Using MaxEnt modeling to predict the potential distribution of *Platyrrhinus ismaeli* (Phyllostomidae)

Leidy Azucena Ramírez-Fráncel[1]*, Leidy Viviana García-Herrera[1], and Gladys Reinoso- Flórez[1]

[1] Facultad de Ciencias, Grupo de investigación en Zoología, Universidad del Tolima, Colombia. Calle # 42, Santa Helena parte alta Ibagué-Tolima CP. 546. Colombia. Email: laramirezfr@ut.edu.co (LAR-F), lvgarcia@ut.edu.co (LVG-H), greinoso@ut.edu.co (GR-F).

*Corresponding author

The broad-nosed bat, *Platyrrhinus ismaeli*, is listed as Near Threatened (NT) by the International Union for the Conservation of Nature, and due to the low number of collected specimens, its geographic distribution is poorly known. This study presents the first documented record of this species in the eastern slope of the Colombian Central range. Herein, museum voucher specimens were used as primary sources for the elaboration of a checklist of *Platyrrhinus ismaeli* from Colombia. In addition, the checklist is supplemented with information on life zones and a potential distribution model for Colombia. This distribution map was used to explore the affinities, in species composition, among Colombian ecoregions as outlined by, and the relationship between associated environmental variables. In total, 15 field-based occurrence points and 20 environmental variables (19 bioclimatic and one topographic) were used to model the potential distribution area. The response curves showed that this species prefers habitats with an annual temperature of 12.0 to 25.5 °C, annual precipitation of 1,000 to 4,000 mm, and an elevation range of 1,200 to 2,850 masl. Most of the current potential suitable conditions were located to the north-center of Colombia. We found that *P. ismaeli* is distributed in Colombia in four main regions, including the Biogeographic Chocó, the Magdalena Valley, the Orinoquia, and the Guianan-Amazon region. The spatial distribution of the species is driven by variables such as temperature, precipitation, and elevation. Changes in these variables affect the normal activities of this species with a narrow geographical niche and dispersal ability may particularly reduce the ability of this species to face global climate change consequences. Therefore, it is imperative to continue exploring the effect of these variables in order to better define the distribution patterns and conservation strategies for this species. Our findings can be used to define high-priority areas for the protection and conservation of *P. ismaeli*.

El murciélago de nariz ancha *Platyrrhinus ismaeli*, está catalogado como Casi Amenazado (NT) por la Unión Internacional para la Conservación de la Naturaleza y, debido a la escasa cantidad de recolectas, su distribución geográfica es poco conocida. Este estudio presenta el primer registro en la vertiente Oriental de los Andes centrales colombianos. Aquí, se utilizaron ejemplares de museo como fuente primaria para generar una lista de verificación de *Platyrrhinus ismaeli* para Colombia. Además, la lista de verificación está acompañada por las zonas de vida, así como el modelo de distribución potencial para Colombia. Este mapa de distribución se utilizó para investigar las afinidades, en la composición de las especies, entre las ecorregiones colombianas como se describe en, y la relación entre las variables ambientales. En total, se utilizaron 15 puntos de ocurrencia y 20 variables ambientales (19 bioclimáticas y una topográfica) para modelar el área de distribución potencial. Las curvas de respuesta mostraron que esta especie prefiere hábitats con una temperatura anual de 12.0 a 25.5 ° C, precipitación anual de 1,000 a 4,000 mm y un rango de elevación de 1,200 a 2,850 m.s.n.m. La mayoría de las posibles condiciones adecuadas actuales se ubicaron en los límites del Centro Norte de Colombia. Descubrimos que *P. ismaeli* se distribuye geográficamente en Colombia en cuatro regiones principales, incluyendo: el Chocó Biogeográfico, el valle del Magdalena, la Orinoquia, y la región de la Guiana-Amazonía. La distribución espacial de la especie depende de variables como la temperatura, la precipitación y la elevación. Estos cambios en estas variables afectan las actividades normales de esta especie con un nicho geográfico estrecho y la capacidad de dispersión puede reducir particularmente la capacidad de esta especie para enfrentar las consecuencias del cambio climático global. Por lo tanto, es importante continuar estudiando el efecto de estas variables para ajustar los patrones de distribución y estrategias de conservación de esta especie. Nuestros hallazgos se pueden usar para definir las áreas de alta prioridad para la protección y conservación de *P. ismaeli*.

Key words: Chiroptera; department of Tolima; distribution; expansion; geographic range; Phyllostomidae.

Introduction

In the Neotropics, bats represent the most diverse group amongst mammals (Vaughan 1997; Medellin *et al.* 2000; Sampaio *et al.* 2003; Bracamonte 2011), showing the greatest variety of dietary habits; this flexibility accounts for the morphological, physiological, and ecological complexity of this group (Altringham 2011). Bats of the genus *Platyrrhinus* (Phyllostomidae) are frugivores that play a key role in seed dispersal and the redistribution of nutrients (Medellin 2003; Velazco and Gardner 2009; Estrada-Villegas *et al.* 2010).

In recent decades, a number of studies have confirmed the role of this genus in forest succession and ecological restoration, because they consume pioneer species and are among the most important seed dispersers in fragmented and early successional ecosystems (Galindo-González *et al.* 2000; Marques and Fisher 2009; Castro-Luna and Galindo-González 2012; García-Herrera *et al.* 2019). Therefore, the species of this genus have the potential to provide functional services to the environment because they disperse large amounts of seeds in Neotropical forests.

The genus *Platyrrhinus* includes 20 recognized species, representing one of the most diverse genera within the family Phyllostomidae (Velazco and Patterson 2008; Velazco and Lim 2014; Velazco *et al.* 2018), only surpassed

by the genera *Sturnira* with 24 species (Velazco and Patterson 2019) and *Artibeus* with 23 species grouped into two subgenera (*Artibeus* and *Dermanura*; Cirranello *et al.* 2016; Velazco and Patterson 2019). In Colombia, *Platyrrhinus* is represented by 14 species (Ramírez-Chaves *et al.* 2016), with geographic and altitudinal ranges that vary widely (Velazco and Solari 2003; Gardner 2008; Velazco and Gardner 2009). As part of the most recent IUCN (International Union for Conservation of Nature) Global Mammal Assessment, three species of *Platyrrhinus* are listed as Threatened (*Platyrrhinus chocoensis*, VU, *P. ismaeli* and *P. matapalensis*, NT).

Platyrrhinus ismaeli lives mainly in lowland and montane forests (Tirira 2011). The high rate of habitat destruction throughout the tropical Andes may soon cause *P. ismaeli* to be assigned to the Near Threatened (NT) category (IUCN 2019), thus highlighting the importance of generating in-depth information on the geographic distribution and status of their populations, which is needed to advance conservation actions.

In Colombia, *P. ismaeli* has been recorded in 26 localities along the Andes (Velazco and Gardner 2009); these include eigth localities in the western range (Departments of Risaralda and Valle del Cauca), nine in the central range (Departments of Antioquia, Cauca, Huila, Putumayo, and Quindío), and nine in the eastern range (Departments of Boyacá, Caquetá, Cundinamarca, Norte de Santander and Meta). Records in Colombian collections support that *P. ismaeli* inhabits a wide variety of habitats within an altitudinal gradient of 1,230 to 2,950 m (Muñoz 2001; Solari et al. 2013). Although this species seemingly prefers high-montane forests (Table 1), there are some records of *P. ismaeli* in the foothills of the western range, in the eastern side of the Department of Chocó, suggesting that it also inhabits the premontane very humid forest (Asprilla-Aguilar *et al.* 2016).

The distribution range reported for this species comprises the eastern slope of the central range (Departments of Nariño and Tolima), the eastern range (Departments of Santander and Casanare), and the low montane forest and low montane wet forest of Colombia (according to Holdridge [1987] system, Table 1), which are highly fragile and threatened ecosystems for impacts related to human activities. Accordingly, we analyzed the potential distribution of *P. ismaeli*, provide cranial measurements and information on the life zones for the new localities (Tables 1, 2, Figure 1, 2, Appendix 1), and discuss the scenarios that might determine the distribution of this species in Colombia. Our objectives were: to predict the current potential distribution, and to identify the key environmental factors that are highly correlated with the distribution range of *P. ismaeli*. This information sets the basis for generating data for the conservation of this species, needed to face the current habitat loss and fragmentation issues, and other impacts to the life zones of populations of this species in Colombia.

Materials and Methods

The main sources used for this update included research articles, taxonomic revisions, and direct examination of the zoological collections of the University of Tolima (CZUT-M,

Ibagué), Instituto de Investigación de Recursos Biológicos Alexander von Humboldt (IAvH-M, Villa de Leyva), Instituto de Ciencias Naturales at Universidad Nacional de Colombia (ICN, Bogotá), and Universidad del Valle (UV, Cali). Secondary sources include records available in the online databases of the National Museum of Natural History, Smithsonian Institution (NMNH; VertNet), and cataloged specimens reported in regional checklists (for example, Asprilla-Aguilar *et al.* 2016; Jimenez-Ortega 2013). For specimens to which we had direct access, we took external and cranial measurements with digital calipers to the nearest 0.1 mm (Table 2). Data on total length (TL) and weight (W) were obtained from specimen labels, recorded at the time of collection.

We reviewed all available specimens housed at the CZUT-M, searching for vouchers of *P. ismaeli*. Based on our review, and because they were suspected of being misidentified, we also included four specimens formerly identified as *Vampyrops aurarius* (Bejarano-Bonilla *et al.* 2007), plus another identified as *P. aurarius* by Galindo-Espinosa *et al.* (2010), and five *Chiroderma salvini* (identified by Galindo-Espinosa *et al.* 2010). To assess the accuracy of their identifications, we compared each specimen with the characters provided by Velazco (2005) and Velazco and Gardner (2009), and described the morphological characters, external, and cranial and dental measures of *P. ismaeli* distributed in Colombia.

Data sources and selection of variables. In order to elaborate the checklist, we reviewed and gathered occurrence data from *P. ismaeli* records in museum collections in Colombia (CZUT-M, ICN, IAvH-M, UV, and NMNH. Including: coordinates, elevation, locality, geographic region, and life zone according to the classification of Holdridge 1987; Table 1), confirmed by reviewing the morphology and taxonomic identification of specimens (Velazco 2005; Velazco and Gardner 2009), as well as from records reported in the scientific literature. Occurrence localities from specimen tag data were then thoroughly georeferenced (*i. e.*, for those lacking field GPS readings; Sánchez-Cordero and Guevara 2016). To reduce issues associated with spatial sampling biases (Merow *et al.* 2013; Boria *et al.* 2014), we spatially thinned our original dataset consisting of 38 localities using the spThin package in R (Aiello-Lammens *et al.* 2015).

Nineteen variables were retrieved as predictors to model the potential environmental niche of *P. ismaeli* based on the current presence dataset in 15 different localities (Velazco and Gardner 2009; Table 1), plus other available records. In particular, 19 bioclimatic layers (Table 3) and one topographic variable (elevation) were obtained from the WorldClim version 2 database (WorldClim: Global Climate Data 2017; Hijmans *et al.* 2005) at a spatial resolution of 30 arc-second (*ca.* 1 × 1 km). Elevation, slope, and aspect data were extracted using ArcGIS 10.4.1. The overall environmental variables are summarized in Table 3. In order to eliminate multicollinearity and select the most fitting predictors that show more contribution power to the model, Variance Inflation Factors (VIFs) of 22 environmental

Table 1. Records of *Platyrrhinus ismaeli* in Colombia used for modeling the potential distribution of the species. Life zones: A) low montane humid forest, B) low montane very humid forest, and C) premontane very humid forest. Regions: Central Range (CR), Eastern Range (ER), and Western Range (WR); Vereda (Ver); Life zone (LZ).

Voucher	Latitude	Longitude	Elev.	Municipality	Department	Region	LZ
ICN 16503	5.5882	-75.9294	2,010	Andes, Ver. La Soledad	Antioquia	CR	A
ICN 17165	6.1654	-74.3173	1,860	Santa María, Ver. Caño Negro	Boyacá	ER	C
ICN 15066	4.9667	-73.3440	1,269	Santa María, Margen izquierda río Batá	Boyacá	ER	C
ICN 16352	4.9443	-73.3252	1,259	Santa María, Sitio Represa Chivor.	Boyacá	ER	C
ICN 5441	5.3066	-72.7138	1,970	Pajarito, Hacienda Camijoque.	Boyacá	ER	C
ICN 19320	5.4166	-71.2750	1,085	Trinidad, Banco de la Cañada	Casanare	ER	C
MHNUC 1467, 1501; USNM 483575	2.4010	-76.1306	2,638	Moscopas, 1 Mi N Moscopas	Cauca	CR	A
ICN 8467, 8468	2.5518	-76.0912	2,253	Inza, Ver. Tierras Blancas, Km. 78 carril Popayan	Cauca	CR	A
CMCH 1136	5.8982	-76.1487	2,950	El Carmen de Atrato	Chocó	WR	A
ICN 5293, 5295	4.6830	-74.3894	1,870	Tena, Laguna de Pedro Pablo	Cundinamarca	ER	C
FMNH 58732, 58733, 58734, 58735, 58736, 58737, 58738.	2.0178	-75.7459	1,100	Parque Natural Nacional "Cueva de los Guacharos"	Huila	CR	C
IAvH-M 1930, 1932, 1934, 1990, 1992, 1994, 1996.	1.6000	-76.1301	2,800	Parque Natural Nacional "Cueva de los Guacharos". Puente superior en Río Suaza	Huila	CR	A
ICN 13087	11.1430	-73.8282	1,050	Sierra Nevada de Santa Marta, Alto de Mira, 3 Km W Río Buritaca.	Magdalena		C
ICN 14372	4.2749	-73.5874	1,090	Restrepo, Salinas de Upin	Meta	ER	C
ICN 14800	3.8262	-73.8435	1,000	Cubarral, Ver. Aguas Claras	Meta	ER	C
Jiménez Ortega	1.6812	-78.1417	1,004	Barbacoas	Nariño	WR	C
IAvH-M 6681, 6682	7.2584	-72.2259	1,608	Toledo, Ver. San Isidro	Norte de Santander	ER	C
ICN 21022	1.1336	-76.6328	2,000	Mocoa, El Mirador	Putumayo	CR	A
IAvH-M 6818, 6823	1.0715	-76.7353	1,922	Mocoa, El Mirador	Putumayo	CR	C
ICN 12476	4.6706	-75.6179	1,975	Finlandia, Ver. El Roble	Quindío	CR	C
ICN 12448	4.6834	-75.5244	2,634	Salento, Reserva Natural Cañon Quindio, frente de reforestación Monte Loro	Quindío	CR	A
UV 12694	4.7299	-75.5766	2,250	Quimbaya, Ver. La Suiza	Risaralda	ER	A
ICN 8150, 8972, 8973	6.0967	-73.2036	1,790	Charalá, Margen derecho del Río Guillermo	Santander	ER	C
ICN 17585, 17586, 17587	6.4535	-72.8266	2,013	Encino, Vereda Río Negro, Las Tapias, finca El Aserradero.	Santander	ER	A
ICN 16660, 16661	7.1333	-72.9941	2,150	Tona, Ver. Guarumales, finca El Pajal.	Santander	ER	A
ICN 12448	7.1334	-72.9832	1,800	Tona, Sitio El Mortiño, carretera Bucaramanga-Cúcuta Km 18.	Santander	ER	C
CZUT-M 58.	4.4258	-75.3697	1,557	Cajamarca, Ver. Peñaranda parte Baja	Tolima	CR	C
CZUT-M 83, 84, 144, 145.	4.4830	-75.4532	2,055	Cajamarca, Ver. Planadas	Tolima	CR	A
CZUT-M 208, 317.	4.3865	-75.3417	2,084	Cajamarca, Ver. El salitre	Tolima	CR	A
CZUT-M 57.	4.5440	-75.4204	2,398	Ibagué, Ver. Toche	Tolima	CR	B
CZUT-M 206, 207	4.5000	-75.3000	1,777	Ibagué, Quebrada La Plata	Tolima	CR	C
UV 12402, 12403, 12405, 12407, 13022, 13023.	3.8920	-76.2800	1,124	Buga, Ver. El Janeiro	Valle del Cauca	WR	C

variables were tested. VIFs are based on correlation coefficients (R^2) estimated from regressions for all predictors, implemented through the 'sdm' package in R (version 3.1.1). As a result, 14 variables with VIFs > 5 were excluded (Chatterjee and Hadi 2006) and only eight variables were kept to establish the distribution model of *P. ismaeli* under the current conditions (Table 4).

MaxEnt model. In our study, the model was run using the MaxEnt algorithm (version 3.4.1 k; Guisan and Thuiller 2005; Jarvis *et al.* 2005; Phillips *et al.* 2006) with default settings. We analyzed the presence of the species in the different geographic regions, and the distribution along the Colombian Andes (Table 2) as proposed by Morrone (2014). We employed 10 replicates and the average of probability maps for habitat suitability (Hoveka *et al.* 2016). The train-

ing and test data points were 80 % and 20 %, respectively. The relative importance of each environmental predictor for the models of *P. ismaeli* was assessed using the percent contribution of the Jackknife test (Phillips *et al.* 2006), which is the best index for small sample sizes (Pearson *et al.* 2007).

To determine the accuracy of the resulting models, we computed the Area Under the Curve (AUC) of the Receiver Operating characteristic Curve (ROC). AUC is the dominant tool to measure model performance, mainly due to its independence from threshold choices (Bosso *et al.* 2013; Fois *et al.* 2018; Yi *et al.* 2016). Higher AUC values (closer to 1) indicate better model performance (Fielding and Bell 1997; Phillips *et al.* 2006). The AUC graph was obtained by plotting true positive predictions (sensitivity) versus false positive predictions (1-specificity; Fielding and Bell 1997).

In addition, the minimum difference between training and testing AUC data (AUC$_{Diff}$) was also considered; a smaller difference indicates lesser overfitting in the model (Fois *et al.* 2018; Warren and Seifert 2011).

The logistic output of MaxEnt application is a map, indexing the environmental suitability of *P. ismaeli* with values ranging from 0 (unsuitable) to 1 (optimal). For further analysis, the MaxEnt results were imported into ArcGIS 10.4.1, and four classes of potential habitats were grouped as follows: unsuitable (≤ 0.10), low potential (0.11–0.30), moderate potential (0.31 – 0.70), and high potential (≥ 0.71; Yang *et al.* 2013; Choudhury *et al.* 2016; Qin *et al.* 2017).

Results

The re-examination of the 10 specimens reported by Bejarano-Bonilla *et al.* (2007; CZUT-M 206 to 208, 0317) and Galindo-Espinosa *et al.* (2010; CZUT-M 57, 58, 83, 84, 144, 145), as *P. aurarius* or *Ch. salvini*, revealed the presence of *P. ismaeli* on the foothills of the eastern slope of the central Andes of Colombia, reported herein for the first time. These records expand the known distribution of *P. ismaeli* to approximately 328 km southeast of the nearest known locality in the Department of Huila, in the Parque Nacional Nevado del Huila, "Cueva de los Guacharos" on the Acevedo trail (FMNH 58732, 58736, 58733 to 58735, 58737, 58738, Figure 1).

These new localities correspond to low montane forest and low montane wet forest, located in the Andean mountains, bordered by the dry tropical valleys of the Magdalena River. These landscapes are characterized by slopes with trees measuring approximately 12 m high and vegetation that includes plant species such as *Pseudobomba septenatum*, *Calophyllum lucidum*, *Maclura tinctoria*, *Poulsenia armata*, and *Virola sebifera*. These life zones are located primarily in areas subjected to intense agricultural and urban development, where the original forest has been cleared and replaced by plantations of coffee, fruit trees, vegetables, and other monocultures.

The diagnostic characters of the *P. ismaeli* specimens collected match the original description of the species (Velazco 2005; Diaz *et al.* 2016). The key features to recognize our specimens were: dorsal and ventral hairs with three bands; dense long hairs on the edge of the uropatagium; a medium forearm, less than 55 mm; upper central incisors with one or two cusps, but not cylindrical; presence of nasals; lingual cingulum not continuous from paracone to metacone (sulcus not continuous between paracone and metacone) of M1 (Figure 2); and cranial measurements (Table 2).

Potential habitat suitability of P. ismaeli over current conditions. Our models showed high levels of predictive performances with values of AUC (training, 0.974 ± 0.001; test, 0.957 ± 0.009) and AUC$_{Diff}$ (0.010 ± 0.007) indicating a good performance with low levels of errors and correctly identifying all the localities where the species has been reported (Figure 1). The results of the contribution of variables using the Jackknife test in distribution modeling of *P. ismaeli* are

Figure 1. Map for potential current habitat suitability for *Platyrrhinus ismaeli* in Colombia from records in the various Colombian collections. Habitat suitability classes include: unsuitable, low potential, moderate potential, and high potential.
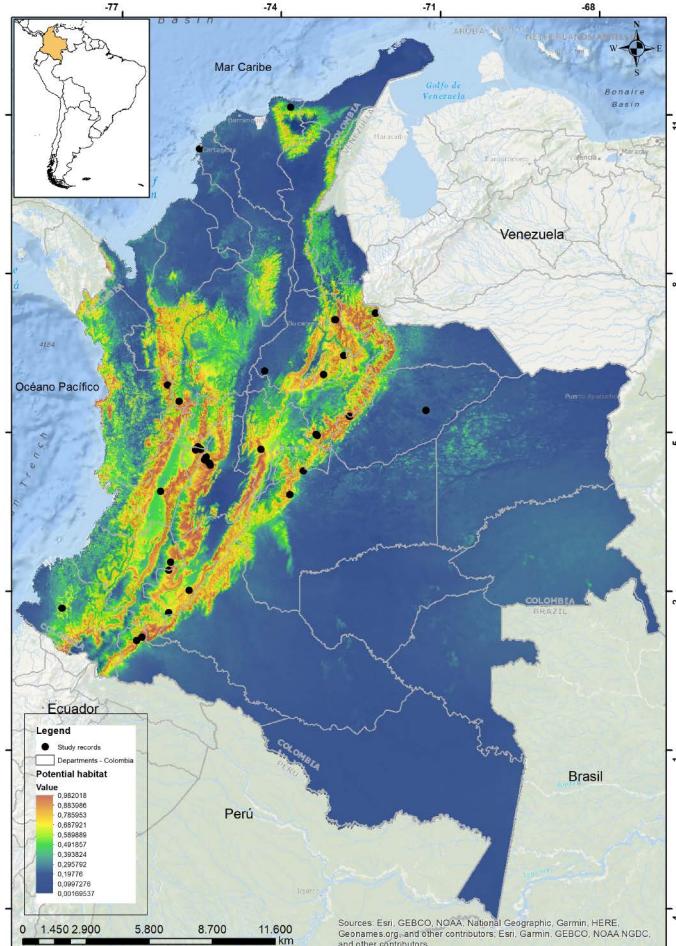
showed in Table 2. Environmental predictors that exhibited the highest mean contributions are annual precipitation (Bio12), annual mean temperature (Bio1), and elevation (Elev). At the same time, Bio1, Bio12, Bio9, Elev, and Bio5 provided high gains (> 2) to the model when used individually, indicating that each of these variables separately contribute the most useful information than the rest of variables. Considering the permutation importance, Bio1, Bio12, and Elev were the main environmental variables that have influenced the potential distribution of *P. ismaeli* (Table 2). The model predicts a continuous distribution range in the Colombian Andean region, spreading across the three cordilleras, *i. e.*, western, central, and eastern, from the south in Nudo de los Pastos up to the Catatumbo subregion in the Department of Norte de Santander, including the Choco-Magdalena, Orinoquia, and North-Andean biogeographic provinces.

The response curves of eight variables related to *P. ismaeli* habitat suitability are shown in Figure 3. While considering temperature probabilities, the mean annual temperature range (Bio1) of *P. ismaeli* was 12.0 to 25.5 °C, whereas the mean diurnal temperature (Bio2) ranged from 16.5 to 20.15 °C. In addition, the range of isothermality (Bio3) varied from 43.1 to 46.3, whereas the mean temperature of the driest quarter (Bio9) varied from 28.0 to 32.0 °C. On

Table 2. Selection of external and cranial measurements of *P. ismaeli* specimens collected in the central Andes eastern slope, Colombia. The measurements of the holotype and paratype of *P. ismaeli* were taken from Velazco (2005).

Characteristics	This study CZUT-M 0058,0084		Holotype MUSM 4946		Paratypes FMNH 129134, 129136
Sex	Male	Female	Male	Female	Male
Weight	32.00	39.00	35.00	40.00	38.00
Total length	88.32	80.40	84.00	82.00	87.00
Hind foot length	17.89	13.35	18.00	13.00	18.00
Ear length	22.75	21.03	10.00	21.00	22.00
Forearm length	52.65	53.25	52.00	53.00	54.00
Tibia length	21.35	19.75	21.68	19.52	21.68
Greatest length of skull	28.20	27.08	27.94	27.77	28.15
Condyloincisive length	27.30	26.59	27.10	26.57	27.47
Condylocanine length	26.92	26.07	26.22	26.07	26.88
Postorbital breadth	6.40	6.15	6.54	6.27	6.57
Zygomatic breadth	17.90	16.8	17.13	16.93	18.21
Braincase breadth	12.18	11.5	12.00	11.57	12.29
Mastoid breadth	13.69	12.5	13.99	13.63	14.72
Maxillaty tooth row length	11.78	11.05	11.35	11.43	11.66
Breadth across maxilla	20.71	20.56	12.63	12.65	23.81
Palatal length	15.94	14.9	–	–	–
Molariform teeth row length	12.04	11.14	–	–	–
Width across first upper molars	13.67	21.67	–	–	–
Width across second upper molars	13.89	21.97	–	–	–
Dentary length	24.60	28.00	–	–	–
Length of mandible toothrow	15.70	21.56	–	–	–
Coranoid height	7.07	14.96	–	–	–
Width at mandible condyles	8.36	15.59	–	–	–
Breadth across molars	15.42	22.83	–	–	–

the other hand, the range of annual precipitation (Bio12) was 1,000 to 4,000 mm per year while the suitable habitat occurs under a precipitation seasonality of 1,400 to 4,000, with a peak at 1,658 mm.

Furthermore, there is a positive relationship between habitat suitability for *P. ismaeli* and precipitation of the driest month. The elevation range suitable for *P. ismaeli* was 1,200 to 2,850 masl, with an optimal elevation at around 2,500 masl. Indeed, the conditions of highest suitability for *P. ismaeli* were an annual temperature of 21 °C, annual precipitation of 4,000 mm, and an elevation of 2,500 masl. By contrast, areas with an elevation above 3,000 masl or below 1,200 masl, and with an annual temperature above 30 °C were the least suitable for *P. ismaeli*.

The potential distribution map of *P. ismaeli* in Colombia is shown in Figure 3. Out of the total area of 1,141,748 km², some 5,103 km² were potentially suitable for *P. ismaeli*. This area was divided into 1,793 km² with a low potential, 1,758 km² with a moderate potential, and only 1,551 km² with a high probability of suitable ecological conditions. The majority of suitable habitats (≥ 0.71) were located in areas located in the mid-north of Colombia.

Discussion

Our results update and show a wider distribution range of *P. ismaeli* in Colombia (Table 1). This work is the first record of this species in the eastern slope of central range of Colombia. The existing records of the species correspond to the life zones low montane forest, low montane wet forest and premontane very humid forest. These life zones in Colombia are subjected to an increasing destruction and degradation of habitats, primarily due to agriculture, forestry, illegal crops, and mining, which altogether have resulted in a decline of more than 30 % of the populations of *P. ismaeli* (Ramírez-Chaves and Suárez-Castro 2014; Solari 2016); thus, the species is currently listed as Near Threatened (NT).

The records reported here also represent an extension of the ecological range of *P. ismaeli*. The life zone represented by low montane very humid forest has environmental and climatic characteristics that differ from others previously reported for the species, with precipitation between 2,000 to 4, 000 mm and temperature between 12 to 18 °C. Natural forests in this area were characterized by broad extensions, several arboreal strata, many epiphytes, and fertile soils; however, today most of the forest has been transformed into pastures for agriculture and cattle raising, which causes overgrazing and excessive clearing (Guzmán-González 1996).

Our results show that under the current climatic conditions, the areas with the best environmental suitability for *P. ismaeli* are located in the north-center regions of Colombia. This finding is consistent with the records in Colom-

Figure 2. a) Dorsal, ventral, and occlusal views of the skull and jaw of a male of *Platyrrhinus ismaeli* (CZUT-M 317) captured in El Salitre trail, municipality of Cajamarca, Department of Tolima, Colombia, in July 2003. **b)** Occlusal views of the left first upper molar (M1) and second upper molar (M2). Lingual cingulum not continuous from paracone to metacone of first upper molar.
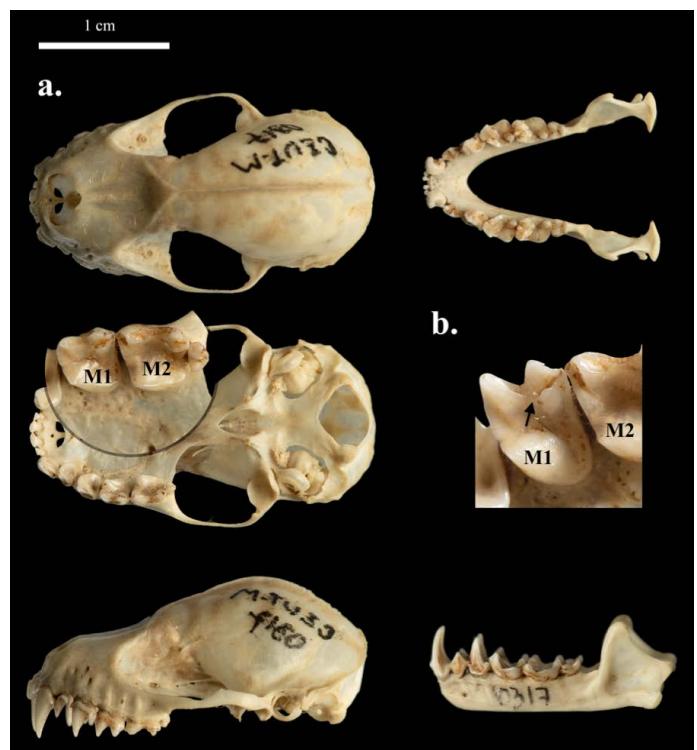
bian collections and the known distribution reported in the literature ([Solari *et al.* 2013](#)), and suggests that the current distribution represents the optimum climatic conditions for the species, in sites of high altitude (2,500 masl) and near steep slopes, with riparian vegetation ecosystems.

The results of the model show that all the current and predicted sites fulfill suitable conditions for *P. ismaeli, i. e.*, high elevation (1,200 to 2,850 masl), low temperature (12.0 to 25.5 °C), and annual precipitation range of 1,000 to 4,000 mm. Consequently, warm sites with elevation < 1,200 masl are less suitable for the species. These results are in line with those from [Solari *et al.* (2013)](#), which report that *P. ismaeli* mainly lives in wet habitats with a narrow elevation range from 1,230 to 2,950 masl.

However, some studies also report the presence of *P. ismaeli* in premontane forests in mountain ranges ([Asprilla-Aguilar *et al.* 2016](#)). In fact, this species prefers secondary forests with abundant vegetation cover, rather than pastures and monocultures or moderately fragmented areas ([Tirira 2011](#)), to the extent that it is considered endemic to Yungas in Perú, the ecoregion with the largest number of endemic species ([Pacheco *et al.* 2009](#)). The distribution of *P. ismaeli* covers the driest forests of the western slopes of the Andes in northern Perú ([Rengifo *et al.* 2011](#)).

Table 3. Environmental variables used for modeling the potential distribution of *P. ismaeli*. Issues related to collinearity were avoided by removing variables with variance inflation factor (VIF) values > 5. Variables highlighted in bold were selected through a multi-collinearity test and were used in modeling. All the variables were obain from the WorldClim.

Variable	Code/Unit	VIF
Mean Annual Temperature	Bio1 (ºC)	1.74
Mean Diurnal Range (Mean of monthly (max temp - min temp)	Bio2 (ºC)	2.68
Isothermality (BIO2/BIO7) (* 100)	Bio3	1.10
Temperature Seasonality (Standard deviation *100)	Bio4 (ºC)	8.53
Max. Temp. Warmest Month	Bio5 (ºC)	12.90
Min. Temp. Coldest Month	Bio6 (ºC)	14.20
Temperature Annual Range (BIO5-BIO6)	Bio7 (ºC)	13.40
Mean Temp. of the Wettest Quarter	Bio8 (ºC)	9.20
Mean Temp. of the Driest Quarter	Bio9 (ºC)	3.14
Mean Temp. of the Warmest Quarter	Bio10 (ºC)	9.15
Mean Temp. of the Coldest Quarter	Bio11 (ºC)	9.23
Annual Precipitation	Bio12 (mm)	2.51
Precipitation of the Wettest Month	Bio13 (mm)	8.93
Precipitation of the Driest Month	Bio14 (mm)	3.39
Precipitation Seasonality (Coefficient of Variation)	Bio15	1.85
Precipitation of the Wettest Quarter	Bio16 (mm)	12.86
Precipitation of the Driest Quarter	Bio17 (mm)	6.60
Precipitation of the Warmest Quarter	Bio18 (mm)	9.90
Precipitation of the Coldest Quarter	Bio19 (mm)	12.30
Elevation	Elev (m)	3.65

Table 4. Estimates of average contribution and permutation importance of the environmental variables used in the MaxEnt modeling for *P. ismaeli*.

Variable	Percent contribution	Permutation importance
Bio1	13.6	29.5
Bio2	0.6	2.3
Bio3	3.6	7.4
Bio9	1.5	3.6
Bio12	33.6	8.0
Bio14	1.5	1.4
Bio15	0.3	1.1
Elev	12.5	5.3

Our analysis revealed that the highest probability of occurrence of *P. ismaeli* is recorded in the center of the North Andean Province in the Departments of Antioquia, Caldas, Cundinamarca, Huila, Tolima, Quindío, and Valle del Cauca. The model also predicts a high probability of occurrence in the Choco--Magdalena region and the east of the Orinoquia region. Altogether, this suggests that the distribution of *P. ismaeli* is governed by the ecological association between the Chocó biogeographic region and the valleys of the Magdalena and Cauca rivers, an exchange zone of the biological elements of these areas with those of the cis-Andean and Magdalena valleys, moving through the foothills of the Orinoquia, the Burbua depression, and the Catatumbo basin. This pattern has

Figure 3. Response curves of eight environmental predictors used in the ecological niche model for *P. ismaeli*. For abbreviations, see Table 3.
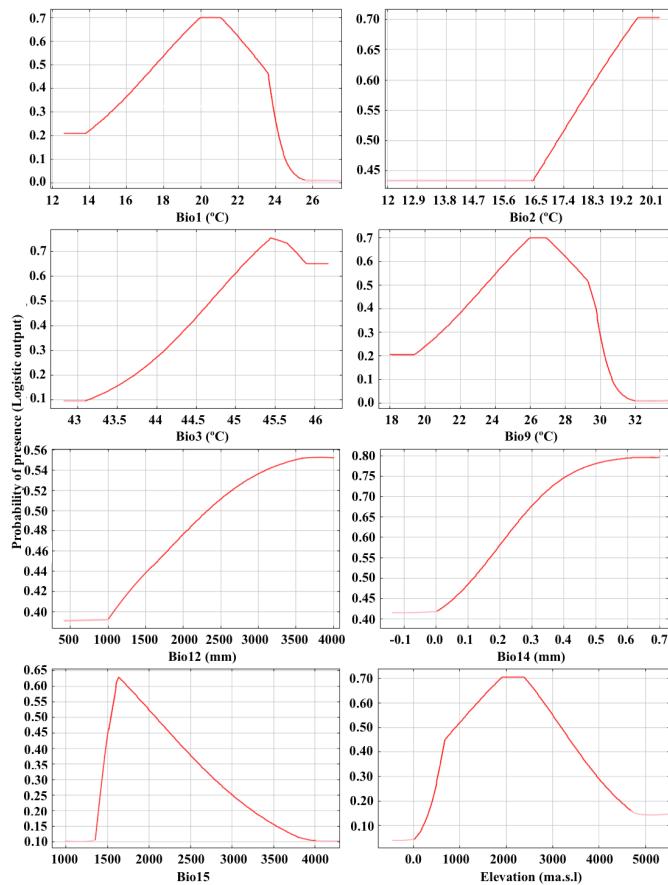
been documented for different groups of animals, including bats (Hernández-Camacho *et al.* 1992; Mantilla-Meluk *et al.* 2009; García- Herrera *et al.* 2018).

In addition, MaxEnt outputs under the current conditions indicate that the distribution range of *P. ismaeli* is influenced primarily by annual temperature, annual precipitation, and elevation. This is consistent with factors affecting the suitable habitats of several groups of vertebrates such as amphibians, non-volant mammals, bats, and birds (Moura *et al.* 2016), where climatic factors and elevation resulted core drivers of the distribution of vertebrate species (Ferro Muñoz *et al.* 2018).

This study provides ecological information about the habitats occupied by this species, as well as a detailed geographic distribution in the Andean region. This information can be used to support the development of scientifically sound conservation plans, as well as detailed and reliable distribution maps for Colombia, thus allowing the identification of areas that are suitable for the conservation of this species in the country. However, further studies are required addressing the distribution of species in the Central range of Colombia, a region that maintains some high-biodiversity areas in spite of the recent anthropogenic impacts.

Acknowledgments

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Appendix 1

Specimens analyzed: For each specimen, the collection acronym and museum number are provided, and the localities are listed by country, Department, and specific locality.

Platyrrhinus ismaeli —**Colombia**. **Antioquia:** Andes, Vereda La Soledad (ICN 16503). **Boyacá:** Santa María, Vereda Caño Negro, camino entre las fincas Santa Rosita y El Tesoro, ruta a Palo Negro (ICN 17165). **Casanare:** Trinidad, Banco de la Cañada (ICN 19320). **Cauca:** Moscopas, 1 Mi N Moscopas (MHNUC 1467, 1501; USNM 483575). **Choc***ó:* El Carmen de Atrato (CMCH 001136). **Cundinamarca:** Tena, alrededor de la laguna de Pedro Pablo (ICN 5293, 5295). **Huila:** Parque Natural Nacional "Cueva de los Guacharos". Puente superior en Río Suaza (FMNH 58732 to 58738;IAvH-M 1930, 1932, 1934, 1990,1992, 1994, 1996). **Meta:** Restrepo, Salinas de Upin (ICN 14372). Cubarral, Vereda Aguas Claras, Escuela Santa Clara, finca La Reforma (ICN 14800). **Nariño:** Barbacoas (Jiménez Ortega). **Norte de Santander:** Toledo, Vereda San Isidro (IAvH-M 6681, 6682). **Putumayo:** Mocoa, El Mirador (ICN 21022; IAvH-M 6818, 6823). **Quindio:** Filandia, Vereda El Roble (ICN 12476). **Risaralda:** Quimbaya, Vereda La Suiza (UV 12694). **Santander:** Charalá, Margen derecha del Río Guillermo, inspección de policía Virolín (ICN 8150). **Tolima:** Cajamarca, Vereda Peñaranda parte Baja (CZUT-M 58). Vereda Planadas (CZUT-M 83, 84, 144, 145). Vereda El salitre (CZUT-M 208, 317). Ibagué, Vereda Toche (CZUT-M 57). Quebrada La Plata (CZUT-M 206, 207). **Valle del Cauca:** Buga, Vereda El Janeiro (UV 12402 to 12405, 12407, 13022, 13023).