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Research

Grasshopper (Orthoptera: Acridomorpha) diversity in response to fallow-land use in southern Cameroon with recommendations for land management

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The sensitivity of grasshoppers to disturbance makes them useful bioindicators for land management. The current study compared the grasshopper communities of three fallow-lands at different levels of human pressure: heavily used land (Ongot), moderately used land (Zamakoe), and least-used land (Ngutadjap). Grasshoppers were sampled by nets, pitfall traps, and box quadrats. Their species composition was analyzed using species-richness, abundance, abundance distribution-model, occurrence, and diversity indexes. Species number was not very different between localities. However, the opening up of forests by human activities offers suitable environment for the development or proliferation of the pest grasshopper populations such as *Zonocerus variegatus* (Linnaeus, 1758), *Eyprepocnemis plorans* (Charpentier, 1825), and *Catantops sylvestris* Jago, 1984, which are adapted to the very common Asteraceae found in fallow lands. Native forest species [such as *Mazaea granulosa* Stål, 1876, *Holopercna gerstaeckeri* (Bolívar, 1890), *Digentia fasciata* Ramme, 1929] were, generally absent or rare and were collected in only forest/fallow-land ecotones. Low abundance and low occurrence of ecotone species fitted the log-normal abundance distribution model. The grasshopper communities of the less degraded localities were quite similar, but different from the Ongot community. Forest management by reforestation, reduction of slash-and-burn agriculture, and wood cutting, would restore the original grasshopper assemblages and general environmental health.

Key words: grasshopper, species-richness, abundance, diversity, land-use

Introduction

The Congo Basin, located in central Africa, is the second largest forest in the world. It covers 240 million hectares of forest and feed about 80 million people (White et al. 2021). The diversity of life remains insufficiently studied in Africa (Basset et al. 2001), particularly in the Congo Basin where forest ecosystems are unfortunately being rapidly destroyed. In this area, the rate of deforestation doubled between 1990 and 2005 (Tchatchou et al. 2015), and from 2007 to 2017, these forests were subject to one of the highest rates of degradation in Africa, reaching about 10% of canopy lost (Hansen et al. 2013). In 2019, deforestation in the Congo Basin resulted in the disappearance of more than 500,000 hectares of woodland (White et al. 2021). The direct causes of this environmental degradation in Central Africa are the expansion of slash-and-burn agriculture, intensification of mining, population expansion, development of economic infrastructures, and logging industries (Wasseige et al. 2012). These threats lead to considerable changes in the carbon budget, climate, and biodiversity of the Congo Basin forests (Rejou-Mechain et al. 2021). Slash and burn agriculture, mainly practised by locals in this area, destroys forest resources (Brown 2006). The resulting vegetation after deforestation is less diverse fallow-land dominated by Asteraceae, such as *Dichrocephala integrifolia* (L.f.) Kuntze, 1891 and *Chromolaena odorata* (L.) R.M.King & H.Rob., 1970, Gramineae (e.g., *Echinochloa pyramidalis* (Lam.) Hitchc. & Chase, 1917) or Euphorbiaceae, such as *Acalypha arvensis* Poepp. (Westphal et al. 1981).

The biophysical structure of natural environment and the ecosystem balance change and favor the introduction of some new species (Brown 1997). But on the other hand, such shifts can lead to the extinction of native species due to disappearance of preferred food resources or changes in interspecific competition (Cahill et al. 2013). The loss of canopy cover is the main disturbance factor (Brewer et al. 2012). Degradation of the natural environment also negatively impacts the insect diversity (Chinery 1993), including grasshoppers (Bazelet and Samways 2011). These insects have short life cycles, which are linked to the phenology of plants in natural habitats.

Moreover, there are some apterous and brachypterous species which are less mobile and hence have difficulty in escaping disturbance.

Grasshoppers represent one of the largest groups among Orthoptera. The suborder Caelifera encompass 11 families and more than 1,700 genera (Cigliano et al. 2022). Grasshoppers are an essential component of terrestrial ecosystems and show high rates of endemism (Crous et al. 2013). Grasshoppers play an important role in food chains as the prey of many other animals, such as amphibians, reptiles, birds, mammals, and many other arthropods, like spiders. Some of the defoliator species even recycle plant matter (Amedegnato 1977). Their functional importance and sensitivity to disturbance make grasshoppers potentially useful bioindicators for land management worldwide (Joshi et al. 1999, Spungis 2007, Latchininsky 2008, Bazelet and Samways 2011, Youqing-Chen et al. 2011, Borchard et al. 2013, Hao and Wang 2015, Kuppler et al. 2015, Adu-Acheampong 2017, Soliman et al. 2017). Some authors have found that the richness and abundance of grasshopper species increase with land use (Spungis 2007, Latchininsky 2008) while others have stated that the diversity of these insects decreases in open environments after perturbation (Joshi et al. 1999, Hao and Wang 2015, Soliman et al. 2017).

The rapid use of natural resources due to strong population growth threatens Congo Basin forests (Rejou-Mechain et al. 2021). The management of the disturbed forests involves mastering degradation effects on natural biodiversity and requires the participation of indigenous people in conservation actions (Keenan 2015). The composition of current grasshopper communities in central African forests remains weakly studied. In the Congo Basin, Cameroon is recognized as a hotspot of biodiversity and has one of the richest grasshopper faunas in Africa (Dirsh 1965). Despite the high level of forest degradation observed, research on the responses of grasshopper communities to environmental disruption is lacking. The main studies on Cameroonian grasshopper ecology have been conducted by Seino et al. (2013), Kekeunou et al. (2017), Yetchom-fondjo et al. (2020), and Oumarou-Ngoute et al. (2020). The latter studied the grasshoppers in the forests of southern Cameroon and the present is a comparative study of grasshoppers in fallow-lands in the same region, as part of investigating the effects of human activities on grasshopper communities. The following questions are addressed: do the number of grasshopper species increase or decrease with the clearing of forests and the subsequent level of human pressure? Does it lead to quantitative augmentation or reduction in the sizes of species populations? Does it structure grasshopper communities into perceptible levels of assemblages? We hypothesized that fallow-land use decreases: (i) the number of grasshopper species, (ii) the species abundance, and (iii) structures the grasshopper assemblages as a function of the level of environment perturbation. To test these hypotheses, the overall aim of the current work was to compare the grasshopper communities of fallow-lands at different levels of human pressure.

Materials and Methods

Study Sites

Grasshoppers were collected in three different localities (Ngutadjap, Ongot, and Zamakoe) in the south Cameroon plateau (Fig. 1). This plateau is of about 650 to 700 m above sea level (Westphal et al. 1981). Its climate is the Guinean type with four seasons: two rainy seasons and two dry seasons. The annual rainfall is 1,500 to 2,000 mm (Santoir and Bopda 1995). In this area, vegetation shows different assemblages depending on plant species composition, soil, and human activities (Rejou-Mechain et al. 2021). Southern Cameroon is dominated by Sterculiaceae and Ulmacae plant species (Westphal et al. 1981). Its natural environment is progressively modified by human activities, such as logging and agriculture (Santoir and Bopda 1995). The main food crops are cocoa, coffee, cassava, groundnut, plantain, maize, oil palm, sweet banana, and yam (Westphal et al. 1981).

Grasshoppers were sampled in three fallow-lands from three different localities, under different degrees of human pressure. At Ongot, which is close to the city of Yaoundé, the population density was 14 to 88 inhabitants per km^2. In Zamakoe, near the town of Mbalmayo, the human density was 10 to 41 inhabitants per km^2, while in Ngutadjap, in the vicinity of Ebolowa town, there were 2 to 15 inhabitants per km^2 (Gockowski 1996). People of Ongot live more on income from paid work, agriculture, and logging. The villagers of Ngutadjap live from hunting and fishing, while the locals of Zamakoe have living conditions intermediate between those of Ongot and Ngutadjap (Gockowski 1996). At Ongot, the average age of fallow-lands is three years old; at Zamakoe fallow-lands are five years old while at Ngutadjap fallow-lands are less used and average seven years old (Gockowski 1996). During the current study, plant species richness in fallow-lands was highest in the most degraded locality of Ongot (142 plant species), followed by Zamakoe (88 plant species), and lowest at Ngutadjap (83 plant species) (Supplementary Table S1).

Grasshopper Sampling

Grasshoppers were sampled for 17 months, from April 2016 to August 2017. Samples were collected using sweep nets, box quadrats, and pitfall traps. A total of 1,683 samples were collected: 561 in each locality, viz 374 in box quadrats, 170 in pitfall traps and 17 in continuous sweeps of vegetation with a net. Sampling by net was made randomly in vegetation for 30 min once per month at each locality. Grasshoppers were also captured monthly in each fallow-land, using 22 movable box quadrats of one square meter (1 m^2) each. Consecutive box quadrats were spaced 10 m apart on two parallel transects of 110 m each, separated from each other by 10 m (Oumarou-Ngoute et al. 2020). Ten pitfall traps (diameter: 8 cm each) were one-third filled with 5% formalin as a preservative (Oumarou-Ngoute et al. 2020). In the transects, traps were placed at 20 m away from the box quadrats. Pitfall traps were removed one month after installation and grasshopper specimens found were identified at species level and then counted.

Grasshopper Identification

For this purpose, the following identification keys were used: Dirsh (1958, 1965, 1970), Donskoff (1991), Grunshaw (1991), Hollis (1975), Jago (1984, 1989, 1994a, 1994b), Karsch (1891), Keith and Kevan (1969, 1974), Ramme (1929), Rowell et al. (2015), Rowell and Hemp (2017, 2018).

Data Analysis

Species Richness and Sampling Effort

To test whether species richness increases or not with land use, the following estimators were used: Abundance-based Coverage (ACE), Bootstrap, Chao1, and Michaelis Menten Mean (MMM) (Marcon 2015). We used EstimateS software version 9.1.0 (Colwell 2013) to compute theoretical values of grasshopper species richness in each locality. Sampling efforts calculated were high and similar in all three localities. Almost the entire estimated species assemblages were sampled at Ongot (94.5 ± 1.3%), Zamakoe (95.7 ± 1.4%), and Ngutadjap (96.0 ± 1.4%) (Table 1).

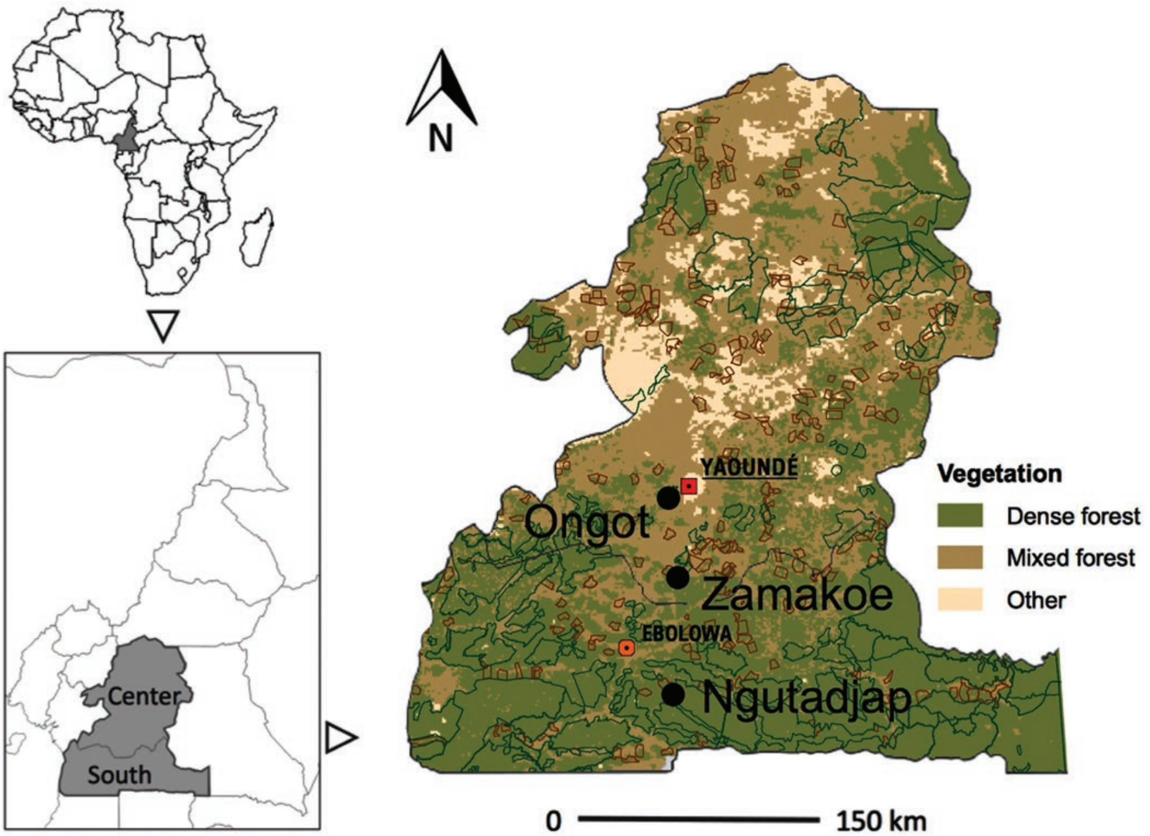

Fig. 1. Study sites in relation to vegetation types in southern Cameroon rainforest area (Mertens et al. 2012, Oumarou-Ngoute et al. 2020).

Table 1. Sampling effort and diversity of grasshoppers in the different fallow-lands. The values in brackets represent the theoretical species richness; a and b: the results of the *t*-test for two samples; the same letter between two sites shows no significant difference between the values of the Shannon (H′) index

Estimator/diversity	Ongot	Zamakoe	Ngutadjap
Number of taxa	33	36	32
Number of individuals	1,215	975	918
Shannon H′	2.66b	2.9a	2.66b
Evenness H′/H′max	0.43	0.53	0.45
Chao1	94% (35.1)	99% (36.4)	98% (32.6)
ACE	94% (35.1)	97% (37.1)	98% (32.6)
Bootstrap	92% (35.9)	94% (38.3)	96% (3.33)
MMM	98% (33.7)	93% (38.7)	92% (34.8)
Mean of estimators	94.5 ± 1.3% (34.9)	95.7 ± 1.4% (37.6)	96.0 ± 1.4% (33.3)

Relative Abundance

To test whether species abundance increases or not with land use, the relative abundance (Marcon 2015) of the different grasshopper species from each locality was calculated as the ratio of: the sum of abundances of a species over the sum of abundances of all the species from the studied locality. Mean abundance values of a given species in the three localities were compared using the Kruskal-Wallis (H) test while pairwise comparisons were made by the Wilcoxon W-test. All analyses were performed using the PAST software version 4.10 (Hammer et al. 2001). Relative abundance (f_x) of a given species was categorized according to Dajoz (1982) as follows: $f_x > 50\%$ = species very abundant; $25\% \leq f_x \leq 50\%$ = species abundant; $1\% \leq f_x < 25\%$ = species less abundant; $f_x < 1\%$ = species rare.

Frequency of occurrence, abundance distribution models, diversity, and similarity indexes tested whether the structures of the different grasshopper assemblages correspond or not to each level of land use in the studied localities.

Frequency of Occurrence

The frequency of occurrence reflects the occupation of the available space (in a fallow-land) by the different grasshopper species. It is the ratio of the number of samples in which a given species is present over the total number of samples realized in the field. The frequency of occurrence (f_r) of a given species was also categorized according to Dajoz (1982) as follows: $f_r > 50\%$ = constant species; $25\% \leq f_r \leq 50\%$ = accessory species; $f_r < 25\%$ = accidental species. Analyses were performed using the PAST software.

Abundance Distribution Models

The models provide information on how the grasshopper species share the available resources in each fallow-land (Havyarimana et

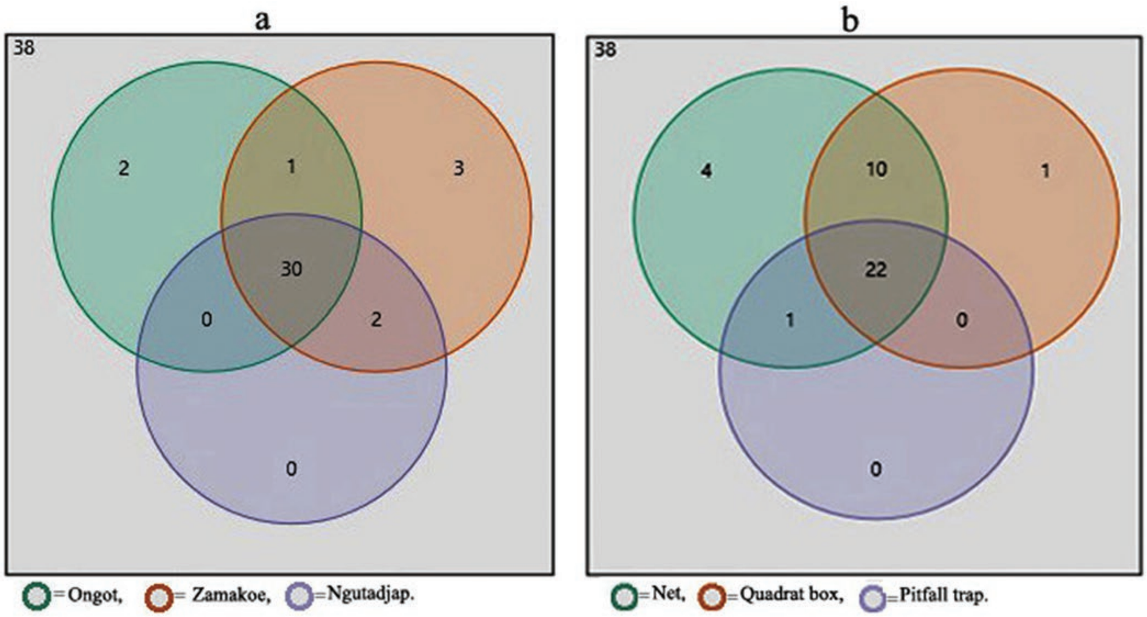

Fig. 2. Grasshopper species richness (38 species) between the different fallow-lands and sampling methods. a) between the fallow-lands; b) between the sampling methods.

al. 2013). The theoretical species abundance distribution models of Fisher (log-series model), Mac-Arthur (broken stick model), Motomura (geometric model), and Preston (log-normal model) (Carlo et al. 1998, Cielo-Filho et al. 2012, Marcon 2015) were generated then compared to our dataset via the Chi2 ($\chi 2$) test. Analyses were performed using the PAST software.

Diversity and Similarity

The diversity indexes were used to assess the degree of complexity of the grasshopper assemblages in the studied localities. The Shannon (H′) and evenness (H′/H′max) indexes (Marcon 2015, Raghavender and Vastrad 2017) allowed to express diversity in each locality. The t-test was used to compare H' values between two localities (Hutcheson 1970). The Bray-Curtis index (C_n) and the species correspondence analysis (Bray and Curtis 1957, Yelland 2010, Raghavender and Vastrad 2017) allowed to evaluate the similarities between the grasshopper communities. Paired Group Method (UPGMA) was used to perform cluster analysis. The Euclidean distances between species and/or localities were generated automatically by the PAST software.

Results

Species Richness

Thirty-eight grasshopper species from two families were identified: 33 Acrididae and 5 Pyrgomorphidae (Appendix 1). Catantopinae was the most diversified subfamily (11 species) followed by the Acridinae (7 species), Coptacrinae (5 species), Pyrgomorphinae (5 species), Oxyinae and Oedipodinae (3 species each), Eyprepocnemidinae (2 species), Spathosterninae and Cyrtacanthacridinae one species each (Appendix 1).

Grasshopper species richness was almost the same in the studied localities: 33 species collected at Ongot, 36 species at Zamakoe, and 32 species from Ngutadjap. *Taphronota calliparea* was collected only in the most disturbed fallow-land (Ongot) (Fig. 2a); the only specimen of *Pterotiltus aplicalis* was also collected there. *Pyrgomorpha virgnaudii* was only collected from Zamakoe, the moderately disturbed area; and single specimens of *Digentia fasciata* and *Oxya hyla* were also collected there. *Pteropera descampsi* was found only in the two most disturbed fallow-lands (Ongot and Zamakoe), while *Stenocrobylus festivus* and *Morphacris fasciata* were collected only from Zamakoe and Ngutadjap. No species was specific to the least disturbed fallow-land (Ngutadjap), nor shared by the most and the least disturbed areas (Ongot and Ngutadjap). The remaining 30 species co-occurred in all three localities (Fig. 2a). Thirty-seven species were captured by nets and 33 species collected in box quadrats, while 23 species were sampled by pitfall traps (Fig. 2b).

Relative Abundance

A total of 3,108 grasshopper specimens (Appendix 1) were sampled in the three studied localities. Among them, 918 (28.98 ± 1.7%) were collected from Ngutadjap (least anthropized fallow-land), 975 (31.26 ± 2.03%) from Zamakoe (moderately anthropized fallow-land), and 1,215 (39.76 ± 1.4%) from Ongot (most anthropized fallow-land) (Table 2). In general, abundance of grasshoppers increased with human pressure on the fallow-land ($H = 15.45$, $P < 0.001$). All the studied grasshopper species were categorized as either 'less abundant' or 'rare'. *Zonocerus variegatus* was the most numerous (15.39 ± 3.1%) of the overall samples; however, its abundance did not significantly differ among the three localities ($H = 1.09$, $P = 0.57$) (Table 2). Besides *Z. variegatus*, the most sampled species were *Catantops sylvestris* (12.96 ± 1.8%), *Eyprepocnemis plorans* (9.22 ± 1.3%), *Chirista compta* (8.27 ± 1.3%), *Odontomelus kamerunensis* (7.24 ± 1.02%), *Serpusia opacula* (5.78 ± 1.02%), *Parapropacris notatus* (5.57 ± 0.7%), *Eucoptacra anguliflava* (5.16 ± 0.4%), and *Atractomorpha acutipennis* (4.73 ± 0.5%). Most species were found equally in each of the locations except for *C. compta* and *Roduniella insipida* that were significantly more common in the least disturbed area, Ngutadjap and *O. kamerkunensis*, *S. opacula*, *Heteracris guineensis*, and *Taphronota calliparea* that were more

Table 2. The relative abundance (%) of grasshoppers between the different fallow-lands. Each value is: mean ± standard error; H: value of the Kruskal–Wallis test; *P*: probability; a, b, and c: the results of the comparisons of two samples by the Wilcoxon W-test

Taxa	Ongot	Zamakoe	Ngutadjap	H	*P*	Total
Acrididae MacLeay, 1821						
Acridinae MacLeay, 1821						
Acrida turrita (Linnaeus, 1758)	0.02 ± 0.02	0.08 ± 0.06	0.058 ± 0.03	0.2	0.75	0.16 ± 0.07
Chirista compta (Walker, 1870)	1.13 ± 0.3b	1.41 ± 0.4b	5.73 ± 0.9a	17.31	<0.001	8.27 ± 1.3
Coryphosima stenoptera (Schaum, 1853)	0.054 ± 0.05b	1.07 ± 0.5a	0.45 ± 0.1a	6.06	0.02	1.58 ± 0.6
Gymnobothrus temporalis (Stål, 1876)	0.17 ± 0.1	0.33 ± 0.1	0.74 ± 0.3	1.7	0.31	1.24 ± 0.4
Holopercna gerstaeckeri (Bolívar, 1890)	0.34 ± 0.1	0.31 ± 0.1	0.27 ± 0.09	0.27	0.84	0.92 ± 0.1
Odontomelus kamerunensis Ramme, 1929	5.92 ± 0.9b	0.70 ± 0.1a	0.62 ± 0.1a	23.34	<0.0001	7.24 ± 1.02
Roduniella insipida (Karsch, 1896)	0.04 ± 0.04b	0.05 ± 0.4b	1.06 ± 0.8a	4.06	0.02	1.15 ± 0.8
Catantopinae Brunner von Wattenwyl, 1893						
Abisares viridipennis (Burmeister, 1838)	0.14 ± 0.06	0.21 ± 0.1	0.14 ± 0.09	0.36	0.95	0.49 ± 0.14
Parapropacris notatus (Karsch, 1891)	1.07 ± 0.2	2.52 ± 0.5	1.98 ± 0.3	4.68	0.09	5.57 ± 0.7
Catantops sylvestris Jago, 1984	3.72 ± 0.8	5.17 ± 0.08	4.07 ± 0.3	3.08	0.21	12.96 ± 1.8
Phaeocatantops signatus (Karsch, 1891)	0.13 ± 0.1a	0.87 ± 0.2b	0.1 ± 0.05a	5.33	0.02	1.1 ± 0.3
Exopropacris rheni (Sjöstedt, 1923)	0.19 ± 0.1	0.36 ± 0.1	0.24 ± 0.08	0.32	0.79	0.79 ± 0.2
Eupropacris coeruleus (Drury, 1773)	0.39 ± 0.1	0.87 ± 0.1	0.23 ± 0,09	8.14	0.01	1.49 ± 0.1
Oxycatantops congoensis (Sjöstedt, 1929)	0.6 ± 0.1b	1.4 ± 0.4b	0.2 ± 0.08a	7.59	0.01	2.2 ± 0.4
Pteropera carnapi Ramme, 1929	0.25 ± 0.1	0.74 ± 0.1	0.53 ± 0.1	5.75	0.052	1.52 ± 0.2
Pteropera descampsi Donskoff, 1981	0.5 ± 0.1	0.29 ± 0.1	0	7.42	0.005	0.79 ± 0.1
Serpusia opacula Karsch, 1891	4.61 ± 0.7b	1.0 ± 0.3c	0.12 ± 0.05a	3.55	<0.0001	5.78 ± 1.02
Stenocrobylus festivus Karsch, 1891	0	0.12 ± 0.1	0.11 ± 0.1	1.13	0.20	0.24 ± 0.1
Coptacrinae Brunner von Wattenwyl, 1893						
Cyphocerastis tristis Karsch, 1891	0.1 ± 0.04	0.2 ± 0.1	0.2 ± 0.1	0.25	0.81	0.5 ± 0.1
Cyphocerastis hopei Bruner, 1920	0.73 ± 0.1	0.6 ± 0.2	0.45 ± 0.1	1.7	0.41	1.78 ± 0.3
Cyphocerastis laeta Karsch, 1891	0.05 ± 0.05	0.09 ± 0.09	0.03 ± 0.03	0.001	0.99	0.18 ± 0.1
Epistaurus succineus (Krauss, 1877)	0.93 ± 0.2b	0.53 ± 0.2b	0.03 ± 0.03a	13.77	<0.001	1.50 ± 0.3
Eucoptacra anguliflava (Karsch, 1893)	1.9 ± 0.3	1.54 ± 0.2	1.72 ± 0.2	0.22	0.89	5.16 ± 0.4
Cyrtacanthacridinae Kirby, 1910						
Acanthacris ruficornis (Fabricius, 1787)	0.12 ± 0.07	0.44 ± 0.2	0.39 ± 0.1	1.69	0.33	0.95 ± 0.3
Eyprepocnemidinae Brunner von Wattenwyl, 1893						
Eyprepocnemis ibandana (Charpentier, 1825)	4.7 ± 1.1	1.82 ± 0.3	2.69 ± 0.5	4.51	0.1	9.22 ± 1.3
Heteracris guineensis (Krauss, 1890)	0.55 ± 0.1b	0.15 ± 0.6a	0.09 ± 0.04a	6.67	0.01	0.79 ± 0.1
Spathosterninae Rehn, 1957						
Spathosternum pygmaeum Karsch, 1893	0.05 ± 0.05	0.19 ± 0.1	0.42 ± 0.3	0.46	0.57	0.66 ± 0.5
Oedipodinae Walker, 1871						
Heteropternis thoracica (Walker, 1870)	0.58 ± 0.2	1.21 ± 0.4	0.81 ± 0.2	1.62	0.43	2.61 ± 0.5
Morphacris fasciata (Thunberg, 1815)	0	0.03 ± 0.03	0.1 ± 0.07	0.48	0.34	0.13 ± 0.07
Trilophidia conturbata (Walker, 1870)	0.10 ± 0.1	0.07 ± 0.04	0.12 ± 0.06	0.41	0.61	0.29 ± 0.1
Oxyinae Brunner von Wattenwyl, 1893						
Digentia fasciata Ramme, 1929	0	0.02 ± 0.02	0	1.16	0.36	0.02 ± 0.02
Oxya hyla Serville, 1831	0	0.05 ± 0.03	0	0.64	0.12	0.05 ± 0.03
Pterotiltus apicalis Bolívar, 1905	0.03 ± 0.03	0	0	0.16	0.36	0.03 ± 0.03
Pyrgomorphidae Brunner von Wattenwyl, 1874						
Pyrgomorphinae Brunner von Wattenwyl, 1874						
Atractomorpha acutipennis (Guérin-Méneville, 1844)	2.8 ± 0.5b	1.4 ± 0.3a	0.53 ± 0.2a	13.92	<0.001	4.73 ± 0.5
Pyrgomorpha vignaudii (Guérin-Méneville, 1847)	0	1.15 ± 0.2	0	13.14	<0.0001	1.15 ± 0.2
Taphronota calliparea (Schaum, 1853)	0.51 ± 0.3	0	0	0.64	0.12	0.51 ± 0.3
Taphronota ferruginea (Fabricius, 1781)	0.55 ± 0.3	0.09 ± 0.06	0.23 ± 0.09	1.54	0.33	0.87 ± 0.3
Zonocerus variegatus (Linnaeus, 1758)	6.68 ± 2.1	4.25 ± 1.6	4.45 ± 1.00	1.09	0.57	15.39 ± 3.1
H	269	227.5	223.3			357.9
P	<0.0001	<0.0001	<0.0001			<0.0001
Total	39.76 ± 1.4b	31.26 ± 2.03a	28.98 ± 1.7a	15.45	<0.001	100

common in the most disturbed area, Ongot (Table 2). The other species were generally rare (Table 2).

Frequency of Occurrence

Generally, in the different localities, all the grasshopper species were classified as 'accidental' (Fig. 3). Among them, the most common were (in decreasing order): *Catantops sylvestris* (10%), *Zonocerus variegatus* (8.3%), *Eyprepocnemis plorans* (6.3%), *Chirista compta* (6.2%), and *Odontomelus kamerunensis* (5.4%). All the other taxa were collected in less than 5% of the samples (Fig. 3). *Catantops sylvestris*, *Z. variegatus*, *E. plorans* were more frequently collected on Asteraceae, whereas the other species were more frequently sampled in forest/fallow-land ecotones.

Abundance Distribution Model

The log-normal model of Preston proved to be the best species abundance distribution model of insects at Ngutadjap ($\chi2$ = 2.44, *P* =

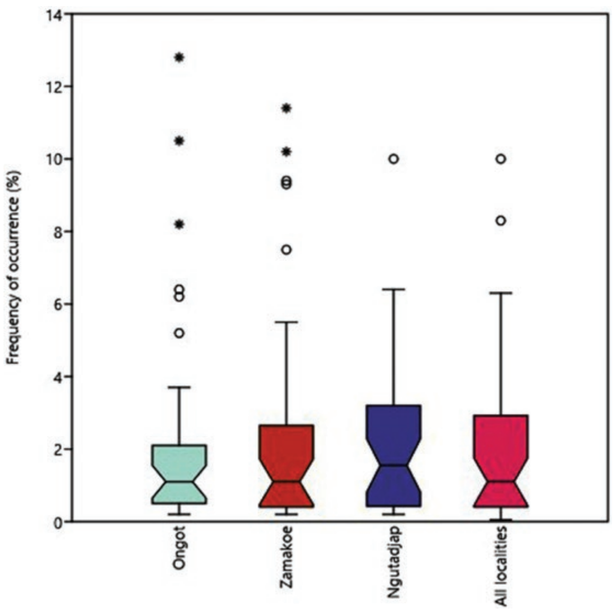

Fig. 3. Frequency of occurrence of grasshoppers in the different fallow-lands.

0.78), Ongot ($\chi2$ = 6.83, P = 0.23), and Zamakoe ($\chi2$ = 5.12, P < 0.4) (Fig. 4).

Diversity and Similarity

The Shannon diversity index was higher (H′ = 2.95) in Zamakoe, the moderately disturbed locality, than in the two other fallow-lands of Ngutadjap (H′ = 2.66) and Ongot (H′ = 2.66) (Table 1). This index did not statistically differ between the two latter localities (t = 0.3, P = 0.85). The cluster analysis showed that the grasshopper communities of Ngutadjap (least anthropized locality) and Zamakoe (moderately anthropized locality) were quite similar (C_n = 0.7), but different from the Ongot (most anthropized locality) community (C_n= 0.55) (Fig. 5a). The correspondence analysis revealed that the studied species were closer to the most degraded locality of Ongot (Fig. 5b).

Comparison of Grasshoppers Collected from Forests and Fallow-lands

Grasshoppers were collected in the forest areas in same regions (Ongot, Zamakoe, and Ngutadjap) of southern Cameroon. The most common species found in the forests (*Mazaea granulosa*) accounted for the vast majority (79.15%) of the specimens caught in the forest, yet it was completely absent from fallow-land (Table 3). Only *Serpusia opacula* was equally common in the forest and fallow-land (6.82% and 5.78% of specimens, respectively). Two species (*Pteropera carnapi* and *Cyphocerastis hopei*) were relatively rare in the forest and while still being rare in the fallow-land were slightly more common there (Table 3). All other species found in the forest were not found in fallow-land and all other species in the fallow-land were not found in the forest. Overall, forest species accounted for only 10.92% of collections from fallow-land and fallow-land species accounted for only 7.36% of those collected from forests (Table 3).

Discussion

Species Richness

Contrary to our first research hypothesis that land-use decreases the number of grasshopper species, we found that species richness was almost the same for all three studied localities. However, some grasshopper taxa were specific to the level of environmental disturbance: *T. calliparea* in the most disturbed fallow-land of Ongot, *P. vignaudii* in the moderately disturbed area of Zamakoe. *P. descampsi* at Ongot and Zamakoe, *S. festivus* and *M. fasciata* at Zamakoe and Ngutadjap. The above cited grasshoppers were all the native species from forest edges. Therefore, the creation of fallow-land did not lead to the introduction of new grasshopper species in southern Cameroon; this result contradicts the finding of Brown (1997) who reported the presence of new taxa in disturbed land in neo-tropical forests. In our study areas, land use reduces habitats of forest grasshoppers via disappearance of the preferred food resources, replaced by Asteraceae plants more suitable for other native grasshopper species (Cahill et al. 2013). Indeed, *Z. variegatus*, *E. plorans*, and *C. sylvestris*, the most numerous species, were found in all the studied localities.

The younger the fallow-land is, the poorer are the host plants and micro-habitats of forest grasshoppers. We collected 38 grasshopper species in the south Cameroon plateau; Yetchom-fondjo et al. (2020) reported this number but in three different ecosystems (forest, fallow-land, and crop field) in the littoral region of Cameroon. Seino et al. (2013) collected 28 species in the West region of Cameroon while Kekeunou et al. (2017) sampled 27 different grasshoppers in the latter region. These differences can be explained by those of the ecoclimatic characteristics between these regions. In fact, the Center and South regions, located in the south Cameroon plateau, have four climatic seasons while both the Littoral and West regions of Cameroon have only two seasons (Njopkou 2014). It is known that the variations in ecoclimatic conditions and vegetations affect the behavior and biology of grasshoppers (Lecoq 1978, Gillon 1983, Latchininsky et al. 2011).

Relative abundance, Occurrence, and Abundance Distribution Models

Contrary to our second research hypothesis that land-use decreases the grasshopper species abundance, we found that abundance increased with fallow-land use. However, the increase was mainly due to the proliferation of a few species (*Z. variegatus*, *E. plorans*, and *C. sylvestris*) which found suitable habitats on Asteraceae plants. The other taxa, from the forest/fallow-land ecotone, had a low frequency of occurrence, which is consistent with the finding of Sergeev (1998) that after degradation, there is a decline in the species abundance of forest grasshoppers. Of the species found in the forests in the same region in southern Cameroon (Oumarou-Ngoute et al. 2020), one (*Serpusia opacula*) was 'less abundant' in the fallow-land, while the rest were rare or absent, including *Mazaea granulosa*, the most common species in the forests that was not found in the fallow-land at all. The species that increase (*Z. variegatus*, *E. plorans*, and *C. sylvestris*), which are known as crop pests (Okunlola and Ofuya 2010, Oladele et al. 2014), find suitable environments for their development (Nkwala et al. 2019).

We therefore suggest that grasshopper species-richness and abundance are a function of the availability of host plants. The low abundance and occurrence of forest/fallow-land ecotone species fitted the log-normal abundance distribution model; this differs from the geometric model reported by Yetchom-fondjo et al. (2020) in the Littoral region of Cameroon. The log-normal abundance model assumes a fairly balanced sharing of the available resources in the fallow-lands and limits the abundance and occurrence of organisms studied (Ramade 2009, Cielo-Filho et al. 2012). It follows from above that abundance and occurrence of forest grasshopper species were limited by abiotic factors (such as temperature, humidity),

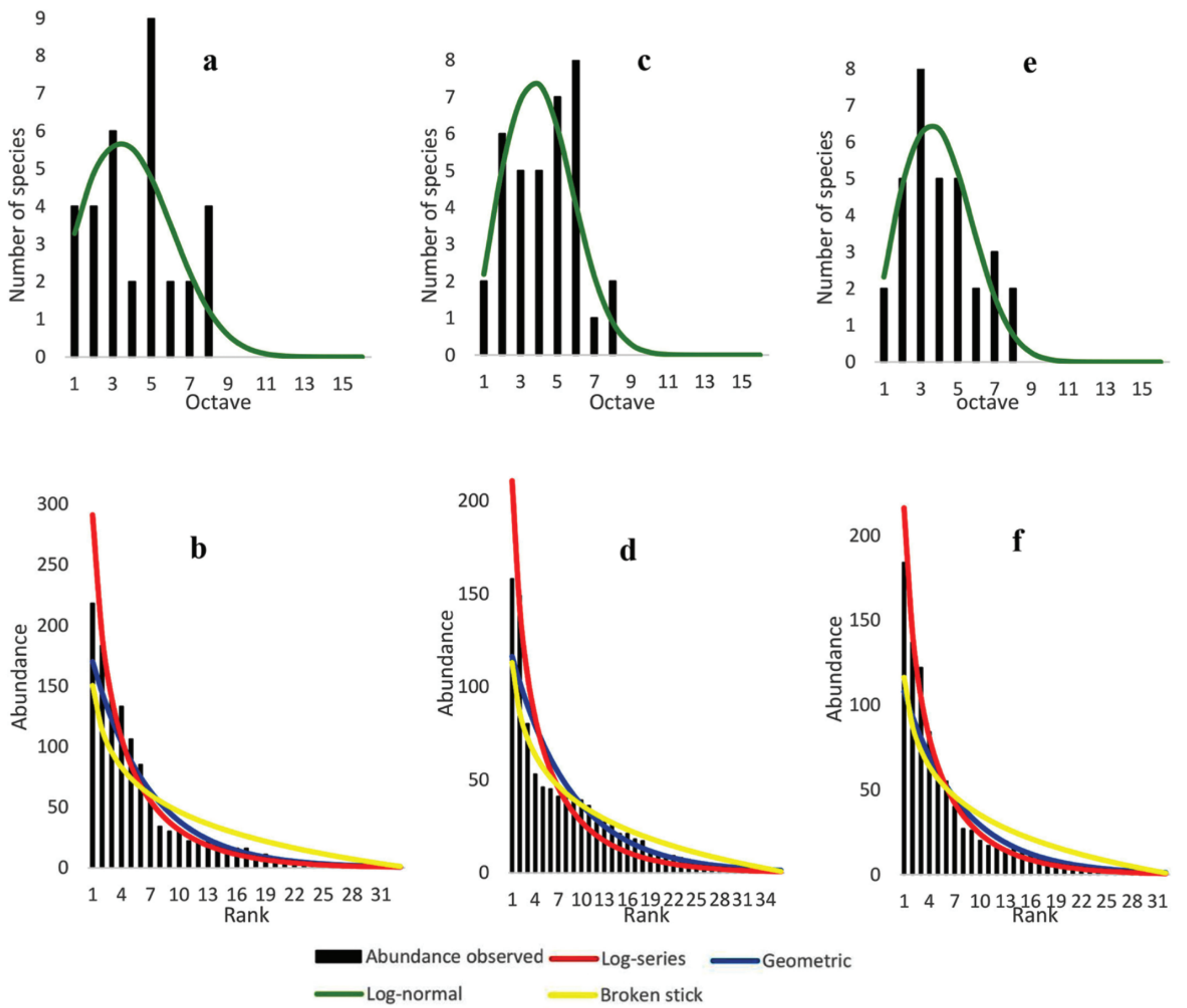

Fig. 4. Abundance distribution models of grasshoppers in the different fallow-lands. a, b) Ongot; c, d) Zamakoe; e, f) Ngutadjap.

biotic factors (interspecific interactions: competition types), physical structure of new habitat (new vegetation structure), and low availability of suitable spaces after disturbance (Lecoq 1978, Soberón 2005, Kalusová et al. 2016).

Diversity and Similarity

Our third research hypothesis was that the fallow-land use structures grasshopper assemblages; in other words, grasshopper communities are specific to each level of fallow-land use. We found that the communities of the less disturbed localities (Ngutadjap and Zamakoe) were quite similar. Conversely, in the Littoral region of Cameroon, Yetchom-fondjo et al. (2020) highlighted the similarity between the grasshopper communities of the more anthropized lands (fallow-land and crop field) compared to forest habitat. It is known that the vegetation structure affects the behavior of grasshoppers (Latchininsky et al. 2011). Therefore, as for other insects, grasshopper diversity is obviously influenced by human activities in the Cameroon rainforest areas. In the Fako Division (Southwest region of Cameroon) insect diversity was higher in secondary forests than in oil palm, banana, or rubber plantations (Nanganoa et al. 2019).

Conclusion and Recommendations for Land Management

The present study gives strong evidence for the dramatic effects of forest clearing on grasshopper assemblages, with direct consequences for the conservation and management. Indeed, in southern Cameroon, most grasshopper species found in forests either declined dramatically or were completely absent from fallow-land cleared of forest. Such effects are likely not only grasshoppers as indicative species, but for many other organisms as well, which means that to retain native flora and fauna, conservation, and restoration measures need to be put in place. The opening up of forests by human activities offers suitable environments for the proliferation of pest grasshopper species populations (such as *Z. variegatus*, *E. plorans*, and *C. sylvestris*), adapted to Asteraceae to the detriment of other native forest species (such as *M. granulosa*, *H. gerstaeckeri*, *D. fasciata*, *A. viridipennis*, *O. hyla*, *Parapetasia* sp., *Gemeneta* sp., and *Pterotiltus* sp.). The direct consequences of this are increased pest activities in crop fields and disruption of the balance of natural ecosystems. Furthermore, forest management by reforestation of degraded areas, along with the reduction of slash-and-burn cultural practices and wood cutting, would restore the original grasshopper assemblages and environment health.

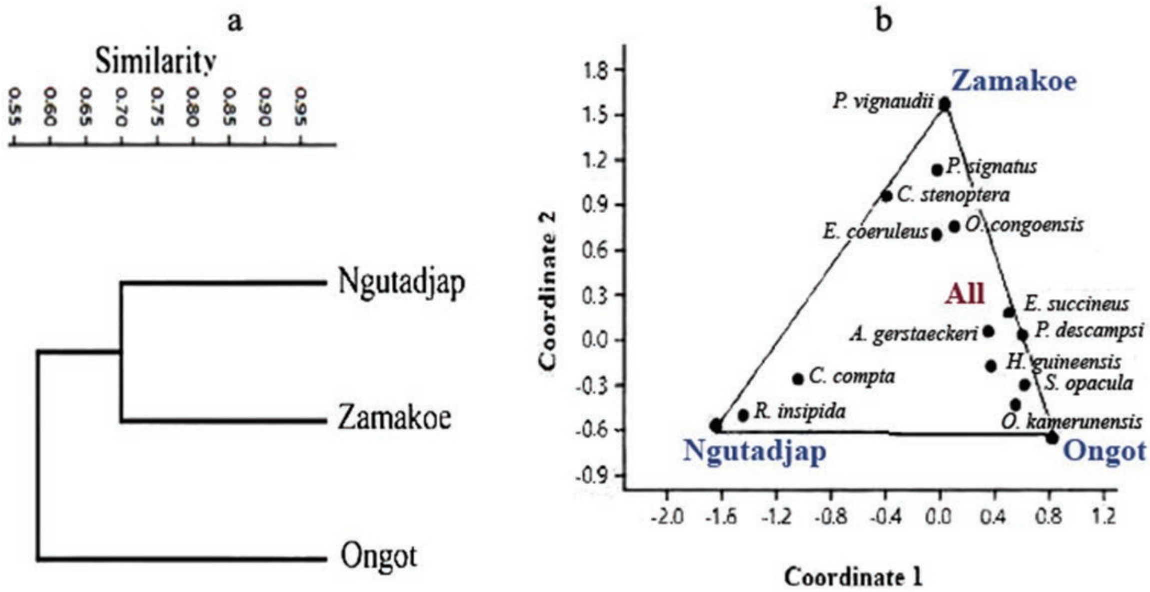

Fig. 5. Similarity between the grasshopper communities of the different fallow-lands. a) using Bray-Curtis index; b) using correspondence analysis.

Table 3. The relative abundance (%) of grasshopper species in the forests and fallow-lands

Species	Forest[a]	Fallow-land
A. Forest species		
Mazaea granulosa	79.15	0
Serpusia opacula	6.82	5.78
Holopercna gerstaeckeri	4.82	0.92
Pterotiltus apicalis	3.48	0.03
Digentia fasciata	2.34	0.02
Pteropera carnapi	0.77	1.52
Cyphocerastis hopei	0.37	1.78
Taphronota ferruginea	0.17	0.87
All other species (4)	2.08	0
Total	100	10.92
B. Fallow-land species		
Zonocerus variegatus	0	15.39
Catantops sylvestris	0	12.96
Eyprepocnemis plorans	0	9.22
Chirista compta	0	8.27
Odontomelus kamerunensis	0	7.24
Serpusia opacula	6.82	5.78
Parapropacris notatus	0	5.57
Eucoptacra anguliflava	0	5.16
Atractomorpha acutipennis	0	4.73
Oxycatantops congoensis	0	2.2
Cyphocerastis hopei	0.37	1.78
Taphronota ferruginea	0.17	0.87
All other species (26)	0	20.83
Total	7.36	100

[a]Data from Oumarou-Ngoute et al. 2020.

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Author Contributions

CON: Conceptualization; Methodology; Funding acquisition; Project administration; Investigation; Data curation; Formal analysis; Writing—original draft; Writing—review & editing. **SK:** Conceptualization; Methodology; Supervision. **CFBB:** Conceptualization; Methodology; Supervision; Writing—review & editing.

Supplementary Material

Supplementary material are available at *Journal of Insect Science* online.

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Appendix 1. The absolute abundance of grasshopper species in the fallow-lands and seasons. n indicates the number of seasons

Taxa/Localities	Short rainy season (n=2)	Short dry season (n=2)	Long rainy season (n=1)	Long dry season (n=1)	Total
Acrididae MacLeay, 1821					
Acridinae MacLeay, 1821					
Acrida turrita (Linnaeus, 1758)	1	2	1	2	6
Chirista compta (Walker, 1870)	53	42	30	134	259
Coryphosima stenoptera (Schaum, 1853)	5	8	29	14	56
Gymnobothrus temporalis (Stål, 1876)	3	0	19	19	41
Holopercna gerstaeckeri (Bolívar, 1890)	10	4	8	7	29
Odontomelus kamerunensis Ramme, 1929	71	34	42	77	224
Roduniella insipida (Karsch, 1896)	1	1	35	7	44
Catantopinae Brunner von Wattenwyl, 1893					
Abisares viridipennis (Burmeister, 1838)	4	4	5	1	14
Parapropacris notatus (Karsch, 1891)	26	27	38	83	174
Catantops sylvestris Jago, 1984	126	80	76	95	377
Phaeocatantops signatus (Karsch, 1891)	2	6	11	15	34
Exopropacris rheni (Sjöstedt, 1923)	6	8	6	3	23
Eupropacris coeruleus (Drury, 1773)	13	10	10	12	45
Oxycatantops congoensis (Sjöstedt, 1929)	21	13	20	10	64
Pteropera carnapi Ramme, 1929	17	7	8	13	45
Pteropera descampsi Donskoff, 1981	7	6	6	4	23
Serpusia opacula Karsch, 1891	47	37	34	52	170
Stenocrobylus festivus Karsch, 1891	0	1	5	1	7
Coptacrinae Brunner von Wattenwyl, 1893					
Cyphocerastis tristis Karsch, 1891	3	6	3	2	14
Cyphocerastis hopei Bruner, 1920	11	14	11	18	54
Cyphocerastis laeta Karsch, 1891	3	0	2	0	5
Epistaurus succineus (Krauss, 1877)	9	11	14	15	49
Eucoptacra anguliflava (Karsch, 1893)	44	31	29	55	159
Cyrtacanthacridinae Kirby, 1910					
Acanthacris ruficornis (Fabricius, 1787)	6	6	8	7	27
Eyprepocnemidinae Brunner von Wattenwyl, 1893					
Eyprepocnemis ibandana (Charpentier, 1825)	58	34	49	129	270
Heteracris guineensis (Krauss, 1890)	6	2	8	8	24
Spathosterninae Rehn, 1957					
Spathosternum pygmaeum Karsch, 1893	1	1	21	3	26
Oedipodinae Walker, 1871					
Heteropternis thoracica (Walker, 1870)	10	5	20	46	81
Morphacris fasciata (Thunberg, 1815)	1	0	1	2	4
Trilophidia conturbata (Walker, 1870)	0	0	0	9	9
Oxyinae Brunner von Wattenwyl, 1893					
Digentia fasciata Ramme, 1929	0	0	0	1	1
Oxya hyla Serville, 1831	0	1	0	1	2
Pterotiltus apicalis Bolívar, 1905	0	1	0	0	1

Appendix 1. Continued

Taxa/Localities	Short rainy season (n=2)	Short dry season (n=2)	Long rainy season (n=1)	Long dry season (n=1)	Total
Pyrgomorphidae Brunner von Wattenwyl, 1874					
Pyrgomorphinae Brunner von Wattenwyl, 1874					
Atractomorpha acutipennis (Guérin-Méneville, 1844)	28	22	33	61	144
Pyrgomorpha vignaudii (Guérin-Méneville, 1847)	9	6	10	14	39
Taphronota calliparea (Schaum, 1853)	0	0	0	21	21
Taphronota ferruginea (Fabricius, 1781)	3	3	3	21	30
Zonocerus variegatus (Linnaeus, 1758)	54	130	143	186	513
Ongot	264	235	276	440	1,215
Zamakoe	234	155	233	353	975
Ngutadjap	161	173	229	355	918
Total	659	563	738	1,148	3,108