|---|---|---|---|---|---|---|---|---|
| | **Deviance** | **AIC** | **BIC** | **Deviance** | **AIC** | **BIC** | **Deviance** | **AIC** | **BIC** |
| Nul | 207,099 | 756,373 | 756,37 | 188,158 | 675,353 | 675,353 | 157,021 | 858,919 | 858,919 |
| Preemption | 77,299 | 628,573 | 631,49 | 37,656 | 526,851 | 529,638 | 38,295 | 742,193 | 745,352 |
| Lognormal | 165,588 | 718,861 | 724,69 | 180,39 | 671,585 | 677,16 | 179,894 | 885,792 | 892,11 |
| Zipf | 498,489 | 1051,763 | 1057,6 | 520,366 | 1011,561 | 1017,14 | 633,55 | 1339,449 | 1345,77 |
| Mandelbrot | 26,954 | 582,228 | 591 | 18,211 | 511,405 | 519,77 | 22,704 | 730,602 | 740,08 |
| | Young cocoa | | | | Forest | | | | |
| Paramètre | Deviance | AIC | BIC | Deviance | AIC | BIC | | | |
| Nul | 157,021 | 858,919 | 858,92 | 177,801 | 1022,608 | 1022,61 | | | |
| Preemption | 38,295 | 742,193 | 745,35 | 61,809 | 908,617 | 911,96 | | | |
| Lognormal | 179,894 | 885,792 | 892,11 | 190,79 | 1039,598 | 1046,29 | | | |
| Zipf | 633,55 | 1339,449 | 1345,8 | 704,239 | 1553,047 | 1559,74 | | | |
| Mandelbrot | 22,704 | 730,602 | 740,1 | 61,089 | 911,896 | 921,938 | | | |

Bold values represent the best theoretical Adjustment model. AIC and BIC respectively represent the Akaike Criteria and the Bayesian Information Criteria

This distribution reflects a strong tendency for some species of the community to disperse the few workers they have over a large area; which reflects the first stage in the process of colonization of an ecosystem where no species exerts real control over a territory. The species *Carebara perpusilla*, *Monomorium invidum* and *Axinidris* sp.1 contributed significantly to such structure. In the forest habitat, the distribution model of ant communities fitted best with the Preemption theoretical model (AIC = 908.617). This characterizes communities in which the status of the most common species is preserved while the less frequent species gradually become scarce in the environment over time due to limited resources. This distribution is the result of the presence in the forest of highly territorial species such as *Tetramorium aculeatum*, *Oecoplylla longinoda* and *Crematogaster africana*.

### 3.5. Occurrence of dominant ant species between habitats

Of the 306 ant species identified in this study, only 8 were dominant (cumulative species occurrence for all five habitats ≥ 20%) in sampled communities (Table 5). *Pheidole megacephala* (90.90%) was most represented at the banana farm compared to Palm grove (88.64%), Young cocoa and old cocoa (86.36%) and forest (75%). Myrmecofauna of banana, young cocoa, and old cocoa farm was also dominated by *M. opaciventris* with (84.09%), (65.91%) and (81.82%) respectively. A similar trend was observed for *Odontomachus* with a higher relative occurrence in banana (79.55%) and palm grove (79.55%). *Camponotus flavomarginatus* was dominant at the banana farm (84.09%) and palm grove (81.82%) while *Axinidris* sp.1 dominated at the old cocoa farm (84.09) and forest (68.18). Species occurrence varied significantly between habitats for *Palthothyreus tarsatus* ($\chi 2$ = 25.47, P <0.001), *Carebara perpusilla* ($\chi 2$ = 48.092; P <0.001) and *My. opaciventris* ($\chi 2$ = 114.21; P <0.001). On the other hand, the occurrence of *Ph.megacephala*, *Od.troglodytes* and *Mo. guineense* did not vary significantly amongst habitats (Table 5).

**Table 5:** Variation in the occurrence of dominant ant species collected in Minko'o from 2015-2017

| Sspecies | Habitats | | | | | | $\chi$2 test |
|---|---|---|---|---|---|---|---|
| | Banana farm | Old cocoa | Young cocoa | Forest | Palm grove | Total | |
| *Axinidris* sp.1 | 315 (47.73) a | 555 (84.09) b | 255 (38.64) a | 450 (68.18) a | 390 (59.09) a | 1965 (59.55) | $\chi^2$= 18.82; P< 0.001** |
| *Camponotus flavomarginatus* | 555 (84.09) a | 345 (52.27) b | 480 (72.73) a | 300 (45.45) c | 540 (81.82) a | 2220 (67.27) | $\chi^2$= 27.64; P< 0.001** |
| *Monomorium guineense* | 435 (65.91) | 315 (47.73) | 390 (59.09) | 270 (40.91) | 450 (68.18) | 1860 (56.36) | $\chi$= 9.93; P= 0.41 ns |
| *Myrmicaria, opaciventris* | 555 (84.09) a | 435 (65.91) ac | 555 (84.09) ac | 0 (0.00) b | 540 (81.82) ac | 2085 (63.18) | $\chi$= 114.21; P< 0.0001*** |
| *Odontomachus troglodytes* | 525 (79.55) | 435 (65.91) | 480 (72.73) | 495 (75) | 525 (79.55) | 2460 (74.55) | $\chi$= 2.92; P= 0.57 ns |
| *Carebara perpusilla* | 495 (75)a | 180 (27.27) b | 420 (63.64) a | 135 (20.45) c | 465 (70.45) a | 1695 (51.36) | $\chi$= 48.09; P< 0.0001*** |
| *Palthothyreus tarsatus* | 390 (59.09) a | 510 (77.27) ac | 195 (29.55) b | 405 (61.36) ac | 270 (40.91) a | 1770 (53.64) | $\chi$= 25.47; P< 0.001** |
| *Pheidole megacephala* | 600 (90.90) | 570 (86.36) | 570 (86.36) | 495 (75) | 585 (88.64) | 2820 (85.45) | $\chi$= 4.93; P= 0.29ns |

Legend: The values in bracket represent the relative occurrences of the genera in each habitat; $\chi^2$= Chi-2 Kruskall-Wallis; df = 4; ns: indicates non-significant differences at the 5% threshold; ***: indicates the highly significant differences at the 5% probability threshold; the letters a, b, c indicate the significant differences following the pairwise comparison.

## 4. Discussion

### 4.1. Evaluation of the strength of the sampling effort

For each of the five sites studied, the observed species richness was lower than the average predicted value of the theoretical species richness obtained with the different non-parametric estimators. The rarefaction curve indicates that more than 80% of the species were captured suggesting that the sampling effort was adequate for estimating ant species richness at the different habitats studied.

This assessment agrees with Gotelli *et al.* (2011) [27] who suggested that it is rare to achieve a complete sample of ants because undetected species can sometimes only be found after a decade of continuous sampling. All five curves approached the saturation threshold (asymptote), indicating that species richness changed little at this point despite the increase in the sampling size (Longino, 2000) [38]. This reflects a satisfactory sampling effort and shows a species richness trend that is representative of the areas surveyed. Optimal sampling effort is needed in order to obtain maximum ant diversity at each site.

### 4.2. Ant diversity and distribution models at study sites

**Ant diversity**

The ant community of the habitats studied was relatively diverse. Ant richness ranged from 209 species in the forest to 119 species in the palm grove. Between the two extremes, the old cocoa farm harbored 173 species, banana farm 134 and the young cocoa farm 132 species. Ant richness at the forest site was significantly higher than that obtained in the northern periphery of the Dja Biosphere Reserve in Cameroon where Deblauwe and Dekoninck (2007) [16] recorded 145 species, and in the Mbalmayo reserve forest where Watt *et al.,* (2002) [56] identified 111 species. High diversity at the forest site in this study could be explained by the constant humidity of the litter, soil factors, topography, heterogeneity of litter in food resources, vegetation structure composition.

The palm grove habitat was colonized by the invasive Myrmicaria "tramp species" with its highly aggressive behavior that potentially repelled other ant species. Another factor that may explain the low species richness of ground-dwelling ants at the palm grove site was the almost complete absence of leaf litter resulting in a reduction in the availability of nest sites for litter-nesting species (Vasconcelos *et al.,* 2000) [55]. According to Kenné (2006) [31], *Myrmicaria opaciventris* has several characteristics in common with "tramp species" and are more confined to disturbed environments such as cultivated plantation areas where tree canopy is not contiguous, and soil surface is perfectly open, thereby encouraging high nest density. Differences in ant diversity observed between habitats in this study could be explained by the variation in agro ecological conditions (anthropic pressure) as well as variation in vegetation cover and plant physiognomy (Cardoso *et al.,* 2010 [11]; Tadu *et al.,* 2014) [52].

The Shannon index (H ') shows that the forest was more diverse than the other habitats with a highly significant difference. High species diversity at the forest habitat may also have been due to adequate protection of the area. The value of H' was also high in the old cocoa farm, and could partly be explained by edge effects since this habitat was situated between a pocket of forest and a swamp, thus benefiting from faunal elements from the two biotopes. Furthermore, the plantation was more than 70 years old and thus harbored characteristics of an old secondary forest that could favor the establishment of ant faunal communities. Most of the ant population at the palm grove habitat was dominated by species that successfully repel other species, resulting in the low indices of diversity at this site. According to Majer (1983) [41], palm grove represents a frequently disturbed area since competing plants under the palm trees are cleared away every year. Komthong and Jaitron (2004) [33] showed that the habitat for tramp and other ants of the rubber tree plantation in their study was disturbed by clearing. They also state that *Monomorium* sp. *Carebara* sp. and *Pheidole* species can be collected from disturbed areas. *Axinidris* sp.1, *Aenictus* sp. and *Palthothyreus tarsatus* were commonly detected at less disturbed areas during this study.

### 4.3. Similarity between habitats

Indices of similarity were evaluated by a Kruskal-Wallis test and showed variation in the composition of myrmecofauna across the study sites. The boxplot represented ant occurrence by habitat during the study period and showed significant differences in species composition between habitats. The comparison of species composition between habitats showed differences between banana farm, old cocoa farm, forest and young cocoa farm but not for banana farm and palm grove. This similarity is explained by the fact that the two habitats were closer and given their proximity to the village; they would undergo the same degree of perturbation. It could also be due to the impact of human activities that promote the establishment of common species such as *M. opacivintris*, *Odontomachus troglodytes* and *Camponotus flavomarginatus*. The strong dissimilarity between banana farm -old cocoa, banana-forest, old cocoa-palm grove, young cocoa -forest and Forest-Palm grove may be due to the fact that the vegetation type/composition differed between and around habitats. Many authors have shown that the composition of ant assemblages is strongly linked to habitat and disturbance (Philpott *et al.*, 2014 [47]; Ossala *et al.*, 2015 [45]). According to Cardoso *et al.* (2010) [11], geographic distance may increase dissimilarity between communities. The distance between the habitats could also reflect the dissimilarities observed in the current study.

### 4.4. Ant distribution models at study sites

The species of ants generally structured in mosaics have been classified according to their ecological status: dominant species (numerically dominant species (Davidson, 1997; 1998)) [14, 15], sub-dominant and non-dominant species (Leston, 1971[36]; Majer *et al.*, 1994 [42]; Armbrecht *et al*., 2001[3]) and the communities of ground ants being organized according to a two-dimensional structure. It emerges from our results on the distribution adjustments observed to theoretical models that, banana farm, palm grove, young cocoa and old cocoa are distributed according to the theoretical Mandelbrot model. This distribution reflects a strong tendency among certain species of the community to disperse the few workers they have over a large area; reminiscent of the first stage in the process of colonization of an ecosystem where no species exercises real control over a territory.

They all behave like explorers. The species *Carebara perpusilla*, *Monomorium invidum* and *Axinidris* sp.1, *C. vividus*, *C. flavomarginatus* are said to contribute significantly to obtaining such a structure. However, we observe that the forest best fits the theoretical model of Preemption. This is the characteristic of communities in which the status of the most frequent species is preserved while the less frequent species lose resources and become increasingly rare in the environment over time; the dominant ecological ones exert a pressure of control on the non-dominant ones. This distribution would be the result of the presence in the forest, of highly territorial species such as: *Acropyga* sp.1, *Axinidris* sp.1, *Crematogaster* sp. According to Frontier and Pichod (1991) [24], this model is suitable for the analysis of communities in which each species appropriates the same fraction K of the resources to which it has access; the occurrence of each species is proportional to the resources it has appropriated and even access to the resource is ordered hierarchically in an order of dominance.

### 4.5. Occurrence of dominant ant species between habitats

In the different habitats studied, 8 were the most dominant and more frequent (cumulative relative occurrence ≤ 20%). Although these species were the most dominant, the results of this study show that variation in their occurrences was influenced by habitat. The high dominance of these species may be explained by their opportunistic behavior that enhanced their adaptation to various environmental conditions and theirs ability to nest indoors as well as outdoors. This is the case for *Pheidole megacephala*, *Monomorium guineensis* and *Carebara perpusilla*. According to Room (1975) [49] and Dejean *et al.* (1994) [17], *Ph. Megacephala*, *Myrmicaria opaciventris* and *Camponotus flavomarginatus* are dominant species that occupy space in the ecosystems by excluding less competitive ones with which they share ecological niches. Taylor (1977) [53] et Taylor and Adedoyin (1978) [54] showed that 8 and 6 species of ants respectively were dominant in cocoa and other perennial crops in Nigeria, while 10 dominant species were found in cocoa farms in Ghana (Majer 1972). These frequencies appeared high compared to those of Lee *et al.* (2002) [35] who observed that *M. guineensis* was the most dominant in Malaysia, and accounted for 27.87% of the ant species collected while Bruhl (2001) [10] observed that *M. guineensis* were usually recorded in highly disturbed forests. Bolton (1987) [8] noted *Monomorium* (sp) as a major tramp species. *Myrmicaria opaciventris* was absent in the forest site, and this can be explained by the fact that this species, over time can develop anthropophilic behavior.

## 5. Conclusion

Ant species were sampled at five habitat types (e.g. forest, banana, old cocoa farm, young cocoa and palm grove) to determine the effect of land-use on their diversity and composition. A total of 306 ant species, belonging 11 subfamilies were recorded. Species richness ranges from 209 the forest to 119 in the palm grove habitat. Between the two extremes, the old cocoa farm has sheltered 173 species, the banana farm134 and the young cocoa farm 132 species. The high diversity at the forest site could be explained by the constant humidity of the litter, soil factors, topography, heterogeneity of litter in food resources, and vegetation (structure and composition) that influences the soil fauna and litter of this biome. Statistically significant differences ($P<0.05$) in ant richness were observed between the banana farm and old cocoa farm, forest and young cocoa farm but not between the banana farm and palm grove; indicating that both ant species diversity and community composition varied distinctly across study sites which may be related to their different land use types.

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