Phyllomedusa 13(1):67–70, 2014

ISSN 1519-1397 (print) / ISSN 2316-9079 (online)
doi: http://dx.doi.org/10.11606/issn.2316-9079.v13i1p67-70

SHORT COMMUNICATION

Advertisement call of *Craugastor noblei:* another calling species of the *Craugastor gollmeri* Group (Anura: Craugastoridae)

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Keywords: advertisement call, calling activity, Costa Rica, vocal sac, vocal slits.

Palavras-chave: atividade vocal, canto de anúncio, Costa Rica, fendas vocais, saco vocal.

Anuran communication is dominated by acoustic signals; consequently, most species have well-developed vocal systems that can produce a variety of sounds in different situations (Duellman and Trueb 1986). The advertisement call is the most commonly emitted sound in this repertoire; males produce this vocalization in both reproductive and territorial contexts (Gerhardt 1994, Wells 2007), and it usually is accompanied by the inflation of a vocal sac with pulmonary air (Pauly *et al.* 2006). Vocal sacs occur widely in anurans and are thought to be involved in both acoustic and visual communication (Narins *et al.* 2003, Rosenthal *et al.* 2004).

Received 25 April 2013.
Accepted 28 May 2014.
Distributed August 2014.

Despite this relevance, vocal sacs are absent in many groups such as the basal genera *Alytes, Bombina* and *Discoglossus* (Cannatella 2006), as well as in more derived groups including some New World direct-developing frogs. An example is the *Craugastor gollmeri* Group that contains seven forest-floor frog species distributed from southern Mexico to Panama (Savage 2002). These species were thought not to vocalize because they lacked vocal sacs and vocal slits (Savage 1987). However, Ibañez *et al.* (2012) described the advertisement call of *Craugastor gollmeri* in Panama, providing the first evidence of vocalization in this clade.

Here we describe the previously unknown advertisement call of *Craugastor noblei*, another representative of the *Craugastor gollmeri* Group. This is the second species known to vocalize of the three in the group (*C. gollmeri, C. noblei,* and *C. mimus*) that occur in lower Central

America (Savage 2002). Other natural history notes for the species, such as habitat use, daily calling activity, and calling season are also included. Male *Craugastor noblei* were found vocalizing in the Veragua Rainforest Reserve (9°55'34.90" N, 83°11'27.42" W, 420 m a.s.l.), in Limón Province, Costa Rica, during three consecutive breeding seasons between 2010 and 2013. Between November and December of 2011, we recorded four calling males; one of them was collected and deposited in the Herpetology Collection of Museo de Zoología, Universidad de Costa Rica (UCR21156).

All recordings were made in digital format at a sampling rate of 44.1 kHz and a 16-bit resolution with a Marantz PMD661 Digital Recorder and a Sennheiser ME66 directional microphone positioned at approximately 1 m from the focal individual. The recordings are archived in the audio collection of the Bioacoustics Laboratory of the University of Costa Rica.

Spectrotemporal analysis was performed in Raven 1.2 (Cornell Lab of Ornithology, Ithaca, New York, USA). Sound spectrograms of each recording were produced with a Fast Fourier Transformation, using Hann type window with 124-Hz frequency resolution, 11.6-ms time resolution, and 50% overlap. Calls were produced in long bouts containing an average of 23, but up to 400, calls, each of which consisted of two notes. Two call bouts from each of four males were recorded and 50 calls from each male were analyzed for a total of 200 calls containing 400 notes. For each call, we considered the following variables: call duration, note duration, inter-call interval, dominant frequency, and frequency range. To report the time variables we use milliseconds (ms) and for frequency variables hertz (Hz).

The advertisement call of *Craugastor noblei* is a distinct, loud vocalization consisting of two rapidly repeated notes produced in long bouts at about 0.5-s intervals (Figure 1). Calls can be heard by the human ear from a distance of approximately 30 m. Bouts contained an average of 23 calls, but in some cases, calling males were heard continuously for 5 min, emitting more than 400 calls. Calls have a mean duration of 418 ± 9 ms (N = 200), intercall interval of 507 ± 37 ms (N = 200; min = 415 ms; max = 680 ms). The first note of each call has a mean duration of 37 ± 6 ms (N = 200; min = 26 s; max = 61 ms); the second note has a mean duration of 40 ± 5 ms (N = 200; min = 28 ms; max = 58 ms). The spectral analysis shows that dominant frequency is 717.3 ± 10.4 Hz (N = 400; min = 516.8 Hz; max = 947.5 Hz) (Table 1). The note frequency ranges between 312.9 ± 56.6 and 1977.6 ± 175.0 Hz (N = 400; Bandwidth = 1664.7 ± 182.7 Hz).

We visited the study site weekly between 2010 and 2013 and only heard vocalizations at sunset from November to January 2010–2011, 2011–2012, and 2012–2013. Males were found

Table 1. Means and standard deviations for the spectro-temporal parameters of the advertisement calls produced by four males of *Craugastor noblei*.

Individual	Number of Calls	Temperature (°C)	Call Duration (ms)	Note 1 Duration (ms)	Note 2 Duration (ms)	Call Interval (ms)	Dominant Frequency (Hz)
1	50	24.5	143 ± 14	36 ± 4	39 ±3	487 ± 27	687 ± 57
2	50	24	151 ± 6	40 ± 7	42 ± 7	495 ± 27	700 ± 84
3	50	24	149 ± 6	36 ± 7	40 ± 6	531 ± 43	749 ± 127
4	50	23.5	150 ± 5	38 ± 6	41 ± 4	516 ± 32	734 ± 121

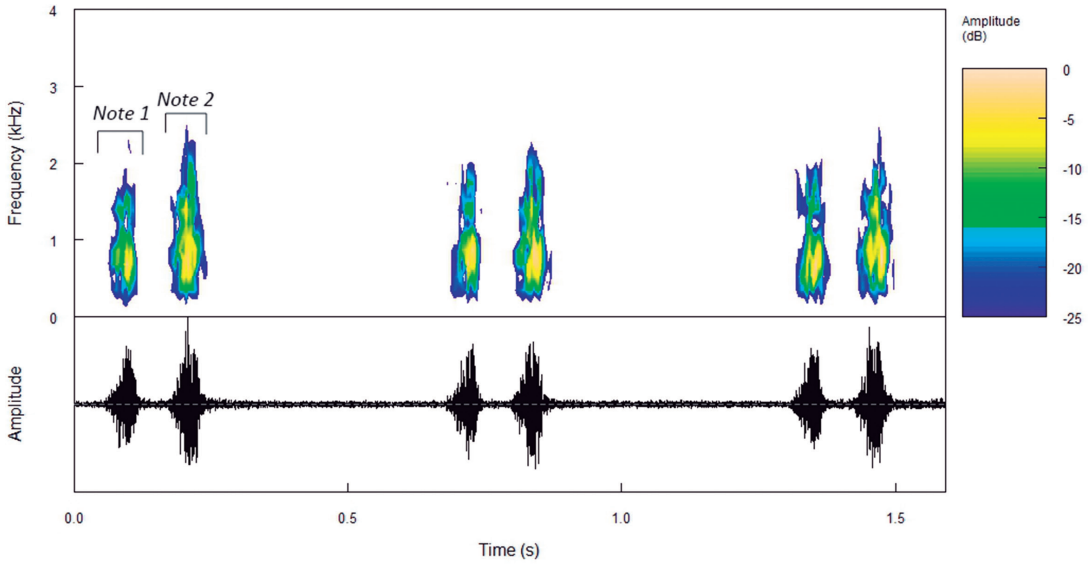

Figure 1. Spectrogram (upper) and oscillogram from a portion of the call of *Craugastor noblei*.

both vocalizing alone and forming a chorus of as many as five individuals, usually grouped in a small area with a diameter of approximately 1.5 m. Such choruses seemed more common after heavy rains. In almost all cases, males were observed calling from hidden places such as holes in the ground, under logs and rocks, and mainly on forest edges.

Cases of vocalization in Costa Rican species lacking vocal sacs include the members of the *Craugastor rhodopis* Group in which both vocals sacs and slits are absent (Savage 2002) and males vocalize at low intensities (pers. observ.). Other similar direct-developing species include *C. gollmeri* that produces a low intensity advertisement call (Ibañez *et al.* 2012). The hylid *Anotheca spinosa* is another example; this species vocalizes from cavities such as open bamboo internodes or bromeliad axils emitting a loud call that can be heard from as far as 100 m (Jungfer 1996, Rodríguez-Brenes *et al.* 2013). Calling from holes, as our study species does, may amplify sound (Lardner and bin Lakim 2002) and could be a strategy for species lacking vocals sacs to take advantage of these potential resonance structures.

As highlighted by Savage (2002), the reproductive behavior of this group of species is poorly known, probably as a result of their short breeding season and hidden calling sites. Our evidence confirms the hypothesis proposed by Ibañez *et al.* (2012) that additional species within the *Craugastor gollmeri* Group produce advertisement calls. We recommend further efforts to document vocalizations of other members of this group. Once described, they will represent a powerful tool to increase detectability of these species and further improve the documentation of their life histories.

Acknowledgments

We thank Wagner Chaves Acuña, José Brenes Andrade, and Stanley Salazar for their help in the field. Federico Bolaños facilitated recording equipment. Gerardo Chaves, Rafael

Márquez, Jody Rowley and one anonymous reviewer made valuable comments on the manuscript. Linda Trueb kindly improved the English of the manuscript. Field work was conducted under permission No. 001-2012-SINAC. This is a contribution of Programa Institucional del Laboratorio de Autómatas y Sistemas Inteligentes en Biodiversidad (PILASIB) at Universidad de Costa Rica funded by Agencia Española de Cooperación Internacional y de desarrollo [AECID funds D/027406/09 (2010) and D/033858 (2011)].

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Editor: Stephen J. Richards