



## RESEARCH PAPER

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## Diversity and structure of ant communities associated with *Toxoptera aurantii* (Boyer, 1941) (Hemiptera, Aphididae) in cocoa farms in the Centre Region of Cameroon: Role of anthropogenic activities

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### Abstract

Ant species encountered with hemipterans are or not associated with them. In such associations, ants disseminate hemipterans on the host plants, protect them from their enemies or from climate constraints. The study of diversity and variation of ant species compositions associated with *Toxoptera aurantii* was conducted from March 2020 to February 2021 on cocoa trees according to the decreasing urbanization gradient from Mfoundi (locality which is highly urbanized) to the peri-urban zones and forest zones. In each locality, ¼ ha per cocoa farm was sampled monthly to check different association types or models on cocoa trees between ant species and *Toxoptera aurantii*; in 60 cocoa farms. Ants and the aphid associated were monthly collected on cocoa trees and preserved in labeled pillboxes tubes containing 70% ethanol, for ulterior identification in the laboratory. A total of 72 ant species belonging to 20 genera, 6 subfamilies (Aenictinae, Dolichoderinae, Formicinae, Myrmicinae, Ponerinae, Pseudomyrmicinae) were recorded during this study. Many genera such as *Camponotus*, *Crematogaster*, *Tapinoma*, etc were associated with *T. aurantii*. From the overall ant population collected, species of Myrmicinae subfamily (86.11%) were most associated with *T. aurantii*; the Nyong-et-Mfoumou locality had the highest number of ant species associated with *T. aurantii* (48 species), but majority of those species were common to the other localities, except in the Mfoundi a highly urbanized locality. *Myrmecaria opaciventris* and *Pheidole megacephala* were the most frequently species associated with *T. aurantii*; they seem to impact positively and significantly the aphid populations on the cocoa farms.

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## Introduction

The entomofauna diversity associated with cocoa plants varies from one agroecosystem to another; but the presence of certain species is relatively constant in cocoa plantations. In addition, among these insects, hemipterans are the most represented and the most harmful taxonomical group for cocoa plants in Cameroon (Yede, 2016). Beside the main known cocoa insect pests in Cameroon, namely *Sahlbergella singularis* Haglund, 1895; *Distantiella theobroma* Distant, 1909; *Helopeltis bergrothi* Signoret, 1858; and *Mesohomotoma tessmanni* Aulmann, 1912, there is also the aphid species *Toxoptera aurantii* Boyer, 1941 (Yede, 2016). Aphids cause direct damages by sucking significant quantities of phloem sap from their host plants; this results in leaf curling, falling-off of prematured leaves, and the withering of leaves and young shoots or stems (Fournier, 2010). Indirect damages due to aphids can be ranged into two categories: (1) the production of honeydew which, in the absence of mutualistic ants, induces the development of sooty mould, and (2) the transmission of plant viruses e.g. the tristeza virus of *Citrus* spp. (Brault *et al.*, 2010). The extent of damages can be directly related to the population size of aphids. The fighting method should take into consideration these different types of damages (Turpeau *et al.*, 2011).

Management of cocoa farms, climatic and edaphic factors and others have a real impact on aphid population dynamics (Tamesse & Messi, 2004). In Cameroon like in other countries, cocoa is traditionally grown up in dense and highly diversified multi-strata vegetation (Sonwa *et al.*, 2007; Bisseleua & Vidal 2008; Babin *et al.*, 2010). In such habitats, arboreal arthropod communities are very diverse, and ants represent the most important part of the animal biomass (Philpott & Armbrrecht, 2006). In cocoa farms, arboreal ant communities are structured in assemblages usually named ant mosaics, with patchy distribution of species (Majer, 1992). Some of these species are often associated with hemipterans (Delabie, 2001; Steiner *et al.*, 2004; Moreira & Del-Claro, 2005; Oliver *et al.*, 2007).

In these assemblages, ants likely disseminate hemipterans on the host plants; in addition, building shelters around their colonies, they are supposed to protect hemipterans from their natural enemies or from climate constraints; reciprocally, hemipterans produce honeydew which is highly prized by the ants (Delabie, 2001; Oliver *et al.*, 2007; Flatt & Weisser, 2000; Morales, 2000). Owing to this statement, ants can be considered as indirect pests; most of their species are generalists and feed on different types of solid, animal liquids or plant foods; however, some species have specialized diets and can be subdivided into several guilds including herbivores, harvesters, granivores and predators (Hölldobler & Wilson, 1990). Among predators, sweet fluids (extrafloral nectarines and honeydew of hemipterans) are important diets for arboreal species (Dejean & Corbora, 1990; Orivel, *et al.*, 1997).

Several studies devoted to the knowledge of the myrmecofauna in general, and arboreal species in particular, have revealed a high species richness of this taxonomic group (Tadu *et al.*, 2014). Moreover, whether in the forest or in agrosystems, the species richness of ants is always much higher than that of other arthropods. If associations between ants and the aphid *T. aurantii* seem benefic to both, knowledge of the species richness and abundance of ants involved in such assemblages, as well as the permanence or not of their activities with respect to aphids in cocoa farms, still raises questions. This is quite particular in the context of agrosystems strongly anthropized. One can rightly wonder whether the associations ants/*T. aurantii* are permanent at all places. In fact, there is very little information on this aspect.

Aphids are considered myrmecophilous; they react following the palpation (antennation) of the extremity of their abdomen by the ants (Hölldobler & Wilson, 1990), then secrete honeydew which is a sugar-rich food supplement for ants. This behavioural relationship, called trophobiosis (Gullan, 1997; Delabie, 2001; Chaubet, 2018) is obligatory or facultative depending of the ant species (Chaubet, 2018).

Aphids have developed types of morphological and/or behavioural adaptations in response to ant maintenance such as: (1) a short or poorly developed cauda (Gratwick, 1992), (2) trophobiotic organs with bristles that allow honeydew retention (Buckley, 1987; Hölldobler & Wilson, 1990), and (3) aggregating in dense colonies minimizing ant rearing territory, which facilitates defense and honeydew collection (Delabie, 2001). Ant species are mostly associated with trophobionts that belong to Dolichoderinae, Formicinae, Myrmicinae (Hölldobler & Wilson, 1990), but also occasionally to Pseudomyrmecinae or Ponerinae (Gullan, 1997). This study was carried out to investigate the diversity of ant species in the potential permanent ants/*T. aurantii* associations and to highlight the impact of the former on the population dynamics of *T. aurantii* in the particular context of urbanisation. This specifically consisted to: (1) inventory the different ants

species which interact with *T. aurantii*, (2) distinguish the main ant species (frequency and abundance), their association models with *T. aurantii*, and (3) characterize the correlation between the cinetic of *T. aurantii* and the main associated ant species.

**Materials and methods**

*Study sites*

This study was carried out in five different localities namely Nkolbisson, Mvé 1, Nkoa-Atsam, Libellingoi and Ebaboto belonging to five Administrative Divisions in the Centre Region of Cameroon (Table 1). These localities were selected on the basis of the presence of cocoa farms. Their characteristics i.e. distance between households and cocoa farms, density of human population, degree of urbanization or level of vegetation disturbance by anthropogenic activities are summarized in Table 1.

**Table 1.** locations and main characteristics of localities.

Localities	Geographic coordinates	Characteristics
NKOLBISSON in Mfoundi division (MFO)	3°51'13.4"N; 11°25'15.8"E; 746 m a.s.l	-Urban zone strongly degraded i.e. Without remaining original forest -high density of human population (up to 500 pers/km <sup>2</sup> ) (cmr-bucep-rgph, 2005)
MVE 1 in Mefou-et-Afamba division (MAF)	3°57'33.0"N; 11° 43'31.9"E; 751 m a.s.l	-Peri-urban zone, where farms are close to households (less than 1 km) -moderate density of human population. (80pers/km <sup>2</sup> ) (cmr-bucep-rgph, 2005)
NKOA-ATSAM in Mefou-et-Akono division (MAK)	3°40'15.1"N; 11°28'44.9"E; 660 m a.s.l	-Peri-urban zone, where farms are close to households (less than 1 km) -moderate density of human population (70pers/km <sup>2</sup> ) (cmr-bucep-rgph, 2005)
LIBELLINGOI in Nyong-et-Kellé Division (NEK)	3°54'12.6"N; 10°55'12.6"E; 406 a.s.l.	-Semi-deciduous forest -cocoa plantations mixed with shade and domestic trees - situated between 1-2 km with low population density (less than 25pers/km <sup>2</sup> )
EBABOTO in Nyong-et-Mfoumou division (NEM)	4°04'23.5"N; 12°25'03.0"E; 590 m a.s.l.	-Semi-deciduous forest partially logged - farms with a lot of shade trees - far (more than 2 km away) from household -low population density (less than 25pers/km <sup>2</sup> ) (cmr-bucep-rgph, 2005)

These localities (Fig. 1) are under the Guinean and equatorial transitional climate type, with a bimodal rainfall regime, characterized by an average rainfall ranged from 1400 to 1600 mm/year (Suchel, 1987), and annual temperature mean around 25°C with weak thermal variations (Bisseleua & Vidal, 2008).

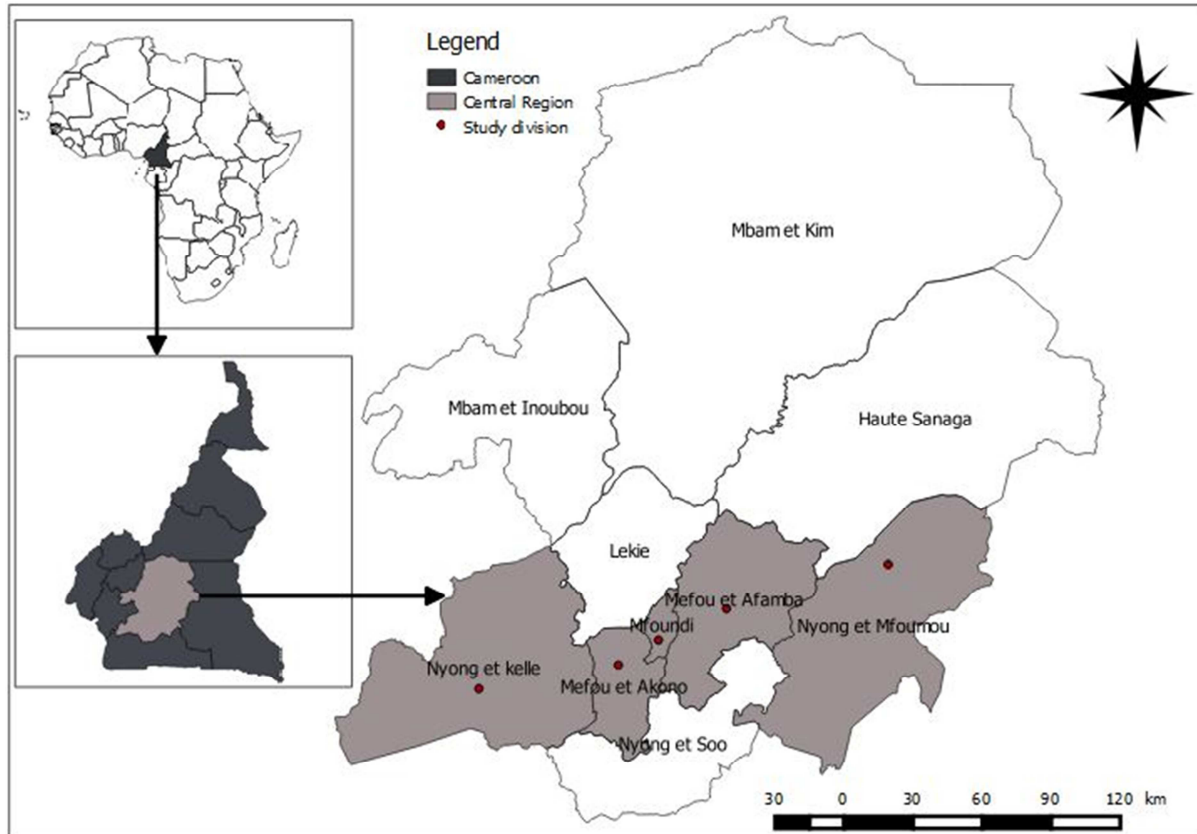
*Inventory of the myrmecofauna associated to Toxoptera aurantii*

*Field collections*

From March 2020 to February 2021, ants were sampled on cocoa tree chupons located at a height of

at least 2m. In each locality, twelve cocoa farm plots of 2500 m<sup>2</sup> each were sampled during 12 months i.e. 1 different plot/month.

At a cocoa tree level, insects (ants and aphids) found in biotic interactions, such as antennation (palpation), transport or collection of honeydew, were collected simultaneously, with the aid of forceps and brushes. They (ants and aphids) were then preserved in the same labeled 50ml pillbox containing 70% ethanol.



**Fig. 1.** Study localities.

#### *Ants Identification*

At the Zoology laboratory, University of Yaounde I, ants were identified under a dissecting microscope (Olympus SZ40 model) using dichotomic keys of Hölldobler & Wilson (1990), Bolton (2016), Fisher & Bolton (2016), and Taylor (2002).

#### *Data analysis*

##### *Assessment of species richness*

Ant species or morphotypes richness noted as "S" (Peet, 1974), and the total absolute abundance of ant species (N) are given per locality, and the entire region.

The relative abundance (RA) of a given species is the ratio of its absolute abundance ( $N_i$ ) to the total number of specimens of all species (N) in the locality, Division, and the entire Region, multiplied by 100. Its formula is  $RA = (N_i/N) \times 100$  (Dajoz, 1982). The abundance of ant species associated with *T. aurantii* was characterized according to the percentage breakdown of Dajoz (1982) slightly modified as follows: if  $RA > 50\%$ , the taxon is very abundant; if

$25\% \leq RA \leq 50\%$ , the taxon is abundant; if  $1\% \leq RA < 25\%$ , the taxon is less abundant; if  $RA < 1\%$ , taxon is rare i.e. it exists in very small number.

#### *Association models between ant species and T. aurantii and criteria to determine main ant species/T. aurantii association on cocoa farms in different localities*

In each locality, the abundance of cocoa trees harboring cases of ant species/*T. aurantii* associations was counted annually. Particular attention was taken to know the number of ant species (1; 2; etc.) involved in a given association. To determine the main ant species per locality, the relative abundance of each specific case of ant species/*T. aurantii* association was computed in relation to the number of cocoa trees exploited. In addition, the relative frequency (RF) of cocoa trees harboring the targeted association was also characterized as above (Dajoz, 1982). Determination of the main ant species/*T. aurantii* association in a locality mainly considered the relative abundance, the

average number of specimens involved, and the percentage of cocoa trees explored.

#### *Ants' diversity*

Each ant community was characterized via Shannon diversity index  $H'$ , Equitability index (E), and Berger-Parker index calculated using the software Estimate v.8.2 (Colwell, 2006).

$H' = -\sum p_i \ln p_i$  and  $E = -\sum p_i \ln p_i / \ln S$  (Kent & Cooker, 1992), with  $p_i = n_i/N$ ;  $n_i$  is the abundance of a given species and N the total number of the different ant species.

*The similarity or Sorensen quantitative index (Is)* between ant communities associated with *Toxoptera aurantii* of two localities was determined annually as follow:  $I_s = (2c/(a+b)) \times 100$ , using the software Estimate v.8.2 (Colwell, 2006). In this formula, a is the total number of species in locality A, b is the total number of species in locality B, and c the number of the common species found in both localities.

#### *Correlation test between population size of Toxoptera aurantii and that of the main ant species associated*

Spearman correlation  $r_s$  was computed using Past Software 3.12 between the number of *T. aurantii* and that of the most abundant associated ant species in each locality at P-value < 0.05. Values of the diversity indices (Shannon, Equitability, Berger Parker and Sorensen) of different ant communities associated with *T. aurantii* were compared using F-test and Tukey's pairwise comparison, while the number of the main ant species associated with *T. aurantii* specimens per cocoa tree in different localities was compared using Kruskal Wallis test then the Mann Whitney test for pairwise comparison.

## Results

#### *Taxonomic composition, abundance and diversity of ant species associated with Toxoptera aurantii*

A total of 53010 ant specimens distributed in 72 morpho-species, 20 genera, and 6 subfamilies (Aenictinae, Dolicoderinae, Formicinae, Myrmicinae, Ponerinae, Pseudomyrmicinae) were found

associated with *T. aurantii*. From the overall community (in the Centre Region) of ants collected, the Myrmicine were the most numerous (45521 specimens: 85.87%) associated with *T. aurantii*, followed in the decreasing order by Formicine (4269 specimens: 8.05%), Dolicoderine (3045 specimens: 5.74%), Aenictine (96 specimens: 0.18%); Pseudomyrmicine (67 specimens (0.13%), and Ponerine (10 specimens: 0.02%). Regarding the relative abundance of the different ants taxa at the regional level, 53 (73.6%) species were rare ( $RA < 1\%$ ) and 19 (26.4%) revealed less abundant ( $1\% \leq RA < 25\%$ ) (Appendix). At the local (division) level, the average ant sample sizes varied significantly (Table 2), being lower ( $190.33 \pm 75.64$ ) in the Mfoundi division and higher ( $1380 \pm 300.37$ ) in the Mefou-et-Akono division.

In addition, Myrmicinae were more diversified (34 species), followed by Formicinae (25 species), Dolicoderinae (10 species), Aenictinae, Ponerinae and Pseudomyrmicinae each with only one species recorded (Appendix). A total of 48, 40, 37, 30 and 5 ant species were recorded in Nyong-et-Mfoumou (NEM), Mefou-et-Afamba (MAF), Mefou-et-Akono (MAK), Nyong-et-Kellé (NEK), and Mfoundi divisions respectively. Averagely, the species richness was significantly lower ( $1.50 \pm 0.45$ ) in Mfoundi, a highly urbanized area, than in the other localities in increasing order; it was followed by the Nyong-et-Kellé with moderate species richness ( $6.58 \pm 0.97$ ) then Mefou-et-Afamba ( $8.67 \pm 1.07$ ), Nyong-et-Mfoumou ( $9.58 \pm 2.08$ ) and Mefou-et-Akono ( $10.17 \pm 1.09$ ) with highest species richness (table 2)

The specific diversity ( $H'$ ) also revealed highly significant variations between localities ( $F=3.96$ ;  $ddl=4$ ;  $p=0.008$ ); the pairwise comparisons showed that the profile is the same as for species richness. The values of the equitability Index (E) also showed significant differences between ant communities of the different localities: two groups were revealed different: in the one hand Mfoundi ( $E= 0.23 \pm 0.01$ ) and the other localities in another hand (Table 2). The Berger-Parker index revealed three groups: one intermediate group i.e. the ant communities in

Mefou-et-Afamba ( $0.57 \pm 0.53$ ), between lower ant species communities in the Mefou-et-Akono ( $0.28 \pm 0.05$ ) and the most distinguished and dominant ant

species communities in the Mfoundi ( $0.50 \pm 0.13$ ), Nyong-et-Mfoumou ( $0.58 \pm 0.07$ ) and Nyong-et-Kellé ( $0.61 \pm 0.07$ ) localities (Table 2).

**Table 2.** Values of the biodiversity indices of ant fauna associated with *T. aurantii* on cocoa farms in different divisions of the Centre region of Cameroon (mean±sd).

Parameters	Localities					F-test
	MAF	MAK	MFO	NEK	NEM	
Sample size _	13161	16541	2284	8363	12661	F=2.60; ddl=4;
N	(1096.67±325.05) <sup>bc</sup>	(1380±300.37) <sup>c</sup>	(190.33±75.64) <sup>a</sup>	(696±140.05) <sup>b</sup>	(1055.25±366.13) <sup>bc</sup>	P=0.037
Taxa_S	40	37	5	30	48	F=3.96; ddl=4;
	(8.67±1.07) <sup>bc</sup>	(10.17±1.09) <sup>c</sup>	(1.5±0.45) <sup>a</sup>	(6.58±0.97) <sup>b</sup>	(9.58±2.08) <sup>bc</sup>	P=0.007
Shannon_H	1.92	2.25	0.34	1.85	2.76	F=3.96; ddl=4;
	(1.17±0.13) <sup>bc</sup>	(1.32±0.12) <sup>c</sup>	(0.21±0.08) <sup>a</sup>	(0.98±0.15) <sup>b</sup>	(1.22±0.22) <sup>bc</sup>	P=0.008
Equitability_E	0.52	0.62	0.21	0.56	0.70	F=2.76; ddl=4;
	(0.57±0.53) <sup>b</sup>	(0.61±0.05) <sup>b</sup>	(0.23±0.01) <sup>a</sup>	(0.56±0.08) <sup>b</sup>	(0.63±0.04) <sup>b</sup>	P=0.032
Berger-Parker	0.31	0.51	0.91	0.52	0.20	F=2.52; ddl=4;
	(0.57±0.53) <sup>ab</sup>	(0.28±0.05) <sup>a</sup>	(0.50±0.13) <sup>b</sup>	(0.61±0.07) <sup>b</sup>	(0.58±0.07) <sup>b</sup>	P=0.042

Legend: N: abundance; S: specific richness; H': Shannon-Weaver index; E: Pielou index; different letter in superscript indicate difference or similitude of index parameters between in pairs sites after pairwise comparisons; x(x̄): x parameter value, x̄ average and standard error

Values of the Sorensen's index revealed that the similarity between ant species communities associated with *T. aurantii* was very low (<15%) between the Mfoundi and the other

localities. In the other pairwise comparisons, the similarity was over 50%, being highest (68.18%) between Mefou-et-Afamba and Nyong-et-Mfoumou (Table 3).

**Table 3:** similarity values of ant communities between localities.

Localities	Localities			
	MAK peri-urban zone	MAF peri-urban zone	NEK semi-deciduous forest	NEM forest partially logged
MFO strongly degraded	14.28%	13.33%	11.42%	11.33%
NEM forest partially logged	61.17%	68.18%	59.70%	
NEK semi-deciduous forest	50.74%	57.14%		
MAF peri-urban zone	64.93%			

*Association models on cocoa trees*

In the regional level, *Toxoptera aurantii* was associated with 1 to 4 different ant species in 72, 47, 21 and 1 different combinations respectively. *Toxoptera aurantii* was found associated with 4 ant species in the Nyong-et-Mfoumou division only. Over the 4101 association cases recorded, 3588 (87.5%), 440 (10.7%), 70 (1.7%), and 3 (0.1%) were observed with 1, 2, 3 and 4 ant species respectively (Table 4). These association cases were dominated everywhere by the monospecific combinations, leaded by the *Myrmicaria opaciventris* /*T. aurantii* association that was found in 38% cocoa trees, and recorded 1378 (38.4%) times with 11664 specimens; then in decreasing order to the following associations: *Pheidole megacephala*/ *T. aurantii* recorded 356 (9.92%) times with 7028 specimens,

*Crematogaster striatula*/ *T. aurantii* recorded 212 (5.90%) times with 2835 specimens, and *Rhoptromyrmex* sp./*T. aurantii* recorded 139 (3.87%) times with 6439 specimens.

With respect to localities, the abundance and the frequency of the different combinations also varied. The *M. opaciventris*/ *T. aurantii* association was: (1) constant in the Nyong-et-Kellé and the Mefou-et-Afamba localities because infecting 58% and 54% of sampled cocoa trees respectively, but (2) accessory in the Nyong-et-Mfoumou and the Mefou-et-Akono with frequencies of 30% and 26% respectively. Many combinations between *T. aurantii* and 2 or 3 different ant species were opportunistic or accidental, their frequencies on cocoa trees being less than 5% at the local level (Table 4).

**Table 4.** Frequency distribution of ant species/*T. aurantii* associations cases in to different localities.

Number of ant species associated with <i>T. aurantii</i>	Number of different combinations	Number of cases per locality					
		MAF	MAK	MFO	NEK	NEM	Total
1	72	1092(26.6%)	941(22.9%)	25(0.6%)	619(15.1%)	912(22.3%)	3588(87.5%)
2	47	125 (3.04%)	108(2.6%)	20(0.5%)	106(2.6%)	81(2%)	440 (10.7%)
3	21	16(0.4%)	21(0.5%)	2(0.1%)	7(0.2%)	24(0.6%)	70 (1.7%)
4	1	0	0	0	0	3(0.1%)	3 (0.1%)

Legend: x(%): x case number of different combinations, (%) percentage of the different combination in the locality.

*Average number of the main ant species associated with Toxoptera aurantii in different localities*

Based on the relative abundance and relative frequency, *Myrmicaria opaciventris* was the most abundant and frequent ant species associated with *T. aurantii* in cocoa farms (Appendix). This species, as well as *Pheidole megacephala*, *Crematogaster striatula* and *Rhoptromyrmex* sp., was considered as the main ant species associated with *T. aurantii* in cocoa farms. Specific average number of ant specimens associated

with *T. aurantii* per cocoa tree varied significantly within studied locality (Table 5). At the local level, *Myrmicaria opaciventris*, was more abundant in three localities: Nyong-et-Kellé (5.79 ± 0.96), Mefou-et-Afamba (2.88 ± 0.70) and Nyong-et-Mfoumou (2.67 ± 0.55). It was followed by *P. megacephala* in the Mefou-et-Akono (5.13 ± 1.40) and *C. striatula* (39.78 ± 15.53) in the Mfoundi. Thus, *M. opaciventris* and *P. megalcephala* are numerically co-dominant in the Nyong-et-Mfoumou (Table 5).

**Table 5.** Average number of the main ant species per cocoa tree in different localities (mean±sd).

Species	Localities				
	MAF	MAK	MFO	NEK	NEM
<i>Crematogaster striatula</i>	0.19 ± 0.18 <sup>a</sup>	1.25 ± 0.59 <sup>a</sup>	39.78 ± 15.53 <sup>b</sup>	0.20 ± 0.17 <sup>a</sup>	0.08 ± 0.05 <sup>b</sup>
<i>Myrmicaria opaciventris</i>	2.88 ± 0.70 <sup>b</sup>	1.49 ± 0.56 <sup>a</sup>	0.79 ± 0.00 <sup>a</sup>	5.79 ± 0.96 <sup>b</sup>	2.67 ± 0.55 <sup>c</sup>
<i>Pheidole megacephala</i>	0.35 ± 0.28 <sup>a</sup>	5.13 ± 1.40 <sup>b</sup>	-	0.23 ± 0.10 <sup>a</sup>	2.37 ± 1.20 <sup>c</sup>
<i>Rhoptromyrmex</i> sp.	1.75 ± 1.63 <sup>ab</sup>	1.80 ± 1.21 <sup>a</sup>	-	-	0.01 ± 0.01 <sup>a</sup>

N=1221; p=0.001 N=1082; p=0.001 N=46; p=0.001 N=732; p=0.001 N=1020; p=0.001

Legend: ddl = 3; N = number of sampled cocoa trees; different letter in superscript indicate difference or statistical equality of the average numbers of main ant species per cocoa tree in the same locality; x±y average number of ant specimens per cocoa tree follow by standard error.

*Correlation between the average monthly number of main ant species and that of T. aurantii on cocoa trees*

Numbers of main ant species specimens and those of *T. aurantii* varied over time within the studied localities

(Table 6). Each month, the number of *T. aurantii* was always greater than that of the main ant species; the sizes of their populations were strongly, positively and significantly correlated (r>70; p <0.05) (Table 6).

**Table 6.** kinetic correlation between main ant species populations and *Toxoptera aurantii* (mean±sd)

Period	MAF		MAK		MFO		NEK		NFO			
	<i>M.opaciventris</i>	<i>T. aurantii</i>	<i>P. megacephala</i>	<i>T. aurantii</i>	<i>C. striatula</i>	<i>T. aurantii</i>	<i>M.opaciventris</i>	<i>T. aurantii</i>	<i>M.opaciventris</i>	<i>T. aurantii</i>	<i>P. megacephala</i>	<i>T. aurantii</i>
March	3.57 ± 0.35	74.50 ± 4/85	15.93 ± 2.67	172.07 ± 40.55	5.20 ± 3.95	104.20 ± 75.03	26.33 ± 4.75	817.50 ± 90.56	6.66 ± 2.38	27.57 ± 4.74	0	0
April	3.25 ± 0.43	49.37 ± 6.21	10 ± 0	75 ± 0	0	0	4.75 ± 1.02	126.50 ± 23.32	0	0	0	0
May	1.22 ± 0.14	35.66 ± 1.16	0	0	0	0	2.80 ± 0.42	43.40 ± 4.40	0	0	0	0
June	7.34 ± 0.89	101.55 ± 11.23	19.58 ± 3.33	207.25 ± 39.40	0	0	9.96 ± 2.82	208.92 ± 54.97	19 ± 8.49	259 ± 59.93	7.41 ± 1.73	60.50 ± 8.36
July	3.24 ± 0.37	70.64 ± 6.55	8.37 ± 1.77	87.50 ± 14.22	0	0	17.68 ± 3.24	243.80 ± 43.55	0	0	0	0
August	7.01 ± 0.65	37.63 ± 3.56	2.50 ± 0.43	52.50 ± 12.30	0	0	7.67 ± 0.69	112 ± 25.53	10.88 ± 246	340.50 ± 74.65	5.33 ± 0.33	23 ± 0
September	5.71 ± 1.61	48.13 ± 14.10	11.47 ± 3.34	97.75 ± 17.98	59.66 ± 13.83	471.33 ± 109.93	10.63 ± 1.94	204.7 ± 28.31	9.18 ± 1.12	144.38 ± 19.86	16.33 ± 4.17	61.20 ± 17.71

Period	MAF		MAK			MFO		NEK		NFO		
	<i>M.opaciventris</i>	<i>T. aurantii</i>	<i>P. megacephala</i>	<i>T. aurantii</i>	<i>C. striatula</i>	<i>T. aurantii</i>	<i>M.opaciventris</i>	<i>T. aurantii</i>	<i>M.opaciventris</i>	<i>T. aurantii</i>	<i>P. megacephala</i>	<i>T. aurantii</i>
October	13.34 ± 2.05	211.05 ± 26.60	17.80 ± 3.95	242.60 ± 85.34	54.57 ± 26.13	305.28 ± 149.49	18.77 ± 7.64	253.10 ± 26.53	9 ± 1.21	57.86 ± 14.29	25.45 ± 6.67	352.45 ± 91.07
November	6.66 ± 1.04	97.88 ± 12.54	2.89 ± 0.60	41.67 ± 63	24 ± 9.44	291.00 ± 154.60	5.10 ± 1.09	63.35 ± 17.25	3.16 ± 0.46	56.12 ± 7.07	4.19 ± 1.19	47.57 ± 18.76
December	2.16 ± 0.16	10.5 ± 0.67	48.36 ± 11.15	291.55 ± 88.24	48.60 ± 16.99	1692.40 ± 596.63	12.70 ± 1.83	135.12 ± 25.40	7.90 ± 2.18	109.30 ± 26.37	16.66 ± 0.88	33 ± 0
January	3.03 ± 0.43	68.77 ± 8.65	28.30 ± 4.63	175.55 ± 32.07	138 ± 61.72	545.8 ± 253.96	11.14 ± 1.96	129.21 ± 25.40	8.16 ± 3.52	54 ± 24.70	32.80 ± 10.59	113.10 ± 28.06
February	7.98 ± 1.01	75.68 ± 10.20	43.17 ± 6.85	146.87 ± 30.82	2	1	6.22 ± 2.45	160.66 ± 58.85	7.91 ± 3.38	54.25 ± 24	46.60 ± 14.33	119.4 ± 36.49
	P < 0.01, r=0.73		P < 0.001, r=0.88			P < 0.0001, r=0.96		P < 0.001, r=0.84		P < 0.001, r=0.89		

**Discussion**

Ant species associated with *T. aurantii* in cocoa farms in the Centre Region-Cameroon belong to six subfamilies; five of them which are known involved in trophobiosis relationships. Indeed Hölldobler & Wilson (1990) noticed that species of Dolichoderinae, Formicinae, and Myrmicinae are currently recorded associated with *T. aurantii*. But some cases of associations with Pseudomyrmecinae or Ponerinae were also reported by Gullan (1997). Our results are similar to those obtained by the above authors, despite the presence, at low relative abundance of Aenictinae *Aenictus decolor* Mayr, 1879 in the Mefou-et-Afamba; this species is considered accidental. Subfamilies list as well as the ant species associated with the aphids *T. aurantii* varied according to the localities. Moreover, Aléne *et al.*, 2019 identified twenty ant species belonging to three subfamilies: Dolichoderinae, Formicinae and Myrmicinae associated to four aphid species. In the current study as in that of Aléne *et al.* (2019), two species of Myrmicinae (*M. opaciventris* and *P. megacephala*) appeared more abundantly associated with *T. aurantii*.

Percentage of similarity of ant communities decreased from the forest zones to the urbanized localities. It was above 50% between semi-deciduous forests therefore weakly urbanized areas. Indeed in the literature, several studies show that ants diversity in the forest is strongly affected by the variability of types of habitats i.e. soil types, soil moisture, physiognomy, vegetation cover, plant and leaf litter cover (Koen & Breytenbach, 1988; Cardoso, *et al.*, 2010; Vasconcelos *et al.*, 2000). Due to increasing habitat fragmentation, changes in ant communities often occur, referred to as changes in species composition (Nakamura *et al.*, 2007; Palladini *et al.*,

2007), and native species demography (Kemel *et al.*, 2001) of the native species. In this study, the ant communities associated with *T. aurantii* were less abundant and diversified in the urbanized zone (MFO) than in peri-urban areas. Resource patterns leading to interspecific competition and territoriality of dominant species are two significant factors affecting structure of ant mosaics (Hölldobler & Wilson 1990). Based on our results, we firmly believe that, progressive destruction of a natural forest for benefit of urbanization or agriculture is unfavorable to the establishment of arthropod assemblages in particular. In fact these activities negatively affect the abundance, diversity and biomass of arthropods (Dangerfield, 1990; McCabe & Gotelli, 2000; Mwabvu, 1997). Non native habitats is linked with the dominance of species *Crematogaster striatula*, possibly due to competition that may have led to the exclusion of ant majority species associated with *T. aurantii*. This can be justified by the higher abundance of this species in the Mfoundi. Urbanization favours the dominance of a single species in detriment of other species. Indeed, Tadu *et al.* 2014 showed in their study that the populations of the most abundant arboreal species, *Oecophylla longinoda*, *Tetramorium aculeatum*, *Crematogaster* spp., spp. were generally aggregated and competitive in plantations.

Ant Associations with *T. aurantii* are more diversified than that with Sternorrhyncha families in tropical regions (Malsch *et al.*, 2001). According to Delabie (2001), the various types of trophobiosis evolved independently; nevertheless the converged pathways in the most diverse families of Hemiptera. Few of these families, or species are obligate mutualistic, but the majority of these associations are only facultative or opportunistic. Apart from species *M. opaciventris*



and *P. megacephala*, the frequency of others ant species association with *T. aurantii* seems out of order in studied localities in most species.

This study showed positive and significant correlations between populations of the main ant species and *T. aurantii*. The presence of ant species on the cocoa trees favours the emergence of aphids, i.e. it contributes to the fitness of the aphid; this observation corroborates that of Stadler & Dixon (2005). Moreover, Maillieux *et al.*, 2003 demonstrated that, for a given aphid species, the quantity of honeydew produced is positively correlates to the number of specimens which determines the number of ant recruited in the colony.

In most cases *T. aurantii* associated with one ant species in cocoa farms mainly with *M. opaciventris*. It is known that some hemipterans, especially those living in large colonies, are often associated with one ant species (Steiner *et al.*, 2004). Nevertheless these associations could be polyspecific. Anyway, poor flying hemipterans such as aphids and coccids depend on their tending ant species for their dispersal. Ants might play an important role in the dissemination of hemipterans within the gardens (Delabie, 2001). They can also amplify or reduce their populations and protect them against natural enemies (Stadler & Dixon, 2005; Oliver *et al.*, 2007). Also it was noticed that the most recurrent associations were made up of aphids and behavioural dominant ants like *M. opaciventris*, *P. megacephala*, etc., which are known to be territorially aggressive (Tadu *et al.*, 2013), and some other such as *C. flavomarginatus*, known to behave as extirpators according to (Delsinne *et al.*, 2007). Anyhow, there is no strict specificity in these associations. Furthermore, ants are considered to be opportunist in the choice of hemipteran species they tend (Delabie, 2001; Blüthgen *et al.*, 2006). Moreover, it was noticed that co-exploitation of *T. aurantii* was less frequent between several ants species of the same subfamily, than that of less abundant species belonging to different subfamilies. Therefore, the few cases of co-exploitation of *T. aurantii* by some ant species observed result from the hazard.

## Conclusion

Ant communities associated with *T. aurantii* on cocoa trees are very diverse, abundant and, similar in some localities in the Centre region of Cameroon. They are dominated by few ant species via their abundance in each locality where the urbanization is not pronounced. *M. opaciventris* is the common dominant ant species that tolerates co-exploitation of *T. aurantii* with other ant species. Associations of *T. aurantii* with one ant species are the dominant modes and the population dynamics of this aphid is positively and strongly correlated with all main ant species, e.g. with *M. opaciventris* and *P. megacephala* probably in trophobiontic relationship. Finally, communities are similar between localities of semi-deciduous forests, but can be seriously modified by anthropogenic activities.

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**Appendix**

Species richness, abundance and spatial distribution of ant species associated with *Toxoptera aurantii* in cocoa trees. The numbers in brackets represent the percentage (%) of specimens per locality.

Subfamilies	Species	MAF	MAK	MFO	NEK	NEM	Total	
Aenictinae	<i>Aenictus decolor</i> Mayr, 1879	85 (0.65)	0 (0)	0 (0)	11(0.13)	0 (0)	96 (0.16)	
	<i>Axinidris</i> sp.1	129 (0.98)	385 (2.32)	0 (0)	17 (0.2)	52 (0.41)	583 (1.09)	
	<i>Axinidris</i> sp.2	3 (0.02)	70 (0.4)	0 (0)	0 (0)	48 (0.38)	121 (0.22)	
	<i>Axinidris</i> sp.3	3 (0.02)	0 (0)	0 (0)	5 (0.06)	9 (0.07)	17 (0.03)	
	<i>Tapinoma lugubre</i> Santchi, 1991	82 (0.62)	150 (0.9)	0 (0)	377 (4.5)	409 (3.26)	1018 (1.92)	
Dolicodorinae	<i>Tapinoma</i> sp.1	89 (0.68)	70 (0.42)	154 (6.74)	0 (0)	65 (0.52)	378 (0.71)	
	<i>Tapinoma</i> sp.2	312 (2.37)	36 (0.21)	0 (0)	0 (0)	331 (2.64)	679 (1.28)	
	<i>Tapinoma</i> sp.3	8 (0.06)	35 (0.21)	0 (0)	0 (0)	173 (1.38)	216 (0.4)	
	<i>Tapinoma</i> sp.	21 (0.16)	7 (0.04)	0 (0)	0 (0)	3 (0.02)	31 (0.06)	
	<i>Tapinoma</i> sp.5	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.01)	1 (0.002)	
	<i>Tapinoma</i> sp.6	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.01)	1 (0.002)	
	<i>Anoplolepis carinata</i> Emery, 1899	38 (0.29)	0 (0)	0 (0)	0 (0)	6 (0.05)	44 (0.08)	
	<i>Camponotus (Myrmacrhaphe)</i> sp.	0 (0)	0 (0)	0 (0)	16 (0.19)	15 (0.12)	31 (0.06)	
	<i>Camponotus (Myrmoceriscus)</i> sp.	0 (0)	0 (0)	0 (0)	0 (0)	34 (0.27)	34 (0.06)	
	<i>Camponotus (Myrmocrema)</i> sp.	0 (0)	0 (0)	0 (0)	0 (0)	9 (0.07)	9 (0.02)	
	<i>Camponotus (Myrmopelta)</i> sp.1	0 (0)	12 (0.07)	0 (0)	0 (0)	9 (0.07)	21 (0.04)	
	<i>Camponotus (Myrmopelta)</i> sp.2	0 (0)	0 (0)	0 (0)	137 (1.64)	0 (0)	137 (0.26)	
	<i>Camponotus (Taneamyrmex)</i> sp.1	0 (0)	0 (0)	0 (0)	0 (0)	90 (0.72)	90 (0.17)	
	<i>Camponotus (Taneamyrmex)</i> sp.2	1 (0.01)	34 (0.21)	0 (0)	0 (0)	9 (0.07)	44 (0.08)	
	<i>Camponotus (Taneamyrmex)</i> sp.3	1 (0.01)	0 (0)	0 (0)	0 (0)	0 (0)	1 (0.002)	
	<i>Camponotus (Taneamyrmex)</i> sp.4	1 (0.01)	9 (0.05)	0 (0)	0 (0)	0 (0)	10 (0.02)	
	<i>Camponotus acvapimensis</i> Mayr, 1862	11 (0.08)	3 (0.02)	0 (0)	12 (0.14)	1810(14.43)	1836 (3.47)	
	<i>Camponotus flavomarginatus</i> Mayr, 1862	0 (0)	262 (1.57)	0 (0)	0 (0)	311 (2.48)	573 (1.08)	
	Formicinae	<i>Camponotus foraminosus</i> Forel, 1879	162 (1.24)	122 (0.74)	0 (0)	30 (0.36)	17 (0.14)	331 (0.63)
		<i>Camponotus haeticus</i> Santschi, 1914	49 (0.37)	164 (0.99)	0 (0)	191 (2.3)	166 (1.32)	567 (1.07)
<i>Camponotus maculatus</i> Fabricius, 1782		17 (0.13)	0 (0)	0 (0)	0 (0)	27 (0.22)	44 (0.08)	
<i>camponotus pompeius</i> Forel, 1879		23 (0.17)	50 (0.30)	0 (0)	0 (0)	35 (0.28)	108 (0.2)	
<i>Lepisota</i> sp.1		3 (0.02)	0 (0)	0 (0)	0 (0)	0 (0)	3 (0.01)	

Subfamilies	Species	MAF	MAK	MFO	NEK	NEM	Total
	<i>Lepisota</i> sp.2	18 (0.14)	0 (0)	0 (0)	17 (0.2)	0 (0)	35 (0.07)
	<i>Lepisota</i> sp.3	3 (0.02)	0 (0)	0 (0)	0 (0)	80 (0.64)	83 (0.16)
	<i>Oecophylla longinoda</i> Latreille, 1802	156 (1.19)	8 (0.05)	0 (0)	42 (0.5)	3 (0.02)	209 (0.39)
	<i>Paratrechina</i> sp.	5 (0.04)	0 (0)	0 (0)	23 (0.28)	4 (0.03)	32 (0.06)
	<i>Polyrachis decemdentata</i> André, 1889	0 (0)	10 (0.06)	0 (0)	0 (0)	0 (0)	10 (0.02)
	<i>Polyrachis laboriosa</i> F. Smith, 1858	2 (0.02)	0 (0)	0 (0)	0 (0)	8 (0.06)	10 (0.02)
	<i>Polyrachis militaris</i> Fabricus, 1782	0 (0)	5 (0.03)	0 (0)	0 (0)	0 (0)	5 (0.01)
	<i>Polyrachis</i> sp	3 (0.02)	0 (0)	0 (0)	0 (0)	0 (0)	3 (0.01)
	<i>Atopomyrmex mocquerysi</i> André, 1888	0 (0)	24 (0.14)	0 (0)	11 (0.13)	0 (0)	35 (0.07)
	<i>Cataulacus erinaceus</i> Stitz, 1910	0 (0)	19 (0.11)	0 (0)	0 (0)	0 (0)	19 (0.04)
	<i>Cataulacus guineensis</i> F. Smith, 1853	6 (0.05)	104 (0.63)	0 (0)	25 (0.3)	180 (1.32)	315 (0.57)
	<i>Crematogaster (Crematogaster)</i> sp.1	2993 (22.74)	464 (2.8)	0 (0)	925 (11.15)	3 (0.02)	4385 (8.2)
	<i>Crematogaster (Crematogaster)</i> sp.2	0 (0)	0 (0)	0 (0)	0 (0)	6 (0.05)	6 (0.01)
	<i>Crematogaster (Crematogaster)</i> sp.3	0 (0)	13 (0.08)	0 (0)	0 (0)	0 (0)	13 (0.02)
	<i>Crematogaster (Crematogaster)</i> sp.4	0 (0)	0 (0)	0 (0)	198 (2.37)	0 (0)	198 (0.37)
	<i>Crematogaster (Sphaerocrema)</i> sp.1	0 (0)	195 (1.18)	0 (0)	686 (8.25)	427 (3.4)	1308 (2.47)
	<i>Crematogaster (Sphaerocrema)</i> sp.2	0 (0)	0 (0)	0 (0)	0 (0)	347 (2.77)	347 (0.66)
	<i>Crematogaster (Sphaerocrema)</i> sp.3	0 (0)	0 (0)	0 (0)	0 (0)	174 (1.39)	174 (0.33)
	<i>Crematogaster (Sphaerocrema)</i> sp.4	0 (0)	0 (0)	0 (0)	4 (0.05)	22 (0.18)	26 (0.05)
	<i>Crematogaster (Sphaerocrema)</i> sp.5	0 (0)	0 (0)	0 (0)	0 (0)	20 (0.16)	20 (0.04)
	<i>Crematogaster Concava</i> Emery, 1899	7 (0.05)	0 (0)	0 (0)	0 (0)	360 (2.87)	367 (0.69)
	<i>Crematogaster depressa</i> Latreille, 1802	9 (0.07)	0 (0)	0 (0)	17 (0.2)	832 (6.63)	858 (1.62)
	<i>Crematogaster gabonensis</i> Emery, 1899	73 (0.55)	220 (1.33)	0 (0)	101 (1.2)	251 (2)	645 (1.22)
	<i>Crematogaster olivieri</i> Olivier, 1792	0 (0)	0 (0)	12 (0.53)	0 (0)	0 (0)	12 (0.02)
Myrmicinae	<i>Crematogaster pulchella</i> Bernard, 1952	56 (0.43)	255 (1.54)	0 (0)	0 (0)	912 (7.27)	1223 (2.31)
	<i>Crematogaster striatula</i> Emery, 1892	339 (2.58)	1403 (8.46)	2090 (91.51)	213 (2.55)	220 (1.75)	4265 (8.06)
	<i>Decamorium</i> sp.	0 (0)	40 (0.24)	0 (0)	0 (0)	0 (0)	40 (0.08)
	<i>Monomorium</i> sp.1	3 (0.02)	0 (0)	0 (0)	5 (0.06)	0 (0)	8 (0.02)
	<i>Monomorium</i> sp.2	0 (0)	0 (0)	0 (0)	510 (6.1)	23 (0.18)	533 (1.01)
	<i>Monomorium</i> sp.3	0 (0)	3 (0.02)	0 (0)	0 (0)	0 (0)	3 (0.01)
	<i>Myrmecaria opaciventris</i> Emery, 1893	4119 (31.29)	1843 (11.12)	27 (1.18)	4383 (52.43)	2646 (20.89)	13015 (24.55)
	<i>Pheidole megacephala</i> Fabricus, 1793	258 (1.96)	5391 (32.52)	0 (0)	216 (2.60)	1329 (10.6)	7194 (13.6)
	<i>Pheidole</i> sp.1	0 (0)	1498 (9.04)	0 (0)	0 (0)	0 (0)	1498 (2.83)
	<i>Pheidole</i> sp.2	0 (0)	0 (0)	0 (0)	0 (0)	22 (0.18)	22 (0.04)
	<i>Pheidole</i> sp.3	0 (0)	0 (0)	0 (0)	0 (0)	979 (7.81)	979 (1.85)
	<i>Pheidole</i> sp.4	0 (0)	0 (0)	0 (0)	45 (0.54)	0 (0)	45 (0.09)
	<i>Rhoptromyrmex</i> sp.	3407 (25.89)	2985 (18.01)	0 (0)	0 (0)	47 (0.37)	6439 (12.17)
	<i>Solenopsis geminata</i>	0 (0)	0 (0)	1 (0.04)	0 (0)	0 (0)	1 (0.002)
	<i>Tetramorium aculeatum</i> Mayr, 1866	333 (2.53)	36 (0.22)	0 (0)	98 (1.17)	0 (0)	467 (0.88)
	<i>Tetramorium brevispinosum</i> Stitz, 1910	312 (2.37)	555 (3.35)	0 (0)	0 (0)	133 (1.05)	1000 (1.85)
	<i>Tetramorium</i> sp.1	18 (0.14)	0 (0)	0 (0)	0 (0)	0 (0)	18 (0.03)
	<i>Tetramorium</i> sp.2	0 (0)	22 (0.13)	0 (0)	21 (0.25)	0 (0)	43 (0.08)
Ponerinae	<i>Odontomachus assimiensis</i> Latreille, 1802	0 (0)	0 (0)	0 (0)	4 (0.05)	6 (0.05)	10 (0.02)
Pseudomyrmicinae	<i>Tetraponera anthracina</i> Santschi, 1910	3 (0.02)	39 (0.24)	0 (0)	25 (0.3)	0 (0)	67 (0.13)
	Total	13161	16541	2284	8363	12661	53010

Mfoundi (MFO); Mefou-et-Afamba (MAF); Mefou-et-Akono (MAK); Nyong-et-Kellé (NEK); Nyong-et-Mfoumou (NEM)