

On the systematics of the harlequin frogs (Amphibia: Bufonidae: *Atelopus*) from Amazonia. I: Description of a new species from the Cordillera Azul, Peru

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Zusammenfassung

Zur Systematik der Harlekinfrösche (Amphibia: Bufonidae: *Atelopus*) aus Amazonien.
I: Beschreibung einer neuen Art aus der Cordillera Azul, Peru.

Atelopus spumarius sensu lato umschließt im amazonischen Peru mindestens drei Arten. Die systematischen Beziehungen innerhalb des Komplexes sind jedoch problematisch. Als hilfreiche Merkmale erweisen sich Lebendfärbung, Verhalten, Bioakustik und Larvalmerkmale. In dieser Arbeit wird eine neue Art aus der Cordillera Azul beschrieben. Markante Verhaltensmerkmale von ihr sind visuelle (Winken) sowie aus unterschiedlichen Komponenten zusammengesetzte akustische Signale; bei letzteren überwiegt der ungepulste Anteil.

Schlagwörter: Amphibia: Bufonidae: *Atelopus reticulatus* sp. nov.; *A. spumarius*-Artenkomplex; Bioakustik; Peru.

Abstract

Atelopus spumarius sensu lato in Amazonian Peru comprises three species at least. Systematics remain problematic, however. The consideration of living colours, behavioural, bioacoustic and tadpole data is helpful. In this paper, a new species from the Cordillera Azul is described. Significant behavioural traits of it are visual (hand waving) as well as acoustic signals; the latter consist of different components among which the unpulsed parts (i.e. pure tone calls) predominate.

Key words: Amphibia: Bufonidae: *Atelopus reticulatus* sp. nov.; *A. spumarius* species complex; bioacoustics; Peru.

1 Introduction

Amazonian Peru belongs to the regions of highest biological diversity on Earth. Amphibian species richness is especially remarkable (e.g. DUELLMAN & RODRÍGUEZ 1994), with continuous discoveries of species new to science. Many of these species are quite similar to others. As a result, many nominal species actually represent complexes of species. An example is *Atelopus spumarius* COPE, 1871 (Fig. 1). The many different forms belonging to this species complex range from the eastern versant of the Andes in Peru via almost the entire Amazon Basin into the Guyanas. Their relationships are a matter of controversy (e.g. RIVERO 1968, LESCURE 1974, 1981, LÖTTERS 1996, COCROFT et al. 1990).

For more than a decade, the senior author has focused on systematics of *Atelopus* from Amazonian Peru (e.g. LÖTTERS & DE LA RIVA 1998, LÖTTERS & HENZL 2000), being aware that *A. spumarius* sensu lato in Peru contains three different taxa at least: (i) *Atelopus spumarius* sensu stricto, (ii) *Atelopus pulcher* (BOULENGER, 1882), that needs to be taken out of the synonymy of *A. spumarius* (LÖTTERS et al. in press), and (iii) an unnamed species from the Cordillera Azul that was illustrated in colour by HESELHAUS & SCHMIDT (1988: 37-39). However, alphataxonomy of *Atelopus* is a difficult matter, because sometimes species are externally very similar to each other

(cf. LÖTTERS 1996). For the same reason it is not even clear if the three mentioned species within *A. spumarius* sensu lato are phylogenetically related. COLOMA et al. (2000) showed that the consideration of living colours, behavioural, bioacoustic and tadpole data is helpful in *Atelopus* systematics.

One of us (WH) kept different Peruvian *Atelopus* in captivity (e.g. HAAS 1995), including *A. pulcher* and an unnamed species from the Cordillera Azul. Observations made in captivity may be artificial, but they may provide informative data on anuran biology. In the absence of field observations laboratory data may help to understand species in a better way (cf. JUNGFER 1996). We used laboratory data to characterise *A. pulcher* (LÖTTERS et al. in press) and the new species from the Cordillera Azul which is described below.

2 Material and Methods

Specimens examined are deposited in the AMNH (American Museum of Natural History, New York), BM (British Museum, London), CBF (Colección Boliviana de Fauna, La Paz), ICN (Instituto de Ciencias Naturales, Museo de Historia Natural, Universidad Nacional de Colombia, Santafé de Bogotá), KU (The University of Kansas, Natural History Museum, Lawrence), MNHNP (Muséum national d'Histoire Naturelle, Paris), NHMW (Naturhistorisches Museum Wien) and ZFMK (Zoologisches Forschungsinstitut und Museum Alexander Koenig, Bonn). All material studied is listed in the Appendix.

Description scheme for adults follows LÖTTERS & HENZL (2000). We describe webbing formulae using the system of SAVAGE & HEYER (1969) as modified by MYERS & DUELLMAN (1982) and SAVAGE & HEYER (1997). Sex determination of adults was by external characters as used by previous authors (cf. LÖTTERS 1996). Morphometric data to nearest 0.1 mm were obtained by measuring adult specimens with dial callipers, when necessary under a dissection microscope, by the senior author. Definitions of measurements for adults follow GRAY & CANNATELLA (1985) except SW (cf. COLOMA 1997). Abbreviations of measurements are: SVL (snout-vent length), HDWD (head width), HLSQ (head length from the squamosal), EYDM (eye diameter), ITNA (internarial distance), EYNO (eye to nostril distance), SW (sacrum width at widest), TIBL (tibia length), FOOT (foot length), HAND (hand length), THBL (thumb length).

Vocalisations were recorded in captivity using a Sony WM D6C Walkman and a Sony ECM 957 microphone. For analysis, Avisoft, SASLab Pro (Berlin), was used. Captive conditions were described by HAAS (1995).

3 Systematics

Atelopus reticulatus sp. nov.

(Figs. 2-6)

Atelopus spumarius spumarius (non COPE, 1871) — HESELHAUS & SCHMIDT 1988: 37

Holotype: ZFMK 76247, an adult female from the eastern versant of the Cordillera Azul, circa 3 km by road after Divisoria on the Tingo María-Pucallpa road (ca. 9°9'S, 75°45'W, approximately 1600 m above sea level), Departamento Ucayali, Peru; leg. V. ENNENBACH, 1980.

Paratype: ZFMK 76246, an adult male, same data as holotype.

Diagnosis: A medium-sized *Atelopus* (SVL of one adult female 27.4 mm and one adult male 24.7 mm) that can be distinguished from all other known species of the genus by the following combination of characters: (1) body slender (SW/SVL 0.21-0.24; n = 2), snout acuminate with tip gently rounded; (2) neural spines not visible externally; (3) hind limbs long, tibiotarsal articulation reaches to or anterior to eye when leg adpressed forward along body (TIBL/SVL 0.45-0.46; n = 2); (4) foot shorter than tibia (FOOT/TIBL 0.83-0.87; n = 2); (5) tympanic membrane absent; (6) small warts (no spiculae or coni) present on dorsal and lateral surfaces of body and extremities (except from dorsal and lateral surfaces of snout, hand and distal foot), ventral surface free of warts; (7) foot webbing formula I0 - 0 or I-III - I+III - 2- or 2+IV2- or 2 - 1- or 1+V; (8) thumb short (THBL/HAND 0.42-0.45; n = 2); (9) plantar and palmar surfaces almost smooth, with ill-defined subarticular tubercles on some phalanges; thenar tubercle almost absent; (10) in preservative and in life, dorsal body surfaces uniform yellowish green, with dark reticulation and yellowish greenish dorsolateral band; ventral side uniform cream (occasionally, in part, with brownish reticulation), with the posterior belly red in life (pink in preservative) only in males; soles and palms red in life (pink in preservative).

Atelopus reticulatus is most similar to *A. andinus* RIVERO, 1968, *A. pulcher*, *A. spumarius* sensu lato (including *A. pulcher hoogmoedi* LESCURE, 1974 "1973"), *A. siranus* LÖTTERS & HENZL, 2000 and *A. tricolor* BOULENGER, 1902 (including its junior synonyms *A. rugulosus* NOBLE, 1921 and *A. willimani* DONOSO-BARROS, 1969) from the same general area and *A. minutulus* RUÍZ-CARRANZA & HERNÁNDEZ-CAMACHO & ARDILA, 1988 from the eastern versant of the Cordillera Oriental of Colombia. *Atelopus pulcher* and *A. spumarius* sensu lato show similar colours in life (green and yellow or tan) and share red sole and palm with *A. reticulatus* (cf. LÖTTERS et al. in press). The former and most populations within *A. spumarius* sensu lato have smooth skin (versus warts are present in *A. reticulatus*) and, generally speaking, are larger with adult female SVL > 32.0 mm (cf. LESCURE 1974 and LÖTTERS et al. in press versus SVL of one adult female of *A. reticulatus* 27.4 mm). Nevertheless, *A. spumarius* sensu stricto is similar in adult size to *A. reticulatus* and exhibits small warts behind the eye



Fig. 1. Dorsal and ventral views of female neotype of *Atelopus spumarius* (MNHNP 1979/8382). – Photo J. KÖHLER.

Dorsal- und Ventralansicht vom Neotypus von *Atelopus spumarius*, Weibchen (MNHNP 1979/8382).



Fig. 2. Dorsal and ventral views of female holotype of *Atelopus reticulatus* sp. nov. (ZFMK 76247). – Photo: S. LÖTTERS.

Dorsal- (A) und Ventralansicht (B) des Holotypus von *Atelopus reticulatus* sp. nov., Weibchen (ZFMK 76247).

(versus warts are present on all dorsal and lateral surfaces in *A. reticulatus*). But *A. spumarius* sensu stricto shows reticulation only within the yellowish dorsolateral band (while *A. reticulatus* is dorsally entirely yellowish green reticulated; cf. Figs. 1-3). In addition to skin texture and size, *A. pulcher* lacks yellowish green dorsal reticulation (cf. LÖTTERS et al. in press) and, if present, *A. spumarius* sensu lato shows reticulation only within the yellow or tan dorsolateral band (cf. LESCURE 1981). All other species mentioned except *A. minutulus* lack reticulation and are more cryptically coloured; in addition, warts are more prominent in *A. tricolor* and *A. siranus* than in *A. reticulatus* (cf. LÖTTERS & DE LA RIVA 1998, LÖTTERS & HENZL 2000). Among them, only *A. andinus* is larger than the new species with four adult paratype



Fig. 3. Lateral and ventral views of adult male of *Atelopus reticulatus* sp. nov. in life (paratype ZFMK 76246). – Photo: W. HAAS.

Laterale- und Ventralansicht eines ausgewachsenes Männchen von *Atelopus reticulatus* sp. nov. im Leben (Paratypus ZFMK 76246).

females (see Appendix for specimens examined) reaching 30.2-36.9 mm SVL (versus SVL of one adult female of *A. reticulatus* 27.4 mm). *Atelopus minutulus* is the only other member of the genus having dorsal reticulation (RUÍZ-CARRANZA et al. 1988); life specimens are dorsally greenish with reddish sole and palm like *A. reticulatus*. *Atelopus minutulus* differs from the new species by somewhat smaller size (SVL of largest female in *A. minutulus* type series is 25.5 mm and of largest male is 19.1 mm versus 27.4 mm and 24.7 mm in *A. reticulatus*) and by having whitish warts on the sides and orange to brown in females or bluish in males venter in life (cream and reddish respectively in *A. reticulatus*). The only other *Atelopus* described from eastern Peru are *A. erythropus* BOULENGER, 1903 and *A. seminiferus* COPE, 1874. The single known (adult?) specimen of the former is slightly smaller than adult *A. reticulatus* (SVL of *A. erythropus* holotype 20.4 mm), lacks dorsal pattern (at least in preservative), has a more blunt snout and exhibits small warts between eye and forearm only (cf. LÖTTERS & DE LA RIVA 1998). Adult *A. seminiferus* are considerably larger than *A. reticulatus* (SVL of *A. seminiferus* holotype 40.0 mm; GRAY & CANNATELLA 1985). In addition, specimens tentatively referred to *A. seminiferus* and examined by us (see Appendix) are overall dark brown to black.

Description of type specimens (if holotype, Fig. 2, is deviate, this is indicated): Body slender; no neural spines externally visible; head longer than broad; head length less than one third of SVL; snout acuminate with tip gently rounded, dorsally depressed; in lateral aspect, upper jaw extending beyond lower; nostril lateral, not visible from above; tongue about two to three times as long as wide (about two times as long as wide), broadest anteriorly, free for two thirds of its length; canthus rostralis straight from nostril to tip of snout, slightly concave and longer from nostril to anterior corner of eye – most concave immediately anterior to eye; eye width larger than distance from nostril to anterior corner of eye; loreal area barely concave; upper lip fleshy; immediate lateral postorbital area slightly convex, becoming straighter at temporal area; tympanic membrane absent; dorsal postorbital crest poorly developed. Tibia long, less than half SVL, tibiotarsal articulation extending to eye or anterior to eye (as in holotype) when hind limb adpressed forward along body; foot shorter than tibia; relative length of toes: $I < II < III < V < IV$; outer metatarsal tubercle weak, inner metatarsal tubercle almost not defined, about half size of the outer tubercle; rest of sole smooth with ill-defined subarticular tubercles present at joints of phalanges of Toes II-V; foot webbing formula is $I0 - 0$ or $1\cdot III1 - 1\cdot III1 - 2$ or $2\cdot IV2$ or $2 - 1$ or $1\cdot V$ ($I0 - 1\cdot III1 - 1\cdot III1 - 2\cdot IV2 - 1\cdot V$ in the holotype). Forearm short, less than one third of SVL, proximally slightly wider than distally in male paratype only; relative length of fingers: $I < II < IV < III$; palmar tubercle indistinct, rounded; thenar tubercle almost absent; rest of palm smooth with ill-defined subarticular tubercles at joints of phalanges of Fingers II to IV; thumb relatively short, distance from tip to outer edge of palmar tubercle less than half hand length; keratinized nuptial pads present on thumbs in the male paratype only. Dorsal and lateral surfaces of most body including extremities with small warts, concentrated and most prominent on anterior dorsum to temporal area; ventral surfaces free of warts. Spiculae or coni absent.

In preservative, dorsal surfaces are completely yellowish green, darker anteriorly, with brownish reticulation; reticulation is absent from dorsolateral area resulting in a yellowish green band from behind the eye to groin. Venter cream with few brownish stipples on shank in holotype and reticulation on arms and legs in paratype; sole and palm of both types and posterior portion of belly of paratype pink.

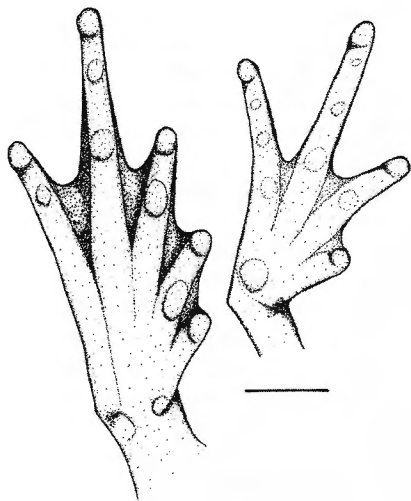


Fig. 4. Sole and palm of female holotype of *Atelopus reticulatus* sp. nov. (ZFMK 76247). Line equals 2.0 mm.

Fuß- und Handunterseite vom Holotypus von *Atelopus reticulatus* sp. nov., Weibchen (ZFMK 76247). Die Linie entspricht 2,0 mm.

Life coloration was similar with reddish colours more bright (see Fig. 3). The iris was greenish golden. Topotypic individuals illustrated by HESELHAUS & SCHMIDT (1988: 38-39) resemble the type specimens.

Measurements and proportions of the holotype (and paratype) are: SVL 27.4 (24.7); SW 5.7 (5.9); HDWD 6.8 (6.2); HLSQ 7.5 (6.7); EYDM 2.2 (2.1); ITNA 2.4 (1.9); EYNO 1.9 (1.8); TIBL 12.7 (11.0); FOOT 10.5 (9.6); HAND 7.2 (5.8); THBL 3.0 (2.5); SW/SVL 0.21 (0.24); HDWD/SVL 0.25 (0.25); HDWD/HLSQ 0.91 (0.93); HLSQ/SVL 0.27 (0.31); TIBL/SVL 0.46 (0.45); FOOT/TIBL 0.83 (0.87); THBL/HAND 0.42 (0.45).

Sexual dimorphism is indicated by larger female size and apparently by colour of posterior belly (whitish in females versus red in males).

Distribution: The new species is known only from the type locality.

Life history and vocalisation: Both type specimens were kept in captivity. The holotype died soon after receipt; the male paratype was kept in captivity for several months. According to the observations made by WH, *A. reticulatus* is a diurnal terrestrial species. The male regularly produced vocalisation both when another individual could be seen or not. Accompanying hand waving, as known in few other species of the genus (e.g. LINDQUIST & HETHERINGTON 1998), was commonly observed when other specimens of *Atelopus* (e.g. of *A. pulcher*) could be seen. Waving was a rotational movement with the left hand only, directing the reddish palm to the front.

A series of calls recorded 25 December contained 25 calls with each call consisting of a single note (cf. Figs. 5 A, 6). The majority of calls (i.e. 1, 4-23) was unpulsed (cf. Figs. 5 B, 6 left) with a note length of 0.29-0.42 (0.34 ± 0.04 ; $n = 21$) s and a dominant frequency of 3368 Hz. Calls 2 (Fig. 5 C; note length 0.35 s, dominant frequency 3360 Hz) and 3 (Fig. 5 D; note length 0.43 s, dominant frequency 3282 Hz) were pulsed containing of 27 and 32 pulses, respectively (i.e. 76 and 75 pulses/s). Both calls had a prolonged pulse in the end and call 2 also in the beginning. Call 24 (note length 0.33 s, dominant frequency 3496 Hz) was an intermediate vocalisation with an

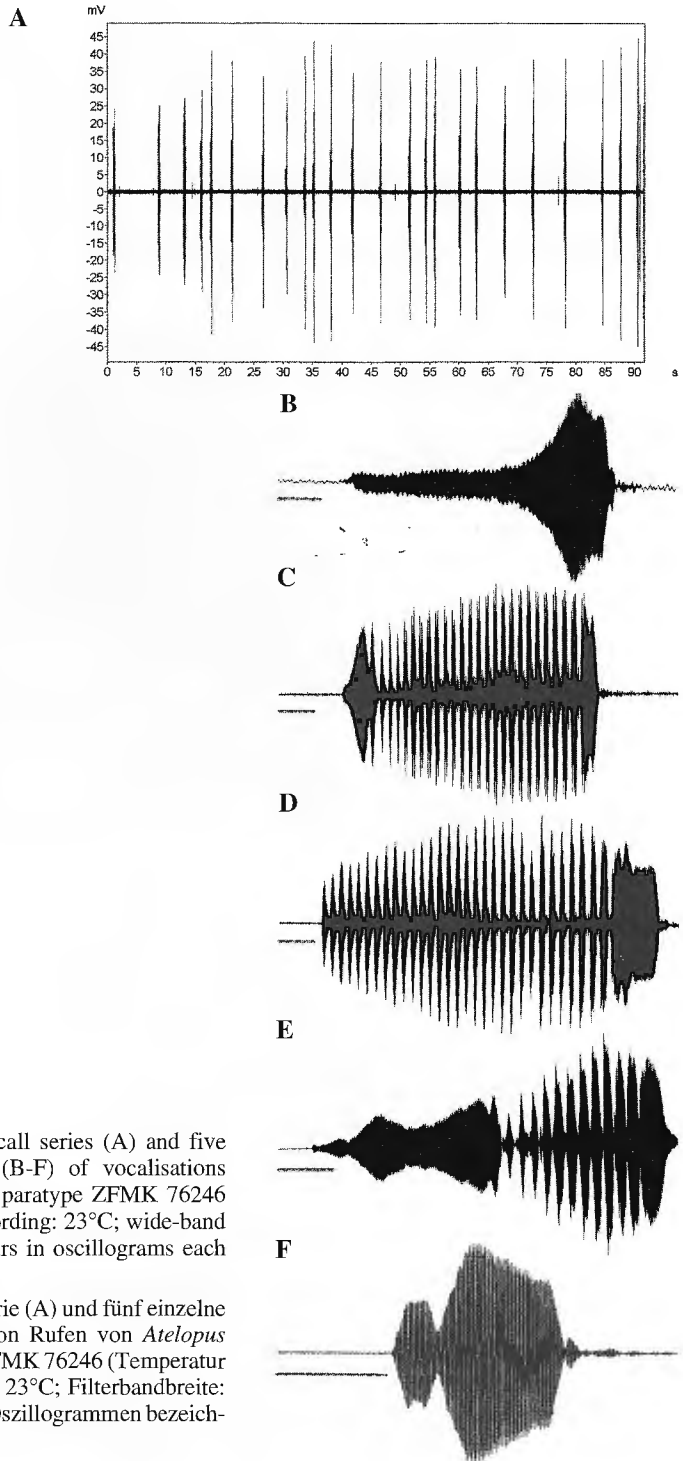


Fig. 5. Oscillogram of call series (A) and five extracted oscillograms (B-F) of vocalisations of *Atelopus reticulatus*, paratype ZFMK 76246 (temperature during recording: 23°C; wide-band filter: 300 Hz). Time bars in oscillograms each indicate 50 ms.

Oscillogram einer Rufserie (A) und fünf einzelne Oscillogramme (B-F) von Rufen von *Atelopus reticulatus*, Paratypus ZFMK 76246 (Temperatur während der Aufnahme: 23°C; Filterbandbreite: 300 Hz). Zeitmarken in Oscillogrammen bezeichnen jeweils 50 ms.

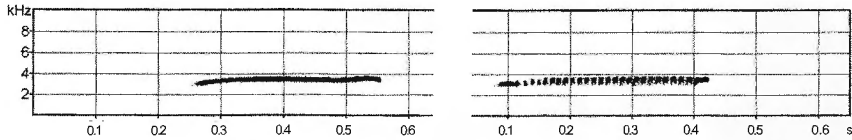


Fig. 6. Sound spectrogram of un-pulsed (left) and pulsed call of *Atelopus reticulatus*, paratype ZFMK 76246 (temperature during recording: 23 °C; wide-band filter: 300 Hz).

Klangspektrogramm eines ungepulsten (links) und gepulsten Rufes von *Atelopus reticulatus*, Paratypus ZFMK 76246 (Temperatur während der Aufnahme: 23 °C; Filterbandbreite: 300 Hz).

un-pulsed anterior and a pulsed posterior portion containing 13 pulses (i.e. 39 pulses/s) with the last pulse prolonged (Figs. 5 E, 6 right). The final call was a short un-pulsed note (Fig. 5 F; note length 0.08 s, dominant frequency 3297 Hz) with a different amplitude to other un-pulsed calls as shown in Figure 5 B.

COCROFT et al. (1990) reviewed vocalisations in the genus *Atelopus*. Usually, species produce similarly structured pulsed calls (cf. Fig. 6 right). According to these authors, there are three species of *Atelopus* from which un-pulsed calls also are known that are similar in overall structure to those of *A. reticulatus* (cf. Fig. 6 left). This type of vocalisation was called pure tone call and has been reported from *A. chiriquiensis* SHREVE, 1936, *A. cruciger* (LICHTENSTEIN & MARTENS, 1856) and *A. minutulus* (cf. COCROFT et al. 1990). The function of pure tone calls remains unclear but may be related to aggressive encounter in *A. chiriquiensis* (cf. JASLOW 1979). Among the species compared with *A. reticulatus*, vocalisations are known, in addition to *A. minutulus*, from *A. pulcher*, *A. spumarius* sensu lato and *A. tricolor* (LESCURE 1981, COCROFT et al. 1990, LÖTTERS et al. 1999, LÖTTERS et al. in press). From these species, pure tone calls are unknown. Pulsed calls in them and *A. minutulus* are generally similar to those of *A. reticulatus*. Although there is overlap, generally speaking, the note length is shorter and the number of pulses per second as well as dominant frequency is slightly less in *A. minutulus*. Vocalisations of *A. pulcher* are also similar to those of *A. reticulatus* (cf. LÖTTERS et al. in press) but the number of pulses per second is lower in this species (i.e. < 36 versus > 39 in *A. reticulatus*). Moreover, dominant frequency is remarkably higher in *A. reticulatus* (i.e. > 3280 Hz versus < 2850 Hz in *A. pulcher*). Pulsed calls of *A. spumarius* sensu stricto are similar to those of *A. reticulatus* concerning the number of pulses per second as well as dominant frequency. However, according to LESCURE (1981) and ASQUITH & ALTIG (1987), note length in *A. spumarius* sensu stricto is longer (i.e. > 0.65 s). *Atelopus spumarius* sensu lato from Brazil and French Guyana (LESCURE 1981, COCROFT et al. 1990) also shows significantly longer notes (> 1.0 s), whereas pulsed calls of *A. tricolor* (cf. LÖTTERS et al. 1999) are extremely short (ca. 0.1 s).

Communication behaviour in *A. reticulatus* reported and discussed remains tentative since a single captive individual was observed only.

Etymology: The specific name refers to the dorsal colour pattern.

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Appendix: Material Examined

Atelopus andinus: PERU: San Martín: upper Río Biabo valley, AMNH A 42657 (paratype), A 43200 (holotype); Loreto: Río Pisqui, AMNH A 43545 (paratype); border area of San Martín-Loreto: Río Cachiyacu (Tocachi), AMNH A 42914, A 43296-927 (paratypes). *Atelopus erythropus*: PERU: Puno: Santo Domingo, Cordillera Carabaya, BM 1947.2.14.65 (holotype). *Atelopus minutulus*: COLOMBIA: Meta: km 13-15 on Guayabetal-Manzanares road, ICN 13709 (holotype), 4851-853, 5028, 7085-891, 12898 (paratypes). *Atelopus pulcher*: ECUADOR: Morona-Santiago: Chancha, Normandía, AMNH A 16695-712 (tentatively assigned); Cordillera de Cutucú, AMNH 33913-915 (tentatively assigned); Pastaza: Río Villani, Villano, BM 1970.68-69, 1970.117-118 (tentatively assigned); PERU: Loreto (?): Chyavetas (= Chayahuitas?), BM 1947.2.1480, 1947.2.1482 (syntypes); San Martín: vicinity of Tarapoto, KU 211676-683, 212530, ZFMK 48573, 50680-685, 76243-244. *Atelopus reticulatus*: PERU: Ucayali: Cordillera Azul, circa 3 km by road after Divisoria on the Tingo María-Pucallpa road, ZFMK 76246-247 (para- and holotype). *Atelopus* cf. *semiferus*: PERU: Piura: Cerro Chinguela region, KU 196633-42. *Atelopus spumarius* sensu stricto: PERU: Loreto: Colonia, Río Ampiyacu, MNHNP 1979/8382 (neotype); 3 km north-east of Pebas, AMNH A 103-31-35. *Atelopus spumarius* sensu lato: BRAZIL: Amapá: Serra do Navio, ZFMK 54384-385; Pará: Sudam Floral Reserve, 74 km north-east of Santarém, KU 129954-960; COLOMBIA: Amazonas: Igara Parana, BM 1905.1.31.10-11; FRENCH GUYANA: Haut Maroni, Monts Atachi-Bacca, MNHNP A 522 (holotype of *A. pulcher hoogmoedi*), A515, A518, A519-521 (paratypes of *A. pulcher hoogmoedi*); SURINAME: Brownsberg, AMNH 7749, KU 206405-406. *Atelopus siranus*: PERU: Huánuco: Serranía de Sira, NHMW 33906:1 (paratype), NHMW 33906:2 (holotype). *Atelopus tricolor*: PERU: Cuzco: Marcapata valley, BM 1947.2.14.57-59 (paralectotypes), ZFMK 28103 (lectotype); 4 km south-west of Santa Isabel, Río Cosñipata, KU 162988; Puno: vicinity of Juliaca, AMNH 6097 (holotype of *A. rugulosus*); BOLIVIA: La Paz: 17 km from Carrasco, Serranía de Bellavista, CBF 285-288; Río Ñeques, circa km 10 on Charazani-Apolo road, Yungas de La Paz, CBF 2502; Pilon-Lajas, CBF 2487; Cochabamba: Río Ronco, Chapare, CBF 892; “old” road from Villa Tunari to Cochabamba, Chapare, ZFMK 69919-920.

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