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Diversity of mammals in Cerro Páramo Miraflores Regional Park, Huila, Colombia: analysis of structure and composition

Diversidad de mamíferos del Parque Regional Cerro Páramo Miraflores, Huila, Colombia: análisis de su estructura y composición

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The lack of field studies on the biodiversity of the Cerro Páramo de Miraflores Regional Park (PRCPM), Colombia, highlights the importance of obtaining reliable information to improve its management as a protected natural area. To this end, we evaluated the structure and composition of the assemblage of terrestrial and flying mammals of the high Andean and sub-páramo. For the recording of terrestrial and flying small, medium, and large mammals, we set transects of 100 Sherman traps, 8 mist nets, and 39 camera traps in the high Andean and sub-páramo zones of the PRCPM. With the records obtained and indirect traces, we calculated the alpha and beta diversity indices (Fisher's Alpha, Simpson, Shannon-Wiener, Whittaker, and Morisita-Horn). We recorded 21 species; the most abundant species were *Thomasomys dispar* (22.5 %), *T. baeops* (13.75 %), and *Sturnira erythromos* (8.75 %). We also documented flagship species such as *Tremarctos ornatus* and *Puma concolor*, as well as new geographic distribution records of *Neomicroxus bogotensis*, *T. prínceps, Cryptotis squamipes*, and *Histiotus montanus* for the department of Huila. Both zones showed medium diversity (*H'* = 2.317 and 1.885), with species dominance (*D* = 0.8612 and 0.8209) and high species turnover (*B*w = 0.75; I_{M-H} = 0.32). The PRCPM highlands are home to species typical of conserved environments and diverse trophic guilds, which indicate a good state of conservation. The highest similarity in species richness was found with the Perijá and Chingaza mountain ranges, with less than 50 % of species shared among the 11 Colombian Andean páramos. Although its species composition partially matches other páramopáramos, it differs in the mammal assemblage structure.

Key words: Biodiversity; high Andean; mammals; páramo; protected areas.

La falta de estudios en campo sobre la biodiversidad del Parque Regional Cerro Páramo de Miraflores (PRCPM), en Colombia, resalta la importancia de obtener información confiable para mejorar su gestión como área natural protegida. Para esto, evaluamos la estructura y composición del ensamblaje de mamíferos terrestres y voladores de la franja altoandina y de subpáramo. Para el registro de micromamíferos terrestres y voladores, y mamíferos medianos y grandes instalamos transectos de 100 trampas Sherman, 8 redes de niebla y 39 cámaras trampa en las franjas altoandina y de subpáramo del PRCPM. Con los registros obtenidos junto con los rastros indirectos calculamos los índices de diversidad alfa y beta (Alfa de Fisher, Simpson, Shannon-Wiener, Whittaker y Morisita-Horn). Registramos 21 especies, de las cuales *Thomasomys dispar* (22.5 %), *T. baeops* (13.75 %) y *Sturnira erythromos* (8.75 %) fueron las más abundantes. También documentamos la presencia de especies bandera como *Tremarctos ornatus* y *Puma concolor*, además de nuevos registros de distribución geográfica para el departamento del Huila de *Neomicroxus bogotensis*, *T. prínceps, Cryptotis squamipes* e *Histiotus montanus*. Ambas franjas presentaron una diversidad media (H' = 2.317 y 1.885), con dominancia de especies (D = 0.8612 y 0.8209) y alto recambio de especies (B_w = 0.75 I_{M-H} = 0.32). Las tierras altas del PRCPM albergan especies propias de ambientes conservados y diversidad de gremios tróficos, lo que indica su buen estado de conservación. La mayor similitud de riqueza se encontró con la serranía del Perijá y Chingaza, con menos del 50 % de especies compartidas entre los 11 páramos andinos colombianos. Aunque coincide parcialmente en composición de especies con otros páramos, difiere en la estructura del ensamblaje.

Palabras clave: Altoandino; áreas protegidas; biodiversidad; mamíferos; páramo.

Mammals are frequently considered umbrella species because of their habitat needs and ecological functions, which ensure the subsistence of other organisms (Kattan *et al.* 2014; Díaz-Pulido *et al.* 2015). In Colombia, 543 mammal species belonging to 14 orders are reported (Ramírez-Chaves *et al.* 2021), of which 70 species thrive in high-mountain ecosystems (Muñoz-Saba 2015). These ecosystems are classified as high Andean, sub-páramo, páramo, and super páramo, according to the plant cover of the biotope (Rangel-Ch 2000).

Fourty-nine percent of the world's páramos are located in Colombia, covering 1.7 % of the territory with a total area of 1, 932. 395 ha (IAvH 2013; Cabrera and Ramírez 2014; Jiménez-Rivillas *et al.* 2018). Páramos are considered wildlife endemism and diversification centers, as well as one of the most vulnerable biomes due to the heavy exploitation of their resources, which is why they have been called "hotspots" (Garavito Rincón 2015). Although research and conservation efforts have been made in the páramos of central and northern Colombia (López-Arévalo *et al.*

1993; Vargas Ríos and Pedraza 2004; Corredor-Carrillo and Muñoz-Saba 2007; Medina *et al.* 2015; Muñoz-Saba 2015), there are little-explored areas in the south of the country (Trujillo *et al.* 2014). The study of mammal assemblages in high Andean forests and páramos of Colombia has yielded crucial information for the conservation of these unique ecosystems (Moreno 2001; Ramírez and Gutiérrez-Fonseca 2015). One of these areas corresponds to the Cerro Páramo de Miraflores Regional Park (PRCPM, in Spanish), located on the convergence of Amazonian, Andean, and Magdalena basin ecosystems (Armenteras *et al.* 2003).

As of the date of this study, no field research has been published on any aspect of PRCPM biodiversity. In particular, mammal diversity in high-mountain areas above 2,000 m has not been addressed, given the presence of armed groups over the past decades. Management plans and delimitation processes for these areas have been planned from secondary sources (Hofstede 2013; CAM 2017). These approaches have revealed the orders of greatest biological richness, mainly rodents, carnivores, and bats (Mena *et al.* 2012).

The present study, pioneering in the study area, was carried out under the framework of the PRCPM management plan update within the cooperation agreement between the Alto Magdalena Regional Autonomous Corporation (CAM, in Spanish) and the Francisco José de Caldas District University. This study will provide information to infer the conservation status of the high Andean and sub-páramo zones of the PRCPM in the municipality of Garzón, Huila, Colombia, based on the evaluation of the structure and composition of terrestrial and flying mammals.

The PRCPM is located on the western slope of the department of Huila's eastern mountain range, in the municipalities of Algeciras, Garzón, and Gigante. This park has Andean forest and páramo ecosystems, with an annual precipitation of 2,000 mm to 4,000 mm and an altitude of 2,200 m to 3,470 m (Figure 1; Tovar Lizcano and Olaya Amaya 2014). During the sampling carried out in February 2017, we identified 2 sampling zones in the study area, according to the vegetation cover observed in the field: the high Andean zone (2,700 m–3,100 m) and the sub-páramo zone (3,100 m–3,400 m). In this month, we sampled terrestrial and flying mammals in both ranges.

For the recording of small terrestrial mammals, we used 100 Sherman traps that operated 24 hr and were checked at 06:00 hr each day. The traps were placed along 4 linear transects traced on the edge and interior of the forest, scrubland, ravines, and open areas of each zone. For bat sampling, we installed 8 mist nets (2 of 6 m long; 2 of 9 m long, and 4 of 12 m long), which remained open from 06:00 hr to 18:00 hr.

Medium and large mammals were recorded with camera traps and indirect traces. We used 39 Bushnell Trophy Cam traps (Vista Outdoor, Overland Park, Kansas) installed 0.5 m to 1.5 m above the ground at different points between 2,500 m and 3,380 m. Traps were placed on trails, inside the forest, and adjacent to water bodies where mammal footprints or traces were observed. Camera traps were set to operate for 24 hr, recording a 31-sec video and a sequence of 3 photos with a 1-sec interval between photos. Indirect traces were obtained during the surveys and trap installation tours. All traps were marked with reflective tape and georeferenced with a Garmin GPSmap 62s handheld navigator.

Each captured individual was measured following the guidelines by DeBlase and Martin (1975), Simmons and Muñoz-Saba (2005), and Brito (2013). We collected data on sex, age, and reproductive status, and captured a photographic record of each individual. To avoid recounting individuals, the rodents and bats captured were marked with a rabbit tattoo on the ear and at the base of the dactylopathagium, respectively. Since there are no previous studies on mammals in the PRCPM and as per the recommendations of Barquez *et al.* (2021), advocating the collection of at least 1 specimen to document the systematic identity of the species studied in a site of ecological interest, we carried out the first collections of skin, skull, and liver (preserved in Eppendorf tubes and 96 % alcohol, as needed) of small mammals, under the collection permit provided by the cooperation agreement No. 352 of 2016 between the Alto Magdalena Regional Autonomous Corporation and the Francisco José de Caldas District University. All specimens from this study were deposited in the Natural History Museum at Francisco José de Caldas District University (MUD).

We assessed the representativeness of the sampling effort and success for each type of collection. For Sherman traps, sampling effort was calculated as the number of traps times the number of days, and success as the number of individuals captured divided by sampling effort, expressed as a percentage (Llaven-Macías 2013). For mist nets, these parameters were calculated as the sum of the total net meters times the number of sampling hours per night (Medellín 1993), and the number of individuals captured per square meter divided by the number of sampling hours, respectively (Pérez-Torres 2004). For camera traps, sampling effort was calculated as the number of hours times the number of days in operation, and success as the number of photographs per individual divided by the number of sampling days (Dillon 2005).

Regarding the individualization of the records obtained through indirect traces and camera traps, we assumed that the records were of different individuals whenever records were captured more than 2 hr apart (Díaz-Pulido and Payán 2012). For the analysis of mammal diversity, we tested the data for normality with the Shapiro-Wilk test using the Paleontological Statistics Software Package (PAST) v 4.0 (Hammer and Ryan 2001). As the data were not normally distributed ($P < 0.05$), we used non-parametric methods. To compare different sampling efforts, we plotted rarefaction, extrapolation, and sampling cover curves with the iNEXT function in R with a 0.95 confidence interval and 100 replicates. To assess alpha diversity in terms of composition and evenness, we calculated Fisher's alpha, Simpson's dominance, and evenness within the structure with the

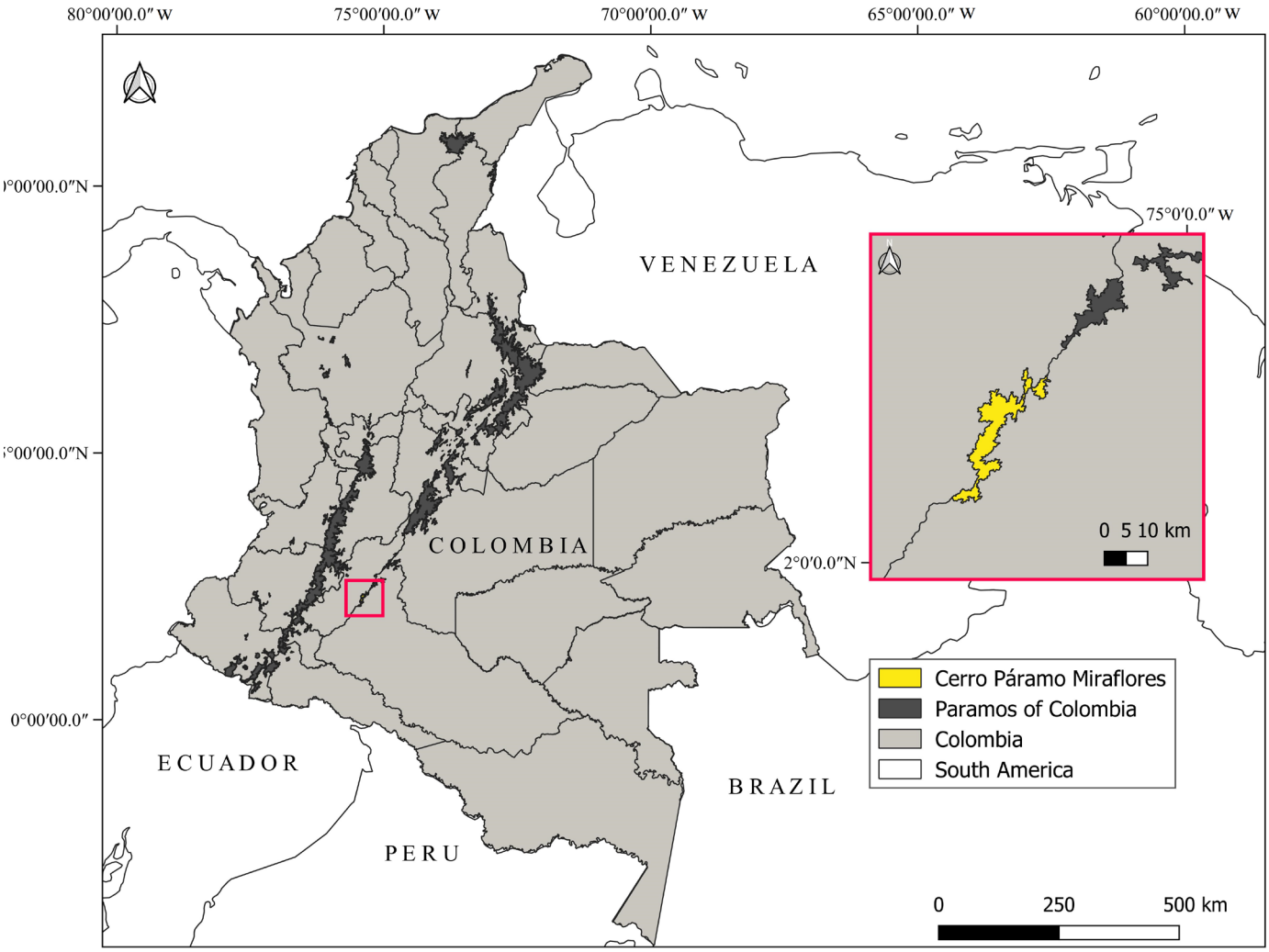

Figure 1. Geographic location of the Cerro Páramo Miraflores Regional Natural Park, Huila, Colombia.

Shannon-Wiener index. Beta diversity was estimated with the Whittaker and Morisita-Horn indices to analyze the species exchange and similarity between the zones. Alpha and beta diversity indices were estimated with the Vegan package in R (Oksanen *et al.* 2022; R Core Team 2023). We tested for statistically significant differences (95 %) between the alpha diversity of each stipe using a Mann-Whitney U test in the PAST v 4.0 program (Hammer and Ryan 2001).

We recorded a total of 80 specimens of mammals in the PRCPM, belonging to 21 species in 11 families and 8 orders (Table 1). Seven species correspond to small terrestrial mammals, 7 to small flying mammals, and 7 to medium and large mammals (6 captured with camera traps and only 1 was detected through indirect traces). The most abundant species were *Thomasomys dispar* (22.5 %), *T. baeops* (13.75 %), and *Sturnira erythromos* (8.75 %). The total sampling effort for small terrestrial mammals was 1,780 traps/day with a success rate of 2.2 %; for flying mammals, it was 15,984 net-m/hr, with a success rate of 0.12 %; and for medium and large mammals, it was 1,248 camera trap-hr/day, with a success rate of 14.38 %.

We obtained 39 captures of 38 individuals belonging to the orders Eulipotyphla, Paucituberculata, Rodentia, and Didelphimorphia, and 20 captures without recapture of the order Chiroptera. As for medium and large mammals, we recorded the orders Carnivora, Cetartiodactyla, Lagomorpha, and Rodentia by camera traps and indirect traces (Table 1).

The rarefaction and extrapolation curves show a higher species diversity associated with larger numbers of individuals captured. In the high Andean zone, a larger number of species were recorded (16 species, 59 individuals). Since the curve does not reach the expected asymptote, this can be interpreted as a positive relationship, *i.e.*, a large number of individuals recorded would be associated with a larger number of species in the area (Figure 2a). In the sub-páramo zone, although a smaller number of species was observed (8 species, 21 individuals), this number would not tend to increase with a larger number of individuals recorded (Figure 2a). Thus, sampling completeness was 88 % for the high Andean zone and 92 % for the sub-páramo zone; accordingly, the sampling effort should be increased in this former zone (Figure 2b).

Table 1. Species, type of capture, IUCN threat category, number of individuals captured, and relative abundance of each species of terrestrial and flying mammals recorded in the Cerro Páramo Miraflores Regional Natural Park. IUCN: International Union for Conservation of Nature. TS: Sherman Trap. RN: mist net. CT: camera trap. RI: indirect record. LC: Least Concern. DD: Data Deficient. VU: Vulnerable. CA: Near Threatened.

	Order	Family	Species	Capture method/ record	IUCN threat category	High Andean zone	Sub-páramo zone	Total	Total relative abundance
Small terrestrial mammals	Didelphimorphia	Didelphidae	*Marmosops sp*	TS		1	0	1	0.01
	Paucituberculata	Caenolestidae	*Caenolestes fuliginosus*	TS	LC	4	0	4	0.05
	Eulipotyphla	Soricidae	*Cryptotis squamipes*	TS	LC	1	0	1	0.01
			Neomicroxus bogotensis	TS	LC	1	0	1	0.01
			Thomasomys baeops	TS	DD	11	0	11	0.14
			Thomasomys dispar	TS	LC	16	2	18	0.23
	Rodentia	Cricetidae	*Thomasomys princeps*	TS	DD	3	0	3	0.04
			Anoura latidens	RN	LC	2	0	2	0.03
			Platyrrhinus nigellus	RN	LC	3	0	3	0.04
			Sturnira bidens	RN	LC	0	2	2	0.03
Flying mammals			*Sturnira erythromos*	RN	LC	6	1	7	0.09
		Phyllostomidae	*Sturnira ludovici*	RN	LC	4	0	4	0.05
			Histiotus montanus	RN	LC	1	0	1	0.01
	Chiroptera	Vespertilionidae	*Myotis nigricans*	RN	LC	1	0	1	0.01
			Leopardus pardalis	CT	LC	1	0	1	0.01
			Leopardus tigrinus	CT	VU	0	1	1	0.01
		Felidae	*Puma concolor*	RI	LC	1	2	3	0.04
Medium and large mammals		Ursidae	*Tremarctos ornatus*	CT	VU	3	0	3	0.04
	Carnívora	Cervidae	*Mazama rufina*	CT	VU	0	6	6	0.08
	Rodentia	Cuniculidae	*Cuniculus taczanowskii*	CT	CA	0	5	5	0.06
	Lagomorpha	Leporidae	*Sylvilagus brasiliensis*	CT	LC	0	2	2	0.03
					Total	59	21	80	1.0

Fisher's alpha index showed similar richness values for the high Andean (8.82) and sub-páramo (7.82) zones. The Simpson dominance index showed values close to unity for both zones (high Andean zone = 0.8612, sub-páramo zone = 0.8209), indicating a marked dominance of some species in both areas (Moreno 2001). In the high Andean zone, this dominance may be represented by the number of catches of *Thomasomys dispar* (n = 16) *versus* the average number of catches for the remaining species (n = 3.5). On the other hand, the Shannon-Wiener index yielded intermediate diversity values according to Magurran (1988), of 2.317 for the high Andean zone and 1.885 for the sub-páramo zone. Despite the differences in species richness and abundance recorded between zones, these were not statistically significant (Z = -0.43, P = 0.66).

The Whittaker index showed a high species turnover between the zones (0.75). Only *T. dispar, S. erythromos,* and *P. concolor* were found in both zones. The Morisita-Horn index calculated a similarity of 0.32, given the relative abundance of the 3 common species across the zones studied. Similarly, the Morisita-Horn index indicates that, due to the number of records of common species in both zones, the probability of finding *S. erytrhormos* and *T. dispar* is higher in the high Andean zone than in the sub-páramo, while the opposite occurs with *P. concolor*. We also highlight the presence of the substitute species *Tremarctos ornatus, Puma concolor, Leopardus pardalis*, and *L. tigrinus,* as well as new geographic records of *Neomicroxus bogotensis* (MUD-M1370), *Thomasomys princeps* (MUD-M1371), *Cryptotis squamipes* (MUD-M1374), and *Histiotus montanus* (MUD-M1367) for the department of Huila.

The 21 species recorded in the PRCPM represent about 40 % of the species that thrive above 2,700 m in the department of Huila (Solari *et al.* 2013). The higher richness observed in the orders Chiroptera, Rodentia, and Carnivora is not entirely usual in the tropical Andes, where rodent richness is usually higher than bat richness with increasing height (Mena *et al.* 2012). Nonetheless, small terrestrial mammals were the most abundant group.

The diversity of rodents can be associated with their use of different plant covers where they can move without making much noise and which serve as camouflage (Barnum *et al.* 1992; López-Arévalo *et al.* 1993). Likewise, the presence of the remaining small terrestrial mammals is worth highlighting, as they are species that live in inhospitable regions and are difficult to capture, so they are also scarcely represented in biological collections (Guevara 2019).

The presence of insectivores, frugivores, and nectarivores of the order Chiroptera has been related to the availability and abundance of food resources for all these trophic

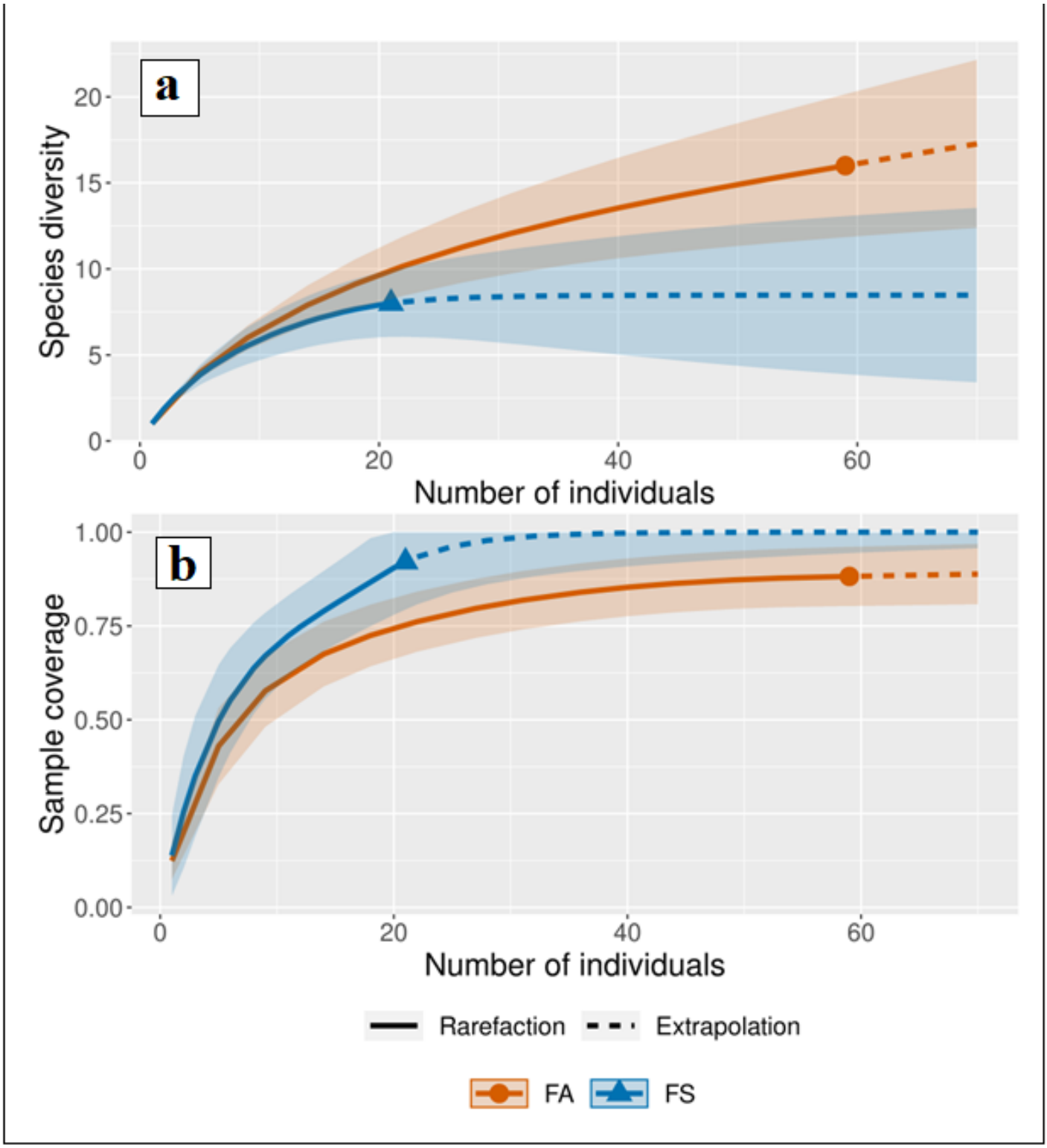

Figure 2. Rarefaction and extrapolation curves of terrestrial and flying mammals recorded in the high Andean and sub-páramo Belt of Cerro Páramo Miraflores Regional Park, Huila, Colombia, based on sample size (a) and sample cover (b). FA: high Andean zone. FS: Sub-páramo zone.

guilds (Pérez-Torres 2004; Loayza *et al.* 2006). On the other hand, the presence of carnivores in high Andean forests and sub-páramo areas has been associated with the availability of large prey such as *Mazama rufina* and *Cuniculus taczanowskii,* in addition to small vertebrates such as rodents and marsupials (Chinchilla 1997; Pacheco Jaimes *et al.* 2018). Therefore, we also highlight the presence of the order Carnivora, since its species are also frequently used as a conservation badge (Beschta and Ripple 2009; Kattan *et al.* 2014).

The low abundance and richness of the sub-páramo zone agrees with Muñoz-Saba (2015), according to whom this zone is the least diverse of the páramo ecosystems, partly due to the change in the heterogeneity of niches and habitats (Suárez del Moral and Chacón-Moreno 2011).

Species similarity between 2 localities may be positively related to distances of 2 to 3 km that can be easily traveled (Rodríguez *et al.* 2003). In the PRCPM, both sampled zones are contiguous and the abundance of small mammals suggests that these species are dispersed over an area larger than the one delimited for each zone or are able to travel distances that include both zones (Galindo-González 1998). Likewise, the wide displacement exhibited by large carnivores makes it feasible for them to move across the 2 zones, even if their presence in the sub-páramo zone is temporary (Muñoz-Saba 2015).

By contrasting our results with those obtained in 10 páramos of the Andes (López-Arévalo *et al.* 1993; Pérez-Torres and Correa 1995; Vargas Ríos and Pedraza 2004; Mejía Correa 2009; Tirira and Boada 2009; Viancha Sánchez *et al.* 2012; Brito 2013; Díazgranados 2015; Medina *et al.* 2015; Muñoz-Saba 2015), the southernmost points in the El Carchi region of Ecuador (Tirira and Boada 2009; Brito 2013) show the most similar conditions within the reference group. However, the lowest similarity in the composition of mammals was observed relative to these and other surrounding areas. As a northernmost point, we considered the Serranía del Perijá (Corredor-Carrillo and Muñoz-Saba 2007), where bats were captured at lower altitudes, similar to other studies. However, it represents one of the sites with the highest number of species shared with the PRCPM, along with the Chingaza National Natural Park, also north of the Andes (Appendix 1).

The PRCPM is home to species typical of conserved environments, rodents associated with a high shrub density, bats of various trophic guilds, large carnivores, and medium-sized prey. This diversity of mammal groups can be a positive indicator of the conservation status of its highlands and the importance of preserving this area. For this reason, it is recommended to carry out conservation actions to protect the diversity of the area, along with a greater research effort.

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Appendix 1

Terrestrial and flying mammal species reported in 11 páramos of the Andes. PNR: Regional National Park. PNN: Natural National Park. Mi: Cerro Páramo Miraflores PNR. Ca: Carpanta Biological Reserve. Ch: Chingaza PNN. Su: Sumapaz PNN. Pu: Puracé PNN. Mu: Munchique. Sp: Serranía de Perijá. Pr: Rabanal páramo. Ra: Ranchería-Paipa PNR. Ec: El Carchi Province, Ecuador. An: El Angel Ecological Reserve.

Order	Species	Mi	Ca	Ch	Su	Pu	Mu	Sp	Pr	Ra	Ec	An
Didelphimorphia	*Didelphis marsupialis*			x				x				
	Didelphis pernigra							x	x			
	Didelphis albiventris		x	x		x						
	Marmosa sensu lato									x		
Paucituberculata	*Marmosops sp.*	**x**										
	Caenolestes fuliginosus	**x**	x	x		x				x	x	x
	Caenolestes obscurus		x									
Cingulata	*Cabassous unicinctus*							x				
	Dasypus novemcinctus							x	x			
Pilosa	*Bradypus variegatus*							x				
	Tamandua mexicana							x				
Eulipotyphla	*Cryptotis squamipes*	**x**										
	Cryptotis thomasi		x	x				x	x	x		
Chiroptera	*Mormoops megalophylla*										x	
	Anoura geoffroyi			x							x	
	Anoura latidens	**x**										
	Dermanura bogotensis							x				
	Platyrrhinus nigellus	**x**						x				
	Platyrrhinus vittatus							x				
	Sturnira bidens	**x**		x							x	
	Sturnira bogotensis			x								
	Sturnira erythromos	**x**		x	x	x		x			x	
	Sturnira ludovici	**x**										
	Eptesicus andinus										x	
	Histiotus montanus	**x**					x	x	x		x	
	Myotis nigricans	**x**					x	x				
	Myotis oxyotus										x	
Carnívora	*Leopardus pardalis*	**x**						x				
	Leopardus tigrinus	**x**	x	x	x							
	Leopardus wiedii							x				
	Puma concolor	**x**		x	x	x		x				
	Puma yagouaroundi			x								
	Cerdocyon thous			x				x				
	Lycalopex culpaeus					x						
	Urocyon cinereoargenteus		x						x			
	Conepatus semistriatus							x				
	Eira barbara		x					x				
	Mustela frenata			x		x			x			
	Bassaricyon gabbii							x				
Perissodactyla	*Nasua nasua*		x		x		x					
	Nasuella olivacea		x	x	x	x	x	x				
	Tremarctos ornatus	**x**	x		x		x	x				
	Tapirus pinchaque			x		x						
Artiodactyla	*Tayassu pecari*							x				
	Mazama rufina	**x**	x	x	x	x	x	x	x			
	Odocoileus virginianus		x	x	x			x				
Primates	*Pudu mephistophiles*					x	x					
	Alouatta seniculus		x				x					

	Sciurus granatensis		x	x				x				
	Reithrodontomys mexicanus					x						
	Reithrodontomys soderstromi										x	x
	Akodon laterbricola											x
	Akodon mollis										x	x
	Chilomys instans									x		
	Microryzomys altissimus											x
	Microryzomys minutus		x	x				x	x	x		
	Neomicroxus bogotensis	**x**	x	x	x			x	x	x		
	Nephelomys albigularis									x	x	
	Oligoryzomys fulvescens									x		
	Oryzomys albigularis		x					x				
	Rhipidomys caucensis						x					
	Rhipidomys fulviventer									x		
	Rhipidomys latimanus			x								
	Thomasomys aureus		x							x		x
Rodentia	*Thomasomys baeops*	**x**									x	x
	Thomasomys cinereiventer					x						
	Thomasomys cinnameus										x	
	Thomasomys dispar	**x**										
	Thomasomys laniger		x	x						x		
	Thomasomys niveipes		x	x	x				x	x		
	Thomasomys paramorum										x	x
	Thomasomys princeps	**x**										
	Thomasomys rhoadsi											x
	Cavia aperea								x			
	Cavia porcellus		x	x	x			x				
	Cuniculus paca							x				
	Cuniculus taczanowskii	**x**	x	x				x	x			
	Dasyprocta punctata							x				
	Dinomys branickii		x	x								
	Olallamys albicauda		x	x								
Lagomorpha	*Sylvilagus brasiliensis*	**x**	x	x	x			x	x			