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Status and habitat preferences of montane endemic skinks, genera *Lacertaspis*, *Leptosiaphos*, and *Trachylepis*, in the central Cameroon Volcanic Line

M. Marina Kameni N.[1,*], LeGrand N. Gonwouo[1], Walter P. Tapondjou N.[2], Arnaud M. Tchassem F.[1], Thomas Doherty-Bone[3], Kaitlin E. Allen[2], and Abraham Fomena[4]

Abstract. Montane species in the tropics are characterized by high endemicity and small range sizes and are thus vulnerable to habitat loss and climate change. Due to lack of data on habitat requirements, there is no effective conservation action plan on endemic skinks of the Cameroon Volcanic Line (CVL), despite the likelihood of severe threats from anthropogenic activities and the fact that their populations are declining. In this study, we assessed habitat and microhabitat associations of montane skinks (genera *Lacertaspis*, *Leptosiaphos*, and *Trachylepis*) along the CVL on Mts. Oku, Bamboutos, and Manengouba. Skinks were sampled over a two-year period at elevations of 1500–3000 m using visual encounter surveys. Rare species we encountered included *La. lepesmei* and *Le. pauliani*, while the most common species included *Le. ianthinoxantha* and *Le. vigintiserierum*. *Lacertaspis lepesmei* and *T. mekuana* were recorded only on Mt. Bamboutos, supporting their endemicity to this mountain, though *T. mekuana* has also been recorded on one adjacent mountain (Mt. Lefo). Most skink species were abundant in grassland habitat with only *La. chriswildi* exclusively occurring in montane forest. Montane skink species showed a nested elevational range, particularly *La. christwildi*, *La. lepesmei*, and *T. mekuana*, occurring in narrow elevational ranges above 2000 m. The habitats of these species are affected by many human activities, including agricultural encroachment, overgrazing, fires, and climate change. As many of these skink species are dependent on montane forest and grassland, a neglected habitat for conservation in the Afromontane realm, they each warrant prompt conservation assessment.

Key words. Africa, elevation, lizard, montane grassland, Scincidae, skinks

Introduction

Montane ecosystems and their associated biodiversity are under pressure from climate change and shifting land use. This is partly due to their high sensitivity to small changes in temperature (Janzen, 1967; Razgour et al., 2021), with species highly specialized for life at lower temperatures compared to their lowland relatives (Garavito, 2012; Bax et al., 2021). These pressures are exacerbated further by certain characteristics of montane species, including small range size, low population density, and geographically small populations (IUCN, 2016). Many montane skink species have ranges restricted to mountaintops and, therefore, naturally low population sizes.

Successful conservation of montane endemics skink species depends on our ability to protect their habitat (Fischer et al., 2003), especially for those species restricted to a single mountain. Variation in species' geographic ranges is controlled by habitat availability, and the preferential habitat must be examined to understand the causes of variation in species diversity across different localities (Johnson et al., 2006). A habitat preference for mountain forest or grassland is also correlated with prey availability, the incidence of canopy cover, and the presence of preferential microhabitat (Fischer et al., 2003). Disturbance of habitat can have serious long-term negative consequences on a species microhabitat if the preference of the species is not diverse (Pike et al., 2010).

The Cameroon Volcanic Line (CVL) is one of the most important biodiversity hotspots in Africa (Myers et al.,

[1] Laboratory of Zoology, University of Yaoundé I, Yaoundé, Cameroon.
[2] Department of Ecology and Evolutionary Biology, University of Kansas, Lawrence, Kansas 66045, USA.
[3] Conservation Program, Royal Zoological Society of Scotland, 134 Corstorphine Road, Edinburgh, EH12 6TS, Scotland, United Kingdom.
[4] Laboratory of Parasitology, University of Yaoundé I, Yaoundé, Cameroon.
[*] Corresponding author. E-mail address: marinafr05@yahoo.fr

2000; Burgess et al., 2007; Missoup et al., 2012). This sky island archipelago is made up of several peaks that harbour endemic species, including a number of reptiles (Herrmann et al., 2005; Gonwouo et al., 2007; Ineich et al., 2015). The distribution and diversity of Cameroon reptiles have been widely studied during the previous two decades, so far revealing over 274 species spread across the national territory (Chirio and LeBreton, 2007). Within this large checklist, skinks are well represented among the mountain endemic lizards, with eleven species recorded from the CVL (Chirio and LeBreton, 2007). Six of these species have been recorded from three mountains in the centre of the CVL: Mt. Oku is home to *Lacertaspis chriswildi* (Böhme & Schmitz, 1996), Mt. Bamboutos has five species, namely *La. lepesmei* (Angel, 1940), *Leptosiaphos ianthinoxantha* (Böhme, 1975), *Le. vigintiserierum* (Sjöstedt, 1897), *Le. pauliani* (Angel, 1940), and *Trachylepis mekuana* (Chirio & Ineich, 2000), and *Le. ianthinoxantha* and *Le. vigintiserierum* occur on Mt. Manengouba (see Chirio and LeBreton, 2007). The ecology of these montane skinks, such as habitat requirements, is not well known and in need of assessment for conservation planning (Ineich et al., 2015). These three mountains face anthropogenic pressures such as expansion of agriculture, agrochemicals, logging, and livestock grazing (Stewart, 2009; Doherty-Bone and Gvodik, 2017; Tchassem et al., 2021).

Data on skink distributions across the CVL originated from expeditions in the 1990s and mid 2000s (Gartshore, 1986; LeBreton, 1999; Chirio and LeBreton, 2007). These studies were qualitative and short term in nature, with detailed data on ecology lacking. For example, in montane skinks, dependence on forest habitat is not robustly known, though some studies have provided insights on the variation of species' distributions by elevation (Herrmann et al., 2005). These distributional data are in need of updating to re-evaluate the status of montane endemic species, particularly in light of enigmatic frog declines on these same mountains (Hirschfeld et al., 2016; Tchassem et al., 2021). Obtaining accurate data on elevation range is particularly important to trace potential upslope displacements from climate change (*sensu* Raxworthy et al., 2008). As elevational gradients promote the co-occurrence of many species (Lomolino, 2001), it is possible Cameroonian mountain skinks also partition their range based on elevation.

To help create a conservation strategy for endemic skinks in the CVL, the habitat requirements of each species were investigated on three primary mountains, Mts. Oku, Bamboutos, and Manengouba, in western Cameroon. We addressed whether montane skink species persist in their known localities, confirming their distribution (hence endemicity), and assessed preferential habitat and microhabitat. Threats to skink population densities in this mountain range are hypothesized based on initial field observations, and further research is proposed to test these.

Materials and Methods

Study area. The CVL is made of a mountain range in western Cameroon and eastern Nigeria, extending from Mt. Cameroon in southwestern Cameroon to the Adamawa Plateau in the northeast (Gonwouo et al., 2006; Allen et al., 2017). This study was carried out on three mountains of the CVL (Fig. 1), Mt. Oku (3011 m elevation), Mt. Bamboutos (2740 m), and Mt. Manengouba (2411 m). These mountains are situated in northwest, west, and littoral/southwest regions of Cameroon, respectively. They are characterised by different habitat types: montane forest and montane grassland on Mt. Oku (Ineich et al., 2015), gallery forest and montane grassland on Mt. Bamboutos (Tchassem et al., 2021), and a well-developed forest up to the Eboga Caldera at 1800 m elevation and montane grassland up to the top of Mt. Manengouba (Gonwouo et al., 2006; Zangmo et al., 2014). The three mountains are all impacted by anthropogenic activities (Fig. 2), including conversion of montane forest to agriculture and pasture grassland (Doherty-Bone and Gvoždík, 2017; Tchassem et al., 2021).

Surveys. Fieldwork was carried out from March 2015–July 2017 during both rainy and dry seasons. To evaluate elevational distributions, surveys were conducted from 1500–3000 m, following the elevational distribution limits for these montane skinks described by Chirio and LeBreton (2007). Sampling was done using Visual Encounter Surveys, which included direct excavation of microhabitats by lifting rocks, shrubs, and logs (Crump and Scott, 1994), all of which were restored to minimize habitat alteration. For each specimen collected, type of habitat (savannah or montane forest), nature of microhabitat (leaf litter, under or on rocks, grass or moving on the ground), degradation level of the habitat (low or high), canopy cover (open, closed or partially open), season, time of day, and GPS coordinates were recorded. Specimens were identified using available identification keys, measured, and released in the same area (Böhme and Schmitz, 1996; Chirio and LeBreton, 2007; Gonwouo et al., 2007; Ineich et al., 2015).

Data analysis. Data analysis considered only montane skink species (*Lacertaspis*, *Leptosiaphos*, *Trachylepis*)

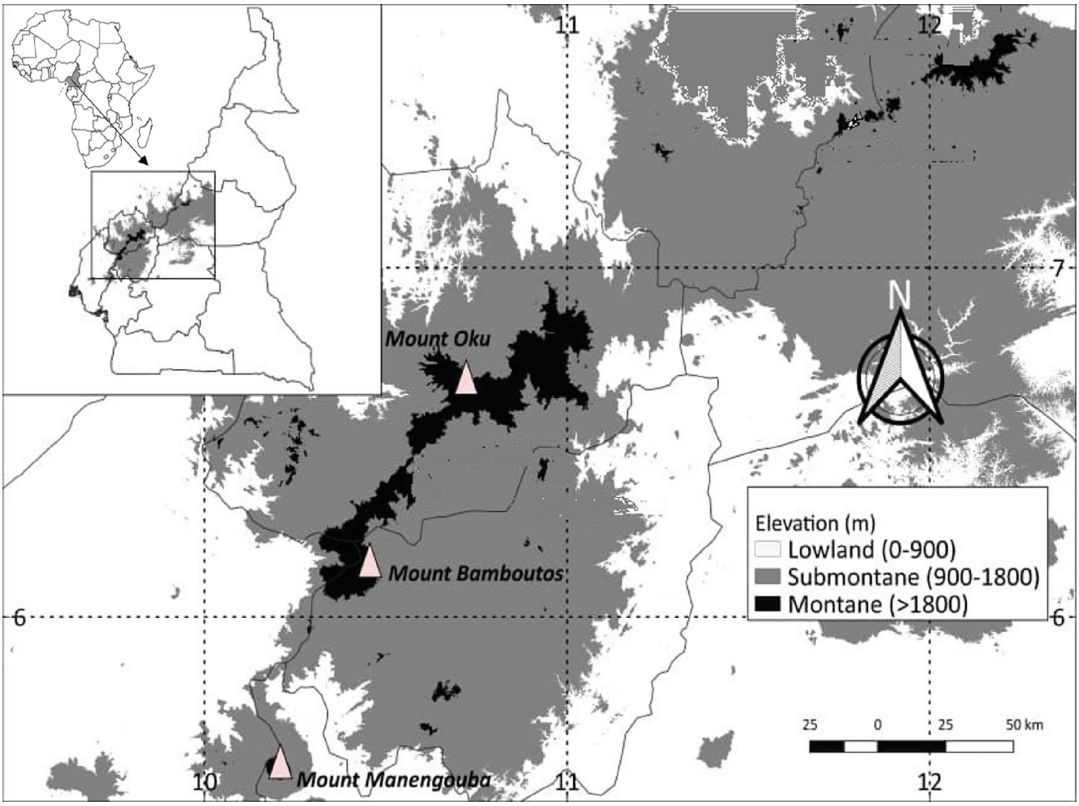

Figure 1. Map of the Cameroon Volcanic Line study area, with white triangles indicating Mts. Oku, Bamboutos, and Manengouba.

encountered at elevations ranging from 1500–3000 m. Species with broader, lowland distributions, such as *T. maculilabris* (Gray, 1845) and *Mochlus fernandi* (Burton, 1836), were encountered but not included in the analysis. We estimated species frequency categories following the classification of Duellman (1965) and Gonwouo et al. (2007), defining abundant (A, > 10 individuals), moderately abundant (M, 4–10 individuals), and rare (R, 1–3 individuals) for the observed individuals. To test the association between species and habitat/microhabitat, a correspondence analysis was undertaken using the R packages *FactoMineR* and *factoextra* (Lê et al., 2008). We also incorporated the parameters season, microhabitat, and elevation into a series of generalized linear models (GLM) to assess their individual or combined influence on the abundance of skink species with more than five records. The best-performing model is the one with the smallest Akaike's Information Criterion (AIC; Mazerolle, 2004). All analyses were performed with the statistical software R v. 4.0.3 (R Core Team, 2020).

Results

A total of 256 endemics skinks from seven species (Fig. 2) in three genera were recorded during the research period (Table 1). Mt. Bamboutos was the most diverse site with seven species, followed by Mt. Manengouba with three species, and Mt. Oku with only one species (*La. chriswildi*). On Mt. Bamboutos, the montane skink community consisted of *Le. ianthinoxantha* (42.2% of collected individuals), *Le. vigintiserierum* (28.5%), *T. mekuana* (19.8%), *La. chriswildi* (5.2%), *La. lepesmei* (1.7%), a currently unidentified species of *Trachylepis* (1.7%), and *Le. pauliani* (0.9%). On Mt. Manengouba, the skink community consisted of *Le. ianthinoxantha* (50.0%), *Le. vigintiserierum* (41.4%), and *Le. pauliani* (8.6%). Our records of *La. chriswildi* and *Le. pauliani* are the first for Mts. Bamboutos and Manengouba, respectively. The majority of specimens (91.0%) was obtained by excavation, with the remaining 9.0% observed actively moving across their habitat.

Montane skink species showed stratification in elevational range from medium elevations to high elevations (Fig. 3). *Trachylepis mekuana* occurred

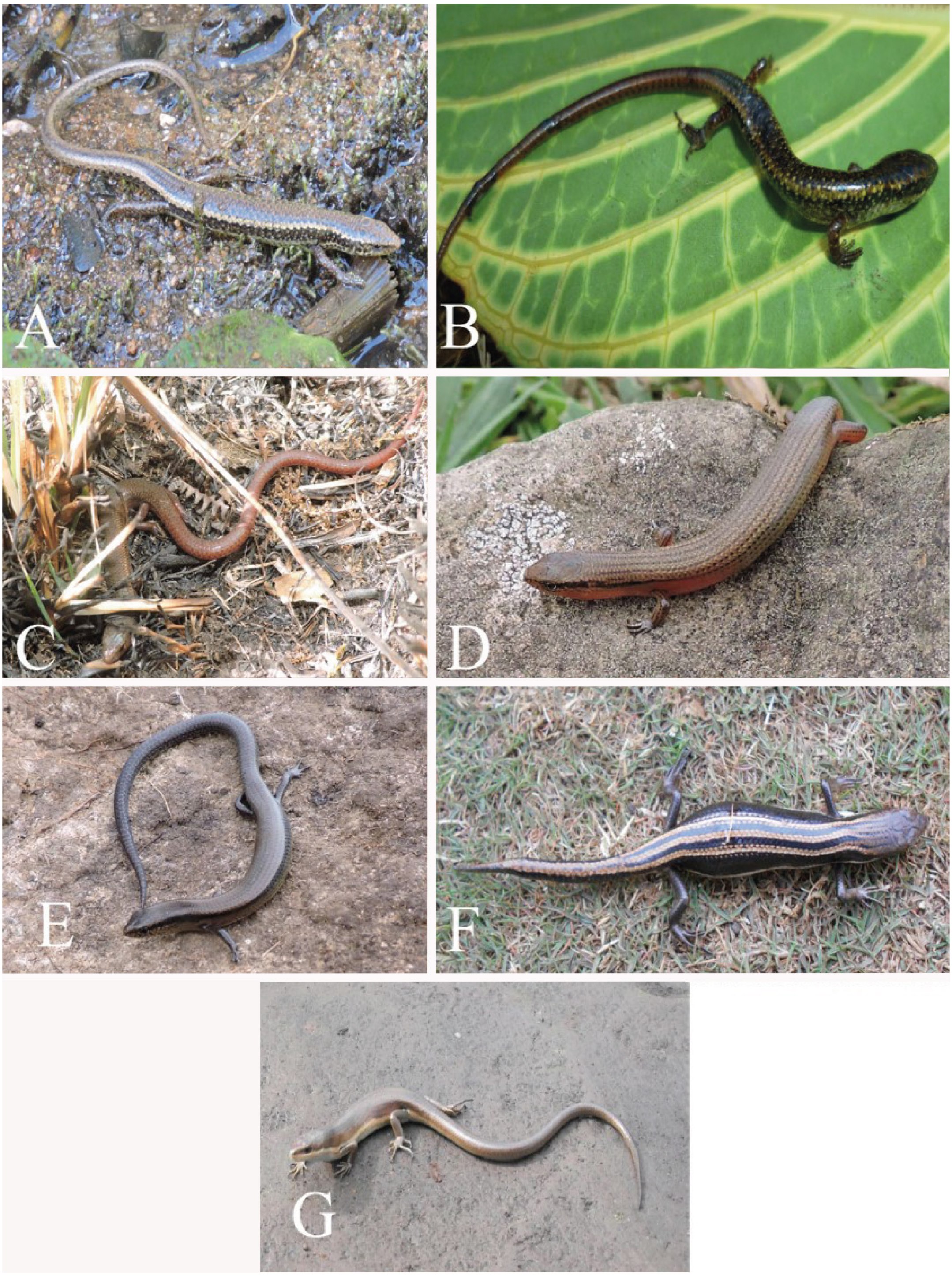

Figure 2. Montane skink species surveyed in the study. (A) *Lacertaspis chriswildi*. (B) *La. lepesmei*. (C) *Leptosiaphos ianthinoxantha*. (D) *La. pauliani*. (E) *Le. vigintiserierum*. (F) *Trachylepis mekuana*. (G) *Trachylepis* sp.

Table 1. Abundance and distribution of seven skink species (genera *Lacertaspis*, *Leptosiaphos*, and *Trachylepis*) sampled on three mountains in Cameroon. Superscripted letters indicate relative abundance (see text), with A = abundant, M = moderately abundant, and R = rare.

Taxa	**Locality**			
	Mt. Manengouba	**Mt. Oku**	**Mt. Bamboutos**	**Total**
Lacertaspis chriswildi		12^{A}	6^{M}	18^{A}
Lacertaspis lepesmei			2^{R}	2^{R}
Leptosiaphos ianthinoxantha	64^{A}		49^{A}	113^{A}
Leptosiaphos pauliani	11^{A}		1^{R}	12^{A}
Leptosiaphos vigintiserierum	53^{A}		33^{A}	86^{A}
Trachylepis mekuana			23^{A}	23^{A}
Trachylepis sp.			2^{R}	2^{R}
Total	128	12	116	256

at higher elevations with a narrower range, followed by *Trachylepis* sp. and *La. chriswildi*. *Leptosiaphos ianthnoxantha* and *Le. vigintiserierum* were observed at an elevation range of 1500–2700 m, whereas *Le. pauliani* occurred at the lowest of the sampled elevations.

The Pearson's Chi-square test of the correspondence analysis shows a high dependence of each skink species on a specific habitat type ($\chi^2 = 211.68$, $df = 12$, $p < 0.001$) and on a particular microhabitat ($\chi^2 = 263.37$, $df = 24$, $p < 0.001$). *Leptosiaphos vigintiserierum* and *Le. ianthinoxantha* shared both grassland and rocky stream banks (rupicolous areas), while *Le. pauliani* occurred in grassland areas. *Trachylepis mekuana*, *Trachylepis* sp., and *La. lepesmei* are highly associated with rupicolous areas. *Lacertaspis chriswildi* was highly associated with forest (Fig. 4A).

Concerning associations with microhabitats, *La. chriswildi* was frequently associated with riverbanks, where its eggs were also found, indicating that this microhabitat is used for breeding. *Lacertaspis lepesmei*, *Le. ianthinoxantha*, *Le. vigintiserierum*, and *Le. pauliani* were mostly observed under rocks, and *T. mekuana* was often associated with open ground where they were mostly observed basking (Fig. 4B).

The result of the GLM on abundances for all species with at least five observations show a significant effect of season on two species of skinks (*La. chriswildi* and *Le. pauliani*). These species were observed more often in the rainy season than the dry season. The other parameters (i.e., elevation and microhabitat) did not influence the abundance of each species (Table 2). The best models that predicted the occurrence of *La. chriswildi* were habitat or

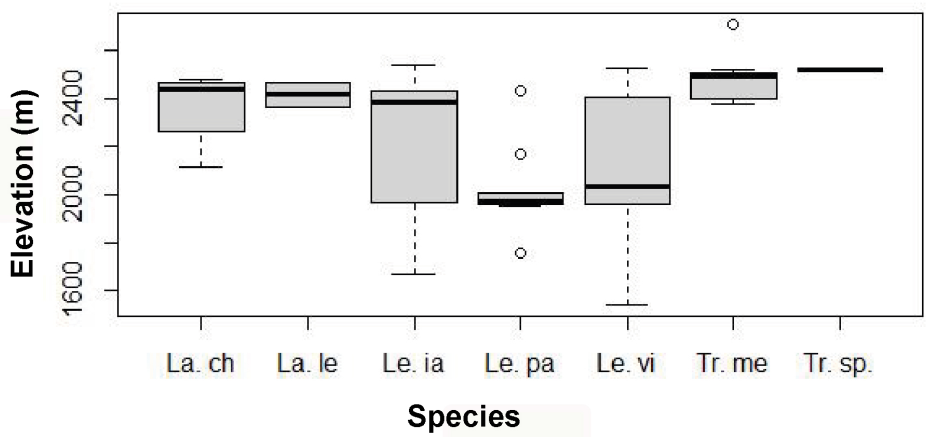

Figure 3. Elevational distribution of montane skink species. Abbreviations are for *Lacertaspis chriswildi* (La.ch), *La. lepesmei* (La.le), *Leptosiaphos ianthinoxantha* (Le.ia), *Le. pauliani* (Le.pa), *Le. vigintiserierum* (Le.vi), *Trachylepis mekuana* (Tr.me), and *Trachylepis* sp. (Tr.sp).

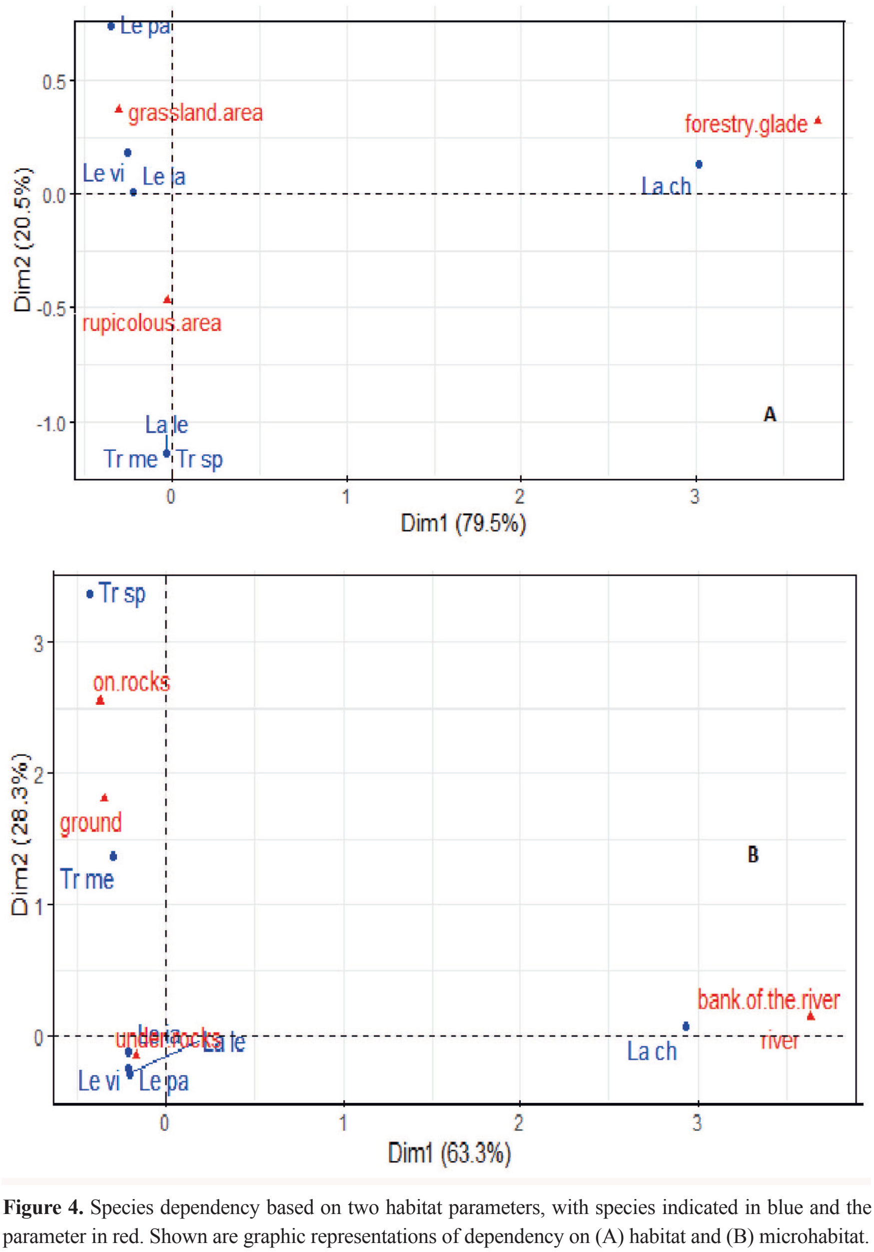

Figure 4. Species dependency based on two habitat parameters, with species indicated in blue and the parameter in red. Shown are graphic representations of dependency on (A) habitat and (B) microhabitat.

season. Microhabitat or season provided the best model predicting the presence of *Le. ianthinoxantha*. Elevation, season, and microhabitat also significantly influenced the model for *Le. pauliani* and *Le. vigintisserierum*. Season and microhabitat combined, or only elevation or season, provided the model with the best fit (i.e., the lowest AIC) for *T. mekuana*. For no species did a single parameter provide the best-performing model.

Discussion

This study reappraised the ecology of endemic montane skinks from three mountains in the CVL over a two-year period, gathering data on their habitat use. Studies that assess the ecology and preferential habitat of skinks are lacking in Cameroon, except for some shorter term, qualitative studies from the past two decade (Gartshore, 1986; Herrmann et al., 2005; Ineich et al., 2015). The skink diversity sampled during this study represents 60%

Table 2. Generalized linear models comparing parameters influencing abundance of each surveyed skink species on the three mountains, showing degrees of freedom (*df*), residual deviance (RD), *p*-value, the Akaike Information Criterion (AIC), and the difference from the best-performing model (ΔAIC). The best-performing models have ΔAIC values of zero.

Model Parameters	*df*	RD	*p*	AIC	ΔAIC
Lacertaspis chriswildi					
Elevation	12	6.3632	0.41	38	1
Season	11	1.3114	0.02*	39	2
Microhabitat	10	1.2852	0.87	41	4
Elevation * season	9	0.0000	0.27	37	0
Elevation * microhabitat	9	0.0000	0.27	41	4
Season * microhabitat	9	0.0000	0.27	39	2
Elevation * season * microhabitat	9	0.0000	0.27	39	2
Leptosiaphos ianthinoxantha					
Elevation	97	9.5786	0.69	226	3
Season	96	9.5786	1.00	223	0
Microhabitat	95	9.5786	1.00	223	0
Elevation * season	94	9.5786	1.00	230	7
Elevation * microhabitat	93	9.5786	1.00	230	7
Season * microhabitat	92	9.5786	1.00	227	4
Elevation * season * microhabitat	92	9.5786	1.00	236	13
Leptosiaphos pauliani					
Elevation	12	6.3632	0.40	39	0
Season	11	1.3114	0.02*	39	0
Microhabitat	10	1.2852	0.87	41	2
Elevation * season	9	0.0000	0.26	41	2
Elevation *microhabitat	9	0.0000	0.26	41	2
Season * microhabitat	9	0.0000	0.26	41	2
Elevation * season * microhabitat	9	0.0000	0.26	39	0
Leptosiaphos vigintiserierum					
Elevation	71	9.904	0.74	174	137
Season	70	9.904	1.00	171	137
Microhabitat	69	9.904	1.00	171	137
Elevation * season	69	9.904	1.00	41	0
Elevation * microhabitat	69	9.904	1.00	41	0
Season * microhabitat	69	9.904	1.00	41	0
Elevation * season * microhabitat	69	9.904	1.00	178	137
Trachylepis mekuana					
Elevation	21	0.000	1.00	50	0
Season	20	0.000	1.00	50	0
Microhabitat	18	0.000	1.00	52	2
Elevation * season	17	0.000	1.00	54	4
Elevation * microhabitat	15	0.000	1.00	58	8
Season * microhabitat	15	0.000	1.00	56	6
Elevation * season * microhabitat	15	0.000	1.00	63	13

(seven) of the 11 estimated Cameroon mountain endemic skinks (Chirio and LeBreton, 2007). Range extensions of some species were recorded from certain mountains, such as *La. chriswildi* on Mt. Bamboutos and *Le. pauliani* on Mt. Manengouba. Mt. Bamboutos harbours significant species diversity of skinks despite suffering greater anthropogenic pressures observed during this study than Mts. Manengouba and Oku (Hirschfeld et al., 2016; Doherty-Bone and Gvoždík, 2017; Tchassem et al., 2021). The confirmed forest-dependence of *La. chriswildi* further highlights the need for forest conservation on Mts. Bamboutos and Oku, as well as elsewhere in the CVL (Gartshore, 1986; Ineich et al., 2015).

Some of the lower elevation distribution limits previously recorded for montane skinks were not corroborated in this study (*Le. pauliani* and *Le. vigintisserierum*). This may be explained by pressures of anthropogenic activities at lower elevations combined with climate change (Lynn and Lindle, 2002; Kutt and Woinarski, 2007). It is also notable that one of the predicted biological responses to climate warming is the upslope displacement of species distributions (Raxworthy et al., 2008). This may be the case for *La. chriswildi*, which was not found at elevations below 2000 m during this study despite its known 1000–2800 m range (Ineich et al., 2015). It is also possible that the time and the period of sampling facilitate the observation of more individuals at different altitudes (Table 3). Some species extend their ranges in search of food and more preferential habitats (Pawar, 1999; Driscoll, 2004; Bell and Donnelly, 2006; Bickford et al., 2010; Lopez-Alcaide and Macip-Rios, 2011). *Trachylepis mekuana* was not found at higher elevations on Mt. Oku as suspected by Chirio and LeBreton (2007), despite the presence of the species' preferential habitat. To understand this absence, further studies on abiotic and biotic factors, such as egg deposition/nursery sites (e.g., under rocks and logs) are necessary. The presence of *Le. pauliani* on Mt. Manengouba differed from observations by previous researchers that observed the species on Mts. Bamboutos, Nlonako, and Kupe (Herrmann et al., 2005; Ineich et al., 2015). Mt. Manengouba is a new record for *Le. pauliani* at a similar elevational range than elsewhere. Similarly, our record of *La. chriswildi* on Mt. Bamboutos is new (Herrmann et al., 2005, 2006; Ineich et al., 2015). Finding new populations of endemics skinks on these mountains shows that the distribution ranges might be even wider than previously expected within the CVL (Gvoždík et al., 2018).

Correspondence analysis indicated that skink species appear to be dependent on montane grassland and, to a lesser extent, forest (Fig. 4A). With regard to microhabitat, species like *Le. ianthinoxantha, Le. vigintiserierum*, and *Le. pauliani* were most often found under rocks (Fig. 4B). While some species were found in the same microhabitat (for example, *Le. ianthinoxantha* and *Le. vigintiserierum* were sometimes found under the same rock), most other species were found under different rocks in the same habitat, suggesting competitive exclusivity. These findings support an ecological role as mountain savanna specialists for these species. The dependence of *Trachylepis* on rupicolous microhabitat is likely explained by their use of rocks for thermoregulation, as with montane skinks from other regions (Vitt and Caldwell, 2003; Herrmann et al., 2005; Petford et al., 2019).

This study updates our knowledge about the ecological roles of montane skinks in three mountains at the centre of the CVL, allowing a better understanding of their habitat requirements. The three mountains surveyed are threatened by ongoing anthropogenic activities, notably the expansion of crop cultivation, livestock production, and likely climate change, that could impact endemic skink habitats. Some of the endemic skinks have already been classified nationally as fully protected, such as *La. lepesmei* (MINFOF, 2020). Despite this effort, it is important to protect both mountain savannah and forest habitats. Our findings offer key insights that should inform conservation and policy decisions regarding these species. The apparent upslope migration of certain species as a result of agro-pastoral activities serves as an early warning to protect the remaining savannah and forests of other mountains. The restricted elevational and distribution ranges of *La. lepesmei*, *Le. pauliani*, and *T. mekuana* require further monitoring to determine the exact number of remaining populations and their abundance on different mountains. Species like *Le. pauliani* and *La. lepesmei* were found to be rare in their habitat, indicating low population sizes. *Trachylepis mekuana* is primarily restricted to Mt. Bamboutos, with high abundances around the peak of Mt. Mekua (Allen et al., 2019), although a single specimen was recorded on the lower slopes of Mt. Lefo, suggesting a slightly larger historical range (Ineich et al., 2015).

Mt. Bamboutos faces increasing pressure from agricultural encroachment and pasture burning that leads to deforestation (Tchassem et al., 2021), thus an urgent conservation action plan is required. There have already been calls for conservation interventions on Mt. Bamboutos to protect forest-dependent montane endemic frog species, with few savannah-dependent frogs noted (Tchassem et al., 2021). This study highlights the need to consider montane skink species recorded during this study as part of these plans. This is also the case on

Table 3. Previous distribution records and those found in this study for seven species of montane skinks, showing relevant elevation data along the Cameroon Volcanic Line and IUCN Red List status (NT = Near Threatened, EN = Endangered, VU = Vulnerable). Elevations are provided in metres.

Species	IUCN Status	Previous Distribution	New Records	Published Elevations	Observed Elevations	Sources
Lacertaspis						
chriswildi	NT	Mt. Kupe, Mt. Oku, Takamanda Forest, Tchabal Mbabo Massif	Mt. Bamboutos	1000–2800	2114–2418	Hofer et al., 2000; Sunderland et al., 2003; Herrmann et al., 2007; Ineich et al., 2015
lepesmei	CR	Mt. Bamboutos		2350–2700	2364–2478	Gartshore, 1986; Chirio et al., 2007; Ineich et al., 2015
Leptosiaphos						
ianthinoxantha	VU	Mt. Bamboutos, general Bamenda Highlands	Mt. Manengouba	1300–2700	1668–2543	Gartshore, 1986; Chirio et al., 2007; Ineich et al., 2015
pauliani	EN	Mt. Bamboutos, Mt. Kupe (Nyassosso; Mt Nlonako)	Mt. Manengouba	1300–2000	1760–2432	Gartshore, 1986; Hofer et al., 2000; Herrmann et al., 2005; Ineich et al., 2015
vigintiserierum	NT	Mt. Manengouba; Mt. Nlonako; Mt. Bamboutos; Mt. Oku; Mt. Cameroon		1000–2450	1543–2524	Gartshore, 1986; Herrmann et al., 2005; Ineich et al., 2015
Trachylepis						
mekuana	EN	Mt. Bamboutos, Bali-Ngemba (Mt. Lefo)	N/A	2400–2700	2380–2708	Chirio et al., 2007; Ineich et al., 2015
sp.	N/A	N/A	Mt. Bamboutos	N/A	2510–2527	N/A

Mts. Oku and Manengouba, with forest protection and restoration needed for *La. chriswildi*, as well as a more fine-scale understanding of grassland biological integrity and structure to inform appropriate management and protection of mountain endemics skinks, which likely have an interaction with livestock practices in these habitats. This highlights the need to conserve a mosaic of habitats in the highlands of Cameroon and elsewhere in Africa's richly biodiverse mountains.

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