

Research article

[urn:lsid:zoobank.org/pub:B86B7FC2-EA09-404C-8542-3458777FE499](https://zoobank.org/pub:B86B7FC2-EA09-404C-8542-3458777FE499)

Diversity of bats (Mammalia: Chiroptera) along an altitudinal gradient in the western region of Cameroon

Ervis Manfothang Dongmo¹, Eric-Moise Bakwo Fils^{2,*}, Aaron Manga Mongombe³ & Fernand-Nestor Tchuenguem Fohouo⁴

^{1,2,3}Department of Biological Sciences, Faculty of Sciences, University of Maroua, P.O. Box 814, Maroua, Cameroon

⁴Department of Biological Sciences, Faculty of Science, University of Ngaoundéré, P.O. Box 454 Ngaoundéré, Cameroon

*Corresponding author: Email: filsbkw27@gmail.com

¹[urn:lsid:zoobank.org/author:23BE5FBF-E2DF-4DF5-A34B-9BBC10AB5AAC](https://zoobank.org/author:23BE5FBF-E2DF-4DF5-A34B-9BBC10AB5AAC)

²[urn:lsid:zoobank.org/author:A971C795-09AE-49DF-BB2C-51F397E18D0F](https://zoobank.org/author:A971C795-09AE-49DF-BB2C-51F397E18D0F)

³[urn:lsid:zoobank.org/author:1556516C-665A-4F8C-9E0A-70C297CD3304](https://zoobank.org/author:1556516C-665A-4F8C-9E0A-70C297CD3304)

⁴[urn:lsid:zoobank.org/author:77453B9B-A647-425B-BDED-E8C8CA929E72](https://zoobank.org/author:77453B9B-A647-425B-BDED-E8C8CA929E72)

Abstract. We investigated the patterns of bat species richness, abundance and distribution along an altitudinal gradient in the West region of Cameroon from December 2016 to November 2018 with the use of mist nets. Captures were conducted at 32 sites distributed over six distinct elevational ranges, comprising five sites in elevation range I (< 750 m a.s.l.), four sites in elevation range II (750–1,000 m a.s.l.), eight sites in elevation range III (1,000–1,250 m a.s.l.), six sites in elevation range IV (1,250–1,500 m a.s.l.), six sites in elevation range V (1,500–1,750 m a.s.l.) and two sites in elevation range VI (> 1,750 m a.s.l.). A total of 442 bats were captured during 95 sampling nights, comprising 25 species, 16 genera and six families. Out of the 25 species, *Myonycteris angolensis* was the most abundant species captured with 80 individuals, followed by *Micropteropus pusillus* (61 individuals) and *Eidolon helvum* (60 individuals). Moreover, species richness peaked at the mid-elevation range III (1,000–1,250 m a.s.l.), with 13 species, with richness decreasing both at higher and lower elevations. Elevation range I had the second highest species richness with 12 species, while elevational range VI had the least species richness with three species. Species abundance peaked at elevation range IV (750–1,250 m a.s.l.) and decreases at higher elevations. The sample efficiency was estimated as 72.8% and a species accumulation curve of bats did not reach an asymptote, indicating that our sampling was incomplete. Our data showed that species richness and abundance is affected by elevation, with species richness probably depending on habitat types and availability of resources such as food and suitable roost sites. Our data also contributes to a better description of the local fauna and fills gaps on the species distribution for high altitude sites.

Key words. Bat, elevation range, diversity, West region, Cameroon, altitudinal gradient.

INTRODUCTION

The western region of Cameroon is characterized by a heterogeneous landscape, of series of high plateaus formed by volcanic massifs, the most important of which are the Bamboutos Mountains (2,740 m a.s.l.), interspersed among lowland areas such as the Nkam and Noun valleys, and the Tikar Plain (Temgoua 2011). This heterogeneous landscape composed of montane forest remnants, grassland savannah and gallery forest in valleys is part of the Mount Cameroon-Bioko ecoregion. This region harbors some of the most threatened ecosystems in the country (Temgoua 2011). Indeed, very little of the region's native biota remained, a consequence of decades of deforestation to make way for agriculture and urbanization. Moreover, the region harbors the highest population density of the country with 13% of the national population, concentrated in only 3% of the territory (MINEPAT 2010). The consequences of these strong anthropic pressures are

particularly evident on the Western High Plateau, where poor soil and low rainfall have aggravated the effects of deforestation, converting the area to grassland (Temgoua 2011). As pointed out by Estrada & Coates-Estrada (2002), human-induced land use changes, due to agriculture and urbanization are known to alter bat assemblages, depending on the functional identity of bat species.

Bats are a species-rich group of mammals with about 357 species recorded in Africa (ACR 2018). They are found in every biome throughout the African continent with the exception of some extremely hot regions, and the tops of high mountains (Happold & Happold 2013). Several authors suggest that species richness and distribution of bats is influenced by the availability of resources such as drinking sites, food and suitable roost (Curran et al. 2012; Happold & Happold 2013). The potential distribution of each bat species can be affected by these ecological variables. In the tropics, vegetation types correlated with altitude are the principal factors that deter-

mine bat species distribution (Kaňuch & Krištín 2006; Weier et al. 2016). Mammalian species show varied responses to altitudinal gradient, among which two patterns stand out for bats: a clinal pattern in which species richness is higher in lower elevations and decreases with altitude (Graham 1983, 1990; Patterson et al. 1996; Pinares 2006; Flores-Saldana 2008; Peters et al. 2016; Peters et al. 2019), or modal pattern with a peak in richness at mid-altitudes (Sanchez-Cordero 2001; McCain 2005). In addition, Curran et al. (2012), recorded some bat species mainly at higher altitudes, mid-altitudes and others preferred both low and high altitudes. They further pointed out that bat activity and capture rates in the tropics are greater at lower altitudes because water is not a limiting factor.

Although many surveys have focused on the mammalian fauna of Cameroon, few of these studies concerned bats until recently. To the best of our knowledge none of these studies assessed how bat species richness varies with altitude in heterogeneous landscapes such as the West region of Cameroon. Moreover, bats are not included in conservation and wildlife management programs in tropical ecosystems despite their ecological and economic importance (Bakwo Fils 2009, 2010). This lack of ecological information about the bats fauna of Cameroon hinders any development and implementation of conservation strategies (Bakwo Fils 2010).

In the western region of Cameroon elevations reach as high as 2,000 m a.s.l. in some areas such as the Bamboutos and dip as low as 500 m a.s.l. in others such as the Noun and Nkam valleys. To our knowledge, bat diversity along an altitudinal gradient in the region has never been studied. This study provides novel data for the West region of Cameroon, a region poorly surveyed for bats. Furthermore, knowledge of species-landscape relationship and species distribution is essential for proper planning and efficient management of biodiversity (Jaberg & Guisan 2001).

The present study aims to investigate patterns of distribution of bat species, species richness and abundance along an elevational gradient in the western region of Cameroon. We hypothesize that altitudinal pattern of bat assemblages in the region would vary with altitude and habitat heterogeneity, and that abundance and species richness would decrease with increasing elevation.

MATERIALS AND METHODS

Study site

This study was conducted in the western region of Cameroon. The region is situated between 5° and 6° N and 10° and 11°30' E. The region covers a total surface area of 13,892 km² (Olivry 1975; Brenac 1988). The vegetation is principally woodland savannah of the Sahel type,

interspersed among open dry forest. Very little of the natural vegetation still exists because deforestation has turned most of the area into grassland (Temgoua 2011). The climate of the western region of Cameroon is of the Equatorial, Guinean type characterized by two major seasons: a rainy season from mid-March to November with peak precipitation in August and a dry season from December to April. The annual rainfall varies between 1,000 mm and 2,000 mm depending on the year (Rivière 2000). The average annual temperature varies between 21.3°C and 29°C (Brenac 1988).

Bats capture and identification

The survey was conducted from December 2016 to November 2018 at different altitudinal ranges (Fig. 1). Sampling was conducted over 95 nights across 32 sites. Bat activity was investigated in six different elevational ranges that represent a mosaic of different landscapes of the West region of Cameroon as described by Temgoua (2011), notably mountainous relief, plateaus and plains: Mbo plain (< 750 m a.s.l.), Tika plain (750–1,000 m a.s.l.), Noun plain (1,000–1,250 m a.s.l.), Bamoun plateau (1,250–1,500 m a.s.l.), Bamileke plateau (1,500–1,750 m a.s.l.) and the isolated volcanic massif (> 1,750 m a.s.l.).

During each sampling night, mist nets (12 m × 2.5 m; mesh, 40 mm) were deployed at particular sites based on prior knowledge of bat activity (over slow-flowing streams, cultivated farms, clearings, cave openings and tree hollows). Mist nets were deployed at each site between 6 pm to 12 midnight and checked every 15 min. For each bat captured, morphometric measurements were taken using a Vernier caliper (Ecotone-Poland 150/0.1 mm), weight was recorded using a Pesola spring balance (Ecotone-Poland Light Line 200g/0.2), the sex, reproductive conditions and age class were also noted. Morphological measurements from each captured bat were used for the identification of each species using the keys in Rosevear (1965), Hayman and Hill (1971), Pateron and Webala (2012) and Happold & Happold (2013). Bats were released after identification and species that could not be identified in the field were kept as voucher, and preserved in 70% alcohol and deposited at the Laboratory of Biological Sciences of the University of Maroua-Cameroon. The geographical positions of each site sampled were recorded using a hand-held GPS (Garmin eTrex).

Data Analysis

In order to test the relationship between abundance and species richness, the Generalized Linear Mixed-effects Models (GLMMS) was used to discern the potential effects of some altitudinal variables. We performed a Kruskal-Wallis ANOVA followed by HSD tests (at 95 % family-wise confidence level) in order to determine

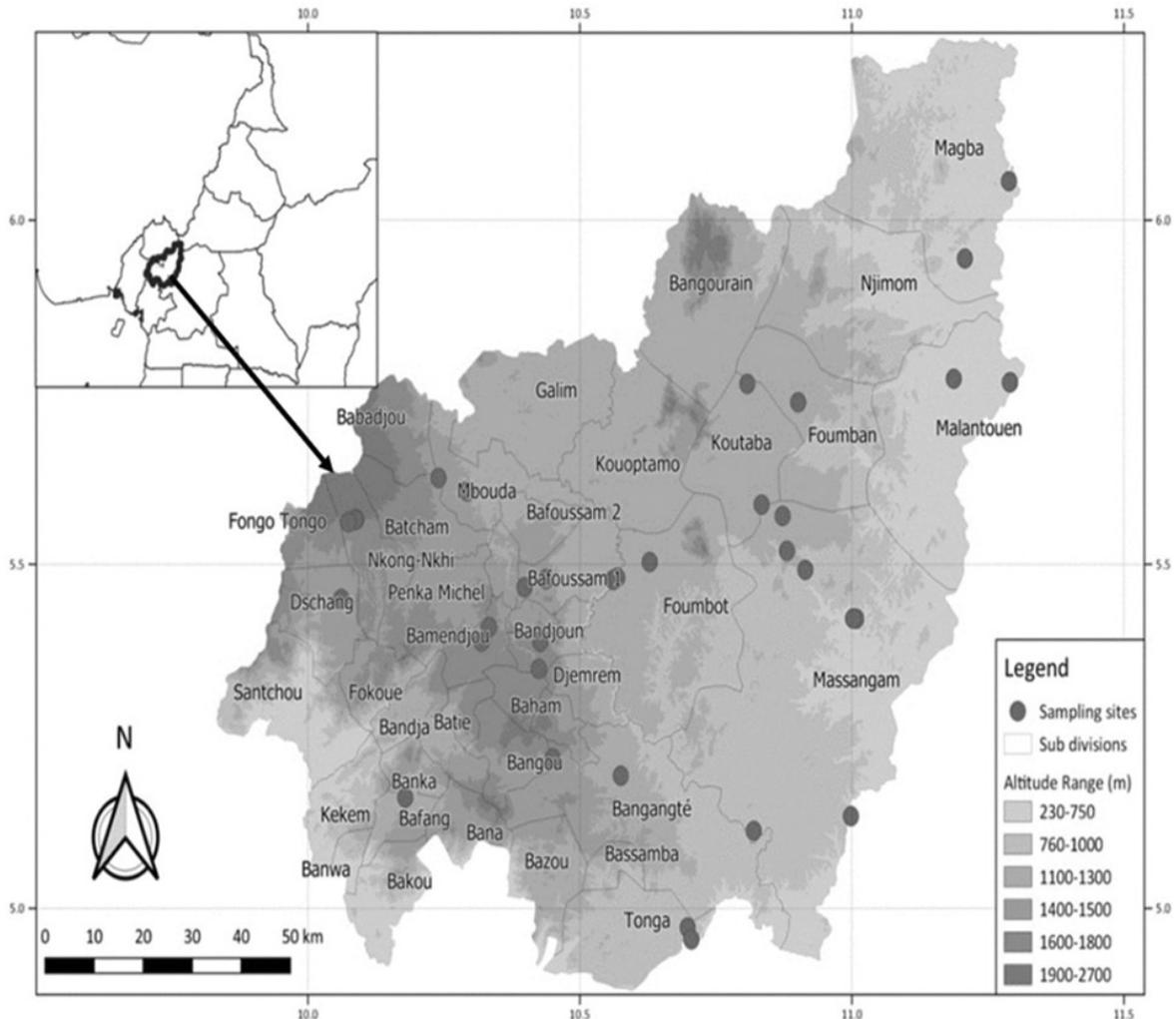


Fig. 1. Map of Cameroon showing the West Region, and sites sampled for bats from November 2016 to November 2018.

if species richness, abundance, diversity and equitability differed among elevation ranges. The software Estimate S 9.0 (Colwell 2013) was used to calculate the number of species (X) using the averages of Chao 1 (mean), ACE (mean), Jack 1 (mean) and Bootstrap (mean) and to generate a species accumulation curve. The sampling efficiency was calculated based on the formula below:

$$\text{Sampling efficiency} = \frac{\text{observed number of species}}{\text{estimated number of species}} \times 100$$

Cluster analysis was performed for all altitudinal ranges to test the degree of similarity between them and to test if bat communities represent different assemblages. The Sorensen index (Sorensen 1948), was calculated and used in cluster analysis following the UPGMA (Unweighted Pair-Group) method using the arithmetic aver-

age (Magurran & McGill 2011). Sorensen/Bray-Curtis similarity dendrogram was then plotted using packages of R software version 3.4.1 (R Core Team 2017).

RESULTS

Species richness and sampling success

During 95 sampling nights, we recorded a total of 442 bats, comprising 25 species, 16 genera and six families. The family Pteropodidae had 7 species, followed by Hipposideridae with 6 species, Vespertilionidae with 5, Rhinolophidae with 4, Molossidae with 2, and Nycteridae with 1 species (Table 1). The species with the highest capture frequency in the region was *Myonycteris angolensis* (Bocage, 1898) (18.1% of all captures), followed

Table 1. Individuals per species captured along an elevational gradient in the West region of Cameroon sampled from December 2016 to November 2018.

Taxon	Range I <750m	Range II 750–1,000m	Range III 1,000–1,250m	Range IV 1,250–1,500m	Range V 1,500–1,750m	Range VI >1,750m	Total
Pteropodidae							
<i>Micropteropus pusillus</i>	2	18	20	12	7	1	60
<i>Eidolon helvum</i>	1	1	18	41	0	0	61
<i>Myonycteris torquata</i>	0	1	2	6	2	0	11
<i>Myonycteris angolensis</i>	0	0	8	42	30	0	80
<i>Rousettus aegyptiacus</i>	13	0	1	0	0	0	14
<i>Hypsignathus monstrosus</i>	0	0	1	0	0	0	1
<i>Epomops franqueti</i>	0	1	0	0	0	0	1
Vespertilionidae							
<i>Pipistrellus nanulus</i>	0	0	0	0	0	1	1
<i>Pipistrellus grandidieri</i>	2	0	0	0	0	0	2
<i>Neoromicia nana</i>	1	0	2	0	4	0	7
<i>Scotoecus hirundo</i>	1	0	0	0	0	0	1
<i>Neoromicia tenuipinnis</i>	0	0	4	0	0	0	4
Hipposideridae							
<i>Hipposideros abae</i>	1	0	0	0	0	0	1
<i>Hipposideros beatus</i>	2	0	0	0	0	0	2
<i>Doryrhina cyclops</i>	11	0	3	0	0	0	14
<i>Hipposideros ruber</i>	15	26	0	0	0	0	41
<i>Hipposideros caffer</i>	0	0	1	0	0	0	1
<i>Hipposideros fuliginosus</i>	25	0	4	0	0	0	29
Molossidae							
<i>Chaerephon pumilus</i>	0	0	29	0	4	0	33
<i>Mops nanulus</i>	0	0	15	0	0	0	15
Rhinolophidae							
<i>Rhinolophus landeri</i>	0	28	0	8	0	1	37
<i>Rhinolophus clivosus</i>	0	1	0	0	0	0	1
<i>Rhinolophus simulator</i>	0	22	0	0	0	0	22
<i>Rhinolophus alcyone</i>	2	0	0	0	0	0	2
Nycteridae							
<i>Nycteris arge</i>	0	1	0	0	0	0	1
Species abundance	76	99	108	109	47	3	442
Species diversity	12	9	13	5	5	3	25
Shannon diversity(H')	2.8	2.3	3.0	1.9	1.7	1.6	3.7

by *Eidolon helvum* (Kerr, 1792) (13.8%) and *Micropteropus pusillus* (Peters, 1868) (13.6%) (Table 1).

Species richness was highest in elevational range III (1,000–1,250 m a.s.l.) (13 species) and its bat fauna was represented by Pteropodidae, Vespertilionidae, Hipposideridae and Molossidae (Table 1). *Chaerephon pumilus* (Cretzschmar, 1826) (n = 29), was the most abundant species captured at this elevational range, followed by *Micropteropus pusillus* (n = 20) and *Mops (Xiphonycteris) nanulus* J. A. Allen, 1917 (n = 15). In elevation range I (< 750 m a.s.l.), we recorded a total of 12 spe-

cies, represented by Pteropodidae, Vespertilionidae, Hipposideridae and Rhinolophidae. *Hipposideros fuliginosus* (Temminck, 1853) was the most abundant (n = 25), followed by *Hipposideros ruber* (Noack, 1893) (n = 15) and then *Rousettus aegyptiacus* (E. Geoffroy, 1810) (n = 13). In elevational range II (750–1,000 m a.s.l.), we recorded 9 species, belonging to Pteropodidae, Hipposideridae, Rhinolophidae and Nycteridae. *Rhinolophus landeri* Martin, 1838 was the most frequently captured bat (n = 28), followed by *Hipposideros ruber* (n = 26) and then *Rhinolophus simulator* K. Andersen, 1904 (n =

22). At elevational range IV (1,250–1,500 m) we recorded 5 species, represented by the families Pteropodidae and Rhinolophidae. Elevation range VI (> 1,750 m a.s.l.) was the least diverse, with 3 species (*Pipistrellus nanulus*, *Rhinolophus landeri* and *Micropteropus pusillus*). There was considerable difference in species diversity and abundance across the different elevational ranges (Table 1; Fig. 2).

Species similarity along the elevational gradient

The Sorensen/Bray Curtis similarity test revealed that the bat community structure of the six different elevational ranges were similar (r -value = 0.8395) (Fig. 4). Range I (< 750 m) and range II (750–1,000 m) form a similar cluster, and range III (1,000–1,250 m) and range IV (1,250–1,500 m) also form a similar cluster, indicating

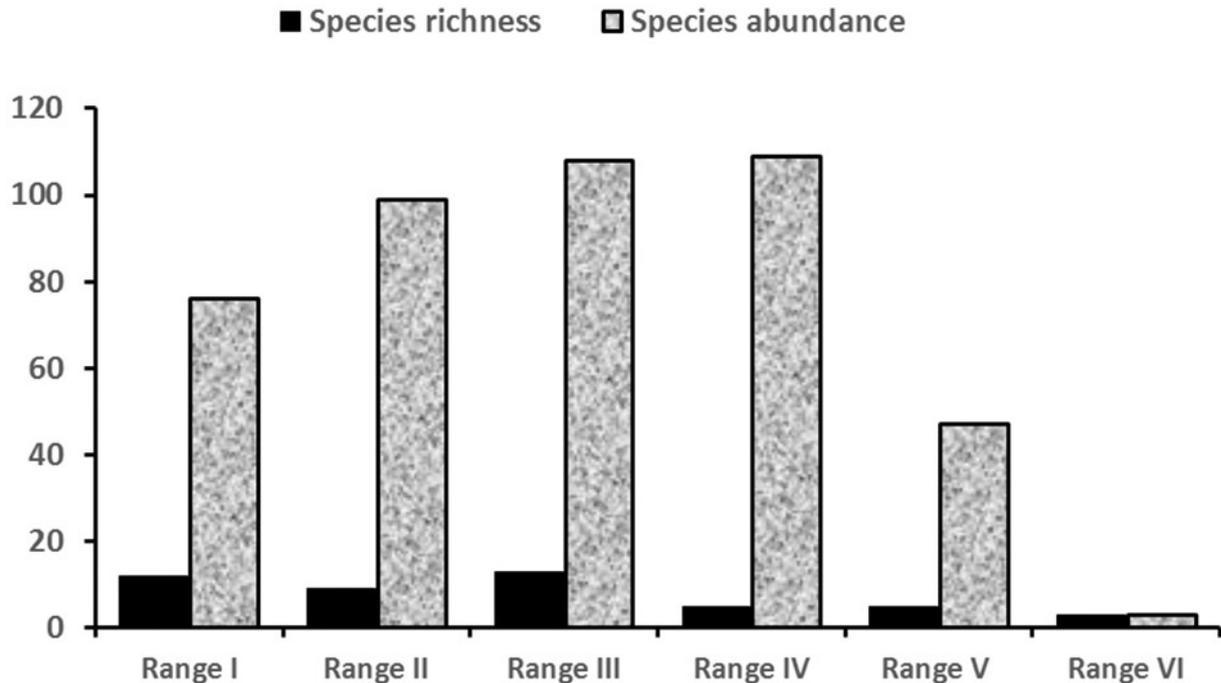


Fig. 2. Species diversity and abundance recorded at each elevational range in the West Region of Cameroon from November 2016 to November 2018.

Species richness and diversity along the elevational gradient

Estimated species richness using Chao 1 (mean), ACE (mean), Jack 1 (mean) and Bootstrap (mean) is 31.9; 38.5; 36.7; and 30.2 species respectively. The average (\bar{x}) of these four estimators is 34.3 species. The species accumulation curve in the study area did not reach an asymptote (Fig. 3), indicating that our sampling was incomplete. The sample efficiency was 72.8 %, which indicates that additional survey work is needed. The results of the non-parametric one-way Kruskal-Wallis ANOVA showed that mean species abundance of the six altitudinal ranges did not differ statistically significantly at $p < 0.05$ level ($\chi^2 = 2.8651$, $df = 5$, $P = 0.7208$). There was also no statistically significant difference in species richness between elevational ranges ($\chi^2 = 0.38798$, $df = 3$, $p = 0.9427$).

similarity in bat community structure. The dendrogram also indicates that bat community structure of elevational range V (1,500–1,750 m a.s.l.) and elevational range IV was quite different from the cluster formed by range I (< 750 m) and range II (750–1,000 m) and that formed by range III (1,000–1,250 m) and range IV (1,250–1,500 m) (Fig. 4).

Altitudinal species richness and abundance relationship

The results of the Generalized Linear Mixed-effects Modes (GLMMS) showed that there is variation in bat species richness and abundance along the altitudinal gradient. There is also a negative relationship between bat species richness and altitude. Indeed, it summarizes the output of the binary logistic model used to discern the potential effects of some altitudinal range on the observed

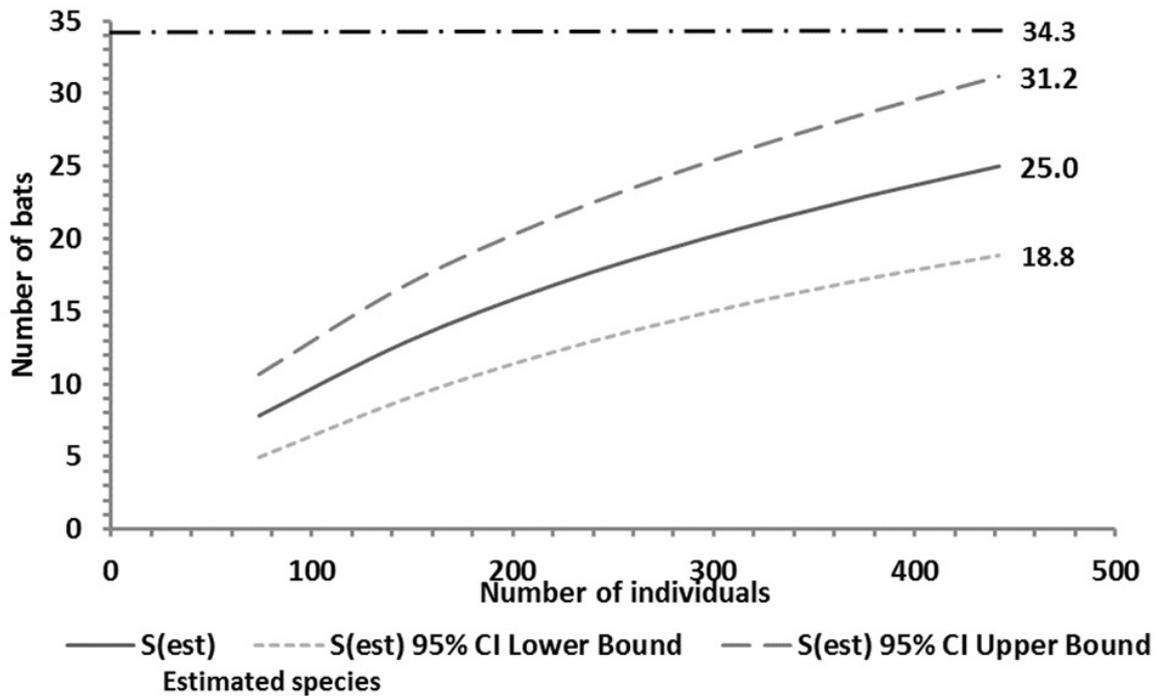


Fig. 3. Species accumulation curve of bats captured in the West Region of Cameroon from November 2016 to November 2018. Horizontal line (34.3) = average of four species richness estimators.

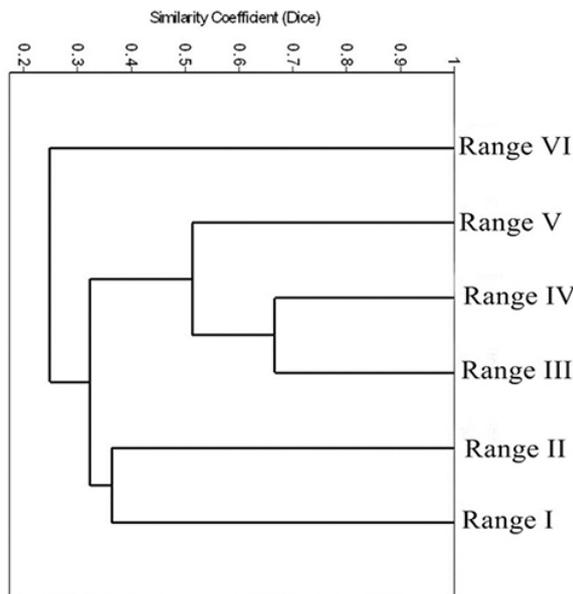


Fig. 4. Sorensen/Bray – Curtis similarity test Dendrogram for altitudinal ranges of bats captured in the West region of Cameroon from November 2016 to November 2018.

total species richness. The model showed no statistically significant difference in species richness at $p < 0.05$ level among the six elevational ranges (estimate = 0.757 ± 0.357 , $t = 2.118$, $p = 0.0341$). The smallest t-value found between the elevational ranges I and III, showed no statistically significant difference in species composition. The t-values of comparisons of the species composition between the groups, IV, V and VI showed the highest difference.

Abundance was positively correlated with elevational ranges I, IV and VI respectively (estimate = 1.216 ± 0.195 , $z = 6.227$, $P < 0.001$), (estimate = 0.824 ± 0.360 , $z = 2.290$, $P = 0.02200$) and (estimate = -1.620 ± 0.701 , $z = -2.309$, $p = 0.02092$). However, the elevational range III and V respectively (estimate = -0.17492 , $z = -1.084$, $p = 0.27815$), (estimate = -0.39744 , $z = -0.992$, $p = 0.32107$) were negatively correlated with altitude.

DISCUSSION

Our data show that bat species richness in the western region of Cameroon shows a low-plateau with a mid-elevational peak at elevational range III (1,000–1,250 m a.s.l.), after which species richness declines (Table 1). A low-plateau with a mid-elevational peak was also observed for bats at Mount Mulanje, Malawi (Curran et al.

2012). A number of hypotheses have been proposed to explain the decrease in species richness with altitude among which the most frequently cited explanations include the mid-domain effect (MDE) (Rahbek 1997) and environmental factors such as climatic variables, productivity and habitat heterogeneity (Nogués-Bravo et al. 2008; Sanders & Rahbek 2012). Indeed, Peters et al. (2016) stressed the importance of temperature as the main predictor of species diversity in both plant and animal communities. Furthermore, Peters et al. (2019) specified that variation in species diversity in tropical mountains is mostly driven by the interaction of both climate and human land use changes. The MDE on the other hand suggest that if species ranges are randomly shuffled within a bounded geographical domain free of environmental gradients, ranges overlap increasingly toward the center of the domain, creating a “mid-domain” peak of species richness (Colwell & Hurtt 1994; Colwell & Lees 2000). According to McCain (2009) water availability is higher at lower elevations. More open water leads to an increase in activity of insects and subsequently to an increase in activity of insectivorous bats (Korine & Pinshow 2004). Furthermore, MacArthur & MacArthur (1961) argued that lower elevations may also possess greater structural complexity in vegetation that provide more resources and hence support a larger number of species. However, differences in species richness pattern observed along the elevational gradient may also be explained by the interaction between climatic factors, vegetation structure and anthropic land use. Also, more species were captured at lower and intermediate elevations than at the highest elevation, this can be partly explained by the fact that relatively fewer sites were sampled at higher elevations.

Twenty-five bat species were recorded at different elevational ranges. *Myonycteris angolensis* was the most abundant bat captured. This forest species is common in Cameroon, and was previously recorded in Buea (Matschie 1891), Bibundi, Bonge, Ndiang, (Sjöstedt 1897a, b), Bimbia, Tombel (Eisenraut 1941), Eseka (Haiduk et al. 1981), Ngaoundere (Müller et al. 1981), Dja Reserve (Bakwo Fils 2009), and Mpem and Djim National Park (Atagana et al. 2018). The abundance of this species at mid-elevations may be due to the existence of numerous natural and manmade structures that provide day roosts. Meredith Happold pointed out that *Myonycteris angolensis* is apparently common in some localized areas where fruiting trees and caves or cave-like day roosts are present (Happold 2013a – as *Lissonycteris angolensis*). Indeed, ACR (2018) established that *Myonycteris angolensis* is widely distributed at elevations ranging from sea level to 4000 m a.s.l. in Africa. *Micropteropus pusillus* was recorded in all ranges and its distribution in not homogeneous across the elevation gradient. According to Atagana et al. (2018), *Micropteropus pusillus* is widespread in Cameroon, and inhabits forest, savannah, plantation and ecotone areas. Eisenraut (1973)

also recorded *Micropteropus pusillus* at elevations up to 1,800 m at Mount Manengouba. *Eidolon helvum*, *Rousettus aegyptiacus* and *Myonycteris torquata* were recorded at low and mid-elevations. *Eidolon helvum* was recorded at elevations between 750 m and 1,500 m. Curran et al. (2012) on Mount Mulanje in Malawi recorded *E. helvum* only at mid-elevation (1,220–1,320 m). Indeed, this species also preferred disturbed habitats and forms large colonies around human habitations. *Rousettus aegyptiacus* was only recorded at elevation below 1,250 m and was conspicuously absent at higher altitudes. This result contrast with that obtained in West Africa by Verschuren (1976) and Denys et al. (2013) who reveal the abundance of *Rousettus aegyptiacus* at high elevations. Kwiecinski & Griffiths (1999) showed that the abundance of *Rousettus aegyptiacus* at high elevation may be due to the existence of numerous caves that provide day roost. In Cameroon, this forest species was previously recorded in both primary and secondary forest by Sanborn (1936), Sanderson (1940), Maisel et al. (2001), Bakwo Fils (2009) and Atagana et al. (2018). *Epomops franqueti* (Tomes, 1860) was recorded at mid-altitudes. These findings are similar to those obtained by Eisenraut (1973) who recorded *Epomops franqueti* at an altitude below 1,000 m on Mount Cameroon. Our study recorded only a single individual of *Hypsignathus monstrosus* H. Allen, 1861 at mid-altitudes. According to Bergmans (1989), *Hypsignathus monstrosus* is common in the rainforest, and its abundance is determined by the availability of ripe fruits. This species inhabits areas below 1,800 m and was not recorded beyond this elevation (Happold 2013b).

This study revealed that vespertilionids were recorded in all altitudinal ranges. *Pipistrellus nanulus* Thomas, 1904 and *Neoromicia tenuipinnis* (Peters, 1872) were recorded at high and mid-altitudes respectively. *Pipistrellus cf. grandidieri* (Dobson, 1876) and *Scotoecus hirundo* (de Winton, 1899) were recorded at low altitudes. However, *Neoromicia nana* was recorded at both low and mid-altitudes. According to Soriano (2000), some species of vespertilionids may be better adapted to higher altitudes with colder climate despite their size. Bat species of the family Molossidae were captured at mid-altitudes around man-made structures that provide day roost. These findings corroborate those of McWilliam (1989) and Esbérard (2003) who suggested that there is a high probability of sampling molossids in front of their exit or near possible roosts in roof linings of human residences. Bats of the family Hipposideridae, Rhinolophidae and Nycteridae have a higher richness and abundance in both low and mid-altitudes. Our result is consistent with the findings of Curran et al. (2012) who previously captured a higher amount of bat species of the families Hipposideridae, Rhinolophidae and Nycteridae between 630 and 1,030 m altitude on Mount Mulanje in Malawi. Rosevear (1965), Schober & Grimmberger (1997), Georgiakakis (2010) and Happold & Happold (2013) suggested that

the distribution of some species like *Hipposideros ruber*, *H. fuliginosus*, *Rhinolophus landeri* and *R. simulator* are most consistently associated with day roosts and food availability. Our data reveals the presence of a single individual of *Rhinolophus landeri* Martin, 1838 at high altitude in a cultivated area. At Mount Cameroon, Rosevear (1965) recorded *R. landeri* in montane vegetation at 1,400 m, while Largen et al. (1974) captured it in Ethiopia from 515 to 1,800 m and found no marked altitudinal preference. We recorded only a single individual each of *Hipposideros abae* J. A. Allen, 1917, *H. caffer* (Sundevall, 1846), *Rhinolophus clivosus* Cretzschmar, 1828, and *Nycteris arge* Thomas, 1903 in our study, probably indicating the rarity of these species.

This study has allowed us to obtain data on the distribution of bat species with respect to the landscape of the western region of Cameroon. However, we observed that insectivorous bats are more diversified (18 species) but less abundant (214 individuals) compared to frugivorous bats that are less diverse (seven species), but more abundant (228 individuals). This may be related to a bias in the capture method that involved the use of understory mist nets that are known to be efficient at capturing sub-canopy frugivorous bats (Fleming 1982). Additionally, it is well established that mist nets have good success only in open environments (streams, cultivated farms, clearings) (Martins et al. 2015). As pointed out by Kaňuch & Krištín (2006), Rhinolophidae, Hipposideridae and some Vespertilionidae can easily avoid mist nets because of their efficient echolocation calls. Therefore, for more exhaustive studies we recommend the use of harp traps, echolocation recording and canopy netting to supplement standard mist-netting. Our sampling efficiency was estimated as 72.8%, confirming that additional surveys might significantly improve our chances of recording species new to the area. The similarity found between the elevational ranges IV and V, and between elevation ranges III and IV, V, is probably related to the higher turnover of bat species between these elevations (Martins et al. 2015). According to Lomolino (2001), biotic turnover varies along the elevation gradient and depends directly on the richness of the overlapping community.

In conclusion, our study provides baseline data on the altitudinal ranges of bats in the western region of Cameroon. Species richness and abundance was higher at low and mid-elevations but lower at higher altitudes. This pattern of diversity is probably driven by differences in ecological heterogeneity among the different elevational ranges that provide suitable habitats for a number of species. However, further research may be required to evaluate the impact of different habitats types on populations of bat species in the western region of Cameroon.

ACKNOWLEDGMENTS. We express our appreciation to IDEA WILD for providing field material. Our grateful thanks goes to the lecturers of the Department of Animal Biology Uni-

versity of Maroua for their constructive criticisms and suggestions during field work. The research permit was granted by Cameroon Ministry of Scientific Research and Innovation (Ref: 0000011 /MINRESI /B00 /C00/C10/C14).

REFERENCES

- Aellen V (1952) Contribution à l'Étude des Chiroptères du Cameroun. Mémoires de la Société Neuchâteloise de Sciences Naturelles 8 (1): 1–121
- African Chiroptera Report (2018) African Bats NPC. Pretoria. i–xvi, 1–8028 accessed on December 28, 2009
- Atagana PJ, Bakwo Fils EM, Mbeng DW, Tsague KJA, Kekeunou S (2018) The bat fauna of the Mpem and Djim National Park, Cameroon (Mammalia Chiroptera). Biodiversity Journal 9: 241–254
- Bakwo Fils EM, Bol A Anong D, Badoana TD, Guieké B, Tsala DE, Kuate FA (2014) Diversity of bats of the Far North Region of Cameroon—with two first records for the country. Biodiversity 15 (1): 16–22
- Bakwo Fils EM (2009) Inventaire des Chauves-souris de la Réserve de Biosphère du Dja, Cameroun. Le Vespère 2 (1): 11–20
- Bakwo Fils EM (2010) The Bats of Cameroon: Proving the Benefits of Forgotten Fruit Bats. Bats 28 (2): 11–13
- Bergmans W (1989) Taxonomy and biogeography of African fruit bats (Mammalia, Megachiroptera). The genera *Microp-teropus* Matschie, 1899, *Epomops* Gray, 1870, *Hypsignathus* H. Allen, 1861, *Nanonycteris* Matschie, 1899 and *Plerotes* Andersen, 1910. Beaufortia 39: 89–153
- Brenac P (1988) Evolution de la végétation et du climat dans l'Ouest-Cameroun entre 25 000 et 11 000 ans BP. Inst. fr. Pondichéry, Trav. Sec. Sci. Tech. 75: 91–103
- Colwell RK (2013) Estimate S, version 9; statistical estimation of species richness and shared species from samples. User's guide and application. <http://purl.oclc.org/estimates>
- Colwell RK, Hurtt GC (1994) Nonbiological gradients in species richness and a spurious rapoport effect. The American Naturalist 144: 570–595
- Colwell RK, Lees DC (2000) The mid-domain effect: geometric constraints on the geography of species richness. Trends in Ecology and Evolution 15: 70–76
- Curran M, Kopp M, Beck J, Fahr J (2012) Species diversity of bats along an altitudinal gradient on Mount Mulanje, southern Malawi. Journal of Tropical Ecology 28: 243–253
- Denys C, Kadjo B, Missoup AD, Monadjem A, Aniskine V (2013) New records of bats (Mammalia: Chiroptera) and karyotypes from Guinean Mount Nimba (West Africa). Italian Journal of Zoology 80 (2): 279–290
- Eisentraut M (1941) Beitrag zur Oekologie Kameruner Chiropteren. Mitteilungen aus dem Zoologischen Museum in Berlin 25 (2): 245–273
- Eisentraut M (1973) Die Wirbeltierfauna von Fernando Poo und Westkamerun unter besonderer Berücksichtigung der Bedeutung der pleistozänen Klimaschwankung für die heutige Faunenverbreitung. Bonner Zoologische Monographien 3: 1–428
- Ellena Y, Maryanto I, Suryobroto B (2015) The fruit bats (Megachiroptera, Pteropodidae) from Bawakaraeng mountain, South Sulawesi. Borneo Science 36: 33–43
- Esbérard CEL (2003) Diversidade de morcegos em área de Mata Atlântica regenerada no sudeste do Brasil. Revista Brasileira de Zoociências 5: 189–204

- Estrada A, Coates-Estrada R (2002) Bats in continuous forest, forest fragments and in an agricultural mosaic habitat-land at Los Tuxtlas, Mexico. *Biological Conservation* 103: 237–245
- Fleming TH (1982) Foraging strategies of plant visiting bats. Pp. 287–326 in: Kunz TH (ed.) *Ecology of bats*. New York (NY): Plenum Press
- Flores-Saldaña MG (2008) Estructura de las comunidades de murciélagos en un gradiente ambiental en la Reserva de la Biosfera y Tierra Comunitaria de Origen Pilon Lajas, Bolivia. *Mastozoología Neotropical* 15: 309–322
- Georgiakakis P, Vasilakopoulos P, Mylonas M, Dusso D (2010) Bat species richness and activity over an elevation gradient in Mediterranean Shrublands of Crete. *Hystrix, Italian Journal of Mammalogy* (n.s.) 21(1): 43–56
- Gotelli NJ, Colwell RK (2001) Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecology Letters* 4: 379–391
- Graham GL (1983) Changes in bat species diversity along an elevational gradient up the Peruvian Andes. *Journal of Mammalogy* 64: 559–571
- Graham GL (1990) Bats versus birds: comparisons among Peruvian Volant vertebrate faunas along an elevational gradient. *Journal of Biogeography* 17: 657–668
- Haiduk MW, Baker RJ, Robbins LW, Schlitter DA (1981) Chromosomal evolution in African Megachiroptera: G- and C-band assessment of the magnitude of change in similar standard karyotypes. *Cytogenetics and Cell Genetics* 29: 221–232
- Happold, M (2013a) *Lissonycteris angolensis* Angolan Soft-furred Bat. Pp. 263–265 in: Happold M & Happold DCD (eds) *Mammals of Africa Volume IV: Hedgehogs, shrews and bats*. Bloomsbury Publishing, London
- Happold, M (2013b). *Hypsignathus monstrosus* Hammer-headed Fruit Bat. Pp. 260–262 in: Happold M & Happold DCD (eds) *Mammals of Africa Volume IV: Hedgehogs, shrews and bats*. Bloomsbury Publishing, London
- Hayman RW, Hill JE (1971) *The Mammals of Africa: An identification manual. Part 2. Order Chiroptera*. Smithsonian Institution Press. Washington, D. C.
- Jaberg C, Guisan A (2001) Modelling the distribution of bats in relation to landscape structure in a temperate mountain environment. *Journal of Applied Ecology* 38(6):1169–1181
- Kaňuch P, Krištín A (2006) Altitudinal distribution of bats in the Polana Mts area (Central Slovakia). *Biologia, Bratislava* 61 (5): 605–610
- Korine C, Pinshow B (2004) Guild structure, foraging space use, and distribution in a community of insectivorous bats in the Negev Desert. *J. Zool., Lond.* 262: 187–196
- Kwieceński G, Griffith's TA (1999) *Rousettus aegyptiacus* [sic]. *Mammalian Species* 611: 1–9
- Largen MG, Kock D, Yalden DW (1974) Catalogue of the mammals of Ethiopia. I. Chiroptera. *Monitore Zoologico Italiano (N.S.)*, Supplemento V. 16: 221–298
- Lomolino MV (2001) Elevation gradients of species-density: historical and prospective views. *Global Ecology and Biogeography* 10: 3–13
- MacArthur RH, MacArthur JW (1961) On bird species diversity. *Ecology* 42: 594–598. <https://doi.org/10.2307/1932254>
- Magurran AE, McGill BJ (2011) *Biological Diversity: Frontiers in Measurement and Assessment*. Oxford University Press Inc, New York, USA
- Maisels F, Keming E, Kemei M, Toh C (2001) The extirpation of large mammals and implications for montane forest conservation: The case of the Kilum-Ijim Forest, North-west Province, Cameroon. *Oryx* 35: 322–331
- Martins MA, de Carvalho WD, Dias D, Franca de SD, de Oliveira MB (2015) Bat species richness (Mammalia, Chiroptera) along an elevational gradient in the Atlantic Forest of Southeastern Brazil. *Acta Chiropterologica* 17 (2): 401–409
- Matschie P (1891) Ueber einige Säugetiere von Kamerun und dessen Hinterlande. *Archiv für Naturgeschichte* 57: 351–356
- Mayara AM, William DDC, Daniela D, Débora DSF, Marcione BDO, Adriano LP (2015) Bat Species Richness (Mammalia, Chiroptera) Along an Elevational Gradient in the Atlantic Forest of Southeastern Brazil. *Acta Chiropterologica* 17 (2): 401–409
- McCain CM (2005) Elevational gradients in diversity of small mammals. *Ecology* 86: 366–372
- McCain CM (2007) could temperature and water availability drive elevational species richness patterns? A global case study for bats. *Global Ecology and Biogeography* 16: 1–13
- McCain CM (2009) Global analysis of bird elevational diversity. *Global Ecology and Biogeography* 18: 346–360. <https://doi.org/10.1111/j.1466-8238.2008.00443.x>
- McWilliam AN (1989) Emergence behavior of the bat *Tadarida (Chaerophon) pumila* (Chiroptera: Molossidae) in Ghana, West Africa. *Journal of Zoology, London* 219: 698–701.
- MINEPAT (2010) Rapport Régional de Progrès des Objectifs du Millénaire pour le Développement: Région de l'Ouest
- Müller P, Nagel P, Flacke W (1981) Ecological side effects of dieldrin application against tsetse flies in Adamaoua, Cameroon. *Oecologia* 50: 187–194
- Nogués-Bravo D, Araújo MB, Romdal T, Rahbek C (2008) Scale effects and human impact on the elevational species richness gradients. *Nature* 453: 216–219
- Olivry JC (1975) Régimes Hydrologiques en Pays Bamiléké (Cameroun). Thèse Présentée à l'Université des Sciences et Techniques du Languedoc pour obtenir le grade de Docteur de Spécialité (Géologie Appliquée, mention Hydrologie) 3^{ème} Cycle
- Patterson BD, Pacheco V, Solari S (1996) Distribution of bats along an elevational gradient in the Andes of south-eastern Peru. *Journal of Zoology* 240: 637–658
- Patterson BD, Webala PW (2012) *Keys to the East African Bats*. Fieldiana: Life and Earth Sciences (Museum of Natural History)
- Peters MK; Hemp A, Appelhans T, Behler C, Classen A, Ensslin A, Ferger S, Helbig-Bonitz M, Hemp C, Kindeketa WJ, Mwangomo E, Ngeresa C, Röder J, Rutten G, Schellenberger Costa D, Zancolli G, Eardley CD, Eardley CD, Peters R, Ssymank A, Kakengi VA, Zhang J, Böhning-Gaese K, Brandl R, Kalko E, Kleyer M, Nauss T, Tschapka M, Fischer M, Steffan-Dewenter I (2016) Predictors of elevational biodiversity gradients change from single taxa to the multi-taxa community level, *Nature Communications* 7. <https://doi.org/10.1038/ncomms13736>
- Peters MK, Hemp A, Appelhans T, Becker JN, Behler C, Classen A, Detsch F, Ensslin A, Ferger SW, Frederiksen SB; Gebert F, Gerschlaue F, Gütlein A, Helbig-Bonitz M, Hemp C, Kindeketa WJ, Kühnel A, Mayr AV, Mwangomo E, Ngeresa C, Njovu HK, Otte I, Pabst H, Renner M, Röder J, Rutten G, Costa DS, Sierra-Cornejo N, Vollstädt MGR, Dulle HI, Eardley CD, Howell KM, Keller A, Peters RS, Ssymank A, Kakengi V, Zhang J, Bogner C, Böhning-Gaese K, Brandl R, Hertel D, Huwe B, Kiese R, Kleyer M, Kuzyakov Y, Nauss T, Schleuning M, Tschapka M, Fischer M, Steffan-Dewenter I (2019) Climate-land-use interactions shape tropical

- mountain biodiversity and ecosystem functions. *Nature* 568 (7750): 88–92
- Pinares SEV (2006) Análisis de distribución altitudinal de mamíferos pequeños en el Parque Nacional Yanachaga Chémillén, Pasco, Perú. M.Sc. Tesis, Facultad de Ciencias Biológicas, Universidad Nacional Mayor de San Marcos, Lima
- R Core Team (2016) A language and environment for Statistical Computing. R foundation for Statistical Computing, Vienna, Austria. ISBN3-900051-07-0
- Rahbek C (1997) The relationship among area, elevation, and elevational gradients: species richness of small mammals in regional species richness in Neotropical birds. *American Naturalist* 149: 875–902
- Rivière Y (2000) Paysages et Agroforets en Pays Bamiléké (Ouest-Cameroun) Mémoire de stage en «Gestion des Systèmes Agro-Sylvo-Pastoraux en Zones Tropicales». Université de Dschang, Cameroun et Université de Paris-Val-de-Marne
- Rosevear DR (1965) The Bats of West Africa, Trustees of the British Museum (Natural History), London, 401 pp.
- Sanborn CC (1936) Descriptions and records of African bats. Field Museum of Natural History. Zoological series 20: 107–114
- Sánchez-Cordero V (2001) Elevation gradients of diversity for rodents and bats in Oaxaca, Mexico. *Global Ecology and Biogeography* 10: 63–76
- Sanders NJ, Rahbek C (2012) The patterns and causes of elevational diversity gradients. *Ecography* 35: 13. <https://doi.org/10.1111/j.1600-0587.2011.07338.x>
- Sanderson IT (1940) The mammals of the North Cameroons Forest Area. Being the results of the Percy Sladen Expedition to the Mamfe Division of the British Cameroons. *Transactions of the Zoological Society of London* 24: 623–725
- Schober W, Grimmberger E (1997) The Bats of Europe and North America. T.F.H. Publications, Neptune
- Sjöstedt Y (1897a) Säugetiere aus Kamerun, West-Afrika. *Bintang Till Kungl. Svenska Vetenskap-Akademiens Handlingar* 423: 1–50
- Sjöstedt Y (1897b) Die Säugethiere des nordwestlichen Kamerungebietes. *Kungl. Svenska vetenskap-sakademiens handlingar* 10: 22 pp.
- Sorenson T (1948) A method of establishing groups of equal amplitudes in plant sociology based on similarity of species content and its application to analyses of the vegetation on Danish commons. *Kongelige Danske Videnskabernes Selskab, Biologiske Skrifter* 5: 1–34
- Soriano PJ (2000) Functional structure of bat communities in tropical rainforests and Andean cloud forests. *Ecotropicos* 13: 1–20
- Temgoua LF (2011) Déterminants socio-économiques et écologiques de la plantation d'arbres producteurs de bois d'œuvre et d'artisanat dans l'Ouest du Cameroun. Thèse de Doctorat en «Géographie tropicale», Université Michel de Montaigne Bordeaux 3, Bordeaux, France
- Verschuren J (1976) Les cheiroptères du Mont Nimba (Liberia). *Mammalia* 40: 615–632
- Weier SM, Valerie MGL, Gaigher I, Patrick JCW, Taylor PJ (2016) Changes of bat species composition over altitudinal gradients on northern and southern aspects of the Soutpansberg mountain range, South Africa. *Mammalia* 81: 49–60