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On the distribution of Neotropical climbing salamanders (*Bolitoglossa paraensis*) in a forest fragment of the eastern Amazon

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The spatial distribution of a species provides valuable insights into how it uses its habitat. In general, species are found at sites that provide resources adequate for their survival and reproduction (Grinnel 1917, Hutchinson 1957, van Buskirk 2005, Bowles et al. 2006, Indemaur et al. 2010, Menin et al. 2011). The way in which a species uses these resources, such as specific microhabitats, may vary considerably in both time and space, resulting in a heterogeneous distribution of individuals within the environment (Pianka 1973). This variation in the distribution of individuals has been studied widely in all vertebrate groups, including amphibians. In amphibians, researchers have observed that environmental factors (e.g., the structure of the vegetation and microclimate) determine the spatial distribution of individuals (Spotila 1972, Crawford & Semilitsch 2008, Correa et al. 2012). These factors may be affected by anthropogenic impacts, such as forest fragmentation leading to edge effects. The response of the species to these impacts in terms of the distribution of species may be either positive or negative, or neutral (Murcia 1995, Ries et al. 2004, Harper et al. 2005).

Some species of salamander (Caudata) respond negatively to anthropogenic disturbance (Messere & Ducey 1998, Harper & Guynn 1999, Marsh & Beckman 2004). Salamanders are amphibians that occupy an enormous variety of habitats (e.g., bodies of water, forests, caves) and microhabitats (e.g., leaf litter, rocks, vegetation) in various parts of the world (Vitt & Caldwell 2014). In arboreal salamanders, the adults and juveniles typically occupy distinct strata in the vegetation (Waldron & Humphries 2005), with seasonal variations in the use of substrates by the different individuals (Sequeira et al. 2001).

A considerable diversity of salamanders is found in the Neotropics, and the genus *Bolitoglossa* is the most diverse, with more than 100 known species (Frost 2015), which are found in forest habitats, primarily in the leaf litter and vegetation (Duellman 1978, Chan 2003, Ortega et al. 2009, Neckel-Oliveira et al. 2011). Despite the overall diversity of Neotropical salamanders, most ecological studies have focused on reproductive traits or microhabitat use (e.g., Houck 1977, Bruce 1997, Chan 2003, Ortega et al. 2009, Neckel-Oliveira et al. 2011) and little is known of their distribution in the habitat.

Five species of *Bolitoglossa* are known to occur in the Amazon basin of Brazil, including *Bolitoglossa paraensis* (Brcko et al. 2013). This species is found in the understorey vegetation (Neckel-Oliveira et al. 2011), where its ethology is influenced by climatic variables, such as rainfall and relative humidity (Correa et al. 2012). Populations of *B. paraensis* are known to occur in forest fragments in the northeast of the Brazilian state of Pará (Brcko et al. 2013), which is an area of intense deforestation due to farming and urban growth (Gerwing 2002, Souza et al. 2003, Börner et al. 2007, Pacheco 2009). We investigated the variation in the distribution of *Bolitoglossa paraensis* specimens during different periods of the year. The goal of this paper is to answer two questions: (i) is the distribution of specimens affected by the distance to the forest edge? And (ii) is the distribution of the specimens related to their size?

We conducted our study in the Gunma Ecological Park (GEP), a 540-ha forest fragment in the municipality of Santa Bárbara do Pará (01°13'86" S, 48°17'41" W) in the northeast of the state of Pará, Brazil. The GEP is covered mainly by dense 'terra-firme' rainforest (61% of the area), with can-

opy trees of more than 25 m in height. There are also areas of floodplain (5%) and secondary forest (34%) (Amaral et al. 2009). The GEP is intersected by two dirt roads and the PA-391 state highway. Perpendicular to the dirt roads, there are four trails (< 1 m wide), more than 400 m from one another.

The local climate is humid equatorial, with a marked rainy season between December and May, and a period of reduced precipitation between June and November (Albuquerque et al. 2010). During our study period, the National Meteorological Institute (INMET) recorded monthly precipitation at the nearby town of Belém of between 55.7 mm in November and 662.2 mm in March (Fig. 1). At the GEP, the median temperature inside the forest varied from 24.1 to 25.1°C, while the median humidity ranged at 86–95% during our study period (Correa et al. 2012).
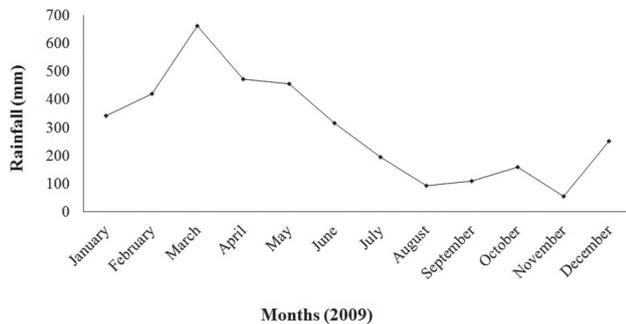

Figure 1. Monthly rainfall at Belém as obtained from a database made available by the Meteorological National Institute (INMET, http://www.inmet.gov.br).

We demarcated twenty-three 250-m² (5 × 50 m) plots within the area of the park, at a distance of at least 200 m from each other. This method was adapted from Rödel & Ernst (2004), and appears to be the most effective for long-term studies of terrestrial amphibians. The plots were located randomly within the existing GEP trail system and georeferenced with a Garmin 76 WAAS GPS receiver. We used the georeferenced position of the plots to locate them on a schematic map of the study area and calculated the distance of each plot to the nearest forest edge (Fig. 2).

We collected data during four periods in 2009: the mid rainy season (March–April), late rainy season (May–June), mid dry season (August), and late dry season (October). On some nights during the rainy season, the rainfall was so heavy that it impeded fieldwork. For this reason, two plots were sampled during the first two days of April (mid rainy season) and three days during the first three days of June (late rainy season). While June coincides with the onset of the dry season, we considered the data from this month (taken on the first three days) to be representative of the late rainy season.

We surveyed all 23 plots once during each period for the presence of *Bolitoglossa paraensis*, based on active visual searches conducted between 19:00 and 22:00 h. During each survey, three people systematically walked through the plot looking for salamanders on the different substrates known to be used by this species, such as the surfaces of leaves, herbaceous plants, lianas and tree trunks up to a height of 3 m (Neckel-Oliveira et al. 2011). When an individual was found, we recorded the period of the year, plot, height above the ground, and snout–vent length (SVL). We measured the height above the ground for each
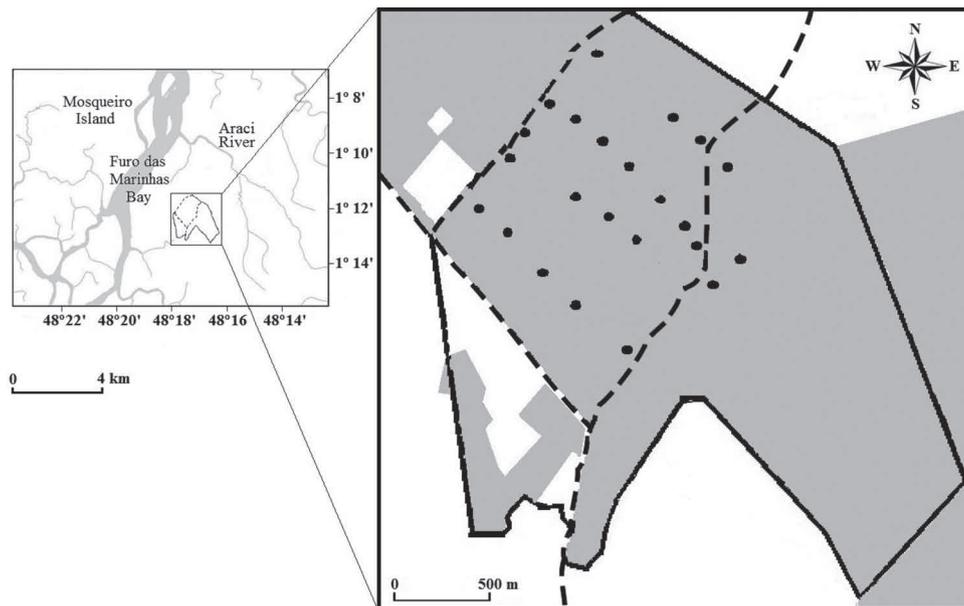

Figure 2. Map of the Gunma Ecological Park in northeastern Pará, Brazil, showing the distribution of the sample plots. Legend: grey – forested; white – open areas; black marks – sample plots; dashed lines – highways and roads.

individual with a 5-m measuring tape and used a 0.1-mm digital calliper to measure SVL.

We analysed our data separately for each of the four study periods. Because they did not assume a normal distribution according to the results of the Shapiro-Wilk test even after transforming them, we analysed our data using non-parametric tests, as suggested by ZAR (2010).

As individuals may be distributed homogeneously or heterogeneously within the forest, we compared their observed distribution (number of individuals in each plot) with the null-expected distribution using a Chi-square test. The alternative hypothesis indicates a heterogeneous distribution of individuals within the forest. During each period, we recorded 'outliers', that is, data collected in atypical nights (when it rained for up to 30 min prior to the surveys), as proposed by CORREA et al. (2012). While we collected data following the standard procedures during these nights, we ran Chi-square tests with and without 'outliers' in order to test their reliability. In addition, we used a Spearman coefficient to test for correlation between the number of salamanders in each plot and their distance to the nearest forest edge.

We tested the variation in the median height above the ground at which salamanders were found between the different sample periods using a Kruskal-Wallis nonparametric analysis of variance. When the null hypothesis was rejected ($p < 0.05$), we used a multiple comparison test to identify which periods contributed significantly to the observed variation. We also used a Spearman coefficient to test for correlation between the size of individuals and their height above the ground. We ran all analyses in PAST (HAMMER et al. 2001) and the R packages Pgirmess and Stats (R Development Core Team 2013).

In the 23 plots, we recorded 90 individuals of *Bolitoglossa paraensis* in March–April (mid rainy season), 46 in May–June (late rainy season), 45 in August (mid dry season), and 25 in October (late dry season). When the outliers were included in the analyses, the individuals were distributed heterogeneously over the plots during all four periods of the year (Table 1). When the outliers were excluded, however, a heterogeneous distribution was found only for the mid rainy season (Table 1). No correlation was found in any period between the number of salamanders per plot and the distance to the forest edge (Table 2).

The median height above the ground of *B. paraensis* specimens varied significantly over the study period (H = 39.924; $p < 0.01$), with differences in the mid rainy season and the two periods of dry season ($p < 0.01$). We also found a negative correlation between salamander size and height above the ground in the mid rainy season, whereas no correlation was observed in any other period (Table 2, Fig. 3).

In tropical amphibians, variation in the distribution of specimens is usually associated with the breeding season and the availability of prey, which vary according to climatic conditions (WATLING & DONNELLY 2002, CHAN 2003, WHITFIELD & DONNELLY, 2006, RODRIGUES & SANTOS-COSTA 2014). In this context, some ecological characteristics of *Bolitoglossa paraensis*, such as reproduction (NECK-

Table 1. Results of the Chi-square tests for the differential distribution of *Bolitoglossa paraensis* in the plots in the four periods of the year surveyed in the Gunma Ecological Park.

	With outliers		Without outliers	
	χ^2	P-value	χ^2	P-value
March–April	90.933	< 0.01	47.536	< 0.01
May–June	34	0.049	29.218	0.257
August	41.378	< 0.01	18.657	0.607
October	45.84	< 0.01	25	0.247

Table 2. Spearman correlation coefficients for the distance to the forest edge vs. the number of individuals per plot (DFE) and salamander size vs. height above the ground (BSH) during each of the four study periods.

	DFE		BSH	
	r_s	P-value	r_s	P-value
March–April	-0.118	0.598	-0.224	**0.028**
May–June	-0.316	0.139	0.114	0.436
August	0.069	0.781	0.011	0.947
October	0.175	0.419	0.259	0.201

el-Oliveira et al. 2011) and abundance patterns (CORREA et al. 2012), are influenced by climate in some periods of the year, but not in others. In our study, we observed a similar pattern in the distribution of salamanders within the forest.

We observed that the distribution of *B. paraensis* within the forest is not homogeneous, at least during mid rainy season, when rainfall levels are highest (March–April, Fig. 1). Plethodontid salamanders tend to use microhabitats with high relative humidity to avoid dehydration (SPOTILA 1972). *Bolitoglossa paraensis* appears to be especially sensitive to the variation in relative humidity, given that more active individuals were observed during periods with increased humidity (CORREA et al. 2012).
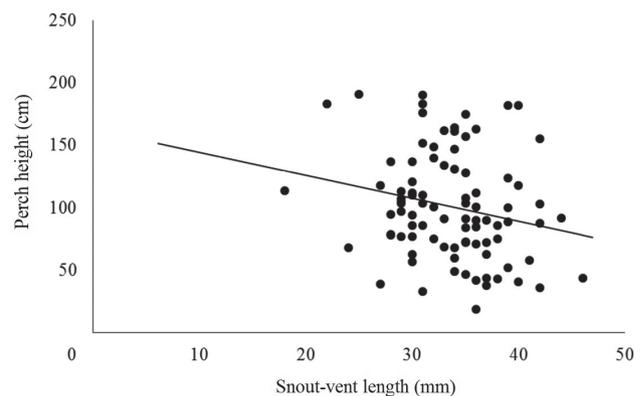

Figure 3. Correlation between *Bolitoglossa paraensis* size and the height above the ground of the specimens encountered during surveys.

Bolitoglossa paraensis reproduces during the rainy and early dry seasons, when the relative humidity inside the forest is relatively high (Neckel-Oliveira et al. 2011). During the breeding season, salamanders aggregate at specific points in the forest, influenced primarily by two factors: microhabitat quality and the presence of conspecifics, as observed by Quinn & Graves (1999) in a population of *Plethodon cinereus* (Plethodontidae). This is typical of aggregations associated with the distribution of resources in the habitat (Pounds & Crump 1987, Hews 1993, Bertona & Chiaraviglio 2003), which may be food, mates or breeding sites.

While the distribution of salamanders within the forest was not homogeneous, we did not find any evidence of an edge effect. In this case, *B. paraensis* may be considered to be a non-edge-avoiding species in the classification proposed by Lethinen et al. (2003). In the tropics, the effects of forest fragmentation have been widely studied in anuran amphibians (e.g., Vallan 2000, Lehtinen et al. 2003, Dixo & Martins 2008, Correa & Rodrigues 2015), but not salamanders, which have only been studied in a temperate region (Gibbs 1998a, b), where some species presented a negative response, while others were unaffected. However, while *B. paraensis* is unaffected by the distance to the edge, it does need forested habitats, in which it is typically found on the surfaces of the leaves of trees and herbaceous plants (Neckel-Oliveira et al. 2011). As in other plethodontid salamanders (Spotila 1972), *B. paraensis* is also affected by relative humidity (Correa et al. 2012), which is much higher in forest habitats than in open areas (Chen et al. 1999). Our results thus differ from the expected pattern for salamanders, given that temperatures are usually higher near the forest edge, while relative humidity will be lower here than inside the forest (Saunders et al. 1991, Murcia 1995), and that such changes in microclimate are known to have a negative effect on plethodontids (Spotila 1972), including *B. paraensis* (Correa et al. 2012). However, at the GEP, relative humidity does not appear to vary in relation to the distance from the forest edge, at least not enough to affect the distribution of *B. paraensis* within the forest.

During the mid rainy season (March–April, Fig. 1), the larger salamanders tended to be found lower down in the forest, in contrast with the positive relationship between size and height above the ground observed in *Bolitoglossa* cf. *pandi* (Río-García et al. 2014), and the lack of any relationship in other *Bolitoglossa* species (Mead & Boback 2002, Ortega et al. 2009). In these studies, however, data were collected throughout the year, rather than the seasonal analyses conducted here, and these differences may contribute to the differences found in the results. It is important to note that the ecological characteristics of amphibians may vary considerably between seasons (Watling & Donnelly 2002, Chan 2003, Whitfield & Donnelly 2006, Correa et al. 2012, Rodrigues & Santos-Costa, 2014) and that this variation may not be detected if the data are not analysed separately.

The fact that larger salamanders were found more frequently at lower heights during the mid rainy season may be accounted for by the *B. paraensis* breeding season. In *B. nicefori*, gravid females are much heavier and may be less able to climb vegetation, and thus remain low down in the substrate or on the leaf litter, where they lay their eggs (Ortega et al. 2009). This is consistent with the fact that *B. paraensis* reproduces mainly during the mid rainy season (Neckel-Oliveira et al. 2011), when both adult females and males occupy the lowest strata in the vegetation for mating.

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