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Diversity, structure and natural history of amphibians in the upper Claro River basin, a buffer zone of the National Natural Park Los Nevados, Central Cordillera of Colombia

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Abstract: We present an assessment on composition, diversity and structure of amphibians in three zones along an elevation gradient (2,400–3,000 m) in the Central Cordillera of Colombia. For this purpose, we carried out two field trips in November 2014 and February 2015, covering rainy and dry seasons, respectively. Diurnal (08:00–12:00 h) and nocturnal (18:00–22:00 h) visual encounter surveys were made without spatial restrictions. The diversity for each zone (alpha) and for the entire landscape (gamma) was evaluated by the effective number of species, and the structure of the communities was analyzed by range-abundance curves. The inequality factor for each of the sampling zones was also calculated. A total of 15 species belonging to seven genera and three families were recorded, all of the order Anura. Craugastoridae with 11 species (73.3% of richness) and *Pristimantis* (eight species) were the most diverse family and genus, respectively. The average alpha diversity per zone was 6.6 effective species, with zone A being the most diverse with eight species. In terms of beta diversity we found 2.5 effective communities at the landscape level, and differences between zones are given by the rare species, while the most abundant ones (e.g., *Pristimantis uranobates*) are shared between them. It is presumed that the greater diversity of zone A is due to the lower elevation and better state of conservation if compared to the other two zones. Of the total species recorded, three are threatened with extinction: Endangered (*Hypodactylus latens*, *Osornophryne percrassa*), and Critically Endangered (*Niceforonia adenobrachia*). The finding of three yet undescribed species is highlighted.

Keywords: Andean landscapes, diversity, endemic species, threatened amphibians.

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INTRODUCTION

The study of biodiversity in the mega-diverse countries is a condition without which development models could not be implemented in a sustainable manner (Erhlich & Wilson 1991; Adams et al. 2004; Greene et al. 2005). Therefore, to carry out research that generates knowledge about diversity, distribution, uses and threats to biodiversity, it is an obligation to delineate these models at different scales. Colombia is characterized by its high biodiversity, highlighting a considerable richness of anuran amphibians (757 species with 354 endemics; Acosta & Cuentas 2018), being the second richest amphibian country in the world after Brazil (Frost 2017). Contrary to this, near to 28% of Colombian amphibian species are threatened with extinction (Acosta & Cuentas 2018) due to different factors, such as climate change, habitat transformation, chytridiomycosis, and introduction of exotic species (Stuart et al. 2008). The highest proportion of threatened species is concentrated in the Andean region, where the greatest diversity occurs with more than 400 species (Lynch et al. 1997; Acosta 2000; Kattan et al. 2004; Bernal & Lynch 2008; Acosta & Cuentas 2018).

Located in Central Cordillera and delimited from east to west by the basins of the Magdalena and Cauca rivers, respectively, the department of Caldas is one of the smallest departments (geographic political units) of Colombia. Despite having a small geographic area (7888km^2), its amphibian fauna represents approximately 14% of the known richness for Colombia (Acosta 2009; Rojas-Morales et al. 2014a). Such diversity can be attributed to its location within the north Andean region, which represents the global Hotspot (Myers et al. 2000) with the highest amphibian diversity in the world (Hutter et al. 2017). In some areas above 2,500m of elevation and up to the Páramo level (3,200–3,700 m), there is still an information gap regarding composition and diversity of amphibians. At this area, landscape configuration has been modified since the mid-nineteenth century to expand livestock farms, and subsequently extensive potato crops (*Solanum tuberosum*). This has considerably transformed the original habitat of this mountain region (Valencia 1985; Márquez 2001).

Although in recent years there have been numerous studies to quantify the amphibian's diversity at different spatial scales in Colombia particularly to compare between natural and modified habitats (e.g., Arroyo et al. 2003; Urbina & Londoño 2003; Cadavid et al. 2005; García et al. 2007; Cáceres-Andrade & Urbina-Cardona 2009; Osorno et al. 2011), the metrics used are not the most appropriate because they do not represent the diversity per se of the communities. Indexes such as Shannon or Simpson dominance are measures of entropy, but do not correspond with the number of effective elements that make up a biological community. For that reason it is difficult to interpret and compare results from different studies with this mathematical application (Ricotta 2003; Jost 2006; Moreno et al. 2011). Only until very recent years, a different approach has been used to measure the diversity (including amphibians), taking into account the conversion of indexes into values of number of effective species, to represent the species diversity (Jost 2006; Rös et al. 2012; Acevedo et al. 2016; Méndez-Narváez & Bolívar-G 2016; Vargas-Salinas & Aponte-Gutierrez 2016; Casas-Pinilla et al. 2017). The approach proposed by Jost (2006) is more effective to account diversity, because results are given in number of species, which facilitates interpretation of results.

In this paper we present an analysis of amphibian diversity and structure, between three zones of an Andean river in the Central Cordillera of Colombia. We follow Jost's proposal (Jost 2006) for the analysis of species diversity, assuming the effective number of species as the diversity measurement. In addition, we provide information on natural history, distribution, and identification of the threatened species encountered in the study.

MATERIALS AND METHODS

Study area

The study was carried out in the area of the geothermal project of the "Nereidas Valley", located in the upper Claro River basin, Playa Larga Village, municipality of Villamaría, department of Caldas, Colombia, on the western slope of the Central Cordillera. This area occupies approximately 8km^2 of extension, and is located within the buffer zone of Los Nevados National Natural Park (Fig. 1). Fieldwork was carried out specifically in the farms "La Laguna" (zone A), "Playa Larga" (zone B) and "Laguna Alta" (zone C). The sampling zones are between 2,400–3,000 m of elevation, with a temperature and a relative humidity ranging between 8–16 ^{0}C and 78–93%, respectively. The average annual rainfall reaches 2,076mm, with two rainy periods between March–May and October–November (Acosta-Galvis 2009). Two life zones are recognized in this area (sensu Holdridge 1982), which correspond to the very humid low montane forest (bmh-MB) from

2,400–2,600 m, and the pluvial montane forest (bp-M) above this elevation, in the Zone B.

Landscape at this area is dominated by pastures for livestock (> 70% of the landscape) with introduced grass species such as *Pennisetum clandestinum*, *Holcus lanatus*, and *Paspalum* sp. (Poaceae). Secondary forests are the main natural coverage, restricted to the hilltops and stream borders that normally do not exceed 100m in width. All this area is drained by the Claro River, and Molinos and Nereidas streams, which make up the upper Claro River basin (Image 1).

Zone A - "La Cadena": (4.919^{0}N & -75.455^{0}W, WGS84, 2,420m). This is a secondary forest fragment in advanced state of succession with low anthropic intervention located in a narrow canyon with a steep slope (> 50%). The forest shows four differentiable strata with trees that reach up to 50m height (*Ceroxylon quindiuense*) (Image 2a). Highest strata are represented by species such as *Weinmannia pubescens, W. elliptica* (Cunoniaceae), *Brunellia comocladifolia* (Brunelliaceae), *Faramea flavicans* (Rubiaceae), *Guarea kunthiana* (Meliaceae), *Lippia schlimii* (Verbenaceae), *Drimys granadensis* (Winteraceae), *Oreopanax floribundus* (Araliaceae), *Turpinia occidentalis* (Staphyleaceae), *Ficus gigantosyce* (Moraceae) and *C. quindiuense* (Arecaceae). The understory is rich in herbaceous and growing trees, mainly of the genus *Piper* spp. (Piperaceae) and *Miconia* spp. (Melastomataceae), covered prolifically by mosses and lichens, as well as epiphytes such as bromeliads (*Mezobromelia capituligera*, *Guzmania multiflora*), and orchids (*Odontoglossum* spp., *Cyrtochilum diceratum*). This zone has a thick layer of leaf litter that remained humid during the two field trips. Inside the forest runs "La Cadena", a 2.5–3 m wide and 15–60 cm deep stream, which flows into the Claro River almost 300m downstream from this zone.

Zone B - "Playa Larga": (4.911^{0}N & -75.428^{0}W, WGS84, 3,000m). This area corresponds to a farm dedicated exclusively to cattle raising for milk production, whose forest fragments are characterized by presenting early stages of succession, dominated by species such as *Chusquea* spp. (Poaceae), *Erato vulcanica*

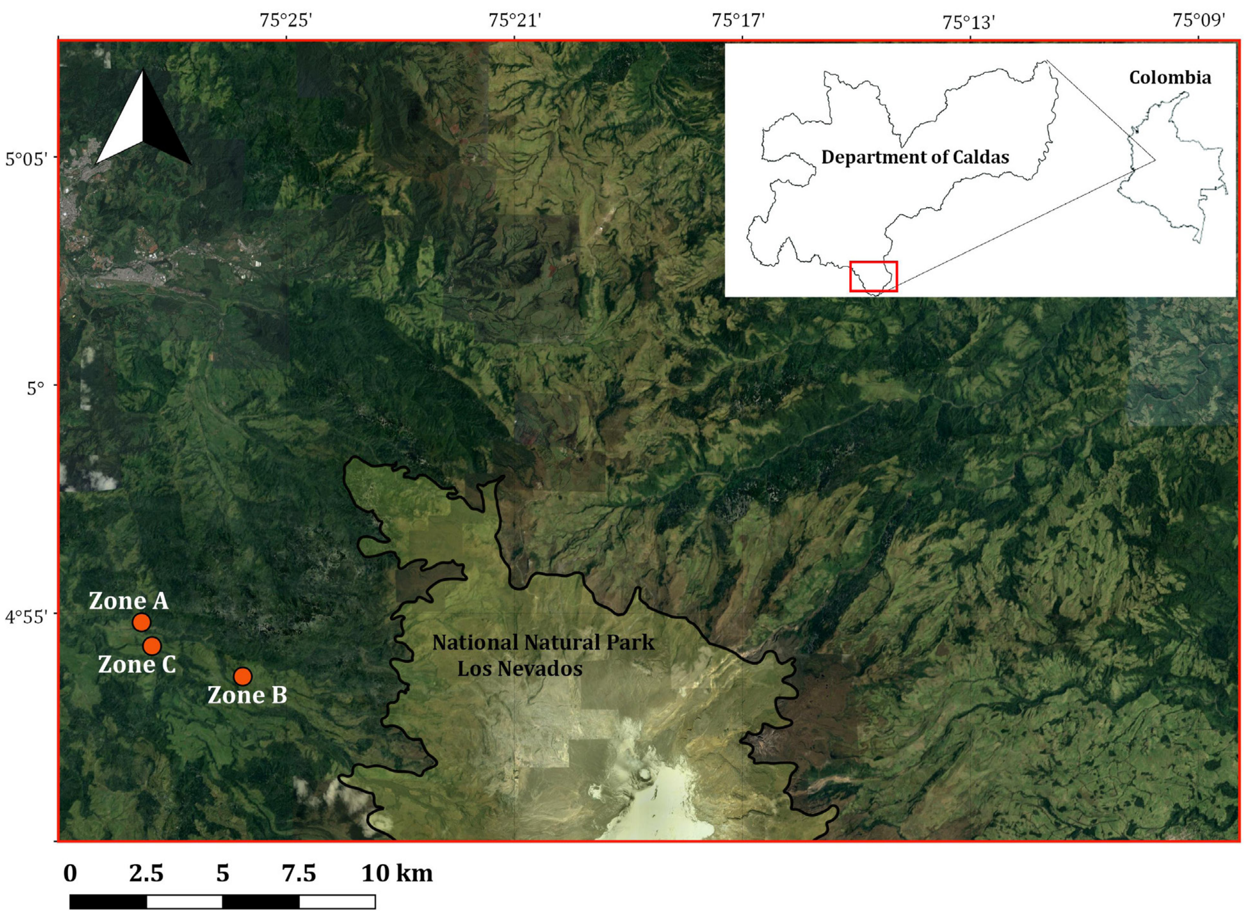

Figure 1. Study area indicating the sampling zones (red dots). Los Nevados National Natural Park is highlighted in light yellow.

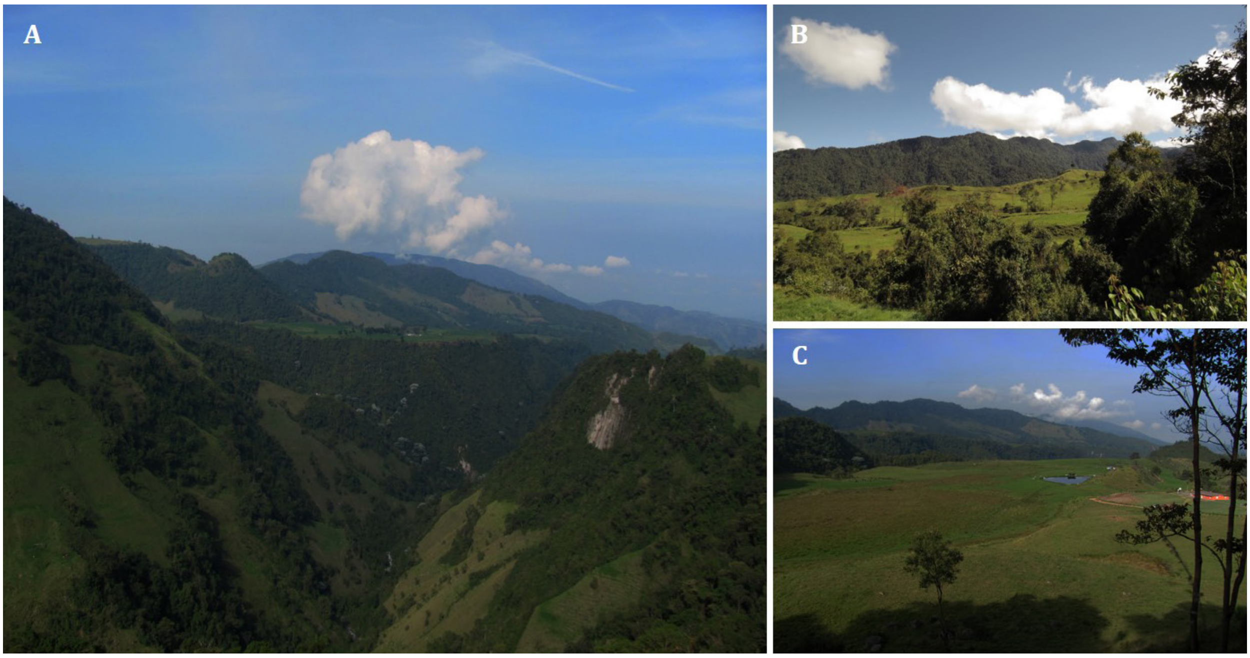

Image 1. Study area in the upper Claro River basin, municipality of Villamaría, department of Caldas, Colombia.
(A) Canyon of the Claro River at 2,500m elevation, showing the abrupt geomorphology in this area. (B) Zone B at 3,000m, evidencing the dominance of pastures for livestock; on the background there is a block of forest corresponding to the Forest Protective Reserve of the CHEC. (C) Zone C at 2,400m, showing the transformation of the natural forest to pastures and crops of potatoes (*Solanum tuberosum*) and onion (*Allium fistulosum*). © Julián Andrés Rojas.

(Asteraceae), *Solanum* spp. (Solanaceae), *Iresine* spp. (Amaranthaceae), *Gunnera* spp. (Gunneraceae), with a low presence of arboreal and shrub species; however, in the surroundings there are considerable forested areas restricted to the hilltops of the mountains, with slopes greater than 70% (Image 2b) crossed by streams that fall in cascades into the Claro River.

Zone C - "Laguna Alta": (4.925^{0}N & -75.458^{0}W, WGS84, 2,380m). This area also corresponds to a cattle farm for milk production, comprising a homogeneous matrix of introduced pastures. The forests are associated with the edge of the Claro River canyon.

Fieldwork

We carried out two field trips between November 11–17, 2014, and February 1–6 in 2015, covering rainy and dry periods, respectively. During each field trip the three zones were sampled, investing two consecutive days/night for each one. For the observation and capture of amphibians, diurnal (08:00–12:00 h) and nocturnal (18:30–22:00 h) samplings were carried out by two people, using the methodology of visual encounters surveys (VES) (Crump & Scott 1994), covering all possible habitats such as streams, inside forest, and open areas. The samplings were made from the ground to 2.5m above, being therefore an understory herpetofaunal research.

Amphibians were manually captured, and kept in plastic bags with vegetation inside to maintain humidity. For all individuals we registered their snout-vent length (SVL) (mm) and weight (g). In addition to this, the specific microhabitat was recorded classified as bare soil, litter, rock, trunk, leaf and water. Height of the perch and the distance to the nearest water body (m), besides temperature (°C) and relative humidity (%) for each register point, were registered too. We follow Frost (2017) for the taxonomic arrangement and for species identification we used the works of Cochran & Goin (1970), Lynch (1975, 1989, 1991), Lynch et al. (1994), Ardila-Robayo et al. (1996), Kaplan (1997), and Rivera-Correa & Faivovich (2013). Individuals were identified in the field as far as possible, but some specimens with taxonomic uncertainty were collected with the permission granted by the environmental authority (Corporación Autónoma Regional de Caldas - Resolution 1166 of 09 October 2014). Collected individuals were euthanized and prepared following the animal care protocol (Cortés et al. 2006). Specimens were deposited in the Herpetological Collection of the Museo de Historia Natural of the Universidad de Caldas (MHN-UCa), Colombia.

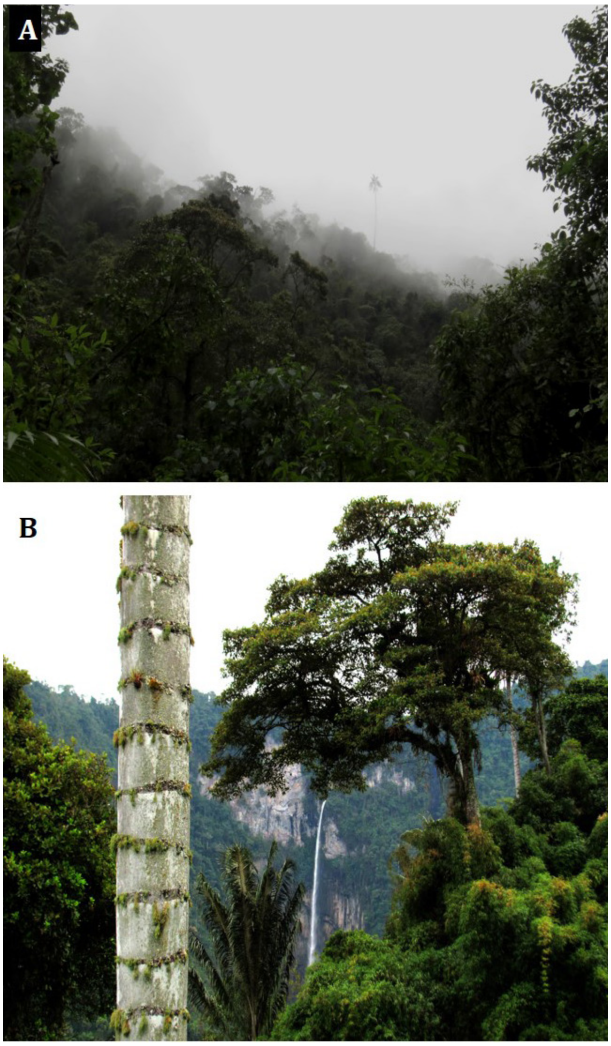

Image 2. Natural habitats sampled in the upper basin of the Claro River, municipality of Villamaría, department of Caldas, Colombia. (A) Interior of the forest in zone A. A semi-permanent fog covered the forest (cloud forest). (B) Zone B showing the beauty of the landscape characterized by the forest, steep slopes and waterfalls. © Julián Andrés Rojas (A) and César Duque Castrillón (B).

Data analysis

Diversity was evaluated in terms of the effective number of species "^qD" (Jost 2006), an approach that is equivalent to Hill's numbers (Hill 1973). ^qD is an ecological measure to quantify and compare the diversity expressed in biologically interpretable units (effective number of species) (Jost 2006). Three orders of diversity *q* were taken into account: order 0 (^0D, species richness), 1 (^1D, Shannon's entropy exponential) and 2 (^2D, Simpson's inverse). Exponent *q* determines the influence of the species abundance on the values of diversity. In this way the species richness (^0D) is not sensitive to the abundance of species and gives disproportionate weights to the rare species (Jost 2006). In ^1D (Diversity of Shannon), the contribution of each species is commensurate with its abundance in the community, and thus can be interpreted as the typical diversity or the number of common species in the community (Jost 2006). Finally, ^2D can be interpreted as the number of "very abundant" or "dominant" species in the community (Jost 2006). The completeness was evaluated as percentage of the community represented in the total of captured individuals (Chao & Jost 2012). The sampling coverage varies between 0% (low completeness) to 100% (high completeness). The estimation of the sampling coverage and diversity were made with the iNEXT package for R (Hsieh et al. 2016).

The structure of communities was analyzed through range-abundance graphs using the relative abundances of each species. This is to observe dominant and rare species and the equity of the sampled communities. The inequality value for each one of the sampling zones was also calculated using the inequality factor $IF_{0,q}$, using in this case the values of ^2D (Jost 2010):

$$IF_{0,2} = {}^0D/{}^2D$$

Where ^0D corresponds to the values of species richness and ^2D to the values of the second order diversity. A scale that oscillates between zero and one was standardized, where zero corresponds to low values of inequality and one to high values. For this the standardized formula (RI0, q) was used for the value previously calculated (IF0, q) and the number of species (S):

$$IR0, q = (IF0,q - 1)\ (S - 1)$$

To check whether the species showed any preference for a given geographical zone a chi-square based test of association was performed on the contingency matrix containing the species with their respective abundance in a given zone (Table 1). Correspondence analysis was performed to visualize the distribution of species in the three zones. Statistical analysis was performed in PAST 3.19 (Hammer et al. 2001). As the threatened species that were recorded are poorly represented in literature, we also present a description with useful characteristics for their identification in the field, and specific annotations about their distribution and natural history (Appendix II, Images 5–8).

RESULTS

Richness and species composition

After 96 hours/man in general for all sites (32h/site), 77 individuals were recorded, belonging to 15 species, seven genera and three families, all of the order Anura (Table 1). Craugastoridae was the best represented family, with 73.3% (11 species) of the records, and *Pristimantis* was the richest genus with eight species (Image 3); one of them represents a new species in the process of taxonomical description (González-Durán pers. comm.). The Hylidae family was represented by two species: *Dendropsophus bogerti* (Cochran & Goin 1970) and *Colomascirtus larinopygion* (Duellman 1973), as well as the family Bufonidae with *Osornophryne percrassa* Ruiz & Hernández, 1976 and *Rhinella* sp. The species *Rhinella* sp. and *Niceforonia* sp. also represent undescribed taxa (Image 4). The most abundant species in all sites was *Pristimantis uranobates* (n = 19), followed by *P. paisa* (n = 15) and *P. permixtus* (n = 14). The less abundant species were *Hypodactylus latens* (Lynch 1989), *P. thectopternus* (Lynch 1965), *Niceforonia* sp., *Pristimantis* sp. 1 (Image 3F) and *Pristimantis* sp. 3 (Image 3H), which had a single register during the entire study.

Sampling coverage and structure of the community

For zone A, sampling coverage reached 89%, with a total of 29 individuals, belonging to eight species, four genera and three families. Craugastoridae family was the most representative (75% of the species); *P. uranobates* (n = 11) was the most abundant species followed by *C. larinopygion* (n = 8) and *P. paisa* (n = 4). Species such as *H. latens* and *P. permixtus* had a single record (Fig. 2A, B). The value of the inequality factor for this zone was 0.08, being the site with the lowest value (Table 2). At this zone, *P. uranobates* and *C. larinopygion* accounted for 27% of the total abundances, followed by *P. paisa* representing 13%, *Rhinella* sp. and *P. boulengeri* 10%, and the rest of the species 3.4% (Fig. 2). For zone B, 93% sampling coverage was obtained, with 31 individuals represented by seven species, three genera and two families (Table 1). The most abundant species was *P. permixtus* (n = 13), followed by *P. uranobates* (n = 8) and *Pristimantis* sp. 2 (n = 4). The species that had a single record in this site were *Niceforonia* sp. and *P. paisa* (Fig. 2). The value of the inequality factor for this site was 0.15 (Table 2). In zone C, a total of 17 individuals were found distributed in five species, two genera and two families. The most abundant species was *P. paisa*

Table 1. Anuran species and number of individuals by zone in the upper Claro River basin, municipality of Villamaría, department of Caldas, Colombia. Threat categories are according to IUCN 2017 (International Union for Conservation of Nature). Categories represent Not evaluated (NE); Least Concern (LC); Near Threatened (NT); Endangered (EN); Critically Endangered (CR).

Taxa	Zone A	Zone B	Zone C	Total	Code	IUCN Red List
Bufonidae						
Osornophryne percrassa	-	2	-	2	A	EN
Rhinella sp.	3	-	-	3	B	
Craugastoridae						
Hypodactylus latens	1	-	-	1	C	EN
Niceforonia sp.	-	1	-	1	D	
Niceforonia adenobrachia.	-	2	-	2	E	CR
Pristimantis boulengeri	3	-	-	3	F	LC
Pristimantis paisa	4	1	10	15	G	LC
Pristimantis permixtus	1	13	-	14	H	LC
Pristimantis sp. 1	1	-	-	1	I	
Pristimantis sp. 2	-	4	-	4	J	
Pristimantis sp. 3	-	-	1	1	K	
Pristimantis thectopternus	-	-	1	1	L	LC
Pristimantis uranobates	8	8	3	19	M	LC
Hylidae						
Dendropsophus bogerti	-	-	2	2	N	LC
Colomascirtus larinopygion	8	-	-	8	O	NT
Total	29	31	17	77		

Image 3. Species of the genus *Pristimantis* (Craugastoridae) recorded during this study. (a) *P. boulengeri* SVL 23,4mm; (b) *P. paisa* SVL 25,6mm; (c) *P. permixtus* SVL 25,5 mm; (d) *P. thectopternus* SVL 24,3mm; (e) *P. uranobates* (green morph) SVL 20,3mm; (f) *Pristimantis* sp. 1 SVL 22,7mm; (g) *Pristimantis* sp. 2 SVL 26mm; (h) *Pristimantis* sp. 3 SVL 58mm. © Julián Andrés Rojas.

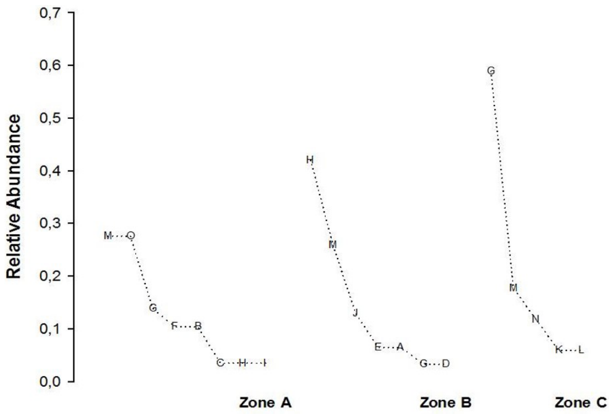

Figure 2. Range-abundance amphibian curves for each zone in the upper Claro River basin, municipality of Villamaria, department of Caldas, Colombia. Letters represent species code, see Table 1.

(n = 10) followed by *P. uranobates* (n = 3) and *D. bogerti* (n = 2). *Pristimantis thectopternus* and *Pristimantis* sp. 3 had a single record (Fig. 2). The sampling coverage for this site was 88% and the inequality value was 0.25, this being the highest value among all sites (Table 2).

Diversity profiles

The species richness (^0D) shows that zone A has a greater number of effective species (8), followed by zone B (7) and finally zone C (5) (Fig. 3). In the same way, the diversity of order ^1D indicates that zone A presents a greater number of effective species with respect to the other two zones with 6.1, followed by zone B with 4.7 and zone C with 3.3 effective species (Fig. 3). When expressing this results in equivalences, zone B may contain 77% of the diversity found for zone A. On the other hand, it is observed that zone A presented almost twice the diversity of species with respect to zone C, and when comparing zones B and C, it was found that the latter may contain 70% of the diversity recorded for zone B. With the order ^2D measure of diversity, all the sites result with a lower number of effective species (Fig. 3), since this measure focuses only on the most abundant species (Jost 2006). With this measure of diversity zone A reached 5.1 effective species, being the most diverse zone followed by zone B with 3.7 effective species, and finally zone C with 2.5 effective species. This is due to the fact that in zone A (which presented the lowest values of inequity, see Table 2), the most abundant species represent 27% of the total of individuals, while for zone B the most abundant species represent 41% of the total, and in zone C 58%; this leads to greater equity in the distribution of abundances among the species common to zone A compared to the other two sites.

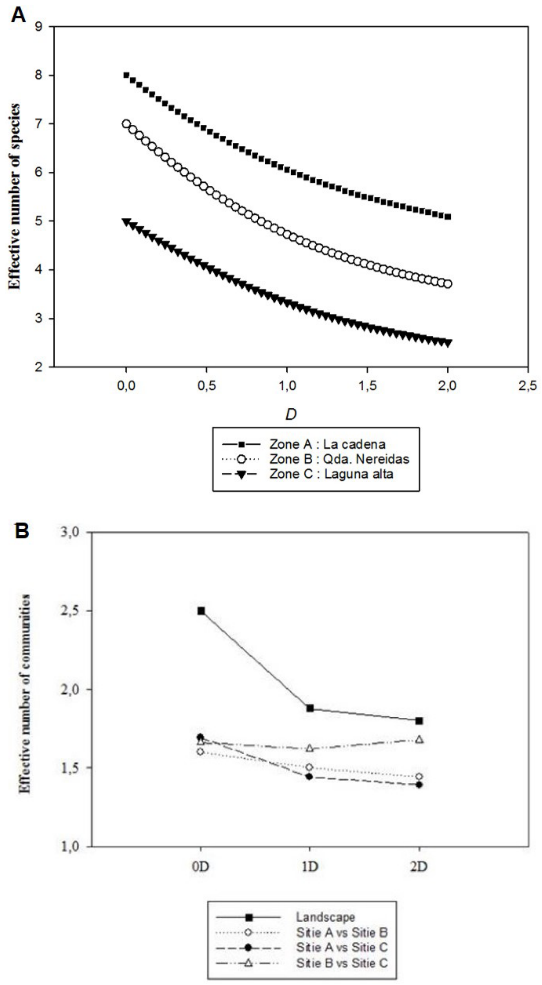

Figure 3. Amphibian diversity profiles for three zones in the upper Claro River basin, municipality of Villamaria, department of Caldas, Colombia. (A) Diversity in effective number of species; (B) Diversity in terms of communities.

Table 2. Values of the inequality factor for the three sampled zones in the upper Claro River basin, municipality of Villamaría, department of Caldas, Colombia.

Factor of inequality	$IF_{0,2}$	$RI_{0,2}$
Zone A-La Cadena	1.57	0.08
Zone B-Playa Larga	1.89	0.15
Zone C-Laguna Alta	1.99	0.25

With respect to beta diversity, it was found that there are 2.5 effective communities at the landscape level (^0D), 1.9 according to the diversity ^1D, and 1.8 according to ^2D, respectively. These results indicate that the differences between the sampled areas are given for the rare species, while some abundant species are shared, as *P. uranobates*, which was the most

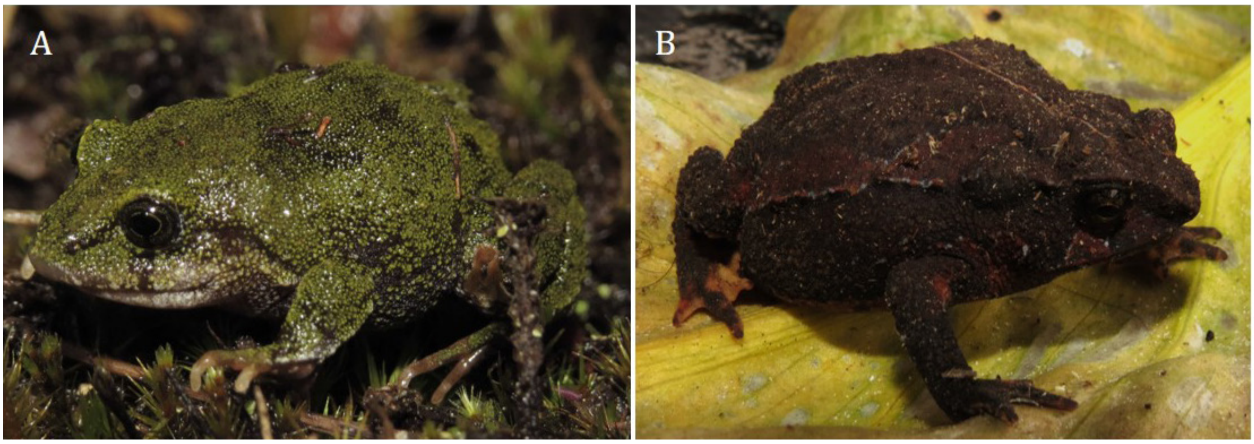

Image 4. Undescribed amphibian species registered for the upper Claro River basin, municipality of Villamaria, department of Caldas, Colombia. (A) *Niceforonia* sp. (Craugastoridae) SVL 22.9mm; (B) *Rhinella* sp. (Bufonidae) SVL 34.1mm. © Julián Andrés Rojas.

abundant species being found in all the sampling zones (Tabla 1, Fig. 2). When making comparisons between pairs of zones, it is observed that for zone A the results of ^1D and ^2D for beta diversity are lower than the ^0D expression (Fig. 3). This shows that zone A differs from the other two mainly because of its rare species ($^1D < {}^0D$), and some of the most abundant species are still shared ($^2D < {}^1D$). When comparing zone B with respect to C, it is observed that the values of ^1D (1.62 effective communities) are lower than for species richness ^0D (1.66 effective communities), while the values of ^2D are greater (1.68 effective communities). This indicates that the differences between these two sites are given to a greater extent by the abundant species ($^2D > {}^0D$), although some of these are shared ($^1D < {}^0D$). The most abundant species for zone B and C were *P. permixtus* and *P. paisa*, respectively (Fig. 2).

There was a significant association between the zones and the species (chi-square = 88.779, df = 28, $P < 0.0001$), indicating that the amphibians had a preference for a particular zone. Correspondence analysis (Fig. 4) showed that the amphibian fauna of the zones was distinct from each other. *Colomascirtus larinopygion*, *H. latens*, *P. boulengeri*, *Pristimantis* sp. 1 and *Rhinella* sp. were restricted to Zone A; *N. adenobrachia*, *Niceforonia* sp., *O. percrassa* and *Pristimantis* sp. 2 were restricted to Zone B, while *D. bogerti*, *P. thectopternus* and *Pristimantis* sp. 3 were restricted to Zone C. Although *P. paisa*, *P. permixtus* and *P. uranobates* were present in all three zones, *P. uranobates* was more ubiquitous in all three zones as compared to *P. permixtus* that was more abundant in Zone B and *P. paisa* that was more abundant in Zone C (Table 1).

Natural history observations and conservation status of the species

During fieldwork most of the individuals were observed at twilight and night hours, between 18:00–21:00 h, mainly stream-dwelling frogs such as *C. larinopygion*, which were observed by calling males. *Dendropsophus bogerti* was only observed in the flooded pastures during the first fieldtrip, formed by the constant rains during that period. Leaf-litter and understory frogs, like those of the genus *Pristimantis* (Image 3, Appendix I), were common both inside and on the edge of forests, and also in the pastures that surrounded them. Species such as *Rhinella* sp. and *H. latens* (Appendix I) were observed only during the day (10:30–12:00 h) on the litter or into the flooded soil. Typical nocturnal species, such as *P. uranobates* and *P. permixtus* were observed during the day, immobile on the ground, or hidden under leaf litter.

Of the 15 registered species, four are threatened with extinction according to the International Union for the Conservation of Nature (IUCN 2017). *Niceforonia adenobrachia* is Critically Endangered (CR) due to their very restricted distribution range (< $100km^2$) (see Appendix II). *Hypodactylus latens* and *Osornophryne percrassa* (Appendix II) are Endangered (EN), both equally with restricted and fragmented distributions (< $5000km^2$), and because the extension and quality of their habitat is decreasing in response to human intervention in cloud forests (Castro et al. 2004; IUCN SSC Amphibian Specialist Group 2015). Finally, the hylid frog *C. larinopygion* is Near Threatened (NT) due to their fragmented distribution, although it is a relatively common species where it has been registered (Bolívar et al. 2010) (Appendix II). On the other hand, *Pristimantis* frogs present a state of Least Concern (LC) and their populations apparently remain stable; however, how species are responding to habitat intervention at local scale is unknown. The undescribed species *Rhinella* sp., *Niceforonia* sp. and *Pristimantis* sp. 2 are not yet categorized and therefore their conservation status is unknown.

DISCUSSION

Richness and species composition

Among current ectothermic vertebrates, amphibians are the most diversified group in the high mountain ecosystems of the tropical Andes (Lynch 1999a; Lynch & Suárez-Mayorga 2002; Navas 2006; Bernal & Lynch 2008; Hutter et al. 2013), however, amphibian distribution patterns show that there is a decrease in diversity as elevation increases, similar to latitudinal reduction patterns (Lynch 1986). In this study we recorded 15 amphibian species with a representativeness between 89–93 % for the three evaluated zones, indicating that the fauna observed is a representative sample, but possibly some additional species can be found with an increasing sampling effort. Among the latter, members of the family Centrolenidae (glass frogs), which are known to be important components of the Andean amphibian communities (Guayasamin et al. 2009; Hutter et al. 2013; Rojas-Morales et al. 2014b; and references therein included), were not found in this study. It is possible that species such as *Centrolene buckleyi* (Boulenger, 1882), *C. robledoi* Ruiz-Carranza & Lynch, 1995, *C. quindianum* Ruiz-Carranza & Lynch, 1995 and *Nymphargus grandisonae* (Cochran & Goin, 1970) are also present in the study area, but because of their arboreal habits and possible seasonal reproduction, they were not observed during this study.

On the other hand, the richness and representativeness of the *Pristimantis* genus registered in this study, is not surprising because these frogs represent about a third of the known amphibians in Colombia, being highly diversified in Andean ecosystems (Acosta & Cuentas 2018). In addition, its greatest peak of diversity is between 1,750–2,400 m (Lynch & Duellman 1980, 1997; Lynch & Rueda-Almonacid 1997). The high diversity of these frogs seems to be associated with their reproductive modes, which include terrestrial eggs and direct development, which does not limit their reproduction to aquatic environments. In this way, these frogs can inhabit all terrestrial environments that have sufficient moisture for the development of eggs and survival of juveniles and adults (Lynch & Duellman 1980, 1997; Lynch & Rueda-Almonacid 1997; Lynch et al. 1997; Lynch 1999a, b; Duellman & Lehr 2009).

Diversity and structure of the community

In amphibians, species diversity is affected by ecological traits, such as forest structure, microclimate and topography (Vonesh 2001; Dixo & Martins 2008; Santori & McManus 2014; Meza-Joya & Torres 2016).

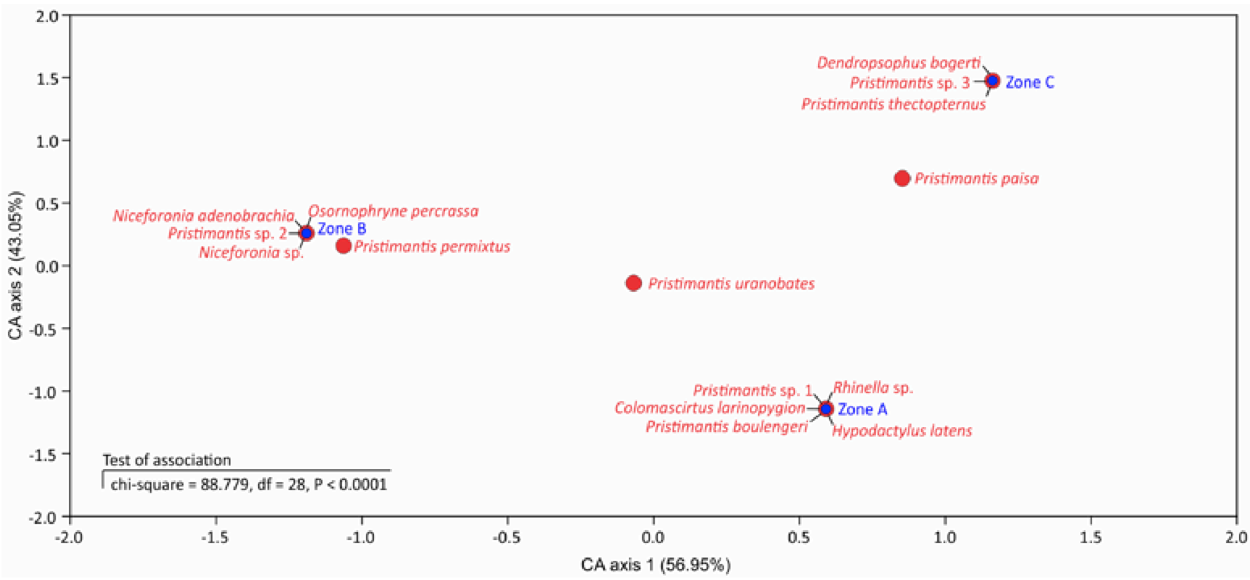

Figure 4. Correspondence analysis (CA) depicting the distribution of amphibians in the three zones evaluated. Test of association is shown in the inset. Percentage contribution by each CA axis is provided in parenthesis.

In this study, the zone A showed the highest diversity among all sites, with higher values in the three orders of diversity *q*, as well as the lowest values for the inequality factor (Table 2). This result may be due to the interaction of several factors, such as environmental conditions and elevation (2,400m); in addition, this is the area where the least intervened ecosystem persists. In spite of diversity values in zone A, it is important to emphasize that between this zone and zone B there was not a significant difference respect to the species richness, but they are not similar in species composition, mainly due to rare and threatened species. This is important, since the loss of these habitats due to deforestation could lead to the local extinction of some of these populations (Dodson & Gentry 1991). Unlike these two zones, zone C presented the lowest values of diversity, probably because this area has a greater degree of anthropogenic intervention, evidenced in large areas of open grasslands, with a minimum proportion of native forest.

On the other hand, although the elevation gradient between the zones is low (600m), 2.5 effective communities were found (beta diversity at the landscape level), and the differences between zones are given for its rare species in greater measure (Fig. 4). It is very likely that the 2.5 effective communities in this gradient correspond to the change in life zones across the landscape. In high mountain ecosystems it has been recognized that species composition can be relatively heterogeneous between localities at small spatial scales (Moen et al. 2009). We suggest that the 2.5 effective communities are composed, on the one hand, of species belonging to higher elevation ecosystems (Páramos, and high Andean forest), such as *O. percrassa* and *N. adenobrachia* (Ardila-Robayo et al. 1996; Bernal & Lynch 2008), and *Rhinella* sp., and *C. larinopygion* to medium elevation Andean forest. These species in turn were rare species within the sampling zones. On the other hand, it was found that *Pristimantis* frogs are important elements of the communities in all the zones evaluated. These frogs, as already mentioned, are the most specious genus in the Neotropics (Lynch & Rueda-Almonacid 1997; Santori & McManus 2014); in addition, most of their species are highly generalistic in the use of their resources, found in a wide range of habitats and microhabitats, and feeding on a great variety of prey (Arroyo et al. 2008; García et al. 2015; Santori & McManus 2014; Gutiérrez-Cárdenas et al. 2016). In the case of *P. uranobates*, which was the most abundant species and was also found in all zones, it has been reported that it may tolerate intervened environments and also have a wide altitudinal distribution (Lynch 1991; Lynch et al. 1996).

Conservation status of species

Of all species recorded in this study, three of them are threatened with extinction: two Endangered (EN) and one Critically Endangered (CR) (Table 1, Appendix II). The record of these species within the buffer zone of Los Nevados National Natural Park is highly significant, because the buffer zones have a management policy that permits the development of productive activities, such as cattle breeding and agriculture. Records of *Niceforonia* sp. (Fig. 5A) and *N. adenobrachia* (Appendix II) are of great value, because the former is an undescribed species and possibly has a restricted distribution like the other species of the genus (see Acosta-Galvis 2000); in the case of *N. adenobrachia*, this register represents one of the few known populations for the species (see Appendix II). It is very probable that the distribution of these threatened species (and also of *Hypodactylus latens*) encompasses the strict conservation area of the Los Nevados National Natural Park. For this reason, we suggest that it is important to delimit areas of protection within the farms, mainly the forest associated to creeks and streams, in order to establish a limit for the advance of human activities that threaten biodiversity outside of protected areas. In addition, it is important to restore the structural connectivity between forest fragments to mitigate the fragmentation of amphibian populations due to deforestation. Other recognized threats to amphibians such as climate change evidenced in extreme seasons (e.g., extended droughts), the introduction of exotic species, and emerging diseases such as chytridiomycosis, however, represent a latent risk for amphibian communities even within protected areas (see Lips et al. 2003, 2004; La Marca et al. 2005; Lampo et al. 2006; Acevedo et al. 2016).

REFERENCES

Acevedo, A.A., R. Franco & D.A. Carrero (2016). Diversity of Andean amphibians of the Tamá National Natural Park in Colombia: a survey for the presence of *Batrachochytrium dendrobatidis*. *Animal Biodiversity and Conservation* 39(1): 1–10; https://abc.museucienciesjournals.cat/files/ABC_39-1_pp_1-10.pdf

Acosta, A.R. (2000). Ranas, Salamandras y Caecilias (Tetrapoda: Amphibia) de Colombia. *Biota Colombiana* 1(3): 289–319; https://redalyc.org/pdf/491/49110303.pdf

Acosta-Galvis, A.R. (2009). Estado del conocimiento de los anfibios y reptiles del departamento de Caldas. Vacíos de información y las prioridades de conservación. Corporación Autónoma Regional de Caldas (Corpocaldas). Manizales, Caldas. 142 pp.

Acosta, A.R. & D. Cuentas (2018). Lista de los Anfibios de Colombia: Referencia en línea V.05.2015.0 (acceso 02-04-2016). Página web accesible en https://www.batrachia.com; Batrachia, Villa de Leyva,

Boyacá, Colombia.
Adams, W.M., R. Aveling, D. Brockington, B. Dickson, J. Elliot, J. Hutton, D. Roe, B. Vira & W. Womer (2004). Biodiversity conservation and the eradication of poverty. *Science* 306(5699): 1146–1149; https://www.researchgate.net/publication/51370569_Biodiversity_Conservation_and_the_Eradication_of_Poverty
Ardila-Robayo, M.C., P.M. Ruiz-Carranza & M. Barrera-Rodriguez (1996). Una nueva especie de *Phrynopus* (Amphibia, Anura, Leptodactylidae) de la Cordillera Central Colombiana. *Lozania* 67: 1–10.
Arroyo, S., A. Jerez & M.P. Ramírez-Pinilla (2003). Anuros de un bosque de niebla de la cordillera Oriental de Colombia. *Caldasia* 25(1): 153–167; https://www.unal.edu.co/icn/publicaciones/caldasia/25(1)/zoologia1.pdf
Arroyo, S.B., V.H. Serrano-Cardozo & M.P. Ramírez-Padilla (2008). Diet, microhabitat and time of activity in a *Pristimantis* (Anura, Strabomantidae) assemblage. *Phyllomedusa* 7(2): 109–119; https://doi.org/10.11606/issn.2316-9079.v7i2p109-119
Bernal, M.H. & J.D. Lynch (2008). Review and analysis of altitudinal distributions of the Andean anurans in Colombia. *Zootaxa* 1826: 1–25; https://www.researchgate.net/publication/276505871_Review_and_analysis_of_altitudinal_distribution_of_the_Andean_anurans_in_Colombia
Bolívar, W., L.A. Coloma, S. Ron & J.M. Rengifo (2010). *Hyloscirtus larinopygion*. The IUCN Red List of Threatened Species 2010: e.T55531A11328178. Downloaded on 17 March 2017; https://doi.org/10.2305/IUCN.UK.2010-2.RLTS.T55531A11328178.en
Cáceres-Andrade, S.P. & J.N. Urbina-Cardona (2009). Ensamblajes de anuros de sistemas productivos y bosques en el piedemonte llanero, departamento del Meta, Colombia. *Caldasia* 31(1): 175–194; https://revistas.unal.edu.co/index.php/cal/article/view/36085/37485
Cadavid, J.G., C. Román-Valencia & A.F. Gómez (2005). Composición y estructura de anfibios en un transecto altitudinal de los Andes centrales de Colombia. *Revista del Museo Argentino de Ciencias Naturales* 7(2): 103–118.
Casas-Pinilla, L.C., O. Mahecha-C, J.C. Dumar-R & C. Ríos-Maláver (2017). Diversidad de mariposas en un paisaje de bosque seco tropical, en la Mesa de los Santos, Santander, Colombia (Lepidoptera: Papilionoidea). *SHILAP Revista de Lepidopterología* 45(177): 83–108; https://www.redalyc.org/articulo.oa?id=45550375010
Castro, F., M.I. Herrera & J.D. Lynch (2004). *Hypodactylus latens*. The IUCN Red List of Threatened Species 2004: e.T56702A11517360. Downloaded on 07 January 2017; https://doi.org/10.2305/IUCN.UK.2004.RLTS.T56702A11517360
Chao, A. & L. Jost (2012). Coverage-based rarefaction and extrapolation: standardizing samples by completeness rather than size. *Ecology* 93(12): 2533–2547; https://doi.org/10.1890/11-1952.1
Cochran, D.M & J.C. Goin (1970). Frogs of Colombia. *Publications of the United States National Museum. Smithsonian Institution* 288: 1–641.
Cortés, C., A.M. Suárez-Mayorga& F.J. López-López (2006). Preparación y preservación de material científico, pp173–220. In: Angulo, A., J.V. Rueda-Almonacid, J.V. Rodríguez-Mahecha & E. La Marca (eds.). *Técnicas de inventario y monitoreo para los anfibios de la región tropical andina*. Conservación Internacional, Bogotá D.C., Colombia.
Dixo, M. & M. Martins (2008). Are leaf-litter frogs and lizards affected by edge effects due to forest fragmentation in Brazilian Atlantic forest? *Journal of Tropical Ecology* 24: 551–554; https://www.cambridge.org/core/journals/journal-of-tropical-ecology/article/are-leaflitter-frogs-and-lizards-affected-by-edge-effects-due-to-forest-fragmentation-in-brazilian-atlantic-forest/CD8F424D246CDDF9358D2BFE9C15D103
Dodson, C.H. & A.H. Gentry (1991). Biological extinction in western Ecuador. *Annals of the Missouri Botanical Garden* 78: 273–295.
Duellman, W.E. (1973). Descriptions of new Hylid frogs from Colombia and Ecuador. *Herpetologica* 29: 219–227; https://sci-hub.tw/https://www.jstor.org/stable/3892005
Duellman, W.E. & E. Lehr (2009). Terrestrial-Breeding Frogs (Strabomantidae) in Peru. Münster: Natur und Tier-Verlag GmbH. 382 p.
Duellman, W.E. & T.J. Berger (1982). A new species of Andean tree frog (Hylidae). *Herpetologica* 38: 456–460.
Duellman, W.E. & D.M. Hillis (1990). Systematic of frogs of the *Hyla larinopygion* group. *Occasional Papers of the Museum of Natural History, The University of Kansas, Lawrence, Kansas* 134: 1–23; https://archive.org/details/biostor-212
Ehrlich, P.R. & E.O. Wilson (1991). Biodiversity studies: Science and policy. *Science* 253(5021): 758–762.
Faivovich, J., C.F.B. Haddad, P.C.A. García, D.R. Frost & J.A. Campbell (2005). Systematic review of the frog family Hylidae, with special reference to Hylinae: Phylogenetic analysis and taxonomic revision. *Bulletin of the American Museum of Natural History* 294:1–240; https://digitallibrary.amnh.org/bitstream/handle/2246/462/B294.pdf?sequence=1
Frost, D.R. (2017). Amphibians Species of the World: an online reference. Version 6.0 (last Access on 25 September 2017). Electronic database accesible at https://research.amnh.org/herpetology/amphibia/index.html. American Museum of Natural History, New York, USA.
García J.C., H. Cárdenas & -F. Castro-H (2007). Relación entre la diversidad de anuros y los estados sucesionales de un bosque muy húmedo montano bajo del Valle del Cauca, suroccidente colombiano. *Caldasia* 29: 363–374; https://revistas.unal.edu.co/index.php/cal/article/view/39203/41056
Garcia, R.J.C., C.E. Posso-Gómez & H. Cárdenas-Henao (2015). Diet of Direct-Developing frogs (Anura: Craugastoridae: *Pristimantis*) from the Andes western Colombia. *Acta Biológica Colombiana* 20 (1): 79–87; https://www.scielo.org.co/pdf/abc/v20n1/v20n1a09.pdf
Greene, R.E., A. Balmford, P.R. Crane, G.M. Mace, J.D. Reynolds & R.K. Turner (2005). A framework for improved monitoring of biodiversity: Response to the world Summit on sustainable development. *Conservation Biology* 19(1): 56–65; https://johnreynolds.org/wp-content/uploads/2012/07/green-et-al-cons-bio-05.pdf
Gutiérrez-Cárdenas, P.D.A., K. Castillo, D. Martínez, C.F. Rocha & M.A. Rojas-Rivera (2016). Trophic ecology of *Pristimantis labiosus* (Anura: Craugastoridae) from Southwestern Colombia. *North-Western Journal of Zoology* 12(1): 102-109; https://www.researchgate.net/publication/304042766_Trophic_ecology_of_Pristimantis_labiosus_Anura_Craugastoridae_from_south-western_Colombia
Hammer, Ø., D.A.T. Harper & P.D. Ryan (2001). Past: Paleontological Statistics Software Package for education and data analysis. *Paleontología Electrónica* 4: 1–9.
Hill, M.O. (1973). Diversity and evenness: A unifying notation and its consequences. *Ecology* 54: 427–432; https://www.fcnym.unlp.edu.ar/catedras/ecocomunidades/Hill%20-%20Diversity%20and%20Evenness--%20A%20Unifying%20Notation%20and%20Its%20Consequences.pdf
Holdridge, L.R. (ed.) (1982). Ecología basada en zonas de vida. San José, Costa Rica. IICA. 215 pp.
Hutter, C.R., J.M. Guayasamin & J.J. Wiens (2013). Explaining Andean megadiversity: the evolutionary and ecological causes of glassfrog elevational richness patterns. *Ecology Letters* 16(9): 1135–1144; https://doi.org/10.1111/ele.12148
Hutter, C.R., S.M. Lambert & J.J. Wiens (2017). Rapid diversification and time explain Amphibian richness at different scales in the Tropical Andes, earth's most biodiverse Hotspot. *The American Naturalist* 190(6): 828–843; https://www.wienslab.com/Publications_files/Hutter_et_al_AmNat_2017.pdf
Hsieh, T.C., K.H. Ma & A. Chao (2016). iNEXT: An R package for rarefaction and extrapolation of species diversity (Hill numbers). *Methods in Ecology and Evolution* 7(12): 1451–1456; https://chao.stat.nthu.edu.tw/wordpress/paper/120_pdf_appendix.pdf
IUCN SSC Amphibian Specialist Group (2015). *Osornophryne percrassa*. The IUCN Red List of Threatened Species 2015: e.T54858A60783778. Downloaded on 02 March 2017. https://doi.org/10.2305/IUCN.UK.2015-2.RLTS.T54858A60783778.en
Jost, L. (2006). Entropy and diversity. *Oikos* 113(2): 363–375.

Jost, L. (2010). The relation between evenness and diversity. *Diversity* 2: 207–232; https://www.researchgate.net/publication/41667724_The_Relation_between_Evenness_and_Diversity

Kaplan, M. (1997). On the status of *Hyla bogerti* Cochran and Goin. *Journal of Herpetology* 31: 536–541.

Kattan, G.H., P. Franco, V. Rojas & G. Morales (2004). Biological diversification in a complex region: a spatial analysis of faunistic diversity and biogeography of the Andes of Colombia. *Journal of Biogeography* 31: 1829–1839; https://doi.org/10.1111/j.1365-2699.2004.01109.x/abstract

La Marca, E., K. Lips, S. Lötters, R. Puschendorf, R. Ibáñez, J.V. Rueda-Almonacid, , R. Schulte, C. Marty, F. Castro, J. Manzanilla-Puppo, J.E. García-Pérez, F. Bolaños, G. Chaves, J.A. Pounds, E. Toral & B.E. Young (2005). Catastrophic population decline and extinctions in Neotropical harlequin frogs (Bufonidae: *Atelopus*). *Biotropica* 37: 190–201; https://doi.org/10.1111/j.1744-7429.2005.00026.x

Lampo, M., A. Rodríguez-Contreras, E. La Marca & P. Daszak (2006). A chytridiomycosis epidemic and a severe dry season precede the disappearance of *Atelopus* species from the Venezuelan Andes. *Herpetological Journal* 16: 395–402; https://www.researchgate.net/publication/233616507_A_chytridiomycosis_epidemic_and_a_severe_dry_season_precede_the_disappearance_of_Atelopus_species_from_the_Venezuelan_Andes

Lips, K.R., D.E. Green & R. Papendick (2003). Chytridiomycosis in wild frogs from southern Costa Rica. *Journal of Herpetology* 37: 215–218; https://www.nwhc.usgs.gov/publications/documents/03KRL.JH01.pdf

Lips, K.R., Mendelson, J.R. III., A. Muñoz-Alonso, L. Canseco-Márquez & D.G. Mulcahy (2004). Amphibian population declines in montane southern Mexico: resurveys of historical localities. *Biological Conservation* 119: 555–564; https://www.sciencedirect.com/science/article/pii/S0006320704000217

Lynch, J.D. (1975). The identity of the frog *Eleutherodactylus conspicillatus* (Günther), with descriptions of two related species from northwestern South America (Amphibia, Leptodactylidae). Contributions in Science. *Natural History Museum of Los Angeles County* 272: 1–19.

Lynch, J.D. (1986). Origins of the high Andean herpetological fauna. Pp. 478–499. En: Vuilleumier, F. & Monasterio, M. (Eds.). High Altitude Tropical Biogeography. Oxford University Press. Oxford, UK.

Lynch, J.D. (1989). Intrageneric relationships of mainland *Eleutherodactylus* (Leptodactylidae). I. A review of the frogs assigned to the *Eleutherodactylus discoidalis* species group. *Contributions in Biology and Geology. Milwaukee Public Museum* 79: 1–25.

Lynch, J.D. (1991). A new diminutive *Eleutherodactylus* from the Cordillera Central of Colombia (Amphibia: Leptodactylidae). *Journal of Herpetology* 25(3): 344–352.

Lynch, J.D. (1999a). Ranas pequeñas, la geometría de la evolución, y la especiación en los Andes colombianos. *Revista de la Academia de Ciencias Exactas, Físicas y Naturales* 23(86): 143–159.

Lynch, J.D. (1999b). Lista anotada y clave para las ranas (Género *Eleutherodactylus*) chocoanas del Valle del Cauca y apuntes sobre las especies de la Cordillera Occidental adyacente. *Caldasia* 21(2): 184–202.

Lynch, J.D. & W.E. Duellman (1980). The Eleutherodactylus of the Amazonian slopes of the Ecuadorian Andes (Anura: Leptodactylidae). Miscellaneous Publication, University of Kansas Museum of Natural History 69: 1–86.

Lynch, J.D. & W.E. Duellman (1997). Frogs of the genus *Eleutherodactylus* in western Ecuador: systematic, ecology and biogeography. Museum of Natural History. University of Kansas. Special publication No 23. 236 pp.; https://www.biodiversitylibrary.org/bibliography/7951#/summary

Lynch, J.D. & J.V. Rueda-Almonacid (1997). Three new frogs Eleutherodactylus: Leptodactylidae) from cloud forest in eastern Departamento Caldas, Colombia. *Revista de la Academia Colombiana de Ciencias Exactas, Físicas y Naturales* 21: 131–142.

Lynch, J.D. & A.M. Suárez-Mayorga (2002). Análisis biogeográfico de los anfibios paramunos. *Caldasia* 24(2): 471–480; https://www.bdigital.unal.edu.co/37602/1/39427-175445-1-PB.pdf

Lynch, J.D., P.M. Ruiz-Carranza & M.C. Ardila-Robayo (1994). The identities of the Colombian frogs confused with *Eleutherodactylus latidiscus* (Boulenger) (Amphibia: Anura: Leptodactylidae). *Occasional Papers of the Museum of Natural History, University of Kansas* 170: 1–42; https://www.biodiversitylibrary.org/page/4466887#page/5/mode/1up

Lynch, J.D., P.M. Ruiz-Carranza & M.C. Ardila-Robayo (1996). Three new species of *Eleutherodactylus* (Amphibia: Leptodactylidae) from high elevations of the Cordillera Central of Colombia. *Caldasia* 18: 329–342.

Lynch, J.D., P.M. Ruiz-Carranza & M.C. Ardila-Robayo (1997). Biogeographic patterns of Colombians frogs and toads. *Revista de la Academia de Ciencias Exactas, Físicas y Naturales* 21: 237–248; https://zoologia.puce.edu.ec/vertebrados/Recursos/publicaciones/Cientifica/Lynch_and_Ruiz_Carranza1997.pdf

Mantilla-Castaño, J.C., S. Escobar-Lasso, J.A. Rojas-Morales & J.V. González-Arenas (in press). First record of the Colombian endemic toad *Osornophryne percrassa* Ruíz-Carranza and Hernández-Camacho 1976 (Anura: Bufonidae) from the department of Risaralda, Central Cordillera of Colombia. *Revista de Biodiversidad Neotropical*

Márquez, G. (2001). De la abundancia a la escasez: La transformación de ecosistemas en Colombia. Pp. 325–452. En: Palacio, G. (Ed.). Naturaleza en disputa. Ensayos de historia ambiental en Colombia 1850-1995. Universidad Nacional de Colombia, Bogotá, Colombia.

Méndez-Narváez, J. & W. Bolívar-G (2016). Complementary ecological approaches to understand decreases in frog diversity in altered Andean ecosystems. *South American Journal of Herpetology* 11(1): 1–11; https://www.researchgate.net/publication/301732403_Complementary_Ecological_Approaches_to_Understand_Decreases_in_Frog_Diversity_in_Altered_Andean_Ecosystems

Meza-Joya, F.L. & M. Torres (2016). Spatial diversity patterns of *Pristimantis* frogs in the Tropical Andes. *Ecology and Evolution* 6(7): 1901–1913; https://doi.org/10.1002/ece3.1968

Moen, D.S., S.A. Smith & J.J. Wiens. (2009). Community assembly through evolutionary diversification and dispersal in Middle American treefrogs. *Evolution* 63: 3228–3247; https://www.researchgate.net/publication/26725896_Community_Assembly_Through_Evolutionary_Diversification_and_Dispersal_in_Middle_American_Treefrogs

Myers, N., R.A. Mittermeier, C.G. Mittermeier, G.A.B. Da Fonseca & J. Kent (2000). Biodiversity hotspots for conservation priorities. *Nature* 403: 853–858; https://www.nature.com/articles/35002501

Navas, C.A. (2006). Patterns of distribution of anurans in high Andean tropical elevations: Insights from integrating biogeography and evolutionary physiology. *Integrative and Comparative Biology* 46(1): 82–91; https://www.researchgate.net/publication/51218756_Patterns_of_distribution_of_anurans_in_high_Andean_tropical_elevations_Insights_from_integrating_biogeography_and_evolutionary_physiology

Osorno, M., D.L. Gutiérrez-Lamus & J.C. Blanco (2011). Anfibios en un gradiente de intervención en el noroccidente de la Amazonia Colombiana. *Revista Colombia Amazónica* 4: 143–160; https://www.sinchi.org.co/revista-colombia-amazonica-iv

Ricotta, C. (2003). Parametric scaling from species relative abundances to absolute abundances in the computation of biological diversity: a first proposal using Shannon's entropy. *Acta Biotheoretica* 51: 181–188; https://link.springer.com/article/10.1023/A%3A1025142106292?no-access=true

Rivera-Correa, M. & J. Faivovich (2013). A new species of *Hyloscirtus* (Anura: Hylidae) from Colombia, with a rediagnosis of *Hyloscirtus larinopygion* (Duellman, 1973). *Herpetologica* 69(3): 298–313; https://www.researchgate.net/publication/256458524_A_New_Species_of_Hyloscirtus_Anura_Hylidae_from_Colombia_with_a_Rediagnosis_of_Hyloscirtus_larinopygion_Duellman_1973

Rojas-Morales, J.A., H.F. Arias-Monsalve & G.A. González-Durán (2014a). Anfibios y reptiles de la región centro-sur del departamento de Caldas, Colombia. *Biota Colombiana* 15(1): 73–93; https://www.

redalyc.org/pdf/491/49140738005.pdf

Rojas-Morales, J.A., A. Castro-Gómez & S. Escobar-Lasso (2014b). Joyas de los Andes Tropicales: Colombia, tierra de ranas de cristal. *Bioma* 19: 6–39; https://www.academia.edu/6948400/Joyas_de_los_Andes_tropicales_Colombia_tierra_de_ranas_de_cristal

Rös, M., F. Escobar & G. Halffter (2012). How dung beetles respond to a human-modified variegated landscape in Mexican cloud forest: a study of biodiversity integrating ecological and biogeographical perspectives. *Diversity and Distributions* 18(4): 377–389; https://www.researchgate.net/publication/230540150_How_dung_beetles_respond_to_a_human-modified_variegated_landscape_in_Mexican_cloud_forest_A_study_of_biodiversity_integrating_ecological_and_biogeographical_perspectives

Ruiz-Carranza, P.M. & J.I. Hernández-Camacho (1976). *Osornophryne*, género nuevo de anfibios bufónidos de Colombia y Ecuador. *Caldasia* 6: 93−148; https://revistas.unal.edu.co/index.php/cal/article/view/34333/34534

Santori, C. & N. McManus (2014). Herpetofaunal abundance and species diversity in coastal Ecuador: differences between forest types, the role of abiotic factors and edge effects. Tropical Conservation, Permaculture & Research Internship Jama-Coaque Ecological Reserve. 23 pp.

Stuart, S.N., M. Hoffmann, J.S. Chanson, N.A. Cox, R.J. Berridge, P. Ramani & B.E. Young (2008). *Threatened Amphibians of the World*. Lynx Edicions, Barcelona, Spain; IUCN, Gland, Switzerland; and Conservation International, Arlington, Virginia, USA.

Urbina, C.J.N. & M.C. Londoño (2003). Distribución de la comunidad de herpetofauna asociada a cuatro áreas con diferente grado de perturbación en la isla Gorgona, pacífico colombiano. *Revista de la Academia de Ciencias Exactas, Físicas y Naturales* 27(102): 105–113; https://www.researchgate.net/profile/Nicolas_Urbina-Cardona/publication/216019359_Distribucion_de_la_comunidad_de_herpetofauna_asociada_a_cuatro_areas_con_diferente_grado_de_perturbacion_en_la_Isla_Gorgona_Pacifico_colombiano/links/07ab43354ba7e91da7405dc5/Distribucion-de-la-comunidad-de-herpetofauna-asociada-a-cuatro-areas-con-diferente-grado-de-perturbacion-en-la-Isla-Gorgona-Pacifico-colombiano.pdf

Valencia, A. (1985). La colonización y el desarrollo económico-social del Gran Caldas (Siglo XIX). Revista Universidad de Caldas 5(2): 146.

Vanegas-Guerrero, J. & J.D. Fernández-Roldán (2014). *Osornophryne percrassa* Ruiz-Carranza y Hernández-Camacho 1976. *Catálogo de Anfibios y Reptiles de Colombia* 2: 21−24.

Vanegas-Guerrero, J., G.A. González-Duran & S. Escobar-Lasso (2016). Distribution, diet, and vocalizations of the endangered Colombian toad *Osornophryne percrassa* (Anura, Bufonidae). *Herpetological Conservation and Biology* 11(1): 90−100; https://www.herpconbio.org/Volume_11/Issue_1/Vanegas-Guerrero_etal_2016.pdf

Vargas-Salinas, F. & A. Aponte-Gutiérrez (2016). Diversidad y recambio de anfibios y reptiles entre coberturas vegetales en una localidad del valle del Magdalena medio, departamento de Antioquia, Colombia. *Biota Colombiana* 17(2): 117−137; www.redalyc.org/pdf/491/49151352010.pdf

Vonesh, J.R. (2001). Patterns of richness and abundance in a tropical African leaf-litter herpetofauna. *Biotropica* 33(3): 502–510; https://doi.org/10.1111/j.1744-7429.2001.tb00204.x

Appendix 1. Ecological traits for the anurans recorded in the upper Claro River basin, municipality of Villamaría, department of Caldas, Colombia. The values correspond to the data range. Activity: calling (C), motionless (I), movement (M), perched (P).

Family	Species	Substrate	Perch height (m)	Distance from water (m)	Activity
Bufonidae	*Osornophryne percrassa*	Moss, leaf-litter	0	4–70	C, I
	Rhinella sp.	Leaf-litter, fallen trunk	0	12–15	M
Craugastoridae	*Hypodactylus latens*	Muddy ground	0	3	M
	Niceforonia adenobrachia	Fallen trunk, moss	0.25–1	70–80	M, I
	Niceforonia sp.	Moss	0	30	M
	Pristimantis boulengeri	Leaf-litter, ferns	0.9–1.65	2–15	C, M
	Pristimantis paisa	Pastures, ground	0–1	0–>100	C, I, P, M
	Pristimantis permixtus	Pastures, moss, leafs, ferns	0–1.02	13–80	C, I, P, M
	Pristimantis uranobates	Leaf-litter, pasture, leafs, ferns	0–2.5	0–>100	C, I, P, M
	Pristimantis thectopternus	Leaf-litter	0	>100	M
	Pristimantis sp. 1	Ground	0	>100	M
	Pristimantis sp. 2	Bamboo leafs	0,3–1,3	50–100	C, P, M
	Pristimantis sp. 3	Pasture	0,3	>100	
Hylidae	*Dendropsophus bogerti*	Flooded pasture	0	0	C
	Colomascirtus larinopygion	Leafs, branches, ferns	0–>5	0–3	C

Appendix 2. Particular comments on threatened amphibians recorded in this study.

Amphibia: Anura
Family Bufonidae

Osornophryne percrassa
Ruiz-Carranza & Hernández-Camacho, 1976
Herveo Plump Toad (Image 5)

Conservation status: Endangered (EN) B1ab(iii)

Abundance in the study area: Rare. During fieldwork only two individuals were recorded, both on moss and litter at the edge of the secondary forest in zone B (3,000m).

Morphological characters: A small toad with short limbs that limit it to an exclusively slow locomotion (Ruiz-Carranza & Hernández-Camacho 1976). It does not present parotoid glands as well as tympanic rings; manual and pedial fingers very reduced and little differentiated, wrapped by a thick integument like a palm that reaches almost to the distal end of the fingers. The skin of the whole body is covered with tubercles of variable size and shape, and ventrally more uniform in number and arrangement. It presents a uniform dark dorsal coloration, variable between black, dark brown and olive, and ventrally present yellow spots of variable size, especially concentrated in the posterior region of the belly, forearms and thighs (Image 5) (Ruiz-Carranza & Hernández-Camacho 1976; Vanegas-Guerrero & Fernández-Roldán 2014).

Distribution: This species is endemic to Colombia, being known for the Páramo and cloud forest biomes on both sides of the Central Cordillera, from 2,700–3,840 m (Bernal & Lynch 2008, Vanegas-Guerrero et al. 2016). Politically it is registered in the departments of Antioquia, Caldas, Risaralda, Quindío, Tolima, and Valle del Cauca (Vanegas-Guerrero et al. 2016; Mantilla-Castaño et al. in press).

Family Craugastoridae

***Hypodactylus latens* (Lynch, 1989)**
Boqueron Robber Frog (Image 6)

Conservation status: Endangered (EN) B1ab(iii)

Abundance in the study area: Very rare, although this may be a result of its cryptic behavior. A single individual (Image 6) was registered during the field work, specifically in zone A (2,400m) buried in marshy ground inside secondary forest (10:55h; 16.6^{0}C, 91% HR). It is presumed that its presence is restricted to forests with adequate moisture conditions and vegetation cover.

Morphological characters: Small frog with a robust body and short extremities with thin, short, well-differentiated fingers without discs; the first manual finger longer than the second; absent manual and pedial membranes; tympanic ring absent. *Hypodactylus latens* has a finely granular skin, with relatively smooth flanks. Its coloration is variable, from light brown with a thin white line crossing the back, to dorsal uniform purple, with the exception of the groins, armpits and flanks that have yellow spots, which is characteristic of the species (Image 6). It also has a dark rostral band that is not very conspicuous and the edge of the eyelid is outlined in pale yellow. Iris reddish-brown to dark brown.

Distribution: Endemic to high mountain ecosystems (cloud forests, subpáramo and páramo, between 2,600–3,200 m) in the Central Cordillera of Colombia. Politically it is registered in the departments of Antioquia, Caldas, Quindío and Tolima. The record in the study area was to 2,400m, 200m below the lowest known limit for the species.

Niceforonia adenobrachia
(Ardila-Robayo, Ruiz-Carranza & Barrera-Rodríguez, 1996)
(Image 7)

Conservation status: Critically Endangered (CR) B1ab(iii)+2ab(iii)

Abundance in the study area: Very rare, although possibly due to its cryptic behavior. Two individuals (males) were registered during the field work, both in zone B (3,000m). Both individuals were active at night between 21:30–22:07 h (12-13.8 ^{0}C, 90–92 % RH). One of them was moving on a fallen trunk 80cm above the ground and more than 100m from the Nereidas Stream. The second individual was registered on moss that covered a rock on the edge of a secondary forest. This finding represents the fourth known population for the species, expanding its distribution in 23.7km to the southwest of its type locality on the western flank of the Central Cordillera.

Morphological characters: A small frog (range SVL 14.5–23.1 mm, Ardila-Robayo et al. 1996), with a robust body, oval in shape, with the head narrower than the body. Dorsal skin smooth with few small and scattered tubercles; presents one or two tubercles in the eyelids, and a conical tubercle prominent in the heels; the skin of the belly is slightly granular; forearms widened in the males; the fingers of the hands are short, the first and the second of equal size and do

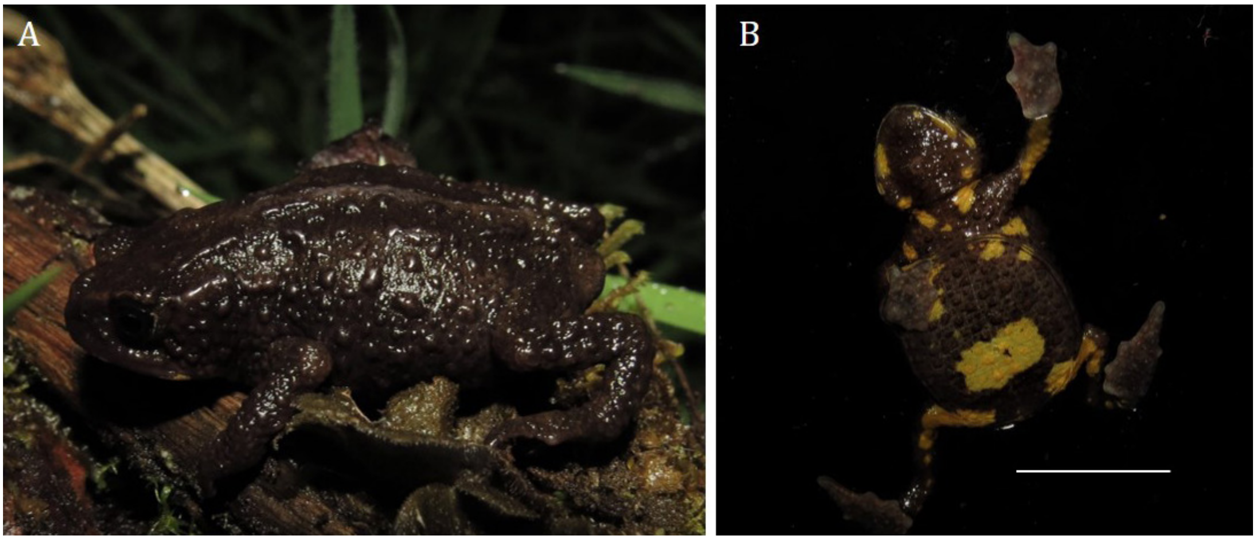

Image 5. Dorsolateral (a) and ventral view (b) of *Osornophryne percrassa* (SVL 21.3mm; weight 2.4g), from Nereidas Stream, Playa Larga Village, municipality of Villamaría, department of Caldas, Colombia. Scale bar 10mm. © Julián Andrés Rojas.

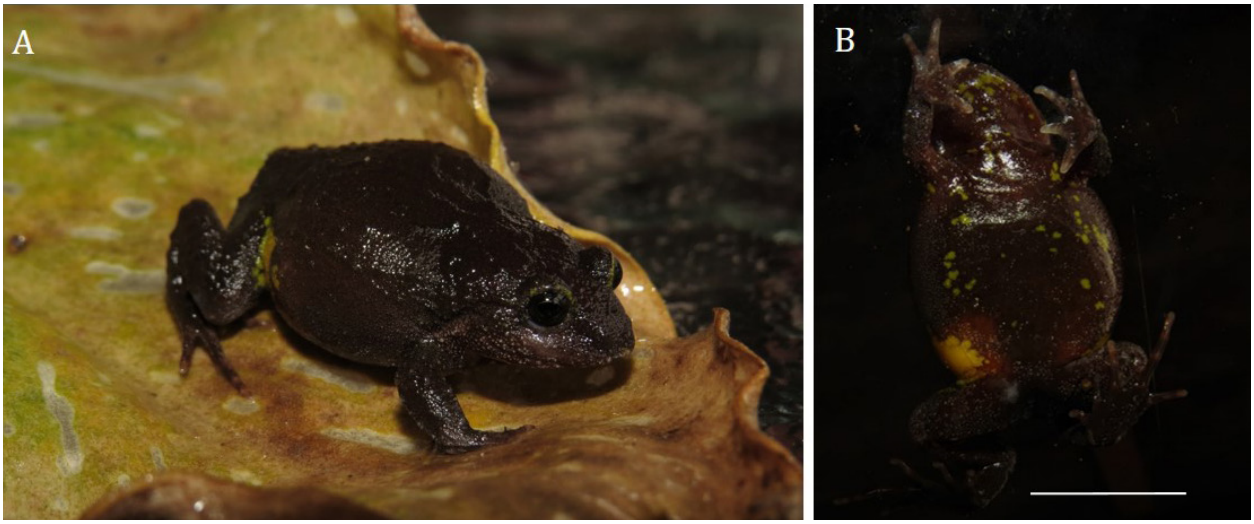

Image 6. Dorsolateral (a) and ventral views (b) of a *Hypodactylus latens* (female SVL 30.4mm; weight 2.7g) from La Cadena Stream, Playa Larga Village, municipality of Villamaría, department of Caldas, Colombia (MHN-UCa 0765). Scale bar 10mm. © Julián Andrés Rojas.

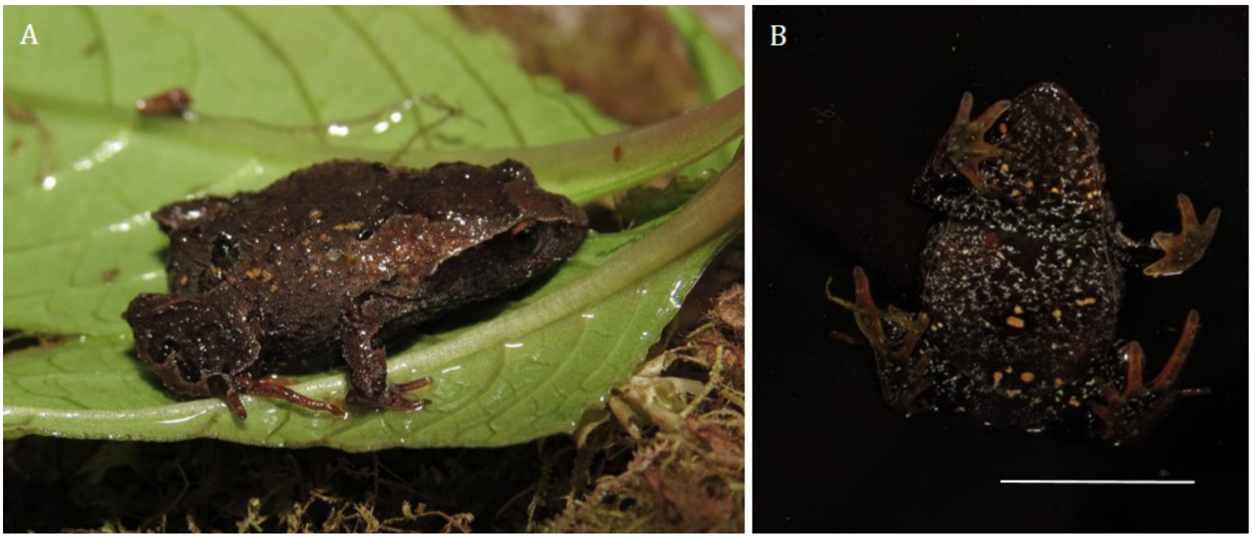

Image 7. Dorsolateral (a) and ventral view (b) of *Niceforonia adenobrachia* (male SVL 18.5mm; weight 0.8g) (MHN-UCa 0775), from the Nereidas Stream, Playa Larga Village, municipality of Villamaría, department of Caldas, Colombia. Scale bar 10mm. © Julián Andrés Rojas.

not have terminal discs; the toes are longer and thinner; absence of interdigital membranes in hands and feet. The face is short, sub-acuminate in dorsal view and inclined in lateral view. Tympanic ring absent. The coloration of the back varies from light to dark brown, with an axillary and inguinal cream spot; some individuals have a thin longitudinal white dorsal line. It presents a dark brown post-ocular band resembling a mask. Fingers and hands light orange. Copper iris with red crosslinks. The belly has a black and white crosslinking, accompanied by some dark brown spots on the reticulations, and some yellow spots of variable shape and arrangement in the interspaces (Image 7).

Distribution. Endemic to Colombia, *N. adenobrachia* is known from a small number of localities around Los Nevados National Natural Park, in the department of Caldas (this register), Tolima (Ardila-Robayo et al. 1996; Romero-García et al. 2015) and Quindío (Buitrago-González et al. 2016). Its type locality is the Cerro Bravo Volcano, Páramo of Letras, Albania village, municipality of Herveo, department of Tolima, between 3,000–3,400 m), in the Central Cordillera of Colombia.

Family Hylidae

***Colomascirtus larinopygion* (Duellman, 1973)**
(Image 8)

Conservation status: Near Threatened (NT)

Abundance in the study area: A common species, inhabitant of primary and secondary forests associated with rapid flow streams. In the study area and Los Nevados Natural National Park, this is a characteristic element of the tree frogs associated with creeks and streams.

Morphological field characters: A medium-sized tree frog with a robust body (see Duellman 1973, Duellman & Berger 1982, Duellman & Hillis 1990, Rivera-Correa & Faivovich 2013 for a detailed description).

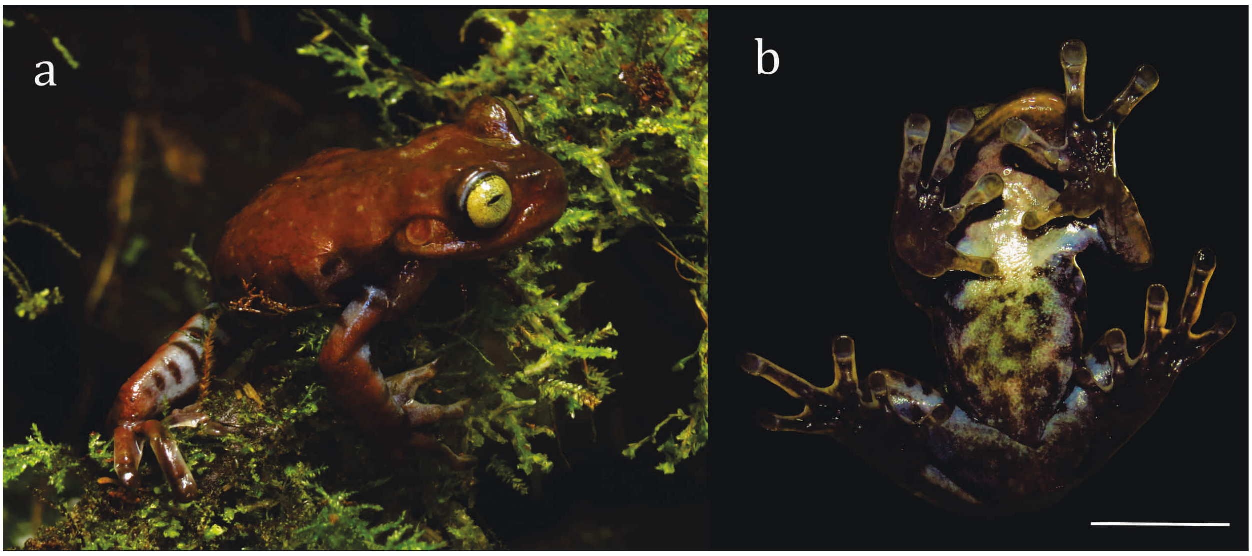

Image 8. Dorsolateral (a) and ventral view (b) of an *Colomascirtus larinopygion* (SVL 47.6mm, weight 3.7g), from La Cadena stream, Playa Larga village, municipality of Villamaría, department of Caldas, Colombia. © Julián Andrés Rojas.

Individuals in the study area have an average of SVL 56.6±3 mm (n = 8). This is an easily distinguishable species in the study area by the following set of characters: head as wide as the body, with the face truncated in dorsal and lateral view; protruding eyes, bordered by a black line on top and back; elliptical pupil and yellow iris; tympanic ring present; long and slender manual fingers, terminated in expanded discs; the discs of the pedial fingers are smaller than those of the hands. Thick forearms and thin, slender hind legs. Basal manual membranes and extended on the feet. Anal region markedly swollen and bordered by a white line. Skin smooth and slightly corrugated on the flanks. Dorsal coloration dark brown uniform, in some individuals purple; flanks, belly, and inner surface of the fingers, thighs and forearms pale blue color with black stripes that radiate from the belly. Ventrally the coloration is dark gray (Image 8).

Distribution. *Colomascirtus larinopygion* is the widest distributed species of the *larinopygion* group (Faivovich et al. 2005), inhabiting cloud forests of the northern Andes in Colombia and Ecuador. In Colombia it is distributed on both flanks of the Central and Western Cordilleras, between 1,950–3,100 m (Acosta 2000; Bernal & Lynch 2008; Rivera-Correa & Faivovich 2013). Politically it is registered in the departments of Antioquia, Caldas, Cauca, Huila, Quindío, Tolima and Valle del Cauca (Rivera-Correa & Faivovich 2013).

Spanish abstract: Resumen: Presentamos una evaluación sobre la composición, diversidad y estructura de los anfibios en tres zonas a lo largo de un gradiente de elevación (2,400–3,000 m) en la Cordillera Central de Colombia. Para esto, se llevaron a cabo dos jornadas de muestreo, una en noviembre 2014 y otra en febrero 2015, en períodos de lluvia y seco, respectivamente. Los muestreos fueron tanto diurnos (08:00–12:00 h) como nocturnos (18:00–22:00 h) usando la metodología de relevamiento por encuentros visuales, sin restricciones espaciales. La diversidad fue evaluada en términos del número efectivo de especies para cada zona (alfa) y para todo el paisaje en general (gamma), y la estructura de las comunidades fue analizada mediante curvas de rango-abundancia. Se calculó un factor de inequidad para cada zona de muestreo. Se registró un total de 15 especies pertenecientes a siete géneros y tres familias, todas del orden Anura. La familia Craugastoridae fue la más rica con 11 especies (73,3%), y el género más rico fue *Pristimantis* con ocho especies. La diversidad alfa promedio por zona fue de 6,6 especies efectivas, siendo la zona A la más diversa con ocho especies. En términos de la diversidad beta, existen 2,5 comunidades efectivas a nivel de todo el gradiente evaluado. Las diferencias de composición entre zonas están dadas por las especies raras, mientras que las especies más abundantes (p. ej. *Pristimantis uranobates*) son compartidas entre las mismas. Se presume que la mayor diversidad en la zona A es debido a su ubicación a menor elevación y por presentar un hábitat en mejor estado de conservación respecto a las otras dos zonas. Del total de especies registradas, dos están amenazadas de extinción: *Hypodactylus latens* (En Peligro), y *Niceforonia adenobrachia* (Peligro Crítico). Se resalta el hallazgo de tres especies indescritas.

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