

# Activity, acoustic repertoire and social interactions of the Red Toadlet, *Brachycephalus pitanga* (Anura: Brachycephalidae)

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Manuscript received: 24 October 2016

Accepted: 2 May 2017 by STEFAN LÖTTERS

**Abstract.** The genus *Brachycephalus* is endemic to the Brazilian Atlantic Forest with most of its known species having been described only recently. In contrast to growing body of knowledge regarding the taxonomy of this genus, there remains a lack of general knowledge about their biology. Herein, we aim to describe the acoustic repertoire, social interactions between males and temporal pattern of reproductive activity of *Brachycephalus pitanga*. Humidity was the main explanatory factor for variation in the number of calling males throughout the year. We describe five calls types for the species: advertisement, territorial, encounter, warm-up and antiphony. The contexts in which these call types are emitted and their temporal and spectral parameters are discussed. During territorial disputes male frogs exhibited increasing levels of aggressiveness, beginning with the emission of territorial calls, escalating through encounter calls and visual signals and culminating in physical contests.

**Key words.** Behavior, vocalizations, visual communication, Atlantic Forest.

## Introduction

Temporal patterns of activity in anurans are usually related to environmental conditions, especially temperature and humidity, with the most common pattern involving breeding during the rainy season (DUELLMAN & TRUEB 1994). Interactions among males during this period usually include disputes for females and territories, and acoustic and visual signaling (WELLS 2007). A recent revision defined 13 types of anuran vocalizations associated with reproductive, aggressive, and defensive contexts (TOLEDO et al. 2014). The most thoroughly studied is the advertisement call, which is primarily emitted by males to attract conspecific females for reproduction, but it also can play an important role in the maintenance of territories among males.

Visual communication is more conspicuous in diurnal species, although it also occurs in nocturnal anurans (e.g. GIASSON & HADDAD 2006, TOLEDO et al. 2007) and may be associated with reproduction, territoriality, and agonistic interactions (HÖDL & AMEZQUITA 2001).

Few studies have focused on the breeding biology of toadlets of the genus *Brachycephalus* (Brachycephalidae), endemic to the Atlantic Forest of Brazil. Descriptions of advertisement calls are available for *B. ephippium* (POMBAL et al. 1994), *B. pernix* (WISTUBA 1998), *B. hermogenesi* (VERDADE et al. 2008), *B. tridactylus* (GAREY et al. 2012), *B. pitanga* (ARAÚJO et al. 2012) and *B. crispus* (CONDEZ et al. 2014),

while visual signaling has been reported for just *B. ephippium* (POMBAL et al. 1994) and *B. pernix* (WISTUBA 1998).

We studied the activity, acoustic repertoire and social interactions of the Red Toadlet, *B. pitanga* ALVES, SAWAYA, REIS & HADDAD, 2009, a recently described species with little known regarding its biology. We aimed to describe the call types emitted by males and the associated social contexts in which they are emitted, as well as document the temporal pattern of reproductive activity for the species.

## Material and methods

We conducted field studies in an area of Atlantic Forest of the Núcleo Santa Virgínia (NSV), Parque Estadual da Serra do Mar, São Luiz do Paraitinga, São Paulo, Brazil (23°21'09.57"S, 45°07'58.21"W). Elevation at NSV ranges from 870 to 1100 m above sea level and the vegetation is composed of a mosaic of montane rain forest, high montane rain forest and anthropized areas (OLIVEIRA-FILHO & FONTES 2000). Mean annual temperature for the area is 21°C, with total annual rainfall of around 2200 mm. Surveys were carried out between January 2011 and March 2012. During the wet season (September to March) surveys were performed once a month, whereas during the dry season (April to August) they were performed twice a month. Surveys lasted from three to seven days for a total of 54 days.

From February 2011 to January 2012, we counted calling males along a 400 m trail three times a day: morning (8:30 h to 9:30 h), midday (11:30 h to 12:30 h) and afternoon (17:00 h to 18:00 h). We observed few males vocalizing before 8:30 h and after 18:00 h, which represent the beginning and the end of diurnal activity, respectively, and so we limited our surveys to these three time periods because we would be more likely to encounter active individuals. We collected data on temperature and humidity using a digital thermo-hygrometer (measurement accuracy  $\pm 1^\circ\text{C}$  and  $\pm 5\%$ ). We aimed to find a relationship between the number of calling males and the following environmental variables: month, period of day, temperature, and humidity. Four models were tested: Poisson, negative binomial, generalized Poisson and generalized negative binomial. Model choice was based on the values of Global Deviance, AIC and SBC, which were lowest for the negative binomial model, and thus the best fit to our data. Data were analyzed using the R package gamlss 4.2-0. For all statistics we considered  $p < 0.05$  to be significant.

Vocalizations of 41 males of *Brachycephalus pitanga* were recorded in March, September and November 2011 during the day (8:00h to 18:00h) with a Marantz PMD 660 digital recorder and a Sennheiser ME 64 directional microphone with sample frequency of 44.1 kHz. Distance of the microphone from calling males ranged from 30 to 100 cm, and the individuals recorded were usually beneath leaf litter. We analyzed the call parameters using the software Raven Pro 1.3 with FFT = 250, following definitions of 'call', 'note' and 'pulse' of TOLEDO et al. (2014). Sonograms were constructed in the software Sound Ruler.

Behavioral observations were made following LEHNER (1987) and recorded through photographs and digital video

using a Fujifilm Finepix S1800 camera. Lastly, we analyzed the photographs and videos and illustrated the behaviors to provide a clearer depiction. Due to the reduced number of digits in *Brachycephalus* we were not able to mark individual frogs using toe clipping. Therefore, we used dorsal color patterns to identify individuals during field observations.

## Results

### Period of activity

We found individuals of *Brachycephalus pitanga* active during the day from 6:20 h to 19:20 h. Significant relationships between the number of calling males and the month ( $SE = 0.07$ ,  $t = 1.74$ ,  $p = 0.09$ ), the period of day ( $SE = 0.31$ ,  $t = 0.42$ ,  $p = 0.67$ ) or temperature ( $SE = 0.07$ ,  $t = 1.68$ ,  $p = 0.10$ ) could not be confirmed. Humidity was the main explanatory factor for variation in the number of calling males ( $SE = 0.03$ ,  $t = 2.57$ ,  $p = 0.01$ ).

### Calling behavior

Male *Brachycephalus pitanga* were observed calling exposed only on very wet days, and usually on leaf litter, but four individuals were observed up to 1 m high on tree trunks and seedlings. When relative humidity was  $< 80\%$ , individuals were heard calling only under leaves in the leaf litter. When calling, males had their upper body raised, arms extended and legs slightly extended (Fig. 1A), with the abdomen exhibiting rapid intense movements related to the pumping of air for the production of sound.

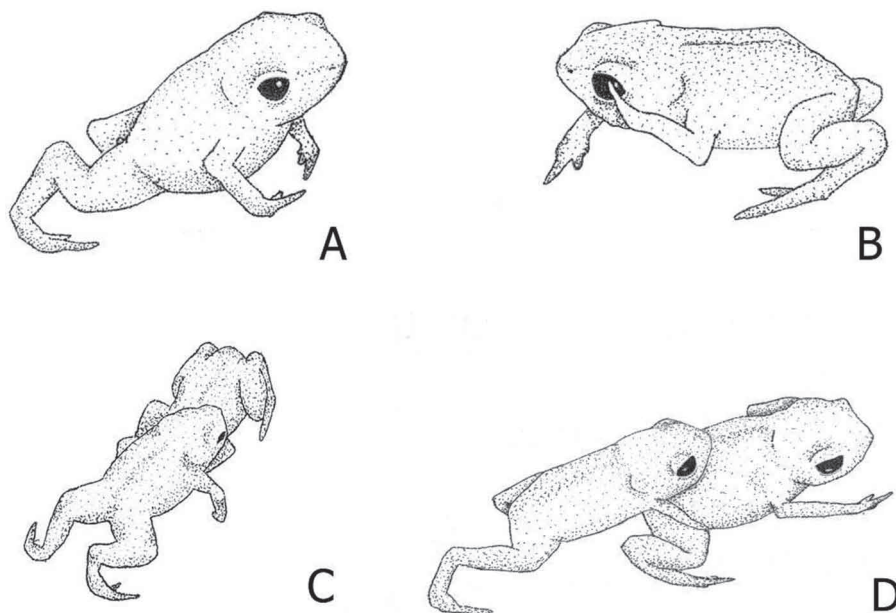


Figure 1. Schematic drawings of male-male interactions of *Brachycephalus pitanga*: (A) Calling male; (B) visual signaling; (C) male on the left calling over the head of male on the right; and (D) 'embrace' of two males during a territorial contest.

Table 1. Physical parameters of the five different call types of *Brachycephalus pitanga*. Data are shown as mean  $\pm$  standard deviation. Below each call type the number of notes analyzed and the number of males recorded are given in parentheses. The encounter call is subdivided into notes A and B; all other calls possessed only one type of note.

| Call                    | Pulses per note             | Note duration (s)              | Interval between notes (s)     | Dominant frequency (Hz)               |
|-------------------------|-----------------------------|--------------------------------|--------------------------------|---------------------------------------|
| Advertisement (210; 21) | 10.86 $\pm$ 1.66<br>(6–15)  | 0.19 $\pm$ 0.03<br>(0.13–0.26) | 0.27 $\pm$ 0.05<br>(0.03–0.45) | 4804.9 $\pm$ 429.9<br>(3292.9–5790.1) |
| Territorial (140; 14)   | 8.57 $\pm$ 1.06<br>(5–11)   | 0.14 $\pm$ 0.02<br>(0.08–0.21) | 0.21 $\pm$ 0.04<br>(0.02–0.33) | 4925.2 $\pm$ 238.3<br>(4500.8–5445.4) |
| Antiphony (50; 5)       | 8.9 $\pm$ 1.14<br>(7–11)    | 0.16 $\pm$ 0.02<br>(0.13–0.2)  | 0.23 $\pm$ 0.04<br>(0.18–0.34) | 4829.2 $\pm$ 331.5<br>(4336.8–5390.9) |
| Warm-up (13; 1)         | 3.7 $\pm$ 0.6<br>(3–5)      | 0.07 $\pm$ 0.02<br>(0.04–0.14) | 0.24 $\pm$ 0.01<br>(0.21–0.28) | 5053.4 $\pm$ 105.1<br>(4883.4–5274.3) |
| Encounter (7; 2)        | A 6.5 $\pm$ 1.27<br>(5–8)   | 0.12 $\pm$ 0.04<br>(0.06–0.17) | -                              | 5238.2 $\pm$ 162.6<br>(5103.8–5575.0) |
|                         | B 2.5 $\pm$ 0.50<br>(2 – 3) | 0.04 $\pm$ 0.01<br>(0.02–0.07) | 0.11 $\pm$ 0.01<br>(0.08–0.14) | 5206.4 $\pm$ 163.0<br>(4657.9–5650.2) |

### Call structure

We were able to identify five call types and their related behavioral contexts: advertisement call, territorial call, warm-up call, encounter call and an antiphony call similar to the territorial call (audio files are available at <https://soundcloud.com/eli-garcia-883319399/sets/brachycephalus-pitanga-calls>). The structures of all call types were similar: a set of trills made of a variable number of pulses, ranging from three in the warm-up call to 14 in the advertisement call. Frequency amplitude was the only parameter similar among all call types, and ranged from 3500 to 7500 Hz. Statistical support for differences in the calls of *Brachycephalus pitanga* can be found in TANDEL et al. (2014).

Of all the call types identified, the advertisement call (Table 1; Fig. 2A) was the most frequently heard. It was the longest call type and possessed the lowest note emission rate ( $2.19 \pm 0.34$  notes/s). The duration of the advertisement call ranged from less than 30 s to 4 min, with 2 min being the most frequent length. The territorial call (Table 1; Fig. 2B), also composed of one note, was emitted when a male approached another calling male. The note repetition rate was higher for the territorial call than for the advertisement call ( $2.81 \pm 0.39$  notes/s) and the two were distinguishable by ear. For the analysis of the antiphony call (Table 1; Fig. 2C), we considered only recordings in which it was possible to distinguish the calls of the two individuals involved, as shown in Figure 2C. This vocalization was composed of a single note and the number of pulses, note duration, and interval between notes were less than those of the advertisement call, but we found no significant differences between the parameters of the territorial call and the antiphony call. The emission rate of the antiphony call (about  $2.54 \pm 0.38$  notes/s) was higher than that of the advertisement call.

Males emitted encounter calls (Table 1; Fig. 2D) directly towards other males during agonistic encounters when they were less than 30 cm from each other; this vocaliza-

tion could precede physical combat. The structure of the encounter call differed from those of the other call types in having an introductory note (A note), followed by a sequence of  $11.28 \pm 9.10$  shorter notes (B notes).

Male *B. pitanga* emitted the warm-up call when they started to vocalize prior to emitting advertisement calls (Table 1). Although it was heard very frequently, the warm-up call was recorded for only one male because it was not possible to predict their emission. The warm-up call was made up of a single note repeated 13 times and possessed less than half the number of pulses as the advertisement call. The emission rate of the warm-up call was 3.21 notes/s.

### Territorial behavior

Physical combats were observed only in October, November and December when relative humidity was close to 100%. We followed five territorial contests, the longest of which lasted 1.5 hrs. When a calling resident male noticed the presence of a calling intruder, it interrupted its advertisement calls and began to emit territorial calls. At this time, the two males could emit territorial calls in antiphony ( $N = 4$ ). On each occasion when individuals came within 30 cm of each other, both individuals were observed emitting encounter calls, which always preceded physical combat. As one or both males approached each other they both made visual signals (Fig. 1B) by passing a hand in front of their eye in an up-and-down manner similar to the behavior observed when cleaning eyes of soil particles.

When resident and intruding males met, one of them emitted an encounter call with the vocal sac positioned above the head of the other ( $N = 2$ ) (Fig. 2C), and combat ensued. Each male tried to seize its opponent using their arms, and when a male embraced the inguinal region of the other they would walk over the leaf litter like an amplexed pair (Fig. 2D). Both males emitted encounter calls when embraced. The embraced male tried to detach itself

by kicking the opponent and jumping. When one of the males attempted to gave up and depart, the other after it and combat continued ( $N = 3$ ).

### Discussion

Call activity was positively correlated with increasing air humidity, but was not correlated with month or period of day. This finding leads us to think that there is a dependence on particular optimal microclimatic conditions, which can vary greatly even over just a few days. Previous studies only reported males vocalizing under leaf litter (ARAÚJO et al. 2012), however, we observed them calling exposed on very wet days, as has also reported for *Brachycephalus brunneus*, *B. ephippium*, *B. ferrugineus*, *B. izecksohni*, *B. pombali*, *B. tridactylus*, and *B. toby* (POMBAL et al. 1994, RIBEIRO et al. 2005, ALVES et al. 2006, VERDADE et al. 2009, HADDAD et al. 2010, GAREY et al. 2012).

Vocalizing while hidden under leaf litter does not seem to be an efficient strategy from an acoustical point of view

(WELLS & SCHWARTZ 1982), but the size of *B. pitanga* and its terrestrial habits make desiccation a more serious problem than it is for most anurans (OLALLA-TÁRRAGA et al. 2009). Furthermore, vocalization can increase exposure to predators (ENDLER 1992, RYAN et al. 1992), and so males of *B. pitanga* only call from the top of leaf litter when environmental conditions are optimal.

Our results report that the advertisement call of *B. pitanga* has fewer pulses, a lower note emission rate, a shorter duration and a lower dominant frequency than that previously reported for this species (ARAÚJO et al. 2012). We suggest that this discrepancy can be explained by the different sample sizes analyzed by us and in the previous study. In comparison to other species of *Brachycephalus*, the advertisement call of *B. pitanga* has fewer pulses than *B. ephippium*, but a longer note duration and interval between notes (POMBAL et al. 1994). The structure of the advertisement call of *B. hermoogenesi* (VERDADE et al. 2008) and *B. tridactylus* (GAREY et al. 2012) differ from that of *B. pitanga* in having shorter call durations and higher dom-

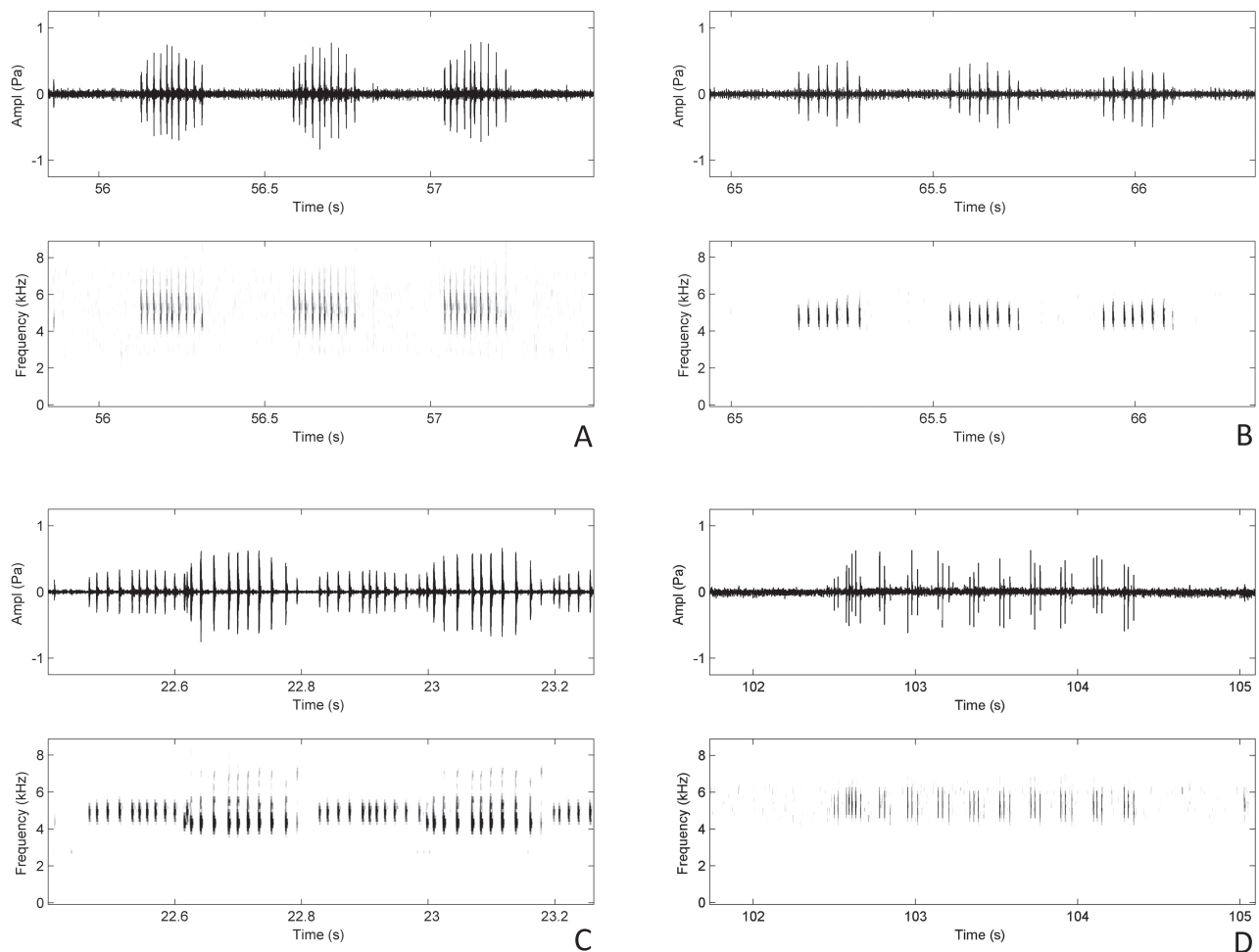


Figure 2. Sonograms and spectrograms of (A) advertisement call, (B) territorial call, (C) antiphony call and (D) encounter call of *Brachycephalus pitanga* from São Luís do Paraitinga, São Paulo, Brazil.

inant frequencies. When compared to *B. crispus* (CONDEZ et al. 2014), *B. pitanga* possesses a similar number of pulses and dominant frequency, but a longer note duration and interval between notes.

Generally, among anurans, aggressive and advertisement calls have similar dominant frequencies but differ in temporal structure (WELLS & SCHWARTZ 2006), just as we observed for *B. pitanga*. The encounter call we report for *B. pitanga* has an introductory note followed by a sequence of short notes. ARAÚJO et al. (2012) reported this call as 'territorial' but here we use the term 'encounter call' because of the behavioral context in which it was heard (sensu TOLEDO et al. 2014).

The acoustical parameters we measured easily distinguish the antiphony call from the advertisement call, but not from the territorial call (TANDEL et al. 2014). The antiphony call is a common vocalization in anurans and can have several functions, such as reducing signal interference, facilitating male spacing, aiding in the location of males by females and the preservation of temporal information in calls (SCHWARTZ 1987). In the case of *B. pitanga*, the structure of the antiphony call, and its resemblance to the territorial call, lead us to conclude that it is used in an aggressive context, and does not seem to play a role in other functions, such as the attraction of females, as reported for other species (WELLS & SCHWARTZ 1984, TOLEDO & HADDAD 2005).

Three categories of territorial behaviors are recognized among anurans: defense of resources needed for survival, defense of oviposition sites and defense of courtship areas (WELLS 1977). As reported for *B. ephippium* (POMBAL et al. 1994) and *B. pernix* (WISTUBA 1998), territorial behavior in *B. pitanga* seems to be related to defense of courtship areas. In some species aggressive interactions occur only at the beginning of diurnal activity, when males are still establishing their territories (e.g. WELLS & BARD 1987). This was not the case in *B. pitanga*, as we found males engaging in territorial contests throughout the day.

Physical contests are costly in terms of time, energy and risk of injury and so they are frequently avoided in favor of using vocal and visual signaling to solve contests, leaving physical aggression as an ultimate option (PARKER 1974, WELLS 1978). Also, a gradation of aggressiveness in calls has been previously reported for anurans, with a change in call usually being the first behavior observed in a territorial contest (MARTINS & HADDAD 1988, KADADEVARU & KANAMADI 2001, WELLS & SCHWARTZ 2006, TOLEDO et al. 2014). This gradation was observed by us in *B. pitanga*, with males presenting four call types: advertisement, territorial, encounter and antiphony.

We observed visual communication in association with encounter calls. Visual communication is found particularly among diurnal frogs that live in environments with minimal visual obstruction (ENDLER 1992) and/or noise, which could hamper acoustic communication by sound interference (e.g. HEYER et al. 1990, HADDAD & GIARETTA 1999). Though, *B. pitanga* does not live near areas with river or waterfall noise, background noises (such as rain, wind

and other animal vocalizations) may be louder than their calls, as reported for *B. ephippium* (POMBAL et al. 1994). The observed visual signaling in *B. pitanga* may have derived from cleaning behavior, which also seems to occur in *B. pernix* (WISTUBA 1998) and *B. ephippium* (POMBAL 1992). When covered with soil particles, individuals of *B. pitanga* clean themselves by wiping their head with the limbs, making movements that resemble their visual signals.

When disputes among males were not resolved through acoustic and visual signaling, we observed males in physical combat, similar to that reported for *B. ephippium* (POMBAL 1992) and *B. pernix* (WISTUBA 1998). Territorial behavior is similar for all three species for which it has been studied (*B. ephippium* (POMBAL 1992), *B. pernix* (WISTUBA 1998) and *B. pitanga*, leading us to hypothesize that this territorial behavior may be uniform throughout the genus, which only future research can confirm.

### Acknowledgements

The collecting permit was issued by COTEC (SMA process number 260108 - 000.669/2011) and SISBIO/IBAMA (process number 23501-2). Financial support was provided by São Paulo Research Foundation (FAPESP grant #2008/50928-1) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq). N. PUPIN, L. BANDEIRA, K. DUARTE, D. DELGADO, C. GUSSONI, T. CONDEZ and K. MELLO helped with field and laboratory work. S. LOIBEL and M. TANDEL helped with the statistical analysis. We thank PESM Núcleo Santa Virgínia staff and J. P. VILLANI for logistical support. C. A. BRASILEIRO and C. P. A. PRADO gave helpful suggestions on the manuscript. We also thank ERIK WILD and an anonymous reviewer for revising the English of the manuscript.

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