Distribution, habitat suitability, conservation state and natural history of endangered salamander *Bolitoglossa pandi*

Teddy Angarita-Sierra [Corresp., 1, 2, 3], Maria A. Bonilla-Gómez [3], David A. Sánchez [1, 4], Andres R. Acosta-Galvis [5], Hefzi Medina-Ovalle [3], Anggi Solano-Moreno [3], Simon Ulloa-Rengifo [3], Daniela Guevara-Guevara [3], Juan J. Torres-Ramirez [3], Juan S. Curaca-Fierro [3], Diego M. Cabrera-Amaya [1], Jhon A. Infante-Betancour [1], Luisa F. Londoño-Montaño [1], Diana X. Albarán-Montoya [6], Lesly R. Peña-Baez [6]

[1] YOLUKA ONG, Fundación de investigación en Biodiversidad y Conservación, Bogotá, Colombia

[2] Vicerectoria de investigación, Universidad Manuela Beltrán, Bogotá, Colombia

[3] Grupo de Investigación de Biología de Organismos Tropicales (BIOTUN), Departamento de biología, Universidad Nacional de Colombia, Bogotá, Colombia

[4] Instituto Amazónico de Investigaciones Científicas SINCHI, Leticia, Amazonas, Colombia

[5] Colecciones Biológicas IAvH, Subdirección de Investigaciones, Instituto de Investigación de Recursos Biológicos Alexander von Humboldt, Villa de Leyva, Boyacá, Colombia

[6] Fundación Ecotrópico Colombia, Bogotá, Colombia

Corresponding Author: Teddy Angarita-Sierra
Email address: tgangaritas@unal.edu.co

Background. Pandi's mushroom-tongue salamander *Bolitoglossa pandi* is one of the most threatened amphibians in South America, as well as a spotlight species on conservation Colombian agenda. Few studies have provided relevant information that helps Colombian government to formulate lines of action for its conservation. Given this dearth of information, its threat assessments have been based on very limited information.

Methods. We conducted surveys for salamanders in four municipalities of Cundinamarca–Colombia, using two approaches: visual encounter surveys (Guaduas and Villeta) and the basic sampling protocol for single-species occupancy modeling (Supatá and Venecia). A multivariate approach was employed to explore correlation between habitat structure and natural history traits, abundance, as well as detection / non-detection of *B. pandi.* We evaluated *B. pandi* activity pattern through kernel density curves for each sampling occasion and explored salamander abundance variability during their activity period by performing a nested ANOVA.

Results. We report the discovery of two new populations of *B. pandi* which represent the most northwestern records known for the distribution of this species. A significant correlation between body length, body mass and habitat structure were observed. Multivariate analyses indicated that leaf litter depth, environmental mean temperature, percent vegetation cover, and altitude were the habitat variables that explain 60.32% of *B. pandi* abundance variability, as well as being the main drivers of its optimal habitat. *B. pandi* exhibit an activity pattern characterized by two main activity peaks, in which niche partitioning was observed. We found a healthy, stable, highly dense, with high replacement rate between body size classes and constant recruitment rate population of *B. pandi* (>1300 individuals).

Discussion. Given the high habitat specificity of *B. pandi,* it is highly vulnerable to local changes on its habitat variables. Thus, we recommend that *B. pandi* is retained as Endangered (EN) on the IUCN Red List based on the IUCN Criterion B, given its restricted extent of occurrence (ca. 2,500 km2), as well as the ongoing habitat loss within its range due to agriculture, cattle ranching, logging, and urban development that constantly reduce its suitable habitat.

1   **Distribution, habitat suitability, conservation state and natural history of**
2   **endangered salamander *Bolitoglossa pandi***
3

4   Teddy Angarita-Sierra[1, 2, 3*], María A. Bonilla-Gómez[3], David A. Sánchez[1,6], Andrés R.
5   Acosta-Galvis[4], Hefzi Medina-Ovalle[3], Anggi Solano-Moreno[3], Simon Ulloa-Rengifo[3],
6   Daniela Guevara-Guevara[3], Juan J. Torres-Ramirez[3], Juan S. Curaca-Fierro[3], Diego M.
7   Cabrera-Amaya[1], Jhon A. Infante-Betancour[1], Luisa F. Montaño-Londoño[1], Diana X.
8   Albarán-Montoya, [5] and Lesly R. Peña-Baez.[5]
9

10   [1] YOLUKA ONG, Fundación de Investigación en Biodiversidad y Conservación Bogotá,
11   Colombia.
12   [2] Vicerrectoria de Investigación, Universidad Manuela Beltrán, Bogotá, Colombia.
13   [3] Grupo de Investigación de Biología de Organismos Tropicales (BIOTUN),
14   Departamento de Biología, Universidad Nacional de Colombia, Bogotá-Colombia.
15   [4] Subdirección de Investigaciones, Colecciones Biológicas, Instituto de Investigación de
16   Recursos Biológicos Alexander von Humboldt, Claustro de San Agustín, Villa de Leyva,
17   Boyacá, Colombia.
18   [5.]Fundación Ecotrópico Colombia, Bogotá, Colombia.
19   [6]Instituto Amazónico de Investigaciones Científicas Sinchi.
20
21

22   Corresponding author:
23   Teddy Angarita-Sierra. [1]
24   Carrera 68B # 23-88, Bogotá, Colombia, Zip code: 110931.
25   Email address: tgangaritas@unal.edu.co
26

27 **Abstract**

28

29 **Background.** Pandi's mushroom-tongue salamander *Bolitoglossa pandi* is one of the
30 most threatened amphibians in South America, as well as a spotlight species on the
31 Colombian conservation agenda. Few studies have provided relevant information that
32 helps the Colombian government to formulate lines of action for its conservation; so,
33 given this dearth of information, its threat assessments have been based on very limited
34 information.
35 **Methods.** We conducted surveys for salamanders in four municipalities of
36 Cundinamarca–Colombia, using two approaches: visual encounter surveys (Guaduas
37 and Villeta) and the basic sampling protocol for single-species occupancy modeling
38 (Supatá and Venecia). A multivariate approach was employed to explore the correlation
39 between habitat structure and natural history traits, abundance, as well as detection /
40 non-detection of *B. pandi.* We evaluated the *B. pandi* activity pattern through kernel
41 density curves for each sampling occasion and explored the salamander abundance
42 variability during their activity period by performing a nested ANOVA.
43 **Results.** We report the discovery of two new populations of *B. pandi,* which represent
44 the most northwestern records known for the distribution of this species. A significant
45 correlation between body length, body mass, and habitat structure as was observed.
46 Multivariate analyses indicated that leaf litter depth, environmental mean temperature,
47 percent vegetation cover, and altitude were the habitat variables that explain the
48 60.32% of the *B. pandi* abundance variability, as well as the main drivers of its optimal
49 habitat. *B. pandi* exhibits an activity pattern characterized by two main activity peaks, in
50 which niche partitioning was observed. We found a healthy, stable, highly dense, with
51 high replacement rate between body size classes and constant recruitment rate
52 population of *B. pandi* (>1300 individuals).
53 **Discussion.** Given the high habitat specificity of *B. pandi,* the species is highly
54 vulnerable to local changes on its habitat variables. Thus, we recommend that *B. pandi*
55 is retained as Endangered (EN) on the IUCN Red List based on the IUCN Criterion B,
56 given its restricted extent of occurrence (ca. 2,500 km2), as well as the ongoing habitat
57 loss within its range due to agriculture, cattle ranching, logging, and urban development
58 that constantly reduce its suitable habitat.

59

60 **Introduction**
61 Colombia is home to more than 850 species of amphibians, and much of this diversity is
62 concentrated in the Andean Forest (Acosta-Galvis, 2019). Geographic distributions of
63 fauna in this biome are often restricted, and also endemism is common (Lynch &
64 Suárez-Mayorga, 2002). Andean forests are the most threatened habitats in the country
65 due to the drastic transformation of native vegetation by urban growth, mining,
66 agriculture, and cattle ranching (Etter, Andrade, Saavedra, & Cortés, 2018). As a

67   consequence, and given that the majority of threatened Colombian amphibian species
68   are concentrated between 1800-3600 a.s.l., habitat loss is their shared major threat.
69   Among threatened Colombian amphibians, salamanders of the *Bolitoglossa*
70   genus are one of the spotlight amphibian groups on Colombian conservation agenda.
71   This genus is the most diverse and geographically widespread lineages of
72   Plethodontidae salamanders inhabiting the Neotropics. Currently, *Bolitoglossa*
73   comprises 131 species, 24 of which reside in Colombia across several types of tropical
74   habitats (Wake, 2017; Acosta-Galvis, 2019). Many species of *Bolitoglossa* exhibit
75   patterns of restricted geographic ranges [i.e. *Bolitoglossa capitana* (Brame & Wake,
76   1963b), *B. hypacra* (Brame Jr & Wake, 1962), *B. hiemalis* (Lynch, 2001), among
77   others]. However, the high morphological crypsis and an incomplete understanding of
78   the morphological variability among Andean *Bolitoglossa* species make suitable
79   taxonomic decisions about their distributional ranges hard to achieve (Acosta-Galvis &
80   Gutiérrez-Lamus, 2012).
81   The ecology and life history of *Bolitoglossa* salamanders are poorly understood
82   compared to their Nearctic congeners;so less than 11.5% of *Bolitoglossa* species have
83   been investigated with published research on their diet, reproduction, foraging activities,
84   thermal ecology, ecological interactions, microhabitat use, or habitat preferences
85   (Anderson & Mathis, 2006; Bruce, 1997; Cadenas, Pérez-Sánchez, Villa, & De
86   Ascenção, 2009; Cruz, Galindo, & Bernal, 2016; del Río-Gracía, Serrano-Cardozo, &
87   Ramírez-Pinilla, 2014; Houck, 1977; Jimenez, 1994; Ortega, Monares-Riaño, &
88   RamÍrez-Pinilla, 2009; Salgado-Aráuz, 2005; Sarmento et al., 2011). Given this dearth
89   of information, the conservation status of many of these species is Data Deficient (DD)
90   or has been based on limited information.
91   According to the IUCN Red List of Threatened Species, *Bolitoglossa pandi*
92   (Brame & Wake, 1963b) is Endangered B1ab (iii), based on its restricted geographical
93   range; it was originally described based on a single specimen (holotype ZSZMH 2858,
94   an adult female with SVL 50.4 mm, collected in 1913 by Wilhelm Frietsche) from the
95   municipality of Pandi, Cundinamarca (exact locality unknown), in the cloud forests on
96   the western slope of the Cordillera Oriental of Colombia. Subsequently, Hanken and
97   Wake (1982) reported a second specimen 75km north (airline) from the type locality, in
98   a bromeliad inside the primary cloud forest, near the municipality of Albán
99   (Cundinamarca), at 2400 m a.s.l.
100   Acosta-Galvis and Rueda-Almonacid (2004) reported a third specimen (an adult
101   female with snout-vent length (SVL) 44.7 mm, collected by Franz Kaston, ICN 45500)
102   from nearby the type locality and described the associated habitat as relict wet areas
103   covered by lush trees and shrubs. Acosta-Galvis and Gutiérrez-Lamus, (2012) included
104   a new record for the Supatá region (adult male with SVL 37.63 mm, MUJ 7921)
105   representing the northernmost record of the species. Hence, the known distribution of *B.*
106   *pandi* includes four localities from the sub-Andean forests between 1300-2400 m a.s.l.,

107   throughout the western slopes of the Cordillera Oriental. Since its first extinction risk
108   assessment was performed 14 years ago, few studies have provided relevant
109   information for the formulation of strategies and an action plan for its conservation (del
110   Río-García et al., 2014).
111   The aims in this study are: (1) to describe the geographic range extension of *B.*
112   *pandi* along the western slopes of the Cordillera Oriental; (2) to explore the relationship
113   between habitat structure and natural history traits of this species; (3) to describe its
114   activity pattern and population structure; (4) to expand the knowledge of the variability of
115   certain morphological characters and life-history traits of this poorly known species; (5)
116   and to provide a conservation state reassessment of *B. pandi.*
117

118   **Materials & Methods**
119   **Ethics statement**
120   Sex was not determined on living salamanders due to the high risk of injury to the
121   animal. Fieldwork was done under the scientific research non-commercial purpose
122   permit of collection of wild specimens of biological diversity issued by the National
123   University of Colombia (Research Project 38615), and the Colombian National
124   Environmental Licensing Authority (ANLA) by resolution No. 0255 of 14 March 2014.
125   This study was conducted following the Colombian animal welfare law and the collection
126   of wild specimens of the biological diversity acts (Ley 1774, 2016; Decreto 1376, 2013),
127   as well as considering the Universal Declaration on Animal Welfare (UDAW) endorsed
128   by Colombia in 2007.
129

130   **Study area**
131   We searched for salamanders at nine localities in four municipalities of Cundinamarca
132   located on the western slope of the Cordillera Oriental of Colombia: Guaduas, Supatá,
133   Villeta, and Venecia (Fig. 1). Searches at each locality were carried out within an
134   altitudinal gradient ranging from 1638 to 2315 m a.s.l (Table 1). The sampled area
135   includes sub-Andean and Andean forests, as well as areas transformed by urban
136   growth, agriculture, and cattle ranching. The sampling area is characterized by bimodal
137   climate [high dry season (2nd half of Dec, Jan, Feb, 1st half of Mar); high rainy season
138   (2nd half of Mar, Apr, May, Jun); low dry season (Jul, Aug, 1st half of Sept), low rainy
139   season (2nd half of Sept, Oct, Nov, 1st half of Dec)]. We monitored the environmental
140   temperature (ET) and relative humidity (RH) at sampling sites using thermo-
141   hygrometers model EBI 20-TH1 Ebro®.
142

143 **Sampling and data collection**
144 We conducted surveys for salamanders using two approaches. First, during the rainy
145 season in April–May 2013, we performed visual encounter surveys (VES; Crump &
146 Scott, 1994) in three localities associated with cloud forests throughout an altitudinal
147 gradient (1648-2002 m a.s.l) at the municipalities of Guaduas and Villeta (Table 1). Two
148 researchers surveyed day and night for five consecutive days investing a total of 100 h
149 of sampling effort.
150   Second, we employed the basic sampling protocol described by Mackenzie et al.,
151 (2003) for single-species occupancy modeling in six localities, three in the municipality
152 of Supatá and three in Venecia. We randomly selected a total of 296 quadrats (5 m x 5
153 m), which were located throughout an altitudinal gradient at each sampling locality
154 (1600–2300 m a.s.l), grouping the following vegetation covers: relicts of the Andean
155 forest, restored the Andean riparian forest, grove pastures, pastures and roadsides
156 (Table 1). During three sampling occasions (September–October 2017, March 2018,
157 and July 2018), each quadrat was surveyed day and night for five consecutive days by
158 ten researchers, resulting in a total of 2100 h of sampling effort. During each survey, the
159 detection / non-detection of *B. pandi* specimens were recorded. When a salamander
160 was present, we measuredits perch height using a measuring tape (±0.1 cm). Once
161 salamanders were caught, we measured their weight (Mass g) with a Pesola®
162 dynamometer of 50g (±0.1 g) and took photographs to measure their body size [SVL =
163 snout-vent length (mm), TL = Tail length (mm)] using the software Image–J version 1.52
164 (Schneider, Rasband, & Eliceiri, 2012). The sex was not determined on living
165 salamanders due to the high risk of injury to the animal. All specimens of *B. pandi* were
166 subsequently released near the quadrat in which they were sighted.
167   Based on 17 specimens collected, euthanized using lidocaine 2%, and fixed in
168 10% formalin (Chen & Combs, 2001), we described the morphological variability of *B.*
169 *pandi*. We made a small incision in the groin region to identify the sex and sexual
170 maturity through macroscopic observation of the gonads. All the morphological
171 terminology employed follows several contributions (Brame Jr & Wake 1962, 1963;
172 Acosta-Galvis & Restrepo 2001; Lynch 2001; Acosta-Galvis & Hoyos 2006; Acosta-
173 Galvis & Gutierrez-Lamus 2012; Brcko, Hoogmoed, & Neckel-Oliveira, 2013; Bingham,
174 Papenfuss, Lindstrand, & Wake, 2018). All these specimens were deposited in the
175 amphibian collection at Instituto de Investigación de Recursos Biológicos Alexander von
176 Humboldt, (IAvH-Am), as well as in the amphibian collection at the Instituto de Ciencias
177 Naturales de la Universidad Nacional de Colombia (ICN).
178
179 **Habitat structure data collection**
180 We used the Point Intercept Method described by Elzinga, Salzer, and Willoughby
181 (1998) for estimatioof the percent vegetation cover. We grouped the plants into eight life
182 forms: graminoids, forbs, palm trees, mosses, lichens, vines, shrubs, and trees. We

183   divided vegetation into layers: 0–0.1 m, 0.1–1 m, 1–1.5 m, 1.5–3 m, 3–5 m, 5–12 m. We
184   also considered the cover of other abiotic items such as leaf litter, bare soil and bare
185   rocks. We estimated the vegetation cover of each of the quadrants where salamanders
186   were surveyed, employing a set of 15 intercept points distributed in three parallel lines
187   of five points separated by one meter of distance. At each point, we used a sampling
188   bar of 1.5 m to register the contact of the life forms of each vegetation layer below 1.5
189   m. This provided us with a 6.67% cover resolution by layer. We assessed the vegetation
190   percentage cover of the vegetation layers above 1.5 m (mostly trees) using five
191   intercept points: the corners of the quadrant and the central point of the third line. In this
192   way, we reached a 20% cover resolution for upper layers.
193
194   **Statistical analysis**
195   We evaluated the association between the habitat structure and the natural history traits
196   of *B. pandi* by multiple correlation analysis, with $P < 0.05$ as the significance criterion.
197   The following variables were considered: SVL (mm), weight (g), perch height (mm), leaf
198   litter depth (mm), vegetation layers, vegetation life form, vegetation percentage cover,
199   and altitude. Using the habitat variables, we performed a principal component analysis
200   (PCA) to explore which of these variables presents greater variability between quadrats
201   with the detection / non-detection of *B. pandi* and, therefore, which of these are
202   responsible for the differences observed between them. The variable suitability for PCA
203   analysis was tested performing a Kaiser-Meyer-Olkin test (KMO > 0.5, $P < 0.05$).
204   Afterward, a quadratic discriminant analysis was performed to determine which of the
205   habitat variables have the greatest discrimination capacity between quadrants where *B.*
206   *pandi* was detected or non-detected.
207   We assessed the variability in the salamander abundance observed in the
208   Supatá population through multiple regression analysis. First, we considered the
209   following habitat structure variables at each sampling quadrant: leaf litter depth (mm),
210   vegetation layers, vegetation life form, vegetation percentage cover, altitude,
211   temperature, and relative humidity of the environment. All variables were Ln–
212   transformed previously to perform the statistical analysis.
213   Second, we evaluated assumptions of normality, autocorrelation, and
214   homoscedasticity using Kolmogorov–Smirnov's test, Durbin–Watson test and Breusch–
215   Pagan test, respectively. Given that the p–value of the Durbin–Watson test can easily
216   be less than 0.05 when data size is very large, we used the Durbin–Watson statistic test
217   (DW) as an autocorrelation criterion. According to Durbin and Waston (1950), a DW of
218   less than 1 indicates a strong positive autocorrelation, a DW greater than 4 indicates a
219   strong negative autocorrelation, values between 1 and 3 suggest a moderate
220   autocorrelation, and a value close to 2 means that there is no autocorrelation.
221

222   Third, we tested for multicollinearity between the aforementioned variables using the
223   variance inflation factor (VIF) with a threshold of 10. Fourth, we selected the "best"
224   regression model employing the Akaike Information Criterion (AIC; Akaike, 1973),
225   considering that models with ΔAIC values of less than two are equally plausible (White
226   & Burnham, 1999). Finally, we used the hierarchical partitioning method to evaluate the
227   contribution of all the independent variables of the regression model (Chevan &
228   Sutherland, 1991).
229
230   **Activity pattern and population structure**
231   We only assessed the activity pattern and the population structure of the *B. pandi*
232   population at the Cuzcungos locality given the remarkable abundance observed (Table
233   1). We estimated the activity pattern through Kernel Density Curves for each sampling
234   occasion and explored the salamander abundance variability during their activity period
235   by performing a nested ANOVA. Hence, the activity period of *B. pandi* was divided into
236   nine-time intervals (from H1 = 18:30–19:30, H2 = 19:31–20:30, H3 =… until H9 =
237   02:31–03:30), and each salamander sighting was allocated into its respective interval.
238   The sampling occasion was employed as the primary factor, and the time intervals as
239   the secondary factor nested in the primary factor. We evaluated assumptions of
240   normality and homogeneity of variances using a Shapiro-Wilk test and Levene test,
241   respectively. Additionally, we analyzed the variability in observed body size over the
242   nine-time intervals through a non-parametric ANOVA using a Kruskal-Wallis test (KW)
243   as a measure of the central tendency of the samples (Sokal & Rohlf, 1981).
244   We used SVL as a descriptive variable of the population structure of *B. pandi*.
245   We compared the variability in population structure between sampling occasions
246   through a Wilcoxon test, with the null hypothesis that the median of the population
247   structure is the same across all sampling occasions. According to the categories
248   proposed by Acosta-Galvis and Gutierrez-Lamus (2012) and Del Río-Gracía et al
249   (2014), as well as the reproductive stage of the collected salamanders, the population
250   was divided into body size classes as follows: neonates (≤ 23 mm), juveniles (24–30
251   mm), and adults (≥ 30 mm).
252   All statistical analyses were performed using the software Rwizard 4.3
253   (Guisande-Gonzáles C, Vaamonde-Liste, A. Barreiro-Felpeto, 2014) and the following R
254   packages: car (Fox & Weisberg, 2019), hier.part (Walsh & Macnally, 2015), lawstat
255   (Hui, Gel, & Gastwirth, 2008), nortest (Gross & Ligges, 2015), overlap (Meredith &
256   Ridout, 2017) stat (R Core Team, 2012) and usdm (Naimi, Hamm, Groen, Skidmore, &
257   Toxopeus, 2014).
258
259   **Results**
260   **Geographic distribution**

261 We found a total of 34 individuals of *B. pandi* in three new localities, extending the
262 geographical range of the species by 96.5 Km (airline) northwest from the type-locality,
263 and 33.6 Km (airline) west from the northernmost locality in the municipality of Supatá
264 (Fig. 1). These new localities belong to the municipalities of Guaduas and Villeta in the
265 department of Cundinamarca. All the salamanders in the new localities were found at
266 night, within the understory of oak groves dominated by ferns. The salamanders were
267 sighted in different vertical strata ranging from leaf litter, where they remained hidden, to
268 shrubby substrates up to 2.5 m. Also, two salamanders were found in ecotonal areas
269 associated with sugar cane crops and rangeland areas for livestock.
270
271 **Associations of habitat structure and natural history traits**
272 We observed a significant association between habitat structure and natural history
273 traits. Snout-vent length, tail length, and mass were significantly associated with all the
274 habitat structure variables assessed, but less so with the vegetation layers. SVL, TL,
275 and mass showed a negative correlation with leaf litter and altitude (Table 2). In
276 contrast, SVL and mass showed a positive correlation with perch height and percent
277 vegetation cover (Fig. 2). The square coefficients obtained indicate that the variability of
278 SVL, TL, and mass correlated in 19.3%, 16.8%, and 18.6%, with habitat structure
279 variables respectively.
280　　　　Similarly, the habitat structure variables explain the detection or non-detection of
281 *B. pandi* throughout the sampling quadrants. The first two components of the PCA
282 analysis explained 62.41% of the variability observed. The habitat structure variability
283 was clustered in two groups associated with the detection or non-detection of *B. pandi*
284 (Fig. 3A). These groups were moderately overlapped in multivariate spaces, but they
285 were strongly differentiated by altitude, leaf litter depth, and percent vegetation cover:
286 the presence of *B. pandi* was positively correlated with quadrants highly structured and
287 with a depth of leaf litter (Table 3). The quadratic discriminant analysis confirms that the
288 detection or non-detection of *B. pandi* depends on habitat variables. The cross-
289 validation percentage was 92.6%, indicating that the quadrants in which *B. pandi* was
290 detected can be clearly distinguished by habitat variables such as vegetation layers,
291 leaf litter and environmental mean temperature (Fig. 3B).
292　　　　Results of the multiple regression analysis showed that leaf litter depth,
293 environmental mean temperature, percent vegetation cover, and altitude were the
294 variables that contributed the most to explaining the observed variability in the
295 abundance of *B. pandi* (R^2 = 60.32%, P< 0.001). These habitat variables also composed
296 the "best" fitted regression model (Table 4). However, this model showed a moderate
297 autocorrelation (DW = 1.10), signifying that the autocorrelation is very small and the
298 variance explained by the habitat variables may be close to 60.32% (Fig. 4).
299
300 **Activity pattern**

301 *Bolitoglossa pandi* is completely nocturnal,its activity period extends throughout the
302 night, beginning from 18:30 h until 05:00 h. The environmental temperature and relative
303 humidity recorded during this activity period ranged from 12.6–25.6 °C ($\square$ =15.3), 73.8–
304 98.8 RH ($\square$ = 80.3). The activity peaks were all subject to environmental influences
305 showing a significant association with the local weather conditions. The observed
306 salamander abundance was strongly and positively correlated with the environmental
307 temperature (R_{ET} = 0.251, P < 0.001), whereas the moderately and negatively were
308 correlated with the relative humidity (R_{RH} = -0.174; P = 0.017). Despite the sampling
309 occasion, we observed two main activity peaks, the first from 20:30 h to 21:30 h, and
310 the second from 23:30 h to 00:30 h (Fig. 5). Results of the nested ANOVA indicated that
311 salamander abundance between these peaks was significantly different ($F_{9\text{-}259}$ = 4.57, P
312 < 0.001; Table 5), being more abundant in the second activity peak during the second
313 and third sampling occasions, and the opposite during the first sampling occasion (Fig.
314 6A).
315 Likewise, the observed body length of the salamanders showed significant differences
316 between the two activity peaks (K_{8df} = 99.70, P < 0.001, Fig. 6B), suggesting niche
317 partitioning between body size classes. Most of the salamanders observed during the
318 first activity peak had SVL > 30 mm (juveniles and adults), whereas the salamanders
319 observed at the second activity peak had SVL < 27 mm (juveniles and neonates).
320 However, in contrast with the differences in observed abundance between activity
321 peaks, the variation between salamander SVL were consistent across the three
322 sampling occasions.
323
324 **Population structure**
325 A total of 1391 individuals of *B. pandi* were observed throughout the study in the Supatá
326 population, exhibiting a population density ranging from 0.04– 1.44 individuals/m^2. The
327 population structure showed significant differences between sampling occasions,
328 suggesting a high replacement rate between body size classes (Table 6). Regardless of
329 the variability observed in the population structure of *B. pandi*, the population is mostly
330 dominated by juveniles and neonates which represent between 34–64% of the
331 individuals (Fig. 7). Neonates were observed across all sampling occasions, indicating
332 constant recruitment. During the second sampling occasion, a notorious bias in the SVL
333 median value toward small body length salamanders was observed, suggesting that the
334 major recruitment peak occurs during March (Fig 7B). Adults were conspicuous
335 throughout all sampling occasions, although predominantly in the first sampling
336 occasion.
337
338 **Morphological variability**
339 *Bolitoglossa pandi* is a tiny species recognizable by SVL = 13.4–51 mm (n = 1034),
340 13.4–48mm adult males (n =7), and SVL 14–51 mm adult females (n = 8). Extensively

341 webbed hands and feet with third toes and fingers triangular; ventral surfaces of digit
342 tips without terminal flattened tubercles; snout short and rounded in the lateral profile;
343 head length 4.9–10.1 mm; head width 5.1–7.9 (n =17); snout rounded in dorsal view
344 irregular white spots,cream nasolabial grooves, and edges of the lips irregularly dark
345 brown with irregular light spotting (Fig. 8A–B); protruding eyes on dorsal view, brown iris
346 with black reticules (Fig. 8B); well-defined post-cephalic constriction; ventral surfaces
347 (preserved); brown or dark grey with numerous tiny cream guanophores (Fig.
348 8C);inverted bracket shaped scapular spots (Fig. 9F); males have white testes.
349   *Bolitoglossa pandi* can be distinguished from its Colombian congeners by having
350 an extensive webbing of hands and feet (versus absence of extensive webbing of hands
351 and feet in *B. adspersa, B. hiemalis, B. hypacra, B. palmata, B. ramosi, B. savagei, B.*
352 *tamaense, B. tatamae, B. walkeri* and *B. vallecula*); also, It can be distinguished from
353 species with extensive webbing as *Bolitoglossa lozanoi* and *B. nicefori*, in having more
354 protruding eyes, and longer and triangular third finger. *B. pandi* also differs from *B.*
355 *biseriata* and *B. silverstonei* by having a dark brown or dark grey ventral surface with
356 irregular white dots (versus cream ventral surface with brown suffusions and pits in *B.*
357 *biseriata* and *B. silverstonei*), brown-reddish iris with black reticles (versus golden with
358 brown pits in *B. biseriata* and *B. silverstonei*), and white testes in adult males (versus
359 black mesorchium in testes of adult males of *B. biseriata*). It also differs from *B. medemi*
360 by the absence of digital depressions in digital tips on the fingers and toes (present in *B.*
361 *medemi*). *B. pandi* has an upper lip with irregular light spotting (versus uniform in *B.*
362 *guaneae*). *B. pandi* can be differentiated from *B. altamazonica* and *B. leandrae*
363 byhaving extensive interdigital webbing with a longer and triangular third finger
364 (complete webbing and tips rounded in *B. altamazonica* and *B. leandrae*). *B. pandi* is
365 morphologically very similar to *B. phalarosoma,* but it differs by having a dark brown or
366 dark grey ventral surface with diffuse white pits and some white blotches (versus usually
367 light brown ventral surfaces, with some irregular cream spots in *B. phalarosoma*),
368 plantar and palmar regions in ventral dark brown or dark grey view (versus cream in *B.*
369 *phalarosoma*). *B. pandi* also differs from *B. capitana* by having smaller adult size with a
370 longer and triangular third finger (versus rounded third finger in *B. capitana*) and less
371 head width.
372
373 **Color variability**
374 *Bolitoglossa pandi* exhibited a wide polychromatic variability ranging from a uniform
375 dorsal color pattern of different shades of light to a dark brown one (Fig. 9A); one
376 reddish-brown pattern that can have diffused grey or dark blotches scarcely
377 distinguishable to the dorsolateral region (Fig. 9B), or an ochre pattern, with some
378 diffuse irregular dark brown, yellow or cream spots (Fig. 9C–E). Some specimens
379 exhibit an exceptionally diffuse band in the paravertebral region covering almost the
380 entire dorsal surface or including a dark brown inverted triangle shape in the interorbital

381 region (Fig. 9 F–G). The caudal region is highly variable, ranging from uniform reddish-
382 brown or completely ochre segments, with very small scattered white pits (Fig. 9 A,B, D)
383 to irregular cream, yellow or orange patches (Fig. 9C, D), and very small or irregular
384 longitudinal black spots (Fig. 9F–G). The distal end of the tail becomes uniform light
385 brown and has cream blotches towards the proximal region in some individuals (Fig.
386 9B). The cephalic region is dark brown with some white spots with irregular pits up to
387 the supralabial region in lateral view (Figure 8B); a loreal region with ochre patches and
388 light brown iris with black reticles; nasolabial projections are creams; the ventrolateral
389 surface is dark brown. Ventral surfaces are dark brown with some cream and white
390 blotches with scattered pits; the mental and gular surfaces are uniformly dark brown or
391 dark grey with some irregular white circular spots bordering the maxillary region. In adult
392 males the mental gland is light brown; the palmar and plantar surfaces are always dark
393 brown or dark grey.
394

395 **Discussion**
396 The new localities added to *Bolitoglossa pandi* distribution and the detailed examination
397 of the Supatá population have allowed not only the expansion of knowledge about the
398 distribution and natural history traits of this species but also the reassessment of its
399 conservation status and the validation of its characters for the taxonomic identification
400 among its congeners. The apparent local endemism of *B. pandi* is the result of a
401 general misunderstanding due to the examination of restricted samples, insufficient
402 sampling effort, lack of comparisons with the relevant type material, and the incomplete
403 knowledge of the variability of certain morphological characters of *Bolitoglossa*
404 salamanders (Wake, 2017).
405   Since Brame and Wake's (1963a) original description of *B. pandi,* several
406 characters such as dorsal surfaces color (Figure 9) have had conflicting or ambiguous
407 diagnostic characters (Acosta-Galvis and Gutiérrez-Lamus, 2012). However, our
408 findings significantly increased the understanding of the morphological variability of *B.*
409 *pandi*. The chromatic variations reported here contrast with the original description
410 (Brame and Wake, 1963b) because these have not been described in life (and the
411 holotype is poorly preserved), and evidence of a broad intrapopulational
412 polychromatism was not available due to restricted sampling. Our findings allow
413 clarification of taxonomical misidentifications in the literature. For example, Acosta-
414 Galvis and Rueda-Almonacid (2004), during the first threat assessment of *B pandi,*
415 included erroneously a picture of *B. walker* as the species' portrait. The color and
416 morphological description provided here comes from living specimens obtained in the
417 municipalities of Guaduas, Supatá, and Villeta.
418   Neotropical salamanders have been considered inconspicuous amphibians of the
419 Andean Forest (Brame and Wake, 1963; Gibbons, 1983; Barrio-Amoros and Fuentes,
420 1999; Acosta-Galvis and Gutiérrez-Lamus, 2012). Nevertheless, our results challenge

421   this general assumption and provide support to previous studies relating specific
422   environmental conditions with high abundance and density of Andean salamander
423   populations (Cadenas, Pérez-Sánchez, Villa, & De Ascenção, 2009; Ortega et al., 2009;
424   Gutiérrez-Lamus, Lynch, & Martínez-Villate, 2011; del Río-García et al., 2014). Altitude
425   (1700-2000 m. a.s.l), leaf litter depth (> 6 cm), vegetation layers (> 5 vegetation strata),
426   and environmental mean temperature (16–19 °C) arise as the "best" predictor variables
427   of presence, abundance and population density of *B. pandi.* Given the *B. pandi´s*
428   arboreal habits, diet preferences , as well as thermoregulation behavior of
429   Bolitoglossines (del Río-García et al., 2014; Cruz et al 2016; Mendieta Donaire et al.,
430   2019);), the selection of these predictor variables by the regression models was
431   expected.
432   Likewise, highly homogenous sampling quadrants in which pastures, graminoids,
433   bare soil, and rocks were dominant, as a result of human activities, showed the lowest
434   or no detection grade of *B. pandi*. Conversely, sampling quadrants in which *B pandi* was
435   present were positively correlated with highly structured habitats and deep leaf litter,
436   characteristics associated with relicts of conserved Andean forest or highly restored
437   Andean riparian forest (Rangel-Ch, Lowy, & Aguilar, 1997; Alvear, Betancur, & Franco-
438   Rosselli, 2010; Quintero Vallejo, Benavides, Moreno, & Gonzalez-Caro, 2017). This
439   result indicates that *B. pandi* requires Andean forests in a good conservation state and
440   a narrow range of environmental conditions. This strong link between *B. pandi* and a
441   narrow range of environmental conditions has been observed in other Andean
442   salamanders such as *B. adspersa, B. altamazonica, B. nicefori,* and *B. orestes*
443   (Valdivieso & Tamsitt, 1965; Cadenas et al., 2009; Gutiérrez-Lamus et al., 2011;
444   Leenders & Watkins-Colwell, 2013).The detection and high local abundance of these
445   species are strongly correlated with the same habitat variables that promoting the
446   detection and abundance of *B. pandi*. Thus, the deep dependency of a narrow
447   environmental range of conditions makes the Andean Bolitoglossines highly vulnerable
448   to local changes in habitat variables.
449   Our study provided evidence for the first time of intraspecific niche partitioning on
450   Bolitoglossine salamanders. Niche partitioning has been plenty reported on populations
451   of Nearctic salamander species (Jaeger & Gergits, 1979; Wicknick, 1995; Arif, Adams,
452   & Wicknick, 2007; Jaeger, Gollman, Anthony, Gabor, & Kohn, 2016). Evidence of
453   Nearctic salamander's niche intraspecific partitioning has been explained as a life
454   history strategy to maximize foraging success, predator avoidance, and mating success
455   (Jaeger & Gergits, 1979; Holomuzki, 1986; Cloyed & Eason, 2017). Nevertheless, our
456   data are insufficient to infer any fundamental ecological trade-off between body size and
457   microhabitat use, activity and vulnerability to predation, or activity and foraging success.
458   Future experimental studies must be addressed to understand how niche intraspecific
459   partitioning is acting through environmental heterogeneity in the ecology and evolution

460   of the South American Bolitoglossines. Also, future conservation efforts must consider
461   this life history strategy into conservation interventions.
462
463   **Conclusions**
464   Our result agrees with the general pattern observed in other amphibian taxa in which
465   habitat disturbance driven by human activities has deleterious effects on presence or
466   population densities given their high habitat specificity (Lips, 1998; Collins & Storfer,
467   2003). Habitat loss continues protruding as the central threat for *B. pandi*. This fact has
468   significant importance in conservation issues because the Andean forest is one of the
469   most threatened ecosystems by human activities in Colombia (Etter et al., 2018).
470   Therefore, despite that we directly observed a healthy and stable salamander
471   population that showed high population density, high replacement rate between body
472   size classes and constant recruitment in the municipalities of Supatá, Guaduas, and
473   Villeta, we recommend that *B. pandi* is retained as Endangered (EN) on the IUCN Red
474   List based on the IUCN Criterion B, given its restricted extent of occurrence (ca. 2,500
475   km^2), as well as the ongoing habitat loss within its range due to agriculture, cattle
476   ranching, logging, and urban development that constantly reduce its suitable habitat.
477
478   **Acknowledgments**
479   We thank all students of the Grupo de Investigación de Biología de Organismos
480   Tropicales (BIOTUN) of the Universidad Nacional de Colombia for their help and
481   support during the fieldwork and lab procedures. We especially thank Maria Carolina
482   Becerra (Biology department, UNAL) for her friendship and support through all this
483   study; the staff of the NGO YOLUKA for their general support; Rebeca Morantes-
484   Zamora for her help with the maps; John D. Lynch from the Instituto de Ciencias
485   Naturales of Universidad Nacional for his support, advice and for allowing us to use the
486   lab equipment under his care. Special thanks to Adriana Zuleta and Alejandro López for
487   giving us the support and freedom to seek salamanders at Cuzcungos Natural Reserve;
488   William Gutierrez Moreno, coordinator of the Project Management Programme of
489   Universidad Nacional de Colombia for his support. We thankKelsey Neam (IUCN SSC
490   Amphibian Specialist Group, Global Wildlife Conservation) for an early review of the
491   manuscript. Special thanksto all the community of the municipalities of Guaduas,
492   Supata, Venecia, and Villeta to allow us to work together for the amphibian and reptile
493   conservation of Colombia. Finally, thanks to all the anonymous reviewers for their
494   valuable comments on this paper.
495
496   **References**
497
498   Acosta-Galvis, A.R., & Rueda-Almonacid, J. V. (2004). Salamandra de Pandi
499   Bolitoglossa pandi. In J. V. Rueda-Almonacid, J. D. Lynch, & A. Amezquita (Eds.),
500   *Libro rojo de anfibios de Colombia* (pp. 206–209). Bogotá D.C.

501   Acosta-Galvis, A.R, & Gutiérrez-Lamus, D. L. (2012). A new species of salamander
502   (Bolitoglossa: Plethodontidae) from the Cordillera Oriental of the Colombian Andes.
503   *Papéis Avulsos de Zoologia (São Paulo)*, *52*(18), 201–218.
504   https://doi.org/10.1590/s0031-10492012001800001
505   Acosta-Galvis, Andrés Rymel. (2019). Lista de los Anfibios de Colombia: Referencia en
506   linea. Retrieved February 12, 2019, from https://www.batrachia.com
507   Akaike, H. (1973). Information theory and an extension of the maximum likelihood
508   principle. In B. Petrovand & F. Caski (Eds.), *Proceeding of the isecond international*
509   *Symposium on Information Theory* (pp. 1–451). Budapest: Akademiai Kiado.
510   Alvear, M., Betancur, J., & Franco-Rosselli, P. (2010). Floristic diversity and structure of
511   andean forests remnants near to los nevados national park, central colombian
512   andes. *Caldasia*, *32*(1), 39–63.
513   Anderson, M. T., & Mathis, A. (2006). Diets of Two Sympatric Neotropical Salamanders,
514   Bolitoglossa mexicana and B. rufescens, with Notes on Reproduction for B.
515   rufescens. *Journal of Herpetology*, *33*(4), 601. https://doi.org/10.2307/1565576
516   Arif, S., Adams, D. C., & Wicknick, J. A. (2007). Bioclimatic modeling, morphology, and
517   behavior reveal alternative mechanisms regulating the distributions of two
518   parapatric salamander species. *Evolutionary Ecology Research*, *9*(5), 843–854.
519   Bingham, R. E., Papenfuss, T. J., Lindstrand, L., & Wake, D. B. (2018).
520   Phylogeography and Species Boundaries In the Hydromantes shastae Complex,
521   With Description of Two New Species (Amphibia; Caudata; Plethodontidae).
522   *Bulletin of the Museum of Comparative Zoology*, *161*(10), 403–427.
523   https://doi.org/10.3099/mcz42.1
524   Brame, A. H., & Wake, D. B. (1963a). Contributions to the Salamanders of South
525   America. *Contributions In Science. Natural History Museum of Los Angeles County*,
526   *69*, 1–72.
527   Brame, A. H., & Wake, D. B. (1963b). The Salamanders of South America, (69), 1–71.
528   Brame Jr, A. H., & Wake, D. B. (1962). A new plethodontid salamander (genus
529   Bolitoglossa) from Venezuela with redescription of the Ecuadorian B. palmata
530   (Werner). *Copeia*, *1962*(1), 170–177.
531   Brcko, I. C., Hoogmoed, M. S., & Neckel-Oliveira, S. (2013). Taxonomy and distribution
532   of the salamander genus Bolitoglossa Duméril, Bibron & Duméril, 1854 (Amphibia,
533   Caudata, Plethodontidae) in Brazilian Amazonia. *Zootaxa*, *3686*(4), 401–431.
534   https://doi.org/10.11646/zootaxa.3686.4.1
535   Bruce, R. C. (1997). Society for the Study of Amphibians and Reptiles Life History
536   Attributes of the Salamander Bolitoglossa colonnea, *31*(4), 592–594.
537   Cadenas, D. A., Pérez-Sánchez, A. J., Villa, P. ., & De Ascenção, A. A. (2009). Relative
538   Abundance, Habitat Use and Diet of Bolitoglossa orestes (Urodela: Plethodontidae)
539   in a Venezuelan Andean Cloud Forest. *ECOTRÓPICOS*, *22*(2), 99–109.
540   Chen, M. ., & Combs, C. (2001). An alternative killing agent for amphibians.
541   *Herpetological Review*, *32*(2), 93–94.
542   Chevan, A., & Sutherland, M. (1991). Hierarchical partitioning. *The American*
543   *Statistician*, *45*, 90–96. https://doi.org/1080/00031305.1991.10475776
544   Cloyed, C. S., & Eason, P. K. (2017). Niche partitioning and the role of intraspecific
545   niche variation in structuring a guild of generalist anurans. *Royal Society Open*
546   *Science*, *4*(3). https://doi.org/10.1098/rsos.170060

547 Collins, J., & Storfer, A. (2003). Global amphibian declines: sorting the hypotheses.
548   *Diversity and Distributions*, *9*(2003), 89–98.
549 Crump, M. L., & Scott, N. J. (1994). Visual encounters surveys. In W. Heyer, M. Donelly,
550   R. MacDiarmind, L. Hayeck, & M. Foster (Eds.), *Measuring and monitoring*
551   *biological diversity, standard methods for amphibians* (pp. 354–352). Washington:
552   Smithsonian Institution Press.
553 Cruz, E. X., Galindo, C. A., & Bernal, M. H. (2016). Dependencia térmica de la
554   salamandra endémica de Colombia Bolitoglossa ramosi (Caudata, Plethodontidae).
555   *Iheringia. Série Zoologia*, *106*(0). https://doi.org/10.1590/1678-4766e2016018
556 del Río-Grácía, J. S., Serrano-Cardozo, V. H., & Ramírez-Pinilla, M. P. (2014). Diet and
557   Microhabitat Use of Bolitoglossa cf. pandi (Caudata: Plethodontidae) from the
558   Cordillera Oriental of Colombia. *South American Journal of Herpetology*, *9*(1), 52–
559   61. https://doi.org/10.2994/sajh-d-13-00031.1
560 Elzinga, C. L., Salzer, D. W., & Willoughby, J. W. (1998). *Measuring and monitoring*
561   *plant populations*. Denver: U.S. Dept. of the Interior, Bureau of Land Management.
562 Etter, A., Andrade, Á., Saavedra, K., & Cortés, J. (2018). Actualización de la Lista Roja
563   de los Ecosistemas Terrestres de Colombia. In G. I. Moreno, L. A., Rueda, C. y
564   Andrade (Ed.), *Biodiversidad 2017. Estado y tendencias de la biodiversidad*
565   *continental de Colombia* (p. 19). Investigación de Recursos Biológicos Alexander
566   von Humboldt, Instituto de Ciencias Naturales de la Universidad Nacional de
567   Colombia, WWF Colombia y Universidad de Manizales.
568 Fox, J., & Weisberg, S. (2019). *An R Companion to Applied Regression* (Third edit).
569   Thousand Oaks: Sage.
570 Gross, J., & Ligges, U. (2015). nortest. Viena. Retrieved from https://cran.r-
571   project.org/web/packages/nortest/index.html
572 Guisande-Gonzáles C, Vaamonde-Liste, A. Barreiro-Felpeto, A. (2014). Rwizard. Vigo:
573   Universidad de Vigo. Retrieved from http://www.ipez.es/RWizard/
574 Gutiérrez-Lamus, D. L., Lynch, J. D., & Martínez-Villate, G. C. (2011). Population
575   estimators and adult sex ratio for a population of Bolitoglossa altamazonica
576   (Caudata: Plethodontidae). *Basic and Applied Herpetology*, *25*(2011), 43–54.
577   https://doi.org/10.11160/bah.11008
578 Hanken, J., & Wake, D. B. (1982). Genetic differentiation among plethodontid
579   salamanders (genus Bolitoglossa) in Central and South America: implications for
580   the South American invasion. *Herpetologica*, *32*(2), 272–287.
581 Holomuzki, J. R. (1986). Predator Avoidance and Diel Patterns of Microhabitat Use by
582   Larval Tiger Salamanders. *Ecology*, *67*(3), 737–748.
583 Houck, L (1977). Reproductive biology of a Neotropical Salamander, Bolitoglossa
584   rostrata. *Copeia*, *1977*(1), 70–83.
585 Hui, W., Gel, Y. R., & Gastwirth, J. L. (2008). Lawstat: An R package for law, public
586   policy, and biostatistics. *Journal of Statistical Software*, *28*(3).
587   https://doi.org/10.18637/jss.v028.i03
588 Jaeger, R.G., Gollman, B., Anthony, D. D., Gabor, C. R., & Kohn, N. (2016). *Behavioral*
589   *Ecology of the Eastern Red-backed Salamander: 50 Years of Research*. New York:
590   Oxford University Press.
591 Jaeger, Robert G., & Gergits, W. F. (1979). Intra- and interspecific communication in
592   salamanders through chemical signals on the substrate. *Animal Behaviour*,

593   *27*(PART 1), 150–156. https://doi.org/10.1016/0003-3472(79)90134-9

594 Jimenez, C. E. (1994). Utilization of Puya dasylirioides (Bromeliaceae: Pitcairnoideae)
595   as foraging site by Bolitoglossa subpalmata (Plethodontidae: Bolitoglossini).
596   *Revista De Biologia Tropical*, *42*(3), 703–710. Retrieved from
597   http://search.ebscohost.com/login.aspx?direct=true&db=boh&AN=BACD19959840
598   4277&site=ehost-live

599 Leenders, T. A. A. M., & Watkins-Colwell, G. J. (2013). Morphological and behavioral
600   adaptations in Bolitoglossa colonnea (Caudata, Plethodontidae) in relation to
601   habitat use and daily activity cycle. *Phyllomedusa: Journal of Herpetology*, *2*(2),
602   101. https://doi.org/10.11606/issn.2316-9079.v2i2p101-104

603 Lips, K. (1998). Decline of a tropical amphibian fauna. *Conservation Biology*, *12*(1),
604   106–117.

605 Lynch, J. D. (2001). A small amphibian fauna from a previously unexplored páramo of
606   the Cordillera Occidental in western Colombia. *Journal of Herpetology*, *35*(2), 226–
607   231.

608 Lynch, J. D., & Suárez-Mayorga, A. M. (2002). Análisis Biogeográfico de los Anfibios
609   Paramunos. *Caldasia*, *24*(2), 471–480. https://doi.org/10.1007/s11051-017-4041-1

610 Mendieta Donaire, R. A., Zolotoff Pallais, J. M., Chung, J. S., Cobos Rizo, M. A., De los
611   Santos Rosales, M., Jun Lee, J., … Casco-Robles, M. M. (2019). Constricted
612   spatiotemporal foraging of the regenerating salamander, Bolitoglossa
613   mombachoensis. *Ecosphere*, *10*(10). https://doi.org/10.1002/ecs2.2897

614 Meredith, M., & Ridout, M. (2017). Overview of the overlap package. *R Project*.
615   https://doi.org/10.1016/j.contraception.2006.09.005

616 Naimi, B., Hamm, N. A. S., Groen, T. A., Skidmore, A. K., & Toxopeus, A. G. (2014).
617   Where is positional uncertainty a problem for species distribution modelling?
618   *Ecography*, *37*(2), 191–203. https://doi.org/10.1111/j.1600-0587.2013.00205.x

619 Ortega, J. E., Monares-Riaño, J. M., & RamÍrez-Pinilla, M. P. (2009). Reproductive
620   Activity, Diet, and Microhabitat Use in Bolitoglossa nicefori (Caudata:
621   Plethodontidae). *Journal of Herpetology*, *43*(1), 1–10. https://doi.org/10.1670/07-
622   250r2.1

623 Quintero Vallejo, E., Benavides, A. M., Moreno, N., & Gonzalez-Caro, S. (2017).
624   *Bosques Andinos, estado actual y retos para su conservación en Antioquia*. (E.
625   Quintero Vallejo, A. M. Benavides, N. Moreno, & S. Gonzalez-Caro, Eds.).
626   Medellín: Fundación Jardín Botánico de Medellín Joaquín Antonio Uribe.

627 R Core Team. (2012). R: A language and environment for statistical computing. Viena:
628   R Foundation for Statistical Computing. Retrieved from http://www.r-project.org/

629 Rangel-Ch, O. J., Lowy, P. ., & Aguilar, M. (1997). Distribución de los tipos de
630   vegetación en las regiones naturales de Colombia. In *Colombia diversidad biótica*
631   *II: tipos de vegetación en Colombia* (pp. 383–402). Bogotá D.C: Instituto de
632   Ciencias Naturales-Universidad Nacional de Colombia, Ministerio de Medio
633   Ambiente.

634 Salgado-Aráuz, H. . (2005). Caracterización de la población y del hábitat de la
635   salamandra endémica (Bolitoglossa mombachoensis) en la Reserva Natural
636   Volcán Mombacho. *Encuentro*, *37*(73), 77–86.

637 Sarmento, J. F. M., Neckel-Oliveira, S., Fáveri, S. B., Lima, A. A., Galatti, U., Lima, C.,
638   & Suárez, P. (2011). Reproductive Traits of the Brazilian Salamander Bolitoglossa

639   paraensis (Urodela: Plethodontidae). *Copeia*, *2011*(3), 457–462.
640   https://doi.org/10.1643/ce-08-219
641 Schneider, C. ., Rasband, W. ., & Eliceiri, K. (2012). ImageJ. *Nature Methods*, *9*(7),
642   671–675. https://doi.org/10.1007/978-1-84882-087-6_9
643 Sokal, R. ., & Rohlf, R. (1981). *Biometry: The principles and practice of statistics in*
644   *biological research* (First edition). San Francisco: W.H. Freeman.
645 Valdivieso, D., & Tamsitt, J. R. (1965). Reproduction in a Neotropical Salamander,
646   Bolitoglossa adspersa (Peters). *Herpetologica*, *21*(3), 228–236.
647 Wake, D. B. (2017). Persistent Plethodontid Themes: Species, Phylogenies, and
648   Biogeography. *Herpetologica*, (July). https://doi.org/10.1655/herpetologica-d-16-
649   00065
650 Walsh, C., & Macnally, R. (2015). Hierarchical Partitioning. Viena. Retrieved from
651   https://cran.r-project.org/web/packages/hier.part/index.html
652 White, G. ., & Burnham, K. (1999). Program MARK: survival estimation from 594
653   populations of marked animals. *Bird Study*, *4*(sup1), S120–S139.
654   https://doi.org/10.1080/00063659909477239
655 Wicknick, J. A. (1995). *Interspecific competition and territoriality between a widespread*
656   *species of salamander and a species with a limited range*. University of
657   Southwestern Louisiana.
658
659

Figure 1

Distribution range of the poorly-known salamander *Bolitoglossa pandi*

New Northwestern records for the known distribution of *Bolitoglossa pandi* (IAvH-Am 10303-4, IAvH-Am 10305-8). Pentagon with a white square inside: La Esmeralda (municipality of Villeta), black star: Granada (municipality of Villeta), broad diamond: El Trigo (municipality of Guaduas). Sampled localities in the municipality of Supatá. Black square: San Marcos, asterisk: Cuzcungos Natural Reserve, solid pentagon: "El Alto" Vereda Monterey. Sampled localities in the municipality of Venecia. Narrow diamond: Buenos Aires, invert triangle: El Alto de la Chorrera, triangle: El Mirador.
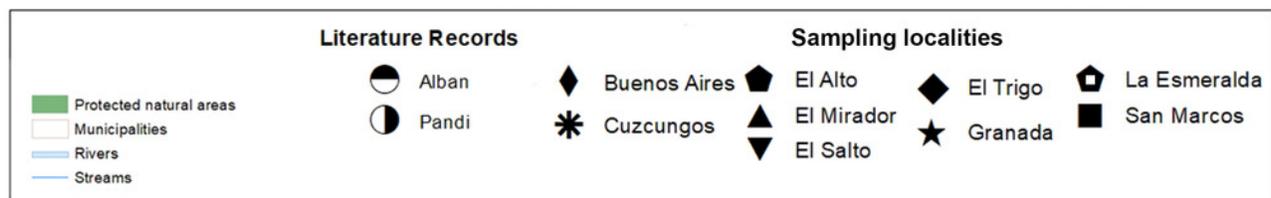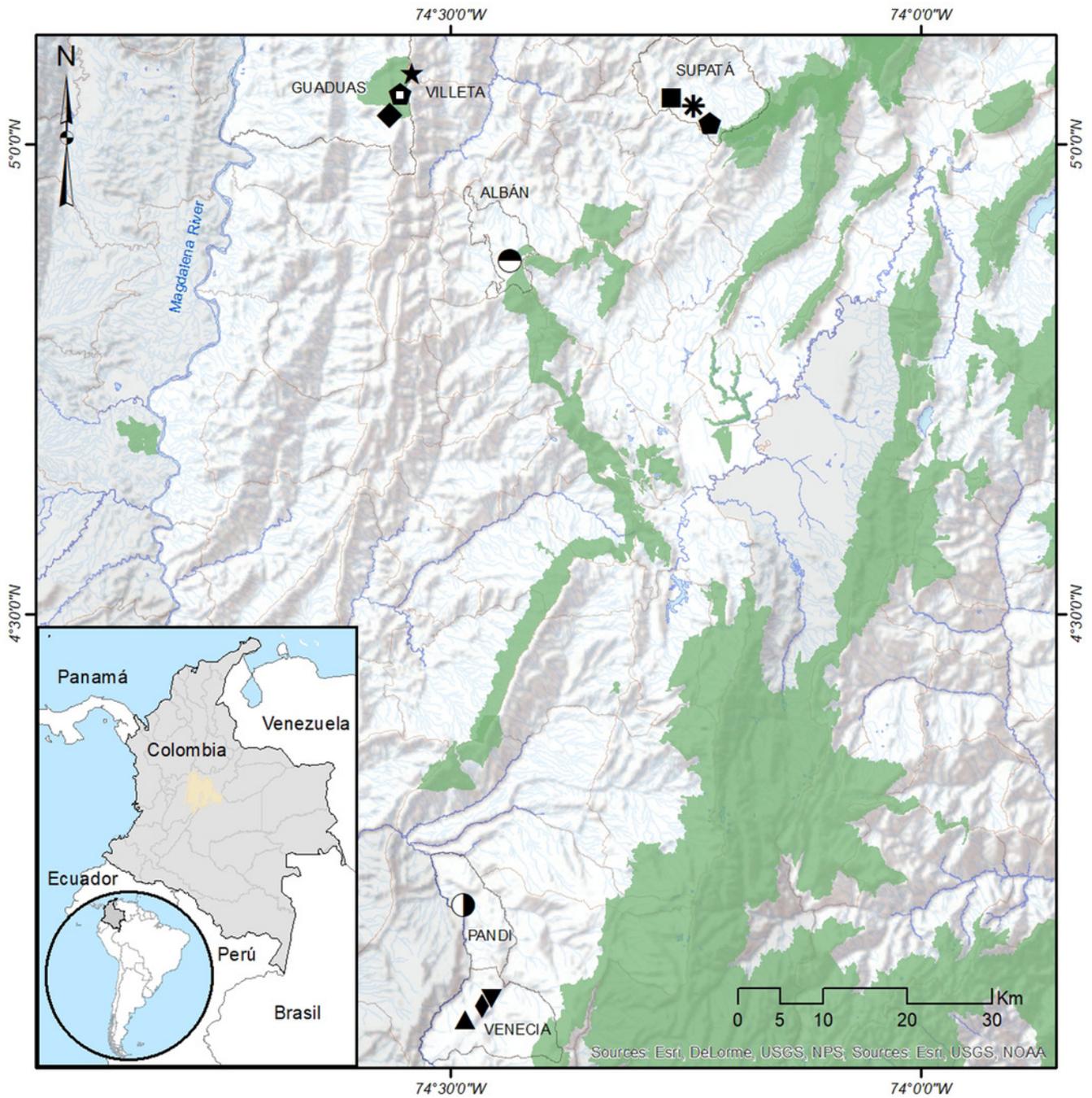
Figure 2

Scatterplot depicting the positive correlation between body length, weight and perch high
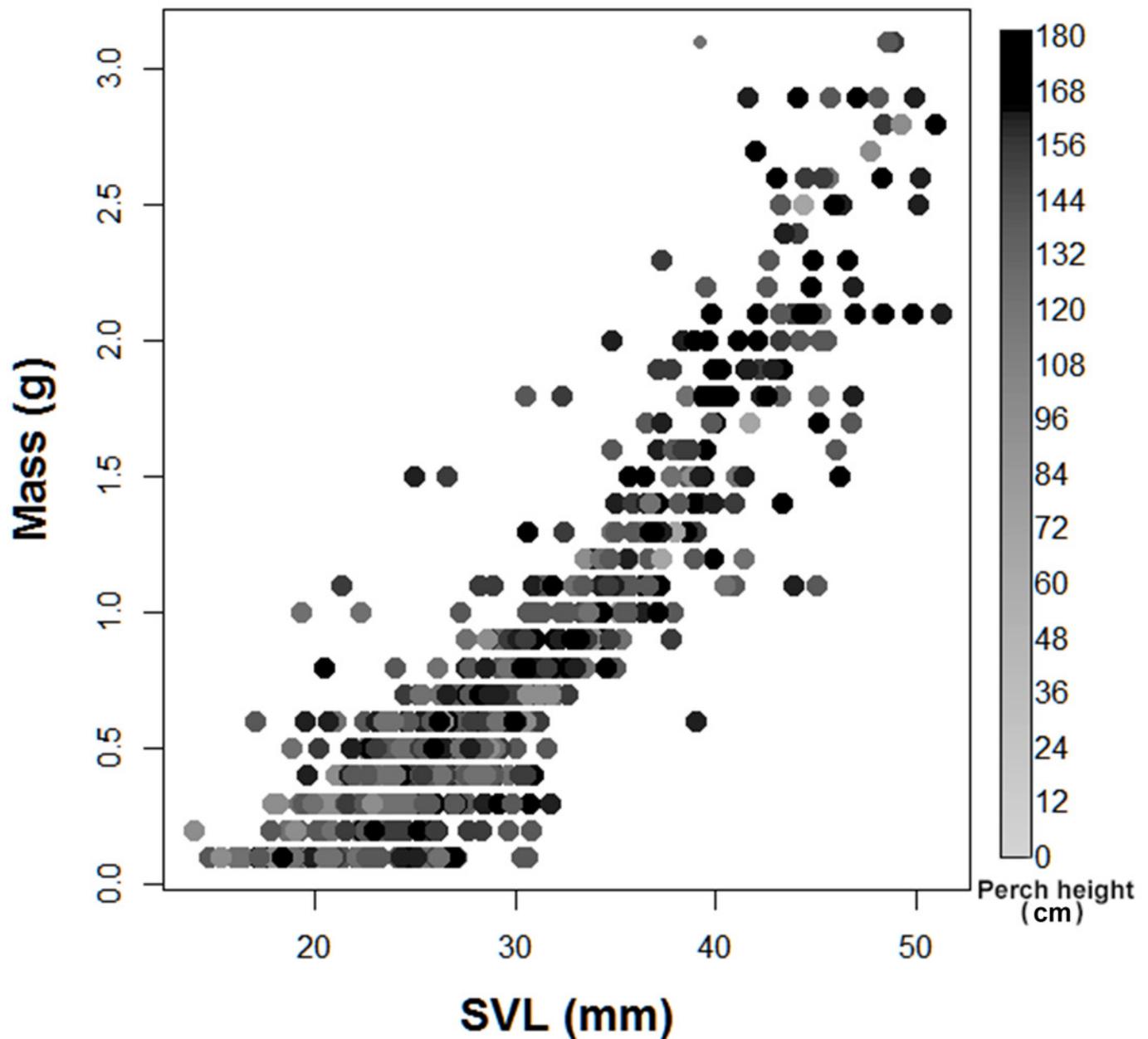
Figure 3

Main drivers of the *Bolitoglossa pandi* optimal habitat

(A) Principal component analysis showing the observed variability in habitat structure attributes between quadrats with detection /non-detection of Bolitoglossa pandi. PC1 = First principal component (38.8%). PC2 = Second principal component (23.6%). Veg.leyers= Vegetation layers. Veg.per.cover = Vegetation percentage cover. Mean Temp = Environmental mean temperature. Black squares = detection of *Bolitoglossa pandi*. Grey dots = Non-detection of *Bolitoglossa pandi*. The inner ellipse represents 0.5 of significance; the outer ellipse represents 0.95 of significance. (B) Quadratic discriminant analysis depicting the habitat variables that have the greatest discrimination capacity between quadrants where *Bolitoglossa pandi* was detected or non-detected. The length of the vector denotes the discrimination capacity of each habitat variable.
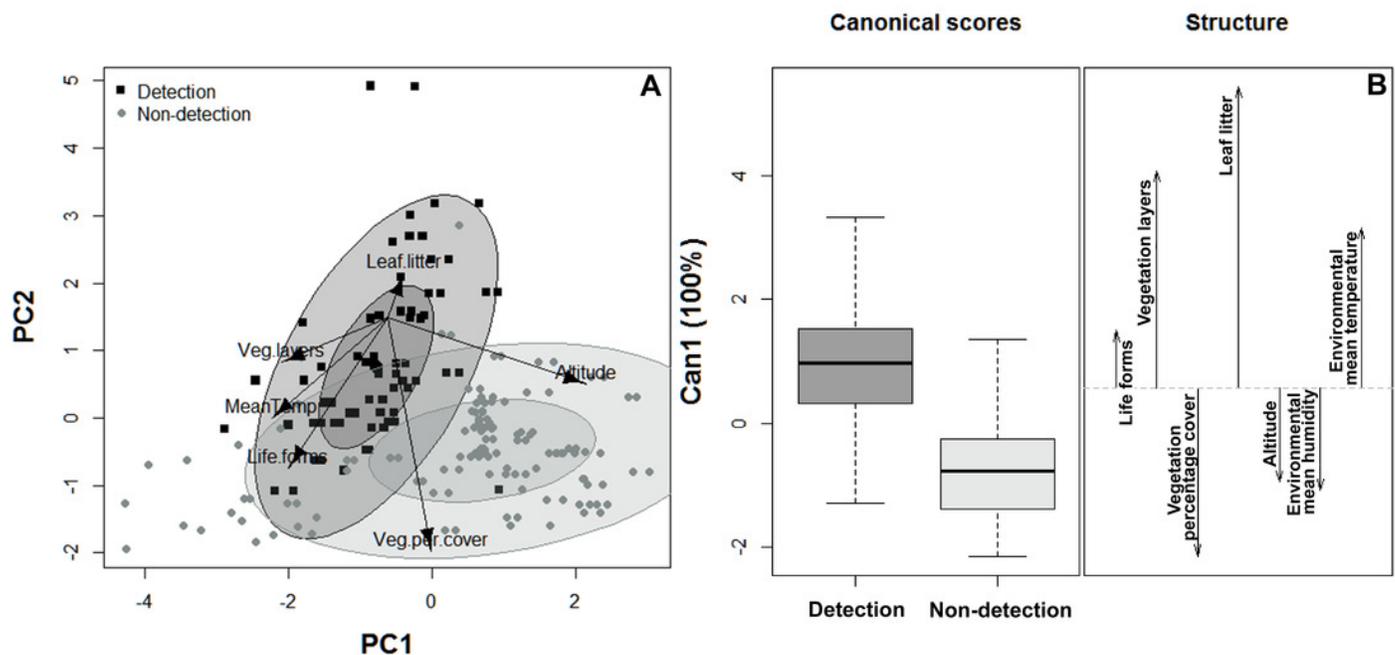
Figure 4

The "best" multiple regression model that relates *Bolitoglossa pandi* abundance and habitat structure variables

(A) Plots depicting linear regressions between *B. pandi* and habitat structure variables assessed. (B) Relative contributions of the variables that compose the "best" regression model.
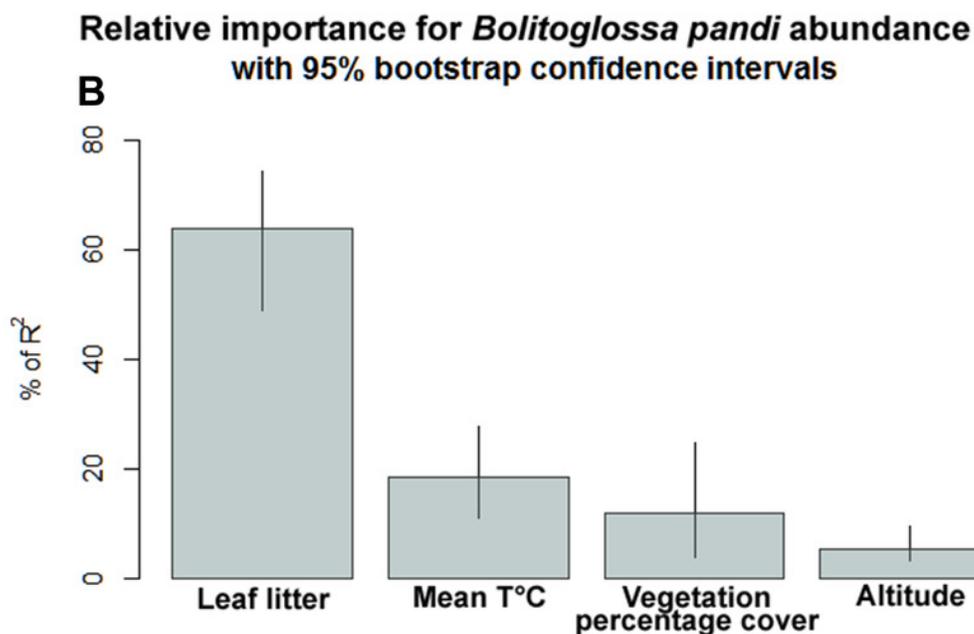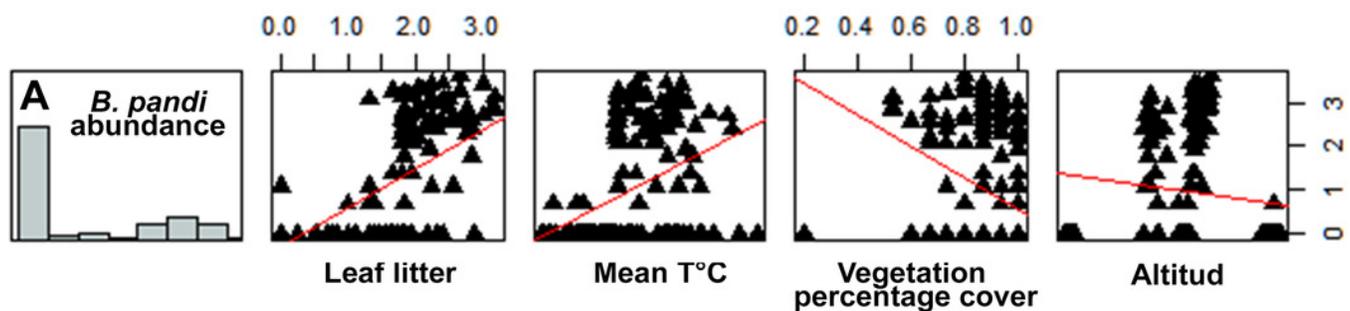
Figure 5

Circular kernel density models showing overall daily activity patterns of *Bolitoglossa pandi* during each sampling occasion.

The small vertical bars on the bottom depicts the independent detections observed during day and night for five consecutive days by ten researchers. (A) First sampling occasion, September–October 2017. (B) Second sampling occasion, March 2018. (C) Third sampling occasion, July 2018.
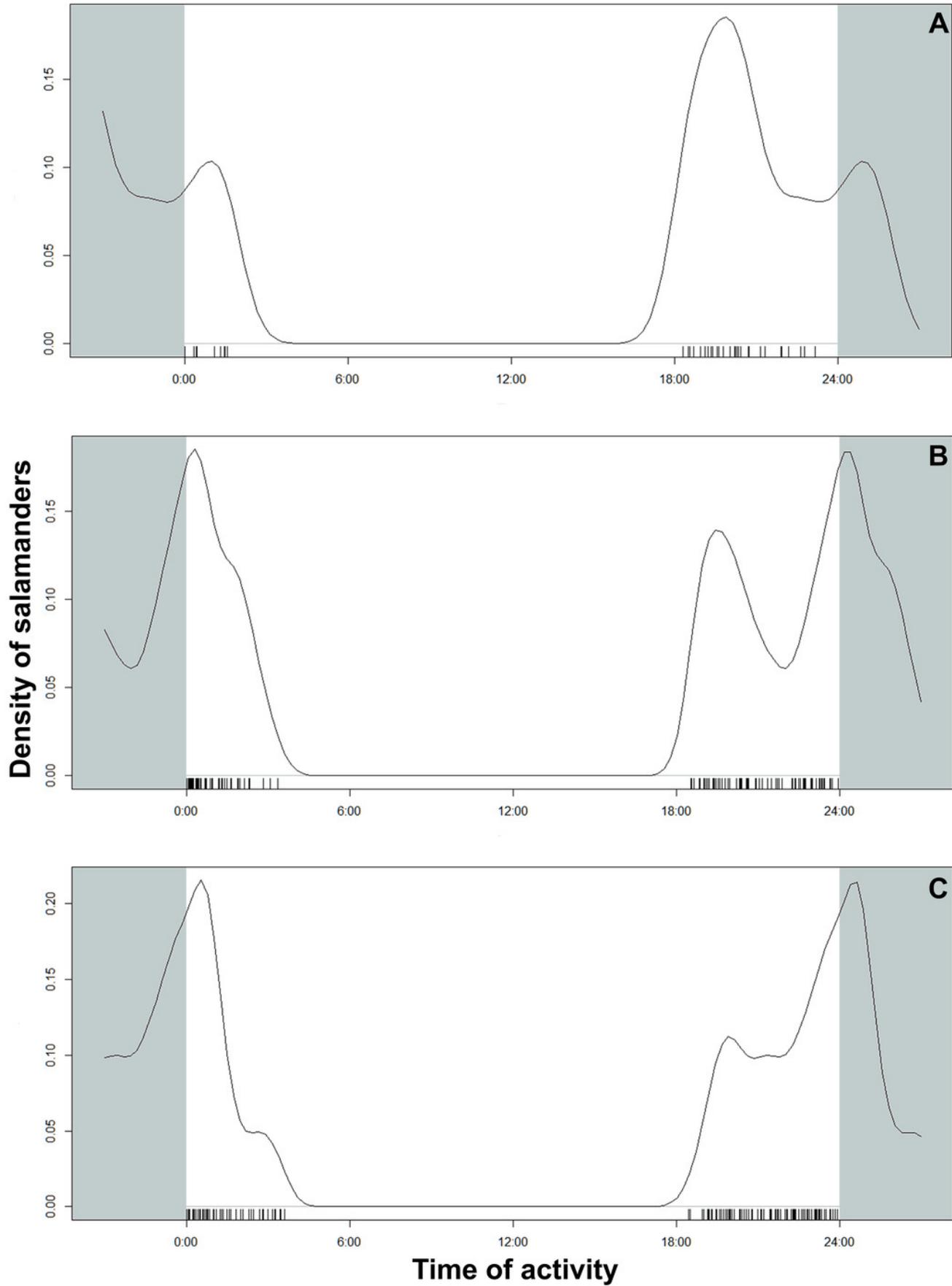
Figure 6

Abundance and body size variability during the activity of *Bolitoglossa pandi.*

(A) Nested ANOVA depicting the abundance variability among the activity peaks observed.

(B) Kruskal-Wallis test depicting niche partitioning between the body size classes
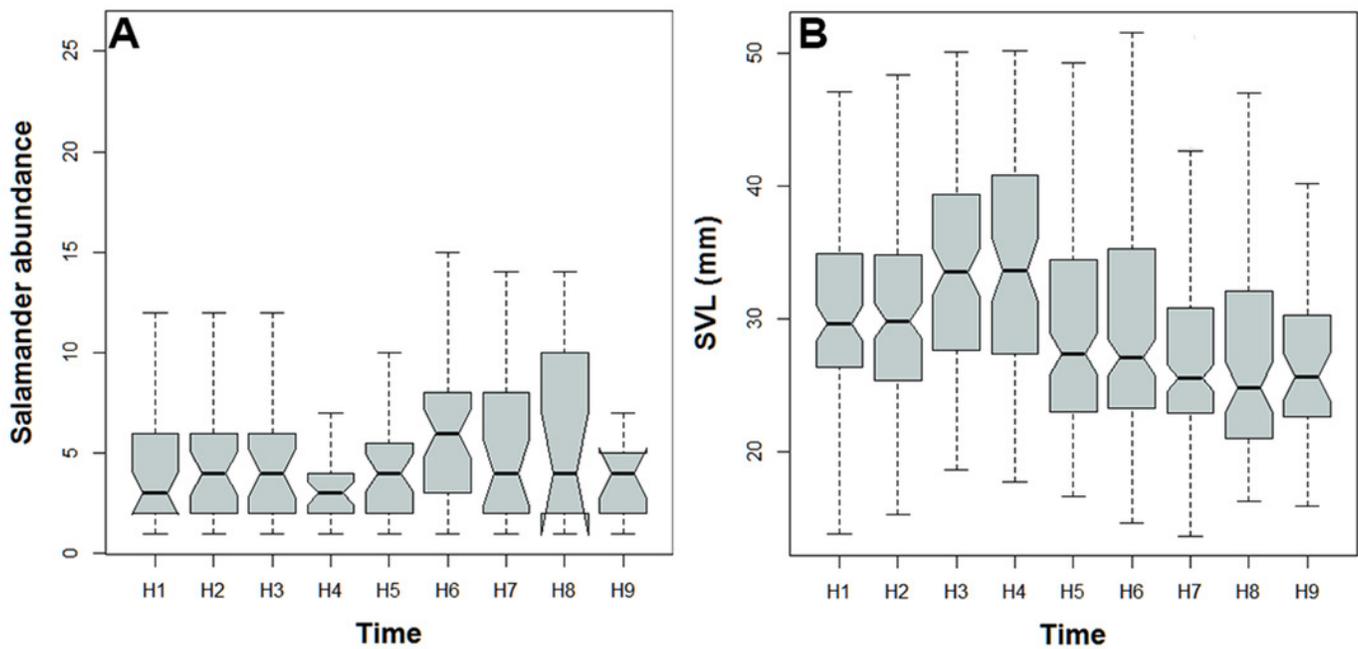
Figure 7

Population structure of the *Bolitoglossa pandi* population at the Cuzcungos locality across the sampling period.

(A) First sampling occasion, September–October 2017. (B) Second sampling occasion, March 2018. (C) Third sampling occasion, July 2018.
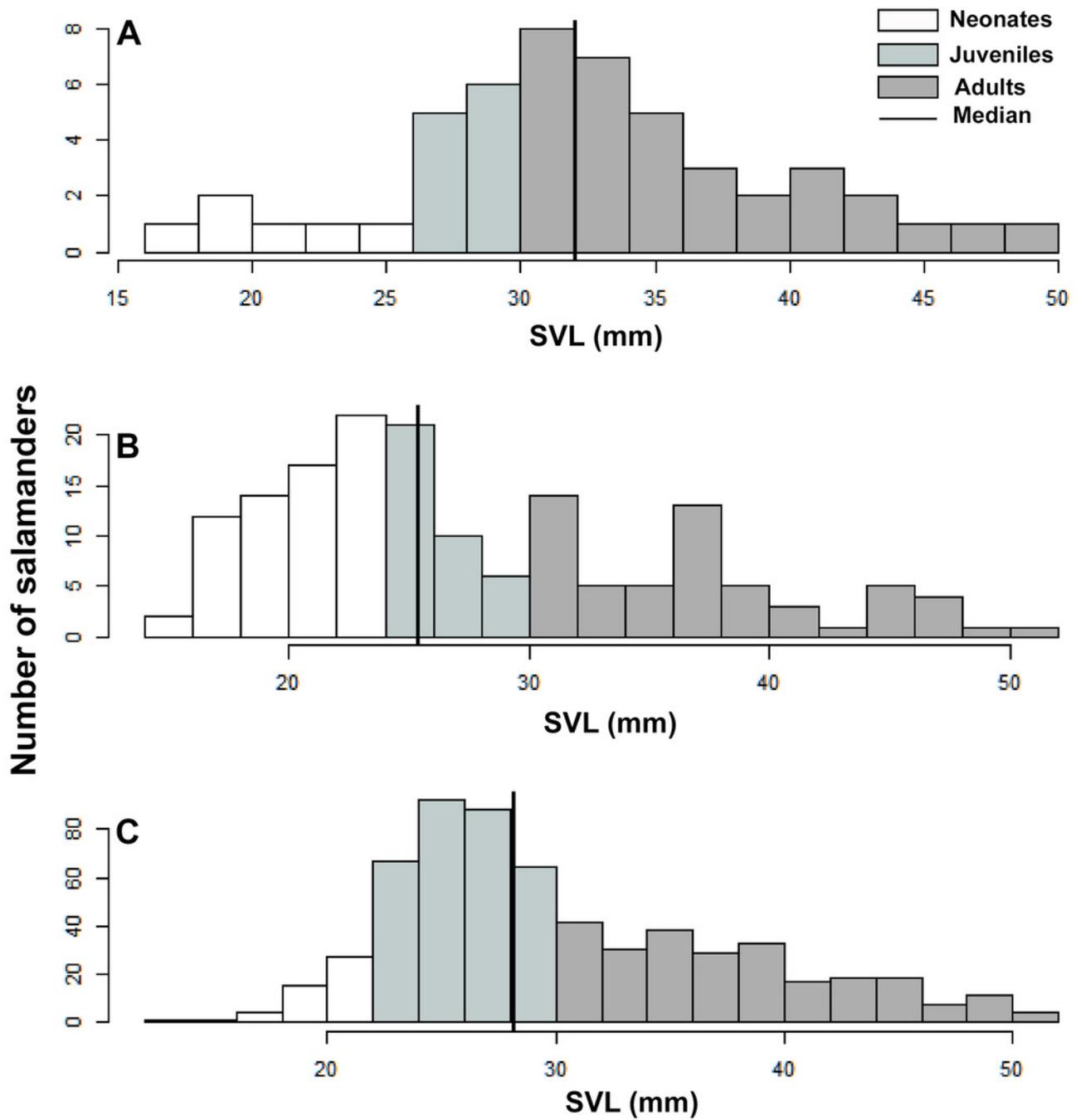
Figure 8

Color variability on ventral surfaces in preserved specimens of *Bolitoglossa pandi.*

(A) ventral surface of the head (ICN 45000; Pandi, Cundinamarca). (B) Lateral view of the lip of the edge showing the color pattern irregularly dark brown with irregular light spotting (ICN 58501, in life. Supatá, Cundinamarca). (C) ventral surfaces uniformly dark brown or dark grey with some irregular white circular spots (ICN 45000; Pandi, Cundinamarca. ICN 58502, Supatá, Cundinamarca).

Figure 9

Polychromatic variability observed in living specimens of *Bolitoglossa pandi* obtained in the municipalities of Guaduas, Supatá, and Villeta.

(A) uniform dorsal color pattern. (B) reddish-brown dorsal color that can have diffused grey or dark blotches scarcely distinguishable to the dorsolateral. (C-E) dorsal surfaces exhibiting ochre pattern, with some diffuse irregular dark brown, yellow or cream spots. (F-G) Diffuse dorsolateral band in the paravertebral surfaces covering almost the entire dorsal surface or including a dark brown inverted triangle shape in the interorbital region.

Table 1(on next page)

Sampling localities on the western slope of the Cordillera Oriental of Colombia.

VES: Visual encounter surveys (Crump and Scott 1994). QRS: Quadrats. N: Number of quadrants randomly selected.

Municipalities Vereda/locality	Latitude North	Longitude West	Altitude (m) a.s.l	Sampling protocol	*B. pandi* specimens observed	*B. pandi* specimens collected
Supatá						
Vereda Las Lajas/Monterey	From 5° 2' 18.5" To 5° 1' 59.9"	74° 14' 6.6" 74° 14' 3.5"	2119–2315	QRS (N = 45)	1	0
Vereda Las Lajas/ Cuzcungos Natural Reserve	From 5° 2' 27.7" To 5° 2' 27.2"	74° 14' 32.2" 74° 14' 27.9"	1931–2016	QRS (N = 43)	1390	12
Vereda San Marcos	From 5° 2' 58.9" To 5° 2' 58.3"	74° 15' 53.7" 74° 15' 54.9"	1743–1773	QRS (N = 28)	0	0
Villeta						
Vereda La Esmeralda	5° 3' 17.9"	74° 32' 49.1"	1996	VES	15	6
El Tigre site	5° 2' 9.2"	74° 33' 48.8"	1650	VES	12	0
Guaduas						
Vereda Granada	5° 4' 1.49"	74° 32' 59.6	1816	VES	7	0
Venecia						
Vereda Buenos Aires	From 4° 4' 57.9" To 4° 4' 44.1"	74° 27' 57.7" 74° 27' 33.3"	1809–2128	QRS (N = 90)	0	0
Vereda El Diamante/El salto de la Chorrera	From 4° 5' 24.6" To 4° 5' 21.0"	74° 27' 25.5" 74° 27' 33.2"	1637–1735	QRS (N = 36)	0	0
Vereda El Alto/ Road Venecia- Cabrera	From 4° 4' 5.2" To 4° 4' 11.1"	74° 29' 6.9" 74° 28' 54.8"	2034–2114	QRS (N = 54)	0	0

1

Table 2(on next page)

Multiple correlation analysis.

Bold values denote statistical significance at the p < 0.05 level.

Habitat structure variable	SVL (mm)	TL (mm)	Mass (g)	Perch height (mm)	Life forms	Percentage of vegetation cover	Vegetation layers	Leaf litter	Altitude (m) a.s.l
SVL (mm)	*****	0.890	0.901	0.316	0.216	0.287	0.006	-0.306	-0.155
TL (mm)	<0.001	*****	0.820	0.281	0.241	0.262	-0.037	-0.306	-0.126
Mass (g)	<0.001	<0.001	*****	0.288	0.194	0.271	0.018	-0.266	-0.134
Perch height (mm)	<0.001	<0.001	<0.001	*****	0.084	0.141	0.029	-0.058	0.004
Life forms	<0.001	<0.001	<0.001	0.026	*****	0.490	-0.039	-0.448	-0.043
Percentage of vegetation cover	<0.001	<0.001	<0.001	<0.001	<0.001	*****	0.063	-0.396	-0.152
Vegetation layers	0.883	0.322	0.627	0.445	0.300	0.096	*****	0.203	0.133
Leaf litter	<0.001	<0.001	<0.001	0.125	<0.001	<0.001	<0.001	*****	0.092
Altitude (m) a.s.l	<0.001	0.001	<0.001	0.906	0.260	<0.001	<0.001	0.015	*****

1

PeerJ

Table 3 (on next page)

Principal component correlation matrix.

KMO: Kaiser-Meyer-Olkin test. BST: Kaiser-Meyer-Olkin test

Habitat structure variables	Life forms	Vegetation percentage cover	Vegetation layers	Leaf litter	Altitude (m) a.s.l	Environmental mean temp °C	KMO	BST
Life forms	*****	0.481	0.263	0.002	-0.384	0.368		
Vegetation layers	**<0.001**	*****	-0.078	0.340	-0.364	0.410		
Percentage of vegetation cover	**<0.001**	0.285	*****	-0.274	0.045	-0.061		
Leaf litter	0.979	**<0.001**	**<0.001**	*****	0.149	0.060	0.6	**<0.0001**
Altitude (m) a.s.l	**<0.001**	**<0.001**	0.541	0.040	*****	-0.629		
Environmental mean temp °C	**<0.001**	**<0.001**	0.401	0.409	**<0.001**	*****		

1

Table 4(on next page)

Multiple regression models.

Akaike Information Criterion (AIC) employed to select the 'best model' that relates the fluctuation in habitat structure variables and the abundance of *Bolitoglossa pandi*. Dependent variable: Ln–transformed abundance of *B. pandi* (Lnn). Independent variables: Veg.per.cover = Vegetation percentage cover. Ln–transformedMean Temp = Environmental mean temperature. LnMeanH = Ln–transformed relative humidity. Lnlife forms = Ln–transformed number of vegetation life form Veg.leyers = Vegetation layers. Lnleaf litter= leaf litter depth. Nor.test = Kolmogorov–Smirnov's test for normality, Hom.test = Breusch–Pagan test for homoscedasticity, and Aut.test = Durbin–Watson test for autocorrelation. Values shown are standard error (SE) and *t* test-value. Bold values denote statistical significance at the p < 0.05 level.

Multiple regressions models	AIC	∆AIC	Nor.t est	Hom.test	DW
Lnn~Lnleaf litter+LnMean temp+Veg.per.cover+Altitude	−73.64	0.0			
Lnn~Lnleaf litter+LnMean temp+Veg.per.cover+Altitude+Lnlife forms	−73.08	−0.56			
Lnn~Lnleaf litter+LnMean temp+Veg.per.cover+Altitude+LnMeanHr	−71.92	−1.72	0.45	0.06	1.10
LnAbundance~Lnleaflitter+LnMeantemp+Veg.leyers+Veg.per.cover+Altitude+LnMeanH+Lnlife forms	−70.04	−3.60			
The "best" multiple regression model	**Estimate**	**SE**	*t*-value	**P(>|*t*|)**
Intercept	3.33	1.93	2.79	**0.006**
Ln leaf litter	0.88	0.071	12.34	**< 0.0001**
Ln Mean temp	0.69	0.167	4.12	**< 0.0001**
Vegetation percentage cover	−1.87	0.50	-3.73	**< 0.001**
Altitude	−0.001	0.0004	−2.46	**0.014**
F= 69.18, df= 4–182, P < 0.0001				

1

Table 5(on next page)

Nested ANOVA results.

Values shown are mean standard error (SE) and *t* test-value. Bold values denote statistical significance at the p < 0.05 level.

Time interval	Salamander observed	Estimate	SE	t value	P(>|t|)	Normality test	Levene test
H1 (18:30 a 19:30)	Max= 16, Min= 1 □= 4.16, N= 154	-0.0257	0.0234	-1.085	0.279		
H2 (19:31 a 20:30)	Max= 20, Min= 1 □= 4.91, N= 172	0.010	0.022	0.461	0.645		
H3 (20:31 a21:30)	Max= 12, Min= 1 □= 4.73, N= 123	0.013	0.023	0.525	0.599		
H4 (21:31 a 22:30)	Max= 8, Min= 1 □= 3.46, N= 97	-0.047	0.023	-2.037	**0.042**		
H5 (22:31 a 23:30)	Max= 16, Min= 1 □= 4.393, N= 158	-0.006	0.020	-0.309	0.757	P = 0.08	P = 0.2
H6 (23:31 a 00:30)	Max= 20, Min= 1 □= 6.05, N= 260	0.049	0.020	2.493	**0.013**		
H7 (00:31 a 01:30)	Max= 18, Min= 1 □= 4.73, N= 196	0.040	0.022	1.834	0.067		
H8 (01:31 a 02:30)	Max= 26, Min= 1 □= 6.47, N= 116	0.003	0.030	0.100	0.920		
H9 (02:31 a 03:30)	Max= 26, Min= 1 □= 4.43, N= 62	0.003	0.030	0.100	0.920		

1

Table 6(on next page)

Wilcoxon test results.

N= number of salamanders observed. Bold values denote statistical significance at the p < 0.05 level.

Sampling occasion	Occasion 1	Occasion 2	Median	Neonates	Juveniles	Adults
Occasion 1	–	–	32.05	N = 4 (8%)	N= 13 (26%)	N = 33 (66%)
Occasion 2	W= 11825, P < 0.001	–	25.40	N = 55 (34%)	N= 49 (30%)	N = 57 (36%)
Occasion 3	W= 22590, P = 0.006	W = 84198, P < 0.001	28.20	N = 76 (13%)	N= 277 (46%)	N = 252 (42%)

1