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Diversity and distribution of millipedes (Diplopoda) in the Campo Ma'an National Park, southern Cameroon

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Abstract

Diplopods (millipedes) are one of the important groups of terrestrial Arthropoda in tropical forest ecosystems. Despite their ecological importance, data on millipede populations are still scarce and outdated in Cameroon. The first comparative eco-faunistic analysis is presented of two local populations of Diplopoda in two lowland rainforests (nearly primary and secondary) during 12 months (2015–2016) at the southern periphery of the Campo Ma'an National Park in southern Cameroon. The millipedes were collected using pitfall trapping and quadrat sampling, their diversity and distribution analyzed with the help of two diversity indexes and two nonparametric estimators. Overall, 27 species in eighteen genera, ten families and four orders were revealed in the two forests, yet each faunule was about equally rich (23 and 22 species in the primary and secondary forest, respectively) and peculiar (five and four species unique, respectively). The Odontopygidae was the most abundant family, which made up to 33% of the total species diversity. The most abundant species in both forests was *Aporodesmus gabonicus* (26.8% of occurrences). This study shows that despite the similarity in millipede species richness between both habitats, the species composition of all habitats was different. Some species occurred in two habitats whilst others were restricted to only one habitat.

Key words: diplopod, ecology, fauna, lowland tropical rainforest, southern Cameroon

Résumé

Les diplopodes (mille-pattes) sont un groupe important d'arthropodes terrestres des écosystèmes forestiers tropicaux. Malgré cette importance écologique, les données sur leurs populations sont encore rares et obsolètes au Cameroun. La première analyse éco-faunistique est présentée ici pour deux populations de diplopodes dans deux forêts pluviales de basse altitude (presque primaire et secondaire), pendant 12 mois (2015–2016) à la périphérie sud du Parc National de Campo-Ma'an, au sud du Cameroun. Les mille-pattes ont été collectés dans des pièges à fosse et par échantillonnage dans des quadrats, leur diversité et leur distribution analysées à l'aide de deux indices de diversité et de deux estimateurs non paramétriques. En tout, 27 espèces appartenant à Dix-huit genres, Dix familles et quatre ordres ont été découvertes dans les deux forêts, et chaque microfaune y était à peu près aussi riche (23 et 22 espèces dans la forêt primaire et secondaire, respectivement) et particulière (cinq et quatre espèces uniques, respectivement). Les *Odontopygidae* étaient la famille la plus abondante, qui composait jusqu'à 33% du total de la diversité des espèces. L'espèce la plus abondante dans les deux forêts était *Aporodesmus gabonicus* (26.8% des rencontres). Cette étude montre que malgré la similarité de la richesse en espèces de mille-pattes dans les deux habitats, la composition des espèces dans ces habitats était différente. Certaines espèces étaient présentes dans les deux habitats alors que d'autres étaient restreintes à un seul.

Introduction

Diplopoda (millipedes) are a mega-diverse group of terrestrial Arthropoda after Insecta and Arachnida. Comprising

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globally an estimate of perhaps up to 80,000 species or subspecies, of which only about 12,000 have been described (Hoffman, 1980, 1982; Shelley, 2007; Brewer, Sierwald & Bond, 2012), diplopods are widespread on all continents except Antarctica (Hoffman *et al.*, 2002). Millipedes are mostly found in their typical habitats (forest litter, rotting wood, plant debris and compost), as well as in the high mountains, in caves or in the soil, only occasionally to marginally occurring also on the marine littoral, in freshwater habitats, in the desert, in tree canopies or a few other environments regarded as extreme for this arthropod group (Golovatch & Kime, 2009). The Diplopoda constitutes a major component of soil-litter macrofauna in temperate, subtropical and tropical forest ecosystems (Dangerfield, 1990), being especially diverse, both taxonomically and ecologically, in tropical rainforest (Golovatch & Kime, 2009).

Millipedes are one of the major groups involved in the breakdown of organic matter. Being considered as macrodetritivores because they consume dead organic matter (Crawford, 1992), millipedes enhance microbial activities (Anderson & Bignell, 1980) and play important roles as potential bioindicator taxa owing to their little tolerance and high sensitivity to habitat change (e.g. Wytwer, 1992) due to human disturbances (Mwabvu, 2006).

Despite their ecological importance, millipedes are still very poorly known and have long been neglected in all areas of biological research in Cameroon. Although rather many millipede species, mostly endemic ones, have been described or recorded from Cameroon (e.g. Voges, 1878; Porat, 1893, 1894; Attems, 1914, 1931, 1937, 1938, 1940; Hoffman, 1953, 1963, 1984, 1990, 2005; Kraus, 1960, 1966; Jeekel, 1968; Mauriès, 1968, 1989; Demange, 1970, 1971, 1973; Krabbe, 1982; Enghoff *et al.*, 2015; Golovatch, Nzoko Fiemapong & Vandenspiegel, 2015; Vandenspiegel, Golovatch & Mauriès, 2016) studies on millipede ecology and populations in the country are virtually wanting. The sole survey of the millipede fauna of Cameroon (Porat, 1894) is highly incomplete and strongly outdated. Thus, this study aimed to provide a quantitative description of millipede fauna associated with different vegetations in Cameroonian lowland rainforest.

Material and methods

Study sites

Millipedes were collected between June 2015 and June 2016 in the Campo Ma'an National Park (CMNP), southern Cameroon. The site is situated between the latitudes 2°10′–2°52′N and the longitudes 9°50′–10°54′E (Fig. 1). The altitude is between 100 and 200 m a.s.l. The CMNP covers about 776,202 ha comprising a National Park (234,064 ha), five forest management units (UFA), two agro-industrial plantations (Hevecam and Socapalm) and a so-called buffer zone.

Two sites located at the southern periphery of the CMNP and separated by Ntem River were selected for this study (Fig. 1): a nearly primary forest site (PF) located in the protection zone (Dipikar Island) and a secondary forest site (SF) situated in one of the five logging concessions surrounding the park 'UFA 09025'. In general, the vegetation of the CMNP forms part of the Atlantic Biafran forest and Lowland evergreen forest of the Congo Basin and Equatorial Guinea, rich in Caesalpinioideae with *Calpocalyx heitzii* and *Sacoglottis gabonensis* (Letouzey, 1985; Tchouto *et al.*, 2009). In nonprotected area (SF), forest ecosystems are highly threatened by human activities through conversion to agriculture, timber production, pasture, over-hunting, collection of fire wood and construction materials, whereas in protected area (PF), the access and the uses of any of natural resources are forbidden. The CMNP lies within the humid forest zone characterized by a bimodal rainfall distribution, and four distinct seasons: two wet seasons (from mid-March to early July, from September to mid-November) and two dry seasons (from July to the end of August, from mid-November to mid-March). Annual rainfall averages 2797 mm and the mean annual temperature is about 25°C.

Survey methods

Two common sampling methods were used for the collection of specimens: quadrat sampling and pitfall trapping (see Domingo & Alonso, 2010). Two parallel transects (110 m long and 10 m apart) made up of 20 samples each (ten quadrats and ten pitfalls) were set up at each site. Two sampling events were conducted at 100 m intervals during 12 months at each site.

Quadrat sampling

Twenty quadrat plots (3 m^2 each) were set in two rows (10 m apart) with 10 quadrats in each row. Quadrats were spaced 10 m apart. All shelters or microhabitats suitable for millipedes such as under stones, bark, fallen branches, layers of leaf litter or directly in the soil were inspected. Millipedes were collected by four individuals for 60 min in each quadrat using forceps or mouth aspirator.

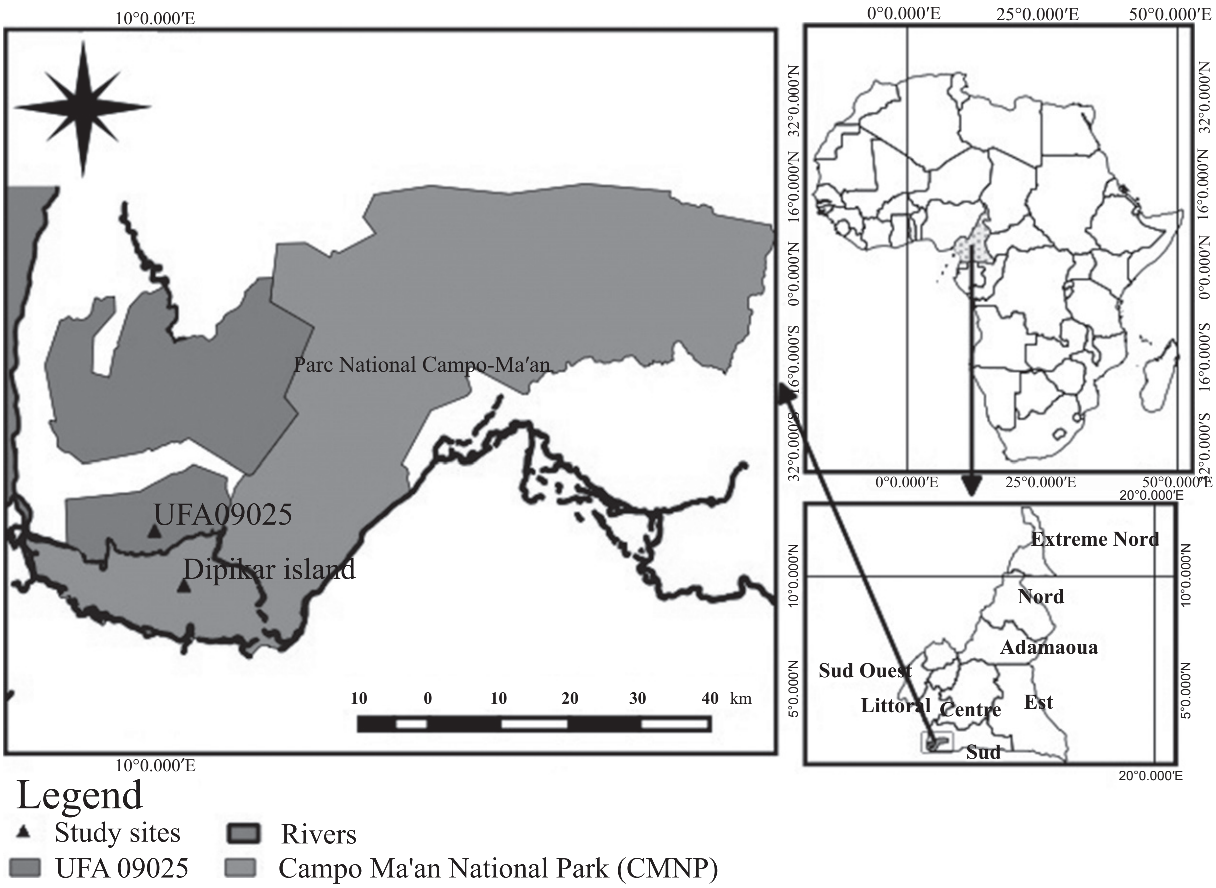

Fig 1 Map of the Campo Ma'an National Park, showing the study sites

Pitfall trapping

Each pitfall trap consisted of a plastic drinking cup (85 mm top diameter) placed into a buried section of PVC pipe so that the rim of the cup was flushed with the ground surface. Prior to the beginning of trapping, the pitfall traps were left for 3 days to reduce 'digging-in' effects. After that, each trap was filled with ~75 ml of 50% ethanol and 5% glycerol as a preservative. Twenty traps were set in two rows with 10 traps in each row. Traps were spaced 10 m apart and 5 m from the nearest quadrat plot. Each pitfall was covered by an aluminium roof to prevent rain fall into the traps.

Millipede identification

All millipedes were collected and preserved in labelled vials containing 70% ethanol. Specimens were photographed, dissected and identified in the laboratory to the genus or species level using available dichotomic keys or other relevant literature (Kraus, 1960, 1966; Demange & Mauries, 1975; Krabbe, 1982; Hoffman *et al.*, 1996; Hamer, 1999; Hoffman, 2005). Unidentified species were assigned to morphospecies. Voucher specimens were deposited within the reference collections of the Laboratory of Zoology at the University of Yaounde 1.

Data analysis

The presence or absence was chosen for analysis, and the percentage of occurrence was used to estimate the relative abundance of all species at each site. The number of species unique to each site was also determined. For analyses, only adult individuals were considered whilst juvenile individuals which usually could not be identified were excluded from the study.

For estimating the species richness in the two habitats concerned, two nonparametric estimators were used:

Bootstrap and the Incidence-based coverage estimate (ICE). For details see Colwell & Coddington (1994), and Longino (2000). Plots of cumulative species per sample curve were generated, and for each species cumulative curve the sample order was randomized 100 times,and the mean of the Bootstrap and ICE estimates were computed using EstimateS software version 8.2.0 (Colwell, 2005). To characterize the structure of a millipede community, the Shannon diversity index (H') (Krebs, 1999) and the Evenness index (E) (Pielou, 1969) were estimated applying the following formulae:

$$H' = -\sum_{i=1}^{s^*}(P_i * \mathrm{Log}_2 P_i) \text{ and } E = \frac{H''}{H_{\max}} = \frac{H'}{\mathrm{Log}_2(S)}.$$

Where, Pi (= Ni/N) is the proportion of species, i is the population and S, is the total number of species observed in a sample or a set of samples.

Results

Community composition

A total of 250 occurrences representing 27 species or closer unidentified morphospecies from eighteen genera, ten families and four orders were revealed in the two habitats types (Table 1). The Chelodesmidae was the most diverse family with seven species, followed by Odontopygidae (six species) and Spirostreptidae (four species). Odontopygidae were most abundant (33%), followed by the species of Cryptodesmidae (28.4%). The most species-rich genus was *Kyphopyge* with three species. The most abundant species were *Aporodesmus gabonicus* (26.8% of occurrences) followed by *Amblybolus* sp. (14%) and *Coenobothrus bipartitus* (12.5%).

Species richness estimates and sampling efficiency

Bootstrap and ICE estimates showed differences in the number of species in both habitats (Table 2). Using ICE, the estimated number of millipede species was higher in the SF than in the primary one, whereas the highest species diversity was found in the PF compared with the SF with Bootstrap. The mean sampling success was 80% in the primary forest, versus 77.41% in the SF. The species accumulative curve in each habitat was still rising towards the end of the sampling period. Only when the data for the two habitats were combined, they showed that the species accumulative curve just started flattening out towards the end of the sampling period (Fig. 2).

Table 1 Relative abundance of millipede species (%) recorded in primary (PF) and secondary (SF) forests in the National Park of Campo Ma'an, Cameroon

	Site	
Order/Family/Species	PF	SF
Order Polydesmida		
Chelodesmidae		
Kyphopyge granulosa (Attems, 1931)	0.77	1.67
Kyphopyge sp. 1	0.77	0.83
Kyphopyge sp. 2	–	0.83
Cordyloporus aubryi (Attems, 1898)	0.77	–
Paracordyloporus dilatatus (Carl, 1905)	0.77	0.83
Paracordyloporus porati (Verhoeff, 1938)	3.85	3.33
Peltophorus sp.	–	1.67
Cryptodesmidae		
Aporodesmus gabonicus (Lucas, 1858)	23.85	30.00
Aporodesmus minimus (Mauriès, 1968)	2.31	0.83
Oxydesmidae		
Crystallomus schoutedeni (Attems, 1937)	1.54	0.83
Crystallomus thyridotus (Cook, 1896)	1.54	0.83
Paradoxosomatidae		
Scolodesmus porati (Mauriès, 1968)	1.44	–
Scolodesmus sp.	0.77	–
Pyrgodesmidae		
Urodesmus cornutus Golovatch, Nzoko Fiemapong & Vandenspiegel, 2015	–	2.50
Trichopolydesmidae		
Mecistoparia sp.	0.77	–
Order Spirostreptida		
Odontopygidae		
Coenobothrus bipartitus (Porat, 1894)	15.38	9.17
Coenobothrus detruncatus (Carl, 1905)	7.69	4.17
Odontopygidae gen. sp. 1	4.62	–
Odontopygidae gen. sp. 2	–	0.83
Patinatiella uncinata (Porat, 1894)	3.08	3.33
Spinotarsus sp.	4.62	6.67
Spirostreptidae		
Kartinikus colonus (Attems, 1914)	10.77	5.00
Onychostreptus canaliculatus (Porat, 1894)	4.62	1.67
Urotropis carinatus (Porat, 1893)	0.77	0.83
Urotropis sp.	0.77	0.83
Order Spirobolida		
Pachybolidae		
Amblybolus sp.	6.92	21.67
Order Stemmiulida		
Stemmuilidae		
Stemmuilus sp.	1.54	1.67

Table 2 Species observed (S_{obs}), expected number of species and diversity index of the two habitat types

	Site	
Parameters	PF	SF
Species richness estimate		
S_{obs}	23	22
Individuals	130	120
ICE	32 (75)	36 (68.75)
Bootstrap estimator	28 (85.71)	26 (84.61)
Mean	30 (80)	31 (77.41)
Diversity and equitability index		
H'	2.59	2.33
E	0.56	0.52
Unique species	5	4

The sampling success given as the proportion of sampled species (S_{obs}) to the estimated species numbers are given in brackets. PF, primary forest; SF, secondary forest.

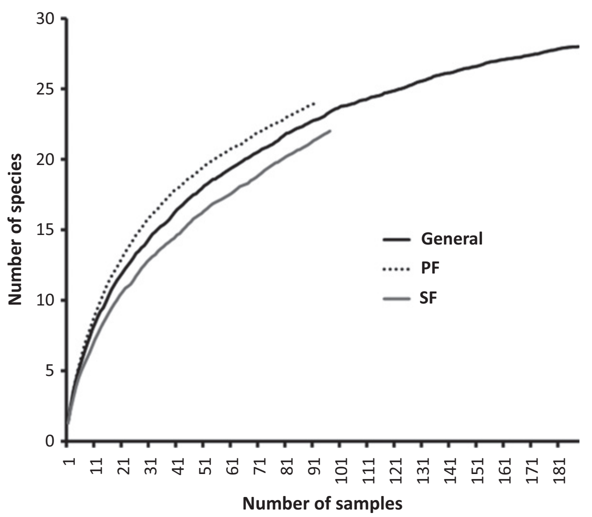

Fig 2 Randomized (100 runs) species accumulation curves of the two habitat types. General, overall data recorded at both sites; PF, primary forest; SF, secondary forest

Abundance and diversity

The abundance and number of millipede species were greater in the PF (130 occurrences, 23 species) than in the SF (120 occurrences, 22 species; Table 2). In the primary forest, the most abundant species were *A. gabonicus* (15.38%) and *Kartinikus colonus* (10.77%), whilst *A. gabonicus* (30%) and *Amblybolus* sp. (21.67%) were abundant in the SF. According to Shannon index, PF (H'_1 = 2.59) was more diverse than SF (H'_2 = 2.33). Overall, both habitats shared about 50% of the total number of species.

Distribution patterns

Five species were unique to the primary forest: *Cordyloporus aubryi,* Odontopygidae gen. sp. 1, *Scolodesmus porati, Scolodesmus* sp. and *Mecistoparia* sp., whilst four species were confined solely to the SF: *Urodesmus cornutus,* Odontopygidae gen. sp. 2, *Peltophorus* sp. and *Kyphopyge* sp. 2. Eighteen species were found to occur in both habitats: *Kyphopyge granulosa, Kyphopyge* sp. 1, *Paracordyloporus dilatatus, Paracordyloporus porati, A. gabonicus, Aporodesmus minimus, C. bipartitus, Crystallomus detruncatus, Partinatiella uncinata, Spinotarsus* sp., *Crystallomus schoutedeni, Crystallomus thyridotus, Amblybolus* sp., *K. colonus, Onychostreptus canaliculatus, Urotropis* sp., *Urotropis carinatus* and *Stemmuilus* sp.

Discussion

Millipede community

We have determined the diversity and distribution of millipede species in two habitats types in the CMNP in southern Cameroon. The number of species per local fauna, or faunule, is high and rather typical of a tropical rainforest (23 and 22 in primary and SF, respectively). There are only few places on the globe where a local diplopod faunule exceeds two dozen species, the world records holder being a patch of rainforest in central Amazonia or a monsoon forest in southern Vietnam, where 33 and 36 millipede species have been revealed, respectively (Golovatch, 1997; Golovatch & Kime, 2009; Golovatch, Tiunov & Anichkin, 2011).

The millipede fauna as found in the present study was dominated by Odontopygidae, one of the largest millipede families generally and endemic to the Afrotropical realm. Among odontopygids, there are several significant agricultural pests (Pierrard, 1968, 1987; Demange & Mauriès, 1975; Jolivet, 1986; Nascimento, Sermann & Büttner, 2005). The most species-rich genus recorded in this study was *Kyphopyge*. This genus is mostly native to Cameroon (Attems, 1931), but some of its species occur in the neighbouring countries such as Gabon (Demange, 1971).

Species richness estimates and sample efficiency

The mean species richness estimates appear very similar in the primary and SF. The mean sampling success was above

75% in the two habitats. The performance of most of the estimates ranged between 70% and 86% of the sampling success. The highest efficiency values were obtained with Bootstrap in the PF and the lowest in the SF with ICE. Bootstrap (Efron, 1979) is one of the best species richness estimators because it is completely automatic, requires no theoretical calculations and is not based on asymptotic results (Colwell & Coddington, 1994). Randomized species accumulation curves of both habitats were still rising towards the end of the sampling period. This suggests that additional sampling effort is needed to reach a real asymptotic plateau. In southern Vietnam, in a patch of monsoon forest which holds the world record (33 species) per millipede faunule, an asymptotic plateau was not reached even after a 3-years long sampling effort (Golovatch, Tiunov & Anichkin, 2011).

Distribution and millipede assemblages

The present study shows that the relative abundance varies between habitats and appears to be correlated with the vegetation structure and composition (Dangerfield, 1990; Bogyo *et al.*, 2015). These factors, combined with higher plant species diversity, suggest that resource preemption hypothesis seems to be the most likely explanation for enhanced millipede assemblages in the natural habitats (Dangerfield & Telford, 1992).

Although the species richness was very similar in both habitats, each habitat supported several particular, characteristic species. Indeed, five species appear to be restricted to the PF (*C. aubryi*, Odontopygidae gen. sp. 1, *S. porati*, *Scolodesmus* sp. and *Mecistoparia* sp.) whereas four species are found only in the SF. Most millipedes are highly adapted, largely very local species and their habitat requirements are highly specific (Golovatch & Kime, 2009). Millipede species are known to have narrow tolerances and thus respond quickly to environmental change (Wytwer, 1992); they may therefore be used as a potential indicator group for the monitoring of habitat change. On the other hand, the evenness index between primary and SF was up to 50% suggesting that they have many species in common. Indeed, eighteen species (66%) occurred in two habitats and appear less affected by land-use changes. *Aporodesmus gabonicus* and *Amblybolus* sp. were the most abundant species occurring in both habitats. *Aporodesmus gabonicus* is the largest and most widespread species of the Cryptodesmidae in West African countries (Mauriès, 1968; Hoffman, 1972).

The results of the study indicate that lowland rainforest present a high millipede species richness and composition according to vegetation types. As natural ecosystems such as forest reserves are hotspots of biodiversity and endemicity for numerous species, there is an urgent need for biodiversity assessments to be carried out during the conservation planning process. Millipedes are particularly appropriate organisms to monitor the health of ecosystems, as well as the environment changes for the sustainable management of a humid rainforest.

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