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**THE EVOLUTION OF THE ADVERTISEMENT CALL IN GLASSFROGS
(CENTROLENIDAE TAYLOR, 1951)**

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PONTIFÍCIA UNIVERSIDADE CATÓLICA DO RIO GRANDE DO SUL
ESCOLA DE CIÊNCIAS
PROGRAMA DE PÓS-GRADUAÇÃO EM ZOOLOGIA
LABORATÓRIO DE HERPETOLOGIA

Dissertação de Mestrado

**THE EVOLUTION OF THE ADVERTISEMENT CALL IN GLASSFROGS (CENTROLENIDAE TAYLOR,
1951)**

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The evolution of the advertisement call in glassfrogs (Centrolenidae Taylor, 1951)

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Dedico este trabajo a todos los venezolanos que murieron luchando por un “nuevo amanecer” en Venezuela durante los últimos años. Tengo la esperanza de que un día volvamos a tener una Venezuela linda, que pueda disfrutar junto a mi familia y ver a mis hijos crecer en su tierra. Estoy seguro de que muchos otros también mantienen la esperanza en ese sueño.

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RESUMO

Os anuros emitem cantos de anúncio com o objetivo de atrair parceiros e repelir concorrentes co-específicos. Eu investiguei a associação entre o comprimento do corpo, o sítio de vocalização, o cuidado parental e a variação em propriedades acústicas do canto (duração do canto, número de notas, frequência de pico, largura de banda de frequência e estrutura do canto) em pererecas-de-vidro—uma família de pererecas que habitam florestas neotropicais—controlando para efeitos de ancestralidade compartilhada. Eu também explorei o tempo e o modo de evolução dessas características e as comparei com as de três características morfológicas (comprimento do corpo, largura da cabeça e comprimento da tíbia). Eu gerei e compilei dados acústicos para 72 espécies de pererecas-de-vidro (46 % da riqueza descrita), incluindo representantes de todos os gêneros, e analisei os dados usando métodos comparativos filogenéticos. Descobri que quase todas as características acústicas avaliadas tinham sinal filogenético significativo, mas geralmente modesto. O pico de frequência dos cantos é significativamente associado ao comprimento do corpo, enquanto a estrutura dos cantos é significativamente associada ao sítio de vocalização e ao sexo do adulto que desempenha cuidado-parental. Meus resultados sustentam que, além das restrições filogenéticas, o tamanho do corpo está associado à evolução dos cantos de anúncio em Centrolenidae. A diversificação de características acústicas ao longo da filogenia de pererecas-de-vidro concorda com a radiação dos taxa na transição entre Mioceno e Plioceno. A disparidade estimada para características acústicas foi geralmente maior que a de características morfológicas, e o pico de disparidade de características acústicas geralmente ocorreu mais tarde na evolução do grupo, sugerindo um início historicamente recente da pronunciada divergência acústica entre espécies deste clado.

Palavras chaves: comunicação acústica; anfíbios; método comparativo; Neotropical; disparidade fenotípica.

ABSTRACT

Anurans emit advertisement calls with the purpose of attracting mates and repelling conspecific competitors. I investigated the association between body size, calling site and parental care with call variables (call duration, number of notes, peak frequency, frequency bandwidth and call structure) in glassfrogs—a family of leaf-dwelling frogs which inhabit Neotropical forests—while controlling for effects of shared ancestry. I also explored the tempo and mode of evolution of these traits and compared them with those of three morphological traits (snout-vent length, and relative head width and tibia length). I generated and compiled acoustic data for 72 glassfrog species (46 % of described diversity), including representatives of all genera ($n = 12$), and analyzed the data using phylogenetic comparative methods. I found that almost all acoustic traits evaluated had significant, but generally modest phylogenetic signal. Peak frequency of calls is significantly associated with body-size, while call structure is significantly associated with calling site and with the sex of the caring parent. My results support that, besides phylogenetic constraints, body size is associated with the evolution of advertisement calls in glassfrogs. Diversification of acoustic traits along the phylogeny of glassfrogs is coincident with the radiation of extant taxa at the Miocene-Pliocene boundary. The estimated disparity of acoustic traits was larger than that of morphological traits and the peak in disparity of acoustic traits generally occurred later in the evolution of glassfrogs, suggesting a historically recent outset of the pronounced acoustic divergence in this clade.

Keywords: acoustic communication; amphibians; comparative method; Neotropics; phenotypic disparity.

1. INTRODUÇÃO GERAL

Os anuros emitem um tipo de sinal acústico com o objetivo de atrair fêmeas e repelir concorrentes co-específicos, o qual denomina-se de canto de anúncio (Wells, 2007). A variação deste tipo de sinal acústico é geralmente influenciada por pressões naturais, sexuais e deriva genética, determinando sua evolução (Wilkins *et al.* 2013). A evolução do canto do anúncio em um contexto comparativo (*i.e.*, interespecífico) tem sido estudada desde meados do século passado (Crocoft & Ryan, 1995). Porém, até hoje, a evolução do canto de anúncio só foi investigada em quatro das 56 famílias de anuros atualmente reconhecidas (Erdtmann & Amézquita, 2009; Erdtmann 2012; Santos *et al.*, 2014; Goutte *et al.*, 2016). Possivelmente, a falta de bancos de dados acústicos compreensivos para a maioria das famílias e a falta de filogenias estáveis e bem resolvidas foram os maiores impedimentos para testes de relações entre fatores ecológicos, anatômicos e variabilidade das propriedades acústicas dos cantos de anúncio em anuros.

Neste trabalho, eu estudei a evolução do canto de anúncio em pererecas-de-vidro (Centrolenidae), uma família de anuros neotropicais (Castroviejo-Fisher *et al.*, 2014). Estas pererecas têm hábitos noturnos, territoriais, possuem cuidado parental e cantam a partir da superfície superior ou inferior de folhas na vegetação adjacente a ambientes lóticos (Señaris & Ayarzagüena, 2005; Kubicki, 2007; Cisneros-Heredia & McDiarmid, 2007; Guayasamin *et al.*, 2009). Através da implementação de métodos comparativos filogenéticos (Felsenstein, 1985; Harvey & Pagel, 1991; Pagel, 1999; Paradis, 2014), eu avaliei o potencial papel que a ancestralidade compartilhada, além de fatores intrínsecos (comprimento do corpo, tipo de cuidado parental) e extrínsecos (sitio de vocalização) exerceram durante a evolução das características do canto do anúncio em Centrolenidae.

O produto de meu trabalho é apresentado no capítulo a seguir, como um manuscrito para artigo científico, formatado de acordo com as normas do periódico *Journal of Evolutionary Biology*.

2. CAPÍTULO 1. Manuscrito formatado para artigo

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1 **The evolution of the advertisement call in Glassfrogs (Centrolenidae Taylor, 1951).**

2

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4

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7

8 Short running title: **Acoustic evolution in Glassfrogs**

9

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22 **Abstract**

23 Anurans emit advertisement calls with the purpose of attracting mates and repelling conspecific
24 competitors. I investigated the association between body size, calling site and parental care with
25 call variables (call duration, number of notes, peak frequency, frequency bandwidth and call
26 structure) in glassfrogs—a family of leaf-dwelling frogs which inhabit Neotropical forests—
27 while controlling for effects of shared ancestry. I also explored the tempo and mode of evolution
28 of these traits and compared them with those of three morphological traits (snout-vent length,
29 and relative head width and tibia length). I generated and compiled acoustic data for 72 glassfrog
30 species (46 % of described diversity), including representatives of all genera (n = 12), and
31 analyzed the data using phylogenetic comparative methods. I found that almost all acoustic traits
32 evaluated had significant, but generally modest phylogenetic signal. Peak frequency of calls is
33 significantly associated with body-size, while call structure is significantly associated with
34 calling site and with the sex of the caring parent. My results support that, besides phylogenetic
35 constraints, body size is associated with the evolution of advertisement calls in glassfrogs.
36 Diversification of acoustic traits along the phylogeny of glassfrogs is coincident with the
37 radiation of extant taxa at the Miocene-Pliocene boundary. The estimated disparity of acoustic
38 traits was larger than that of morphological traits and the peak in disparity of acoustic traits
39 generally occurred later in the evolution of glassfrogs, suggesting a historically recent outset of
40 the pronounced acoustic divergence in this clade.

41

42 **Keywords:**

43 acoustic communication; amphibians; comparative method; Neotropics; phenotypic disparity

44 **Introduction**

45 Animal communication is an important behavioral feature that allows individuals to
46 exchange information about their location, territory, condition, sex, size, and presence of
47 potential predators (Duellman & Trueb, 1986; Barnard, 2004; Wells, 2007). There are
48 several ways biological information can be transmitted, such as through visual, chemical, or
49 acoustic signals. The latter are of crucial importance for anurans, considering their ubiquity
50 among taxa and their role in long range communication, especially in visually-cluttered
51 environments (Duellman & Trueb, 1986; Ryan, 1988).

52 In general, anurans have a simple vocal repertoire (Duellman & Trueb, 1986). Most
53 breeding anuran males emit a kind of acoustic signal called advertisement call, which
54 serves for attracting appropriate mates and repelling conspecific males (Wells, 1977). Such
55 calls are genetically determined and highly stereotyped, playing an important role in
56 species recognition and reproductive isolation (Duellman & Trueb, 1986; Wells, 2007; but
57 see Köhler et al., 2017, pp. 39–42 for a recent review on intraspecific variation of
58 advertisement calls). Because of their role in mate attraction, differentiation of these signals
59 among populations may result in speciation in relatively short evolutionary time frames
60 (Barnard, 2004; Vences & Wake, 2007).

61 Advertisement calls have time, frequency, and structural components (the first two are
62 often referred to as temporal and spectral properties of the calls), which depend on multiple
63 intrinsic and extrinsic factors. For example, one may expect that more closely related
64 species should have more similar vocalizations due to the shared ancestry of the anatomy of
65 sound-producing organs (Cocroft & Ryan 1995; Panhuis *et al.*, 2001). It is also known that
66 some spectral properties depend on the size of the vocal apparatus. For example, the

67 dominant frequency of vocalizations is usually negatively correlated with the body size of
68 the emitter (Zweifel, 1968; Duellman & Trueb, 1986; Wells, 2007; Gingras *et al.*, 2013a).
69 Advertisement calls might also be adapted to the transmission environment, and call traits
70 may be temporally and spectrally shaped in order to reduce distortion by attenuation and
71 reverberation of sound signals by structural components of the species's native habitat
72 (Morton, 1975; Kime *et al.*, 2000; Ryan & Kime, 2003; Erdtmann & Lima, 2013). Hence,
73 the causes of variation in acoustic signals among different frog species may include
74 historical (i.e., phylogenetic), anatomical and ecological explanations.

75 Few studies have investigated the evolution of anuran advertisement calls in species-
76 rich clades and at deep evolutionary time-scales. These kinds of studies rely on
77 phylogenetic comparative methods (PCM), a number of analytical approaches that consider
78 a set of species in a historical framework in order to test the evolutionary mechanisms
79 involved in their diversification (Felsenstein, 1985; Harvey & Pagel, 1991; Pagel, 1999;
80 Paradis, 2014). Although applicable in solving many evolutionary puzzles, obtaining
81 meaningful results by applying these methods requires previous knowledge of the
82 genealogical relationships among the species analyzed (i.e., a well-supported phylogeny)
83 and a representative sample (i.e., in size and coverage) of the phenotypic traits of interest
84 for the target taxon. These limitations have resulted in only a handful of empirical studies
85 applying PCM to investigate the evolution of acoustic signals in anuran clades.

86 For instance, in a clade of poison-dart frogs (Dendrobatinae), pulse duration seems to
87 be more associated with the phylogenetic relationships among species than the peak
88 frequency of calls, which is more influenced by selective pressures acting on body size
89 evolution (Erdtmann & Amézquita, 2009). When considering all clades of extant poison-
90 dart frogs and their closest relatives (Superfamily Dendrobatoidea), the evolution of call

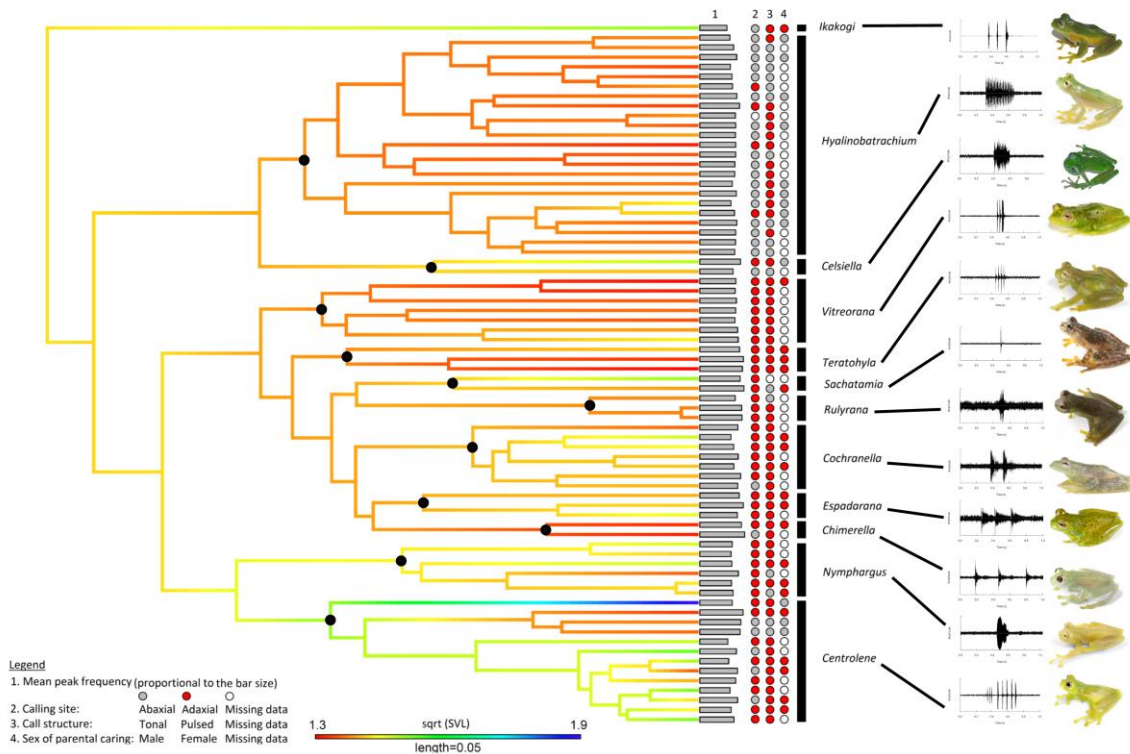
91 traits is also apparently related to the occurrence of aposematic dorsal color patterns, with
92 calls of brightly colored species diversifying at a faster rate than calls of cryptically colored
93 species (Santos *et al.*, 2014). However, poison-dart frogs and their allies are primarily
94 diurnal, and the evolutionary relationships between variation in call properties and
95 morphological traits potentially evolving under natural selection (e.g., warning colors, body
96 size) are not expected to be recovered across most of the extant anuran families, which
97 comprise species that are vocally active during the night.

98 Among true frogs (Ranidae), variation in advertisement call traits (i.e., dominant
99 frequency, frequency bandwidth, frequency modulation and note duration) is probably
100 constrained by acoustic specificities of noisy torrent habitats, in addition to associations
101 between some of these traits with interspecific variation in body size (Goutte *et al.*, 2016,
102 2017). Jointly, these studies encompassed three of the 56 currently recognized anuran
103 families and less than 10 % of the currently recognized anuran species diversity (Frost,
104 2018). Certainly, the paucity of empirical studies hampers our understanding of patterns in
105 the evolution of advertisement calls in anurans.

106 Glassfrogs (Centrolenidae) are charismatic Neotropical anurans characterized by having
107 partially or completely transparent ventral skin (Guayasamin *et al.*, 2009; Castroviejo-
108 Fisher *et al.*, 2014). They constitute a clade of 155 species, distributed in humid forests
109 from Mexico to Bolivia, along the Andes and across the Amazon, with vicariant species
110 distributed in Tobago Island and in the Brazilian Atlantic Forest (Castroviejo-Fisher *et al.*,
111 2014; Frost, 2018).

112 The phylogenetic relationships among glassfrog species are relatively well explored and
113 stable (Fig. 1), with the most complete phylogeny to date including more than 73 % of the
114 described species diversity (Delia *et al.*, 2017). Castroviejo-Fisher *et al.* (2014) inferred that

115 Centrolenidae started to diversify in the Miocene in South America, with 11 independent
 116 dispersals into Central America. Within South America, a mixture pattern of vicariant and
 117 dispersal events among biogeographic areas explains the current species distribution, with
 118 the Northern Andes as the main dispersal source. The diversification of glassfrogs followed
 119 a constantly increasing diversity model and it was further suggested that the success of
 120 some centrolenid clades in spreading across Neotropical rain forests might be related to the
 121 presence of altitudinal generalist species (Castroviejo-Fisher *et al.*, 2014).



122

123 **Figure 1.** Maximum clade credibility tree of Centrolenidae modified from Delia *et al.*
 124 (2017). Only the species included in this study (n = 72) are represented as terminals. Black
 125 dots on nodes represent the ancestral node for Centrolenidae genera. Internal branch
 126 colours represent ML reconstructions of body size (log₁₀ of snout-vent length in mm),
 127 while terminal branch colours represent the average body size of each species. Mean peak
 128 frequency, calling site, call structure and sex of parental caring is shown at tips. Graphs and
 129 photographs represent call waveforms (x-axis = 1 ms) and dorsolateral views of
 130 representative species in Centrolenidae (from top to bottom): *Ikakogi tayrona*;
 131 *Hyalinobatrachium chirripoi*; *Celsiella vozmedianoi*; *Vitreorana ritae*; *Teratohyla spinosa*;
 132 *Sachatamia albomaculata*; *Rulyrana flavopunctata*; *Cochranella mache*; *Espadarana*

133 *prosolepon*; *Chimerella mariaelena*; *Nymphargus griffithsi*; and *Centrolene ballux*.
134 Photos: Santiago R. Ron (Anfibios del Ecuador;
135 <http://www.bioweb.bio/faunaweb/amphibiaweb/>), except *I. tayrona* (Marco Rada), and *C.*
136 *vozmedianoi* (Juan Guayasamin).

137
138 Glassfrogs have arboreal and nocturnal habits, being found near lotic environments.
139 Males of most species vocalize while perched on vegetation overhanging streams, except
140 some *Centrolene*, *Rulyrana* and *Sachatamia* species (roughly 10 spp.) that call from rocks
141 near water (Guayasamin *et al.*, 2009). When calling from vegetation, males assume a
142 calling position on the upper (adaxial) or lower (abaxial) surface of a leaf, and calling
143 position is generally fixed within each glassfrog species (Cisneros-Heredia & McDiarmid,
144 2007; Guayasamin *et al.*, 2009). Male glassfrogs are territorial and, during reproduction,
145 egg clutches are deposited by females near the male's calling site. Eggs are attended by one
146 or both parents, for a period of time that can vary from a few hours to the hatching of
147 tadpoles, depending on the species (Delia *et al.*, 2017). Calling and attending egg clutches
148 are both energetically costly in anurans (Prestwich, 1994; Townsend, 1986; Crump, 1996)
149 and the amount of energy necessary to produce advertisement calls in anurans often relates
150 to temporal traits such as the number of notes or pulses emitted at a given time interval
151 (Gerhardt & Huber, 2002). However, no associations were ever investigated between call
152 traits and investment in parental care by male anurans.

153 The combination of a widely distributed, species-rich clade, with a well-resolved
154 phylogeny, and a relatively good knowledge of the diversity of advertisement calls—to
155 date, the calls of 48 % of glassfrog species have been quantitatively described—makes
156 centrolenids an ideal model to study the relative effect that historical and ecological factors
157 might have had on the evolution of acoustic signals. Using PCM, I herein evaluate the
158 power of historical (phylogeny), intrinsic (body size, exclusively male parental care) and

159 extrinsic (calling site) factors to explain the evolution of advertisement call traits. Based on
160 current knowledge on advertisement call evolution in anurans, I devise five predictions on
161 how call traits and intrinsic and extrinsic explanatory variables potentially relate to each
162 other.

163 First, variation in spectral traits of calls is generally associated with body size because
164 larger frogs have a larger sound-emitting apparatus than smaller frogs (Duellman & Trueb,
165 1986). Hence, I predict that peak frequency of calls will be higher in smaller-sized
166 glassfrog species, independently of their shared ancestry.

167 Second, calling position (adaxial or abaxial leaf surfaces and streamside rocks) is
168 conserved within species of glassfrogs, and several nocturnal anurans are known to
169 vocalize from positions that enhance the transmission of information contained in acoustic
170 signals (Hödl, 1977; Kime *et al.*, 2000; Muñoz & Penna, 2016). Thus, I predict that similar
171 calling positions led to the evolution of similar advertisement calls (in temporal, spectral,
172 and structural traits) because of akin selective pressures on signal transmission efficiency.

173 Third, glassfrog species with males providing parental care invest more time brooding
174 than species with maternal care (Delia *et al.*, 2017). I predict that species with males
175 providing parental care should emit simpler (i.e., of one note and tonal) and shorter calls
176 than species with maternal care, as an energy trade-off between calling and brooding.

177 Fourth, the historical biogeography of centrolenids coupled with large transformations
178 of tropical America environments and landscapes (Castroviejo-Fisher *et al.*, 2014; Hoorn &
179 Wesselingh, 2010) suggests that the intensity of environmental selection may have varied
180 though their evolutionary history, either by dispersal into new regions or by modifications
181 of already inhabited areas. Hence, I expect acoustic diversification in glassfrogs was not

182 constant through the group's diversification, and I predict that major shifts in the disparity
183 of acoustic traits may be coincident with dispersal events into new ecological regions (e.g.,
184 Central America, after the formation of the isthmus of Panama, and the Amazonian plains,
185 after the establishment of the Amazon River drainage) and/or major geological events that
186 transformed the landscape.

187 Fifth, the tempo and mode of evolution of acoustic traits in glassfrogs differ from that
188 of non-sexually selected (i.e., ecology-related) traits because traits directly involved in mate
189 choice are often under directional selection, while ecology-related traits are more likely to
190 be experiencing stabilizing selection (Ridley, 2004; Gonzalez-Voyer & Kolm, 2011). I
191 predict that acoustic traits will show a different tempo and mode of evolution than ecology-
192 related traits (i.e., head width, length of limbs).

193

194 **Materials and methods**

195 **Taxon sampling and acoustic data**

196 I analysed a total of 830 advertisement calls from 67 species, plus a putative undescribed
197 species (*Hyalinobatrachium* aff. *bergeri*), compiled from audio recordings gathered from
198 personal and museum collections (origin of recordings, authorship, and other relevant
199 information are detailed in Dataset S1). This covered 48 % of the species richness in
200 Centrolenidae, including representatives of all genera. I analysed calls of as many
201 individuals as possible for each species (mean = 3 individuals; S.D. = 2.5; range = 1–12
202 individuals) to obtain a good estimate of the central tendency statistics for call properties of

203 each species. I analysed five calls per individual and used the average value for each call
204 property measured among all individuals of each species in all analyses.

205 I measured temporal and spectral call traits from oscillograms and power spectra,
206 respectively. I estimated power spectra using a Fast Fourier Transform (FFT) analysis with
207 a Blackman window of 5 ms of size, 80 % of overlap in time grid and a DFT size of 1024
208 samples in frequency grid. I carried out all bioacoustic analyses using RavenPro v. 1.4
209 (Bioacoustics Research Program, 2011).

210 Acoustic trait definition and terminology followed Köhler *et al.* (2017). I measured four
211 acoustic traits: call duration (CD), measured as the time elapsed between the beginning and
212 the end of the call as viewed in the oscillogram; number of notes (NN), measured as the
213 number of tonal notes or pulse groups that are temporally separated from other notes or
214 pulse groups by large silent intervals; peak frequency (PF), measured as the frequency
215 emitted with the highest energy; and bandwidth (BW), which is the difference between the
216 upper and lower frequency bounds of the notes, as measured 20 dB below the peak
217 frequency. The - 20 dB threshold was adopted in order to avoid considering frequencies
218 originated from background noise in the analyses. Additionally, I categorized the call
219 structure (CS) as pulsed (when at least one note presented sequential 100 % amplitude
220 modulation between pulses) or tonal (when no sequential amplitude modulation was
221 present within any note that formed the advertisement call).

222 Other call variables commonly used in bioacoustics (e.g., number of harmonics in a
223 note, duration of individual notes in a call and duration of the silent intervals between
224 notes) were not considered because of the impossibility of verifying the homology of
225 different call elements (individual notes or intervals) among all species. The display of note
226 harmonics on audiospectrograms or power spectra are also strongly affected by low signal-

227 to-noise ratio. Hence, these elements were more or less detectable as a result of the
228 intensity of background environmental noise captured in each sound recording.

229 I compiled data on the same call traits (except for BW) from the literature for 10
230 glassfrog species for which I could not access original recordings (Dataset S2). Hence, call
231 traits were obtained for a total 78 glassfrog terminals (species plus the putative undescribed
232 species). Nevertheless, only 72 of those terminals are represented in the phylogenetic tree
233 considered in the PCM analyses (see below).

234 In one species, *Centrolene lynchi*, three different calls were found among recordings,
235 associated to three different localities in Pichincha department, Ecuador: (1) “3.5 km NE
236 Mindo, 1541 m a.s.l.” (voucher: KU 164710; sound record: Fonozoo 194-8176); (2)
237 “Reserva Las Galarias, Lucy’s creek” (voucher: unknown; sound records: LS00018,
238 00020, 00029, 00031, and ASL013; source: Ana Salgado); (3) “Tandayapa, 1.0 km SW of
239 on Mindo road, 1640 m a.s.l.” (voucher: RWM 12178; sound record:
240 201486_44k_C_lynchi; source: Macaulay Library). The three localities are approximately
241 at the same distance (~ 37 km) from *Centrolene lynchi*’s type locality in Pichincha (00°21'
242 S, 78°54' W; 1140 m a.s.l.), Ecuador, where no sound recordings were available. For this
243 reason, I kept only calls corresponding to specimens included in the molecular phylogeny,
244 which were obtained from Reserva Las Galarias (Castroviejo-Fisher *et al.*, 2014).

245

246 **Morphological, behavioral and ecological data**

247 I obtained morphometric data for 67 glassfrog species from the literature, and for 11
248 species from fellow researchers (Dataset S3). I selected three morphometric traits of
249 biological relevance in anurans, which were shared among all references, to compare their

250 evolution with acoustic traits: i) snout-vent length (SVL), the most common descriptor of
251 body size in anuran bioacoustics studies (Köhler *et al.*, 2017), ii) head width (HW), which
252 is related to feeding habits, as it limits maximum prey size (Toft, 1980, 1981; Emerson,
253 1985), and iii) tibia length (TL), a hind-limb's measurement, which is related to jumping
254 performance (Emerson, 1978, 1991; Zug, 1978). I considered the average values of SVL
255 and the average values of the ratios HW/SVL and TL/SVL among males of each species for
256 all analyses. Ratios were used instead of the raw values of HW and TL in order to rule out
257 their collinearity with the SVL.

258 I compiled the predominant calling site of each species from the literature (72 species)
259 and complemented it with field observations provided by fellow researchers (Dataset S3). I
260 categorized calling site as abaxial leaf surface or adaxial leaf surface/on rocks, because
261 there was no reason to assume that call traits would be differently affected by different
262 substrates considering the frog's calling position above them (as opposed to a calling frog
263 positioned on the underside of a leaf forming a dome, which could potentially reverberate
264 or absorb differentially certain spectral bands of a sound signal). Parental care (i.e.,
265 prolonged attendance) data was obtained from Delia *et al.* (2017) (Dataset S3), based on
266 field observations of 39 species, distributed in 11 genera. Thirty-three of these species were
267 represented in the acoustic dataset described above (Dataset S3).

268

269 **Phylogeny**

270 To quantify the evolutionary relationships among glassfrog species, I used the most recent
271 and complete molecular ultrametric phylogeny of Centrolenidae (Delia *et al.*, 2017). This
272 phylogeny includes 111 of the 155 currently named species, plus 10 putative undescribed

273 species, and includes representatives of all currently recognized genera. This accounts for
274 72 % of glassfrog species diversity. The phylogeny was based on DNA sequences of up to
275 three mitochondrial and seven nuclear genes (totaling 6645 bp), and was inferred from a
276 Bayesian analysis with the dataset partitioned by gene using a GTR + I + Γ nucleotide
277 substitution model, and dated with the relaxed-clock method (Delia *et al.*, 2017). The
278 topology used in all my analyses corresponds to the maximum clade credibility tree of
279 10,001 trees sampled from the posterior distribution, with mean branch lengths (Dryad;
280 doi:10.5061/dryad.16vc0). The topology is completely resolved and only 13 % of nodes
281 have a posterior probability < 0.90). For the purpose of the PCM, I trimmed the original
282 tree by removing the species for which I had no phenotypic data (Fig. 1), using the
283 “drop.tip” function as implemented in the package APE (Paradis *et al.*, 2004) in R (R Core
284 Team, 2017).

285

286 **Phylogenetic comparative analysis**

287 I used PCM to estimate phylogenetic signal of acoustic traits, to measure correlated
288 evolution between acoustic traits and other variables (i.e., morphology, calling site and
289 parental care), and to infer the tempo of phenotypic evolution of acoustic and morphometric
290 variables.

291 I coded categorical variables (e.g., call structure, calling site) as numeric discrete
292 variables. Continuous traits were log or square root-transformed (Table 1) in order to fulfill
293 requirements of the statistical methods (i.e., normality of the residuals) (Freckleton, 2009)
294 and the assumptions of the evolutionary model (Felsenstein, 1985). For all phylogenetic
295 linear models, I visually assessed distribution of residuals and tested the correlations

296 between the absolute values of the phylogeny-corrected residuals and their predicted
297 values, in order to assess homogeneity of variance (Freckleton, 2009).

298 I estimated the value of the evolutionary parameter λ , a measure of the phylogenetic
299 signal, for each acoustic trait separately. This parameter indicates the extent to which
300 closely related species tend to resemble each other in relation to a given trait (Pagel, 1999).
301 A value of $\lambda = 1$ indicates high phylogenetic signal in a trait (i.e., phylogenetically closer
302 species are more similar to each other), whereas a value of $\lambda = 0$ indicates no phylogenetic
303 signal (i.e., trait similarity among species is independent of shared ancestry; Freckleton *et*
304 *al.*, 2002). The value of λ was estimated through a maximum-likelihood approach assuming
305 a constant-rate Brownian motion model (BM) of evolution (Symonds & Blomberg, 2014),
306 which considers that traits undergo a random process of successive and independent small
307 changes. The net change of the trait is drawn from a normal distribution with mean at zero
308 and variance proportional to the time elapsed (Felsenstein, 1985). Thus, the magnitude of
309 evolutionary change of a phenotypic trait along a branch will be proportional to the branch
310 length (Symonds & Blomberg, 2014). The λ parameter was estimated using the “phylosig”
311 function as implemented in the package PHYTOOLS (Revell, 2012) in R (R Core Team,
312 2017).

313 I estimated the phylogenetic signal of binary traits using the D parameter (Fritz &
314 Purvis, 2010). A value of $D = 0$ indicates high phylogenetic signal in a trait (i.e.,
315 phylogenetically closer species are more similar to each other), whereas a value of $D = 1$
316 indicates no phylogenetic signal (i.e., trait similarity among species is independent of
317 shared ancestry; Fritz & Purvis, 2010). The D parameter was estimated using the “phylo.d”
318 function as implemented in the package CAPER (Orme *et al.*, 2013) in R.

319 In order to address each question of correlated evolution between continuous acoustic
320 traits and other phenotypic or environmental variables, I performed tests using phylogenetic
321 generalized least squares models (PGLS). PGLS is a generalization of Felsenstein's
322 (1985)'s phylogenetic independent contrasts, which incorporates phylogenetic relationships
323 among species into the error structure of the regression formula, considering a model of
324 phenotypic evolution that best fits the observed data (Grafen, 1989). More specifically, the
325 expected covariance structure of the residuals from the regression equation is defined as the
326 amount of shared evolutionary history between the species—the phylogenetic covariance
327 matrix (Symonds & Blomberg, 2014). The λ parameter is a scaling parameter of the
328 phylogeny in the PGLS model. This is a multiplier of the off-diagonal elements of the
329 expected variance-covariance matrix and indicates whether the shared evolutionary
330 histories as specified by the phylogeny produce the patterns of similarity observed in the
331 residuals (Symonds & Blomberg, 2014). I used PGLS models considering the λ 's
332 transformation because their interpretation is less complex than that of alternative
333 transformation parameters. When λ is not statistically different from one, a Brownian
334 model of phenotypic evolution is assumed. The value of λ was estimated by maximum
335 likelihood. Analyses were carried out using the “pgls” function as implemented in the
336 package CAPER (Orme *et al.*, 2013) in R.

337 I assessed associations between binary acoustic traits and phenotypic variables using
338 phylogenetic logistic regressions (Ives & Garland, 2010). The alpha (α) parameter estimates
339 the level of phylogenetic correlation in the regression (Ives & Garland, 2010). Analyses
340 using phylogenetic logistic regressions were carried out using the “phyloglm” function as
341 implemented in the package PHYLLOLM (Ho & Ane, 2014) in R.

342 I studied the tempo of evolution of acoustic (CD, NN, PF, BW) and morphometric
343 (SVL, HW/SVL, TL/SVL) traits by estimating their phenotypic disparity index (DI). I
344 considered the DI *sensu lato* from the Harmon *et al.* (2003)'s morphological disparity index
345 (MDI), such as considered previously for other categories of phenotypic data (Gonzalez-
346 Voyer & Kolm, 2011; Gonzalez-Voyer *et al.*, 2013). The DI is an estimate of the temporal
347 dynamic of phenotypic evolution that describes how phenotypic disparity is partitioned
348 along the phylogeny. DI values > 0 suggest that most of the phenotypic disparity is
349 distributed within clades; negative DI values suggest that disparity is distributed among
350 clades, implicating an early divergence of the trait; DI values near 0 indicate accumulation
351 of phenotypic disparity among and within clades that is consistent with the Brownian
352 motion model. Disparity-through-time (DTT) plots represent the time course of phenotypic
353 diversification using average pairwise Euclidean distances between species (Harmon *et al.*,
354 2003). These plots are meant to visually represent the average relative disparity of each
355 subclade, which is estimated from dividing the average disparity of all subclades whose
356 ancestral lineages were present at that time by the average disparity of the clade as a whole,
357 and repeating this procedure at each node moving up from the root to the tip of the
358 phylogeny (Harmon *et al.*, 2003).

359 The DI was calculated as the sum of the areas between the curve describing the
360 disparity of the trait and the curve describing the disparity under the null hypothesis of
361 Brownian motion (Harmon *et al.*, 2003). I estimated disparity for only the first 4/5 of the
362 phylogeny to avoid artifacts due to incomplete species sampling and overestimation of
363 disparity between closely related species (Harmon *et al.*, 2003; Gonzalez-Voyer & Kolm,
364 2011). I calculated the DI and produced the DTT plots using the “dt” function as
365 implemented in package GEIGER (Harmon *et al.*, 2007) in R. The values of the time-scale

366 generated by default by the DTT plot were replaced with the adjusted first 4/5's of the
367 glassfrog's radiation chronogram estimated by Castroviejo-Fisher *et al.* (2014).

368

369 **Results**

370 The final dataset contained 72 glassfrog species. Forty-three species (60 %) vocalized
371 from the adaxial surface of leaves, whereas 28 species (39 %) vocalized from abaxial
372 surface of leaves. One species (*Centrolene geckoideum*) vocalized from rocks. Seventeen
373 species had tonal advertisement calls, while 54 species had pulsed calls. In one species for
374 which call parameters were obtained from the literature, *Sachatamia ilex*, data on call
375 structure was not available; hence this terminal was coded as missing data for this trait. The
376 mode of NN was 1 note (range: 1–13). Mean call duration (CD) estimated among
377 glassfrogs was 0.274 ms (range: 0.006–1.443 ms), mean peak frequency (PF) was 4880.1
378 Hz (range: 2713.2–7407.4 Hz), mean frequency bandwidth (BW) was 1226.3 Hz (range:
379 810.4–2476.1 Hz). The average SVL among glassfrogs was 23.8 mm (range: 18.4–75.2
380 mm), the mean HW/SVL ratio was 0.36 (range: 0.32–0.41) and the mean TL/SVL was 0.56
381 (range: 0.50–0.67). Thirteen species were described as having the male taking part in
382 parental care, whereas in 20 species parental care is conducted exclusively by the female
383 (Dataset S3).

384

385 **Phylogenetic signal**

386 Estimates of the evolutionary parameter λ indicated that two acoustic traits (PF and BW)
387 had pronounced phylogenetic signal ($\lambda = 0.72$ and 0.73 , respectively). The value of λ for

388 NN was marginally significant but weak ($\lambda = 0.21$), while the value of λ for CD was not
 389 statistically significant (Table 1). The values of D for call structure and calling site
 390 indicated that both have a significant phylogenetic signal (Table 2), although modest for
 391 call structure (D = 0.43). Hence, closely related glassfrog species tend to call while perched
 392 in similar places (over leaves/rocks or under the surface of leaves) and to emit calls with
 393 similar structure (e.g., tonal or pulsed), with more similar peak frequencies and bandwidths.
 394

395 **Table 1.** Maximum likelihood estimates of lambda (λ) and disparity index (DI) for acoustic
 396 and morphometric variables for Centrolenidae. CD = call duration; NN = number of notes;
 397 PF = peak frequency; BW = bandwidth frequency; SVL = snout-vent length; HW = head
 398 width; TL = tibia length. Asterisks indicate significant correlations (*).
 399

Trait	N	λ	Loglik	<i>P</i>	DI	<i>P</i>
Log ₁₀ (CD)	72	0.45	- 43.96	0.11	0.26	0.97
Sqrt (NN)	72	0.21	- 65.42	0.04*	0.16	0.96
Sqrt (PF)	72	0.72	- 239.76	1.56 x 10 ⁻⁵ *	0.03	0.79
Sqrt (BW)	64	0.73	- 173.22	1.02 x 10 ⁻⁷ *	0.27	0.97
Log ₁₀ (SVL)	72	0.94	87.29	1.06 x 10 ⁻⁵ *	-9.9 x 10 ⁻⁴	0.76
Log (HW/SVL)	72	0.77	114.61	4.08 x 10 ⁻⁶ *	0.004	0.75
Log (TL/SVL)	72	0.28	115.50	0.004*	0.23	0.81

400

401

402 Two morphometric traits evaluated, SVL and HW/SVL, had strong phylogenetic signal
 403 ($\lambda = 0.94$ and 0.77 , respectively), whereas TL had a weak but significant phylogenetic
 404 signal (Table 1). This indicates that glassfrog species sharing a more recent common
 405 ancestor are generally more similar in body size (Fig. 1) and head width than species with a
 406 more distant common ancestor.

407

408 **Table 2.** Estimates of the parameter D for binary variables assessed for Centrolenidae. Call
 409 structure was coded as tonal (0) or pulsed (1). Calling site was coded as “upper side of
 410 leaves or rocks” (0) or “underside of leaves” (1).

Trait	N	D	P_{Random}	P_{Brownian}
Call structure	71	0.43	0.012	0.155
Calling site	72	0.04	0	0.478

411

412

413 **Environmental, behavioural, and morphological correlates of call traits**

414 PGLS analysis revealed a significant correlation ($P < 0.001$; $\beta = -36.255$; $R^2 = 0.155$)
 415 between SVL and PF (Table 3). Consequently, body size explained a proportion of the
 416 observed variation of PF in glassfrogs, when accounting for phylogenetic non-
 417 independence of species, suggesting that SVL and PF might have evolved concomitantly.

418

419 **Table 3.** Phylogenetic generalized least squares model of the relationship between peak
 420 frequency and snout-vent length (SVL) for Centrolenidae. Asterisks (*) indicate significant
 421 correlations.

422

	N	$\beta \pm SE$	t value	P value
Sqrt (Peak frequency)	72			
Lambda value = 0.76				
$R^2 = 0.155$				
Intercept		117.476 ± 14.359	8.818	8.47×10^{-12}
Log10 (SVL)		-36.255 ± 10.116	-3.584	$6.21 \times 10^{-4*}$

423

424

425 I only found an association between calling site and call structure ($P = 0.02$; $b_1 = -$
 426 1.458), indicating that similar calling sites evolved alongside with call structure: glassfrogs

427 that call from the underside of leaves tended to emit tonal calls (Tables 4 and 5). Calls of
 428 species with male brooding were generally characterized by pulsed notes (Table 4). I found
 429 no additional associations between acoustic variables and male investment in parental care
 430 (Table 6).

431

432

433 **Table 4.** Phylogenetic logistic regressions of associations between call structure and calling
 434 site (underside of leaves vs. upper side of leaves or rocks), and between call structure and
 435 male attendance during brooding of egg clutch for Centrolenidae. Asterisks (*) indicate
 436 significant correlations.

437

	N	$b \pm SE$	z value	P value
Call structure	70			
Alpha value = 26.57				
Intercept		1.787 ± 0.552	3.237	0.001
Calling site		$- 1.458 \pm 0.617$	- 2.363	0.018*
Call structure	29			
Alpha value = 80.59				
Intercept		1.951 ± 0.695	2.805	0.005
Male brooding		$- 1.784 \pm 0.921$	- 1.934	0.053*

438

439

440

441

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443

444

445 **Table 5.** Phylogenetic generalized least squares models of associations between
 446 advertisement call traits and calling site (underside of leaves vs. upper side of leaves or
 447 rocks) for Centrolenidae. Asterisks (*) indicate significant correlations.
 448

	N	$\beta \pm SE$	<i>t</i> value	<i>P</i> value
Log 10 (Call duration)	71			
Lambda value = 0.33				
R ² = 0.007				
Intercept		- 0.842 ± 0.145	- 5.826	1.71 x 10 ⁻⁷
Calling site		0.092 ± 0.130	0.710	0.480
Sqrt (Number of notes)	71			
Lambda value = 0.23				
R ² = 0.007				
Intercept		1.330 ± 0.170	7.847	4.15 x 10 ⁻¹¹
Calling site		0.116 ± 0.173	0.668	0.507
Sqrt (Peak frequency)	71			
Lambda value = 0.746				
R ² = 0.016				
Intercept		66.300 ± 3.351	19.788	< 2 x 10 ⁻¹⁶
Calling site		1.992 ± 1.889	1.055	0.295
Sqrt (Bandwidth frequency)	63			
Lambda value = 0.703				
R ² = 0.002				
Intercept		34.107 ± 1.738	19.621	< 2 x 10 ⁻¹⁶
Calling site		- 0.358 ± 1.110	- 0.322	0.748

449

450

451 **Tempo and mode of evolution of call and morphological traits**

452 The analyses of DI suggested that CD, NN and BW differ from two morphometric
 453 traits (i.e., SVL and HW) but not TL in terms of their tempo and mode of evolution.

454 Similarly, PF mirrors the pattern of evolution disparity of SVL and HW. Acoustic traits

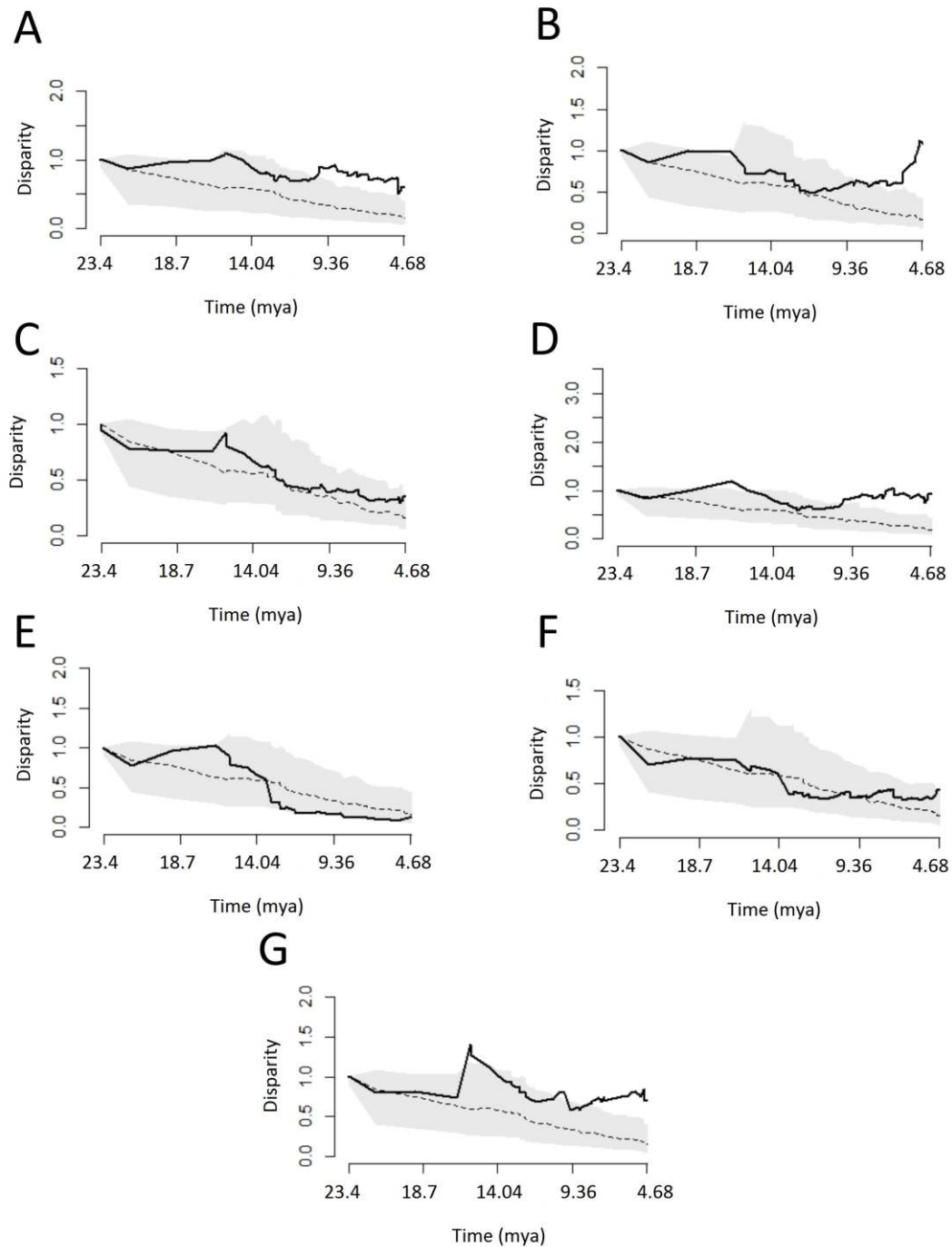
455 had higher DI's when compared to morphometric traits (0.03–0.27 vs. -9.9×10^{-4} –0.004,
 456 respectively; Table 1), except TL, which had a DI = 0.23, close to the maximum DI
 457 estimated for acoustic traits. Peak frequency had the lowest value of DI among acoustic
 458 traits. Considering the disparity-through-time analysis, disparity of all phenotypic traits
 459 peaked (with different magnitudes) at the first third of the centrolenid radiation (around 15
 460 MYA) and then decreased (Fig. 2). However, all acoustic traits except PF increased their
 461 relative DI towards the present, around 10–8 MYA—approximately at the mid time of the
 462 glassfrog's radiation—, deviating from DI values predicted under a BM model (Fig. 2 A–
 463 D). A similar pattern is also observed in TL. This indicates that: i) for most acoustic traits
 464 assessed and TL, a greater proportion of the disparity was concentrated within subclades;
 465 and ii) that acoustic divergence did not follow a purely Brownian model (BM) and, instead,
 466 had a more recent divergence, if compared to morphometric traits (i.e., SVL and HW)—
 467 which present a model of evolution better approximated by a BM model.

468

469 **Table 6.** Phylogenetic generalized least squares models of the relationship between
 470 advertisement call traits with male attendance during brooding of egg clutch for
 471 Centrolenidae. Asterisks (*) indicate significant correlations.

	N	$\beta \pm SE$	<i>t</i> value	<i>P</i> value
Log 10 (Call duration)	29			
Lambda value = 0				
$R^2 = 0.002$				
Intercept		-0.649 ± 0.116	- 5.595	6.20×10^{-6}
Male brooding		-0.050 ± 0.198	- 0.254	0.801
Sqrt (Number of notes)	29			
Lambda value = 0				
$R^2 = 0.084$				
Intercept		1.583 ± 0.137	11.591	5.46×10^{-12}

472



473

474 **Figure 2.** Disparity-through-time (DTT) plots for acoustic and morphometric traits of
 475 Centrolenidae. Vertical axis represents average subclade disparity (an estimate of relative

476 disparity among species within a sub-clade compared with total clade disparity). A) Call
477 duration; B) Number of notes; C) Peak frequency; D) Frequency bandwidth; E) Snout-to-
478 vent-length; F) Head width; and G) Tibia length. The time-scale was estimated from the
479 chronogram of Castroviejo-Fisher *et al.* (2014). The solid line represents the relative
480 disparity through the time estimated from the dataset, the dashed line represent a null model
481 (i.e., Brownian model), and the gray zone represents the 95 % confidence intervals
482 estimated from the simulations under Brownian motion.

483

484 **Discussion**

485 I investigated associations of shared ancestry, body size, calling site and parental care with
486 structural, temporal and spectral properties of advertisement calls in glassfrogs. I found that
487 common ancestry is associated with interspecific variation of all acoustic traits, as they all,
488 but CD, exhibit statistically significant phylogenetic signal (Tables 1, 2). Body size is
489 negatively correlated with the peak frequency of calls, whereas calling site and male
490 parental care are associated with call structure, broadly defined as tonal or pulsed calls
491 (Tables 3, 4). Additional environmental factors deemed to be important selective forces in
492 other families of frogs, such as masking interference with background noise (Vargas-
493 Salinas & Amézquita, 2014; Goutte *et al.*, 2016, 2017) are discussed below.

494 I also uncovered that all studied phenotypic variables share a disparity peak around 15
495 MYA, which is either above the 95 % confidence interval or on its limit (Fig. 2). However,
496 three acoustic (CD, NN and BW) and one morphometric (TL/SVL) variables show a
497 significant increase of phenotypic disparity towards the present, around 10–8 MYA. This
498 later result indicates that the disparity of these four phenotypic variables is
499 disproportionately partitioned within subclades.

500

501 **Phylogenetic signal in acoustic traits**

502 The idea that behavioral characters, such as anuran vocalizations, carry phylogenetic
503 information has a relatively old origin in evolutionary biology. For example, Blair (1958)
504 suggested that, in frogs, “Groups of species within a genus [...] show basic similarities in
505 call structure, which, with other evidence, are indicative of evolutionary relationship”. This
506 notion constitutes the basis for using components of sounds emitted by animals as
507 characters to study phylogenetic relationships. However, difficult issues arise when one
508 tries to code characters with a clear continuous nature (e.g., call duration) and establish
509 homology among non-transitive characters (Cocroft & Ryan, 1995; Goicoechea *et al.*,
510 2010; Wheeler, 2012). A somehow different approach, which I took herein, consists on
511 statistically testing how well observed variation in acoustic parameters can be explained by
512 common ancestry (phylogenetic signal), given a phylogenetic hypothesis.

513 Although behavioral traits are generally deemed more labile than morphological,
514 ecological, and physiological traits in vertebrates (Blomberg *et al.*, 2003; but see Wenzel,
515 1992), my results indicate that all evaluated acoustic traits but one have significant
516 phylogenetic signal. These findings agree with previous studies in other anuran groups that
517 reported phylogenetic signal in most, if not all, acoustic traits assessed (Cocroft & Ryan,
518 1995; Wollenberg *et al.*, 2007; Erdtmann & Amézquita, 2009; Goicoechea *et al.*, 2010;
519 Gingras *et al.*, 2013b; but see Cannatella *et al.*, 1998; Tobias *et al.*, 2011). Although the
520 similarity of acoustic traits among close relatives had been previously suggested for
521 centrolenids (Mc Diarmid, *in* Cocroft & Ryan, 1995; Weng *et al.*, 2012), this is the first
522 quantitative study. I also found that the strength of the phylogenetic signal varied among
523 acoustic traits, with NN having a lower phylogenetic signal than spectral traits. My results
524 indicate that CD is not phylogenetically constraint, which combined with new results
525 indicating that it is a variable with low intraspecific variability among anurans (Khöler *et*

526 al., 2017), may indicate its potential for species identification purposes. Phylogenetic signal
527 was also weaker among acoustic traits when compared to that of morphological traits
528 (Table 1), which may indicate that the evolution of traits under sexual selection is less
529 constraint than other characters.

530

531 **Correlated evolution of peak frequency and body size**

532 It is a well-known principle in bioacoustics that the size of the structure producing a
533 sound is inversely correlated with the peak frequency of the sound (Wilkins *et al.*, 2013). In
534 general, allometric relationships allow us to link body size with the size of sound producing
535 structures, such as the vocal cords of anurans (Wells, 2007). My results show a significant
536 negative correlation between SVL and PF when considering the phylogeny, which is
537 consistent with numerous prior findings for anurans (Zweifel, 1968; Erdtmann &
538 Amézquita, 2009; Gingras *et al.*, 2013a; Vargas-Salinas & Amézquita, 2014; Goutte *et al.*,
539 2017). However, the variation explained by the PGLS analysis is relatively small ($R^2 =$
540 0.155) if compared to body size-peak frequency relationships found in other anurans
541 (Zweifel, 1968; Erdtmann & Amézquita, 2009; Gingras *et al.*, 2013a; Vargas-Salinas &
542 Amézquita, 2014; Röhr *et al.*, 2016).

543 The weak correlation between SVL and PF in glassfrogs could be a result of the limited
544 body size variation in this clade, if compared to those observed in other anuran groups in
545 which the evolution of call parameters has been previously investigated (Erdtmann &
546 Amézquita, 2009; Gingras *et al.*, 2013a; 2013b; Goutte *et al.*, 2016; Röhr *et al.*, 2016).
547 Body size variation in male glassfrogs is largely restricted and skewed towards small sizes

548 (male SVL interquartile range: 20.82–24.86 mm), with a single outlier—the giant
549 *Centrolene geckoideum* (male SVL range: 70.20–80.70 mm; Guayasamín *et al.*, 2018).

550 The restricted variance in body size may be explained by a developmental constraint
551 (Gould, 1980; Smith *et al.*, 1985; Stearns, 1986). Testing this hypothesis would require
552 detailed developmental studies and such data are not available. Nevertheless, mapping body
553 size evolution on the phylogeny reveals several independent evolutionary transitions
554 between relatively large and small species (Fig. 1), which would not be expected if a
555 common developmental constraint limited the distribution of body size among species of
556 glassfrogs. In any case, several species emit calls at frequencies higher than those expected
557 by the PGLS model—which is particularly noteworthy for *Centrolene geckoideum* but not
558 restricted to this species (Fig. S1)—and a historical constraint may not be the only factor at
559 play behind the observed pattern. Glassfrogs' body size could be limited by their arboreal,
560 leaf-dwelling habit, with leaf surfaces acting as calling perches, oviposition sites and
561 background camouflage (Señaris & Ayarzagüena, 2005; Kubicki, 2007). Hence, body sizes
562 should be small enough so leaves can provide support and/or reduce predation risk (a topic
563 further discussed in the following section).

564 Besides developmental constrains or substrate selective pressures, the high-pitched calls
565 of some relatively large species could be an adaptation to outcompete the masking
566 interference of torrent noise. This could also contribute to the weak correlation between
567 SVL and PF. Previous studies have suggested that anurans inhabiting lotic environments
568 tend to emit calls with higher frequencies as a result of acoustic adaptation to reduce
569 interference with the constant noise produced by waterfalls and rapids (Narins *et al.*, 2004;
570 Feng *et al.*, 2006; Boonman & Kurniati, 2011; Goutte *et al.*, 2016; Röhr *et al.*, 2016; Goutte

571 *et al.*, 2017). Background noise produced by running water typically occupies the first 2.5
572 kHz of the sound spectrum (Hödl & Amézquita, 2001; Ellinger & Hödl, 2003; Narins *et al.*,
573 2004), and PF of all glassfrog species analysed here were above 2.5 kHz (around 75 % of
574 the species investigated had peak frequencies ≥ 3.5 kHz). In other words, to be heard in a
575 noisy stream a glassfrog needs to emit a relatively high pitch call and a simple solution to
576 that challenge is to be small. This implies that there should be a correlation between
577 frequency band of background noise at calling sites and peak frequency of glassfrogs. As
578 background noise data was missing for all calls analyzed, I tested associations between
579 potential torrent noise environments and PF using the terrain ruggedness index (TRI) in a
580 90 m radius around each recording site as a proxy to quantify the potential noise of torrent
581 environments. At this very coarse scale, I found no correlation between interspecific
582 variation in PF and variation in the TRI. A detailed description of data acquisition and
583 analyses involving TRI is presented in Appendix 1.

584 As some noise frequencies of torrents are more emphasized than others depending on
585 physical properties of the lotic water bodies and their margins (Narins *et al.*, 2004), future
586 studies could benefit from collecting data on the intensity and bandwidth of the background
587 noise (Schwartz & Bee, 2013; Goutte *et al.*, 2016, 2017). Additionally, as the background
588 noise naturally attenuates along its transmission path as a result of spherical propagation,
589 glassfrog species using different vertical strata of the vegetation overhanging streams
590 should be more or less prone to have their calls masked by noise produced by running water
591 (Señaris & Ayarzagüena, 2005; Kubicki, 2007). Thus, data about the height above the
592 ground occupied by recorded males, as well as standardized measurements of call
593 amplitude along the background noise gradient (Schwartz & Bee, 2013), should be
594 considered in future investigations.

595

596 **Advertisement call and calling site**

597 Glassfrogs use very similar habitats, but dissimilar calling sites (Guayasamin *et al.*,
598 2009). Several anuran species vocalize from positions that enhance the integrity of
599 information contained in acoustic signals along the transmission path (Hödl, 1977; Bailey
600 & Roberts, 1981; Penna & Solis, 1996; Lardner & bin Lakim, 2002; Muñoz & Penna,
601 2016; Schwartz *et al.*, 2016). Thus, I predicted that similar calling positions should led to
602 convergent evolution in temporal, spectral and structural traits of advertisement calls
603 because of similar selective pressures on signal transmission efficiency. However, the
604 acoustic structure of calls (i.e., whether calls contained pulsed or only tonal notes) was the
605 only acoustic trait associated with the type of calling site, which I discuss from the point of
606 view of the perceived ecological costs associated with the calling site.

607 Males that signal from the abaxial surface of leaves may emit tonal calls to minimize
608 the energetic budget, since pulsed calls potentially require more contractions of muscles
609 associated with sound production and hanging upside-down may be energetically more
610 demanding than standing on a flat surface. Alternatively, calling site could drive the
611 acoustic evolution indirectly by selection on body size, which in turn would partially
612 explain the variation in PF (as discussed previously). The ability to adhere to abaxial leaf
613 surfaces or to stand on leaves while not bending them may be limited by body mass which,
614 in anurans, is strongly correlated with the SVL (Santini *et al.*, 2018). However, I found no
615 significant differences in SVL between species that use different calling sites
616 (PHYLANOVA: $F = 1.43$; $P = 0.63$; $n = 72$), ruling out this alternative hypothesis.

617 Calling site has a high and significant phylogenetic signal ($D = 0.04$; $P_{\text{Brownian}} = 0.478$).
618 Nevertheless, since it is not associated with non-structural acoustic traits, neither with body
619 size, differences in calling sites among glassfrogs could be related to predation risk (Travis
620 *et al.*, 1985; Richards & Bull, 1990). Bats have been long recognized as sound-oriented
621 predators, eavesdropping during flight and discriminating edible anuran prey from their
622 acoustic signals (Tuttle & Ryan, 1981). A study of populations of *H. fleischmanni* found an
623 association between the presence of a frog-eating bat (*Trachops cirrhosus*) and a tendency
624 of males to call from the lower surface of leaves (Delia *et al.*, 2010). Thus, species that call
625 from the abaxial leaf surfaces may benefit from using such calling sites as shelters from
626 acoustically-oriented predators, especially those targeting for sound signals emitted at
627 specific frequency bandwidths.

628 Future work would greatly benefit from measuring the size and the resistance of leaves
629 used as calling perches by glassfrogs as well as from analyses of potential vibrational
630 responses of these leaves—for example, by means of laser doppler vibrometry (LDV)—and
631 from experimental approaches investigating the role of bats and nocturnal birds of prey as
632 glassfrog predators.

633

634 **Evolution of parental care and advertisement call**

635 Parental care by males may impose trade-offs with acoustic signaling during
636 reproduction, since both activities are energetically demanding (Townsend, 1986;
637 Prestwich, 1994; Crump, 1996). Anuran males that allocate energy to brooding have shown
638 a decrease in the emission of advertisement call, with a corresponding decrease in mate
639 attraction (Townsend, 1986). I predicted that glassfrog species with males providing
640 parental care would emit simpler and shorter calls than species with exclusive maternal

641 care. However, the association is only significant for call structure (tonal vs. pulsed notes),
642 suggesting that species in which males are involved in parental care generally produce calls
643 that demand a smaller number of muscle contractions.

644 Glassfrog species characterized by paternal care normally invest more time brooding
645 than species with exclusive maternal care (Delia *et al.*, 2017). Hence, the average time
646 invested by the male in brooding in each species could be a better (continuous) predictor of
647 associations between acoustic traits and reproductive behavior in glassfrogs. Unfortunately,
648 behavioral data of this type is currently available for fewer than ten glassfrog species (Delia
649 *et al.*, 2017). Also, the average call rate or note emission, or estimates of calling activity
650 along a particular time span, could be better descriptors of energy spent in calling by male
651 glassfrogs than call structure or call duration. Such rates could not be considered in this
652 study due to limitations of the sound recordings, which were generally too short to allow
653 their estimation.

654

655 **Tempo and mode of phenotypic evolution**

656 Evolutionary radiations, defined as the increase of taxa in a clade, have been a research
657 theme of great interest in evolutionary biology for more than a century (review in Simões *et*
658 *al.*, 2016). Typically, studies have approached evolutionary radiations by analyzing
659 morphological traits (Simões *et al.*, 2016), which relatively fewer studies having explored
660 the temporal pattern of an evolutionary radiation by assessing acoustic traits (e.g.,
661 Gonzalez-Voyer *et al.*, 2013). Here, I investigated the tempo and mode of acoustic
662 evolution in glassfrogs through analyses of trait disparity (DI and DTT, Harmon *et al.*,
663 2003).

664 Several studies have found a rapid and early increase of morphological disparity in
665 some animal clades (Foote, 1997). I found that the disparity of most acoustic traits (CD,
666 NN and FW) is partitioned within subclades, hinting at a late diversification along the
667 glassfrog radiation. Values of mean relative disparity near one indicate that subclades have
668 independently evolved to occupy similar regions of phenotypic space (Harmon *et al.*,
669 2003). Thus, glassfrog subclades could have evolved independently to occupy similar
670 regions of the acoustic space.

671 When considering the historical biogeography of Centrolenidae, a constantly increasing
672 diversity model explains best its species diversification, thus rejecting a diversity-
673 dependent cladogenesis model (Castroviejo-Fisher *et al.*, 2014). However, it also suggests
674 that environmental selection varied along the evolutionary history of this group, in
675 association with dispersal events to different biogeographic regions and elevational
676 specialization (Castroviejo-Fisher *et al.*, 2014). I found that the disparity of most acoustic
677 traits is mainly partitioned within subclades, with an increase in disparity around 10–8
678 MYA—when values of observed disparities raised above the null models' 95% confidence
679 intervals (Fig. 2). Time estimates for the onset of increasing disparity of such acoustic traits
680 coincide with 1) major changes within biogeographic areas already inhabited by ancestral
681 glassfrogs such as the main orogeny of the Andes and the formation of the modern Amazon
682 basin (Hoorn & Wesselingh, 2010); 2) the dispersal into new biogeographic areas such the
683 large radiation of Cochranellini and the colonization of the MRCA of *Teratohyla* of the
684 Amazonian lowlands and of *Celsiella* of the highlands.

685 The uplifting of the Andes and the formation of the modern Amazon basin changed the
686 tropical South American landscape dramatically and may have triggered changes in the way
687 ancestral glassfrogs vocalized. Thus, the dynamic of acoustic disparity in glassfrogs may be

688 explained by differentiation associated to adaptation to new landscapes derived by
689 geological changes. During this period of time, some clades of glassfrogs dispersed into
690 new biogeographic areas and/or expanded their elevational distributions. If vegetation
691 structure varies along elevational gradients and biogeographic regions, then the
692 specialization to certain elevations and the dispersion to new biogeographic areas may have
693 also played a key role in the observed increase in disparity in acoustic traits. Along their
694 evolution, glassfrog species had a small rate of change in their elevational range
695 distribution, and closely related extant species usually inhabit the same biogeographic area
696 (Castroviejo-Fisher *et al.*, 2014). Associations between temporal and spectral properties of
697 sound signals and the cluttering of the transmission environment by vegetation (the
698 Acoustic Adaptation Hypothesis *sensu* Morton, 1975) have been widely reported in birds
699 (Gonzalez-Voyer *et al.*, 2013; reviews in Morinay *et al.*, 2013; Wilkins *et al.*, 2013), but
700 less so in anurans (see Ey & Fisher, 2009; Erdtmann & Lima, 2013). A necessary
701 prediction to this model would be a correlation between elevational distribution of taxa and
702 the density of streamside forests. This hypothesis still needs investigation, as data on
703 streamside forest structure is lacking for the vast majority of sites (if not all) where
704 glassfrog species were recorded. The occupation of vacant acoustic spaces after dispersal
705 into new biogeographic regions, such as those following the diversification Cochranellini
706 15–10 MYA (Castroviejo-Fisher *et al.*, 2014), may be also behind the observed recent
707 boost in acoustic disparity (Fig. 2).

708 Early studies investigating morphological traits supported a rapid and early proliferation
709 of morphological diversity in some animal clades (Foote, 1997). However, my results
710 suggest that the mode of evolution for SVL, HW and PF in glassfrogs was probably
711 constant along time, in agreement to results found in some Neotropical vertebrates (e.g., in

712 *Anolis* and Phrynosomatine lizards - Harmon *et al.*, 2003). More specifically, the evolution
713 of SVL and HW agree with the BM null model, which suggests that diversification in these
714 traits could be explained by fluctuations in selection regimes (O'Meara *et al.*, 2006; Revell
715 *et al.*, 2008), rendering high values of phylogenetic signal (Revell *et al.*, 2008), as
716 effectively observed in the corresponding estimates of λ (Table 1). In contrast, the TL
717 differentiation mirrors the pattern observed in the acoustic variables CD, NN and BW,
718 which occurred more recently in the radiation of the group, hinting at a recent change of
719 selection regime on locomotion, potentially triggered by past environmental changes or by
720 dispersals into new areas.

721 The temporal pattern of evolution can differ between traits of dissimilar nature due to
722 evolutionary contingency or due to different selection regimes acting upon the evolution of
723 each trait. Traits directly involved in mate choice are often under directional selection,
724 whereas traits that are not involved in mate choice could be under stabilizing, disruptive or
725 directional selection (Ridley, 2004; Coyne & Orr, 2004; Gonzalez-Voyer & Kolm, 2011).
726 Examples derived from studies with Tanganyikan cichlids (Gonzalez-Voyer & Kolm,
727 2011) found that disparity in ecological characters (e.g., diet, habitat) was concentrated
728 early in the species radiation, whereas disparity in sexual characters (e.g., mating system,
729 sexual size dimorphism) remained high throughout the evolutionary history of this group.
730 In centrolenids, call traits seem to have diversified within a limited phenotypic space in
731 early stages of the evolutionary history of glassfrogs, such that distant clades independently
732 colonized similar regions of the acoustic space. Explanations for differences in the tempo of
733 evolution of sexual traits among different vertebrate groups could stem from ecological
734 opportunities being available at different historical periods, what has been invoked to
735 explain the tempo and mode of evolution in some morphological traits (Harmon *et al.*,

736 2003). Otherwise, distinct pattern of disparity found among exclusively sexual and other
737 traits may reflect differences in ecological, physiological or genetic constraints.

738

739 **Conclusions**

740 Although this study is the most comprehensive investigation on anuran call evolution at the
741 family level considering the available coverage of species and acoustic data sampling, one
742 cannot help but notice the need for more data as outlined in the Discussion to test some
743 competing hypotheses. It is not only the amount of data which is important but its quality.
744 The vast majority of analyzed recordings follow quality standards for taxonomic studies
745 (Khöler *et al.*, 2017) and are of limited use for evolutionary ecology studies. Nonetheless,
746 my results allow the appreciation of a general scenario, providing a theoretical background
747 for these tests. In this model variation in PF and CS have key relationships with body size,
748 calling position, and parental care. I speculate that variation in PF has been influenced by
749 adaptation to torrent noise and limitation in body size range, mediated by predation risk and
750 other ecological pressures which selected for small animals. Regarding CS, I postulate that
751 the energetic costs associated with dangling upside-down on leaves and with parental care
752 by males limit their ability to produce complex, amplitude modulated calls. I hypothesize
753 that the tempo of acoustic evolution in glassfrogs could be mainly explained by
754 differentiation associated with the occupation of new habitats (vacant acoustic spaces).
755 Finally, future work could also focus on the role of selection by females in shaping
756 advertisement call evolution in glassfrogs, as experimental data on this key factor is scarce.

757

758

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777

778 **References**

779 Bailey, W.J. & Roberts, J.D. 1981. The bioacoustics of the burrowing frog *Heleioporus*
780 (Leptodactylidae). *J. Nat. Hist.* **15**: 693–702.

- 781 Barnard, C.J. 2004. *Animal Behaviour: Mechanism, Development, Function and Evolution*.
782 Pearson, London.
- 783 Bioacoustics Research Program. 2011. Raven Pro: Interactive Sound Analysis Software
784 (Version 1.4) [Computer software]. Ithaca, NY: The Cornell Lab of Ornithology.
785 Available from <http://www.birds.cornell.edu/raven>.
- 786 Blair, F. 1958. Mating call in the speciation of anuran amphibians. *Am. Nat.* **92**: 27–51.
- 787 Blomberg, S.P., Garland Jr, T. & Ives, A.R. 2003. Testing for phylogenetic signal in
788 comparative data: behavioral traits are more labile. *Evolution* **57**: 717–745.
- 789 Boonman, A. & Kurniati, H. 2011. Evolution of high-frequency communication in frogs.
790 *Evol. Ecol. Res.* **13**: 197–207.
- 791 Cannatella, D.C., Hillis, D.M., Chippindale, P.T., Weigt, L., Rand, A.S. & Ryan, M.J.
792 1998. Phylogeny of frogs of the *Physalaemus pustulosus* species group, with an
793 examination of data incongruence. *Syst. Biol.* **47**: 311–335.
- 794 Castroviejo-Fisher, S., Guayasamin, J.M., Gonzalez-Voyer, A. & Vilà, C. 2014.
795 Neotropical diversification seen through glassfrogs. *J. Biogeogr.* **41**: 66–80.
- 796 Cisneros-Heredia, D.F. & McDiarmid, R.W. 2007. Revision of the characters of
797 Centrolenidae (Amphibia: Anura: Athesphatanura), with comments on its taxonomy
798 and the description of new taxa of glassfrogs. *Zootaxa* **1572**: 1–82.
- 799 Croft, R.B. & Ryan, M.J. 1995. Patterns of advertisement call evolution in toads and
800 chorus frogs. *Anim. Behav.* **49**: 283–303.
- 801 Coyne, J.A. & Orr, H.A. 2004. *Speciation*. Sinauer, Sunderland, MA.
- 802 Crump, M.L. 1996. Parental care among the Amphibia. *Adv. Study Behav.* **25**: 109–144.

803 Delia, J., Cisneros-Heredia, D.F., Whitney, J. & Murrieta-Galindo, R. 2010. Observations
804 on the reproductive behavior of a Neotropical glassfrog, *Hyalinobatrachium*
805 *fleischmanni* (Anura: Centrolenidae). *S. Am. J. Herpetol.* **5**: 1–12.

806 Delia, J., Bravo-Valencia, L. & Warkentin, K.M. 2017. Patterns of parental care in
807 Neotropical glassfrogs: fieldwork alters hypotheses of sex-role evolution. *J. Evol. Biol.*
808 **30**: 898–914.

809 Duellman, W.E. & Trueb, L. 1986. *Biology of amphibians*. The John Hopkins University
810 press, Baltimore.

811 Ellinger, N. & Hödl, W. 2003. Habitat acoustics of a neotropical lowland
812 rainforest. *Bioacoustics* **13**: 297–321.

813 Emerson, S.B. 1978. Allometry and jumping in frogs: helping the twain to meet. *Evolution*
814 **32**: 551–564.

815 Emerson, S.B. 1985. Skull shape in frogs: correlations with diet. *Herpetologica* **41**: 177–
816 188.

817 Emerson, S.B. 1991. The ecomorphology of Bornean tree frogs (family Rhacophoridae).
818 *Zool. J. Linn. Soc.* **101**: 337–357.

819 Erdtmann, L.K. & Lima, A.P. 2013. Environmental effects on anuran call design: what we
820 know and what we need to know. *Ethol. Ecol. Evol.* **25**: 1–11.

821 Erdtmann, L. & Amézquita, A. 2009. Differential evolution of advertisement call traits in
822 dart-poison frogs (Anura: Dendrobatidae). *Ethology* **115**: 801–811.

823 Ey, E. & Fischer, J. 2009. The “Acoustic Adaptation Hypothesis”—a review of the
824 evidence from birds, anurans and mammals. *Bioacoustics* **19**: 21–48.

825 Felsenstein, J. 1985. Phylogenies and the comparative method. *Am. Nat.* **125**: 1–15.

826 Feng, A.S., Narins, P.M., Xu, C.H., Lin, W.Y., Yu, Z.L., Qiu, Q. *et al.* 2006. Ultrasonic
827 communication in frogs. *Nature* **440**: 333–336.

828 Foote, M. 1997. The evolution of morphological diversity. *Annu. Rev. Ecol. Syst.* **28**: 129–
829 152.

830 Freckleton, R.P. 2009. The seven deadly sins of comparative analysis. *J. Evol. Biol.* **22**:
831 1367–1375.

832 Fritz, S.A. & Purvis, A. 2010. Selectivity in mammalian extinction risk and threat types: a
833 new measure of phylogenetic signal strength in binary traits. *Conserv. Biol.* **24**: 1042–
834 1051.

835 Frost, D.R. 2018. Amphibian Species of the World: an Online Reference. Version 6.0 (05-
836 12-2018). Electronic Database accessible at [http://research.amnh.org/herpetology/
837 amphibia/index.html](http://research.amnh.org/herpetology/amphibia/index.html). American Museum of Natural History, New York, USA.

838 Gerhardt, H.C. & Klump, G.M. 1988. Masking of acoustic signals by the chorus
839 background noise in the green tree frog: a limitation on mate choice. *Animal Behav.*
840 **36**: 1247–1249.

841 Gerhardt, H.C. & Huber, F. 2002. *Acoustic communication in insects and anurans:*
842 *Common problems and diverse solutions*. University of Chicago Press, Chicago.

843 Gingras, B., Boeckle, M., Herbst, C.T. & Fitch, W.T. 2013a. Call acoustics reflect body
844 size across four clades of anurans. *J. Zool.* **289**: 143–150.

845 Gingras, B., Mohandesan, E., Boko, D. & Fitch, W.T. 2013b. Phylogenetic signal in the
846 acoustic parameters of the advertisement calls of four clades of anurans. *BMC Evol.*
847 *Biol.* **13**: 134.

848 Goicoechea, N., De La Riva, I. & Padial, J.M. 2010. Recovering phylogenetic signal from
849 frog mating calls. *Zool. Scr.* **39**: 141–154.

850 Gonzalez-Voyer, A. & Kolm, N. 2011. Rates of phenotypic evolution of ecological
851 characters and sexual traits during the Tanganyikan cichlid adaptive radiation. *J. Evol.*
852 *Biol.* **24**: 2378–2388.

853 Gonzalez-Voyer, A., Padial, J.M., Castroviejo-Fisher, S., De La Riva, I. & Vilà, C. 2011.
854 Correlates of species richness in the largest Neotropical amphibian radiation. *J. Evol.*
855 *Biol.* **24**: 931–942.

856 Gould, S.J. 1980. The evolutionary biology of constraint. *Daedalus*: 39–52.

857 Goutte, S., Dubois, A., Howard, S.D., Márquez, R., Rowley, J.J., Dehling, J.M. *et al.* 2017.
858 How the environment shapes animal signals: a test of the Acoustic Adaptation
859 Hypothesis in frogs. *J. Evol. Biol.* **31**: 148–158.

860 Goutte, S., Dubois, A., Howard, S.D., Marquez, R., Rowley, J.J., Dehling, J.M. *et al.* 2016.
861 Environmental constraints and call evolution in torrent-dwelling frogs. *Evolution* **70**:
862 811–826.

863 Grafen, A. 1989. The phylogenetic regression. *Phil. Trans. R. Soc. Lond. B* **326**: 119–157.

864 Guayasamin, J.M., Varela-Jaramillo, A. & Frenkel, C. 2018. *Centrolene geckoideum* In:
865 Ron, S.R., Yanez-Muñoz, M.H., Merino-Viteri, A. Ortiz, D.A. (Eds). Anfibios del
866 Ecuador. Version 2018.0. Museo de Zoología, Pontificia Universidad Católica del
867 Ecuador. [https://bioweb.bio/faunaweb/amphibiaweb/FichaEspecie/Centrolene%20geck](https://bioweb.bio/faunaweb/amphibiaweb/FichaEspecie/Centrolene%20geckoideum)
868 [oideum](https://bioweb.bio/faunaweb/amphibiaweb/FichaEspecie/Centrolene%20geckoideum). Date of access: 7 june, 2018.

869 Guayasamin, J.M., Castroviejo-Fisher, S., Trueb, L., Rada, M. & Vila, C. 2009.
870 Phylogenetic systematics of Glassfrogs (Amphibia: Centrolenidae) and their sister
871 taxon *Allophryne ruthveni*. *Zootaxa* **2100**: 1–97.

872 Harvey, P. H. & Pagel, M.D. 1991. *The comparative method in evolutionary biology*.
873 Oxford university press.

- 874 Harmon, L.J., Schulte, J.A., Larson, A. & Losos, J.B. 2003. Tempo and mode of
875 evolutionary radiation in iguanian lizards. *Science* **301**: 961–964.
- 876 Harmon, L.J., Weir, J.T., Brock, C.D., Glor, R.E. & Challenger, W. 2007. GEIGER:
877 investigating evolutionary radiations. *Bioinformatics* **24**: 129–131.
- 878 Ho, L.S.T. & Ane, C. 2014. A linear-time algorithm for Gaussian and non-Gaussian trait
879 evolution models. *Syst. Biol.* **63**: 397–408.
- 880 Hödl, W. & Amézquita, A. 2001. Visual signaling in anuran amphibians. In: *Anuran*
881 *communication*, (M.J. Ryan, ed.). pp. 121–141. Smithsonian Inst. Press, Washington.
- 882 Hödl, W. 1977. Call differences and calling site segregation in anuran species from Central
883 Amazonian floating meadows. *Oecologia* **28**: 351–363.
- 884 Hoorn, C. & Wesselingh, F. 2010. *Amazonia: landscape and species evolution: a look into*
885 *the past*. John Wiley & Sons, Chichester.
- 886 Kime, N.M., Turner, W.R. & Ryan, M.J. 2000. The transmission of advertisement calls in
887 Central American frogs. *Behav. Ecol.* **11**: 71–83.
- 888 Köhler, J., Jansen, M., Rodríguez, A., Kok, P.J.R., Toledo, L.F., Emmrich, M. *et al.* 2017.
889 The use of bioacoustics in anuran taxonomy: Theory, terminology, methods and
890 recommendations for best practice. *Zootaxa* **4251**: 1–124.
- 891 Kubicki, B. 2007. *Glass frogs*. Editorial INBio, Santo Domingo de Heredia.
- 892 Lardner, B. & bin Lakim, M. 2002. Animal communication: Tree-hole frogs exploit
893 resonance effects. *Nature* **420**: 475.
- 894 Morinay, J., Cardoso, G.C., Doutrelant, C. & Covas, R. 2013. The evolution of birdsong on
895 islands. *Ecol. Evol.* **3**: 5127–5140.
- 896 Morton, E.S. 1975. Ecological sources of selection on avian sounds. *Am. Nat.* **109**: 17–34.

897 Muñoz, M.I. & Penna, M. 2016. Extended amplification of acoustic signals by amphibian
898 burrows. *J. Comp. Physiol. A* **202**: 473–487.

899 Narins, P.M., Feng, A.S., Lin, W., Schnitzler, H.U., Denzinger, A., Suthers, R.A. & Xu, C.
900 2004. Old World frog and bird vocalizations contain prominent ultrasonic harmonics.
901 *J. Acoust. Soc. Am.* **115**: 910–913.

902 O'Meara, B.C., Ané, C., Sanderson, M J. & Wainwright, P.C. 2006. Testing for different
903 rates of continuous trait evolution using likelihood. *Evolution* **60**: 922–933.

904 Orme, D., Freckleton, R., Thomas, G., Petzoldt, T., Fritz, S., Isaac, N. & Pearse, W. 2013.
905 Caper: Comparative Analyses of Phylogenetics and Evolution in R. R package version
906 0.5.2. <https://CRAN.R-project.org/package=caper>

907 Pagel, M. 1999. Inferring the historical patterns of biological evolution. *Nature* **401**: 877–
908 884.

909 Panhuis, T. M., Butlin, R., Zuk, M. & Tregenza, T. 2001. Sexual selection and speciation.
910 *Trends Ecol. Evol.* **16**: 364–371.

911 Paradis, E., Claude J. & Strimmer K. 2004. APE: analyses of phylogenetics and evolution
912 in R language. *Bioinformatics* **20**: 289–290.

913 Paradis, E. 2014. An introduction to the phylogenetic comparative method. In: *Modern*
914 *Phylogenetic Comparative Methods and their application in Evolutionary Biology.*
915 *Concepts and practice* (L.Z. Garamszegi, ed.), pp. 3–18. Springer, London. DOI:
916 10.1007/978-3-662-43550-2_1

917 Penna, M. & Solís, R. 1996. Influence of burrow acoustics on sound reception by frogs
918 *Eupsophus* (Leptodactylidae). *Animal Behav.* **51**: 255–263.

919 Prestwich, K.N. 1994. The energetics of acoustic signaling in anurans and insects. *Am.*
920 *Zool.* **34**: 625–643.

921 R Core Team. 2017. R: A language and environment for statistical computing. R
922 Foundation for Statistical Computing, Vienna, Austria. URL [https://www.R-](https://www.R-project.org/)
923 [project.org/](https://www.R-project.org/)

924 Revell, L.J., Harmon, L.J. & Collar, D.C. 2008. Phylogenetic signal, evolutionary process,
925 and rate. *Syst. Biol.* **57**: 591–601.

926 Revell, L.J. 2012. Phytools: an R package for phylogenetic comparative biology (and other
927 things). *Methods Ecol. Evol.* **3**: 217–223.

928 Richards, S.J. & Bull, C.M. 1990. Size-limited predation on tadpoles of three Australian
929 frogs. *Copeia*: 1041–1046.

930 Ridley, M. 2004. *Evolution*. 3rd edition. Blackwell, Malden.

931 Röhr, D.L., Paterno, G.B., Camurugi, F., Juncá, F.A. & Garda, A.A. 2016. Background
932 noise as a selective pressure: stream-breeding anurans call at higher frequencies. *Org.*
933 *Divers. Evol.* **16**: 269–273.

934 Ryan, M.J. & Kime, N.M. 2003. Selection on long-distance acoustic signals. In: *Acoustic*
935 *communication* (A.M., Simmons, Popper, A., Fay, R., eds.), pp. 225–274. Springer,
936 New York.

937 Ryan, M.J. 1988. Constraints and patterns in the evolution of anuran acoustic
938 communication. In: *The Evolution of the Amphibian Auditory System* (B. Fritzschn,
939 Ryan, M.J., Wilczynski, W., Hetherington, T.E. & Walkowiak, W., eds.), pp. 637–677.
940 John Wiley, New York.

941 Santini, L., Benítez-López, A., Ficetola, G.F. & Huijbregts, M.A.J. 2018. Length–mass
942 allometries in amphibians. *Integr. Zool.* **13**: 36–45.

943 Santos, J.C., Baquero, M., Barrio-Amorós, C., Coloma, L.A., Erdtmann, L.K., Lima, A.P.
944 & Cannatella, D.C. 2014. Aposematism increases acoustic diversification and
945 speciation in poison frogs. *Proc. Royal Soc. Lond. B: Biol. Sci.* **281**: 20141761.

946 Schwartz, J.J., Huncce, R., Lentine, B. & Powers, K. 2016. Calling site choice and its impact
947 on call degradation and call attractiveness in the gray treefrog, *Hyla versicolor*. *Behav.*
948 *Ecol. Sociobiol.* **70**: 1–19.

949 Schwartz, J.J. & Bee, M.A. 2013. Anuran acoustic signal production in noisy
950 environments. In: *Animal communication and noise* (H. Brumm, ed.). pp. 91–132.
951 Springer, Berlin, Heidelberg.

952 Señaris, J.C. & Ayarzagüena, J. 2005. *Revisión taxonómica de la familia Centrolenidae*
953 *(Amphibia; Anura) de Venezuela*. Comité Español del programa MaB y de la red
954 IberoMaB de la UNESCO, Madrid.

955 Simões, M., Breitkreuz, L., Alvarado, M., Baca, S., Cooper, J. C., Heins, L., *et al.* 2016.
956 The evolving theory of evolutionary radiations. *Trends Ecol. Evol.* **31**: 27–34.

957 Smith, J.M., Burian, R., Kauffman, S., Alberch, P., Campbell, J., Goodwin, B. *et al.* 1985.
958 Developmental constraints and evolution: a perspective from the Mountain Lake
959 conference on development and evolution. *Q. Rev. Biol.* **60**: 265–287.

960 Stearns, S.C. 1986. Natural selection and fitness, adaptation and constraint. In: *Patterns*
961 *and Processes in the History of Life* (Raup, D.M. & Jablonsky, D., eds.), pp. 23–44.
962 Springer, Berlin, Heidelberg.

963 Symonds, M.R. & Blomberg, S.P. 2014. A primer on phylogenetic generalised least
964 squares. In: *Modern phylogenetic comparative methods and their application in*

965 *evolutionary biology* (L.Z. Garamszegi, ed.). pp. 105–130. Springer, Berlin,
966 Heidelberg.

967 Tobias, M., Evans, B.J. & Kelley, D.B. 2011. Evolution of advertisement calls in African
968 clawed frogs. *Behaviour* **148**: 519–549.

969 Toft, C.A. 1980. Feeding ecology of thirteen syntopic species of anurans in a seasonal
970 tropical environment. *Oecologia* **45**: 131–141.

971 Toft, C.A. 1981. Feeding ecology of Panamanian litter anurans: patterns in diet and
972 foraging mode. *J. Herpetol.*: 139–144.

973 Townsend, D.S. 1986. The costs of male parental care and its evolution in a neotropical
974 frog. *Behav. Ecol. Sociobiol.* **19**: 187–195.

975 Travis, J., Keen, W.H. & Juilianna, J. 1985. The role of relative body size in a predator-
976 prey relationship between dragonfly naiads and larval anurans. *Oikos*: 59–65.

977 Tuttle, M.D. & Ryan, M.J. 1981. Bat predation and the evolution of frog vocalizations in
978 the neotropics. *Science* **214**: 677–678.

979 Vargas-Salinas, F. & Amézquita, A. 2014. Abiotic noise, call frequency and stream-
980 breeding anuran assemblages. *Evol. Ecol.* **28**: 341–359.

981 Vences, M. & Wake, D. 2007. Speciation, species boundaries and phylogeography of
982 amphibians. In: *Amphibian Biology*, Volume 7 (H., Heatwole & Tyler, M, eds.), pp.
983 2613–2671. Surrey Beatty and Sons, Chipping Norton, Australia.

984 Wells, K.D. 1977. The social behaviour of anuran amphibians. *Animal Behav.* **25**: 666–693.

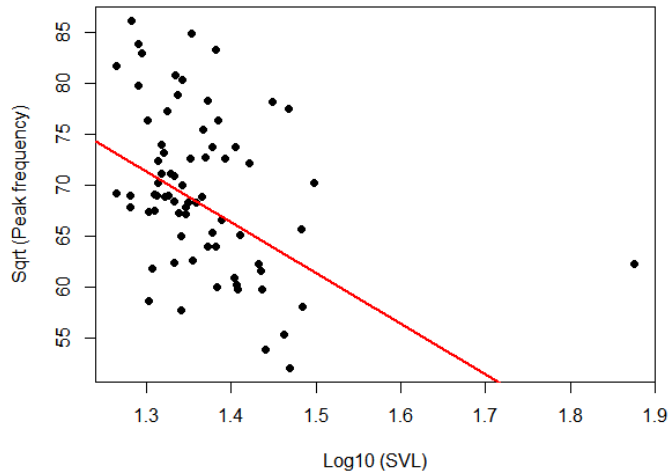
985 Wells, K.D. 2007. *The ecology and behavior of amphibians*. University of Chicago Press,
986 Chicago.

987 Wenzel, J.W. 1992. Behavioral homology and phylogeny. *Annu. Rev. Ecol. Syst.* **23**: 361–
988 381.

- 989 Wheeler, W.C. 2012. *Systematics: A course of lectures*. John Wiley & Sons, Chichester.
- 990 Wilkins, M.R., Seddon, N. & Safran, R.J. 2013. Evolutionary divergence in acoustic
991 signals: causes and consequences. *Trends Ecol. Evol.* **28**: 156–66.
- 992 Wollenberg, K.C., Glaw, F., Meyer, A. & Vences, M. 2007. Molecular phylogeny of
993 Malagasy reed frogs, *Heterixalus*, and the relative performance of bioacoustics and
994 color-patterns for resolving their systematics. *Mol. Phylogenetics Evol.* **45**: 14–22.
- 995 Zug, G.R. 1978. Anuran locomotion: structure and function. 2. Jumping performance of
996 semiaquatic, terrestrial, and arboreal frogs. *Smiths. Contrib. Zool.* **276**: 1–31.
- 997 Zweifel, R.G. 1968. Effects of temperature, body size, and hybridization on mating calls of
998 toads, *Bufo a. americanus* and *Bufo woodhousii fowleri*. *Copeia* **1968**: 269–285.

Supplementary materials

Figure S1. Relationships between square-root of peak frequency and \log_{10} of snout-vent length (SVL) for Centrolenidae ($n = 72$). Each dot represents the average value for each species; the red line represents the fitted PGLS model. See Table 1 for details of the PGLS model.



Appendix 1

The evolution of the advertisement call in Glassfrogs (Centrolenidae Taylor, 1951)

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Association between the terrain ruggedness index and call traits

Most centrolenids habit in the Andes (Hutter et al., 2013), associated to lotic environments (Señaris & Ayarzagüena, 2005). When running on sloped terrain, streams can turn into torrents or waterfalls, producing background noise with sound energy normally peaking on the lower frequency spectrum— mainly around 2.5 kHz (Hödl & Amézquita, 2001; Ellinger & Hödl, 2003; Narins et al., 2004). Some anurans that inhabit lotic environments utter calls with higher frequency, thus potentially reducing the masking interference of background noise (Narins et al., 2004; Feng et al., 2006; Boonman & Kurniati, 2011; Goutte et al., 2016, 2017), and calls with shorter notes and narrower frequency bandwidth (Dubois & Martens, 1984; Goutte et al., 2017). I tested the prediction that the advertisement calls of glassfrogs inhabiting areas with greater topographical variation are shorter, with higher dominant frequencies, and narrower frequency bandwidths.

Methods

I considered the Terrain Ruggedness Index (TRI) as a proxy of the occurrence of potentially noisy streamside environments. The TRI is an objective quantitative measure of the topographic heterogeneity that calculates the sum change in elevation between a grid cell and its eight neighbour grid cells in a digital elevation model (Riley et al., 1999). The presence of waterfalls and fast-flowing streams is expected to be more associated with rugged terrains (high TRI values) than with flat landscapes (low TRI values). Unfortunately, testing associations between TRI and amplitude of the vocalizations (as measured in dB or any descriptor of sound pressure) is hindered by differences in recording procedures and sound equipment among authors of the recordings.

The mean TRI per species was calculated based on the individual values obtained for the localities where the audio recordings were conducted. Geographic coordinates of recording localities were provided by the authors of the recordings or obtained from the literature. In some cases, the localities were georeferenced in Google Earth 7.1.8.3036 (Google Inc. 2017) (Dataset S2). I retrieved the TRI values using the Raster Terrain Analysis plugin as implemented in QGIS v 2.18.7 (Quantum GIS Development Team, 2016) with the available digital elevation model of the NASA Shuttle Radar Topographic Mission (SRTM) with 90 m resolution (Jarvis et al., 2008). The TRI values for recordings with imprecise localities (Dataset S2) were determined as the mean of the TRIs of localities reported for those species in the country from where recordings proceeded (Dataset S3).

Results

The potential presence of noisy streamside environments (as assessed by the TRI) was not associated with interspecific variation in acoustic traits (Table A1). The analysis considering peak frequency of calls as the dependent variable retrieved a marginally significant model, although the variance explained was modest, at best ($P = 0.05$; $\beta = -0.775$; $R^2 = 0.053$). These results are against my predictions, which suggest that topographic characteristics of the breeding habitat of glassfrogs and call traits (call duration, peak frequency, and bandwidth frequency) apparently did not evolve in adaptation to torrent noise.

Table A1. Phylogenetic generalized least squares models of associations between call traits of glassfrogs and the terrain ruggedness index (TRI), which is here used as a proxy to the potential existence of noisy streamside environments, for Centrolenidae. Asterisks (*) indicate significant correlations.

	N	$\beta \pm SE$	t value	P value
Log 10 (Call duration)	72			
Lambda value = 0.14				
$R^2 = 0.004$				
Intercept		-0.674 ± 0.216	- 3.111	0.003
TRI		-0.013 ± 0.025	- 0.495	0.622
Sqrt (Peak frequency)	72			
Lambda value = 0.23				
$R^2 = 0.053$				
Intercept		73.136 ± 3.553	20.586	$< 2 \times 10^{-16}$
TRI		-0.775 ± 0.394	- 1.966	0.053
Sqrt (Bandwidth frequency)	64			
Lambda value = 0.82				

R² = 0.026

Intercept	31.880 ± 2.428	13.129	< 2 × 10 ⁻¹⁶
TRI	- 0.246 ± 0.193	1.278	0.206

References

- Boonman, A. & Kurniati, H. 2011. Evolution of high-frequency communication in frogs. *Evol. Ecol. Res.* **13**: 197–207.
- Dubois, A. & Martens, J. 1984. A case of possible vocal convergence between frogs and a bird in Himalayan torrents. *J. Ornithol.* **125**: 455–463.
- Ellinger, N. & Hödl, W. 2003. Habitat acoustics of a neotropical lowland rainforest. *Bioacoustics* **13**: 297–321.
- Feng, A.S., Narins, P.M., Xu, C.H., Lin, W.Y., Yu, Z.L., Qiu, Q. *et al.* 2006. Ultrasonic communication in frogs. *Nature* **440**: 333–336.
- Goutte, S., Dubois, A., Howard, S.D., Márquez, R., Rowley, J.J., Dehling, J.M. *et al.* 2017. How the environment shapes animal signals: a test of the Acoustic Adaptation Hypothesis in frogs. *J. Evol. Biol.* **31**: 148–158.
- Goutte, S., Dubois, A., Howard, S.D., Marquez, R., Rowley, J.J., Dehling, J.M. *et al.* 2016. Environmental constraints and call evolution in torrent-dwelling frogs. *Evolution* **70**: 811–826.
- Hödl, W. & Amézquita, A. 2001. Visual signaling in anuran amphibians. In: *Anuran communication*, (M.J. Ryan, ed.). pp. 121–141. Smithsonian Inst. Press, Washington.

- Hutter, C.R., Guayasamin, J.M. & Wiens, J.J. 2013. Explaining Andean megadiversity: the evolutionary and ecological causes of glassfrog elevational richness patterns. *Ecol. lett.* **16**: 1135–1144.
- Jarvis, A., Reuter, H.I., Nelson, A. & Guevara, E. 2008. Hole-filled SRTM for the globe, version 4. Available from the CGIAR-CSI SRTM 90m Database (<http://srtm.csi.cgiar.org>).
- Narins, P.M., Feng, A.S., Lin, W., Schnitzler, H.U., Denzinger, A., Suthers, R.A. & Xu, C. 2004. Old World frog and bird vocalizations contain prominent ultrasonic harmonics. *J. Acoust. Soc. Am.* **115**: 910–913.
- QGIS Development Team. 2016. QGIS Geographic Information System. Open Source Geospatial Foundation Project. <http://qgis.osgeo.org>
- Riley, S., DeGloria, S. & Elliot, R. 1999. A terrain ruggedness index that quantifies topographic heterogeneity. *Intermt. J. Sci.* **5**: 23–27.
- Señaris, J.C. & Ayarzagüena, J. 2005. Revisión taxonómica de la familia Centrolenidae (Amphibia; Anura) de Venezuela. Comité Español del programa MaB y de la red IberoMaB de la UNESCO, Madrid.

Dataset S1. Sound recordings analyzed per species, with the corresponding authorship, locality, and coordinates with its source.

Species	Code (track_name)	Autorship	Locality	Lat	Long	Coordinates source
<i>Celsiella vozmedianoii</i>	2_V4b_04	Santiago Castroviejo-Fisher	Venezuela: Sucre: Cerro El Humo	10.69964	-62.61669	Santiago Castroviejo-Fisher
<i>Centrolene altitudinale</i>	9_V1_04	Santiago Castroviejo-Fisher	Venezuela: Mérida: Río Albarregas (2090-2140 m)	8.63080	-71.16075	Georeferenced from Google Earth
<i>Centrolene ballux</i>	Fonozoo 186-7942	W. E. Duellman	Ecuador: Pichincha: 14 km W Chiriboga	-0.23137	-78.89448	Georeferenced from Google Earth
<i>Centrolene buckleyi</i>	Fonozoo 185-7909	W. E. Duellman	Ecuador: Loja: Abra de Zamora, 13 km E Loja	-3.99340	-79.14379	Coordinates from AmphibiaWebEcuador (QCAZ 11330) (http://zoologia.puce.edu.ec/Vertebrados/anfibios/Mapa.aspx?Id=1493)
<i>Centrolene buckleyi</i>	Fonozoo 185-7910	W. E. Duellman	Ecuador: Pichincha: 14 km W Chiriboga,	-0.23137	-78.89448	Georeferenced from Google Earth
<i>Centrolene buckleyi</i>	Fonozoo 185-7911	W. E. Duellman	Ecuador: Loja: Abra de Zamora, 13 km E Loja	-3.99340	-79.14379	Coordinates from AmphibiaWebEcuador (QCAZ 11330) (http://zoologia.puce.edu.ec/Vertebrados/anfibios/Mapa.aspx?Id=1493)
<i>Centrolene condor</i>	002Centrolene condor16032007	Ana Almendariz	Ecuador: Zamora Chinchipe: Paquisha, Paquisha Alto, 2270 m	-3.89605	-78.47668	Almendariz & Batallas 2012
<i>Centrolene daidaleum</i>	Centrolene daidaleum 1ra Qda Las Antenas 12-07-2008	Fernando Rojas-Runjaic	Venezuela: Zulia: Cerro Las Antenas, cuenca del río Lajas, 1430 m	10.34345	-72.56141	Rojas-Runjaic et al. 2012
<i>Centrolene daidaleum</i>	Centrolene daidaleum 1ra Qda Las Antenas 13-07-2008	Fernando Rojas-Runjaic	Venezuela: Zulia: Cerro Las Antenas, cuenca del río Lajas, 1430 m	10.34345	-72.56141	Rojas-Runjaic et al. 2012
<i>Centrolene daidaleum</i>	Centrolene daidaleum Las Antenas 03-2008	Fernando Rojas-Runjaic	Venezuela: Zulia: Cerro Las Antenas, cuenca del río Lajas, 1430 m	10.34345	-72.56141	Rojas-Runjaic et al. 2012
<i>Nymphargus grandisone</i>	Fonozoo 167	Morley Read	Ecuador: ?	?	?	Coordinates from records in GBIF
<i>Nymphargus grandisone</i>	Fonozoo 8124	W. E. Duellman	Ecuador: Pichincha: 4 km N Dos Rios, 1140 m	-0.30526	-78.88081	Coordinates from AmphibiaWebEcuador (QCAZA49925) (http://zoologia.puce.edu.ec/vertebrados/anfibios/Mapa.aspx?Id=1215)
<i>Nymphargus grandisone</i>	Fonozoo 8175	W. E. Duellman	Ecuador: Pichincha: 4 km N Dos Rios, 1140 m	-0.30526	-78.88081	Coordinates from AmphibiaWebEcuador (QCAZA49925) (http://zoologia.puce.edu.ec/vertebrados/anfibios/Mapa.aspx?Id=1215)
<i>Nymphargus grandisone</i>	LS100030_Ng	Ana Salgado	Ecuador: Pichincha: Reserva Las Gralarias, Lucy's creek	0.00400	78.73800	Ana Salgado

Dataset S1. Continued.

Species	Code (track_name)	Autorship	Locality	Lat	Long	Coordinates source
<i>Centrolene heloderma</i>	Fonozoo 158-7135	W. E. Duellman	Ecuador: Pichincha: 14 km W Chiriboga	-0.23137	-78.89448	Georeferenced from Google Earth
<i>Centrolene lynchi</i>	ALS013	Ana Salgado	Ecuador: Pichincha: Reserva Las Gralarias, 1800-2050 m	-0.01697	-78.73334	Maldonado 2012
<i>Centrolene lynchi</i>	LS100018	Ana Salgado	Ecuador: Pichincha: Reserva Las Gralarias, 1800-2050 m	-0.01697	-78.73334	Maldonado 2012
<i>Centrolene lynchi</i>	LS100020	Ana Salgado	Ecuador: Pichincha: Reserva Las Gralarias, 1800-2050 m	-0.01697	-78.73334	Maldonado 2012
<i>Centrolene lynchi</i>	LS100029	Ana Salgado	Ecuador: Pichincha: Reserva Las Gralarias, 1800-2050 m	-0.01697	-78.73334	Maldonado 2012
<i>Centrolene lynchi</i>	Centrolene_lynchi (QCAZ_Ana Salgado)	Ana Salgado	Ecuador: Pichincha: Reserva Las Gralarias, 1800-2050 m	-0.01697	-78.73334	Maldonado 2012
<i>Centrolene peristictum</i>	ALS002	Ana Salgado	Ecuador: Pichincha: Reserva Las Gralarias, 1800-2050 m	-0.01697	-78.73334	Maldonado 2012
<i>Centrolene peristictum</i>	ALS014	Ana Salgado	Ecuador: Pichincha: Reserva Las Gralarias, 1800-2050 m	-0.01697	-78.73334	Maldonado 2012
<i>Centrolene peristictum</i>	ALS015	Ana Salgado	Ecuador: Pichincha: Reserva Las Gralarias, 1800-2050 m	-0.01697	-78.73334	Maldonado 2012
<i>Centrolene peristictum</i>	ALS017X	Ana Salgado	Ecuador: Pichincha: Reserva Las Gralarias, 1800-2050 m	-0.01697	-78.73334	Maldonado 2012
<i>Centrolene peristictum</i>	ALS019	Ana Salgado	Ecuador: Pichincha: Reserva Las Gralarias, 1800-2050 m	-0.01697	-78.73334	Maldonado 2012

Dataset S1. Continued.

Species	Code (track_name)	Autorship	Locality	Lat	Long	Coordinates source
<i>Centrolene peristictum</i>	ALS020	Ana Salgado	Ecuador: Pichincha: Reserva Las Gralarias, 1800-2050 m	-0.01697	-78.73334	Maldonado 2012
<i>Centrolene sabini</i>	Coc28m21-99(1)	Alessandro Catenazzi	Peru: Cusco: near Esperanza, upper Manu National Park, 2805 m	-13.17717	-71.60894	Catenazzi et al. 2009
<i>Centrolene sabini</i>	Coc28m21-99(2)	Alessandro Catenazzi	Peru: Cusco: near Esperanza, upper Manu National Park, 2805 m	-13.17717	-71.60894	Catenazzi et al. 2009
<i>Centrolene sabini</i>	Coc28m21-99(3)	Alessandro Catenazzi	Peru: Cusco: near Esperanza, upper Manu National Park, 2805 m	-13.17717	-71.60894	Catenazzi et al. 2009
<i>Centrolene sabini</i>	Coc28m21-99(5)	Alessandro Catenazzi	Peru: Cusco: near Esperanza, upper Manu National Park, 2805 m	-13.17717	-71.60894	Catenazzi et al. 2009
<i>Centrolene savagei</i>	Macho4Yotoco	Natalia Díaz	Colombia: Valle del Cauca: Reserva Forestal Bosque de Yotoco, 1200-1600 m	3.87197	-76.42173	Georeferenced from Google Earth
<i>Centrolene savagei</i>	MZ000004	Santiago Castroviejo-Fisher	Colombia: Quindío: Vereda El Mendillal, Reserva de Bremen	4.66850	-75.61650	Marco Rada
<i>Centrolene savagei</i>	savagei CATAZ034	Fernando Vargas-Salinas	Colombia: Valle del Cauca: Reserva Forestal Bosque de Yotoco, 1200-1600 m	3.87197	-76.42173	Georeferenced from Google Earth
<i>Chimerella corleone</i>	Chimerella corleone San Jose 1	Evan Twomey	Peru: San Martín: top of a large waterfall, stream near the village of San Jose in the Cainarachi valley near Tarapoto	-6.41739	-76.28926	Twomey et al. 2014
<i>Cochranella erminae</i>		Evan Twomey	Peru: Amazonas: Campanilla	-8.32380	-76.70995	Evan Twomey
<i>Cochranella erminae</i>		Evan Twomey	Peru: Amazonas: Muyo, 629 m	-5.29833	-78.40055	Evan Twomey

Dataset S1. Continued.

Species	Code (track_name)	Autorship	Locality	Lat	Long	Coordinates source
<i>Cochranella euknemos</i>	Fonozoo 21_66959	Roberto Ibañez D., A, Stanley Rand, Michael J. Ryan y Cesar A. Jaramillo A.	Panama: ?	?	?	Coordinates from records in GBIF
<i>Cochranella euknemos</i>	MZ000023	Jesse Delia	Panama: ?	?	?	Coordinates from records in GBIF
<i>Cochranella euknemos</i>	MZ000024	Jesse Delia	Panama: ?	?	?	Coordinates from records in GBIF
<i>Cochranella euknemos</i>	MZ000025	Jesse Delia	Panama: ?	?	?	Coordinates from records in GBIF
<i>Cochranella granulosa</i>	Fonozoo 21_66958	Roberto Ibañez D., A, Stanley Rand, Michael J. Ryan y Cesar A. Jaramillo A.	Panama: ?	?	?	Coordinates from records in GBIF
<i>Cochranella granulosa</i>	Fonozoo 232-8908	Adrián García-Rodríguez	Costa Rica: Limón: Cahuita	9.71817	-82.84241	Georeferenced from Google Earth
<i>Cochranella guayasamini</i>	Cochranella sp2_20C_7-04_S6.41689_W76.29353	Evan Twomey	Peru: San Martin: San Jose, Cainarachi valley	-6.42074	-76.29124	Evan Twomey
<i>Cochranella guayasamini</i>	MZ0000002	Evan Twomey	Peru: San Martin: San Jose, Cainarachi valley	-6.42074	-76.29124	Evan Twomey
<i>Cochranella mache</i>	final	Mauricio Ortega-Andrade	Ecuador: Esmeraldas: Rompe-fuente rivulet, Bilsa Biological Station, 800 m	0.35917	-79.70056	Ortega-Andrade et al. 2013
<i>Cochranella nola</i>	Fonozoo 96-5136	José M. Padial	Bolivia: Santa Cruz: Camino a Bella Vista-Florida	-18.18903	-63.71467	Fonozoo
<i>Cochranella nola</i>	Fonozoo 108-5584	Jörn Köhler	Bolivia: Santa Cruz: Quebrada El Fuerte, 1600 masl, semi-deciduos forest remanent of the Río Piray Valley, Samapaita region, Florida Province	-18.17337	-63.81406	Georeferenced from Google Earth

Dataset S1. Continued.

Species	Code (track_name)	Autorship	Locality	Lat	Long	Coordinates source
<i>Cochranella resplendens</i>	Cochranella resplendens San Jose edit (Jesse Delia)	Jesse Delia	Peru: San Martín: San Jose, Cainarachi valley	-6.42233	-76.28837	Evan Twomey
<i>Cochranella saxiscandens</i>	Ahuashiyacu_1	Evan Twomey	Peru: San Martín: Ahuashiyacu waterfalls, 797 m	-6.45547	-76.30898	Twomey et al. 2014
<i>Cochranella saxiscandens</i>	Ahuashiyacu_2	Evan Twomey	Peru: San Martín: Ahuashiyacu waterfalls, 797 m	-6.45547	-76.30898	Twomey et al. 2014
<i>Cochranella saxiscandens</i>	Ahuashiyacu_3	Evan Twomey	Peru: San Martín: Ahuashiyacu waterfalls, 797 m	-6.45547	-76.30898	Twomey et al. 2014
<i>Cochranella saxiscandens</i>	Ahuashiyacu_4	Evan Twomey	Peru: San Martín: Ahuashiyacu waterfalls, 797 m	-6.45547	-76.30898	Twomey et al. 2014
<i>Cochranella saxiscandens</i>	Ahuashiyacu_5	Evan Twomey	Peru: San Martín: Ahuashiyacu waterfalls, 797 m	-6.45547	-76.30898	Twomey et al. 2014
<i>Cochranella saxiscandens</i>	Ahuashiyacu_6	Evan Twomey	Peru: San Martín: Ahuashiyacu waterfalls, 797 m	-6.45547	-76.30898	Twomey et al. 2014
<i>Cochranella saxiscandens</i>	Ahuashiyacu_7	Evan Twomey	Peru: San Martín: Ahuashiyacu waterfalls, 797 m	-6.45547	-76.30898	Twomey et al. 2014
<i>Cochranella saxiscandens</i>	Ahuashiyacu_8	Evan Twomey	Peru: San Martín: Ahuashiyacu waterfalls, 797 m	-6.45547	-76.30898	Twomey et al. 2014

Dataset S1. Continued.

Species	Code (track_name)	Autorship	Locality	Lat	Long	Coordinates source
<i>Cochranella saxiscandens</i>	Rulyrana tangarana 21.5C (7 km E Pacayzapa) 1	Evan Twomey	Peru: San Martín: 7 km E Pacayzapa, 1047 m	-6.28135	-76.73274	Twomey et al. 2014
<i>Cochranella spinosa</i>	Fonozoo 21_66957	Roberto Ibañez D., A, Stanley Rand, Michael J. Ryan y Cesar A. Jaramillo A.	Panama: ?	?	?	Coordinates from records in GBIF
<i>Espadarana andina</i>	1_V2_04	Santiago Castroviejo-Fisher	Venezuela: Mérida: Quebrada La Azulita (980-1060 m)	8.71418	-71.43902	Georeferenced from Google Earth
<i>Espadarana andina</i>	Espadarana andina Ipika IX-2008	Fernando Rojas-Runjaic	Venezuela: Zulia: headwaters of the Cascada Kusare, near Ipika, Río Tokuko basin, PN Sierra de Perijá, Municipio Machiques, 845 m	10.72019	-72.48794	Rojas-Runjaic et al. 2012
<i>Espadarana audax</i>	Fonozoo 198-8379	José M. Padial	Peru: San Martín: Lamas, Quebrada 3 km de Roque	-6.42431	-76.50836	Georeferenced from Google Earth
<i>Espadarana prosoblepon</i>	Fonozoo 21	Roberto Ibañez D., A, Stanley Rand, Michael J. Ryan y Cesar A. Jaramillo A.	Panama: ?	?	?	Coordinates from records in GBIF
<i>Hyalinobatrachium aff. bergeri</i>	HAF00015	Santiago Castroviejo-Fisher	?	?	?	?
<i>Hyalinobatrachium aff. bergeri</i>	Fonozoo 196-8238	José M. Padial	Peru: Cusco: Ouispicanchis, entre San Miguel y Marcapata	-13.47419	-70.89620	J. Padial
<i>Hyalinobatrachium aff. bergeri</i>	Fonozoo 196-8237	José M. Padial	Peru: Cusco: Ouispicanchis, entre San Miguel y Marcapata	-13.47419	-70.89620	J. Padial

Dataset S1. Continued.

Species	Code (track_name)	Autorship	Locality	Lat	Long	Coordinates source
<i>Hyalinobatrachium anachoretus</i>	Hyalinobatrachium anachoretus Alto Mayo 1	Evan Twomey	Peru: Amazonas (?), Alto Mayo near Puente Nieva	-5.66890	-77.76683	Evan Twomey
<i>Hyalinobatrachium anachoretus</i>	Hyalinobatrachium anachoretus Alto Mayo 2	Evan Twomey	Peru: Amazonas (?), Alto Mayo near Puente Nieva	-5.66890	-77.76683	Evan Twomey
<i>Hyalinobatrachium bergeri</i>	Fonozoo 185-7907	W. E. Duellman	Peru: Ayacucho: Tutumbaro, 1840 m	-12.72364	-73.94801	Georeferenced from Google Earth
<i>Hyalinobatrachium bergeri</i>	Fonozoo 185-7915	W. E. Duellman	Peru: Ayacucho: Tutumbaro, 1840 m	-12.72364	-73.94801	Georeferenced from Google Earth
<i>Hyalinobatrachium bergeri</i>	Fonozoo 196-8249	José M. Padial	Peru: Cusco: Ouispicanchis, A 5 km de San Lorenzo hacia Quince Mil	-13.19672	-70.55578	Fonozoo
<i>Hyalinobatrachium bergeri</i>	Fonozoo 96-5137	José M. Padial	Bolivia: La Paz: Sadiri-Arroyo Yariapo, P. N. Madidi	-14.19028	-67.93611	Fonozoo
<i>Hyalinobatrachium bergeri</i>	Fonozoo 96-5138	José M. Padial	Bolivia: La Paz, Puesto guardaparques-Arroyo Huabudahaida, P. N. Madidi	-14.17012	-67.91890	José M. Padial
<i>Hyalinobatrachium bergeri</i>	Fonozoo 97-5187	José M. Padial	Bolivia: La Paz: Arroyo Pico Plancha, Senda entre San José y Apolo	-14.27214	-68.09336	Fonozoo
<i>Hyalinobatrachium bergeri</i>	bergeri_15000	José M. Padial	Peru: Cusco: Ouispicanchis, 6.1 km de Puente Fortaleza hacia Quince Mil	-13.18603	-70.58060	José M. Padial
<i>Hyalinobatrachium bergeri</i>	bergeri_marcapata-1	José M. Padial	Peru: Cusco: Ouispicanchis, entre San Miguel y Marcapata	-13.47419	-70.89620	José M. Padial
<i>Hyalinobatrachium bergeri</i>	bergeri_marcapata-2	José M. Padial	Peru: Cusco: Ouispicanchis, entre San Miguel y Marcapata	-13.47419	-70.89620	José M. Padial

Dataset S1. Continued.

Species	Code (track_name)	Autorship	Locality	Lat	Long	Coordinates source
<i>Hyalinobatrachium cappellei</i>	12_V3_05	Santiago Castroviejo-Fisher	Venezuela: Bolívar: primera quebrada em el primer campamento antes del Auyán-tepui	5.68485	-62.52562	Santiago Castroviejo-Fisher
<i>Hyalinobatrachium cappellei</i>	2_V4_05	Santiago Castroviejo-Fisher	Venezuela: Bolívar: Quebrada um poco más abajo del campamento El Oso, Auyán-tepui	5.78730	-62.53659	Santiago Castroviejo-Fisher
<i>Hyalinobatrachium cappellei</i>	7_V2_05	Santiago Castroviejo-Fisher	Venezuela: Bolívar: Km.127 Crta. El Dorado - S ^a Elena	5.96700	-61.39412	Santiago Castroviejo-Fisher
<i>Hyalinobatrachium cappellei</i>	8_V4a_04	Santiago Castroviejo-Fisher	Venezuela: Bolívar: Quebrada Jaspe, San Ignacio de Yuruaní, Parque Nacional Canaima	4.91738	-61.09344	Georeferenced from Google Earth
<i>Hyalinobatrachium cappellei</i>	Hyalinobatrachium_cappellei_(crurifasciatum)_AMNH REEL 256 (track 6)	Charles W. Myers, Maureen A. Donnelly & John W. Daly	Venezuela: Amazonas: Sierra Tapirapecó, north base Pico Tamacuari: 1160-1200 m	1.23623	-64.75167	AMNH (corrected to agree with the description of the locality)
<i>Hyalinobatrachium cappellei</i>	Hyalinobatrachium_cappellei_(eccentricum)_A MNH REEL 264 (track 1)	Charles W. Myers	Venezuela: Amazonas: Cerro Yutajé, 1700 m	5.75293	-66.14633	AMNH (corrected to agree with the description of the locality)
<i>Hyalinobatrachium carlesvilai</i>	Fonozoo 200_76055	I. De la Riva	Bolivia: Santa Cruz: Río Cheyo, Parque Nacional Amboró	-17.58330	-63.65000	http://mapasamerica.dices.net/bolivia/mapa.php?nombre=Rio-Cheyo&id=15073
<i>Hyalinobatrachium carlesvilai</i>	carlesvilai_peru_tambo pata_copy1	José M. Padial	Peru: Cusco: Unión, Valle de Kosñipata	-13.05606	-71.54676	José M. Padial
<i>Hyalinobatrachium carlesvilai</i>	carlesvilai_peru_tambo pata_copy2	José M. Padial	Peru: Cusco: Unión, Valle de Kosñipata	-13.05606	-71.54676	José M. Padial
<i>Hyalinobatrachium chirripoi</i>	chirripoi-1.wav	Evan Twomey	Costa Rica: Limón: Río Banano, 80 m	9.89984	-83.15000	Google Earth

Dataset S1. Continued.

Species	Code (track_name)	Autorship	Locality	Lat	Long	Coordinates source
<i>Hyalinobatrachium colymbiphyllum</i>	FNJV 11742	Adão Cardoso	Panama: Gamboa: Rio Frijoles	9.13830	-79.77360	http://pa.geoview.info/rio_frijoles,3709457
<i>Hyalinobatrachium colymbiphyllum</i>	Fonozoo 66963	Roberto Ibañez D., A, Stanley Rand, Michael J. Ryan y Cesar A. Jaramillo A.	Panama: ?	?	?	Coordinates from records in GBIF
<i>Hyalinobatrachium colymbiphyllum</i>	Fonozoo 159-7143	W. E. Duellman	Panama: Dairén: Tacarcuna	8.16574	-77.29520	Georeferenced from Google Earth
<i>Hyalinobatrachium durantei</i>	1_V3_05	Santiago Castroviejo-Fisher	Venezuela: Mérida: Quebrada El Chorotal, entre La Azulita y Mérida (1820-1840 m)	8.66472	-71.38140	http://mapasamerica.dices.net/venezuela/mapa.php?nombre=El-Chorotal&id=56131
<i>Hyalinobatrachium durantei</i>	10_V1_04	Santiago Castroviejo-Fisher	Venezuela: Mérida: Quebrada del Loro, La Mucuy, Parque Nacional Sierra Nevada	8.63152	-71.04045	Georeferenced from Google Earth
<i>Hyalinobatrachium durantei</i>	11_V1_04	Santiago Castroviejo-Fisher	Venezuela: Mérida: Quebrada del Loro, La Mucuy, Parque Nacional Sierra Nevada	8.63152	-71.04045	Georeferenced from Google Earth
<i>Hyalinobatrachium durantei</i>	8_V1_04	Santiago Castroviejo-Fisher	Venezuela: Mérida: Río Albarregas (2090-2140 m)	8.63080	-71.16075	Georeferenced from Google Earth
<i>Hyalinobatrachium fleischmanni</i>	Fonozoo 151-6944	W. E. Duellman	Costa Rica: Cartago: Tapantí	9.75323	-83.78382	Georeferenced from Google Earth
<i>Hyalinobatrachium fleischmanni</i>	Fonozoo 151-6945	W. E. Duellman	Costa Rica: Cartago: Tapantí	9.75323	-83.78382	Georeferenced from Google Earth
<i>Hyalinobatrachium fleischmanni</i>	Fonozoo 151-6954	W. E. Duellman	Costa Rica: Cartago: Tapantí	9.75323	-83.78382	Georeferenced from Google Earth
<i>Hyalinobatrachium fleischmanni</i>	Fonozoo 158-7138	W. E. Duellman	Costa Rica: Cartago: Tapantí	9.75323	-83.78382	Georeferenced from Google Earth

Dataset S1. Continued.

Species	Code (track_name)	Autorship	Locality	Lat	Long	Coordinates source
<i>Hyalinobatrachium fleischmanni</i>	Fonozoo 158-7139	W. E. Duellman	Costa Rica: Cartago: Tapantí	9.75323	-83.78382	Georeferenced from Google Earth
<i>Hyalinobatrachium fleischmanni</i>	Fonozoo 158-7142	W. E. Duellman	Nicaragua: Matagalpa: Hacienda La Cumplida	12.99981	-85.84904	http://lacumplida.com/contacto/
<i>Hyalinobatrachium fleischmanni</i>	Fonozoo 21_66962	Roberto Ibañez D., A, Stanley Rand, Michael J. Ryan y Cesar A. Jaramillo A.	Panama: ?	?	?	Coordinates from records in GBIF
<i>Hyalinobatrachium fleischmanni</i>	Hyalinobatrachium_fleischmanni_AMNH REEL 125 (track 6)	Richard G. Zweifel	Panama: Canal Zone: Barro Colorado	9.15579	-79.84663	Georeferenced from Google Earth
<i>Hyalinobatrachium fleischmanni</i>	Hyalinobatrachium_fleischmanni_AMNH REEL 125 (track 7)	Richard G. Zweifel	Panama: Canal Zone: Barro Colorado	9.15579	-79.84663	Georeferenced from Google Earth
<i>Hyalinobatrachium fragile</i>	12_V2_05	Santiago Castroviejo-Fisher	Venezuela: Cojedes: stream that intersects the road Manrique-La Sierra, near San Carlos, 564 m	9.86222	-68.54944	Wen <i>et al.</i> (2012)
<i>Hyalinobatrachium iaspidiense</i>	H. nouraguensis-01	Michel Blanc	Guyana: Mabura Hill Forest Reserve, Maiko creek, 60 m	5.15536	-58.69973	Castroviejo-Fisher <i>et al.</i> (2011)
<i>Hyalinobatrachium iaspidiense</i>	H. nouraguensis-02	Michel Blanc	Guyana: Mabura Hill Forest Reserve, Maiko creek, 60 m	5.15536	-58.69973	Castroviejo-Fisher <i>et al.</i> (2011)
<i>Hyalinobatrachium iaspidiense</i>	H. nouraguensis-03	Michel Blanc	Guyana: Mabura Hill Forest Reserve, Maiko creek, 60 m	5.15536	-58.69973	Castroviejo-Fisher <i>et al.</i> (2011)
<i>Hyalinobatrachium iaspidiense</i>	H. nouraguensis-04	Michel Blanc	Guyana: Mabura Hill Forest Reserve, Maiko creek, 60 m	5.15536	-58.69973	Castroviejo-Fisher <i>et al.</i> (2011)
<i>Hyalinobatrachium kawense</i>	H. kawense AG 241 Rivière de Kaw 06-02-05	Michel Blanc	French Guiana: Rivière de Kaw 1–10 m	4.60917	-52.05694	Castroviejo-Fisher <i>et al.</i> (2011)

Dataset S1. Continued.

Species	Code (track_name)	Autorship	Locality	Lat	Long	Coordinates source
<i>Hyalinobatrachium kawense</i>	H. kawense présence femelle Rivière de Kaw 16-04-05	Michel Blanc	French Guiana: Rivière de Kaw 1–10 m	4.60917	-52.05694	Castroviejo-Fisher <i>et al.</i> (2011)
<i>Hyalinobatrachium mondolfii</i>	20_V1_05	Santiago Castroviejo-Fisher	Venezuela: Caño Acoima, campamento Amigos de Doñana (localidad tipo)	8.45306	-61.58520	Señaris & Ayarzagüena 2001 (corrected to adjust the specifications of the locality)
<i>Hyalinobatrachium mondolfii</i>	H. mondolfii AG 320 Crique Gabrielle 28-04-07	Michel Blanc	French Guiana: Crique Gabrielle, 2 m	4.68333	-52.30000	Castroviejo-Fisher <i>et al.</i> (2011)
<i>Hyalinobatrachium mondolfii</i>	mondolfii-Guyana_kok	Philippe Kok	Guyana: Mabura Hill Forest Reserve, Maiko creek, 60 m	5.15536	-58.69971	Castroviejo-Fisher <i>et al.</i> (2011)
<i>Hyalinobatrachium mondolfii</i>	MZ000012	Santiago Castroviejo-Fisher	Colombia: Amazonas: Biological station Zafire, 14.4 km SW from Tanimboca	-4.00304	-69.89500	Santiago Castroviejo-Fisher
<i>Hyalinobatrachium orientale</i>	Fonozoo 340_76716	Morley Read	Trinidad & Tobago: Tobago: Main Ridge Forest Reserve	11.28089	-60.61938	Georeferenced from Google Earth
<i>Hyalinobatrachium orientale</i>	19_V1_05	Santiago Castroviejo-Fisher	Venezuela: Monagas: Cueva El Guácharo	10.17417	-63.55167	Santiago Castroviejo-Fisher
<i>Hyalinobatrachium orocostale</i>	11_V3_04	Santiago Castroviejo-Fisher	Venezuela: Guárico: Cerro Platillón, Hacienda Picachitos (1200 m)	9.85639	-67.50253	Santiago Castroviejo-Fisher
<i>Hyalinobatrachium orocostale</i>	7_V3_04	Santiago Castroviejo-Fisher	Venezuela: Guárico: Cerro Platillón, Hacienda Picachitos (1200 m)	9.85639	-67.50253	Santiago Castroviejo-Fisher
<i>Hyalinobatrachium pallidum</i>	Hyalinobatrachium pallidum Las Antenas 03-2008	Fernando Rojas-Runjaic	Venezuela: Zulia: Cerro Las Antenas, cuenca del río Lajas, 1430 m	10.34345	-72.56141	Rojas-Runjaic <i>et al.</i> (2012)

Dataset S1. Continued.

Species	Code (track_name)	Autorship	Locality	Lat	Long	Coordinates source
<i>Hyalinobatrachium pallidum</i>	Hyalinobatrachium pallidum Qda 2da Antena 12-07-2008	Fernando Rojas-Runjaic	Venezuela: Zulia: Cerro Las Antenas, cuenca del río Lajas, 1430 m	10.34345	-72.56141	Rojas-Runjaic <i>et al.</i> (2012)
<i>Hyalinobatrachium pellucidum</i>	MZ000032 (Hyalinobatrachium bergeri near San Jose)	Santiago Castroviejo-Fisher	Peru: San Martín: Cainarachi valley near Tarapoto, 523 m	-6.42131	-76.29125	Twomey <i>et al.</i> (2014)
<i>Hyalinobatrachium pellucidum</i>	pellucidum_San Jose_23C	Evan Twomey	Peru: San Martín: Cainarachi valley near Tarapoto, 523 m	-6.42131	-76.29125	Twomey <i>et al.</i> (2014)
<i>Hyalinobatrachium tatayoi</i>	3_V3_05	Santiago Castroviejo-Fisher	Venezuela: Zulia: Quebrada en la toma de agua de El Tokuko, sierra de Perijá	9.84174	-72.82046	Santiago Castroviejo-Fisher
<i>Hyalinobatrachium tatayoi</i>	4_V3_05	Santiago Castroviejo-Fisher	Venezuela: Zulia: Quebrada en la toma de agua de El Tokuko, sierra de Perijá	9.84174	-72.82046	Santiago Castroviejo-Fisher
<i>Hyalinobatrachium tatayoi</i>	5_V3_05	Santiago Castroviejo-Fisher	Venezuela: Zulia: Quebrada en la toma de agua de El Tokuko, sierra de Perijá	9.84174	-72.82046	Santiago Castroviejo-Fisher
<i>Hyalinobatrachium taylori</i>	Fonozoo 10_67523	Christian Marty & Philippe Gaucher	French Guiana: ?	?	?	Coordinates from records in GBIF
<i>Hyalinobatrachium taylori</i>	Fonozoo 34_73179	Christian Marty & Philippe Gaucher	French Guiana: ?	?	?	Coordinates from records in GBIF
<i>Hyalinobatrachium tricolor</i>	Hyalinobatrachium cf. nouragensis Wapou 2005 stéréo	Michel Blanc	French Guiana: Kaw: Crique Wapou, 2 m	4.43333	-52.15000	Castroviejo-Fisher <i>et al.</i> (2011)
<i>Hyalinobatrachium tricolor</i>	Hyalinobatrachium cf. nouragensis Wapou 2005 stéréo échantillon	Michel Blanc	French Guiana: Kaw: Crique Wapou, 2 m	4.43333	-52.15000	Castroviejo-Fisher <i>et al.</i> (2011)

Dataset S1. Continued.

Species	Code (track_name)	Autorship	Locality	Lat	Long	Coordinates source
<i>Hyalinobatrachium tricolor</i>	Hyalinobatrachium cf. nouragensis Wapou 2005 stéréo échantillon	Michel Blanc	French Guiana: Kaw: Crique Wapou, 2 m	4.43333	-52.15000	Castroviejo-Fisher <i>et al.</i> (2011)
<i>Hyalinobatrachium valerioi</i>	Fonozoo 193-8125	W. E. Duellman	Ecuador: Pichincha: 4 km N Dos Rios, 1140 m	-0.30526	-78.88081	Coordinates from AmphibiaWebEcuador (QCAZA49925) (http://zoologia.puce.edu.ec/vertebrados/anfibios/Mapa.aspx?Id=1215)
<i>Ikakogi tayrona</i>	Ikakogi tayrona 1015 canto	Fernando Vargas-Salinas	Colombia: Magdalena: Sierra Nevada de Santa Marta, Vereda San Lorenzo, 2200 msnm	11.11520	-74.05090	Vargas-Salinas <i>et al.</i> (2015)
<i>Nymphargus bejaranoi</i>	Fonozoo 200_76053	J. Köhler & S. Lötters	Bolivia: Santa Cruz: Remate, Caballero, Parque Nacional Amboró	-17.58330	-63.65000	Coordinates from http://mapasamerica.dices.net/bolivia/mapa.php?nombre=Rio-Cheyo&id=15073
<i>Nymphargus griffithsi</i>	18822_griffithsi2-2	Carl Hutter	Ecuador: Pichincha: Reserva Las Galarias, Heloderma creek	-0.02076	-78.70617	Hutter & Guayasamin (2012)
<i>Nymphargus griffithsi</i>	18854_griffithsi2	Carl Hutter	Ecuador: Pichincha: Reserva Las Galarias, Hercules Giant Tree frog creek	-0.02551	-78.70405	Hutter & Guayasamin (2012)
<i>Nymphargus griffithsi</i>	18885_griffithsi2_2	Carl Hutter	Ecuador: Pichincha: Reserva Las Galarias, Five frog creek	-0.03118	-78.70597	Hutter & Guayasamin (2012)
<i>Nymphargus griffithsi</i>	?	Carl Hutter	Ecuador: Pichincha: Reserva Las Galarias, Kathy's Creek	-0.02335	-78.72953	Hutter & Guayasamin (2012)
<i>Nymphargus griffithsi</i>	34970_griffithsi2	Carl Hutter	Ecuador: Pichincha: Reserva Las Galarias, Five frog creek	-0.03118	-78.70597	Hutter & Guayasamin (2012)
<i>Nymphargus griffithsi</i>	Fonozoo 185-7914	W. E. Duellman	Ecuador: Pichincha: 3.5 km NE Mindo, 1540 m	-0.03987	-78.75286	Georeferenced from Google Earth

Dataset S1. Continued.

Species	Code (track_name)	Autorship	Locality	Lat	Long	Coordinates source
<i>Nymphargus griffithsi</i>	Fonozoo 192-8123	W. E. Duellman	Ecuador: Pichincha: 9 km SE Tandayapa, 2150 masl	-0.04663	-78.63378	Georeferenced from Google Earth
<i>Nymphargus griffithsi</i>	Fonozoo 192-8124	W. E. Duellman	Ecuador: Pichincha: 4 km N Dos Rios, 1140 m	-0.30526	-78.88081	Coordinates from AmphibiaWebEcuador (QCAZA49925) (http://zoologia.puce.edu.ec/vertebrados/anfibios/Mapa.aspx?id=1215)
<i>Nymphargus lasgrarias</i>	?	Carl Hutter	Ecuador: Pichincha: Reserva Las Gralarias, Kathy's Creek	-0.02335	-78.72953	Hutter & Guayasamin (2012)
<i>Nymphargus lasgrarias</i>	?	Carl Hutter	Ecuador: Pichincha: Reserva Las Gralarias, Heloderma creek	-0.02076	-78.70617	Hutter & Guayasamin (2012)
<i>Nymphargus lasgrarias</i>	?	Carl Hutter	Ecuador: Pichincha: Reserva Las Gralarias, Five frog creek	-0.03118	-78.70597	Hutter & Guayasamin (2012)
<i>Nymphargus phenax</i>	Fonozoo 185-7907	W. E. Duellman	Peru: Ayacucho: Tutumbaro, 1840 m	-12.72364	-73.94801	Georeferenced from Google Earth
<i>Nymphargus pluvialis</i>	Cocind35-99(1)	Alessandro Catenazzi	Peru: Cusco: near Buenos Aires, along the road Cusco-Pilcopata, 2360 m	-13.15109	-71.59088	Catenazzi <i>et al.</i> (2009)
<i>Nymphargus pluvialis</i>	Cocind35-99(2)	Alessandro Catenazzi	Peru: Cusco: near Buenos Aires, along the road Cusco-Pilcopata, 2360 m	-13.15109	-71.59088	Catenazzi <i>et al.</i> (2009)
<i>Nymphargus siren</i>	QCAZ46663	Elicio Tapia y Samael Padilla	Ecuador: Provincia Sucumbios: vía Santa Bárbara - La Bonita	0.45113	-77.54565	Coordinates from AmphibiaWebEcuador (QCAZA46683) (http://zoologia.puce.edu.ec/Vertebrados/anfibios/Mapa.aspx?id=1209)
<i>Nymphargus truebae</i>	Coctru149-99(8)	Alessandro Catenazzi	Peru: Cusco: near El Mirador along the Cusco-Pilcopata road, 1800 m	-13.07289	-71.55727	Catenazzi <i>et al.</i> (2009)

Dataset S1. Continued.

Species	Code (track_name)	Autorship	Locality	Lat	Long	Coordinates source
<i>Nymphargus truebae</i>	Coctru149-99(9)	Alessandro Catenazzi	Peru: Cusco: near El Mirador along the Cusco-Pilcopata road, 1800 m	-13.07289	-71.55727	Catenazzi <i>et al.</i> (2009)
<i>Nymphargus truebae</i>	Coctru76-99(5)	Alessandro Catenazzi	Peru: Cusco: near El Mirador along the Cusco-Pilcopata road, 1800 m	-13.07289	-71.55727	Catenazzi <i>et al.</i> (2009)
<i>Rulyrana flavopunctata</i>	QCAZ MR-LS110307	Morley Read	Ecuador: Provincia Napo: Parque Nacional Wawa Sumaco. Morley Read (Coordenadas tentativas; esperar respuesta de Morley)	-0.47035	-77.60092	Georeferenced from Google Earth
<i>Rulyrana spiculata</i>	Cocspi150-99(1)	Alessandro Catenazzi	Peru: Cusco: near San Pedro along the road Cusco-Pilcopata, 1525 m	-13.06077	-71.55118	Catenazzi <i>et al.</i> (2009)
<i>Sachatamia albomaculata</i>	Sachatamia albomaculata_AMNH REEL 226 (track 2)	Charles W. Myers	Panama: Bocas del Toro: Río Changuinola, nr Quebrada El Guabo, [16 km airline W Almirante]: 90 m elev	9.29574	-82.55532	Georeferenced from Google Earth
<i>Teratohyla midas</i>	Fonozoo 198_75654	Morley Read	Ecuador: Provincia Orellana: Boanamo, Saladero Venado	-1.25166	-76.38969	http://www.ais.aviacioncivil.gob.ec/designador/SEBW
<i>Teratohyla midas</i>	LS110878-AmpWeEcu	Morley Read	Ecuador: Provincia Orellana: Boanamo, Saladero Venado	-1.25166	-76.38969	http://www.ais.aviacioncivil.gob.ec/designador/SEBW
<i>Teratohyla midas</i>	Another call of Cochranella yellow spots	Yvain	?	?	?	
<i>Teratohyla midas</i>	MZ000013	Santiago Castroviejo-Fisher	Colombia: Amazonas: Biological station Zafire, 14.4 km SW from Tanimboca	-4.00304	-69.89500	Santiago Castroviejo-Fisher

Dataset S1. Continued.

Species	Code (track_name)	Autorship	Locality	Lat	Long	Coordinates source
<i>Teratohyla midas</i>	T_midas_EJRA_GGU_0688	Giuseppe Gagliardi-Urrutia	Peru: Iquitos: El Aguajal, Estación biológica José Álvarez Alonso	-3.96825	-73.41731	http://iiap.org.pe/ebjaa/spanish.html
<i>Teratohyla midas</i>	T_midas_EJRA_GGU_0689	Giuseppe Gagliardi-Urrutia	Peru: Iquitos: El Aguajal, Estación biológica José Álvarez Alonso	-3.96825	-73.41731	http://iiap.org.pe/ebjaa/spanish.html
<i>Teratohyla midas</i>	Teratohyla midas - Upper Shunte 70 F	Evan Twomey	Peru: Amazonas: Pongo de Rentema, 557 m	-5.29547	-78.40616	Twomey <i>et al.</i> (2014)
<i>Teratohyla pulverata</i>	Fonozoo 21_66961	Roberto Ibañez D., A, Stanley Rand, Michael J. Ryan y Cesar A. Jaramillo A.	Panama: ?	?	?	Coordinates from records in GBIF
<i>Vitreorana castroviejo</i>	10_V4a_04	Santiago Castroviejo-Fisher	Venezuela: Sucre: Cerro El Humo	10.69964	-62.61669	Santiago Castroviejo-Fisher
<i>Vitreorana castroviejo</i>	11_V4a_04	Santiago Castroviejo-Fisher	Venezuela: Sucre: Cerro El Humo	10.69964	-62.61669	Santiago Castroviejo-Fisher
<i>Vitreorana eurygnatha</i>	FNJV 11743	Adão Cardoso	Brazil: Sao Paulo: São José do Barreiro, Parque Nacional da Serra da Bocaina	-23.03030	-44.70320	Georeferenced from Google Earth
<i>Vitreorana eurygnatha</i>	FNJV 11744	Adão Cardoso	Brazil: Minas Gerais: Poços de Caldas, Morro do Ferro	-21.91667	-46.51667	https://www.mindat.org/maps.php?id=30588
<i>Vitreorana eurygnatha</i>	FNJV 11747	Adão Cardoso	Brazil: Minas Gerais: Poços de Caldas, Morro do Ferro	-21.91667	-46.51667	https://www.mindat.org/maps.php?id=30588
<i>Vitreorana eurygnatha</i>	FNJV 11748	Adão Cardoso	Brazil: Minas Gerais: Poços de Caldas, Morro do Ferro	-21.91667	-46.51667	https://www.mindat.org/maps.php?id=30588

Dataset S1. Continued.

Species	Code (track_name)	Autorship	Locality	Lat	Long	Coordinates source
<i>Vitreorana gorzulae</i>	6_V2_05	Santiago Castroviejo-Fisher	Venezuela: Bolívar: Quebrada Km.127 Crta. El Dorado - S ^a Elena	5.96700	-61.39412	Santiago Castroviejo-Fisher
<i>Vitreorana helenae</i>	1_V2_05	Santiago Castroviejo-Fisher	Venezuela: Bolívar: Quebrada Jaspe, San Ignacio de Yuruaní, Parque Nacional Canaima	4.91738	-61.09344	Georeferenced from Google Earth
<i>Vitreorana helenae</i>	3_V2_05	Santiago Castroviejo-Fisher	Venezuela: Bolívar: Quebrada 150 m debajo del salto Karawai	5.69079	-61.86106	Santiago Castroviejo-Fisher
<i>Vitreorana ritae</i>	Co_oyampiensis_SUR	Philippe Kok	?	?	?	
<i>Vitreorana ritae</i>	FNJV_0011063_Vitreorana_ritae_Presidente Figueiredo_AM_Marcio R. Martins	Marcio Martins	Brazil: Amazonas: Presidente Figueiredo, Usina Hidrelétrica de Balbina - Vila Residencial	-1.93549	-59.43026	Coordinates from Google Earth
<i>Vitreorana ritae</i>	Fonozoo 11_67524	Christian Marty & Philippe Gaucher	French Guiana: ?	?	?	
<i>Vitreorana uranoscopa</i>	FNJV 11750	Adão Cardoso	Brazil: São Paulo: Santo André, Paranapiacaba	-23.77429	-46.29569	Coordinates from Google Earth
<i>Vitreorana uranoscopa</i>	FNJV 12951	Cynthia Prado	Brazil: São Paulo: Ilha do Cardoso	-25.16051	-47.97151	Coordinates from Google Earth
<i>Vitreorana uranoscopa</i>	FNJV 12952	Cynthia Prado	Brazil: São Paulo: Ilha do Cardoso	-25.16051	-47.97151	Coordinates from Google Earth
<i>Vitreorana uranoscopa</i>	FNJV 12955	Cynthia Prado	Brazil: São Paulo: Ilha do Cardoso	-25.16051	-47.97151	Coordinates from Google Earth
<i>Vitreorana uranoscopa</i>	Fonozoo 129-6168	Axel Kwet	Brazil: Santa Catarina: Florianópolis (Corrego Grande)	-27.58333	-48.51667	Axel Kwet

Dataset S1. Continued.

Species	Code (track_name)	Autorship	Locality	Lat	Long	Coordinates source
<i>Vitreorana uranoscopa</i>	Fonozoo 129-6173	Axel Kwet	Brazil: Santa Catarina: Florianópolis (Corrego Grande)	-27.58333	-48.51667	Axel Kwet
<i>Vitreorana uranoscopa</i>	Fonozoo 130-6192	Axel Kwet	Brazil: Santa Catarina: Florianópolis (Corrego Grande)	-27.58333	-48.51667	Axel Kwet
<i>Vitreorana uranoscopa</i>	Fonozoo 139-6425	Axel Kwet	Brazil: Santa Catarina: Sao Pedro de Alcantara	-27.56667	-48.78333	Axel Kwet
<i>Vitreorana uranoscopa</i>	Fonozoo 139-6438	Axel Kwet	Brazil: Santa Catarina: Vargem Grande near Águas Mornas	-27.66667	-48.83333	Axel Kwet
<i>Vitreorana uranoscopa</i>	Fonozoo 658_99316	Célio F. B. Haddad, João G. R. Giovanelli, Luis O. Menta Giasson & Luis Felipe Toledo	Brazil: Saulo Paulo: Ribeirão Branco	-24.21585	-48.76569	ww.fonozoo.com
<i>Vitreorana uranoscopa</i>	Fonozoo 13_99858	Axel Kwet	Brazil: Parana: forest pond in Mata Atlantica, at ca. 600 m, near BR 376, Municip. Guaratuba	-25.55000	-49.00000	Axel Kwet

References

- Almendáriz, A., & Batallas, D. (2012). Nuevos datos sobre la distribución, historia natural y el canto de *Centrolene condor* Cisneros-Heredia y Morales-Mite 2008 (Amphibia: Anura: Centrolenidae). *Revista Politécnica* 30(3): 42-53.
- Batallas, D., & Brito, J. (2016). Análisis bioacústico de las vocalizaciones de seis especies de anuros de la laguna Cormorán, complejo lacustre de Sardinayacu, Parque Nacional Sangay, Ecuador. *Revista mexicana de biodiversidad*, 87(4), 1292-1300.
- Castroviejo-Fisher, S., Vila, C., Ayarzagüena, J., Blanc, M., & Ernst, R. (2011). Species diversity of *Hyalinobatrachium* glassfrogs (Amphibia: Centrolenidae) from the Guiana Shield, with the description of two new species. *Zootaxa*, 3132, 1-55.
- Catenazzi, A., Rodríguez, L. O., & Donnelly, M. A. (2009). The advertisement calls of four species of glassfrogs (Centrolenidae) from southeastern Peru. *Studies on Neotropical Fauna and Environment*, 44(2), 83-91.
- Hutter, C. R., & Guayasamin, J. M. (2012). A new cryptic species of glassfrog (Centrolenidae: Nymphargus) from Reserva Las Galarias, Ecuador. *Zootaxa*, 3257, 1-21.
- Maldonado, A. (2012). Cuidado parental y selección sexual en *Centrolene peristictum* (Anura: Centrolenidae). *Disertación previa a la obtención del título de Licenciada en Ciencias Biológicas*. Pontificia Universidad Católica del Ecuador.
- Ortega-Andrade, H. M., Rojas-Soto, O., & Paucar, C. (2013). Novel data on the ecology of *Cochranella mache* (Anura: Centrolenidae) and the importance of protected areas for this critically endangered glassfrog in the Neotropics. *PloS one*, 8(12), e81837.
- Rojas-Runjaic, F. J., Infante-Rivero, E. E., & Cabello, P. (2012). New records and distribution extensions of centrolenid frogs for Venezuela. *Check List*, 8(4), 819-825.
- Señaris, J. C., & Ayarzagüena, J. (2001). Una nueva especie de rana de cristal del género *Hyalinobatrachium* (Anura: Centrolenidae) del Delta del Río Orinoco, Venezuela. *Revista de Biología Tropical*, 49(3-4), 1083-1093.

- Twomey, E., Delia, J., & Castroviejo-Fisher, S. (2014). A review of Northern Peruvian glassfrogs (Centrolenidae), with the description of four new remarkable species. *Zootaxa*, 3851(1), 001-087.
- Vargas-Salinas, F., Bravo-Valencia, L., & Amézquita, A. (2015). The advertisement call and calling site of the early diverging glassfrog *Ikakogi tayrona* (Anura: Centrolenidae). *South American journal of Herpetology*, 10(2), 65-70.
- Wen, A., Vasquez, N., & Castroviejo-Fisher, S. (2012). Description of the previously unknown advertisement calls of *Hyalinobatrachium fragile*, *H. pellucidum*, and *Vitreorana antisthenesi* (Amphibia: Centrolenidae). *Zootaxa*, 3480(1), 80-87.

Dataset S2. Advertisement call data for Centrolenidae species for which literature data was used.

Species	Structure	Source	#Notes	CallDur(s)	PeakFreq(Hz)	Source	Locality
<i>Celsiella revocata</i>	Tonal	Señaris & Ayarzagüena (2005)	1	0.0252	4084.1000	Señaris & Ayarzagüena (2005)	Venezuela: Aragua: Nacientes del río Tuy, Colonia Tovar
<i>Centrolene geckoideum</i>	Pulsed	Grant <i>et al.</i> (1998)	9	0.2951	3874.4087	Grant <i>et al.</i> (1998)	Colombia: Valle del Cauca: Dagua, El Queremal
<i>Centrolene hesperium</i>	Pulsed	Cadle & McDiarmid (1990)	2	0.1200	3630.0000	Cadle & McDiarmid (1990)	Peru: Cajamarca: near the basecamp on trail between Monte Seco and Chorro Blanco, about 2.5 km NE Monte Seco, Río Zaña, 1800 m
<i>Centrolene venezuelense</i>	Pulsed	Señaris & Ayarzagüena (2005)	4	1.1149	4316.2000	Señaris & Ayarzagüena (2005)	Venezuela: Mérida: La Mucuy
<i>Hyalinobatrachium guairarepanense</i>	Tonal	Señaris & Ayarzagüena (2005)	1	0.1950	3923.0000	Señaris & Ayarzagüena (2005)	Venezuela: Distrito Capital: vertiente sur del Parque Nacional El Ávila
<i>Hyalinobatrachium talamancae</i>	Pulsed	Kubicki <i>et al.</i> (2015)	1	0.3000	4900.0000	Kubicki (2007)	Costa Rica: El Limón: Región El Guayacán, 500 masl
<i>Sachatamia ilex</i>	?	Kubicki (2007)	1	0.0500	6000.0000	Kubicki (2007)	Costa Rica: ?
<i>Vitreorana antisthenesi</i>	Pulsed	Wen <i>et al.</i> (2012)	1	0.0400	5431.5000	Wen <i>et al.</i> (2012)	Venezuela: Cojedes: cerca de San Carlos, arroyo que intersecta la carretera Manrique-La Sierra (9°51'44" N, 68°32'58" W; 564 m a.s.l.)
<i>Hyalinobatrachium mesai</i>	Pulsed	Wen <i>et al.</i> (2012)	1	0.0750	4414.5000	Castroviejo-Fisher <i>et al.</i> (2011)	Venezuela: Bolívar: southern slope of Sarisariñama tepui, 420 m
<i>Hyalinobatrachium iaspidiense</i>	Pulsed	Wen <i>et al.</i> (2012)	1	0.0900	4386.6000	Castroviejo-Fisher <i>et al.</i> (2011)	Venezuela: Bolívar: Gran Sabana, Quebrada Jaspe, 800-1000 m
<i>Hyalinobatrachium iaspidiense</i>	Pulsed	Wen <i>et al.</i> (2012)	1	0.0700	4628.5000	Castroviejo-Fisher <i>et al.</i> (2011)	Guyana: Mabura Hill Forest Reserve, Maiko creek, 60 m
<i>Hyalinobatrachium iaspidiense</i>	Pulsed	Wen <i>et al.</i> (2012)	1	0.0600	4810.6000	Castroviejo-Fisher <i>et al.</i> (2011)	French Guiana: ?

References

- Cadle, J. E., & McDiarmid, R. W. (1990). Two new species of *Centrolenella* (Anura: Centrolenidae) from northwestern Peru. *Proceedings of the Biological Society of Washington*, 103 (3): 746-768.
- Castroviejo-Fisher, S., Vila, C., Ayarzagüena, J., Blanc, M., & Ernst, R. (2011). Species diversity of *Hyalinobatrachium* glassfrogs (Amphibia: Centrolenidae) from the Guiana Shield, with the description of two new species. *Zootaxa*, 3132, 1-55.
- Grant, T., Bolivar-G, W., & Castro, F. (1998). The advertisement call of *Centrolene geckoideum*. *Journal of Herpetology*, 452-455.
- Señaris, J.C. & Ayarzagüena, J. 2005. *Revisión taxonómica de la familia Centrolenidae (Amphibia; Anura) de Venezuela*. Comité Español del programa MaB y de la red IberoMaB de la UNESCO, Madrid.
- Kubicki, B. 2007. *Glass frogs*. Editorial INBio, Santo Domingo de Heredia.
- Wen, A., Vasquez, N., & Castroviejo-Fisher, S. (2012). Description of the previously unknown advertisement calls of *Hyalinobatrachium fragile*, *H. pellucidum*, and *Vitreorana antisthenesi* (Amphibia: Centrolenidae). *Zootaxa*, 3480(1), 80-87.

Dataset S3. Morphometric and natural history data for Centrolenidae species considered in the phylogenetic comparative analysis.

Species	Sex predominant parental caring	SVL (mm)	Reference	HW (mm)	Reference	TL (mm)	Reference	Calling site	Reference	Note
<i>Celsiella revocata</i>	?	23.6	Señaris & Ayarzagüena (2005)	8.59	Señaris & Ayarzagüena (2005)	12.65	Señaris & Ayarzagüena (2005)	Abaxial	Señaris & Ayarzagüena (2005)	
<i>Celsiella vozmediano</i>	Male	28.10	Señaris & Ayarzagüena (2005)	10.31	Señaris & Ayarzagüena (2005)	17.70	Ayarzagüena & Señaris (1996)	Adaxial	Señaris & Ayarzagüena (2005)	HL estimated from holotype
<i>Centrolene altitudinale</i>	?	23.20	Señaris & Ayarzagüena (2005)	8.49	Señaris & Ayarzagüena (2005)	13.46	Señaris & Ayarzagüena (2005)	Adaxial	Señaris & Ayarzagüena (2005)	
<i>Centrolene ballux</i>	Female	20.60	Duellman & Burrowes (1989)	7.60	Duellman & Burrowes (1989)	12.40	Duellman & Burrowes (1989)	Abaxial	Duellman & Burrowes (1989)	"All individuals were found at night on the upper surfaces of leaves of bushes"
<i>Centrolene buckleyi</i>	Female	29.00	Guayasam <i>in et al.</i> (2017)*; Lynch & Duellman (1973)	10.63	Lynch & Duellman (1973)	14.85	Lynch & Duellman (1973)	Adaxial	Guayasam <i>in et al.</i> (2017)	*Guayasamín, J. M., Frenkel, C., Varela-Jaramillo, A. y Santiago R. Ron 2017. <i>Centrolene buckleyi</i> En: Ron, S. R., Yanez-Muñoz, M. H., Merino-Viteri, A., Ortiz, D. A. (Eds). <i>Anfibios del Ecuador</i> . Version 2018.0. Museo de Zoología, Pontificia Universidad Católica del Ecuador. https://bioweb.bio/faunaweb/amphibiaweb/FichaEspecie/Centrolene%20buckleyi , acceso Miércoles, 10 de Enero de 2018.
<i>Centrolene condor</i>	?	27.60	Cisneros-Heredia & Morales-Mite (2008)	9.50	Cisneros-Heredia & Morales-Mite (2008)	14.90	Cisneros-Heredia & Morales-Mite (2008)	Adaxial	Guayasamín, <i>et al.</i> (2010)	Guayasamín, J. M., Varela-Jaramillo, A. y Frenkel, C 2010. <i>Centrolene condor</i> . En: Ron, S. R., Guayasamin, J. M., Yanez-Muñoz, M. H., Merino-Viteri, A., Ortiz, D. A. y Nicolalde, D. A. 2016. <i>AmphibiaWebEcuador</i> . Version 2016.0. Museo de Zoología, Pontificia Universidad Católica del Ecuador. < http://zoologia.puce.edu.ec/vertebrados/anfibios/FichaEspecie.aspx?Id=6871 >, acceso febrero 17, 2017.

Dataset S3. Continued.

Species	Sex predominant parental caring	SVL (mm)	Reference	HW (mm)	Reference	TL (mm)	Reference	Calling site	Reference	Note
<i>Centrolene daidaleum</i>	Male	21.70	Ruiz-Carranza & Lynch (1991)	7.62	Ruiz-Carranza & Lynch (1991)	11.87	Ruiz-Carranza & Lynch (1991)	Abaxial	Cardozo-Urdaneta & Señaris (2010)	
<i>Centrolene geckoideum</i>	Male	75.17	Rueda-Almonacid (1994)	27.93	Rueda-Almonacid (1994)	39.51	Rueda-Almonacid (1994)	Rocks	Rueda-Almonacid (1994)	
<i>Centrolene heloderma</i>	?	31.50	Duellman (1981)	10.74	Duellman (1981)	17.45	Duellman (1981)	Abaxial	Duellman (1981)	
<i>Centrolene hesperium</i>	Female	25.5	Cadle & McDiarmid (1990)	9.2	Cadle & McDiarmid (1990)	14.5	Cadle & McDiarmid (1990)	Adaxial	Cadle & McDiarmid (1990)	Holotype measurements
<i>Centrolene lynchi</i>	Female	24.70	Duellman (1980)	8.62	Duellman (1980)	14.77	Duellman (1980)	Abaxial	Duellman (1980)	
<i>Centrolene peristictum</i>	Female	19.70	Lynch & Duellman (1973)	6.42	Lynch & Duellman (1973)	10.80	Lynch & Duellman (1973)	Adaxial	Maldonado (2012)	
<i>Centrolene sabini</i>	?	30.53	Catenazzi <i>et al.</i> (2012)	9.73	Catenazzi <i>et al.</i> (2012)	16.65	Catenazzi <i>et al.</i> (2012)	outro	Catenazzi <i>et al.</i> (2009)	
<i>Centrolene savagei</i>	Male	21.09	Ruiz-Carranza & Lynch (1991)	7.12	Ruiz-Carranza & Lynch (1991)	11.68	Ruiz-Carranza & Lynch (1991)	Abaxial	Vargas-Salinas <i>et al.</i> (2007)	
<i>Centrolene venezuelense</i>	?	30.4	Señaris & Ayarzagüena (2005)	10.52	Señaris & Ayarzagüena (2005)	16.39	Señaris & Ayarzagüena (2005)	Adaxial	Señaris & Ayarzagüena (2005)	
<i>Chimerella corleone</i>	?	19.18	Twomey <i>et al.</i> (2014)	7.20	Twomey <i>et al.</i> (2014)	9.95	Twomey <i>et al.</i> (2014)	Abaxial	Twomey <i>et al.</i> (2014)	

Dataset S3. Continued.

Species	Sex predominant parental caring	SVL (mm)	Reference	HW (mm)	Reference	TL (mm)	Reference	Calling site	Reference	Note
<i>Chimerella mariaelenae</i>	Female	19.5	Guayasamin <i>et al.</i> (2013)*	7.40	Cisneros-Heredia & McDiarmid (2006)	10.80	Cisneros-Heredia & McDiarmid (2006)	Adaxial	Guayasamin <i>et al.</i> (2013)*	*Guayasamin, J. M., Frenkel, C., Varela-Jaramillo, A. y Cisneros-Heredia, D. F. 2013. <i>Chimerella mariaelenae</i> . En: Ron, S. R., Guayasamin, J. M., Yanez-Muñoz, M. H., Merino-Viteri, A., Ortiz, D. A. y Nicolalde, D. A. 2016. <i>AmphibiaWebEcuador</i> . Version 2016.0. Museo de Zoología, Pontificia Universidad Católica del Ecuador. < http://zoologia.puce.edu.ec/vertebrados/anfibios/FichaEspecie.aspx?Id=1572 >, acceso abril 18, 2017.
<i>Cochranella erminea</i>	?	23.40	Torres-Castello <i>et al.</i> (2007)	7.60	Torres-Castello <i>et al.</i> (2007)	13.60	Torres-Castello <i>et al.</i> (2007)	Abaxial	Twomey <i>et al.</i> (2014)	
<i>Cochranella euknemos</i>	Female	23.90	Savage & Starret (1967)	7.67	Savage & Starret (1967)	16.10	*Estimated from Fig. 1 in Savage & Starret (1967)	Adaxial	Kubicki (2007)	
<i>Cochranella granulosa</i>	Female	25.75	Savage (2002)	9.36	Santiago Castroviejo-Fisher	15.21	Santiago Castroviejo-Fisher	Adaxial	Kubicki (2007)	
<i>Cochranella guayasamini</i>	?	23.60	Twomey <i>et al.</i> (2014)	8.10	Twomey <i>et al.</i> (2014)	12.40	Twomey <i>et al.</i> (2014)	Adaxial	Twomey <i>et al.</i> (2014)	
<i>Cochranella mache</i>	?	23.90	Guayasamin <i>et al.</i> (2010)*	8.05	Guayasamin & Bonaccorso (2004)	14.45	Guayasamin & Bonaccorso (2004)	Adaxial	Guayasamin <i>et al.</i> (2010)*	*Guayasamin, J. M., Varela-Jaramillo, A., Frenkel, C. y Pazmiño-Armijos, G. 2010. <i>Cochranella mache</i> . En: Ron, S. R., Guayasamin, J. M., Yanez-Muñoz, M. H., Merino-Viteri, A., Ortiz, D. A. y Nicolalde, D. A. 2016. <i>AmphibiaWebEcuador</i> . Version 2016.0. Museo de Zoología, Pontificia Universidad Católica del Ecuador. < http://zoologia.puce.edu.ec/vertebrados/anfibios/

Dataset S3. Continued.

Species	Sex predominant parental caring	SVL (mm)	Reference	HW (mm)	Reference	TL (mm)	Reference	Calling site	Reference	Note
<i>Cochranella nola</i>	?	20.93	Harvey (1996)	7.77	Harvey (1996)	12.37	Harvey (1996)	Adaxial	Lötters & Köhler (2000)	
<i>Cochranella resplendens</i>	Female	27.30	Lynch & Duellman (1973)	9.50	Lynch & Duellman (1973)	14.61	Lynch & Duellman (1973)	Adaxial	Teran-Valdez <i>et al.</i> (2009)	Eggs on upper surface of leaves
<i>Espadarana andina</i>	?	26.40	Señaris & Ayarzagüena (2005)	8.90	Señaris & Ayarzagüena (2005)	15.29	Señaris & Ayarzagüena (2005)	Adaxial	Señaris & Ayarzagüena (2005)	Eggs on upper surface of leaves
<i>Espadarana audax</i>	Female	23.30	Lynch & Duellman (1973)	8.81	Lynch & Duellman (1973)	12.58	Lynch & Duellman (1973)	Adaxial	Duellman (1975) <i>in</i> Guayasamin <i>et al.</i> (2018)	Guayasamin, J. M., Frenkel, C., Varela-Jaramillo, A. y Cisneros-Heredia, D. F. 2018. <i>Espadarana audax</i> En: Ron, S. R., Yanez-Muñoz, M. H., Merino-Viteri, A. Ortiz, D. A. (Eds). <i>Anfibios del Ecuador</i> . Version 2018.0. Museo de Zoología, Pontificia Universidad Católica del Ecuador. https://bioweb.bio/faunaweb/amphibia web/FichaEspecie/Espadarana%20audax , acceso Sábado, 9 de Junio de 2018.
<i>Espadarana prosoblepon</i>	Female	24.10	Lynch & Duellman (1973)	8.22	Lynch & Duellman (1973)	13.16	Lynch & Duellman (1973)	Adaxial	Savage (2002)	
<i>Hyalinobatrachium aff. bergeri</i>	?	22.23	Santiago Castroviejo-Fisher	7.90	Santiago Castroviejo-Fisher	11.70	Santiago Castroviejo-Fisher	Abaxial	Santiago Castroviejo-Fisher	
<i>Hyalinobatrachium anachoretus</i>	?	21.00	Twomey <i>et al.</i> (2014)	8.10	Twomey <i>et al.</i> (2014)	10.85	Twomey <i>et al.</i> (2014)	Abaxial	Twomey <i>et al.</i> (2014)	
<i>Hyalinobatrachium bergeri</i>	?	21.50	Santiago Castroviejo-Fisher	7.70	Santiago Castroviejo-Fisher	11.80	Santiago Castroviejo-Fisher	Abaxial	Cannatella (1980)	
<i>Hyalinobatrachium cappellei</i>	?	21.80	Castroviejo-Fisher <i>et al.</i> (2011)	8.54	Castroviejo-Fisher <i>et al.</i> (2011)	11.97	Castroviejo-Fisher <i>et al.</i> (2011)	Abaxial	Castroviejo-Fisher <i>et al.</i> (2011)	
<i>Hyalinobatrachium carlesvilai</i>	?	22.85	Castroviejo-Fisher <i>et al.</i> (2009)	8.38	Castroviejo-Fisher <i>et al.</i> (2009)	11.84	Castroviejo-Fisher <i>et al.</i> (2009)	Abaxial	Castroviejo-Fisher <i>et al.</i> (2009)	

Dataset S3. Continued.

Species	Sex predominant parental caring	SVL (mm)	Reference	HW (mm)	Reference	TL (mm)	Reference	Calling site	Reference	Note
<i>Hyalinobatrachium chirripoi</i>	Male	24.50	Taylor (1958)	8.70	Taylor (1958)	13.75	Taylor (1958)	Adaxial	Guayasamín <i>et al.</i> (2010)	Guayasamín, J. M., Varela-Jaramillo, A., Frenkel, C. y Pazmiño-Armijos, G. 2010. <i>Hyalinobatrachium chirripoi</i> . Ron, S. R., Guayasamin, J. M., Yanez-Muñoz, M. H., Merino-Viteri, A., Ortiz, D. A. y Nicolalde, D. A. 2016. AmphibiaWeb Ecuador. Version 2016.0. Museo de Zoología, Pontificia Universidad Católica del Ecuador. < http://zoologia.puce.edu >
<i>Hyalinobatrachium colymbiphylum</i>	Male	25.60	Taylor (1949)	9.23	Taylor (1949)	13.93	Taylor (1949)	Abaxial	Savage (2002)	
<i>Hyalinobatrachium durantii</i>		21.90	Señaris & Ayarzagüena (2005)	8.19	Señaris & Ayarzagüena (2005)	11.69	Señaris & Ayarzagüena (2005)	Abaxial	Señaris & Ayarzagüena (2005)	
<i>Hyalinobatrachium fleischmanni</i>	Male	20.40	Lynch & Duellman (1973)	8.00	Lynch & Duellman (1973)	11.24	Lynch & Duellman (1973)	Abaxial	Varela-Jaramillo <i>et al.</i> (2010)	Varela-Jaramillo, A., Frenkel, C. y Pazmiño-Armijos, G. 2010. <i>Hyalinobatrachium fleischmanni</i> . E Ron, S. R., Guayasamin, J. M., Yanez-Muñoz, M. H., Merino-Viteri, A., Ortiz, D. A. y Nicolalde, D. A. 2016. AmphibiaWeb Ecuador. Vers 2016.0. Museo de Zoología, Pontificia Universidad Católica del Ecuador. < http://zoologia.puce.edu.ec/vertebrados/anfibios/FichaEspecie.aspx?Id=1 >, acceso enero 31, 2017.
<i>Hyalinobatrachium fragile</i>	?	20.30	Señaris & Ayarzagüena (2005)	7.29	Señaris & Ayarzagüena (2005)	10.66	Señaris & Ayarzagüena (2005)	Abaxial	Señaris & Ayarzagüena (2005)	
<i>Hyalinobatrachium guairarepanense</i>	?	22.6	Señaris & Ayarzagüena (2005)	8.68	Señaris & Ayarzagüena (2005)	12.48	Señaris & Ayarzagüena (2005)	Adaxial	Señaris & Ayarzagüena (2005)	
<i>Hyalinobatrachium iaspidiense</i>	?	20.1	Castroviejo-Fisher <i>et al.</i> (2011)	7.6	Castroviejo-Fisher <i>et al.</i> (2011)	11.6	Castroviejo-Fisher <i>et al.</i> (2011)	Abaxial	Castroviejo-Fisher <i>et al.</i> (2011)	

Dataset S3. Continued.

Species	Sex predominant parental caring	SVL (mm)	Reference	HW (mm)	Reference	TL (mm)	Reference	Calling site	Reference	Note
<i>Hyalinobatrachium kawense</i>	?	20.00	Castroviejo-Fisher <i>et al.</i> (2011)	6.90	Castroviejo-Fisher <i>et al.</i> (2011)	10.00	Castroviejo-Fisher <i>et al.</i> (2011)	Adaxial	Castroviejo-Fisher <i>et al.</i> (2011)	Only one male observed
<i>Hyalinobatrachium mesai</i>	?	20.0	Castroviejo-Fisher <i>et al.</i> (2011)	8.0	Castroviejo-Fisher <i>et al.</i> (2011)	11.2	Castroviejo-Fisher <i>et al.</i> (2011)	Adaxial	Castroviejo-Fisher <i>et al.</i> (2011)	
<i>Hyalinobatrachium mondolfii</i>	Male	21.30	Señaris & Ayarzagüena (2005)	8.25	Señaris & Ayarzagüena (2005)	11.72	Señaris & Ayarzagüena (2005)	Abaxial	Señaris & Ayarzagüena (2005)	
<i>Hyalinobatrachium orientale</i>	Male	21.50	Señaris & Ayarzagüena (2005)	8.06	Señaris & Ayarzagüena (2005)	11.89	Señaris & Ayarzagüena (2005)	Abaxial	Señaris & Ayarzagüena (2005)	
<i>Hyalinobatrachium orocostale</i>	?	20.10	Castroviejo-Fisher <i>et al.</i> (2008)	7.44	Castroviejo-Fisher <i>et al.</i> (2008)	10.63	Castroviejo-Fisher <i>et al.</i> (2008)	Abaxial	Castroviejo-Fisher <i>et al.</i> (2008)	
<i>Hyalinobatrachium pallidum</i>	Male	21.90	Señaris & Ayarzagüena (2005)	8.12	Señaris & Ayarzagüena (2005)	11.80	Señaris & Ayarzagüena (2005)	Abaxial	Cardozo-Urdaneta & Señaris (2012)	
<i>Hyalinobatrachium pellucidum</i>	Male	20.82	Guayasamin <i>et al.</i> (2010)*	7.64	Santiago Castroviejo-Fisher	11.67	Santiago Castroviejo-Fisher	Abaxial	Guayasamin <i>et al.</i> (2010)*	
<i>Hyalinobatrachium talamancae</i>	Male	22.0	Taylor (1958)	8.6	Taylor (1958)	12.2	Taylor (1958)	Abaxial	Taylor (1958)	
<i>Hyalinobatrachium tatayoi</i>	?	22.36	Castroviejo-Fisher <i>et al.</i> (2007)	8.36	Castroviejo-Fisher <i>et al.</i> (2007)	12.23	Castroviejo-Fisher <i>et al.</i> (2007)	Abaxial	Castroviejo-Fisher <i>et al.</i> (2007)	

*Guayasamin, J. M., Ron, S. R., Varela-Jaramillo, A. y Frenkel, C. 2010. *Hyalinobatrachium pellucidum*. En: Ron, S. R., Guayasamin, J. M., Yanez-Muñoz, M. H., Merino-Viteri, A., Ortiz, D. A. y Nicolalde, D. A. 2016. *AmphibiaWebEcuador*. Version 2016.0. Museo de Zoología, Pontificia Universidad Católica del Ecuador. <<http://zoologia.puce.edu.ec/vertebrados/anfibios/FichaEspecie.aspx?Id=1213>>, acceso enero 31, 2017.

Dataset S3. Continued.

Species	Sex predominant parental caring	SVL (mm)	Reference	HW (mm)	Reference	TL (mm)	Reference	Calling site	Reference	Note
<i>Hyalinobatrachium taylori</i>	?	19.12	Señaris & Ayarzagüena (2005)	7.18	Señaris & Ayarzagüena (2005)	10.36	Señaris & Ayarzagüena (2005)	Adaxial	Señaris & Ayarzagüena (2005)	
<i>Hyalinobatrachium tricolor</i>	?	20.50	Castroviejo-Fisher <i>et al.</i> (2011)	8.30	Castroviejo-Fisher <i>et al.</i> (2011)	10.85	Castroviejo-Fisher <i>et al.</i> (2011)	Abaxial	Castroviejo-Fisher <i>et al.</i> (2011)	
<i>Hyalinobatrachium valerioi</i>	Male	21.54	Santiago Castroviejo-Fisher	7.90	Santiago Castroviejo-Fisher	11.63	Santiago Castroviejo-Fisher	Abaxial	Savage (2002); Vockenhuber <i>et al.</i> (2008)	
<i>Ikakogi tayrona</i>	Female	29.5	Ruiz-Carranza & Lynch (1991)	10.89	Ruiz-Carranza & Lynch (1991)	16.46	Ruiz-Carranza & Lynch (1991)	Abaxial	Vargas-Salinas <i>et al.</i> (2015)	
<i>Nymphargus bejaranoi</i>	?	24.20	José M. Padial	8.85	José M. Padial	13.60	José M. Padial	Adaxial	Köhler (2000)	
<i>Nymphargus grandisonae</i>	Female	27.20	Duellman (1980)	9.30	Duellman (1980)	15.67	Duellman (1980)	Adaxial	Duellman (1980)	
<i>Nymphargus griffithsi</i>	Female	24.10	Lynch & Duellman (1973)	7.78	Lynch & Duellman (1973)	13.30	Lynch & Duellman (1973)	Adaxial	Lynch & Duellman (1973)	
<i>Nymphargus lasgralarias</i>	Female	25.34	Hutter & Guayasamin (2012)	8.69	Hutter & Guayasamin (2012)	14.83	Hutter & Guayasamin (2012)	Adaxial	Hutter & Guayasamin (2012)	
<i>Nymphargus phenax</i>	?	21.30	Cannatella & Duellman (1982)	?	-	12.13	Cannatella & Duellman (1982)	Adaxial	Cannatella & Duellman (1982)	
<i>Nymphargus pluvialis</i>	?	27.08	Juan C. Chaparro	9.30	Juan C. Chaparro	16.53	Juan C. Chaparro	Adaxial	Cannatella & Duellman (1982)	

Dataset S3. Continued.

Species	Sex predominant parental caring	SVL (mm)	Reference	HW (mm)	Reference	TL (mm)	Reference	Calling site	Reference	Note
<i>Nymphargus siren</i>	?	20.80	Lynch & Duellman (1973)	7.22	Lynch & Duellman (1973)	11.92	Lynch & Duellman (1973)	Adaxial	Duellman <i>in</i> Guayasamin <i>et al.</i> (2010)	Guayasamin, J. M., Varela-Jaramillo, A. y Frenkel, C. 2010. <i>Nymphargus siren</i> . En: Ron, S. R., Guayasamin, J. M., Yanez-Muñoz, M. H., Merino-Viteri, A., Ortiz, D. A. y Nicolalde, D. A. 2016. <i>AmphibiaWebEcuador</i> . Version 2016.0. Museo de Zoología, Pontificia Universidad Católica del Ecuador. < http://zoologia.puce.edu.ec/vertebrados/anfibios/FichaEspecie.aspx?Id=1209 >, acceso febrero 01, 2017.
<i>Nymphargus truebae</i>	?	23.30	Duellman (1976)	8.42	Duellman (1976)	13.44	Duellman (1976)	Adaxial	Duellman (1976)	
<i>Rulyrana flavopunctata</i>	?	21.60	Lynch & Duellman (1973)	7.82	Lynch & Duellman (1973)	12.53	Lynch & Duellman (1973)	Adaxial	Lynch & Duellman (1973)	
<i>Rulyrana saxiscandens</i>	?	22.00	Duellman & Schulte (1993)	7.70	Duellman & Schulte (1993)	12.90	Duellman & Schulte (1993)	Adaxial	Duellman & Schulte (1993); E. Twomey (<i>pers. com.</i>)	
<i>Rulyrana spiculata</i>	?	22.20	Duellman (1976)	8.04	Duellman (1976)	12.65	Duellman (1976)	Adaxial	Duellman (1976)	
<i>Sachatamia albomaculata</i>	Female	22.58	Santiago Castroviejo-Fisher	7.55	Santiago Castroviejo-Fisher	13.83	Santiago Castroviejo-Fisher	Adaxial	Kubicki (2007)	
<i>Sachatamia ilex</i>	?	29.34	Santiago Castroviejo-Fisher	10.11	Santiago Castroviejo-Fisher	17.54	Santiago Castroviejo-Fisher	Adaxial	Kubicki (2007); Guayasamin <i>et al.</i> (2017)	Guayasamin, J. M., Varela-Jaramillo, A. y Frenkel, C. 2017. <i>Sachatamia ilex</i> . En: Ron, S. R., Yanez-Muñoz, M. H., Merino-Viteri, A., Ortiz, D. A. (Eds). <i>Anfibios del Ecuador</i> . Version 2018.0. Museo de Zoología, Pontificia Universidad Católica del Ecuador. https://bioweb.bio/faunaweb/amphibiaweb/FichaEspecie/Sachatamia%20ilex

Dataset S3. Continued.

Species	Sex predominant parental caring	SVL (mm)	Reference	HW (mm)	Reference	TL (mm)	Reference	Calling site	Reference	Note
<i>Teratohyla pulverata</i>	Female	24.23	José M. Padial	8.32	José M. Padial	14.57	José M. Padial	Adaxial	Bustamante <i>et al.</i> (2007)	
<i>Teratohyla midas</i>	Female	18.40	Lynch & Duellman (1973)	6.62	Lynch & Duellman (1973)	10.62	Lynch & Duellman (1973)	Adaxial	Guayasamin <i>et al.</i> (2013)	Guayasamin, J. M., Frenkel, C., Ron, S. R. y Ortiz, D. A. 2013. <i>Teratohyla midas</i> . En: Ron, S. R., Guayasamin, J. M., Yanez-Muñoz, M. H., Merino-Viteri, A., Ortiz, D. A. y Nicolalde, D. A. 2016. AmphibiaWebEcuador. Version 2016.0. Museo de Zoología, Pontificia Universidad Católica del Ecuador. < http://zoologia.puce.edu.ec/vertebrados/anfibios/FichaEspecie.aspx?id=1206 >, acceso febrero 02, 2017.
<i>Teratohyla spinosa</i>	Female	19.50	José M. Padial	6.91	José M. Padial	11.60	José M. Padial	Adaxial	Guayasamin <i>et al.</i> (2010)	Guayasamin, J. M., Varela-Jaramillo, A., Frenkel, C. y Pazmiño-Armijos, G. 2010. <i>Teratohyla spinosa</i> . En: Ron, S. R., Guayasamin, J. M., Yanez-Muñoz, M. H., Merino-Viteri, A., Ortiz, D. A. y Nicolalde, D. A. 2016. AmphibiaWebEcuador. Version 2016.0. Museo de Zoología, Pontificia Universidad Católica del Ecuador. < http://zoologia.puce.edu.ec/vertebrados/anfibios/FichaEspecie.aspx?id=1210 >, acceso febrero 02, 2017.
<i>Vitreorana antisthenesi</i>	?	25.41	Señaris & Ayarzagüena (2005)	9.10	Señaris & Ayarzagüena (2005)	14.15	Señaris & Ayarzagüena (2005)	Adaxial	Señaris & Ayarzagüena (2005)	
<i>Vitreorana castroviejo</i>	?	22.50	Señaris & Ayarzagüena (2005)	7.97	Señaris & Ayarzagüena (2005)	13.10	Ayarzagüena & Señaris 1996	Adaxial	Ayarzagüena & Señaris 1996	HL estimated from the holotype
<i>Vitreorana eurygnatha</i>	?	20.40	Heyer <i>et al.</i> (1990)	7.34	Heyer <i>et al.</i> (1990)	11.22	Heyer <i>et al.</i> (1990)	Adaxial	Heyer <i>et al.</i> (1990)	
<i>Vitreorana gorzulae</i>	?	20.60	Señaris & Ayarzagüena (2005)	8.38	Señaris & Ayarzagüena (2005)	12.38	Señaris & Ayarzagüena (2005)	Adaxial	Señaris & Ayarzagüena (2005)	
<i>Vitreorana helenae</i>	?	19.10	Ayarzagüena 1992	7.70	Ayarzagüena 1992	11.10	Ayarzagüena 1992	Adaxial	Señaris & Ayarzagüena (2005)	

Dataset S3. Continued.

Species	Sex predominant parental caring	SVL (mm)	Reference	HW (mm)	Reference	TL (mm)	Reference	Calling site	Reference	Note
<i>Vitreorana oyampiensis</i>	Female	18.40	Señaris & Ayarzagüena (2005)	7.62	Señaris & Ayarzagüena (2005)	10.54	Señaris & Ayarzagüena (2005)	Adaxial	Señaris & Ayarzagüena (2005)	
<i>Vitreorana uranoscopa</i>	?	21.20	Heyer <i>et al.</i> (1990)	7.63	Heyer <i>et al.</i> (1990)	11.87	Heyer <i>et al.</i> (1990)	Adaxial	Machado <i>et al.</i> (2014); Zaracho (2014); Haga <i>et al.</i> (2014)	

References

- Ayarzagüena, J., & Señaris, J. C. (1996). Dos nuevas especies de *Cochranella* (Anura: Centrolenidae) para Venezuela. Publicaciones de la Asociación de Amigos de Doñana, 8, 1-16.
- Bustamante, M. R., Cisneros-Heredia, D. F., Yáñez-Muñoz, M. H., Ortega-Andrade, H. M., & Guayasamin, J. M. (2007). Amphibia, Centrolenidae, *Cochranella pulverata*, *Hyalinobatrachium aureoguttatum*: distribution extension, Ecuador. Check List, 3(3), 271-276.
- Cadle, J. E., & McDiarmid, R. W. (1990). Two new species of *Centrolenella* (Anura: Centrolenidae) from northwestern Peru. Proceedings of the Biological Society of Washington, 103 (3): 746-768.
- Cannatella, D. C., & Duellman, W. E. (1982). Two new species of *Centrolenella*, with a brief review of the genus in Perú and Bolivia. Herpetologica: 380-388.
- Cannatella, D. C. (1980). Two new species of *Centrolenella* from Bolivia (Anura: Centrolenidae). Proceedings of the Biological Society of Washington, 93, 714-724.
- Cardozo-Urdaneta, A. & Señaris, J. C. 2012 Primer registro de un comportamiento de combate en la rana de cristal *Hyalinobatrachium pallidum* (Rivero, 1985)(Anura: Centrolenidae). ANARTIA, 24: 83 – 88.
- Cardozo-Urdaneta, A., & Señaris, J. C. (2012). Vocalización y biología reproductiva de las ranas de cristal *Hyalinobatrachium pallidum* y *Centrolene daidaleum* (Anura, Centrolenidae) en la sierra de Perijá, Venezuela. Memoria de la Fundación La Salle de Ciencias Naturales, 70(173-174), 87-105.
- Castroviejo-Fisher, S., Vila, C., Ayarzagüena, J., Blanc, M., & Ernst, R. (2011). Species diversity of *Hyalinobatrachium* glassfrogs (Amphibia: Centrolenidae) from the Guiana Shield, with the description of two new species. Zootaxa, 3132, 1-55.
- Castroviejo-Fisher, S., Padial, J. M., Chaparro, J. C., Aguayo, R., & De La Riva, I. (2009). A new species of *Hyalinobatrachium* (Anura: Centrolenidae) from the Amazonian slopes of the central Andes with comments on the diversity of the genus in the area. Zootaxa, (2143), 24-44.

- Catenazzi, A., Rodriguez, L. O., & Donnelly, M. A. (2009). The advertisement calls of four species of glassfrogs (Centrolenidae) from southeastern Peru. *Studies on Neotropical Fauna and Environment*, 44(2), 83-91.
- Duellman, W. E., & Burrowes, P. A. (1989). New species of frogs, *Centrolenella*, from the Pacific versant of Ecuador and southern Colombia. *Occasional papers of the museum of natural history, the University of Kansas*, 132: 1-14.
- Duellman, W. E., & Schulte, R. (1993). New species of centrolenid frogs from northern Peru. *Occasional papers of the Museum of natural history. The Univ. of Kansas*, 155: 1-33.
- Duellman, W. E. (1981). Three new species of centrolenid frogs from the Pacific versant of Ecuador and Colombia (No. 59 UNI). *Museum of Natural History, University of Kansas*, 88: 1-9.
- Duellman, W. E. (1980). The identity of *Centrolenella grandisonae* Cochran and Goin (Anura: Centrolenidae). *Transactions of the Kansas Academy of Science* (1903), 26-32.
- Duellman, W. E. (1980). Centrolenid frogs from Perú. *Occasional papers of the museum of natural history, the University of Kansas*, 52: 1-11.
- Guayasamin, J. M. (2013). A new yellow species of glassfrog (Centrolenidae: *Nymphargus*) from the Amazonian slopes of the Ecuadorian Andes. *Zootaxa*, 3652(1), 193-200.
- Haga, I. A., De Andrade, F. S., Toscano, N. P., Kwet, A., & Giaretta, A. A. (2014). Advertisement call and habitat of *Vitreorana uranoscopa* (Anura: Centrolenidae) in Brazil. *SALAMANDRA* 50 (4): 236-240.
- Heyer, W. R., Rand, A. S., da Cruz, C. A. G., Peixoto, O. L., & Nelson, C. E. (1990). Frogs of Boracéia. *Arquivos de Zoologia (São Paulo)*, 31(4), 231-410.
- Hutter, C. R., & Guayasamin, J. M. (2012). A new cryptic species of glassfrog (Centrolenidae: *Nymphargus*) from Reserva Las Gralarias, Ecuador. *Zootaxa*, 3257, 1-21.

- Köhler, J. (2000). Amphibian diversity in Bolivia: a study with special reference to montane forest regions (No. 48). Zoologisches Forschungsinstitut und Museum Alexander Koenig.
- Kubicki, B. 2007. *Glass frogs*. Editorial INBio, Santo Domingo de Heredia. Lötters & Köhler 2000
- Lynch JD, Duellman WE. 1973. A review of the centrolenid frogs of Ecuador, with descriptions of new species. Occasional Papers, Museum of Natural History, University of Kansas 16: 1–66.
- Machado, I. F., Bühler, D., Abadie, M., Júnior, A. P. S. J., & Santos, R. R. Distribution extension of *Vitreorana uranoscopa* (Anura: Centrolenidae) in the state of Rio Grande do Sul, southern Brazil.
- Maldonado, A. (2012). Cuidado parental y selección sexual en *Centrolene peristictum* (Anura: Centrolenidae). *Disertación previa a la obtención del título de Licenciada en Ciencias Biológicas*. Pontificia Universidad Católica del Ecuador.
- Rueda-Almonacid, J. V. (1994). Estudio anatómico y relaciones sistemáticas de *Centrolene geckoideum* (Salientia: Anura: Centrolenidae). *Trianea*, 5, 133-187.
- Savage, J. M. (2002). *The amphibians and reptiles of Costa Rica: a herpetofauna between two continents, between two seas*. University of Chicago press.
- Señaris, J.C. & Ayarzagüena, J. 2005. *Revisión taxonómica de la familia Centrolenidae (Amphibia; Anura) de Venezuela*. Comité Español del programa MaB y de la red IberoMaB de la UNESCO, Madrid.
- Taylor, E. H. (1952). A review of the frogs and toads of Costa Rica. Revisión de las ranas y sapos de Costa Rica. *The University of Kansas Science Bulletin.*, 35(1), 577-941.
- Terán-Valdez, A., Guayasamin, J. M., & Coloma, L. A. (2009). Description of the tadpole of *Cochranella resplendens* and redescription of the tadpole of *Hyalinobatrachium aureoguttatum* (Anura, Centrolenidae). *Phyllomedusa: Journal of Herpetology*, 8(2), 105-124

- Twomey, E., Delia, J., & Castroviejo-Fisher, S. (2014). A review of Northern Peruvian glassfrogs (Centrolenidae), with the description of four new remarkable species. *Zootaxa*, 3851(1), 001-087.
- Vargas-Salinas, F., López-Aranda, F. A., & Muñoz-González, N. J. (2007). *Cochranella savagei* (Savage's glass frog). *Herpetological Review*, 38(4), 436-437.
- Vockenhuber, E. A., Hödl, W., & Karpfen, U. (2008). Reproductive behaviour of the glass frog *Hyalinobatrachium valerioi* (Anura: Centrolenidae) at the tropical stream Quebrada Negra (La Gamba, Costa Rica). *Stapfia*, 88, 335-348.
- Zaracho, V. H. (2014). Re-description of the advertisement call of *Vitreorana uranoscopa* (Müller, 1924) (Anura, Centrolenidae) from the Argentinean Atlantic forest, with notes on natural history. *South american journal of herpetology*, 9(2), 83-89.

3. REFERÊNCIAS

- Castroviejo-Fisher, S., Guayasamin, J.M., Gonzalez-Voyer, A. & Vilà, C. 2014. Neotropical diversification seen through glassfrogs. *J. Biogeogr.* **41**: 66–80.
- Cisneros-Heredia, D.F. & McDiarmid, R.W. 2007. Revision of the characters of Centrolenidae (Amphibia: Anura: Athesphatanura), with comments on its taxonomy and the description of new taxa of glassfrogs. *Zootaxa* **1572**: 1–82.
- Cocroft, R.B. & Ryan, M.J. 1995. Patterns of advertisement call evolution in toads and chorus frogs. *Anim. Behav.* **49**: 283–303.
- Erdtmann, L. & Amézquita, A. 2009. Differential evolution of advertisement call traits in dart-poison frogs (Anura: Dendrobatidae). *Ethology* **115**: 801–811.
- Erdtmann, L.K. 2012. Propagação e reconhecimento específico do canto de anúncio de anuros: no tempo e espaço. Instituto Nacional de Pesquisas da Amazônia (INPA), Manaus.
- Felsenstein, J. 1985. Phylogenies and the comparative method. *Am. Nat.* **125**: 1–15.
- Goutte, S., Dubois, A., Howard, S.D., Marquez, R., Rowley, J.J., Dehling, J.M. *et al.* 2016. Environmental constraints and call evolution in torrent-dwelling frogs. *Evolution* **70**: 811–826.
- Guayasamin, J.M., Castroviejo-Fisher, S., Trueb, L., Rada, M. & Vila, C. 2009. Phylogenetic systematics of Glassfrogs (Amphibia: Centrolenidae) and their sister taxon *Allophryne ruthveni*. *Zootaxa* **2100**: 1–97.
- Harvey, P. H. & Pagel, M.D. 1991. *The comparative method in evolutionary biology*. Oxford university press.

- Pagel, M. 1999. Inferring the historical patterns of biological evolution. *Nature* **401**: 877–884.
- Paradis, E., Claude J. & Strimmer K. 2004. APE: analyses of phylogenetics and evolution in R language. *Bioinformatics* **20**: 289–290.
- Kubicki, B. 2007. *Glass frogs*. Editorial INBio, Santo Domingo de Heredia.
- Santos, J.C., Baquero, M., Barrio-Amorós, C., Coloma, L.A., Erdtmann, L.K., Lima, A.P. & Cannatella, D.C. 2014. Aposematism increases acoustic diversification and speciation in poison frogs. *Proc. Royal Soc. Lond. B: Biol. Sci.* **281**: 20141761.
- Señaris, J.C. & Ayarzagüena, J. 2005. *Revisión taxonómica de la familia Centrolenidae (Amphibia; Anura) de Venezuela*. Comité Español del programa MaB y de la red IberoMaB de la UNESCO, Madrid.
- Wells, K.D. 2007. *The ecology and behavior of amphibians*. University of Chicago Press, Chicago.
- Wilkins, M.R., Seddon, N. & Safran, R.J. 2013. Evolutionary divergence in acoustic signals: causes and consequences. *Trends Ecol. Evol.* **28**: 156–66.

4. ANEXOS – Pareceres da banca de avaliação da dissertação

DISSERTATION EVALUATION FORM

TITLE OF THESIS/DISSERTATION: The evolution of acoustic mating signals in Glassfrogs
(Centrolenidae Taylor, 1951)

CANDIDATE: Moisés D. Escalona Sulbarán

EVALUATOR: Dr. Walter Hödl

1. FORMAL PRESENTATION OF THE TEXT:

1.1. Quality of figures and tables:

Fully Satisfactory Satisfactory Insufficient

1.2. Correctness of spelling and grammar:

Fully Satisfactory Satisfactory Insufficient

1.3. Language quality regarding precision and objectivity:

Fully Satisfactory Satisfactory Insufficient

2. ORIGINALITY AND RELEVANCE OF THE RESEARCH:

2.1. Does the study qualify as an original research project?

Yes No

2.2. Is the study scientifically relevant?

Yes No

3. IS THE LITERATURE REVIEW SUFFICIENT AND ADEQUATE TO MEET THE PROPOSED OBJECTIVES?

Yes Partially No

4. ARE THE METHODS ADEQUATE TO MEET THE OBJECTIVES OF THE STUDY?

Yes Partially No

5. ARE THE RESULTS RELEVANT AND RELIABLE?

Yes Partially No

6. DISCUSSION AND CONCLUSIONS:

6.1. Are the results discussed employing relevant points and consistent logic?

Yes Partially No

6.2. As the conclusions supported by the data?

Yes Partially No

7. QUALITY OF THE DEFENSE (For Ph.D. Dissertations only).

Fully Satisfactory Satisfactory Insufficient

8. PLEASE COMPOSE A WRITTEN REVIEW OF THE DISSERTATION/THESIS, AND ENCLOSE IT WITH THIS FORM.

The evolution of acoustic mating signals in glassfrogs (Centrolenidae Taylor, 1951)

In his master's dissertation, performed in a two year project, the author analyzed the association of shared ancestry, body size, calling site, and environmental noise and parental care with temporal and spectral call parameters in the anuran family Centrolenidae, by creating phenotypic databases and applying modern phylogenetic comparative methods.

The thesis represents an innovative approach to analyze the causes for the variation of acoustic signals among the glassfrogs, a family comprising over 150 species. Acoustic data were compiled for 72 species including representatives of all genera. Data were mainly taken from audio recordings of museum collections. Morphometric and calling site data as well as phylogenetic data were taken from the literature. Thus the real value of the thesis comes from the compilation of a large data set and its application in assessing the associations between acoustic traits and phenotypic as well as environmental variables. Highly remarkable –although still very speculative- is the effort to analyze the temporal dynamic of phenotypic evolution.

I truly congratulate the author to this fantastic overview of the literature on acoustic, morphological, ecological and phylogenetic aspects with regard to anuran behavior. The thesis is a perfect introduction to the evolutionary aspects of (acoustic) anuran behavior. I just wish that with these sound theoretical analyses, readers (or the author himself?) will use it as a starting point for studying the life history and behavior of a single species, as many of the discussed aspects derive only from (very) anecdotal data.

Since I am not very familiar with phylogenetic comparative methods I just will comment on one aspect, which is related to the lack of ecological and/or life history data in the glass frog family.

Contrary to several recent papers on a similar topic - none of the call traits tested in this thesis correlated with potential environmental noise. Even though the author considered a proxy for the occurrence of potentially noisy streamside environments by the Terrain ruggedness index, streamside environments of glassfrogs do not necessarily provide noisy habitats. I agree with the author and I am actually not surprised. In the contrary: glassfrogs are generally the only reproductively active anurans at – often slow-flowing and almost silent - streams whereas f.e. many pond breeding frogs have to deal with the sound produced by co-occurring species, covering a large range of frequencies. Torrent frogs (and I wouldn't include glassfrogs to this ecologically defined group) such as *Hylodes* spp. or *Staurois* spp. breeding at fast-flowing, turbulent streams or even water falls, however, do show clear adaptations to the very noisy environment by producing high pitched sounds (even species with relatively large body sizes!) and occasionally even in combination with visual signals.

With regard to the title I am not convinced that the term acoustic mating signals is fully appropriate. Mating signals (or mating calls) are per definition signals which lead to or finally end with mating. I am not convinced that all analyzed calls have actually led to mating. Most likely the calls function to attract females and/or to keep off males. For these calls the term advertisement call has been accepted ever since Well's famous *Anim.Beh.* 1977 paper.

In summary I congratulate the author (and his advisor!) to have considered such an attractive and innovative topic. The paper is well written and the methods –to the best of my knowledge- well applied. The discussion and the presentation of the analytical results is clear. Personally I like the thought- and carefulness which is reflected throughout the paper with regard to a speculative topic such as the evolution of acoustic traits in a little known frog family.

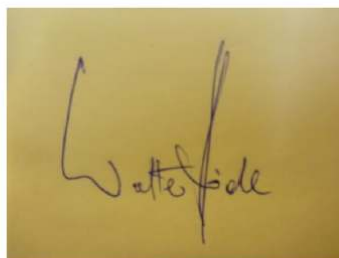
Walter Hödl

Vienna, 23.3.2018

9. As a global assessment, please fill in the box below with the statement “PASS” if you consider the Dissertation or Thesis to have fulfilled the requirements for a Ph.D. or M.Sc. degree, respectively. If you do not consider the Dissertation/Thesis to have achieved such level, fill in the word “FAIL”.

PASS

PLACE AND DATE: Vienna, 23.3.2018



Signature: _____

DISSERTATION EVALUATION FORM

TITLE OF THESIS/DISSERTATION: The evolution of acoustic mating signals in Glassfrogs
(Centrolenidae Taylor, 1951)

CANDIDATE: Moisés D. Escalona Sulbarán

EVALUATOR: Dr. Sandra M. Goutte

1. FORMAL PRESENTATION OF THE TEXT:

1.1. Quality of figures and tables:

Fully Satisfactory Satisfactory Insufficient

1.2. Correctness of spelling and grammar:

Fully Satisfactory Satisfactory Insufficient

1.3. Language quality regarding precision and objectivity:

Fully Satisfactory Satisfactory Insufficient

2. ORIGINALITY AND RELEVANCE OF THE RESEARCH:

2.1. Does the study qualify as an original research project?

Yes No

2.2. Is the study scientifically relevant?

Yes No

3. IS THE LITERATURE REVIEW SUFFICIENT AND ADEQUATE TO MEET THE PROPOSED OBJECTIVES?

Yes Partially No

4. ARE THE METHODS ADEQUATE TO MEET THE OBJECTIVES OF THE STUDY?

Yes Partially No

5. ARE THE RESULTS RELEVANT AND RELIABLE?

Yes Partially No

6. DISCUSSION AND CONCLUSIONS:

6.1. Are the results discussed employing relevant points and consistent logic?

Yes Partially No

6.2. As the conclusions supported by the data?

Yes Partially No

7. QUALITY OF THE DEFENSE (For Ph.D. Dissertations only).

Fully Satisfactory Satisfactory Insufficient

8. PLEASE COMPOSE A WRITTEN REVIEW OF THE DISSERTATION/THESIS, AND ENCLOSE IT WITH THIS FORM.

9. As a global assessment, please fill in the box below with the statement "PASS" if you consider the Dissertation or Thesis to have fulfilled the requirements for a Ph.D. or M.Sc. degree, respectively. If you do not consider the Dissertation/Thesis to have achieved such level, fill in the word "FAIL".

PASS



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PLACE AND DATE: Abu Dhabi, 27 March 2018

Signature: _____

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In his Masters dissertation, Mr Moisés D. Escalona Sulbarán studies call evolution in relation to morphology, habitat, reproductive behavior and shared ancestry in 72 species of glassfrogs. Overall, the dissertation is very well written and agreeable to read, especially for a Masters dissertation. I believe that this manuscript, given some moderate modifications, will be easily published as an article in a scientific journal. The study is overall well designed and complete, although I think that it could have benefitted from being more focused on less questions (see detailed comments below). Mr Escalona Sulbarán clearly put a lot of work in this dissertation, conducting several analyses and sampling an important number of species. This serious work should definitively confer Mr Escalona Sulbarán a M. Sc. degree.

I list below my main comments and attach the annotated manuscript with detailed comments.

Many interesting questions structure this study, and Mr. Escalona Sulbarán came up with six hypotheses to be tested; that might be too many for a single dissertation though. This results in sections that would deserve to be expanded (see comments on the manuscript) and some unsatisfactory tests (hypothesis 2 and 3).

The choice of certain variables would deserve further explanations: Mr Escalona Sulbarán explains that snout-vent length is linked to call dominant frequency, so it does make sense to use it in the analysis. However, the two other morphological measurements, head width and tibia length don't seem directly correlated with acoustic signal production. At several points in the manuscript, one can wonder why these measurements were used. If I understand correctly, those measurements were used especially because they are not linked to call production, in order to compare the evolution rates of morphology and calls. If so, this should be more clearly explained in the methods. It was also not clear to me whether the two measures were corrected for size in the analysis. If that was not the case, then they would mostly reflect size differences between species rather than shape.

I seriously question the use of Terrain Ruggedness Index as a proxy for ambient noise level. Ambient noise level is highly variable both in time and space, with variations between points centimeters away or measures taken at the same point hours from one another. For example, a heavy rain will instantaneously increase noise level. If a stream frog calls next to a boulder, its perceived noise level will highly depend on whether the boulder is in between the stream and the frog or is the frog is between the stream and the boulder. The Terrain Ruggedness Index therefore does not seem an appropriate proxy for ambient noise level. If this work is to be submitted for publication, I would suggest to remove this section altogether; the data is simply insufficient to test hypotheses on call adaptation to noise level (and there is enough data and analyses to make for an interesting paper without this section). This work has some nice results that could be better highlighted by removing unnecessary analyses.

For the call frequency bandwidth, I wonder why Mr. Escalona Sulbarán chose a -20 dB threshold, which is very low.

My evaluation of Mr. Escalona Sulbarán's work was hindered by the fact that I did not have access to any of the data (raw or transformed) in any form. Three datasets are cited in the text but not given. In addition, the Results section is missing a paragraph describing the data: what is a call diversity? What about the morphological measurements? In a Masters dissertation, one would expect to have data and description of the



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various datasets in an organized manner. Also, I would have liked to see more photos of the frogs, calling in the different positions for example!

I ignore if the length of the dissertation is a requirement, but the manuscript would benefit from expansions, in the methods, results and discussion sections. For example, the phylogenetic comparative analyses are described very briefly and vaguely. Overall, this is a very good dissertation and will be a solid publication after a few changes.

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DISSERTATION EVALUATION FORM

TITLE OF THESIS/DISSERTATION: The evolution of acoustic mating signals in Glassfrogs
(Centrolenidae Taylor, 1951)

CANDIDATE: Moisés D. Escalona Sulbarán

EVALUATOR: Dr. Liam J. Revell

1. FORMAL PRESENTATION OF THE TEXT:

1.1. Quality of figures and tables:

Fully Satisfactory Satisfactory Insufficient

1.2. Correctness of spelling and grammar:

Fully Satisfactory Satisfactory Insufficient

1.3. Language quality regarding precision and objectivity:

Fully Satisfactory Satisfactory Insufficient

2. ORIGINALITY AND RELEVANCE OF THE RESEARCH:

2.1. Does the study qualify as an original research project?

Yes No

2.2. Is the study scientifically relevant?

Yes No

3. IS THE LITERATURE REVIEW SUFFICIENT AND ADEQUATE TO MEET THE PROPOSED OBJECTIVES?

Yes Partially No

4. ARE THE METHODS ADEQUATE TO MEET THE OBJECTIVES OF THE STUDY?

Yes Partially No

5. ARE THE RESULTS RELEVANT AND RELIABLE?

Yes Partially No

6. DISCUSSION AND CONCLUSIONS:

6.1. Are the results discussed employing relevant points and consistent logic?

Yes Partially No

6.2. As the conclusions supported by the data?

Yes Partially No

7. QUALITY OF THE DEFENSE (For Ph.D. Dissertations only).

Fully Satisfactory Satisfactory Insufficient

8. PLEASE COMPOSE A WRITTEN REVIEW OF THE DISSERTATION/THESIS, AND ENCLOSE IT WITH THIS FORM.

9. As a global assessment, please fill in the box below with the statement "PASS" if you consider the Dissertation or Thesis to have fulfilled the requirements for a Ph.D. or M.Sc. degree, respectively. If you do not consider the Dissertation/Thesis to have achieved such level, fill in the word "FAIL".

PASS



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PLACE AND DATE:

28 March 2018

Signature: _____

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Written review of thesis: Moisés D. Escalona Sulbarán

I found this thesis on the evolution of acoustic signaling in glass frogs (Centrolenidae) to be generally very well-written and interesting. I made a number of comments on the text; however, these were provided to improve the writing not as a reflection of serious deficiency. To the contrary, compared to other Master's theses I have reviewed, this one was remarkably well-written and clear.

The study used a unique dataset of acoustic traits for the frog call of centrolenids combined with a variety of other morphological, behavioral, ecological, and proxy ecological traits to attempt to understand the basis for call variation among species. In general, the author found high phylogenetic signal and strong evidence for the effect of body size on call attributes, but less evidence for a direct effect of environmental conditions, such as terrain ruggedness, or call position, such as above or below the leaf.

I unequivocally recommend an evaluation of 'pass;' however, I will nonetheless emphasize some comments which I also noted in my review.

- 1) For a thesis in which the phylogeny is so integral, there is very little information presented about how the tree was estimated. This is an oversight that should be addressed.
- 2) Many important references underlying different methods employed in the study are not included. For instance, Paradis (2014) is cited as a general reference for phylogenetic comparative methods, and the phylogenetic regression is attributed to Martins & Hansen (1997).
- 3) The author should be careful not to over-interpret the results of this study. For instance, in one place the author obtains a 'marginally' ($0.05 < P < 0.10$) result, notes it as such, and then proceeds to discuss it for a paragraph as if real. There are other less blatant instances.
- 4) Finally, I'm of the mind that it is almost always better to anticipate criticism than to respond to it. To that end, I would encourage the author to think carefully about the limitations of both data and method. For instance, one possible explanation for the absence of a correlation between TRI and call attributes is that no such correlation exists, or furthermore that relevant variation does not exist because all glass frogs are torrent-adapted (as suggested by the author). Another is that TRI simply does not capture any relevant ecological variation in the environmental attribute (noisiness) of principal interest.

To re-emphasize, however, I think that this document is certainly worthy of being considered a more than worthy Masters' thesis contribution. I look forward to seeing it published.



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