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ACOUSTIC REPERTOIRE OF *BARYCHOLOS TERNETZI* (ANURA: STRABOMANTIDAE) IN CENTRAL BRAZIL

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Abstract. *Barycholos ternetzi* is an anuran species from the Brazilian Cerrado which can be found in gallery forests and Cerrado *sensu strictu.* Currently, the only available information about the natural history of *B. ternetzi* is a previous description of its advertisement call. Herein, we studied the vocal repertoire of this species in October 2009 at Floresta Nacional de Silvânia, Goiás state, Central Brazil. We recognized four distinct vocalizations, of which the advertisement call was the most common. The aggressive call was emitted in response to a neighbor male, while the distress and fighting calls were emitted, respectively, when the male was caught or during physical interactions. We also observed that the dominant frequency was influenced by call duration and body size, while the call duration and repetition rate were influenced by air temperature. Furthermore, we observed that the chorus size influenced the repetition rate of the advertisement call of *B. ternetzi.*

Keywords. Aggressive interaction; Advertisement call; Aggressive call; Distress call; Fighting call.

Introduction

Recently, the acoustic repertoire of some anuran species has been described and several kinds of vocalizations can be observed (Toledo and Haddad, 2005; Wells and Schwartz, 2007; Bastos *et al.,* 2011). These vocalizations are emitted in different contexts such as: competition for calling site (Arak, 1983), mate attraction (Brenowitz and Rose, 1999; Alonso and Rodríguez, 2003) and to maintain space among males (Brenowitz, 1989; Bastos and Haddad, 2002; Gerhardt, 2002). In many anuran species, the reproductive success is dependent on vocalizations; however, these calls can be influenced by several factors such as environmental (Toledo and Haddad, 2005) and morphological characteristics (Bastos *et al.,* 2011), as well as social context (Wells, 1988).

Currently, the genus *Barycholos* Heyer, 1969 is a member of the family Strabomantidae and is composed of only two anuran species: *Barycholos pulcher* (Boulenger, 1898) and *B. ternetzi* (Miranda-Ribeiro, 1937). These species occur in the Pacific lowlands of Ecuador and Central Brazil, respectively (Lynch, 1980; Frost, 2011). *Barycholos ternetzi* was first described as *Paludicola ternetzi,* but was subsequently considered a senior synonym of *Barycholos savagei* Lynch, 1980 (Caramaschi and Pombal, 2001). This species is commonly found in riverine forest litter and permanent streams with a rocky bed in cerrados and gallery forests (Bastos *et al.,* 2003; Araújo *et al.,* 2007). There is little information about its acoustic repertoire and only the advertisement call has been described (Guimarães *et al.,* 2001). Herein, we studied the vocal repertoire of *B. ternetzi* to answer the following questions: (A) how do temporal parameters of calls, environmental variables, morphological characteristics, and distance between males influence the dominant frequency of the advertisement call? and (B) how does chorus size influence the repetition rate of the advertisement call of *B. ternetzi?*

Material and Methods

Field surveys were conducted at Floresta Nacional (FLONA) (16°39'26"S; 48°36'16"W, 900 m a.s.l.), in the municipality of Silvânia, Goiás state, Brazil. The study site is located in the Cerrado domain, where the following vegetation physiognomies can be observed: *campo cerrado, cerrado sensu stritctu,* and gallery forests. The climate is tropical (Koppen AW) with two well-defined seasons: a rainy season (from October to March) and a dry season (from April to September). We observed the males of *B. ternetzi* in three different habitats: preserved and disturbed gallery forests, and open areas.

Males of *B. ternetzi* were observed in October 2009, totaling 50 hours in 10 visits. Fieldwork was conducted from 1800 h until 2400 h, the period of high calling activity. Behavioral observations were conducted with red-light

Table 1. Acoustic parameter of the vocalizations of *Barycholos ternetzi* from Central Brazil. Values are expressed as mean ± SD (range).

Call Parameters	Advertisement call	Aggressive call	Distress call	Fighting call
Call duration (ms)	49 ± 8 (30 – 79)	15 ± 2 (9 – 25)	74	282 ± 81 (159 – 388)
Number of pulses per call	7.16 ± 1.47 (4 – 12)	2.09 ± 0.53 (1 – 3)	—	29 ± 7.84 (18 – 39)
Pulse duration (ms)	7 ± 1 (4 – 9)	8 ± 3 (4 – 20)	—	9 ± 1 (8 – 10)
Dominant frequency (Hz)	3777.70 ± 175.94 (3351.69 – 4312.77)	3718.78 ± 233.61 (3107.38 – 4223.94)	3292	2730.6 ± 99.6 (2615 – 2813)
Fundamental frequency (Hz)	—	1908.96 ± 101.88 (1704.73 – 2170.93)	1623	1395.8 ± 7.16 (1383 – 1399)
Third harmonic frequency	—	—	4915	4154 ± 129.74 (4014 – 4212)
Call repetition rate (calls/min)	35 ± 12.16 (12 – 59)	11 ± 5.44 (1 – 20)	—	45
Sound Level	68.85	—	—	—
N (call/♂ recording)	285/57	265/53	1/1	5/1

flashlight, using focal-animal, all-occurrences, and sequence sampling methods (Lehner, 1979). After each recording, we collected the males, measured their snout-vent length (SVL) to the nearest 0.5 mm with calipers and their mass to the nearest 0.05 g with a Pesola® scale. Air temperature was measured with a thermo-hygrometer to the nearest 0.1°C, following each male recording.

Recordings were made with a Marantz PMD 660 digital recorder and a Sennheiser ME66 directional microphone positioned at about 50 cm from the calling male. Sound level of the calls were measured with a Minipa digital decibilimeter (Type II; Time weighting = Fast; A-weighted) at a distance of 50 cm, with all sound level measurements expressed as dB. Vocalizations were edited at a sampling frequency of 22 kHz and 16-bit resolution and analyzed using Avisoft-Sonograph Light® and Sound Ruler (Gridi-Papp, 2007) software. Frequency information was obtained through Fast Fourier Transformation (FFT, width 1024 points) with a Hanning window function at a 256-band resolution.

The following acoustic variables were measured: dominant frequency (Hz), fundamental frequency (Hz), third harmonic frequency (Hz), call duration (ms), pulse number (pulse/call), repetition rate of calls (calls/min), time spent in call (s) and intensity (dB). The bioacoustics terminology is in agreement with Gerhardt (1998), Gerhardt and Huber (2002), and Wells (2007). Voucher individuals and vocalizations were deposited in the Coleção Zoológica da Universidade Federal de Goiás (ZUFG).

To test whether call parameters, nearest neighbor distance, SVL, body mass, and air temperature influenced the dominant frequency of the advertisement call, we used single and multiple linear regression analysis. To assess the influence of aggregation size (high density > 30 calling males; low density < 15 calling males) on the repetition rate of the advertisement call, we used the Student's t-test. Statistical analysis was performed according to Zar (1999), with a significance level of ≤ 0.05.

Results

The calling activity of *B. ternetzi* began at sunset (1800-1900 h) and decreased near midnight, with males calling amidst the leaf litter in gallery forests or in open areas. The average SVL and body mass of calling males were 27 ± 1.51 mm (23.1 to 29.4 mm; N = 55 males) and 1.8 ± 0.32 g (1.1 to 2.5 g; N = 55 males), respectively. The mean distance between neighbor males was 9.8 m (1.3 to 25.8 m; N = 55 males) and air temperature varied from 19.8 to 28°C (N = 55 measurements).

We identified four kinds of vocalizations in *B. ternetzi,* which were emitted in different social contexts (Table 1): advertisement call (Fig. 1A), aggressive call (Fig. 1B), distress call (Fig. 2A), and fighting call (Fig. 2B). All vocalizations were composed of only one note; however, they showed a distinct physical structure. The advertisement call (N = 55 males) was the most common vocalization, mainly emitted when males were alone. In response to a neighbor male, the calling male emitted an aggressive call. The distress and fighting calls were emitted, respectively, when the male was captured or during physical combats between males.

Two males were observed in physical interaction, in which the resident male repulsed the intruding male. Fighting calls were emitted during this combat. These calls had lower sound levels compared to other calls of *B. ternetzi* and were emitted at irregular intervals in antiphony

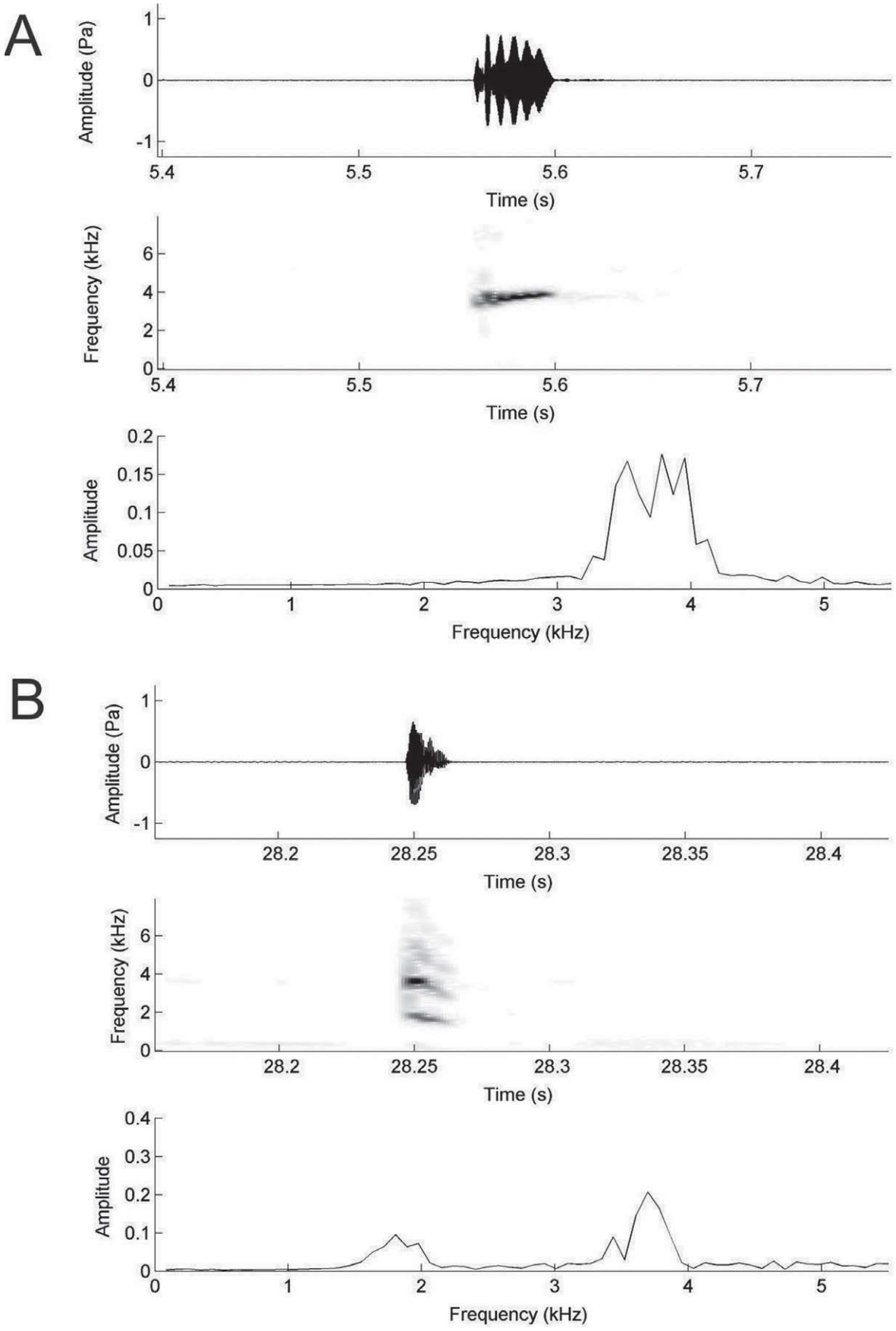

FIGURE 1. Oscilogram, Sonogram, and Spectogram (A) advertisement call and (B) aggressive call of *Barycholos ternetzi,* Floresta Nacional de Silvânia, Goiás state, Central Brazil.

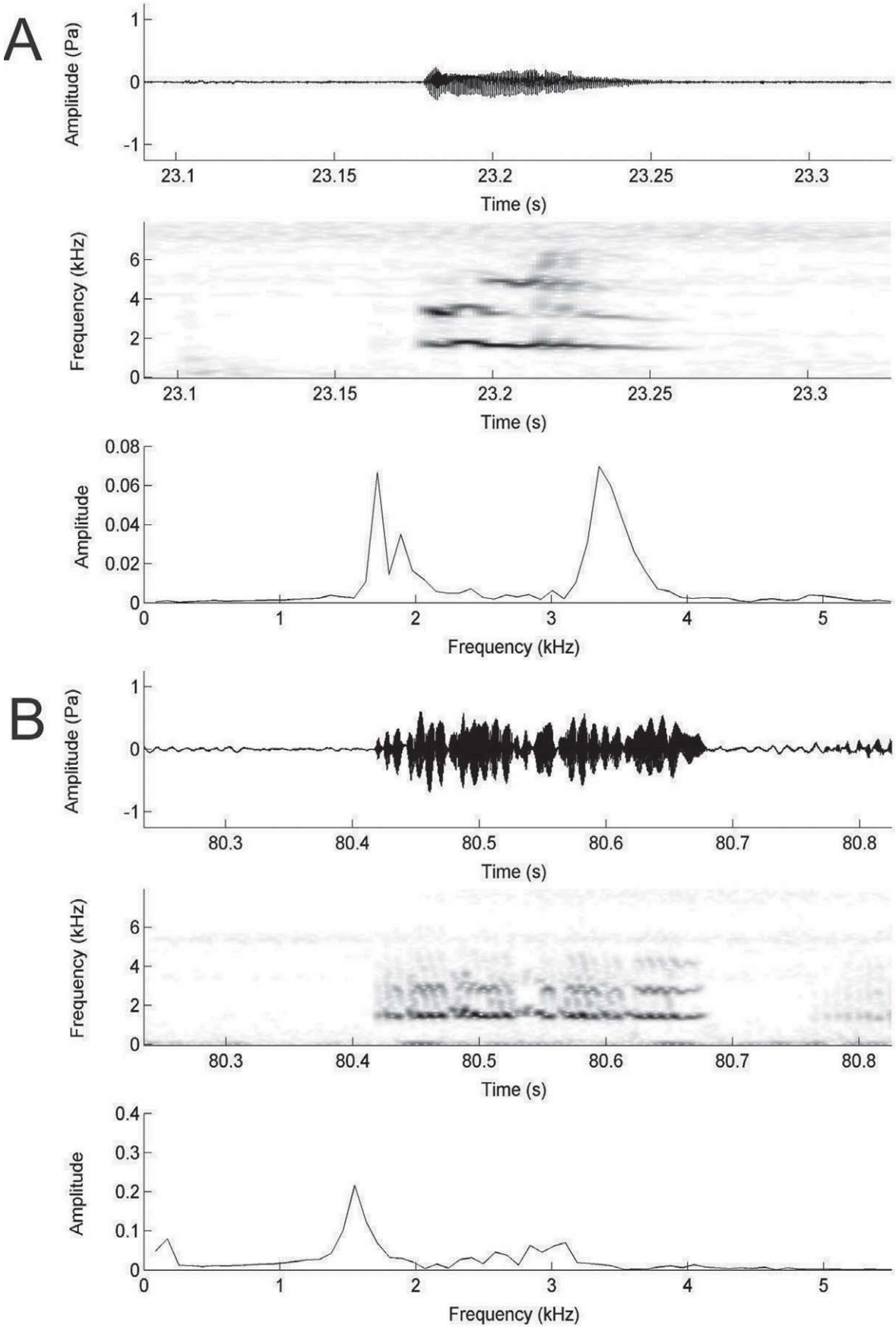

FIGURE 2. Oscilogram, Sonogram, and Spectogram (A) distress call and (B) fighting call of *Barycholos ternetzi,* Floresta Nacional de Silvânia, Goiás state, Central Brazil.

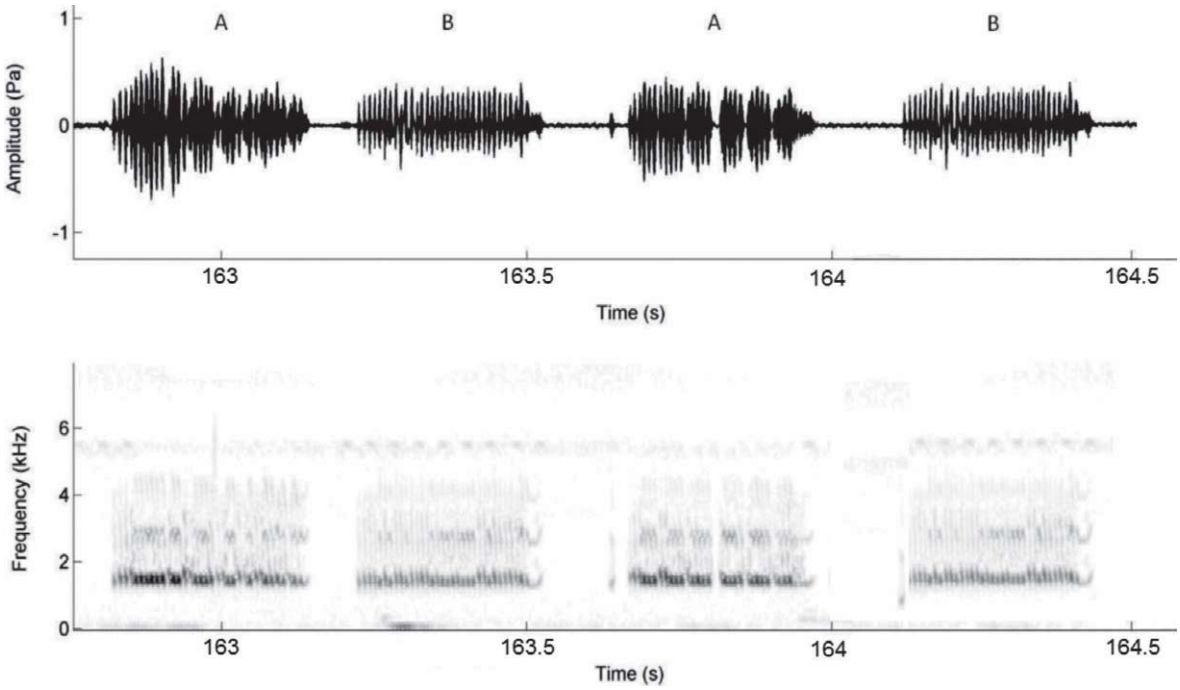

FIGURE 3. Antiphony of the fighting call of *Barycholos ternetzi.* Letters "A" and "B" represent calls emitted by two males during male-male interaction. Recorded in October 2009 (air temperature = 24.2°C; fight duration = 9.84 min) at Floresta Nacional de Silvânia, Goiás state, Central Brazil.

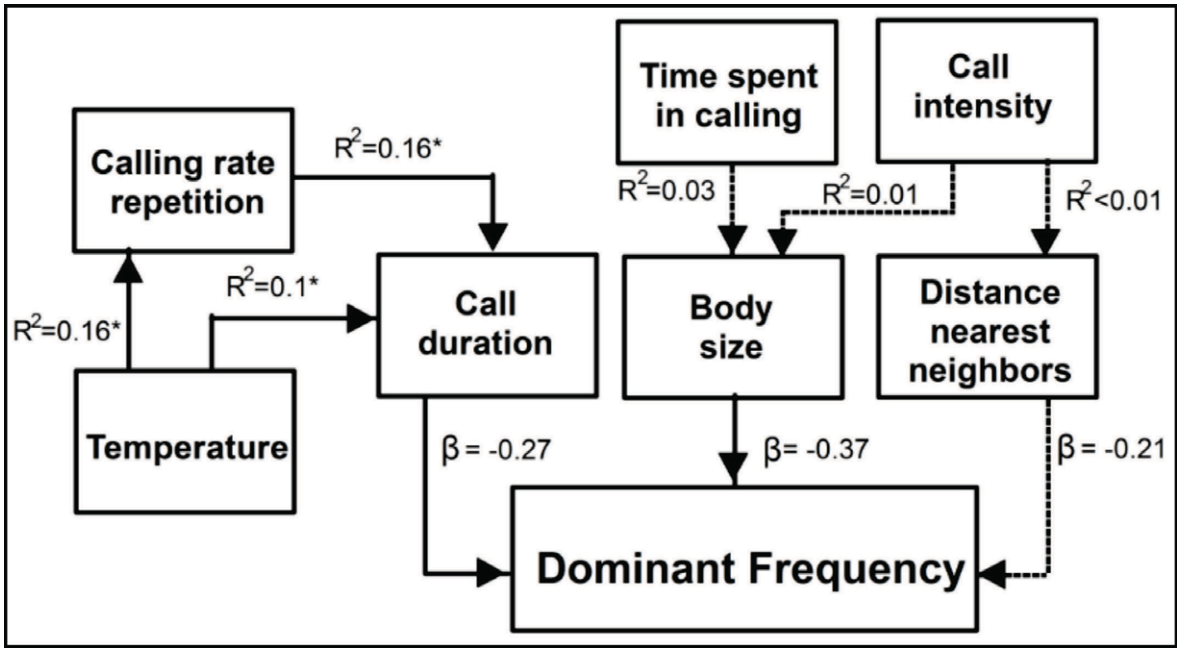

FIGURE 4. Simple and multiple linear regression analysis between call parameters and environmental variables, body size, and distance male, recorded at Floresta Nacional de Silvânia, Goiás state, Central Brazil. * Statistically significant.

(Fig. 3). This aggressive interaction lasted about 10 minutes and we recorded 45 fighting calls per minute.

Our results showed that the dominant frequency of the advertisement call was influenced by call duration ($\beta = -0.269$, $p < 0.05$) and body mass ($\beta = -0.374$; $p < 0.05$) (Fig. 4). Furthermore, air temperature negatively influenced call duration ($y = -1.79x + 9.16$; $R^2 = 0.16$; $P < 0.01$) and calling rate ($y = -1.79x + 9.16$; $R^2 = 0.16$; $P < 0.01$) and there was a positive relationship between calling rate and call duration ($y = 1.82x + 9$; $R^2 = 0.42$; $P < 0.01$). The other acoustic parameters analyzed did not correlate with SVL, mass, environmental variables, nor distance between males

($P > 0.05$ for all cases). Finally, the calling rate ($t = -2.38$; $df = 55$; $p < 0.02$) of *B. ternetzi* was dependent on calling male density at the breeding site; the calling rate increased by about 25% at high densities.

Discussion

Acoustic signals are the most conspicuous way of communication in frogs, in which several types of vocalizations are emitted in different social contexts (Wells, 1977). Currently, the vocal repertoire of some Brazilian anuran species have been described in the literature (Toledo and Haddad, 2005; Hartmann *et al.,* 2006; Lingnau and Bastos, 2007; Bastos *et al.,* 2011) and similar to these species the vocal repertoire of *B. ternetzi* is composed of different kinds of calls. Additionally, we observed that the advertisement call described in this study was similar to that described by Guimarães *et al.* (2001).

Herein, we described aggressive, distress, and fighting calls for *B. ternetzi* and also a physical combat between two males. Additionally, as described for other species (Bastos and Haddad, 1995; Guimarães and Bastos, 2003; Toledo and Haddad, 2005), we observed that *B. ternetzi* males alternated between advertisement and aggressive calls during territorial behavior. During territorial interactions, vocalizations are important to avoid injury or death that could be caused by male-male combats (Martins et al, 1998; Bastos and Haddad, 2002). In this case, we suggest that males of *B. ternetzi* exhibit an escalated aggressive behavior, in which it is possible to decrease the energetic costs of physical interactions between males (Martins *et al.,* 1998).

In general, the vocalizations of *B. ternetzi* have a short duration, being emitted at a high calling rate. However, long periods of silence were observed during the calling activity of *B. ternetzi.* This pattern was also described for *Craugastor fitzingeri* (Höbel, 2005) and *Yunganastes fraudator* (Jansen and Köhler, 2007). The study site is within the distribution area of some carnivorous species of bats, such as *Mimon bennetti* and *Trachops cirrhosus* (P. Mendes pers. comm.), therefore, this behavior could be a defensive mechanism to avoid such predators (Ryan and Tuttle, 1983). Furthermore, according to Höld and Gollmann (1986) and Duellman and Trueb (1994), the distress call, emitted when an individual is caught, is used by some anuran species to warn other individuals of a potential predator. Therefore, the distress call emitted by males of *B. ternetzi* reinforces the existence of the defensive mechanism cited above.

The dominant frequency of the *B. ternetzi* call was inversely related to body size, as observed for other anuran species (Gerhardt, 1994; Giasson and Haddad, 2006; Bastos *et al.,* 2011). Morphological characteristics are known to influence the acoustic parameters of anuran calls (Ryan, 1986) and, since there is a positive correlation between body size and mass of the vocal cords (Martin, 1972), the dominant frequency could be used as an indicator of body size (Bee and Gerhardt, 2001; Lesbarrères *et al.,* 2008). Consequently, males may use the dominant frequency to assess the fighting ability of their opponent (Robertson, 1986).

The acoustic parameters of anuran calls can be influenced by environmental factors (Dullman and Trueb, 1994), where temporal properties (*e.g.,* call duration and repetition rate) are influenced by air temperature (Guimarães and Bastos 2003; Lingnau and Bastos, 2007). Wagner (1989) and Wells *et al.* (1996) described, respectively, for *Acris blanchardi* and *Pseudacris crucifer,* a relationship between the calling rate and air temperature. Additionally, Guimarães and Bastos (2003) found that the number and note duration correlated with air temperature in *Hypsiboas raniceps.* In *B. ternetzi,* the acoustic variables were influenced by air temperature, in which there was a negative correlation between calling rate and call duration with air temperature, following the pattern described for *Hylodes heyeri* (Lingnau and Bastos, 2007) and *Paa spinosa* (Yu and Zheng, 2009). According to Lingnau and Bastos (2007), this relationship may represent a mechanism to avoid an increase in metabolic cost and greater energy expenditure at higher temperatures.

In *B. ternetzi,* acoustic behavior was influenced by male density, following the pattern described for other species (Sullivan and Wagner, 1988; Wagner, 1989). According to Wells (1988), females prefer high calling rates, therefore, it is expected that males increase the calling rate in response to male density increase. Our results are similar to that described by Wagner (1989), in which males increased the calling rate when density was high. As suggested by Wagner (1989), this behavior allows the males to increase their attractiveness to females.

Resumo. *Barycholos ternetzi* é uma espécie de anuro do Cerrado, que pode ser encontrada em floresta de galeria e Cerrado *strictu sensu.* Atualmente, a única informação disponível sobre a história natural desta espécie se restringe a descrição do seu canto de anúncio. Neste trabalho estudamos o repertório vocal desta espécie em outubro de 2009 na Floresta Nacional de Silvânia, estado de Goiás, Brasil Central. Foram reconhecidos seis diferentes tipos de vocalizações, onde o canto de anúncio foi o mais comum. O canto agressivo foi emitido em resposta a machos vizinhos, enquanto o canto de agonia e os cantos de briga foram emitidos, respectivamente, quando o macho era capturado ou durante interações físicas. Também

observamos que a frequência dominante foi influenciada pela duração do canto e tamanho do corpo, enquanto a duração do canto e a taxa de repetição foram influenciadas apenas pela temperatura do ar. Adicionalmente, uma relação positiva entre o tamanho do agregado reprodutivo e a taxa de repetição do canto de anúncio de *B. ternetzi* foi observada.

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