

Ant species richness, abundance and functional groups along an elevational gradient in Central Cameroon

Paul Serge Mbenoun Masse^{1*}, G.L. Mendoua Eboho¹, G. Ebangue Titti¹ & R. Mony¹

¹Département de Biologie et Physiologie Animales, Faculté des Sciences, Université de Yaoundé 1, BP : 812 Yaoundé, Cameroon

*Corresponding author, e-mail: masseserge@yahoo.fr

ABSTRACT

Of all leaf litter-dwelling arthropods, ants are highly diverse, abundant, easy to sample, and thought to be sensitive to environmental changes. In central Africa, ant diversity patterns along the elevational gradients are poorly studied compared to latitudinal gradients. In this study, we evaluated the species richness, abundance and functional groups at Mount Eloundem. Ants were surveyed by pitfall trapping, baiting, Winkler extraction and quadrat sampling from September 2018 to April 2019. A total of 151 morphospecies in 9 sub-families and 42 genera were recorded from all four elevations. Twenty percent of identified species were found to be endemic to the study region while 80% have been introduced to the fauna of Cameroon. The army ant, *Dorylus (Anomma) nigricans*, was the most abundant ant species (51.46%). Ant richness and abundance were highest at both lower (800 and 900 m) and higher elevational bands (1000 and 1150 m) and lowest at moderate elevational bands (900 and 1000 m). Higher similarity of ant species among elevations indicated low species turnover. Six functional groups were found at different elevations, with the “Opportunists” being the most abundant group. Our findings demonstrate the predominance of opportunist, non-native or tramp species and a decline in native ant species along the elevational gradients. This study suggests that the loss of native habitat facilitate the establishment of tramp species, and might lead to homogenisation in ant community composition and functional groups. These results also have implications for management of the low altitude mountains in Central Africa.

KEY WORDS

Diversity; species turnover; Mount Eloundem; sampling methods; Central Africa.

Received 21.11.2020; accepted 28.12.2020; published online 15.03.2021

INTRODUCTION

Elevation-gradient studies are considered as useful tools to understand the ecological mechanisms underlying patterns of biodiversity and the functioning of ecosystems (Fukami & Wardle, 2005; Körner, 2007; Sanders & Rahbek, 2012). Although processes that shape elevational gradients may operate also along the latitudinal gradients, mountainous areas encompass a wide variety of mi-

croclimate and vegetation types along elevational gradients, which make them easier to study species diversity and distribution than latitudinal gradients (Pellissier et al., 2013). A number of factors have been suggested as underlying causes of elevational diversity gradients: Productivity (Rahbek, 1995; Grytnes, 2003), areas (Rahbek, 1995; Sanders, 2002), geometric constraints (Sanders, 2002; Rowe, 2009) and disturbance (Escobar et al., 2007).

Disturbance is generally defined as any event

that removes biomass (Townsend & Hildrew, 1994). There are three principal ways in which disturbance can affect community dynamics: by changing mortality rates (henceforth *D* disturbance), birth rates (*B* disturbance) or carrying capacity (*K* disturbance). Numerous composite disturbances can be defined including any combination of these three types of ecological effects (Dornelas, 2010). Some types of disturbance are inherent to ecosystem dynamics and constitute mechanisms of biodiversity generation and maintenance, while other long-term, large-scale disturbances may challenge species survival. Effects of disturbance on biodiversity have been studied in a great variety of ecosystems (Hobbs, 1988; Pompeu & Alves, 2005; Petsch, 2016) and in a great variety of organisms ranging from arthropods to vertebrates (Lessard & Buddle, 2004; Winfree et al., 2006; Gill, 2007; Ekross et al., 2010).

Arthropods constitute more than 75% of the earth's terrestrial biodiversity. They perform at many levels in an ecosystem (McIntyre et al., 2001; McKinney, 2008). Arthropods typically have large population sizes and generation time is relatively short making them ideal to track year-to-year changes in a particular habitat. Many arthropod groups have been considered as potential indicator taxa due to their high diversity and ecological importance (Williams, 1993; Andersen & Sparling, 1997; Longcore, 2003). For all these reasons, arthropods are excellent candidates for studying factors affecting species assemblages along the latitudinal or elevational gradients.

Ants are one of the most ubiquitous, widespread, and abundant groups of leaf litter and soil-dwelling arthropods. They play critical roles in every terrestrial ecosystem: recycling nutrients, dispersing seeds, engaging in mutualistic associations with other organisms (Beattie, 1985; Hölldobler & Wilson, 1990). Ants are ideal bio-indicators because they have narrow tolerances and thus respond quickly to environmental changes (Agosti & Alonso, 2000; Hoffmann & Andersen, 2003). The sensitivity of ant communities to environmental disturbance, combined with their great functional importance, makes them powerful monitoring and assessment tools in land management (Andersen & Majer, 2004). Like other taxa, many ant species and populations face a range of threats to their survival. The most widespread threats include loss of diver-

sity, changes in species composition, changes in trophic interactions between ant-plants and honeydew-producing hemipterans, and they all come from the loss and disturbance of their natural habitats (Philpott et al., 2010).

Elevational gradient studies in ant diversity are poorly known relative to other arthropods in Central Africa, and in Cameroon in particular. To date, several studies focused on ant diversity along the latitudinal gradients (Watt et al., 2002; Tadu et al., 2014; Fotso et al., 2015). The objective of this study was to investigate the ant community patterns and functional groups along an elevational gradient in the Centre region of Cameroon.

MATERIAL AND METHODS

Study area

This study was conducted at Mount Eloundem (3°49.220'N, 11°26.512'E; 1159 m above sea level (a.s.l) from September 2018 to April 2019 (Fig. 1). Mount Eloundem is located southwest of Yaoundé, the political capital of Cameroon. This region is characterised by four distinct seasons: two wet seasons and two dry seasons. The average annual rainfall is approximately 1500 mm. The mean annual relative humidity is 79.5%. The mean air temperature ranges from 19.2 to 28.6 °C.

The sampling sites were selected at an elevation of 800 m, 900 m, 1000 m, and 1150 m a.s.l. which represent the typical pattern of vegetation of this mountain (Achoundong, 1996).

800 m: 3°50.038'N, 11°26.208'E. The vegetation formerly consisted of semi-deciduous forest and floristically dominated by several plant families such as Meliaceae, Sterculiaceae, Euphobiaceae, and Olacaceae (Achoundong, 1996). Nowadays, anthropised areas represent the largest part of the available area. This elevational level is dominated by human settlements and mixed crop fields including *Manihot esculanta* (Euphorbiaceae), *Xanthosoma sagittifolium* (Araceae), *Musa paradisiaca* (Musaceae), *Elaeis guineensis* (Arecaceae), *Chromolaena odorata* (Asteraceae). As over 80% of surface area is covered by human modified-areas, less than 20%, therefore, remains as a vegetated area.

900 m: 3°49.921'N, 11°26.307'E. The landscape is characterised by hydro-mesophilic and is domi-

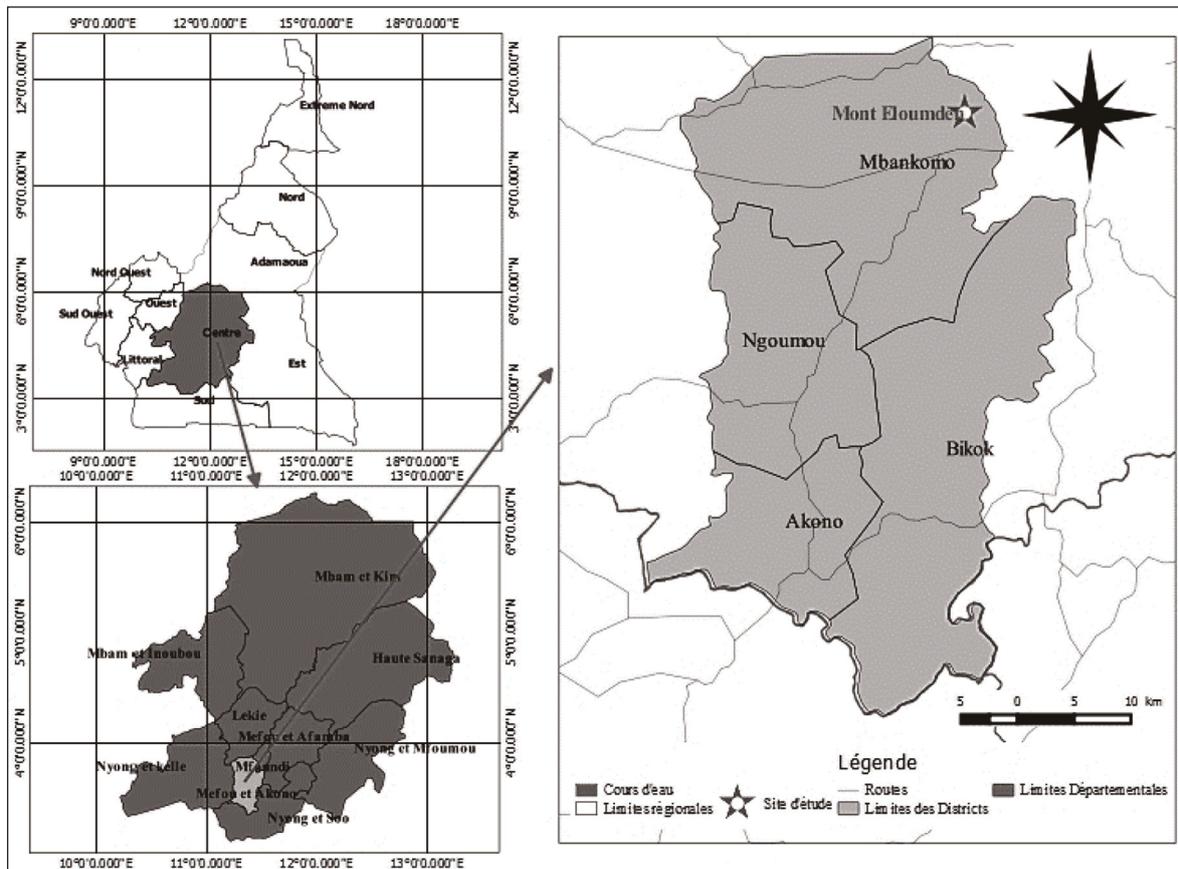


Figure 1. Map indicating the location of study site.

nated by hydrophilic plant species. Plant species at this elevation level are dominated by alien and indigenous trees such as *Musanga cecropioides* (Urticaceae), *Mallotus oppositifolius* (Euphorbiaceae), *Treculia africana* (Moraceae), *Megaphrynium macrostachium* (Marantaceae), *Anielema beniniense* (Commelinaceae), *Alchornea floribunda* (Euphorbiaceae), *Trema orientalis* (Ulmaceae), *Funtumia africana* (Apocynaceae). Human activities represent more than 50% of the surface area and 20-50% constitute vegetated area.

1000 m: 3°49.844'N, 11°26.203'E. This elevation was formerly classified as a submontane forest (Achoundong 1996) and it is now dominated by *Icacina micrantha*, *Diplansum* sp., *Piper umbellatum*, *Onchomane difformis*, *Combretum bucholzii*, *Olyua latifolia*, and *Asparagus africana* plant species. This mid-elevation site is characterised by the steep and rugged rock slopes. The percentage cover by vegetation area is approximately 60-70%

with closed canopy, while the remaining area (less than 30%) is dominated by subsistence farming.

1150 m: 3°49.664'N, 11°26.312'E. The vegetation at the summit presents a reduction in the size of trees and in the number of species. This elevation is highly fragmented and degraded (90%) due to wood extraction and construction of place of worship; therefore, only some plant species persist (10%) including *Makarmia lutea*, *Ipomoea batatas*, *Cyathea* sp., *Nephrolepis bisserata*, *Aframumum* sp. and *Bidens pilosa*.

Sampling and specimen processing

Ants were surveyed every week by four people on the mountain slopes following an elevational gradient. A combination of four sampling methods (pit-fall trapping, baiting, Winkler extraction and quadrat sampling) was used to ensure sampling efforts as complete as possible. Four elevation levels were se-

lected at a constant of 100 m intervals along elevational gradients. At each elevation, four transects (110 m length and 2 m width) with 10 sampling points spaced 10 m apart were set. Eight sampling events were undertaken at different elevations during the study period. A total of 1280 samples were collected in four elevational levels (4 elevation levels \times 10 samples/method \times 4 methods \times 8 replicates):

Hand collection. Ten 3 m² quadrats were set along the first transect. Two consecutive quadrats were 10 m apart and 10 m from the nearest method. Within each elevation level, ants were searched in rotten logs and stumps, under stones, bark, layers of leaf litter and directly in the soil for 15 min of active searching. A total of 320 quadrats (4 elevational levels \times 8 replicates \times 10 sampling points) were sampled at all elevations.

Pitfall trapping. Pitfall traps constituted of plastic cups (diameter 20 mm, 150 mm length) inserted into sunken plastic pipes. A quarter of the cup (about 100 ml) was filled with water (98%) and soap (2%). Pitfall traps were locked and left for 7 days prior to the beginning of the experiment. The contents of all pitfall traps were collected after 7 days and sorted into 70% ethanol.

Litter sifting. Ten 1 m² samples of leaf litter were sifted to remove large leaves, stones and plastic waste. Leaf litter samples were collected near cacao plantation and in old fallow. The sifted litter was then placed in mini Winkler sacks for 48 h. During this time, ants and other invertebrates from within the litter sample migrated out of the litter, as a behavioural response to disturbance of their habitat and eventually fell into a container filled with 70% ethanol.

Baiting. Baits containing a mixture of honey 30%, tuna 50% and soya oil 20% were placed on the ground on a square plastic (20 cm \times 20 cm) and checked after 90 min. At each elevational level, 10 baits were presented simultaneously along the trail systems with a distance between each other of 10 m. A total of 320 baits stations were used during the sampling period at all elevations.

Ants were identified to species level (or to morpho-species) using keys from Hölldobler & Wilson (1990) and Bolton (1994) for genera, and the web site of the sub-Saharan African ants (Taylor, 2011) for species. Ant specimens were mounted on cardboard triangles and then kept as a reference collection at the laboratory.

Statistical analysis

Data from all the sampling methods were pooled at each elevation and entered into a matrix in the form of presence-absence data before analysis. The total occurrence of a species (total number of times a species captured independently in all the samples) was used as estimate of the relative abundance of that species over all elevations.

To assess survey completeness for each elevation zones and sampling methods, species accumulation curves were plotted as a function of both the number of samples and the number of species. Samples were randomised 100 times and means were computed for each elevation zone using the program EstimateS version 9.10 (Colwell 2005). These curves allow one to compare species richness for equivalent levels of sampling effort. To estimate the maximum species richness, four relevant non-parametric richness estimators (ACE, Jack2, Chao 1 and Bootstrap) were used at each elevation.

To analyse the species richness, species occurrence and the differences in community composition between elevation zones, alpha diversity was used with the help of the Shannon–Wiener index (H'), Simpson and the Berger–Parker dominance indices. One-way analysis of variance (ANOVA) was used to test differences in species richness, diversity indices and dominance index among the four elevational levels followed by post-hoc test (Dunnett's test) to separate the means.

Faunal similarity was calculated using Chekanovsky-Sorensen's index: $C-S = 2a/(2a + b + c)$, where a = number of species common at both elevations, b = number of species unique at elevation A, and c = number of species unique at elevation B. Beta diversity was also calculated using Jaccard similarity index. ANOSIM software was used to visualise difference between ant assemblages at different elevational levels. Ant taxa were assigned to functional groups following Greenslade (1978) modified and extended for continental and intercontinental analyses of biogeographical patterns of ant community structure and their responses to environmental stress (Andersen 2000).

All statistical tests were carried out using SPSS software version 16.0 for Windows.

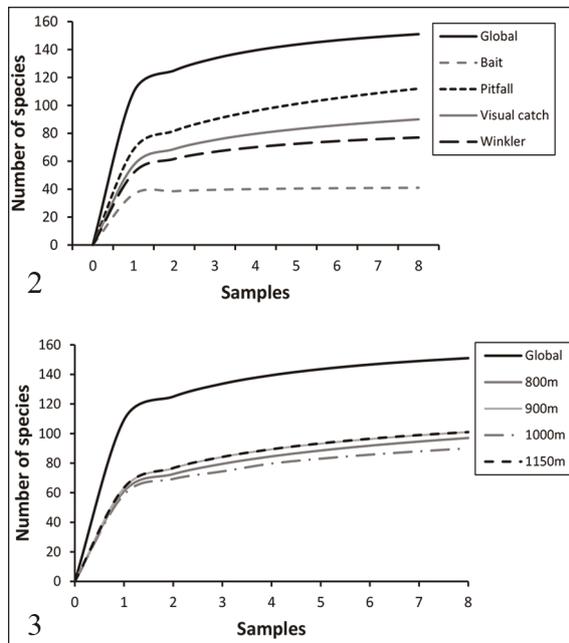
RESULTS

Ant diversity and community composition

A total of 3,130 occurrences from 151 species in 9 subfamilies and 42 genera were recorded in the four elevation levels (see Table 4). Species richness was highest at 900 m and at 1150 m (101 species each) and lowest at 1000 m (90 species) and at 800 m (97 species). Myrmicinae was the most species-rich subfamily (81 species; 53.65%) followed by Ponerinae (32 species; 21.19%). *Dorylus* (*Anomma*) *nigricans*, a lowland forest and warm climate specialist, was the most abundant species (51.46%) followed by *Crematogaster* (*Sphaerocrema*) *concava* (14.85%).

Sampling effort and species richness estimators

Species accumulation curves plotted as function of both the number of sampling periods and the number of species collected using four sampling methods (Fig. 2) and the number of species occurring at each elevation (Fig. 3). All these curves were still rising at the end of sampling pe-



Figures 2, 3. Sample-based species accumulations curves for the four sampling methods used (Fig. 2) and different elevational levels surveyed (Fig. 3) based on an average series of 100 randomisations of the data.

riod, suggesting that more sampling would be required to reach a horizontal asymptote. Sample efficiency ranged from 63.52 to 94.39% at different elevations and from 66.67 to 100% for sampling methods (Table 1). The highest estimated richness was found at 900 m (Jack2 = 159 species) and the lowest at 1150 m (Chao1 = 107 species). With regard to sampling methods, the maximum number of expected species was collected in the pitfall trapping (Jack2 = 168 species) and the minimum in the baiting (ACE and Chao 1 = 41 species each).

Efficiency of sampling methods

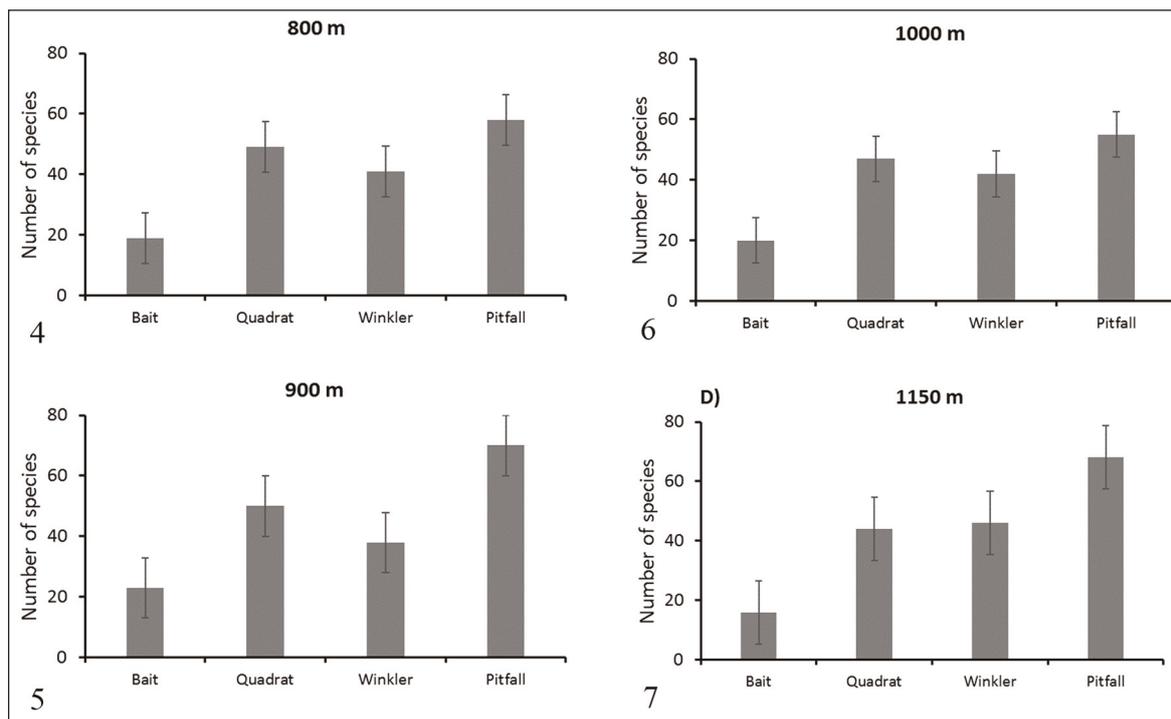
The greatest number of species was collected in the pitfall trapping (112 species; 74.17%) and the lowest number of species was captured in the baiting (41 species; 27.15%) at all elevations (Figs. 4–7). Statistical difference was observed in species richness between the sampling methods. Pitfall trapping represented 38.41% of the total species at 800 m, 46.36% at 900 m, 36.42% at 1000 m and 45.03% at 1150 m. Quadrat sampling collected the highest number of species after pitfall trapping at 800 m (32.45%), 900 m (33.11%) and 1000 m (29.13%), while at 1120 m, Winkler (30.46%) caught more species than quadrat (29.13%).

Diversity and evenness

The mean number of species was highest at 900 m (101 species; 37 ± 14) and 1150 m (101 species; 37 ± 11) and lowest at 800 m (90 species; 36 ± 8) and 1000 m (97 species; 36 ± 9), but no significant difference was detected among elevation levels (Kruskal Wallis ANOVA: $H = 5.03$; d.f = 2; $P > 0.05$) (Table 2). A similar pattern was found in total species occurrence ($H = 7.59$; d.f = 2; $P > 0.05$). In contrast, the ant community was more diverse at 800 m (Shannon Wiener mean: $H' = 2.77$ (2.30 ± 0.41); $E = 0.60$ (0 ± 0.64)) and 1000 m ($H' = 2.08$ (1.79 ± 0.39); $E = 0.46$ (0.50 ± 0.09)) than at 900 m ($H' = 1.86$ (1.68 ± 0.71); $E = 0.40$ (0.47 ± 0.17)) and 1150 m ($H' = 1.51$ (1.36 ± 0.25); $E = 0.33$ (0.38 ± 0.08)), with significant differences for both Shannon-Wiener ($H = 10.73$; d.f = 2; $P < 0.01$) and Equitability indices ($H = 12.94$; d.f = 2; $P < 0.001$). Evenness tend toward one at

900 m (Berger parker: $ID = 0.62 (0.58 \pm 0.22)$) and 1150 m ($ID = 0.60 (0.61 \pm 0.10)$) and toward zero at 800 m ($ID = 0.22 (0.31 \pm 0.14)$) and at 1000 m ($ID = 0.48 (0.53 \pm 0.09)$) ($H = 11.32$; $d.f = 2$; $P < 0.01$). *Dorylus (Anomma) nigricans* was the most dominant species at all elevational levels and ac-

counted for 62.01% of the total of species occurrence at 1150 m, 60.06% at 900 m, 47.97% at 800 m and 21.86% at 1000 m (Fig. 8). Overall, the ant community composition was not statistically different among elevations (ANOSIM: $R = 0.8248$, $P > 0.05$).



Figures 4–7. Species richness as a function of the sampling methods at different elevations along an elevational gradient: Fig. 4) at 800 m, Fig. 5) at 900 m, Fig. 6) at 1000 m and Fig. 7) at 1150 m. Error bars ± 1 SD.

Estimators	Elevation				Sampling methods			
	800 m	900 m	1000 m	1150 m	Bait	Pitfall	Quadrat	Winkler
RSO	97	101	90	101	41	112	90	77
ACE	114(85.09)	112(90.18)	103(87.30)	111(90.99)	41(100)	135(82.96)	101(89.11)	81(95.06)
Chao1	112(86.61)	112(90.18)	103(87.38)	107(94.39)	41(100)	133(84.21)	103(87.38)	80(96.25)
Jack2	142(68.31)	159(63.52)	124(72.58)	141(71.63)	58(70.69)	168(66.67)	131(68.70)	103(7.76)
Bootstrap	111(87.39)	117(86.33)	103(87.38)	116(87.07)	46(89.13)	128(87.50)	102(88.24)	88(87.50)
Unique species	14	8	5	18	0	22	6	18
Proportion (%)	0.14	0.08	0.05	0.17	0	16.65	6.66	23.33

Table 1. Observed and expected species richness as function of elevation zones and sampling methods. Proportion and number of unique species at each elevational zone and for each method are also given. Values in bold indicate lowest and highest species richness estimators. Parentheses indicate sampling effort. RSO = total number of species observed at each elevation, ACE = abundance-based coverage estimator

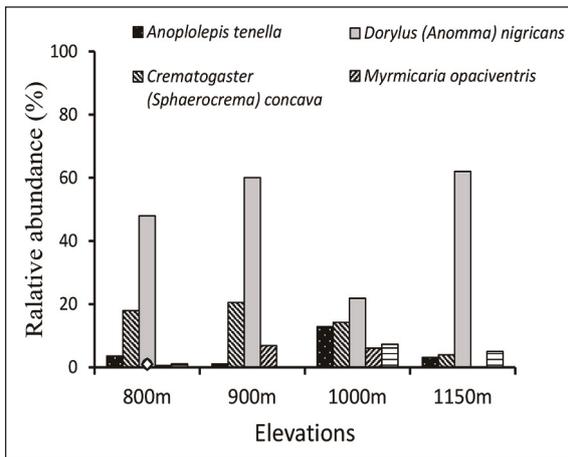


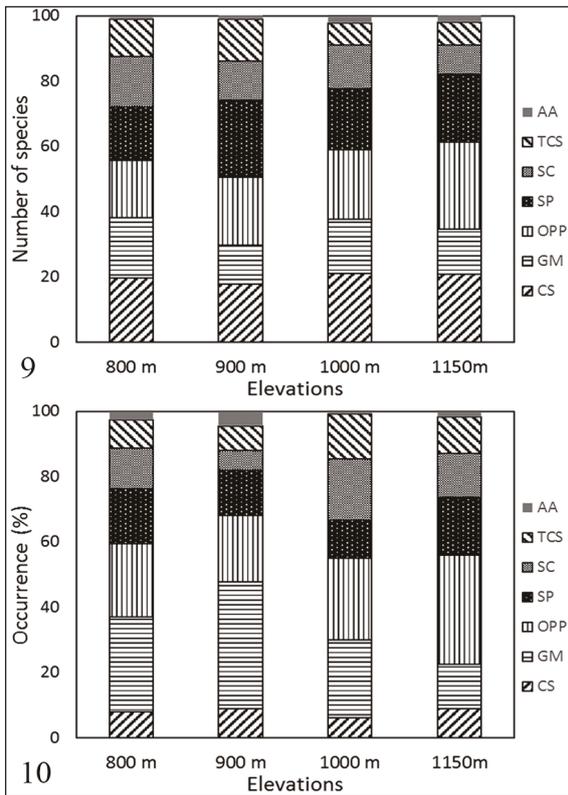
Figure 8. Relative abundance of four dominant species at different elevational levels. Calculation of relative abundance is based on the occurrence of each species at each elevation.

Community composition and species turnover

Fifty-three species (35%) were common to four elevations, against 11% of species to all sampling methods. The number of unique species was less than 20% and 24% in all elevation levels and sampling methods, respectively (Table 1). Fourteen species (14%) occurred only at 800 m, 8 species (8%) at 900 m, 5 species (5%) at 1000 m and 18 species (17%) at 1150 m. The highest value of unique species was found in Winkler extractor (23%) whereas no species was peculiar to baiting. The Sorensen and Jaccard similarity indices indicated a low species turnover among elevations (Table 3). The most similar pairs of communities were at 900 and 1000 m and at 800 m and 900 m.

Functional group composition

Overall, six of Andersen’s functional groups were found in different elevations zones. *Dorylus* genus was placed into a new functional group: Army ants. The most diverse functional group was Opportunist (35 species; 23.18%), followed by Cryptic species (33 species; 21.85%), Specialist predators (28 species; 18.54%), General Myrmicinae (22 species; 14.5%), Subordinate Camponotini (17 species; 11.26%), Tropical climate specialists (14 species; 9.30%) and army ants (2 species; 1.30%) (Fig. 9). The most species-rich functional group was Cryptic species at 800 m (19 species), Specialist predators at 900 m (24 species), Cryptic species and Opportunists at 1000 m (19 species each), and Opportunists at 1150 m (27 species). With the exception of Generalised Myrmicinae ($P < 0.05$), there was no statistical difference in species richness in each functional group among elevations. Moreover, General Myrmicinae was the most frequent functional group at 800 m (29%) and 900 m (38%), while Opportunists was common at 1000 m (25%) and at 1150 m (33%) (Fig. 10).



Figures 9, 10. Functional group composition of ants at mount Eloundem: number of species (Fig. 9) and occurrence (Fig. 10). Data are relative contributions of each functional group to the total species or occurrence. Legend: GM = Generalised Myrmicinae, OPP = Opportunists, SC = Subordinate Camponotini, TCS = Tropical-Climat Specialists, CS = Cryptic species, AA = Army ants and SP = Specialist predators.

DISCUSSION

Overall ant diversity and functional groups

This study investigated the ant community composition and functional groups along an elevational gradient in central Cameroon. A total of 151 ant species and 42 genera were recorded in the present

	Elevation				H	d.f	P
	800 m	900 m	1000 m	1150 m			
S	97(36 ± 9)	101(37 ± 14)	90(36 ± 8)	101(37 ± 11)	5.03	3	> 0.05 ^{ns}
Occurrence	290 (26 ± 12)	294 (37 ± 14)	286 (36 ± 8)	297 (37 ± 11)	7.59	3	> 0.05 ^{ns}
Shannon H	2.77 (2.30 ± 0.41) ^a	1.86 (1.68 ± 0.71) ^{ab}	2.08 (1.79 ± 0.39) ^a	1.51 (1.36 ± 0.25) ^b	10.73	3	< 0.01 ^{**}
Equitability	0.60 (0.64 ± 0.11) ^a	0.40 (0.47 ± 0.17) ^{abc}	0.46 (0.50 ± 0.09) ^b	0.33 (0.38 ± 0.08) ^c	12.94	3	< 0.001 ^{***}
Berger-Parker_ID	0.22 (0.31 ± 0.14) ^a	0.62 (0.58 ± 0.22) ^b	0.48 (0.53 ± 0.09) ^b	0.60 (0.61 ± 0.10) ^b	11.32	3	< 0.01 ^{**}

Table 2. Species richness, occurrence, diversity and evenness indices at different elevations on Mount Eloundem with one-way ANOVA analysis followed by Dunnett's post hoc test. Mean ± SE are given in parentheses.

	800 m	900 m	1000 m	1150 m
800 m	—	0.87	0.87	0.80
900 m	0.6	—	0.92	0.85
1000 m	0.58	0.63	—	0.85
1150 m	0.46	0.58	0.58	—

Table 3. Species turnover between the four elevational zones, based on four sampling methods used at mount Eloundem. The Chekanovsky-Sorensen's index: C-S is above the diagonal and Jaccard similarity index is below.

study. The recorded species richness is higher than that recorded along the latitudinal gradients in urban cities (28 species; Mbenoun et al., 2017), in agro-forestry systems (66 species; Tadu et al., 2014) and in forest reserves (145 species; Deblauwe & Deconick, 2007) in Cameroon. The observed differences in species richness between previous and current studies are likely due to the difference in sampling methods used to collect ants. Indeed, these previous studies used less than three sampling techniques, while ant diversity in the present study was assessed using a combination of four sampling techniques commonly used in studies of ground-dwelling arthropods (Agosti & Alonso, 2000). However, the species richness patterns recorded in our study sites were lower than those encountered along the forest disturbance gradient in southern Cameroon (237 species) by Fotso et al. (2015). Likewise, additional sampling techniques are required to reach a total of 310 ant species recorded in Mount Doudou in Gabon, representing the highest species richness recorded in Africa to date (Fisher, 2004).

The ant fauna in this study was dominated by the Myrmicinae, which made up 53.65% of the total species. Myrmicinae is one of the most dominant and largest ant subfamilies in most terrestrial habitats (Marsh, 1986; Bharti & Sharma, 2009). These results are consistent with other studies carried out in low elevation mountains in Philippines and south-eastern Brazil (Samson et al., 1997; Araújo & Fernandes, 2003).

Our findings showed that the army ant, *Dorylus (Anomma) nigricans* was the most abundant species and widely distributed across elevations. The army ants dominate lowland forest in Africa and possess a unique suite of characteristics: mass foraging, opportunist, nomadism, large aggressive colonies, and competitive dominance (Brady, 2003). As Andersen (2000) pointed out, the impact of low-temperature stress is negligible between 500 m and 1000 m altitudes and therefore the community composition is mainly regulated by competition. This study revealed that army ants, which forage above ground, may be restricted to montane forested area due to a thermal tolerance threshold, once limited in elevation by wet and cold, this predatory ant can move to warmer and less-cloudy higher elevations. Several studies have demonstrated that increase in soil temperature and decrease in soil moisture seem likely to enhance the establishment of aggressive large colony weedy species (Suarez et al., 1998; Dejean & Gibernau, 2000; Lessard & Buddle, 2005). Seven functional groups can be found in four elevational levels at Mount Eloundem. Out of the seven functional groups, six of Andersen's functional groups were found in this study. Other functional groups assigned by Andersen (2010) like Dominant Dolichoderinae and Cold-climate spe-

cialist were not detected. The latter may be peculiar to Australia or temperate regions. Ants with large and aggressive colonies such as *Dorylus* species were placed into a new functional group, namely Army ants. The army ants *Dorylus* are widely distributed in Africa while other army ants Eciton are known in the New World (Brady, 2003). However, original functional group classification is based on ants from Australia, its application to the New World remains problematic (Narendra et al., 2011). Although, the classification applied in this study is based on previous studies carried out on Africa's rainforest ants (Fotso et al., 2015), further studies are required because the borders between these groups are closed and flexible. The opportunists were the most diverse functional group across all the sampled elevations. Several other studies have recorded similar patterns to those found in the present study (Bharti & Sharma, 2009; Fotso et al., 2015). Dominance of opportunist ants may be due to their ability to be able to exploit a wide variety of resources and habitats than other ant species. Moreover, ant species belonging to this functional group of generalist species, typically disturbance specialists, are likely to be less sensitive to narrow changes in edaphic factors.

Efficiency of sampling methods

A combination of four sampling methods led to collection of 151 species. Pitfall trapping yielded more species at each elevation level than the Winkler extractor, baiting and quadrat sampling. Twenty-three percent of species was unique to pitfall trapping while no species was peculiar to baiting. In fact, the species recorded in baiting represent a subset of those collected using the other methods. However, no method recorded all the species present of this study. According to Bestelmeyer *et al.* (2009), each sampling method seems to be specific and records different assemblages. Pitfall traps and quadrat sampling recorded mostly epigeic ant foragers especially in open habitats. Compared to quadrat sampling, the greatest advantage of pitfall is that they take little time to place and operate by themselves. Winkler extractors are especially appropriate in hypogaeic ants inhabiting topsoil and litter layer in forest and woodland habitats. Baiting is commonly used to estimate the composition and richness of active ground-foraging ant fauna. There-

fore, it is widely recommended to use a variety of methods to obtain an adequate impression of the local ant fauna (Fisher, 2002, 2004).

Ant composition and environmental stress

Our results showed that species richness increased at the lowest (800–900 m) and highest (1000–1150 m) elevational bands and decreased at moderate bands (900–1000 m). At lower bands, human modified areas represent the largest part of the available area with fewer green places. The landscape is mainly characterised by human settlements and subsistence farming. The ant fauna at these elevations were dominated by non-native ant species, which represented more than 50% of the total species. Numerous studies have demonstrated that the destruction of forest and canopy cover may favours organisms that can quickly acclimate, adapt, disperse, or change their behaviour (Dejean & Gibernau, 2000; Lessard & Buddle, 2005; Deutsch et al., 2008).

At the moderate bands, species richness and abundance decreased. Steep and rugged rock slopes represent more than half of the surface area at this elevation, with a few crop fields. Interestingly, endemic ant species were more abundant than non-native species and accounted for 62% of the total ant species. It is argued that ant assemblages are strongly influenced by a number of habitat variables including: geology, soil type, soil moisture, physiognomy, vegetation cover, plant and leaf litter cover (Koen & Breytenbach, 1988), and a positive correlation between vegetation structure and the diversity of ants is frequently reported (Room, 1975). At the highest elevation, the vegetation area is highly fragmented and degraded due to wood extraction and construction of worship areas. Habitat transformation has reduced native habitat to small isolated remnant patches. Non-native ant species were abundant and represented 57% of the total ant species. Human-mediated dispersal is increasingly recognised as a key issue in invasion science (Bullock et al., 2018). A majority of non-native species remain confined to human-modified habitats and largely depend on human-mediated dispersal to colonise new and distant locations (Suarez et al., 2001). Some of these species are often referred to as tramp species because of their reliance on human-mediated dispersal (Hölldobler & Wilson, 1990; Passera, 1994).

Subfamilies/species	Native range	800	900	1000	1150
Aenictinae					
<i>Aenictus decolor</i> Mayr, 1879	Nigeria				1
<i>Aenictus weissi</i> Santschi, 1910	Nigeria	1	2		
Cerapachyinae					
<i>Cerapachys foreli</i> Santschi, 1914	Ghana	1	2	2	3
<i>Cerapachys nitidulus</i> Brown, 1975	Ghana		1		1
<i>Cerapachys sudanensis</i> Weber, 1942	Nigeria	1	1		2
Dolichoderinae					
<i>Axinidris</i> sp.		6	21	25	2
<i>Tapinoma</i> sp.1		18	24	2	8
<i>Tapinoma</i> sp.2		12	5	7	
<i>Tapinoma</i> sp.3		8	3	17	9
Dorylinae		6	15	20	35
<i>Dorylus (Anomma) negricans</i> Illiger, 1802	Sierra Leone	6	15	19	32
<i>Dorylus (Dorylus) braunsi</i> Emery, 1895	Tanzania			1	3
Formicinae					
<i>Anoplolepis tenella</i> Santschi, 1911	Nigeria				
<i>Camponotus (Myrmacrhaphe)</i> sp.		5	1	1	1
<i>Camponotus (Myrmopelta)</i> sp.1		3	2	2	
<i>Camponotus (Myrmopelta)</i> sp.2		3	6	1	1
<i>Camponotus (Myrmopelta)</i> sp.3		1	2	4	4
<i>Camponotus (Myrmosericus) flavomarginatus</i> Mayr, 1862	Ghana	3	2	13	7
<i>Camponotus (Myrmotrema) foraminosus</i> Forel, 1879	Cape Verde	5	2	3	
<i>Camponotus (Myrmotrema)</i> sp.		10	3	3	1
<i>Camponotus (Tanaemyrmex) acvapimensis</i> Mayr, 1862	Ghana				1
<i>Camponotus (Tanaemyrmex) brutus</i> Forel, 1886	Angola	41	35	10	4
<i>Camponotus (Tanaemyrmex) maculatus</i> Fabricius, 1782	Sierra leone	59	45	37	26
<i>Lepisiota</i> sp.1		9	5	2	11
<i>Lepisiota</i> sp.2			9	2	1
<i>Lepisiota</i> sp.3		1			1
<i>Oecophylla longinoda</i> Latreille, 1802	Senegal	15	9	1	2
<i>Petalomyrmex</i> sp.			1		
<i>Polyrachis ayousi</i>	C. African Republic	1		2	
<i>Polyrachis concava</i> André, 1889	Sierra Leone	1			
<i>Polyrachis decemdentata</i> André, 1889	Sierra Leone	10	5		
<i>Polyrachis laboriosa</i> Smith, F., 1858	Sierra Leone		2	1	
<i>Polyrachis militaris</i> Fabricius, 1782	Zaire	1	5	13	2
<i>Polyrachis phidias</i> Forel, 1910	Nigeria	3			
<i>Polyrachis weissi</i> Santschi, 1910	Congo Brazzaville	1			
Myrmicinae					
<i>Atopomyrmex mocquerysi</i> , André, 1889	Senegal	15			
<i>Baracidris</i> sp.		1			

<i>Calyptomyrmex nummuliticus</i> Santschi, 1914	Cameroon		2		5
<i>Calyptomyrmex</i> sp.					2
<i>Cardiocondyla wassmanni</i> Santschi, 1926	Panafrican				2
<i>Cataulatus centrurus</i> Bolton, 1982	Cameroon	2	3		8
<i>Cataulatus egenus</i> Santschi, 1911	Nigeria	2	3	2	9
<i>Cataulatus guineensis</i> Smith, F., 1853	Equatorial Guinea	6	1	1	
<i>Cataulatus kohli</i> Mayr, 1895	Sierra Leone	2	1		
<i>Cataulatus lujae</i> Forel, 1911	Zaire		1		
<i>Cataulatus taylora</i> Bolton, 1982	Nigeria	2	2	1	
<i>Crematogaster (Atopogyne) depressa</i> , Latreille, 1802	Guinea	10	2	31	7
<i>Crematogaster (Atopogyne)</i> sp.		1			
<i>Crematogaster (Crematogaster)</i> sp.1				2	2
<i>Crematogaster (Crematogaster)</i> sp.2		1			
<i>Crematogaster (Crematogaster)</i> sp.3		1		5	1
<i>Crematogaster (Orthocrema) pulchella</i> Bernard, 1953	Guinea	6	15	1	
<i>Crematogaster (Sphaerocrema) concava</i> Emery, 1899	Cameroon	49	26	74	133
<i>Crematogaster (Sphaerocrema) gabonensis</i> Emery, 1899	Gabon	1			
<i>Crematogaster (Sphaerocrema)</i> sp.1			1		1
<i>Crematogaster (Sphaerocrema)</i> sp.2			1	3	3
<i>Decamorium</i> sp.					1
<i>Discroapis</i> sp.					1
<i>Melissotarsus weissi</i> Santschi, 1910	Congo Brazzaville	1		4	
<i>Microdaceton tibialis</i> Weber, 1952		1	1		
<i>Monomorium bicolor</i> Emery, 1877					4
<i>Myrmecaria opaciventris</i> Emery, 1893	Zaire	26		17	76
<i>Oligomyrmex diabolus</i> Santschi, 1913	Cameroon	1	11	3	6
<i>Oligomyrmex</i> sp.1		3	2	3	1
<i>Oligomyrmex</i> sp.2				1	2
<i>Oligomyrmex</i> sp.3		3	6	2	3
<i>Pheidole impressifrons</i> , Wasmann, 1905		1		1	
<i>Pheidole pulchella</i> , Santschi, 1910	Cameroon	6	7	22	17
<i>Pheidole</i> sp.1		32	22	16	14
<i>Pheidole</i> sp.2		4	1	1	4
<i>Pheidole</i> sp.3		3	8	9	18
<i>Pheidole</i> sp.4		2	1	7	2
<i>Pheidole</i> sp.5					1
<i>Pheidole</i> sp.6		1		1	
<i>Pheidole</i> sp.7		3	1		
<i>Pheidole speculifera</i> Emery, 1877	Cameroon	26	29	21	24
<i>Pristomyrmex orbiceps</i> Santschi, 1914	Cameroon	3	5	6	2
<i>Pristomyrmex</i> sp.		1	5		
<i>Pyramica (Epitritus)</i> sp.			1	1	3
<i>Pyramica (Glamyromyrmex) sistrura</i> Bolton, 1983	Cameroon	2	2	1	

<i>Pyramica (Glamyromyrmex)</i> sp.		1			
<i>Pyramica (Serrastruma) dotaja</i> Bolton, 1983	Cameroon	1			
<i>Pyramica (Serrastruma)</i> sp.1		8	11	6	9
<i>Pyramica (Serrastruma)</i> sp.2		3	1	1	3
<i>Pyramica (Serrastruma)</i> sp.3			1	1	2
<i>Pyramica (Smithistruma)</i> sp.1			1	2	
<i>Pyramica (Smithistruma)</i> sp.2				1	
<i>Rhoptromyrmex</i> sp.			10	8	1
<i>Strumigenys</i> sp.1					1
<i>Strumigenys</i> sp.2		1			
<i>Strumigenys</i> sp.3		4	5	4	6
<i>Strumigenys</i> sp.4		5	8	14	10
<i>Tetramorium aculeatum</i> Mayr, 1866	Panafrican	38	87	30	2
<i>Tetramorium angulinode</i> Santschi, 1910	Panafrican, Gabon				4
<i>Tetramorium ataxium</i> Bolton, 1980	Nigeria	10	13	6	13
<i>Tetramorium boltoni</i> Hiter Garcia, Fischer et Peters, 2010	West Africa			1	
<i>Tetramorium brevispinosum</i> Stitz, 1910			5	15	36
<i>Tetramorium colorem</i> Mayr, 1901	Cameroon	36	16	3	6
<i>Tetramorium dogieli</i> Karavaiev, 1931	Kenya	1	2		
<i>Tetramorium guineense</i> , Bernard, 1953	Guinea	35	51	18	25
<i>Tetramorium lucayanum</i> Wheeler, W.M, 1905	Bahamas				1
<i>Tetramorium minisculum</i> Santschi, 1914	Cameroon	5	3	1	4
<i>Tetramorium philippwagneri</i> Hiter Garcia, Fischer et Peters, 2010	Cameroon		2		1
<i>Tetramorium sericeiventre</i> Emery, 1877	Panafrican			1	3
<i>Tetramorium</i> sp.1					2
<i>Tetramorium</i> sp.10					1
<i>Tetramorium</i> sp.2					2
<i>Tetramorium</i> sp.3			1		
<i>Tetramorium</i> sp.4					1
<i>Tetramorium</i> sp.5			2		
<i>Tetramorium</i> sp.6				1	
<i>Tetramorium</i> sp.7		2			
<i>Tetramorium</i> sp.8		4	7	3	3
<i>Tetramorium</i> sp.9		3	1	3	3
<i>Tetramorium versiculum</i> Bolton, 1980	Ghana	1	1		
<i>Tetramorium zonacaciae</i> Weber, 1943		7	10	19	12
Ponerinae					
<i>Anochetus</i> sp.1		3	1		1
<i>Anochetus</i> sp.2		8	4	4	5
<i>Anochetus</i> sp.3			2		
<i>Anochetus</i> sp.4			1	2	1
<i>Anochetus</i> sp.5			2		
<i>Anochetus</i> sp.6		2	1	2	1

<i>Hypoponera</i> sp.1		5	13	7	5
<i>Hypoponera</i> sp.2				3	
<i>Hypoponera</i> sp.3			4	1	2
<i>Hypoponera</i> sp.4		1			
<i>Hypoponera</i> sp.5		5		1	1
<i>Hypoponera</i> sp.6					3
<i>Leptogenys</i> sp.1		5	1	4	4
<i>Leptogenys</i> sp.2		2	1	3	
<i>Leptogenys</i> sp.3			1		
<i>Leptogenys</i> sp.4			1		1
<i>Loboponera basalis</i> Bolton et Brown, 2002	Ivory Coast	1			1
<i>Odontomachus assiniensis</i> Emery, 1892	Ivory Coast	30	54	16	20
<i>Pachycondyla (Bothroponera)</i> sp.1		4	1	1	6
<i>Pachycondyla (Bothroponera)</i> sp.2		1	6	5	2
<i>Pachycondyla (Bothroponera)</i> sp.3		4	6	9	11
<i>Pachycondyla (Brachyponera)</i> sp.					3
<i>Pachycondyla (Trachymesopus) brunoi</i> Forel, 1913	Zimbabwe	6	2	2	2
<i>Pachycondyla (Trachymesopus)</i> sp.		15	22	7	13
<i>Pachycondyla (Xiphopelta)</i> sp.1		6	4	5	
<i>Pachycondyla (Xiphopelta)</i> sp.2				1	
<i>Pachycondyla tasartus</i> (Fabricius, 1758)	Senegal		32	49	26
<i>Phrynoponera</i> sp.		2	2	8	2
<i>Platythyrea occidentalis</i> André, 1890	Sierra leone		1		1
<i>Platythyrea</i> sp.		3			
<i>Plectroctena cristata</i> , Emery, 1899	Panafrican,		1	2	2
<i>Plectroctena</i> sp.					2
Proceratiinae					
<i>Discothyrea</i> sp.			2		
<i>Probolomyrmex filiformis</i> Mayr, 1901	South Africa	1	2	1	2
<i>Probolomyrmex</i> sp.			1		1
Pseudomyrmicinae					
<i>Tetraoponera anthracina</i> Santschi, 1910	Congo Democratic	6	6		1

Table 4. A list of subfamilies and species sampled at four elevational levels at mount Eloundem from September 2018 to April 2019. Values in the table indicate occurrence of each species at each elevation.

Species turnover patterns

Our research highlighted a decrease in species turnover in ant assemblages along elevational gradients. According to Blair (2001), environmental stress does not only reduce the number of native species, but may also increase similarity among biotas, a process recognised as biotic homogenisation (Elton, 1958; McKinney & Lockwood, 1999). In biotic homogenisation, some biological differences are

lost and biotas become more similar in taxonomic, functional, phylogenetic, and genetic features (Olden et al., 2011; Petsch, 2016).

CONCLUSIONS

This study evaluates the ant diversity and functional groups along the elevational gradients in a low altitude mountain within the centre region of

Cameroon. We found that ant assemblages include mixtures of native and widespread non-native species. Our results show that non-native species represent more than half of the total of species and they are responsible for increasing in ant species turnover among elevations. Elevation levels are behaviourally and numerically dominated by the ‘‘Opportunists’’ functional group. Our findings suggest that several factors including fragmentation and habitat loss facilitate the establishment of generalist and tramp species, and reduce the abilities of some native species to persist in disturbed environments. Therefore, the presence of ‘‘opportunists’’ and some species of *Monomorium*, *Tetramorium* and *Tapinoma* in the ant fauna indicates a high degree of disturbance on Mount Eloundem. These ant species and particular functional groups might be used as indicators for assessing environmental changes in land management areas. It is urgent to implement conservation actions on the mountain in order to mitigate or stop habitat loss in key elevations which inhabit endemic species that might be new species to science.

ACKNOWLEDGEMENTS

Editorial improvements by Fatcheu Clinton are gratefully acknowledged. Thanks are also due to two anonymous reviewers who gave useful comments on the manuscript.

REFERENCES

- Achoundong G., 1996. Les forêts sommitales du Cameroun-Végétation et flore des collines de Yaoundé. *Bois et Forêts des Tropiques*, 247: 37–52.
- Agosti D. & Alonso L.E., 2000. The all protocol Ants. In: Agosti D., Majer J.D., Alonso E.L. & Schultz T.R. *Ants: Standard Methods for Measuring and Monitoring Biodiversity*. Smithsonian Institution Press., Washington, DC, U.S.A. 204–214.
- Andersen A.N., 2000. A global ecology of rainforest ants: Functional groups in relation to environmental stress and disturbance. In: Agosti D., Majer J.D., Alonso E.L. & Schultz T.R. *Ants: Standard Methods for Measuring and Monitoring Biodiversity*. Smithsonian Institution Press., Washington, DC, U.S.A., pp. 25–34.
- Andersen A.N., 2010. Functional groups in ant community ecology. In: Lach L., Parr C.L. & Abbott K.L. *Ant Ecology*. Oxford University Press., Oxford, U.K. 142–144.
- Andersen A.N. & Majer J.D., 2004. Ants show the way Down Under: invertebrates as bioindicators in land management. *Frontiers in Ecology and the Environment*, 2: 291–298.
- Andersen A.N. & Sparling G.P., 1997. Ants as indicators of restoration success: relationship with soil microbial biomass in the Australian seasonal tropics. *Restoration Ecology*, 5: 109–114.
- Araújo M.L. & Fernandes G.W., 2003. Altitudinal patterns in a tropical ant assemblage and variation in species richness between habitats. *Lundiana*, 4: 103–109.
- Beattie A.J., 1985. *The Evolutionary Ecology of Ant-Plant Mutualisms*. Cambridge University Press., London, U.K.
- Bestelmeyer B., Agosti D., Alonso L.E., Brandao C.R.F., Brown J.W.L., Delabie J.H.C. & Silvestre R., 2000. Field techniques for the study of ground dwelling ants. In: Agosti D., Alonso E.L. & Schultz T.R. *Ants: Standard Methods for Measuring and Monitoring Biodiversity*. Smithsonian Institution Press, Washington, D.C, U.S.A., pp. 122–154.
- Bharti H. & Sharma Y.P., 2009. Diversity and abundance of ants along an elevational gradient in Jammu-Kashmir Himalaya-I. *Halteres*, 1: 10–24.
- Blair R.B., 2001. Birds and butterflies along urban gradients in two ecoregions of the U.S. In: Lockwood J.L. & McKinney M.L. *Biotic Homogenization*. Kluwer Academic., Norwell, MA, U.S.A. 33–56.
- Bolton B., 1994. *Identification Guide to the Ant Genera of the World*. Harvard University Press., Cambridge, MA, U.S.A.
- Brady S.G., 2003. Evolution of the army ant syndrome: the origin and long-term evolutionary stasis of a complex of behavioural and reproductive adaptations. *Proceedings of the National Academy of Sciences USA*, 100: 6575–6579
- Bullock J.M., Bonte D., Pufal G., Da Silva Carvalho C., Chapman D.S., García C., García D., Matthysen E. & Delgado M.M., 2017. Human-mediated dispersal and the rewiring of spatial networks. *Trends in Ecology and Evolution*, 33: 958–970.
- Colwell R.K., 2005. EstimateS, Version 7.5: statistical estimation of species richness and shared species from samples. Available from <http://viceroy.eeb.uconn.edu/estimates>.
- Deblauwe I. & Dekoninck W., 2007. Diversity and distribution of ground-dwelling ants in a lowland rainforest in southeast Cameroon. *Insectes Sociaux*, 54: 334–342.
- Dejean A. & Giberneau M., 2000. A rainforest ant mosaic: the edge effect (Hymenoptera: Formicidae). *Sociobiology*, 35: 385–402.

- Deutsch C.A., Tewksbury J.J. & Huey R.B., 2008. Impacts of climate warming on terrestrial ectotherms across latitude. *Proceedings of the National Academy of Sciences USA*, 105: 6668–6672.
- Dornelas M. 2010. Disturbance and change in biodiversity. *Philosophical Transactions of the Royal Society B*, 365: 3719–3727.
- Ekross J., Heliölä, J. & Kuussaari., 2010. Homogenization of lepidopteran communities in intensively cultivated agricultural landscapes. *Journal of Applied Ecology*, 47: 459–467. <https://doi.org/10.1111/j.1365-2664.2009.01767.x>
- Elton C.S., 1958. *The Ecology of Invasions by Animals and Plants*. Methuen and Co. Ltd, London, U.K.
- Escobar F., Halffter G. & Arellano L., 2007. From forest to pasture: an evaluation of the influence of environment and biogeography on the structure of beetle (Scarabaeinae) assemblages along three altitudinal gradients in the Neotropical region. *Ecography*, 30: 193–208. <https://doi.org/10.1111/j.0906-7590.2007.04818.x>
- Fisher B.L., 2002. Ant diversity patterns along an elevational gradient in the Reserve Speciale de Manongarivo, Madagascar. *Boissiera*, 59: 311–328.
- Fisher B.L., 2004. Diversity patterns of ants (Hymenoptera: Formicidae) along an elevational gradient on Monts Doudou in southwestern Gabon. *California Academy of Sciences*, 28: 269–286.
- Fotso Kuate A., Hanna R., Tindo M., Nanga S. & Nagel P., 2015. Ant diversity in dominant vegetation types of southern Cameroon. *Biotropica*, 47: 94–100.
- Fukami T. & Wardle D.A., 2005. Long-term ecological dynamics: reciprocal insights from natural and anthropogenic gradients. *Proceeding of the Royal Society. B*, 272: 2105–2115.
- Gill J.A., 2007. Approaches to measuring the effects of human disturbance on birds. *Ibis*, 149: 9–14.
- Grytnes J.A., 2003. Species–richness patterns of vascular plants along seven altitudinal transects in Norway. *Ecography*, 26: 291–300.
- Hobbs R.E., 1988. Species richness of urban forest patches and implications for urban landscape diversity. *Landscape Ecology*, 1: 141–152.
- Hoffman B.D. & Andersen A.N., 2003. Responses of ants to disturbance in Australia, with particular reference to functional groups. *Austral Ecology*, 28: 444–464. <https://doi.org/10.1046/j.1442-9993.2003.01301.x>
- Hölldobler B. & Wilson E.O., 1990. *The ants*. Harvard University Press., Cambridge, MA. U.S.A.
- Koen J.H. & Breytenbach W., 1988. Ant species of fynbos and forest ecosystems in the southern cape. *African Zoology*, 23: 184–188.
- Körner C., 2007. The use of ‘altitude’ in ecological research. *Trends in Ecology and Evolution*, 22: 569–574. <https://doi.org/10.1016/j.tree.2007.09.006>
- Lessard J.P. & Buddle, C.M., 2005. The effects of urbanization on ant assemblages (Hymenoptera: Formicidae) associated with the Molson Nature Reserve, Quebec. *Canadian Entomologist*, 137: 215–225.
- Longcore T., 2003. Terrestrial arthropods as indicators of ecological restoration success in coastal sage scrub (California, USA). *Restoration Ecology*, 11: 397–409.
- Marsh A.C., 1986. Ant species richness along a climatic gradient in the Namib desert. *Journal of Arid Environments*, 11: 235–241.
- Mbenoun Masse P.S., Tindo M., Kenne M., Tadu Z., Mony R. & Djiéto-Lordon C., 2017. Impact of the invasive ant *Wasmannia auropunctata* (Formicidae: Myrmicinae) on ant diversity in southern Cameroon. *African Journal of Ecology*, 55: 423–432. <https://doi.org/10.1111/aje.12366>
- Mcintyre N.E., Rango J., Fagan W.F. & Faeth S.H., 2001. Ground arthropod community structure in a heterogeneous urban environment. *Landscape and Urban Planning*, 52: 257–274.
- Mckinney M.L., 2008. Effects of urbanization on species richness: A review of plants and animals. *Urban Ecosystem*, 11: 161–176. <https://doi.org/10.1007/s11252-007-0045-4>
- Mckinney M.L. & Lockwood J.L., 1999. Biotic homogenization: a few winners replacing many losers in the next mass extinction. *Trends in Ecology and Evolution*, 14: 450–453.
- Narendra A., Gibb H. & Ali. T., 2011. Structure of ant assemblages in Western Ghats, India: role of habitat, disturbance and introduced species. *Insect Conservation and Diversity*, 4: 132–141.
- Olden J.D., Lockwood J.L. & Parr C.L., 2011. Biological invasions and homogenization of faunas and floras. *Conservation Biogeography*, 9: 224–244.
- Passera L., 1994. Characteristics of tramp species. In: Williams D.F. *Exotic Ants: Biology, Impact, and Control of Introduced Species*. Westview Press, Boulder CO., U.S.A, 23–43.
- Pellissier L., Alvarez N., Espindola A., Poter J., Dubuis A., Pradervand J.N. & Guisan A., 2013. Phylogenetic alpha and beta diversities of butterfly communities correlate with climate in the western Swiss Alps. *Ecography*, 36: 541–550.
- Petsch D.K., 2016. Causes and consequences of biotic homogenization in freshwater ecosystems. *International Review of Hydrobiology*, 101: 113–122. <https://doi.org/10.1002/iroh.201601850>
- Philpott S.M., Perfecto I., Armbrrecht I. & Parr P., 2009. Ant diversity and function in disturbed and changing habitats. In: Lach L., Parr C.L. & Abbott K.L. *Ant Ecology*, Oxford University Press., London, pp. 137–156.
- Pompeu P.S. & Alves C.B.M., 2005. The effects of ur-

- banization on biodiversity and water quality in the rio das velhas Basin, Brasil. American Fisheries Society Symposium, 47: 11–22.
- Rahbek C., 1995. Elevational gradient of species richness a uniform pattern. *Ecography*, 18: 200–205.
- Rahbek C., 2005. The role of spatial scale and the perception of large-scale species-richness patterns. *Ecology Letters*, 8: 224–239.
- Room P.M., 1975. Relative distributions of ant species in cocoa plantations in Papua New Guinea. *Journal of Applied Ecology*, 47: 47–61.
- Rowe R., 2009. Environmental and geometric drivers of small mammal diversity along elevational gradients in Utah. *Ecography*, 32: 411–422. <https://doi.org/10.1111/j.1600-0587.2008.05538.x>
- Samson D.A., Rickart E.A. & Gonzales P.C., 1997. Ant diversity and abundance along an elevational gradient in the Philippines. *Biotropica*, 29: 349–363.
- Sanders N.J. & Rahbek C., 2012. The patterns and causes of elevational diversity gradients. *Ecography*, 35: 1–3. <https://doi.org/10.1111/j.1600-0587.2011.07338.x>
- Sanders N.J., 2002. Elevational gradients in ant species richness: area, geometry, and Rapoport's rule. *Ecography*, 25: 25–32.
- Suarez A.V., Bolger D.T. & Case T.J., 1998. Effect of fragmentation and invasion on native ant communities in coastal Southern California. *Ecology*, 79: 2041–2056.
- Suarez A.V., Holway D.A. & Case T.J., 2001. Patterns of spread in biological invasions dominated by long-distance jump dispersal: insights from Argentine ants. *Proceeding of the National Academy of Sciences*, 98: 1095–1100.
- Tadu Z., Djiéto-Lordon C. Yede., Messop Youbi E.B., Fomena A. & Babin R., 2014. Ant diversity in different cocoa agroforest habitats in the Centre Region of Cameroon. *African Entomology*, 22: 388–404. <https://doi.org/http://dx.doi.org/10.4001/003.022.0219>
- Townsend C.R. & Hildrew A.G., 1994. Species traits in relation to a habitat template for river systems. *Freshwater Biology*, 31: 265–275.
- Watt A.D., Stork N.E. & Bolton B., 2002. The diversity and abundance of ants in relation to forest disturbance and plantation establishment in southern Cameroon. *Journal of Applied Ecology*, 39: 18–30. <https://doi.org/10.1046/j.1365-2664.2002.00699.x>
- Williams K.S., 1993. Use of terrestrial arthropods to evaluate restored riparian woodlands. *Restoration Ecology*, 1: 107–116.
- Winfrey R., Griswold T. & Kremen C., 2006. Effect of human disturbance on bee communities in a forested ecosystem, *Conservation Biology*, 21: 213–223. <https://doi.org/10.1111/j.1523-1739.2006.00574.x>