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Review of bioacoustical traits in the genus *Physalaemus* Fitzinger, 1826 (Anura: Leptodactylidae: Leiuperinae)

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Abstract

Given the importance of acoustic communication in intraspecific recognition during mating activity, acoustic traits have been widely used to clarify the taxonomy of anurans. They have been particularly useful in the study of taxa with high morphological similarity such as the Neotropical genus *Physalaemus*. Here, we reviewed the acoustic repertoires of the species of *Physalaemus* based on homology hypotheses in order to make comparisons more properly applicable for taxonomic purposes. We covered all the known clades and species groups for the genus, analyzing 45 species (94 % of the currently recognized taxa). Different call types were labeled with letters (*i.e.*, A, B, and C) to avoid speculative functional propositions for the call types. In order to identify correctly the observed frequency bands, we propose a method to interpret them based on the predicted graphic behavior on audiospectrogram and on the mathematic relationship among bands considering each kind of band production (*e.g.*, harmonics and sidebands). We found different acoustic traits between the major clades *P. signifer* and *P. cuvieri*. Species in the *P. signifer* clade have more than one call type (67 % of species in the clade). Furthermore, all species of this clade have A calls with pulses and/or low fundamental frequency (< 500 Hz). In the *P. cuvieri* clade, species emit only one call type and, in most species, this call is a continuous whine-like emission with relatively high fundamental frequency (> 400 Hz) and several S-shaped harmonics (except for species of *P. henselii* and *P. olfersii* groups, *P. centralis*, and *P. cicada*). Within the *P. signifer* clade, pulsed calls are present in *P. angrensis*, *P. atlanticus*, *P. bokermanni*, *P. crombiei*, *P. irroratus*, *P. moreirae*, *P. nanus*, and *P. obtectus*, whereas within the *P. cuvieri* clade this feature is restricted to a few species (10 % of the clade): *P. jordanensis*, *P. feioi*, and *P. orophilus*. A principal component analysis of the quantitative data indicates two clusters that substantially correspond to the composition of these two major clades with a few exceptions. Overall, the cluster composed of taxa of the *P. signifer* clade has lower fundamental frequency, bandwidth and dominant frequency at the end of the call and higher frequency delta and dominant frequency at the end of the call than the cluster with most taxa of the *P. cuvieri* clade. We also identified and described several similarities among acoustic signals of closely related species, which might correspond to synapomorphies in the evolution of the acoustic signal in the group. Species of the *P. deimaticus* group emit long sequences of very short A calls with low fundamental frequency (< 300 Hz) and short duration (< 0.2 s). Most species in the *P. signifer* group have clearly pulsed calls and emit at least two different call types. Species in the *P. henselii* group have calls with only high frequency bands (> 1700 Hz). Species in *P. cuvieri* group have continuous calls that resemble nasal-like sounds or whines, with downward frequency modulation. Species in the *P. olfersii* group emit long calls (> 1 s) with ascendant and periodic frequency modulation. Calls of the species in the *P. biligonigerus* and *P. gracilis* groups usually have continuous whine-like calls with call envelopes very variable within species. In addition, we describe traits in the genus for the first time, such as complex traits not predicted by simple and linear acoustic models (nonlinear phenomena), and discuss the application of acoustic traits to taxonomy and phylogenetics and morphological constraints of the vocal apparatus that might be related to the different acoustic properties found.

Key-words: Homology, behavior, taxonomy, systematics, Amphibia, vocalizations

Introduction

In anurans, acoustic communication mediates several important life interactions such as mating and aggressive behaviors, antagonistic encounters, and advertises the position of an individual to others (Wilczynski & Chu 2001; Gerhardt & Huber 2002; Wells 1977; 2007; Köhler *et al.* 2017). Many studies have shown the importance of acoustic signals for species-specific recognition in anurans, and then the usefulness for systematics and taxonomy of the group (*e.g.,* Haddad & Pombal 1998; Canedo & Pombal 2007; Hepp *et al.* 2015). Given the stereotypy of the calls and the relatively high morphological similarity of *Physalaemus* species, acoustic features have helped to clarify species boundaries and to posteriorly identify them (*e.g.,* Bokermann 1967; Pimenta *et al.* 2005; Heyer & Wolf 1989). Moreover, recent studies have focused on how to code and propose primary homology of acoustic traits (Robillard *et al.* 2006a; Goicoechea *et al.* 2010). These studies have allowed the use of acoustic characters for estimating phylogenetic relationships in support of molecular and morphological data.

An important issue when applying acoustic traits in comparative studies is how to accurately establish homology between acoustic structures while describing them (Desutter-Grandcolas & Robillard 2003). Wenzel (1992) suggested the application of Remane's (1952) traditional homology criteria typically used on morphological data to behavioral traits as well. Similarly, some authors have applied and claimed the use of the same criteria specifically to acoustic traits (*e.g.*, Mundinger 1979; Price & Lanyon 2002; Desutter-Grandcolas & Robillard 2003; Hepp *et al.* 2017; Folly *et al.* 2018). Most descriptions of anuran acoustical signals have been made based on single species (*e.g.,* Hepp *et al.* 2012; Hepp & Canedo 2013; Caram *et al.* 2014). Since one of the most important pillars of the Remane's criteria is the comparison between related taxa, it is essential analyzing as many species as possible (see Wenzel 1992). Therefore, acoustic reviews with several taxa potentially lead to a better understanding of the structures' homology and then contribute by raising reliable characters for further systematic and taxonomic studies (*e.g.*, Hepp *et al.* 2015; Hepp *et al.* 2017).

Physalaemus currently comprises 48 species (Frost 2019). Among them, 46 species had their calls described (Table 1). Some of them (17 spp.) had their calls described more than once (*e.g.*, *P. bokermanni*, *P. cuvieri*, and *P. maximus*). Although the intense effort in describing the acoustic repertoires of those species, the divergent definitions used when describing the acoustic structures have precluded a straightforward application of acoustic characters in systematic studies. For example, similar structures have often been called by different terms and interpreted as being either homologous or analogous (*e.g.*, frequency bands of *P. maximus*; see Baêta *et al*. 2007b; Santanna & Moura 2011; Peres & Simon 2012).

Historically, *Physalaemus* species have been arranged into species groups based on phenetic traits (Cei 1980; Lynch 1970; Nascimento *et al.* 2005). Few species of the genus (less than ten) had been included in large-scale amphibian phylogenies (Frost *et al.* 2006; Pyron & Wiens 2011). Recently, Lourenço *et al.* (2015) proposed a set of phylogenetic hypotheses for the majority of the *Physalaemus* species (41 spp.) based on molecular data. The authors found two major clades: *P. signifer* and *P. cuvieri* clades. Additionally, seven clades were named as species groups (Lourenço *et al.* 2015), two within *P. signifer* clade (*P. deimaticus* and *P. signifer* groups) and five within *P. cuvieri* clade (*P. biligonigerus*, *P. cuvieri*, *P. henselii*, *P. gracilis*, and *P. olfersii* groups). Among the 41 species included in this analysis, four (two in each clade) were left out of any species group: *P. nattereri*, *P. maculiventris*, *P. cicada*, and *P. aguirrei* (Lourenço *et al*. 2015).

A clade comprising the genera *Edalorhina* and *Engystomops* was found to be the sister group of *Physalaemus* (Lourenço *et al.* 2015). The acoustic traits of *Engystomops* species have been widely studied (*e.g.*, Cannatella & Duellman 1984; Ron 2008), mainly those of *E. pustulosus* (review in Ryan & Guerra 2014). The production processes of the acoustic structures in the vocal apparatus of *E. pustulosus* were addressed by several studies (review in Ryan & Guerra 2014). Some of them also examined the anatomy of the vocal apparatuses of *Physalaemus* species in order to compare morphology and acoustical traits, speculating on possible constraints and connections between the larynges and their emissions (Drewry *et al.* 1982; Martin 1972). The available knowledge about call production physiology in *Physalaemus* and *Engystomops* makes the group a good target for a review of acoustic features. Detailed descriptions and comprehension of the acoustic traits of *Physalaemus* may contribute for further connection between these features and their underlying mechanistic production processes leading to a better understanding of the acoustic communication in this taxon.

Herein we aimed to review the acoustic traits in calls of *Physalaemus* based on all recordings available in zoological and sound collections in order to redescribe the calls using standardized terminology following traditional and modern bioacoustics concepts (*e.g*., Littlejohn 2001; Gerhardt & Huber 2002; Bradbury & Vehrencamp 1998; Köhler *et al*. 2017) and homology criteria (see Remane 1952; Wenzel 1992; Hepp *et al.* 2017; Folly *et al.* 2018). We first applied the homology criteria based on similar acoustic features and position, comparing all available species of *Engystomops* and *Physalaemus*. After establishing homology hypotheses among acoustic structures, we applied the most adequate terms to the homologs to finally make acoustic features comparable among species and clades.

Material and Methods

We analyzed recordings of 45 species of *Physalaemus* (see Appendix I). Additionally, we examined recordings of species of *Engystomops* and *Pleurodema* (not described in this study) in order to add more related species in the application of the homology criteria (see below).

Recordings were obtained from the following collections: AAGARDA of Laboratório de Anfíbios e Répteis at Universidade Federal do Rio Grande do Norte, Natal, RN, Brazil; ASEC, Arquivo Sonoro Professor Elias Pacheco Coelho, Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ, Brazil; CBUFMG, Coleção Bioacústica da Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brazil; CENBAM, Centro de Estudos Integrados da Biodiversidade Amazônica, Manaus, AM, Brazil; CFBH, Collection Célio F. B. Haddad, Rio Claro, SP, Brazil; FonoZoo, Fonoteca Zoológica of the Museo Nacional de Ciencias Naturales, Madrid, Spain; FNJV, Fonoteca Neotropical Jacques Vielliard, Universidade Estadual de Campinas, Campinas, SP, Brazil; and MNVOC, Coleção de Vocalizações de Anfíbios Anuros, Museu Nacional, Rio de Janeiro, RJ, Brazil. Several examined recordings were directly obtained from recordists and researchers (Appendix I).

We examined voucher specimens of some recordings in order to check more diagnostic features during the species identification process. However, since acoustic traits have largely been used as diagnostic characters for species of *Physalaemus* (*e.g*., Bokermann 1967; Heyer & Wolf 1989; Pimenta *et al.* 2005), we were able to identify most calls based on acoustic features only. Additionally, we preferred the recordings closest to the type locality of each species.

The order of the descriptions was defined following the phylogenetic tree topology found by Lourenço *et al.* (2015; Table 1). This organization leads to easier comparisons between sister species, which are usually more morphologically and acoustically similar to each other. Species groups have been traditionally used in *Physalaemus*'s taxonomy (Nascimento *et al.* 2005). Lourenço *et al.* (2015) recognized seven species groups. These groups (now equal to clades) allow us to point out the acoustic traits shared by closely related species. Five species with calls described here were not included in Lourenço *et al.* (2015)'s analysis (*P. angrensis*, *P. atim*, *P. carrizorum*, *P. irroratus*, and *P. orophilus*) and were placed into clades and species groups (Table 1) according to the phylogeny based on molecular and acoustic characters (unpublished data; except for *P. carrizorum*, which was grouped to *P. gracilis* group following the species description; see Cardozo & Pereyra 2018).

TABLE 1. The currently recognized 48 *Physalaemus* species and references for previous descriptions of the acoustic traits of the call types recognized in the present study. Terms in the "Call Name (Literature)" are the original ones given in the respective references. Species are arranged in the same order of the main text. Clade and species group classification follows Lourenço *et al.* (2015). Single asterisks mark the species that were not present in Lourenço *et al.* (2015) analysis (see text). Double asterisks mark species whose calls were not analyzed in the present study. Some authors recognized a higher number of call types for *P. spiniger*, *P. signifer*, and *P. cuvieri* than us (see text).

#	Species	Call Type	Call Name (Literature)	References	Species Group	Clade
1	*Physalaemus nattereri*	A	Call or Nuptial call	Bokermann (1966a)	Not assigned	*P. signifer*
			Advertisement call	Márquez *et al*. (1995)		
2	*Physalaemus maculiventris*	A	Advertisement call	Heyer & Wolf (1989); Heyer *et al.* (1990)		
		B	–	Present study		
3	*Physalaemus deimaticus***	–	–	Unknown	*P. deimaticus*	
4	*Physalaemus erythros*	A	Advertisement call	Baêta *et al.* (2007a)		
		B	–	Present study		
5	*Physalaemus rupestris*	A	Single note of the vocalization 1	Nascimento *et al.* (2001)		
		B	Vocalization 2	Nascimento *et al.* (2001)		
6	*Physalaemus camacan*	A	Advertisement call or Vocalization	Pimenta *et al.* (2005)	*P. signifer*	

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TABLE 1. (Continued)

#	Species	Call Type	Call Name (Literature)	References	Species Group	Clade
7	*Physalaemus obtectus*	A	Call or Courtship call	Bokermann (1966a)	*P. signifer*	*P. signifer*
8	*Physalaemus irroratus**	A	Advertisement call or Vocalization	Cruz *et al.* (2007)		
9	*Physalaemus nanus*	A	Advertisement call	Haddad & Pombal (1998)		
		B	–	Present study		
		C	Second type of vocalization	Haddad & Pombal (1998)		
10	*Physalaemus spiniger*	A	Advertisment call	Haddad & Pombal (1998); Costa & Toledo (2013)		
		B	Encounter call	Haddad & Pombal (1998)		
			Territorial call	Costa & Toledo (2013)		
		?	Fight call	Costa & Toledo (2013)		
		?	Release call	Costa & Toledo (2013)		
		?	Amplexus call	Costa & Toledo (2013)		
11	*Physalaemus crombiei*	A	Advertisment call	Heyer & Wolf (1989)		
		B	–	Present study		
12	*Physalaemus signifer*	A	Call or Nuptial call	Bokermann (1966a)		
			Advertisment call	Wogel *et al.* (2002)		
		B	Territorial call	Wogel *et al.* (2002)		
		?	Fight call	Wogel *et al.* (2002)		
13	*Physalaemus bokermanni*	A	Advertisement call, call or Vocalization	Cardoso & Haddad (1985)		
			Advertisement call	Thomé *et al.* (2007); Giaretta *et al.* (2009)		
		B	–	Present study		
14	*Physalaemus angrensis**	A	Advertisement call or Vocalization	Weber *et al.* (2006)		
		B	–	Present study		
15	*Physalaemus atlanticus*	A	Advertisement call or Vocalization	Haddad & Sazima (2004)		
16	*Physalaemus moreirae*	A	Advertisement call	Heyer *et al.* (1990); Giaretta *et al.* (2009)		
		B	–	Present study		
17	*Physalaemus fernandezae*	A	Call or Nuptial call	Barrio (1965)	*P. henselii*	*P. cuvieri*
18	*Physalaemus henselii*	A	Call or Nuptial call	Barrio (1965)		
			Advertisement call	Maneyro *et al.* (2008)		
19	*Physalaemus albonotatus*	A	Call or Nuptial call	Barrio (1965)	*P. cuvieri*	
			Mating call	Cei (1980)		
			Advertisement call	Köhler 2000; Köhler *et al.* (2017)		
20	*Physalaemus cuqui*	A	Advertisement call	Ferrari & Vaira (2001)		
			Call or Vocalization	Pérez Iglesias & Natale (2013)		

...Continued on the next page

TABLE 1. (Continued)

#	Species	Call Type	Call Name (Literature)	References	Species Group	Clade
21	*Physalaemus atim**	A	Advertisement call	Brasileiro & Haddad (2015)	*P. cuvieri*	*P. cuvieri*
22	*Physalaemus albifrons*	A	Call	Bokermann (1966b)		
			Advertisement call	Pederassi *et al.* (2015)		
23	*Physalaemus erikae*	A	Advertisement call or Vocalization	Cruz & Pimenta (2004)		
24	*Physalaemus kroyeri*	A	Call	Bokermann (1966b)		
25	*Physalaemus centralis*	A	Call or Nuptial call	Barrio (1965)		
			Advertisement call	Padial & Köhler (2001); Vasconcelos *et al.* (2014); Guerra *et al.* (2017)		
26	*Physalaemus cuvieri*	A	Call or Nuptial call	Barrio (1965)		
			Mating call	Cei (1980)		
			Mating call or Nuptial call	Cardoso (1981)		
			Advertisement call	Heyer *et al.* (1990); Gambale & Bastos (2014)		
		?	Courtship call	Gambale & Bastos (2014)		
27	*Physalaemus ephippifer*	A	Advertisement call	Kaefer *et al.* (2011)		
28	*Physalaemus fischeri*	A	Advertisement call	Tárano (2001)		
29	*Physalaemus cicada*	A	Call	Bokermann (1966b)	Not assigned	
30	*Physalaemus aguirrei*	A	Call or Nuptial call	Bokermann (1966a)		
			Advertisement call	Pimenta & Cruz (2004)		
31	*Physalaemus soaresi*	A	Advertisement call	Weber *et al.* (2005); Cassini *et al.* (2010)	*P. olfersii*	
32	*Physalaemus maximus*	A	Advertisement call	Baêta *et al.* (2007b); Cassini *et al.* (2010); Santanna & Moura (2011); Peres & Simon (2012)		
33	*Physalaemus feioi*	A	Advertisement call	Cassini *et al.* (2010)		
34	*Physalaemus orophilus**	A	Advertisement call	Cassini *et al.* (2010)		
35	*Physalaemus lateristriga*	A	Advertisement call	Cassini *et al.* (2010)		
36	*Physalaemus olfersii*	A	Call or Nuptial call	Bokermann (1966a)		
			Advertisement call	Heyer *et al.* (1990); Giaretta *et al.* (2009); Cassini *et al.* (2010)		
37	*Physalaemus riograndensis*	A	Call or Nuptial call	Barrio (1965)	*P. biligonigerus*	
			Mating call	Cei (1980)		

...Continued on the next page

TABLE 1. (Continued)

#	Species	Call Type	Call Name (Literature)	References	Species Group	Clade
38	*Physalaemus biligonigerus*	A	Call or Nuptial call	Barrio (1965)	*P. biligonigerus*	*P. cuvieri*
			Mating call	Cei (1980)		
			Advertisement call	Márquez *et al*. (1995); Salas *et al*. (1998); Giaretta & Menin (2004)		
39	*Physalaemus marmoratus*	A	Advertisement call	Giaretta & Menin (2004)		
40	*Physalaemus santafecinus*	A	Call or Nuptial call	Barrio (1965)		
			Mating call	Cei (1980)		
41	*Physalaemus carrizorum**	A	Advertisement call	Cardozo & Pereyra (2018)	*P. gracilis*	
42	*Physalaemus gracilis*	A	Call or Nuptial call	Barrio (1965)		
			Advertisement call	Cardozo & Pereyra (2018)		
43	*Physalaemus lisei*	A	Advertisement call	Morais & Kwet (2012)		
44	*Physalaemus evangelistai*	A	Call	Bokermann (1967)		
			Advertisement call	Oliveira *et al.* (2013)		
45	*Physalaemus barrioi*	A	Call	Bokermann (1967)		
			Advertisement call	Provete *et al.* (2012)		
46	*Physalaemus jordanensis*	A	Call	Bokermann (1967)		
			Advertisement call	Giaretta *et al.* (2009)		
47	*Physalaemus caete***	–	–	Unknown	Unknown	Unknown
48	*Physalaemus insperatus***	–	–	Unknown		

Recordings were edited with the software Audacity 2.1.3 (Audacity Team 2017). We filtered part of the background noise using the tool "Noise Reduction" of this program. Measurements were made with software Raven Pro 1.5 Beta Version (64-bit version) from the Cornell Laboratory of Ornithology (Bioacoustics Research Program 2014).

We focused our descriptions and comparisons on the most common calls of the species, but we also described unusual calls recorded less frequently. Here we used letters as labels for the calls, using the same letter for calls considered homologous. We established primary homology for calls and their parts/structures according to the following criteria: (a) acoustic similarity, (b) relative position, and (c) connection by intermediate taxa between the call structures analyzed (Remane 1952; Wenzel 1992; Hepp *et al.* 2017; Folly *et al.* 2018). For criterion (a), we identified homology among interspecific bioacoustical structures based on similarity of their durations and envelope shapes (*i.e*., patterns of amplitude values over time) on oscillograms and frequency values, such as dominant frequency, and shapes of the bands (*i.e*., patterns of frequency values over time) on audiospectrograms. For criterion (b), we considered similar positions of the structures in relation to the other structures that are close in time (on oscillograms) and/or frequency (on audiospectrograms) within the same recording. If two analyzed structures of two different species are surrounded by the same homologous structures, so those structures are likely to be homologous too (see Remane 1952). The latter criterion (c) is related to inclusion of all structure variations available while comparing relative position and similarity in order to assure homology correspondence (*sensu* Ghiselin 2005) even between extremely different variations by connecting them through intermediate forms present in other taxa (Remane 1952; Wenzel 1992).

After we assessed the homology relationships among structures, we applied the most adequate term to all structures considered homologous, *i.e*., a single term to each homologue. We used two criteria to choose the most adequate terms: (1) the best fit between terms' definitions presented in the literature (*e.g.*, Köhler *et al*. 2017) and structures' traits; and (2) the most common term used in literature for the structures in calls of *Physalaemus* (in order to guarantee certain nomenclatural stability; Hepp & Pombal 2019). We applied the term "call" for the most inclusive homologue. We preferred to use letters as temporary labels for different types of call. The most frequent call in the recordings is usually referred to as "advertisement call" in the literature (see Table 1) and is considered to play an important role in the mating activity of the taxa (*e.g.*, Weber *et al.* 2005; Giaretta *et al.* 2009; Provete *et al.* 2012). This frequent emission was named here as Call A and occasional extra calls recorded were named sequentially as B and C. By applying this nomenclature, we avoided spurious associations between call types (signals with a certain set of acoustic features) and functional definitions that were not addressed here (*e.g.*, Hepp *et al.* 2017).

As a hypothetical example, given we had identified in the recordings of several species similar structures repeated periodically in series with duration of each structure similar to their intervals and each structure with the same complex frequency pattern such as an up-downward modulation, forming arch-shaped bands. The resemblances of the modulation patterns and values of duration and interval suggest that the structures correspond to serial homologues (see Hall 2013). Therefore, each structure received the same name, *e.g.*, "pulse", while the entire series received another name, *e.g.*, "note". In this example, these series were found emitted in groups (short interseries intervals) or isolated throughout the recordings, *i.e.*, males emitted series at no regular rate or interval. Thus, in this case, the series (= note) is the most inclusive homologue detected and then we opted to name it as "call" as well. This approach has commonly been used in most cases in the literature on *Physalaemus* and agrees to the note-centered approach proposed by Köhler *et al*. (2017). It illustrates almost all homology assessment and nomenclature application for most of the complex cases in the present study. However, for a few species (*e.g.*, *P. cicada* and *P. nattereri*; see Discussion), the homology criteria [mainly Remane's criterion (a); see above] have indicated that each structure repeated in a series correspond to those structures labeled as "calls" for other species. Therefore, in these cases, the nomenclature application agrees to the call-centered approach of Köhler *et al*. (2017). These homology incompatibilities while using a single nomenclature approach based on similarity instead of homology correspondence are expected, mainly when a large diversity and variation is taken into account, even within a single genus such as *Physalaemus* (Hepp & Pombal 2019).

Technical terms and definitions used in the sound descriptions follow Bradbury & Vehrencamp (1998), Littlejohn (2001), Gerhardt & Huber (2002), and Köhler *et al*. (2017). Specific terms used here for structures and features are shown in the schemes of the Fig. 1 and 2. For some species, we used the term "sustain" for sections of the sound with little or no amplitude variation positioned between the call rise and fall (Fig. 1). Yet, we applied the same term to segment that did not have the features expected according to the term's etymology (in this case, sustained and constant amplitude) but were considered homologous to typical sustained segments of other species. This procedure guarantees the correspondence of homologous call parts among species under the same name (Hepp & Pombal 2019). We used the expressions "periodic amplitude modulation" (PAM) and "periodic frequency modulation" (PFM) to refer to modulation in amplitude (AM) and frequency (FM) that are repeated periodically or quasi-periodically through time, respectively (Fig. 1). In cases where the AM is weak (not deep) and there is no silence interval as a result of the PAM, we called "cycle" the period between two adjacent amplitude valleys (see Fig. 1). In cases where these cycles are separated by silence intervals, we called them "pulses" (Martin 1972; Littlejohn 2001). Even so, both structures were considered homologous (see Fig. 1F–H). Values of the repetition rates of periodic amplitude modulations are lower than those of the fundamental frequencies of the signal. Usually repetition rates of PAM have very low values and then usually not shown as frequency bands in commonly used audiospectrograms' bandwidths (see details about relationship between shown frequency bands and filter bandwidth of audiospectrograms in Charif *et al.* 2010). Species with PFM and PAM can have both modulations directly or inversely coupled (see examples with bird songs in Greenewalt 1968). Here we call these couplings as directly or inversely proportional, respectively. Occasional segments of non-periodic frequency modulation (FM) are reported specifically for where they occur in the signals (*e.g.*, Fig. 2A and C). Some of these FM segments, particularly the first and last ones, were barely observed without examining the signal in detail by using extreme zoom-in and were described but not illustrated. Segments of non-periodic amplitude modulation are usually described together with the features of the call's envelope (Fig. 1). Terminology describing call envelope and pulse follows Gerhardt (1998) and Littlejohn (2001). Definitions and concepts related to sidebands and harmonics follow Watkins (1967), Greenewalt (1968), Gerhardt (1998), Bradbury & Vehrencamp (1998), Gerhardt & Huber (2002), and Köhler *et al*. (2017). In the last decades, many studies have shown that physical systems including bioacoustical ones can behave in a more complex way than originally predicted (*e.g.*, a vocal apparatus with more than one oscillator vibrating simultaneously). These complex behaviors are usually classified as nonlinear and several species of mammals and birds have had nonlinear dynamics reported in their vocalizations (Wilden *et al.* 1998; Fitch *et al.* 2002).

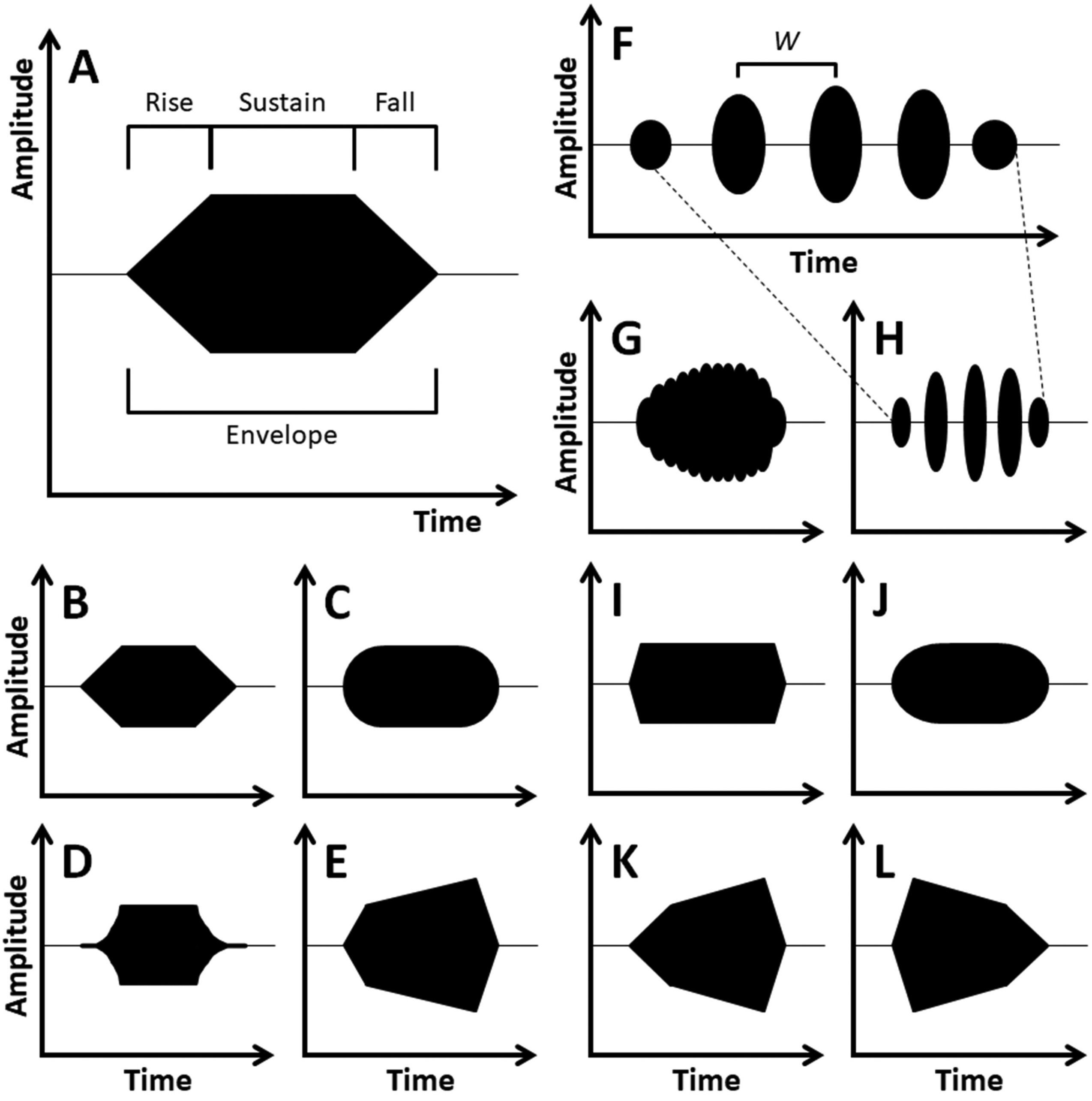

FIGURE 1. Schematic oscillograms of calls of *Physalaemus* species and schematic diagrams for terms related to amplitude traits (A). Gradual call rise and fall (B). Logarithmic call rise and fall (C). Exponential call rise and fall (D). Inclined sustain (E). Demarcation of *w* duration (F). Call with cycle-PAM (periodic amplitude modulation), *i.e.*, absence of silence interval within call (G). Call with pulse-PAM (periodic amplitude modulation), *i.e.*, presence of silence interval within call (H). Different envelopes (I–L). Rectangular envelope (I). Elliptical envelope (J). Triangular envelope pointed left (K). Triangular envelope pointed right (L).

Nonlinear phenomena are those vocal mechanisms responsible for producing complex sounds usually considered abnormal or irregular in the literature (Fitch *et al.* 2002). These phenomena occur in relatively simple and predictable systems, such as anuran and mammalian larynges and avian syrinx, when these systems exhibit “irregular” behaviors, *i.e.*, nonlinearities (Wilden *et al.* 1998; Fitch *et al*. 2002). They are a reflection of abrupt changes in the vibratory mode of the oscillator(s) in the sound producing organ, which are usually caused by abrupt changes in the stimulus energy or by extreme amounts of energy in the oscillatory system (Wilden *et al*. 1998; Suthers *et al*. 2006). Patterns on audiospectrograms such as (a) sudden emergence of extra bands between the harmonics, (b) independent modulations of synchronic frequency bands (*e.g*., one going down and other up), (c) abrupt change of the harmonic series' position causing a discontinuity in the bands, or (d) abrupt change of the narrow frequency bands into a noisy broadband pattern can be events produced by the nonlinear phenomena, respectively: (a) subharmonics, (b) biphonation, (c) frequency jump, and (d) deterministic chaos (Wilden *et al*. 1998; Suthers *et al.* 2006). These sound events have often been classified as "irregularities" and ignored in several bioacoustical studies (Wilden *et al*. 1998; Fitch *et al*. 2002). Here, we reported and described these four types of nonlinear phenomena observed for *Physalaemus* species. Theory and terms about nonlinear phenomena follow Wilden *et al.* (1998) and Fitch *et al.* (2002).

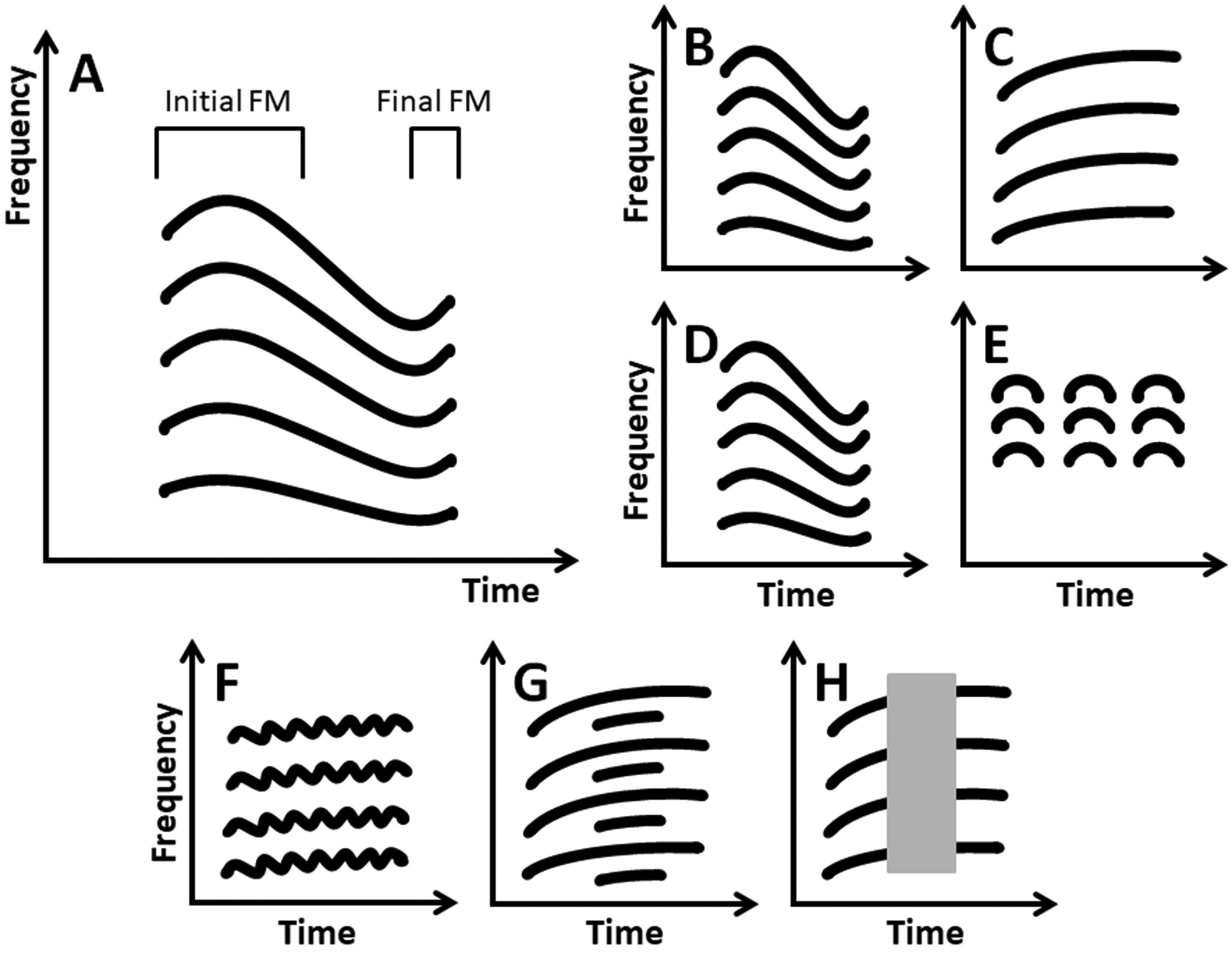

FIGURE 2. Schematic audiospectrograms of calls of *Physalaemus* species and diagrams for terms related to spectral call traits (A); note a initial up-downward FM and a final downward FM at the beginning and end of the call, respectively. General downward FM (B). Upward general FM (C). Shift in the relative energy among the bands; the dominant frequency gets higher toward the end of the call (D). Call energy concentrated in the higher harmonics; lower harmonics absent (E). Periodic frequency modulation, PFM (F). Subharmonics at the middle of the call (G). Deterministic chaos at the middle of the call (H). Note that the call (E) also presents pulses and up-downward FM within each pulse. These features are independent to the energy concentrated in higher harmonics.

Calls were described based on the following features (Fig. 1 and 2): call duration (1); relative duration and shape of the call rise, sustain, and call fall (2); relative position of the amplitude peak of the call (3); shape of the call envelope (4); proportion of the call duration with more than half of the call's energy (5); pulse- or cycle-PAM presence (6); number of pulses/cycles per call (7); relative duration and shape of the pulse/cycle rise and fall (8); relative position of the amplitude peak within the pulse/cycle (9); pulse/cycle duration (10); ratio between the durations of different pulses/cycles throughout the call (11); presence of silence intervals within the call (12); ratio between silence interval and pulse duration (13); pulse/cycle repetition rate (14); presence of harmonics, sidebands, and/or nonlinear phenomena (definition degree of the bands, chaos degree, and average entropy) (15); fundamental frequency (16); dominant frequency (17); number of all dominant harmonics in the call (18); presence of energy increasing pattern of the higher harmonics throughout the call (19); order of the dominant harmonics throughout the call (20); frequency bandwidth (21); presence and direction of general FM of the call (22); presence and directions of short FM segments (23); presence and extension of PFM throughout the call (24); relationship between any synchronic frequency and amplitude modulations (25). Additional measurements are given in Table 2.

The temporal and amplitude traits (features 1–15) were measured directly on the oscillograms, whereas spectral traits (features 16–25) were measured on the audiospectrogram (with window function Hann, amplitude logarithmic, window size 1024 samples, and 99 % overlap). Proportion of the call duration with more than half of the call energy (5), frequency bandwidth (21), center value of the spectral bandwidth, dominant frequency (17), and level of chaos (lack of periodicity of the signal – 15) were calculated using the measurements "IQR (Inter-quartile Range) Duration", "Bandwidth 90%", "Center Frequency", "Max Frequency", and "Average Entropy" on Raven 1.5, respectively (see Charif *et al.* 2010). Periods of structures were measured from the beginning of one structure to the beginning of the following one, thus encompassing the structure duration and the inter-structure interval (Littlejohn 2001). All repetition rates and fundamental frequencies were obtained by calculating the reciprocal of the periods (see Greenewalt 1968; Littlejohn 2001).

We examined the general traits of all obtained calls and males. The sample sizes of this general examination are given at the beginning of each call description as number of recordings, total recording time, number of calls and males (additional information can be found in the Appendix I).

The number of examined calls in very long recordings was estimated by using Raven's tool Band Limited Energy Detector (BLED). First, we manually deleted recordist announcements and other clear non-amphibian sounds from recordings. Then, we set BLED parameters interactively for each recording according to the best fit with the first 40 calls recorded (see Charif *et al*. 2010).

For most audio recordings, the number of recorded males was given by the recordist. For the files without this information, we estimated the number of males by observing constant differences in call amplitude and frequency (fundamental and dominant frequencies). The amplitude differences are consequence of different distances of the recorded males from the microphone, while slight differences in frequency are expected from different males with slightly different body sizes (see Gerhardt & Huber 2002; Wells 2007).

For the detailed numerical measurements, we chose some calls considering the recording quality and, in this case, sample sizes are given in table (Table 2; see below). For the descriptions in text, the values were rounded in order to make easier the comprehension of the acoustic traits. Precise values are given in Table 2.

Some call types were recorded only when many males were calling close to each other (see Results). This close proximity was interpreted when recordings presented many calls clearly from different individuals (*e.g.*, with constant individual differences such as different fundamental frequencies) with short intervals between each other and with similar amplitudes.

In order to verify which acoustic structure was responsible for yielding the observed frequency bands, we compared the repetition rate of the structures with the distance between the bands. We measured every period of all periodically repeated oscillation ("*w*" in Bradbury & Vehrencamp 1998: 58; see Fig. 1F) and then we calculated the reciprocal of the periods (*i.e.*, the frequency of that signal). After that, we identified which rate matched the distance between the bands and identified the structure responsible for the bands (see Greenewalt 1968; Gerhardt & Huber 2002; Watkins 1967; Bradbury & Vehrencamp 1998). To verify whether the bands were sidebands (produced by modulation), we divided the dominant-frequency value (called "instantaneous" dominant frequency by Greenewalt 1968) by the calculated rate of the band-related oscillation within the same delta time. If the factor was an integer number, we treated it as evidence for a harmonic relationship among frequency values (sidebands may have integer-multiple relationships but they are usually unexpected; see Greenewalt 1968: 88-100). Here, harmonic relationships among frequency bands were taken as evidence that they were likely produced by the same morphological structure, or by closely connected and dependent structures, of the vocal apparatus (Greenewalt 1968). Additionally, we plotted the calculated repetition-rate values against the emission time and compared them to the frequency modulation observed in audiospectrograms. If the calculated repetition rate is the fundamental frequency of a harmonic series or the frequency of a modulating signal (yielding sidebands), the variation of its value results in different consequences for the bands in audiospectrograms (Bradbury & Vehrencamp 1998). In the former hypothesis, all the higher bands (*i.e.,* harmonics) will follow the fundamental one, whereas in the latter case, sidebands will get closer or distant to each other when the frequency of the modulating signal gets lower or higher, respectively (Gerhardt & Huber 2002: 428). This method was applied to the most frequent call type (call A) of every species (except *P. fernandezae*, which has a single frequency band) in order to evaluate the vibrating process that underlies the signal emission of the species.

The filter bandwidths (part of the audiospectrogram "resolution") may widely vary even at the same number of samples in FFT, depending on the sampling size used in the recording process (Charif *et al.* 2010). Therefore, we used different number of samples in FFT and different bandwidths for the illustrated audiospectrograms in order to apply the most adequate resolution to the calls presented in the figures.

We ran a Principal Component Analysis (PCA) on the software RStudio Version 1.1.456 (RStudio Team 2118), based on R Version 3.5.1 (R Core Team 2018), to check for acoustic similarity patterns of quantitative variables related to the current species groups assigned for the species. We used the packages "stats" (R Core Team 2018), "ggrepel" (Slowikowski 2018) and "ggplot2" (Wickham 2009). PCA cannot handle analyses with inapplicable or missing data. Therefore, we first removed all the variables conditioned to the presence of certain features or structures. For instance, we removed the variables related to the presence of PAM or PFM, such as duration of cycles or pulses or PFM rate, since there are several species with no PAM and PFM that received a non-numeric symbol indicating inapplicable data for these variables. Although we have some missing data for a few species/variables, all of them were deleted after the variable removal procedure aforementioned. We used the following variables in the PCA: call duration (1); dominant frequency (2); dominant harmonic (3); fundamental frequency (4); dominant frequency at the beginning of the call (5); dominant frequency at the end of the call (6); relative position of the amplitude peak of the call (7); frequency delta of the call (8); frequency bandwidth (9); entropy average of the call (10); center frequency of the call (11); and proportion of the IQR duration (12).

Results

Considering all the analyzed calls of *Physalaemus* species, acoustic traits are very diverse and vary considerably among species groups. Still, there are many common features within some clades and groups. Measurement values for all species are given in Table 2. Call duration varies from 0.03 (*P. cicada*) to 4.6 s (*P. orophilus*), the latter being approximately 150 times longer than the first. Fundamental and dominant frequencies vary *ca.* sevenfold, from 150 (*P. olfersii*) to 1020 Hz (*P. riograndensis*), and 515 (*P. marmoratus*) to 3800 Hz (*P. bokermanni*), respectively. Some species have distinguishably pulsed calls (*P. angrensis*, *P. atlanticus*, *P. bokermanni*, *P. crombiei*, *P. feioi*, *P. henselii*, *P. irroratus*, *P. jordanensis*, *P. moreirae*, *P. nanus*, *P. obtectus*, and *P. orophilus*) whereas others have calls similar to whistles (*P. fernandezae*) or whines that resemble mammalian nasal sounds (remaining species, except *P. cicada*). Nasal-like sounds are attributed to the presence of a high number of highlighted harmonics associated to a low fundamental frequency, resulting in frequency bands close to each other in a dense-harmonic spectrum (Beeman 1998), a remarkable feature in *P. olfersii* species group. In this group, the long nasal-like calls with high pitch resemble, to the human ear, to the cry of human infants. On the other hand, the call of *P. cicada* is very short and emitted in a long call series sounding like a cicada (Cicadoidea, Hemiptera). All species have calls composed of harmonics (but see *P. fernandezae* below). Species such as *P. camacan* and *P. henselii* also have call with sidebands resulting from a modulating signal independent from the carrier one (usually the dominant frequency). The call of *P. fernandezae* is unique in having a single frequency band (but see Cei 1980). Calls with pulse-PAM, such as those of *P. crombiei*, *P. jordanensis*, and *P. obtectus*, or with short duration, such as those of the *P. deimaticus* species group, are also perceived as short nasal-like sounds. In the following sections, we described in detail the acoustic features of 45 *Physalaemus* species as well as the common traits of the named clades; including the species groups *sensu* Lourenço *et al*. (2015).

Physalaemus signifer clade

Species in this clade usually have A calls with low fundamental frequency, below 500 Hz (except *P. bokermanni*; see below). Usually the fundamental band is absent or with very low energy, barely visible in audiospectrograms (all species except some calls of *P. irroratus*, *P. obtectus*, and *P. nanus*). Most of the species (66.6 %) have more than one call type. Nonlinear phenomena, subharmonics and deterministic chaos, are common in the clade (see *P. angrensis*, *P. atlanticus*, *P. bokermanni*, *P. camacan*, *P. crombiei*, *P. irroratus*, *P. moreirae*, *P. nanus*, *P. obtectus*, *P. signifer*, and *P. spiniger*) even though usually restricted to parts of some calls (*i.e.*, polymorphic in presence and position; *vs.* present in all calls in the same call positions in species of *P. cuvieri* clade). Eight species (*P. angrensis*, *P. atlanticus*, *P. bokermanni*, *P. crombiei*, *P. irroratus*, *P. moreirae*, *P. nanus*, and *P. obtectus*) have calls with strong PAM, with silence periods between pulses.

No species group assigned

Physalaemus nattereri **(Steindachner, 1863)**

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note usually emitted in sequences of three or four calls (Fig. 3A and B), but longer sequences, with dozens of calls, can be sporadically emitted.

Call A (Fig. 3A–F and 4A). We examined 15 recordings, a total of 21 minutes, with *ca*. 5500 calls from 28 males. Only some of these calls were measured (see Table 2). Call duration varies from 0.057 to 0.074 s. The abrupt call rise is much shorter than the call fall, which is more gradual; the amplitude peak is within the first third of the call's duration (usually at the very beginning of the call). The envelope of the call resembles a triangle pointed right. More than 50 % of the call energy is concentrated at the first 26 % of the call duration (Fig. 3C, E). The call has no PAM. The call is composed of clear harmonics (Fig. 3D, F, 4A). The fundamental frequency is around 330 Hz and it is usually present with low energy or absent in the audiospectrograms. The dominant frequency of the calls varies from 703 to 1031 Hz. Within each call, the dominant harmonic varies from the first to third, but it is usually the second or third. There is no clear shift in the relative energy among the bands throughout the call. Most of the call energy is between 700 and 1050 Hz (often, two harmonics). Frequency modulations are very subtle in this species. Nonetheless, the frequency bands have a general downward FM with a slight rapid up-downward FM at the beginning and a short down or upward FM at the end. There is no PFM (Fig. 3D, F).

Physalaemus maculiventris **(A. Lutz, 1925)**

We found two different calls, referred to as call A and B. Calls B were common in recordings in which several males were more active and calling close to each other. Calls B are commonly observed after overlapping periods of A calls. Call B resembles a long call A with higher fundamental frequency, pulse-PAM rate, and stronger PFM.

Call A (Fig. 5A–D and 4B). We examined two recordings, a total of six minutes, with *ca*. 400 calls from four males. Only some of these calls were measured (see Table 2). Call duration varies from 0.172 to 0.260 s. The rise of the call is longer than the fall; the amplitude peak is approximately at the end of the first three fourths of the call duration. Since both rise and fall are relatively similar in slope and not too different in duration, the envelope of the call is fairly elliptic (Fig. 5A, C). More than 50 % of the call energy is concentrated in 24 % of the call duration around the amplitude peak. The call has a subtle PAM (there is no silence interval between peaks; Fig. 5C). The rate of the PAM is *ca.* 39 Hz, forming *ca.* six amplitude peaks throughout the call. The call is composed of usually clear harmonics (Fig. 4B), however, eventual decreases of the wave periodicity make the harmonics less clear. The fundamental frequency is approximately 220 Hz and it can be present with low energy or absent in the audiospectrograms. The dominant frequency varies from *ca*. 820 to 1510 Hz (Fig. 5B, D). The dominant harmonic varies from the third to the sixth, but it is usually the fifth. There is no clear shift in the relative energy among the bands throughout the call. Most of the call energy is between 700 and 1500 Hz (often comprising five harmonics). The frequency bands have a general upward FM throughout the call with a rapid up-downward FM at the beginning forming arc-shaped bands in this part of the call and a short downward-FM segment at the end (Fig. 5B). There are irregular PFM segments throughout the entire call; these segments are usually synchronic and directly proportional to the PAM (Fig. 5D).

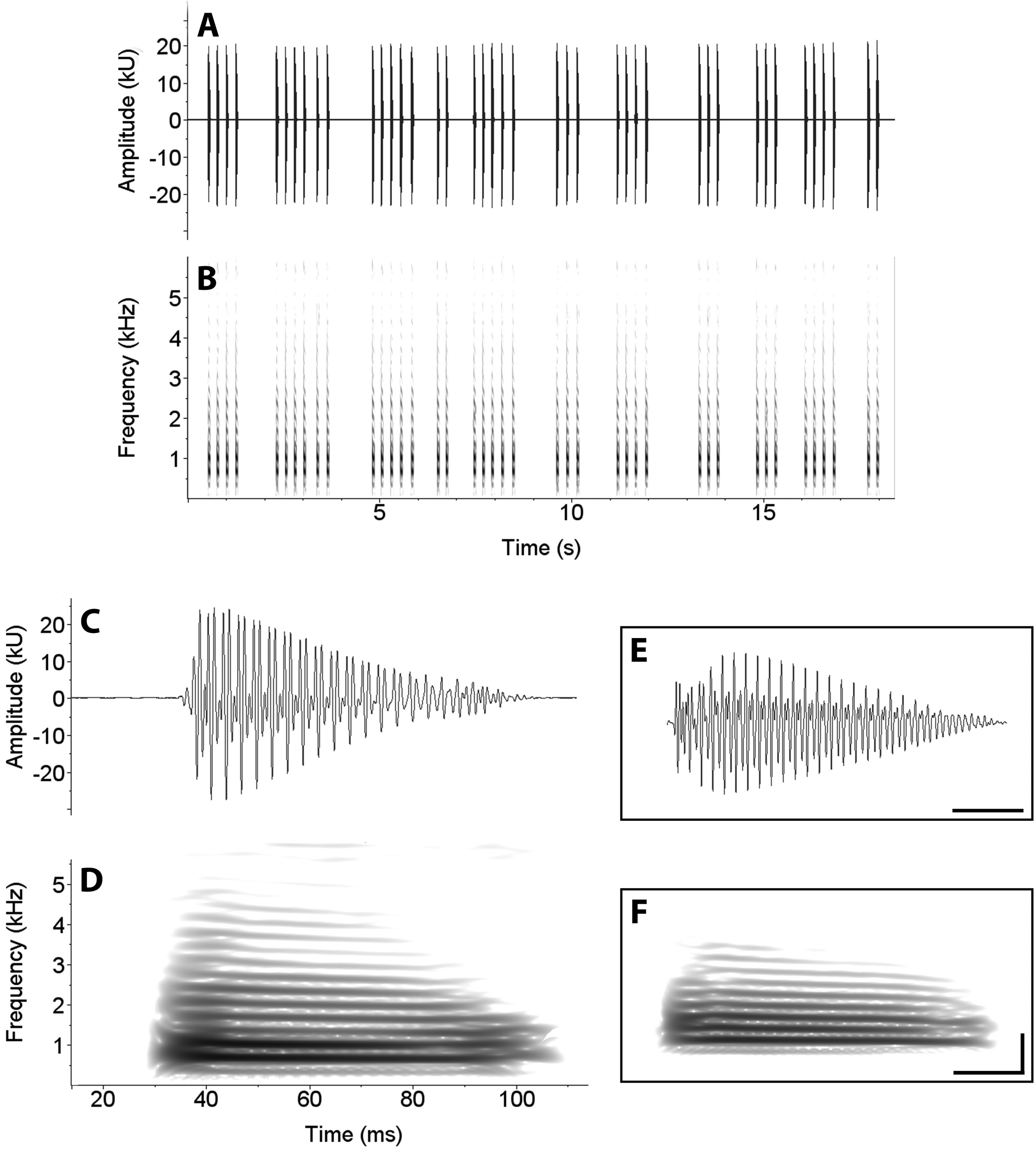

FIGURE 3. Call A of *Physalaemus nattereri*. Oscillograms (A, C, and E) and audiospectrograms (B, D, and F). Sequence of groups of call (A and B). A single typical call (C and D). A single call with a variant envelope (E and F). Horizontal scale bars have 0.2 s; vertical scale bars have 1 kHz. Filter bandwidth (Hz): 92.1 (F); 67.4 (B); 92.1 (D).

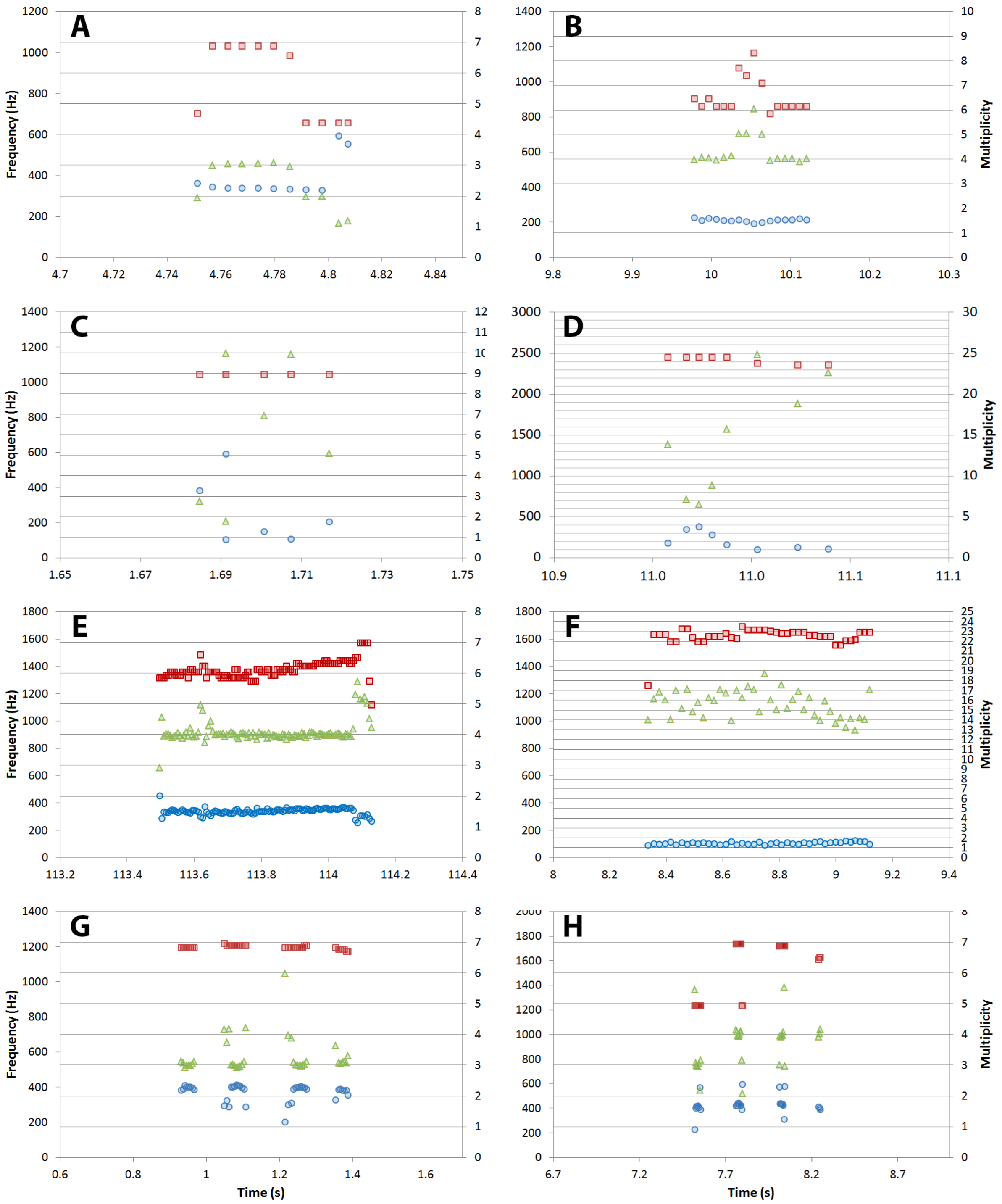

FIGURE 4. Multiplicity relationship between "instantaneous" dominant frequency and *w* of calls A of seven *Physalaemus* species. Each graph shows a single call A of: *P. nattereri* (A), *P. maculiventris* (B), *P. erythros* (C), *P. rupestris* (D), *P. camacan* (E; F), *P. obtectus* (G), *P. irroratus* (H). Grid corresponds to the harmonic values (right y-axis). Red squares are the values of "instantaneous" dominant frequency; blue circles are the values of the reciprocal of *w*; green triangles are the factor values of the ratio "instantaneous" dominant frequency / *w* reciprocal per delta time. Delta time corresponds to the duration of one period *w* of the measured oscillation. Note that factors around integer values suggest harmonic relationship between the frequency calculated (*w* reciprocal) and the dominant frequency. Factors multiple of ½ of the fundamental frequency correspond to sub-harmonics (see *P. irroratus*; H).

TABLE 2. Descriptive statistics of 11 measurements of the calls type A of 45 *Physalaemus* species. Species ordered according to the topology in Lourenço *et al.* (2015; see text and Table 1). Values are given as mean ± standard deviation (minimum – maximum) mode [number of measurements taken / number of calls]. Single asterisks indicate cells with the same values of other call. Double asterisks indicate features present only in part of the analyzed calls (see descriptions in text for details).

Species	Call Type	Call Duration (s)	Cycle or Pulse Duration (s)	Cycle or Pulse Interval (s)	Cycle or Pulse Rate (per s)	Proportion Final Cycle (per s)	Proportion Duration Dominancy Lower Bands	Proportion Initial FM	Frequency Delta Initial FM (Hz)	PFM Rate (per s)	Dominant Frequency (Hz)	Dominant Harmonic
Physalaemus nattereri	Call A	0.065 ± 0.003 (0.057–0.074) 0.067 [41/41]	–	–	–	–	–	0.673 ± 0.076 (0.511–0.831) 0.655 [41/41]	?	–	1023.2 ± 51.2 (703.1–1031.2) 1031.2 [41/41]	2.4 ± 0.6 (1–3) 2 [82/38]
Physalaemus maculiventris	Call A	0.209 ± 0.025 (0.172–0.260) 0.189 [50/50]	0.030 ± 0.016 (0.011–0.107) 0.021 [145/25]	–	39.0 ± 13.8 (9.3–92.4) 46.8 [145/25]	1.305±0.763 (0.403–2.773) [23/23]	–	0.527 ± 0.0171 (0.114–0.792) 0.588 [50/50]	-26.9 ± 65.8 (–172.3–86.1) -43.1 [24/24]	34.5 ± 11.2 (11.8–66.5) 44.3 [118/50]	1043.9 ± 214.6 (818.3–1507.3) 861.3 [50/50]	4.2 ± 0.5 (3–6) 4 [51/3]
	Call B	0.534 ± 0.101 (0.375–0.675) [6/6]	0.034 ± 0.011 (0.014–0.069) 0.032 [64/4]	–	32.4 ± 8.4 (21.6–54.7) 23.1 [17/3]	1.478 ± 0.392 (1.121–1.906) [4/4]	–	?	187.5 ± 132.6 (93.7–375.0) [4/4]	36.1 ± 9.2 (24.5–61.6) 36.2 [19/4]	1171.9 ± 129.3 (1031.2–1312.5) 1031.2 [6/6]	4.8 ± 0.9 (3–8) 5 [103/2]
Physalaemus erythros	Call A	0.056 ± 0.008 (0.041–0.077) 0.055 [38/38]	–	–	–	–	–	–	–	–	1091.7 ± 41.6 (1022.8–1162.8) 1141.3 [38/38]	5.2 ± 2.5 (2–10) 3.0 [23/4]
	Call B	0.587 ± 0.192 (0.200–0.875) [17/17]	0.045 ± 0.018 (0.015–0.087) 0.045 [86/4]	–	26.6 ± 12.8 (11.5–66.5) 22.2 [86/4]	0.750 ± 0.442 (0.179–1.495) [4/4]	–	–	–	26.6 ± 12.8 (11.5–66.5) 22.2 [86/4]	1083.6 ± 220.4 (843.8–1781.2) 1031.2 [17/17]	4.1 ± 1.3 (3–9) 3 [99/2]
Physalaemus rupestris	Call A	0.106 ± 0.026 (0.057–0.149) 0.112 [18/18]	0.056 ± 0.014 (0.036–0.085) 0.046 [22/11]	0.009 ± 0.006 (0.000–0.022) 0.000 [11/11]	15.2 ± 2.8 (10.3–19.0) 17.7 [18/18]	1.565 ± 0.362 (1.033–2.202) [11/11]	–	–	–	–	2321.2 ± 162.9 (1890.6–2546.9) 2343.8 [18/18]	12.7 ± 6.7 (5–38) 8 [147/18]
	Call B	1.556 ± 0.152 (1.269–1.727) [10/10]	0.040 ± 0.028 (0.005–0.173) 0.037 [122/6]	0.027 ± 0.012 (0.011–0.071) 0.019 [177/6]	18.9 ± 1.6 (16.3–21.1) [6/6]	3.545 ± 0.780 (2.420–4.459) [6/6]	–	–	–	–	2368.8 ± 144.9 (2062.5–2562.5) 2365.0 [10/10]	22.9 ± 10.3 (7–57) 15 [240/6]

...Continued on the next page

TABLE 2. (Continued)

Species	Call Type	Call Duration (s)	Cycle or Pulse Duration (s)	Cycle or Pulse Interval (s)	Cycle or Pulse Rate (per s)	Proportion Final Cycle (per s)	Proportion Duration Dominancy Lower Bands	Proportion Initial FM	Frequency Delta Initial FM (Hz)	PFM Rate (per s)	Dominant Frequency (Hz)	Dominant Harmonic
Physalaemus camacan	Call A	0.773 ± 0.100 (0.676–0.980) 0.698 [30/30]	0.084 ± 0.017(0.047–0.117) 0.088 [50/5]	–	12.6 ± 2.5 (8.6–18.1) 13.9 [45/5]	0.955 ± 0.287 (0.498–1.219) [5/5]	–	–	–	33.6 ± 6.7 (24.5–53.6) 35.4 [56/13]	1519.1 ± 85.8 (1378.1–1656.2) 1485.8 [29/29]	3.6 ± 0.6 (2–6) 4 [631/3]
Physalaemus obtectus	Call A	0.475 ± 0.041 (0.415–0.553) 0.429 [20/20]	0.052 ± 0.010 (0.026–0.091) 0.050 [87/20]	0.074 ± 0.013 (0.042–0.093) 0.066 [67/20]	9.1 ± 0.5 (8.4–10.1) 8.7 [20/20]	0.957 ± 0.307 (0.424–1.545) [20/20]	–	–	–	9.1 ± 0.5 (8.4–10.1) 8.7 [20/20]	1218.8 ± 9.3 (1207.0–1230.5) 1218.8 [20/20]	3.2 ± 0.7 (3–7) 3 [75/2]
Physalaemus irroratus	Call A	0.743 ± 0.085 (0.489–0.954) 0.706 [27/27]	0.035 ± 0.011 (0.007–0.059) 0.037 [111/27]	0.192 ± 0.031 (0.034–0.234) 0.189 [84/27]	5.6 ± 0.4 (5.1–6.9) 5.7 [27/27]	0.103 ± 0.034 (0.047–0.185) [27/27]	–	–	–	5.6 ± 0.4 (5.1–6.9) 5.7 [27/27]	1648.1 ± 144.2 (1250.0–1718.8) 1703.1 [27/27]	3.9 ± 1.0 (2–9) 4 [74/3]
	Call A	0.193 ± 0.012 (0.178–0.218) 0.186 [21/21]	0.028 ± 0.011 (0.005–0.066) 0.025 [115/21]	0.015 ± 0.061 (0.000–0.598) 0.011 [94/21]	28.3 ± 2.3 (25.5–33.5) 26.8 [21/21]	2.024 ± 0.499 (0.971–2.823) [21/21]	–	–	–	28.3 ± 2.3 (25.5–33.5) 26.8 [21/21]	2346.1 ± 106.9 (2239.5–2540.9) 2325.6 [21/21]	2.4 ± 0.6 (2–4) 2 [30/5]
Physalaemus nanus	Call B	0.047 ± 0.023 (0.027–0.090) [6/6]	–	–	–	–	–	–	–	90.5 ± 21.3 (74.7–114.7) [3/3]	1787.3 ± 65.3 (1679.6–1851.9) 1765.7 [6/6]	13.6 ± 7.1 (7–41) 10 [62/3]
	Call C	0.266 ± 0.047 (0.188–0.311) [5/5]	*	*	*	*	–	–	–	*	*	*
Physalaemus spiniger	Call A	0.260 ± 0.059 (0.221–0.492) 0.229 [31/31]	–	–	–	–	–	0.096 ± 0.006 (0.083–0.107) 0.097 [14/14]	53.6 ± 48.2 (0.0–93.8) 93.8 [14/14]	?	1359.7 ± 204.8 (1119.7–1981.1) 1312.5 [31/31]	3.7 ± 0.8 (2–6) 4 [384/3]
	Call B	0.432 ± 0.047 (0.376–0.512) [6/6]	–	–	–	–	0.555 ± 0.079 (0.447–0.678) [6/6]	0.074 ± 0.016 (0.047–0.093) [6/6]	14.3 ± 35.1 (-43.1–43.0) [6/6]	–	1564.8 ± 203.2 (1162.8–1722.7) 1593.5 [6/6]	5.5 ± 1.4 (3–12) 6 [161/3]

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TABLE 2. (Continued)

Species	Call Type	Call Duration (s)	Cycle or Pulse Duration (s)	Cycle or Pulse Interval (s)	Cycle or Pulse Rate (per s)	Proportion Final Cycle (per s)	Proportion Duration Dominancy Lower Bands	Proportion Initial FM	Frequency Delta Initial FM (Hz)	PFM Rate (per s)	Dominant Frequency (Hz)	Dominant Harmonic
Physalaemus crombiei	Call A	0.429 ± 0.113 (0.319–0.774) 0.333 [80/80]	0.040± 0.010 (0.027–0.081) 0.038 [271/29]	0.004 ± 0.002 (0.000–0.009) 0.005 [242/29]	24.5 ± 1.9 (20.7–20.8) 23.3 [242/29]	1.844 ± 0.145 (1.553–2.206) [29/29]	–	–	–	23.8 ± 2.5 (21.5–41.2) 24.0 [60/60]	1081.5 ± 52.8 (1012.1–1378.1) 1055.1 [80/80]	3.1 ± 0.4 (2–4) 3 [57/10]
	Call B	0.827 ± 0.167 (0.709–0.945) [2/2]	0.052 ± 0.002 (0.051–0.053) [2/2]	–	19.3 ± 0.6 (18.9–19.7) [2/2]	?	–	–	–	19.3 ± 0.6 (18.9–19.7) [2/2]	1089.9 ± 99.5 (1019.5–1160.2) [2/2]	3.0 ± 0.0 (3–3) 3 [102/1]
Physalaemus signifer	Call A	0.516 ± 0.033 (0.453–0.579) 0.495 [50/5-]	0.022 ± 0.005 (0.014–0.045) 0.022 [125/6]	–	47.8 ± 8.5 (22.0–71.3) 45.2 [125/6]	1.538 ± 0.501 (0.924–2.086) [6/6]	–	0.412 ± 0.042 (0.308–0.471) 0.426 [20/20]	17.2 ± 24.3 (0–86.2) 0.0 [30/30]	44.4 ± 8.4 (28.7–73.9) 42.6 [94/9]	1134.4 ± 305.1 (861.3–1550.4) 861.3 [50/50]	3.0 ± 0.2 (3–5) 3 [199/3]
	Call B	1.029 ± 0.133 (0.883–1.355) [10/10]	0.071 ± 0.049 (0.019–0.270) 0.054 [84/1]	–	18.9 ± 10.3 (3.7–52.0) 18.5 [84/1]	1.289 ± 0.548 (0.664–2.180) [9/9]	–	–	–	18.9 ± 10.3 (3.7–52.0) 18.5 [84/1]	874.3 ± 36.9 (839.8–947.5) 861.3 [10/10]	3.9 ± 0.3 (3–5) 4 [104/1]
Physalaemus bokermanni	Call A	0.188 ± 0.006 (0.177–0.197) 0.187 [15/15]	0.006 ± 0.002 (0.003–0.012) 0.007 [88/15]	0.032 ± 0.013 (0.006–0.071) 0.031 [73/15]	34.5 ± 21.6 (13.1–105.6) 22.1 [73/15]	1.612 ± 0.218 (1.048–1.964) [15/15]	–	–	–	–	3166.8 ± 261.4 (2842.4–3660.6) 3143.8 [15/15]	4.8 ± 1.8 (2–10) 4 [16/3]
	Call B	1.428 ± 0.196 (0.947–1.868) [15/15]	0.039 ± 0.017 (0.020–0.106) 0.032 [65/5]	–	28.5 ± 8.1 (9.4–51.1) 31.1 [65/5]	0.687 ± 0.456 (0.257–1.542) [6/6]	–	–	–	–	3800.0 ± 122.1 (3562.5–4125.0) 3843.8 [15/15]	3.9 ± 1.2 (2–7) 3 [58/1]
Physalaemus angrensis	Call A	0.508 ± 0.032 (0.431–0.605) 0.503 [57/57]	0.015 ± 0.007 (0.008–0.063) 0.014 [501/17]	0.002 ± 0.001 (0.000–0.006) 0.000 [484/17]	58.2 ± 2.0 (49.2–60.8) 59.7 [46/46]	3.716 ± 0.507 (2.975–4.818) [17/17]	–	–	–	58.2 ± 2.0 (49.2–60.8) 59.7 [46/46]	1687.5 ± 46.0 (1593.8–1781.2) 1687.5 [57/57]	4.0 ± 0.4 (3–5) 4 [53/1]
	Call B	0.330 ± 0.012 (0.309–0.353) 0.323 [13/13]	–	–	–	–	–	–	–	52.5 ± 11.8 (33.6–69.2) 65.3 [18/18]	1171.9 ± 83.4 (1078.1–1312.5) 1125.0 [13/13]	3.8 ± 0.7 (2–7) 4 [54/1]

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TABLE 2. (Continued)

Species	Call Type	Call Duration (s)	Cycle or Pulse Duration (s)	Cycle or Pulse Interval (s)	Cycle or Pulse Rate (per s)	Proportion Final Cycle (per s)	Proportion Duration Dominancy Lower Bands	Proportion Initial FM	Frequency Delta Initial FM (Hz)	PFM Rate (per s)	Dominant Frequency (Hz)	Dominant Harmonic
Physalaemus atlanticus	Call A	1.258 ± 0.084 (1.096–1.377) [12/12]	0.009 ± 0.006 (0.004–0.061) 0.008 [359/6]	0.012 ± 0.004 (0.004–0.032) 0.009 [353/6]	47.5 ± 0.7 (46.7–48.7) [6/6]	5.573 ± 3.212 (2.797–8.342) [6/6]	–	–	–	–	1252.5 ± 170.7 (947.5–1378.1) 1378.1 [12/12]	2.4 ± 0.5 (2–3) 2 [58/1]
Physalaemus moreirae	Call A	0.532 ± 0.023 (0.499–0.567) [7/7]	0.019 ± 0.017 (0.003–0.133) 0.012 [156/7]	0.005 ± 0.002 (0.002–0.009) 0.003 [149/7]	42.4 ± 2.6 (38.1–46.0) [7/7]	6.2 ± 1.846 (4.072–9.806) [7/7]	–	–	–	42.4 ± 2.6 (38.1–46.0 [7/7]	1027.5 ± 236.5 (775.2–1248.9) 1205.9 [7/7]	4.2 ± 1.2 (3–8) 4 [81/2]
	Call B	0.254 [1/1]	–	–	–	–	–	–	–	63.8 ± 6.8 (54.1–68.5) 68.5 [4/1]	861.3 [1/1]	3.4 ± 0.6 (2–5) 3 [34/1]
Physalaemus fernandezae	Call A	0.715 ± 0.144 (0.339–0.969) 0.587 [20/20]	0.033 ± 0.007 (0.018–0.078) 0.033 [115/5]	–	31.2 ± 2.5 (26.5–33.5) [7/7]	1.509 ± 0.605 (0.829–2.311) [5/5]	–	–	–	31.2 ± 2.6 (26.5–33.5) [7/7]	3044.8 ± 119.5 (2885.4–3230.0) 3057.7 [20/20]	93.2 ± 11.5 (71–119) 84 [33/3]
Physalaemus henselii	Call A	0.371 ± 0.037 (0.289–0.493) 0.375 [38/38]	0.008 ± 0.003 (0.002–0.016) 0.009 [563/30]	0.011 ± 0.007 (0.000–0.035) 0.000 [563/30]	54.1 ± 7.7 (46.1–85.9) 51.6 [30/30]	2.422 ± 0.934 (1.073–4.390) [30/30]	–	–	–	54.1 ± 7.7 (46.1–85.9) 51.6 [30/30]	1857.7 ± 130.5 (1687.5–2156.2) 1781.2 [38/38]	17.9 ± 18.3 (4–65) 6 [45/1]
Physalaemus albonotatus	Call A	1.385 ± 0.032 (1.333–1.429) [7/7]	0.040 ± 0.004 (0.026–0.050) 0.039 [67/2]	–	24.6 ± 0.6 (23.8–25.4) [5/5]	–	0.241 ± 0.002 (0.239–0.242) [2/2]	0.362 ± 0.007 (0.357–0.367) [2/2]	-23.5 ± 33.2 (-46.9–0.0) [2/2]	24.5 ± 3.0 (18.8–32.1) 23.3 [34/2]	2209.9 ± 314.9 (1593.8–2437.5) 2343.8 [7/7]	4.6 ± 0.7 (1–6) 5 [337/1]
Physalaemus cuqui	Call A	1.335 ± 0.083 (1.215–1.500) [11/11]	0.047 ± 0.008 (0.021–0.073) 0.045 [150/9]	–	20.9 ± 0.6 (20.1–21.9) 20.1 [9/9]	–	0.498 ± 0.018 (0.476–0.531) 0.476 [11/11]	0.545 ± 0.053 (0.480–0.645) 0.514 [11/11]	31.3 ± 20.1 (0.0–43.0) 43.0 [11/11]	21.1 ± 3.3 (13.9–32.2) 19.3 [112/11]	2842.4 ± 0.0 (2842.4–2842.4) 2842.4 [11/11]	4.2 ± 2.2 (1–6) 6 [320/1]
Physalaemus atim	Call A	0.861 ± 0.067 (0.779–0.995) [8/8]	0.033 ± 0.010 (0.015–0.055) 0.040 [40/4]	–	45.1 ± 14.9 (24.5–80.2) 59.8 [31/4]	?	0.229 ± 0.027 (0.176–0.260) 0.220 [8/8]	0.174 ± 0.040 (0.114–0.237) [7/7]	34.5 ± 19.3 (0.0–43.1) 43.1 [5/5]	–	2261.0 ± 115.1 (1981.1–2325.6) 2282.5 [8/8]	4.8 ± 1.7 (1–7) 6 [352/2]

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TABLE 2. (Continued)

Species	Call Type	Call Duration (s)	Cycle or Pulse Duration (s)	Cycle or Pulse Interval (s)	Cycle or Pulse Rate (per s)	Proportion Final Cycle (per s)	Proportion Duration Dominancy Lower Bands	Proportion Initial FM	Frequency Delta Initial FM (Hz)	PFM Rate (per s)	Dominant Frequency (Hz)	Dominant Harmonic
Physalaemus albifrons	Call A	0.283 ± 0.008 (0.263–0.297) 0.280 [42/42]	–	–	–	–	0.469 ± 0.023 (0.426–0.517) 0.491 [42/42]	0.723 ± 0.059 (0.606–0.819) 0.710 [42/42]	42.4 ± 32.4 (0.0–140.6) 46.8[42/42]	–	2573.6 ± 52.6 (2437.5–2671.9) 2578.1 [42/42]	5.1 ± 1.6 (2–9) 5 [118/2]
Physalaemus erikae	Call A	0.539 ± 0.036 (0.478–0.566) [5/5]	–	–	–	–	0.541 ± 0.023 (0.516–0.575) [5/5]	0.521 ± 0.029 (0.484–0.550) [5/5]	30.2 ± 11.8 (21.5–43.1) 43.1 [5/5]	–	2889.7 ± 31.9 (2842.4–2928.5) 2885.4 [5/5]	4.7 ± 1.9 (1–7) 6 [251/2]
Physalaemus kroyeri	Call A	0.715 ± 0.023 (0.673–0.759) [10/10]	–	–	–	–	0.414 ± 0.028 (0.355–0.470) [10/10]	0.409 ± 0.019 (0.386–0.451) [10/10]	28.1 ± 45.3 (0.0–93.7) 0.0 [10/10]	–	2071.9 ± 29.6 (2062.5–2156.2) 2062.5 [10/10]	4.5 ± 1.3 (2–6) 6 [309/2]
Physalaemus centralis	Call A	0.492 ± 0.055 (0.404–0.550) 0.415 [17/17]	–	–	–	–	0.355 ± 0.022 (0.328–0.404) 0.336 [17/17]	0.355 ± 0.022 (0.328–0.404) 0.336 [17/17]	38.6 ± 27.4 (0.0–93.8) 46.9 [17/17]	–	1453.1 ± 33.2 (1406.2–1500.0) 1453.1 [17/17]	12.4 ± 5.5 (4–21) 18 [122/6]
Physalaemus cuvieri	Call A	0.291 ± 0.013 (0.257–0.311) 0.286 [57/57]	–	–	–	–	0.456 ± 0.040 (0.408–0.623) 0.450 [55/55]	0.616 ± 0.035 (0.506–0.716) 0.636 [57/57]	-3.0 ± 21.3 (-43.1–43.1) 0.0 [57/57]	–	759.3 ± 25.3 (689.1–775.2) 775.2 [57/57]	1.0 ± 0.1 (1–2) 1 [112/2]
Physalaemus ephippifer	Call A	0.501 ± 0.015 (0.466–0.523) 0.498 [18/18]	0.041 ± 0.007 (0.017–0.053) 0.045 [147/18]	–	25.5 ± 6.5 (18.8–60.3) 22.3 [147/18]	?	0.500 ± 0.013 (0.465–0.521) 0.492 [18/18]	0.470 ± 0.025 (0.423–0.516) [18/18]	67.0 ± 22.0 (43.1–86.2) 43.1 [18/18]	22.6 ± 2.1 (19.9–30.6) 21.7 [47/18]	1320.7 ± 833.7 (818.3–2627.1) 818.3 [18/18]	3.1 ± 2.3 (1–6) 1 [224/2]
Physalaemus fischeri	Call A	0.826 ± 0.014 (0.795–0.850) 0.820 [24/24]	–	–	–	–	0.524 ± 0.021 (0.481–0.570) 0.521 [24/24]	0.592 ± 0.021 (0.550–0.636) 0.602 [24/24]	39.0 ± 61.3 (-93.7–93.7) 93.7 [24/24]	–	843.8 ± 0.0 (843.8–843.8) 843.8 [24/24]	2.0 ± 0.0 (2–2) 2 [262/2]
Physalaemus cicada	Call A	0.027 ± 0.003 (0.004–0.047) 0.025 [2447/2447]	–	–	–	–	0.314 ± 0.047 (0.143–0.396) 0.322 [52/52]	0.408 ± 0.058 (0.305–0.527) 0.353 [52/52]	-37.8 ± 20.8 (-46.8–46.8) -46.8 [52/52]	–	3182.2 ± 270.0 (1406.2–3562.5) 3046.9 [2447/2447]	8.1 ± 0.7 (7–10) 8 [80/16]

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TABLE 2. (Continued)

Species	Call Type	Call Duration (s)	Cycle or Pulse Duration (s)	Cycle or Pulse Interval (s)	Cycle or Pulse Rate (per s)	Proportion Final Cycle (per s)	Proportion Duration Dominancy Lower Bands	Proportion Initial FM	Frequency Delta Initial FM (Hz)	PFM Rate (per s)	Dominant Frequency (Hz)	Dominant Harmonic
Physalaemus aguirrei	Call A	0.221 ± 0.011 (0.179–0.237) 0.220 [53/53]	–	–	–	–	0.582 ± 0.027 (0.522–0.625) 0.561 [33/33]	0.327 ± 0.015 (0.296–0.355) 0.322 [19/19]	41.7 ± 22.2 (0.0–107.7) 21.5 [33/33]	–	2578.3 ± 1006.0 (775.2–3375.0) 3281.2 [53/53]	3.1 ± 2.1 (1–6) 1 [113/2]
Physalaemus soaresi	Call A	1.660 ± 0.079 (1.597–1.748) [3/3]	0.068 ± 0.019 (0.032–0.123) 0.059 [54/3]	–	16.0 ± 4.9 (8.1–31.3) 16.9 [54/3]	?	–	–	–	5.9 ± 0.5 (4.9–6.9) 5.5 [20/3]	2842.4 ± 336.3 (2454.8–3057.7) [3/3]	4.5 ± 0.6 (4–7) 4 [490/1]
Physalaemus maximus	Call A	2.200 ± 0.171 (1.887–2.446) 2.237 [10/10]	0.102 ± 0.018 (0.060–0.144) 0.119 [65/3]	–	10.2 ± 1.9 (6.9–16.6) 8.4 [65/3]	–	–	–	–	?	1018.7 ± 14.3 (1000.0–1031.2) 1031.2 [10/10]	6.0 ± 0.9 (3–9) 6 [328/2]
Physalaemus feioi	Call A	4.311 ± 0.419 (3.854–4.920) [8/8]	0.048 ± 0.010 (0.010–0.132) 0.058 [333/4]	0.030 ± 0.010 (0.011–0.064) 0.025 [327/6]	12.8 ± 0.3 (12.5–13.4) [8/8]	1.397 ± 0.838 (0.691–2.609) [4/4]	–	–	–	12.8 ± 0.3 (12.5–13.4) [8/8]	2429.7 ± 40.1 (2343.8–2468.8) 2437.5 [8/8]	7.5 ± 1.1 (6–15) 7 [159/1]
Physalaemus orophilus	Call A	4.624 ± 0.525 (3.724–5.432) [37/37]	0.042 ± 0.007 (0.023–0.073) 0.039 [402/7]	0.048 ± 0.008 (0.003–0.070) 0.048 [395/7]	11.2 ± 0.1 (11.1–11.5) 11.1 [7/7]	1.468 ± 0.244 (1.064–1.847) [7/7]	–	–	–	11.2 ± 0.1 (11.1–11.5) 11.1 [7/7]	2774.7 ± 83.7 (2627.1–2906.2) 2670.1 [37/37]	9.3 ± 1.6 (4–29) 9 [301/1]
Physalaemus lateristriga	Call A	2.883 ± 0.498 (1.330–3.746) [25/25]	0.138 ± 0.044 (0.047–0.303) 0.125 [74/3]	–	8.0 ± 2.9 (3.3–21.1) 8.0 [74/3]	?	–	–	–	7.4 ± 1.7 (4.0–14.3) 6.1 [138/25]	1748.7 ± 48.1 (1593.8–1843.8) 1750.0 [25/25]	9.8 ± 0.7 (9–13) 10 [111/1]
Physalaemus olfersii	Call A	4.177 ± 0.318 (3.530–4.837) [23/23]	?	–	11.0 ± 3.6 (4.5–23.1) 14.3 [139/15]	–	–	–	–	11.0 ± 3.6 (4.5–23.1) 14.3 [139/15]	1689.9 ± 93.6 (1571.9–1873.4) 1722.7 [23/23]	11.9 ± 0.9 (9–19) 12 [320/1]
Physalaemus riograndensis	Call A	0.780 ± 0.035 (0.691–0.835) 0.797 [20/20]	–	–	–	–	0.520 ± 0.048 (0.463–0.648) 0.520 [20/20]	0.682 ± 0.028 (0.645–0.750) 0.697 [20/20]	6.5 ± 15.8 (0.0–43.0) 0.0 [20/20]	–	975.5 ± 25.3 (947.5–1033.6) 990.5 [20/20]	1.0 ± 0.0 (1–1) 1 [718/1]

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TABLE 2. (Continued)

Species	Call Type	Call Duration (s)	Cycle or Pulse Duration (s)	Cycle or Pulse Interval (s)	Cycle or Pulse Rate (per s)	Proportion Final Cycle (per s)	Proportion Duration Dominancy Lower Bands	Proportion Initial FM	Frequency Delta Initial FM (Hz)	PFM Rate (per s)	Dominant Frequency (Hz)	Dominant Harmonic
Physalaemus biligonigerus	Call A	0.613 ± 0.023 (0.546–0.640) 0.617 [18/18]	–	–	–	–	0.553 ± 0.042 (0.460–0.626) 0.538 [18/18]	0.509 ± 0.030 (0.422–0.569) 0.509 [18/18]	-9.6 ± 18.4 (-43.1–0.0) 0.0 [18/18]	–	638.8 ± 16.5 (602.9–646.0) 646.0 [18/18]	2.0 ± 1.9 (1–6) 1 [344/2]
Physalaemus marmoratus	Call A	0.876 ± 0.063 (0.614–0.938) 0.894 [23/23]	–	–	–	–	0.523 ± 0.066 (0.434–0.677) 0.453 [23/23]	0.464 ± 0.055 (0.373–0.651) 0.488 [23/23]	46.9 ± 24.5 (0.0–93.8) 46.9 [23/23]	–	515.6 ± 0 (515.6–515.6) 515.6 [23/23]	1.0 ± 0.0 (1–1) 1 [448/2]
Physalaemus santafecinus	Call A	0.352 ± 0.012 (0.330–0.375) 0.354 [20/20]	–	–	–	–	0.529 ± 0.018 (0.499–0.566) [20/20]	0.339 ± 0.024 (0.287–0.381) 0.350 [20/20]	0.0 [20/20]	–	1649.5 ± 1042.7 (473.7–2627.1) 2540.9 [20/20]	2.3 ± 1.8 (1–6) 1 [258/3]
Physalaemus carrizorum	Call A	2.916 ± 0.661 (2.360–4.118) [10/10]	–	–	–	–	0.431 ± 0.177 (0.068–0.672) [8/8]	0.251 ± 0.091 (0.148–0.401) [10/10]	19.4 ± 21.4 (-21.5–43.0) 43.0 [10/10]	?	1899.2 ± 1017.4 (409.1–2627.1) 2627.1 [10/10]	2.0 ± 1.9 (1–6) 1 [1219/2]
Physalaemus gracilis	Call A	0.520 ± 0.029 (0.451–0.565) 0.525 [20/20]	–	–	–	–	0.465 ± 0.082 (0.302–0.560) 0.560 [20/20]	0.500 ± 0.043 (0.434–0.606) 0.482 [20/20]	-21.6 ± 22.1 (-43.1–0.0) - 43.1 [20/20]	?	2612.0 ± 218.4 (2110.3–2756.2) 2670.1 [20/20]	4.6 ± 1.4 (1–7) 5 [266/2]
Physalaemus lisei	Call A	1.363 ± 0.358 (0.967–1.997) [11/11]	0.042 ± 0.011 (0.022–0.073) 0.038 [50/2]	–	25.6 ± 7.3 (13.7–46.2) 26.0 [50/2]	–	0.375 ± 0.047 (0.282–0.434) [11/11]	0.071 ± 0.019 (0.039–0.103) [7/7]	55.3 ± 32.5 (0–86.1) 85.1 [7/7]	11.1 ± 4.5 (6.4–20.3) [15/15]	2415.6 ± 40.6 (2325.6–2454.8) 20411.7 [11/11]	4.7 ± 0.5 (2–5) 5 [614/2]
Physalaemus evangelistai	Call A	1.190 ± 0.103 (0.976–1.358) [38/38]	0.107 ± 0.011 (0.079–0.127) 0.103 [78/10]	–	9.3 ± 0.7 (8.0–11.5) 9.4 [113/30]	–	0.368 ± 0.022 (0.322–0.385) [8/8]	0.409 ± 0.075 (0.275–0.537) [8/8]	2.7 ± 7.6 (0–21.6) 0 [8/8]	9.2 ± 0.8 (7.6–11.5) 8.8 [119/8]	2719.1 ± 487.1 (667.5–2906.2) 2906.2 [38/38]	3.1 ± 1.7 (1–6) 4 [562/2]
Physalaemus barrioi	Call A	1.680 ± 0.166 (1.323–2.038) 1.715 [23/23]	–	–	–	–	0.552 ± 0.127 (0.353–0.817) [23/23]	0.360 ± 0.107 (0.149–0.459) [23/23]	-11.7 ± 34.8 (-86.1–43.1) 0 [23/23]	–	1614.1 ± 802.1 (473.7–2584.0) 2153.3 [23/23]	1.0 ± 0.4 (1–6) 1 [298/1]
Physalaemus jordanensis	Call A	1.688 ± 0.131 (0.980–1.961) 1.704 [43/43]	0.042 ± 0.014 (0.015–0.145) 0.023 [188/6]	0.009 ± 0.010 (0.000–0.047) 0 [182/6]	19.5 ± 2.9 (16.3–22.9) 19.3 [6/6]	2.626 ± 0.823 (1.428–3.603) [6/6]	0.562 ± 0.042 (0.451–0.643) [43/43]	0.255 ± 0.026 (0.191–0.301) 0.246 [40/40]	-44.5 ± 23.6 (-93.7–0) - 46.8 [40/40]	19.5 ± 2.9 (16.3–22.9) 17.3 [6/6]	2210.6 ± 461.9 (559.9–2437.5) 2343.8 [43/43]	3.3 ± 2.2 (1–6) 1 [219/1]

TABLE 2. (Continued)

Species	Call Type	Fundamental Frequency (Hz)	Proportion Amplitude Peak Position Call	Number Cycles	Dominant Frequency Beginning of the Call (Hz)	Dominant Frequency End of the Call (Hz)	Frequency Delta Call (Hz)	Bandwidth (Hz)	Entropy (bits)	Center Frequency (Hz)	IQR Proportion (s)
Physalaemus nattereri	Call A	334.7 ± 10.9 (318.7–367.0) 339.0 [77/8]	0.13 ± 0.024 (0.069–0.167) [41/41]	–	–	–	-43.1 ± 23.1 (-93.8–0) [25/25]	423.0 ± 7.3 (421.9–468.8) 421.9 [41/41]	2.668 ± 0.046 (2.568–2.780) [41/41]	973.0 ± 48.9 (703.1–984.4) 984.4 [41/41]	0.264 ± 0.022 (0.199–0.300) 0.269 [41/41]
Physalaemus maculiventris	Call A	218.8 ± 14.2 (193.0–288.4) 214.4 [51/3]	0.732 ± 0.038 (0.643–0.795) 0.685 [50/50]	6.3 ± 1.3 (3–8) [23/23]	–	–	-26.9± 65.8 (-172.3–86.1) -43.1 [24/24]	825.2 ± 202.1 (646–1593.5) 732.1 [50/50]	3.780 ± 0.103 (3.521–4.042) 3.637 [50/50]	1129.2 ± 83.1 (1033.6–1248.9) 1076.7 [50/50]	0.240 ± 0.05 (0.165–0.318) 0.271 [50/50]
	Call B	239.8 ± 60.5 (122.9–417.4) 216.3 [104/2]	0.655 ± 0.323 (0.180–0.960) [6/6]	13.2 ± 3.8 (10–19) 10.0 [6/6]	–	–	398.4 ± 193.3 (187.4–656.3) 375.0 [4/4]	828.1 ± 321.6 (562.5–1406.2) 562.5 [6/6]	3.087 ± 0.460 (2.409–3.803) [6/6]	1218.8 ± 83.9 (1125.0–1312.5) 1125.0 [6/6]	0.335± 0.108 (0.202–0.466) [6/6]
Physalaemus erythros	Call A	248.6 ± 105.8 (104.8–397.6) 364.7 [22/4]	0.535 ± 0.081 (0.385–0.694) 0.602 [38/38]	–	–	–	-14.3± 46.9 (-290.7–21.5) 0.0 [40/40]	1758.6 ± 655.0 (990.5–3348.4) 1012.1 [38/38]	6.131 ± 0.306 (5.675–6.914) 6.055 [38/38]	1150.1 ± 17.7 (1119.7–1205.9) 1141.3 [38/38]	0.388 ± 0.022 (0.351–0.431) 0.399 [38/38]
	Call B	247.1 ± 65.6 (107.1–376.1) 189.1 [101/2]	0.948 ± 0.062 (0.723–0.988) 0.976 [17/17]	13.3 ± 4.7 (5–20) 20 [17/17]	–	–	546.0 ± 181.5 (140.7–796.9) 656.2 [17/17]	805.2 ± 137.9 (562.5–1031.2) 843.8 [17/17]	3.879 ± 0.380 (3.166–4.379) [17/17]	1177.4 ± 137.6 (937.5–1359.4) 1218.8 [17/17]	0.292 ± 0.146 (0.087–0.564) 0.255 [17/17]
Physalaemus rupestris	Call A	224.6 ± 96.7 (61.8–439.8) 281.5 [147/18]	0.165 ± 0.056 (0.085–0.280) 0.118 [18/18]	–	–	–	56.4 ± 528.3 (-1703.1–546.9) 528.3 [18/18]	914.1 ± 162.4 (812.5–1531.2) 828.1 [18/18]	5.572 ± 0.127 (5.271–5.750) [18/18]	2304.7 ± 65.3 (2171.9–2421.9) 2250.0 [18/18]	0.282 ± 0.080 (0.192–0.478) [18/18]
	Call B	128.4 ± 57.5 (41.6–356.1) 139.7 [240/6]	0.012 ± 0.003 (0.007–0.018) 0.012 [10/10]	30.5 ± 4.2 (23–34) 33 [6/6]	–	–	156.3 ± 170.4 (-156.2–359.4) 170.4 [10/10]	1304.7 ± 541.4 (943.8–2218.8) 1015.6 [10/10]	6.102 ± 0.200 (5.684–6.376) [10/10]	2320.3 ± 75.5 (2218.8–2417.5) 2312.5 [10/10]	0.448 ± 0.107 (0.307–0.635) [10/10]
Physalaemus camacan	Call A	407.7 ± 61.6 (275.5–684.9) 408.8 [631/3]	0.792 ± 0.057 (0.676–0.881) [11/11]	10.6 ± 1.1 (9–12) 11 [5/5]	–	–	54.7 ± 35.7 (0–125) [10/10]	695.5 ± 291.4 (516.8–1765.6) 559.9 [30/30]	4.935 ± 0.905 (4.145–6.490) [30/30]	1475.1 ± 87.9 (1378.1–1617.2) 1399.7 [30/30]	0.375 ± 0.015 (0.341–0.414) 0.388 [30/30]
Physalaemus obtectus	Call A	377.7 ± 46.0 (185.7–417.4) 403.1 [75/2]	0.397 ± 0.075 (0.256–0.496) 0.394 [20/20]	4.4 ± 0.5 (4–5) 4 [20/20]	–	–	12.9 ± 10.0 (0–35.2) 0 [20/20]	754.1 ± 49.2 (656.2–855.5) 785.2 [20/20]	5.273 ± 0.118 (5.046–5.475) [20/20]	1222.9 ± 7.9 (1207.0–1230.5) 1218.8 [20/20]	0.354 ± 0.030 (0.307–0.432) 0.365 [20/20]

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TABLE 2. (Continued)

Species	Call Type	Fundamental Frequency (Hz)	Proportion Amplitude Peak Position Call	Number Cycles	Dominant Frequency Beginning of the Call (Hz)	Dominant Frequency End of the Call (Hz)	Frequency Delta Call (Hz)	Bandwidth (Hz)	Entropy (bits)	Center Frequency (Hz)	IQR Proportion (s)
Physalaemus irroratus	Call A	404.6 ± 70.3 (178.3–592.4) 410.8 [74/3]	0.536 ± 0.050 (0.461–0.673) 0.524 [27/27]	4.1 ± 0.4 (3–5) 4 [27/27]	–	–	35.3 ± 40.1 (-62.5–109.4) 46.9 [27/27]	759.3 ± 70.6 (546.9–875.0) 796.9 [27/27]	5.135 ± 0.057 (4.913–5.225) 5.133 [27/27]	1636.6 ± 75.8 (1281.2–1687.5) 1656.2 [27/27]	0.379 ± 0.059 (0.299–0.627) 0.355 [27/27]
Physalaemus nanus	Call A	993.2 ± 184.2 (616.9–1082.0) 1031.2 [30/5]	0.263 ± 0.053 (0.193–0.371) 0.237 [21/21]	5.5 ± 0.6 (5–7) 5 [21/21]	–	–	4.3 ± 59.1 (-86.1–86.1) 0 [20/20]	982.3 ± 522.6 (258.4–1636.5) 559.9 [21/21]	3.819 ± 0.172 (3.301–4.081) [21/21]	2286.6 ± 52.6 (2239.5–2454.8) 2239.5 [21/21]	0.419 ± 0.071 (0.309–0.517) [21/21]
	Call B	306.9 ± 93.1 (87.3–454.5) 388.5 [62/3]	0.721 ± 0.084 (0.624–0.832) [6/6]	–	–	–	366.1 ± 462.0 (-86.1–1162.8) [6/6]	875.7 ± 107.8 (689.1–990.5) 904.4 [6/6]	3.625 ± 0.422 (2.903–4.014) [6/6]	1808.8 ± 47.2 (1722.7–1851.9) 1808.8 [6/6]	0.312 ± 0.019 (0.284–0.337) [6/6]
	Call C	*	*	*	–	–	*	*	*	*	*
Physalaemus spiniger	Call A	379.2 ± 50.9 (244.3–618.0) 402.7 [384/3]	0.741 ± 0.182 (0.083–0.980) 0.838 [26/26]	–	–	–	53.6 ± 48.2 (0.0–93.8) 93.8 [14/14]	597.2 ± 107.5 (473.7–818.3) 562.5 [31/31]	2.590 ± 0.263 (2.272–3.205) 2.428 [31/31]	1358.3± 147.6 (1162.8–1636.5) 1312.5 [31/31]	0.350± 0.045 (0.229–0.418) 0.363 [31/31]
	Call B	290.2 ± 39.7 (145.6–465.1) 269.8 [161/3]	0.516 ± 0.320 (0.049–0.937) [6/6]	–	–	–	-244.1 ± 199.5 (-473.7–129.2) -301.5 [6/6]	760.9 ± 111.2 (646.0–947.5) 689.1 [6/6]	3.145 ± 0.259 (2.794–3.490) [6/6]	1586.3 ± 32.4 (1550.4–1636.5) 1593.5 [6/6]	0.432 ± 0.048 (0.377–0.499) [6/6]
Physalaemus crombiei	Call A	366.4 ± 23.4 (253.4–490.4) 368.3 [57/10]	0.638 ± 0.153 (0.289–0.886) 0.814 [72/72]	9.1 ± 1.6 (7–18) 9 [60/60]	–	–	33.7 ± 22.0 (0–86.1) 43.0 [69/69]	434.2 ± 54.0 (409.1–646.0) 409.1 [80/80]	3.422 ± 0.271 (3.090–4.130) 3.350 [80/80]	1102.5 ± 62.9 (1055.1–1313.5) 155.1 [80/80]	0.429 ± 0.036 (0.317–0.508) 0.454 [80/80]
	Call B	335.9 ± 9.4 (307.3–350.3) 342.0 [102/1]	0.318 ± 0.147 (0.214–0.421) [2/2]	7 ± 5.7 (3–11) [2/2]	–	–	210.9 ± 33.1 (187.5–234.3) [2/2]	1347.7 ± 895.0 (714.8–1980.5) [2/2]	4.890 ± 1.348 (3.937–5.843) [2/2]	1300.8± 381.2 (1031.2–1570.3) [2/2]	0.299 ± 0.019 (0.286–0.313) [2/2]
Physalaemus signifer	Call A	281.4 ± 12.9 (180.0–294.0) 282.0 [199/3]	0.837 ± 0.026 (0.781–0.886) 0.810 [30/30]	21.7 ± 1.4 (20–24) 22 [6/6]	–	–	17.2 ± 24.3 (0.0–86.2) 0.0 [30/30]	344.5 ± 0.0 (344.5–344.5) 344.5 [30/30]	2.418 ± 0.031 (2.357–2.511) 2.398 [30/30]	862.7 ± 7.9 (861.3–904.4) 861.3 [30]	0.337± 0.023 (0.307–0.378) 0.314 [30/30]
	Call B	233.4 ± 21.0 (195.7–305.9) 221.3 [104/1]	0.871 ± 0.162 (0.531–0.961) [10/10]	14.2 ± 4.9 (10–24) 10 [10/10]	–	–	25.8 ± 127.9 (-258.4–193.8) 64.6 [10/10]	605.1 ± 126.6 (495.3–904.4) 516.8 [10/10]	3.710 ± 0.188 (3.516–4.163) 3.629 [10/10]	936.7 ± 58.5 (882.9–1033.6) 904.4 [10/10]	0.404 ± 0.035 (0.348–0.480) [10/10]

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TABLE 2. (Continued)

Species	Call Type	Fundamental Frequency (Hz)	Proportion Amplitude Peak Position Call	Number Cycles	Dominant Frequency Beginning of the Call (Hz)	Dominant Frequency End of the Call (Hz)	Frequency Delta Call (Hz)	Bandwidth (Hz)	Entropy (bits)	Center Frequency (Hz)	IQR Proportion (s)
Physalaemus bokermanni	Call A	775.4 ± 280.3 (283.0–1408.5) [16/3]	0.714 ± 0.029 (0.662–0.758) 0.745 [15/15]	5.9 ± 0.4 (5–6) 6 [15/15]	–	–	218.2 ± 207.5 (0–732.1) 0.0 [15/15]	1280.5 ± 57.5 (1162.8–1378.1) 1292.0 [15/15]	5.025 ± 0.229 (4.57–5.352) [15/15]	3255.8 ± 51.0 (3186.9–3359.2) 3230.0 [15/15]	0.410 ± 0.092 (0.244–0.506) 0.434 [15/15]
	Call B	988.8 ± 251.6 (524.1–1661.1) 802.6 [58/1]	0.055 ± 0.034 (0.002–0.114) 0.046 [15/15]	27.6 ± 4.3 (21–38) 29 [15/15]	–	–	37.5 ± 416.0 (-750.0–468.8) 468.8 [15/15]	2325.0 ± 1167.8 (1500.0–5437.5) 1687.5 [15/15]	3.949 ± 0.165 (3.731–4.189) [15/15]	3818.8 ± 55.7 (3750.0–3937.5) 3843.8 [15/15]	0.344 ± 0.099 (0.205–0.558) [15/15]
Physalaemus angrensis	Call A	406.9 ± 29.7 (303.2–436.1) 415.8 [53/1]	0.764 ± 0.070 (0.598–0.911) 0.743 [55/55]	29.9 ± 2.1 (24–34) 30 [46/46]	–	–	58.0 ± 97.7 (-46.9–234.4) 0.0 [38/38]	467.1 ± 128.4 (234.4–703.1) 515.6 [57/57]	3.006 ± 0.253 (2.382–3.274) 3.120 [57/57]	1643.1 ± 33.6 (1593.8–1687.5) 1640.6 [57/57]	0.365 ± 0.062 (0.166–0.470) 0.350 [57/57]
	Call B	315.9 ± 34.5 (164.2–479.4) 323.0 [54/1]	0.783 ± 0.079 (0.670–0.867) 0.867 [13/13]	–	–	–	133.4 ± 65.8 (0.0–234.4) 140.6 [13/13]	439.9 ± 40.8 (375.0–468.8) 468.8 [13/13]	2.439 ± 0.109 (2.304–2.608) [13/13]	1135.8 ± 51.2 (1078.1–1265.6) 1125.0 [13/13]	0.320 ± 0.057 (0.253–0.404) [13/13]
Physalaemus atlanticus	Call A	443.6 ± 31.5 (278.6–465.8) 451.9 [58/1]	0.526 ± 0.033 (0.486–0.583) [12/12]	59.8 ± 4.7 (53–67) 61 [6/6]	–	–	46.7 ± 64.8 (- 43.0–172.3) 43.0 [12/12]	624.5 ± 22.5 (602.9–646.0) 602.9 [12/12]	3.959 ± 0.038 (3.886–4.015) 3.967 [12/12]	1202.3 ± 28.8 (1162.8–1248.9) 1205.9 [12/12]	0.376 ± 0.015 (0.359–0.400 0.359 [12/12]
Physalaemus moreirae	Call A	234.9 ± 34.7 (149.0–390.8) 234.9 [81/2]	0.539 ± 0.088 (0.440–0.711) 0.528 [7/7]	22.6 ± 1.9 (19–24) 24 [7/7]	–	–	36.9 ± 46.0 (-43.1–86.1) 43.1 [7/7]	572.2 ± 21.0 (559.9–602.9) 559.9 [7/7]	3.656 ± 0.054 (3.589–3.756) [7/7]	1015.1 ± 23.0 (990.5–1033.6) 1033.6 [7/7]	0.345 ± 0.015 (0.317–0.359) [7/7]
	Call B	283.3 ± 67.3 (191.4–596.3) 284.4 [34/1]	0.875 [1/1]	–	–	–	-172.3 [1/1]	602.9 [1/1]	3.356 [1/1]	947.5 [1/1]	0.537 [1/1]
Physalaemus fernandezae	Call A	3044.8 ± 119.5 (2885.4–3230.0) 3057.7 [20/20]	0.918 ± 0.037 (0.836–0.976) 0.925 [14//14]	20.7 ± 6.1 (9–29) [7/7]	–	–	447.9 ± 147.5 (172.3–775.2) 516.8 [20/20]	318.7 ± 92.1 (129.2–473.7) 258.4 [20/20]	2.424 ± 0.570 (1.547–3.682) [20/20]	2952.2 ± 60.1 (2885.4–3057.7) 2928.5 [20/20]	0.293 ± 0.158 (0.145–0.836) 0.213 [20/20]
Physalaemus henselii	Call A	1857.7 ± 130.5 (1687.5–2156.2) 1781.2 [38/38]	0.507 ± 0.102 (0.361–0.949) 0.532 [38/38]	19.8 ± 2.9 (14–31) 19 [30/30]	–	–	39.5 ± 110.3 (- 187.6–281.3) 0.0 [38/38]	1458.1 ± 222.0 (843.8–1781.2) 1593.8 [38/38]	3.484 ± 0.199 (3.000–3.892) [38/38]	1897.2 ± 50.8 (1781.2–1968.8) 1875.0 [38/38]	0.528 ± 0.072 (0.343–0.674) 0.383 [38/38]

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TABLE 2. (Continued)

Species	Call Type	Fundamental Frequency (Hz)	Proportion Amplitude Peak Position Call	Number Cycles	Dominant Frequency Beginning of the Call (Hz)	Dominant Frequency End of the Call (Hz)	Frequency Delta Call (Hz)	Bandwidth (Hz)	Entropy (bits)	Center Frequency (Hz)	IQR Proportion (s)
Physalaemus albonotatus	Call A	530.4 ± 39.3 (421.8–784.9) 511.2 [337/1]	0.734 ± 0.005 (0.731–0.737) [2/2]	34.4 ± 0.5 (34–35) 34 [5/5]	632.8 ± 37.4 (562.5–656.2) 556.2 [12/12]	2539.0 ± 62.7 (2437.5–2625.0) 2531.2 [12/12]	-183.5 ± 13.5 (-187.5– -140.6) -187.4[12/12]	1921.9 ± 81.2 (1781.2–1968.8) 1968.8 [7/7]	3.099 ± 0.048 (3.000–3.153) [7/7]	2075.9 ± 282.2 (1875.0–2484.4) 1875.0 [7/7]	0.422 ± 0.025 (0.396–0.459) [7/7]
Physalaemus cuqui	Call A	506.8 ± 39.4 (406.8–597.4) 479.4 [320/1]	0.689 ± 0.032 (0.630–0.735) [11/11]	28.6 ± 2.3 (25–32) 29 [9/9]	520.7 ± 13.0 (516.8–559.9) 516.8 [11/11]	2842.4 ± 0.0 (2842.4–2842.4) 2842.4 [11/11]	-159.3 ± 20.8 (-172.3– -129.2) -172.2 [10/10]	2435.2 ± 22.5 (2411.7–2454.8) 2454.8 [11/11]	3.139 ± 0.041 (3.077–3.201) 3.201 [11/11]	2689.7 ± 64.9 (2584.0–2756.2) 2756.2 [11/11]	0.264 ± 0.016 (0.242–0.293) 0.259 [11/11]
Physalaemus atim	Call A	425.4 ± 57.2 (386.0–594.5) 385.4 [354/2]	0.595 ± 0.162 (0.354–0.694) [4/4]	23.7 ± 2.5 (21–26) [3/3]	468.4 ± 35.9 (430.7–516.8) 473.7 [8/8]	2261.0 ± 115.1 (1981.1–2325.6) 2282.5 [8/8]	-143.6 ± 22.3 (-172.3– -129.2) -129.2 [6/6]	2654.0 ± 1287.3 (1248.9–4263.6) 1593.5 [8/8]	3.761 ± 0.322 (3.240–4.131) [8/8]	2201.8 ± 155.2 (1938.0–2325.6) 2282.5 [8/8]	0.334 ± 0.034 (0.271–0.384) [8/8]
Physalaemus albifrons	Call A	467.6 ± 73.5 (315.1–542.9) 525.2 [118/2]	0.527 ± 0.043 (0.423–0.591) 0.486 [42/42]	–	1053.5 ± 27.9 (984.4–1078.1) 1078.1 [42/42]	2573.6 ± 52.6 (2437.5–2671.9) 2578.1 [42/42]	-171.9 ± 22.3 (-187.5– -140.6) -187.5 [42/42]	2284.6 ± 155.0 (1968.8–2531.2) 2390.6 [42/42]	3.797 ± 0.051 (3.701–3.913) 3.808 [42/42]	2602.7 ± 49.9 (2484.4–2718.8) 2578.1 [42/42]	0.239 ± 0.010 (0.218–0.261) 0.232 [42/42]
Physalaemus erikae	Call A	419.3 ± 63.7 (507.3–642.3) 634.5 [251/2]	0.504 ± 0.022 (0.475–0.523) [4/4]	–	585.7 ± 35.4 (559.9–624.5) 559.9 [5/5]	3113.7 ± 133.3 (2907.0–3230.0) [5/5]	-211.0 ± 35.4 (-236.9– -172.2) -236.9 [5/5]	2545.2 ± 224.5 (2239.5–2756.2) [5/5]	4.109 ± 0.172 (3.912–4.374) [5/5]	2734.7 ± 79.1 (2605.5–2799.3) 2777.8 [5/5]	0.295 ± 0.020 (0.269–0.315) 0.315 [5/5]
Physalaemus kroyeri	Call A	484.5 ± 66.6 (366.3–611.6) 452.9 [309/2]	0.220 ± 0.013 (0.207–0.250) 0.211 [10/10]	–	468.8 ± 0 (468.8–468.8) 468.8 [10/10]	2578.1 ± 91.1 (2343.8–2625.0) 2625.0 [10/10]	-187.5 ± 0 (–187.5– -187.5) -187.5 [10/10]	1706.3 ± 196.6 (1593.8–2250.0) 1687.5 [10/10]	2.981 ± 0.045 (2.900–3.039) [10/10]	2184.4 ± 63.3 (2062.5–2250.0) 2156.2 [10/10]	0.341 ± 0.009 (0.326–0.354) [10/10]
Physalaemus centralis	Call A	93.9 ± 13.8 (75.5–122.1) 100.0 [122/6]	0.480 ± 0.026 (0.426–0.536) 0.459 [17/17]	–	532.2 ± 43.6 (468.8–562.5) 562.5 [17/17]	1453.1 ± 33.2 (1406.2–1500.0) 1453.1 [17/17]	-49.6 ± 35.1 (-93.8–0.0) -46.8 [17/17]	874.1 ± 40.4 (796.9–937.5) 843.8 [17/17]	3.956 ± 0.060 (3.815–4.067) 3.950 [17/17]	1364.9 ± 22.7 (1312.5–1406.2) 1359.4 [17/17]	0.252 ± 0.015 (0.231–0.282) 0.236 [17/17]
Physalaemus cuvieri	Call A	649.1 ± 106.7 (506.8–886.5) 604.6 [112/2]	0.371 ± 0.026 (0.334–0.451) 0.360 [55/55]	–	759.3 ± 25.3 (689.1–775.2) 775.2 [57/57]	1748.4 ± 213.3 (1335.1–1938.0) 1938.0 [57/57]	-240.3 ± 28.1 (-258.4– -129.2) -258.4 [57/57]	658.1 ± 41.3 (559.9–732.1) 646.0 [57/57]	2.140 ± 0.115 (2.019–2.761) 2.073 [57/57]	738.9 ± 30.2 (689.1–775.2) 732.1 [57/57]	0.197 ± 0.013 (0.169–0.238) 0.197 [57/57]

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TABLE 2. (Continued)

Species	Call Type	Fundamental Frequency (Hz)	Proportion Amplitude Peak Position Call	Number Cycles	Dominant Frequency Beginning of the Call (Hz)	Dominant Frequency End of the Call (Hz)	Frequency Delta Call (Hz)	Bandwidth (Hz)	Entropy (bits)	Center Frequency (Hz)	IQR Proportion (s)
Physalaemus ephippifer	Call A	586.2 ± 163.7 (420.7–1252.3) 836.8 [224/2]	0.251 ± 0.013 (0.232–0.286) 0.255 [18/18]	8.2 ± 0.7 (6–9) 8 [18/18]	815.9 ± 10.2 (775.2–818.3) 818.3 [18/18]	2619.9 ± 22.2 (2584.0–2670.1) 2627.1 [18/18]	-339.7 ± 13.9 (-344.5– -301.4) -344.5 [18/18]	2167.7 ± 20.9 (2153.3–2196.4) 2153.3 [18/18]	3.104 ± 0.073 (2.990–3.261) [18/18]	1210.7 ± 79.4 (904.4–1248.9) 1248.9 [18/18]	0.377 ± 0.025 (0.345–0.425) 0.362 [18/18]
Physalaemus fischeri	Call A	411.1 ± 56.9 (324.5–515.5) 479.4 [262/2]	0.415 ± 0.023 (0.376–0.458) 0.392 [24/24]	–	843.8 ± 0.0 (843.8–843.8) 843.8 [24/24]	2167.9 ± 31.7 (2156.2–2250.0) 2156.2 [24/24]	-316.4 ± 54.0 (-375.0– -187.5) -281.3 [24/24]	855.5 ± 115.0 (750.0–1125.0) 750.0 [24/24]	2.295 ± 0.104 (2.108–2.485) 2.311 [24/24]	843.8 ± 0.0 (843.8–843.8) 843.8 [24/24]	0.184 ± 0.005 (0.176–0.197) 0.186 [24/24]
Physalaemus cicada	Call A	409.2 ± 23.7 (336.4–471.9) 405.0 [80/16]	0.414 ± 0.136 (0.307–0.510) 0.452 [300/300]	–	845.6 ± 9.1 (843.8–890.6) 843.8 [52/52]	3136.1 ± 193.4 (2953.1–3421.9) 3000.0 [52/52]	-101.8 ± 20.2 (-140.6– -46.9) -93.7 [52/52]	1933.1 ± 162.3 (984.4–2531.2) 2015.6 [2447/2447]	4.578 ± 0.182 (3.576–5.143) 4.669 [2447/2447]	3115.6 ± 182.9 (1500.0–3468.8) 3093.8 [2447/2447]	0.241 ± 0.031 (0.168–0.477) 0.228 [2447/2447]
Physalaemus aguirrei	Call A	638.6 ± 111.3 (460.8–874.1) 817.7 [113/2]	0.515 ± 0.026 (0.474–0.568) 0.507 [10/10]	–	766.1 ± 23.5 (732.1–818.3) 775.2 [33/33]	3036.8 ± 40.5 (2928.5–3100.8) 3014.6 [33/33]	-291.0 ± 145.1 (-344.5– -193.8) -323.0 [33/33]	2807.3 ± 270.1 (2454.8–3187.5) 3187.5 [53/53]	3.972 ± 0.698 (2.919–4.996) 3.108 [53/53]	2892.1 ± 296.5 (2368.7–3375.0) 3187.5 [53/53]	0.339 ± 0.023 (0.273–0.400) 0.331 [53/53]
Physalaemus soaresi	Call A	603.8 ± 27.2 (348.1–634.9) 613.5 [490/1]	0.499 ± 0.010 (0.491–0.511) [3/3]	22.5 ± 3.5 (20–25) [2/2]	–	–	143.6 ± 49.7 (86.2–172.3) [3/3]	1449.9 ± 587.9 (818.3–1981.1) [3/3]	2.912 ± 0.118 (2.788–3.023) [3/3]	2856.7 ± 163.1 (2670.1–2971.6) [3/3]	0.387 ± 0.074 (0.321–0.466) [3/3]
Physalaemus maximus	Call A	166.0 ± 12.8 (148.7–359.3) 165.1 [328/2]	0.684 ± 0.182 (0.411–0.896) [10/10]	22 ± 0.0 (22–22) 22 [3/3]	–	–	42.1 ± 16.5 (15.6–62.4) 46.8 [10/10]	700.0 ± 28.4 (656.2–734.4) 718.8 [10/10]	3.547 ± 0.098 (3.370–3.674) [10/10]	1071.9 ± 74.8 (1000.0–1171.9) [10/10]	0.362 ± 0.053 (0.285–0.429) [10/10]
Physalaemus feioi	Call A	327.0 ± 39.3 (153.8–424.4) 343.9 [159/1]	0.716 ± 0.165 (0.417–0.875) [6/6]	55.3 ± 6.0 (49–64) 58 [8/8]	–	–	156.2 ± 164.5 (0.0–406.2) 93.7 [8/8]	1574.2 ± 1074.5 (750.0–3093.8) 781.2 [8/8]	4.121 ± 0.307 (3.570–4.394) [8/8]	2445.3 ± 14.5 (2437.5–2468.8) 2437.5 [8/8]	0.445 ± 0.045 (0.386–0.532) [8/8]

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TABLE 2. (Continued)

Species	Call Type	Fundamental Frequency (Hz)	Proportion Amplitude Peak Position Call	Number Cycles	Dominant Frequency Beginning of the Call (Hz)	Dominant Frequency End of the Call (Hz)	Frequency Delta Call (Hz)	Bandwidth (Hz)	Entropy (bits)	Center Frequency (Hz)	IQR Proportion (s)
Physalaemus orophilus	Call A	294.3 ± 35.7 (92.1–631.7) 298.5 [301/1]	0.663 ± 0.258 (0.214–0.960) 0.874 [33/33]	57.4 ± 2.0 (55–61) 58 [7/7]	–	–	276.8 ± 105.1 (172.2–473.8) 171.2 [7/7]	1033.9 ± 560.1 (468.8–1981.1) 796.9 [37/37]	3.984 ± 0.589 (3.366–4.969) 4.953 [37/37]	2848.9 ± 60.2 (2713.2–2928.5) 2906.2 [37/37]	0.434 ± 0.049 (0.195–0.520) 0.431 [37/37]
Physalaemus lateristriga	Call A	170.0 ± 9.1 (126.9–191.0) 167.2 [111/1]	0.630 ± 0.127 (0.326–0.827) [25/25]	29.0 ± 1.4 (28–30) [2/2]	–	–	40.8 ± 81.1 (-125.0–187.5) 31.2 [13/13]	933.8 ± 69.5 (781.2–1031.2) 1000.0 [25/25]	3.893 ± 0.079 (3.754–4.038) 3.760 [25/25]	1763.7 ± 36.2 (1656.2–1812.5) 1781.2 [25/25]	0.394 ± 0.017 (0.369–0.442) 0.396 [25/25]
Physalaemus olfersii	Call A	147.4 ± 8.8 (94.5–177.9) 146.1 [320/1]	0.113 ± 0.119 (0.011–0.437) 0.016 [23/23]	?	–	–	145.1 ± 80.6 (43.0–366.1) 236.9 [23/23]	953.1 ± 43.7 (882.9–1055.1) 925.9 [23/23]	4.388 ± 0.095 (4.241–4.600) 4.406 [23/23]	1789.1 ± 65.5 (1722.7–1938.0) 1744.2 [23/23]	0.462 ± 0.040 (0.368–0.498) 0.472 [23/23]
Physalaemus riograndensis	Call A	1021.1 ± 80.0 (866.6–1254.7) 1089.3 [718/2]	0.552 ± 0.059 (0.454–0.712) 0.540 [20/20]	–	975.5 ± 25.3 (947.5–1033.6) 990.5 [20/20]	3279.5 ± 219.7 (2971.6–3488.4) 3445.3 [20/20]	-223.9 ± 26.5 (-258.4– -172.2) -215.3 [20/20]	254.1 ± 13.3 (215.3–258.4) 258.4 [20/20]	1.84 ± 0.057 (1.770–1.965) [20/20]	984.1 ± 21.1 (947.5–1033.6) 990.5 [20/20]	0.267 ± 0.011 (0.238–0.283) 0.274 [20/20]
Physalaemus biligonigerus	Call A	572.5 ± 95.7 (413.1–843.2) [344/2]	0.371 ± 0.067 (0.307–0.612) 0.370 [18/18]	–	638.8 ± 16.5 (602.9–646.0) 646.0 [18/18]	2660.6 ± 80.3 (2454.8–2885.4) 2670.1 [18/18]	-313.4 ± 19.9 (-344.5– -301.4) -301.4 [18/18]	2416.5 ± 25.1 (2368.7–2454.8) 2411.7 [18/18]	2.838 ± 0.079 (2.769–3.120) [18/18]	648.4 ± 17.9 (602.9–689.1) 646.0 [18/18]	0.303 ± 0.014 (0.281–0.338) 0.294 [18/18]
Physalaemus marmoratus	Call A	512.7 ± 55.4 (419.1–618.0) 498.8 [448/2]	0.292 ± 0.051 (0.221–0.468) [23/23]	–	515.6 ± 0 (515.6–515.6) 515.6 [23/23]	1705.8 ± 74.4 (1640.6–1875.0) 1640.6 [23/23]	-148.8 ± 43.9 (-187.5– -46.9) -187.5 [23/23]	1306.4 ± 205.9 (703.1–1687.5) 1312.5 [23/23]	2.284 ± 0.103 (2.032–2.475) 2.319 [23/23]	525.8 ± 19.8 (515.6–562.5) [23/23]	0.294 ± 0.037 (0.226–0.350) 0.276 [23/23]
Physalaemus santafecinus	Call A	493.7 ± 80.2 (369.0–728.9) 446.6 [258/3]	0.729 ± 0.020 (0.679–0.771) 0.726 [20/20]	–	516.8 ± 24.2 (473.7–559.9) 516.8 [20/20]	2500.0 ± 172.5 (2110.3–2670.1) 2540.9 [20/20]	-234.7 ± 22.0 (-258.4– -215.3) -215.3 [20/20]	2209.3 ± 24.6 (2153.3–2239.5) 2196.4 [20/20]	2.491 ± 0.038 (2.391–2.559) 2.489 [20/20]	1037.9 ± 669.4 (516.8–2110.3) 559.9 [20/20]	0.364 ± 0.063 (0.193–0.426) 0.384 [20/20]

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TABLE 2. (Continued)

Species	Call Type	Fundamental Frequency (Hz)	Proportion Amplitude Peak Position Call	Number Cycles	Dominant Frequency Beginning of the Call (Hz)	Dominant Frequency End of the Call (Hz)	Frequency Delta Call (Hz)	Bandwidth (Hz)	Entropy (bits)	Center Frequency (Hz)	IQR Proportion (s)
Physalaemus carrizorum	Call A	459.9 ± 64.4 (379.5–758.7) 441.9 [1219/2]	0.687 ± 0.300 (0.192–0.915) [10/10]	–	579.2 ± 76.3 (473.7–667.5) 646.0 [10/10]	1886.3 ± 1038.2 (387.6–2648.6) 387.6 [10/10]	-183.0 ± 53.9 (-236.8– -107.6) -236.8 [10/10]	2146.9 ± 1141.3 (409.1–4780.4) 2217.9 [10/10]	2.791 ± 0.504 (1.925–3.656) [10/10]	1651.6 ± 852.3 (409.1–2304.1) 2217.9 [10/10]	0.361 ± 0.058 (0.275–0.432) [10/10]
Physalaemus gracilis	Call A	507.1 ± 52.4 (371.7–633.3) 496.0 [266/2]	0.706 ± 0.125 (0.422–0.831) 0.547 [20/20]	–	600.8 ± 9.6 (559.9–602.9) 602.9 [20/20]	2612.0 ± 218.4 (2110.3–2756.2) 2670.1 [20/20]	-221.8 ± 37.7 (-258.4– -172.2) -258.4 [20/20]	1789.4 ± 242.6 (1335.1–2239.5) 1894.9 [20/20]	3.003 ± 0.120 (2.828–3.345) [20/20]	2573.2 ± 171.1 (2196.4–2713.2) 2627.1 [20/20]	0.321 ± 0.052 (0.210–0.404) [20/20]
Physalaemus lisei	Call A	484.2 ± 48.9 (433.8–1254.7) 470.4 [614/2]	0.975 ± 0.008 (0.953–0.988) [11/11]	25.0 ± 1.4 (24–26) [2/2]	967.0 ± 22.5 (947.5–990.5) 947.5 [11/11]	2415.6 ± 40.6 (2325.6–2454.8) 2411.7 [11/11]	-31.3 ± 38.9 (-129.2–0) 0 [11/11]	2247.3 ± 136.0 (2024.1–2368.7) 2325.6 [11/11]	3.271 ± 0.065 (3.215–3.405) [11/11]	2270.8 ± 168.0 (1981.1–2368.7) 2368.7 [11/11]	0.467 ± 0.039 (0.403–0.511) [11/11]
Physalaemus evangelistai	Call A	541.7 ± 56.5 (394.2–897.7) 519.5 [562/2]	0.686 ± 0.072 (0.538–0.830) [30/30]	9.5 ± 2.2 (5–12) 12 [10/10]	691.8 ± 40.6 (624.5–732.1) 710.6 [8/8]	2551.7 ± 75.5 (2411.7–2605.5) 2605.5 [8/8]	-304.2 ± 59.2 (-409.1– -193.8) -301.5 [8/8]	2436.3 ± 79.8 (2174.9–2625.0) 2437.5 [38/38]	2.672 ± 0.169 (2.503–3.273) 2.593 [38/38]	2700.7 ± 210.2 (2045.7–2906.2) 2812.5 [38/38]	0.356 ± 0.070 (0.221–0.484) [38/38]
Physalaemus barrioi	Call A	462.2 ± 37.6 (405.5–684.9) 444.6 [298/1]	0.632 ± 0.164 (0.320–0.887) 0.376 [29/29]	–	514.9 ± 68.1 (430.7–646.0) 473.7 [23/23]	2136.5 ± 211.7 (1808.8–2713.2) 2153.3 [23/23]	-277.1 ± 50.0 (-387.6– -172.3) -258.4 [23/23]	2078.4 ± 330.9 (1378.1–2627.1) 2196.4 [23/23]	2.927 ± 0.496 (2.143–3.836) [23/23]	1593.4 ± 779.3 (473.7–2196.4) 2153.3 [23/23]	0.387 ± 0.078 (0.314–0.601) [23/23]
Physalaemus jordanensis	Call A	450.5 ± 71.6 (330.8–997.0) 426.4 [219/1]	0.808 ± 0.066 (0.580–0.886) [43/43]	31.3 ± 8.3 (16–38) 30 [6/6]	583.0 ± 67.4 (468.8–703.1) 562.5 [43/43]	2402.7 ± 78.7 (2109.4–2670.1) 3390.6 [43/43]	-305.4 ± 54.3 (-387.6– -172.2) -328.1 [43/43]	2211.9 ± 83.9 (1938.0–2343.8) 2156.2 [43/43]	2.927 ± 0.098 (2.757–3.210) 2.884 [43/43]	1958.5 ± 378.1 (602.9–2156.2) 2062.5 [43/43]	0.451 ± 0.044 (0.302–0.530) 0.468 [43/43]

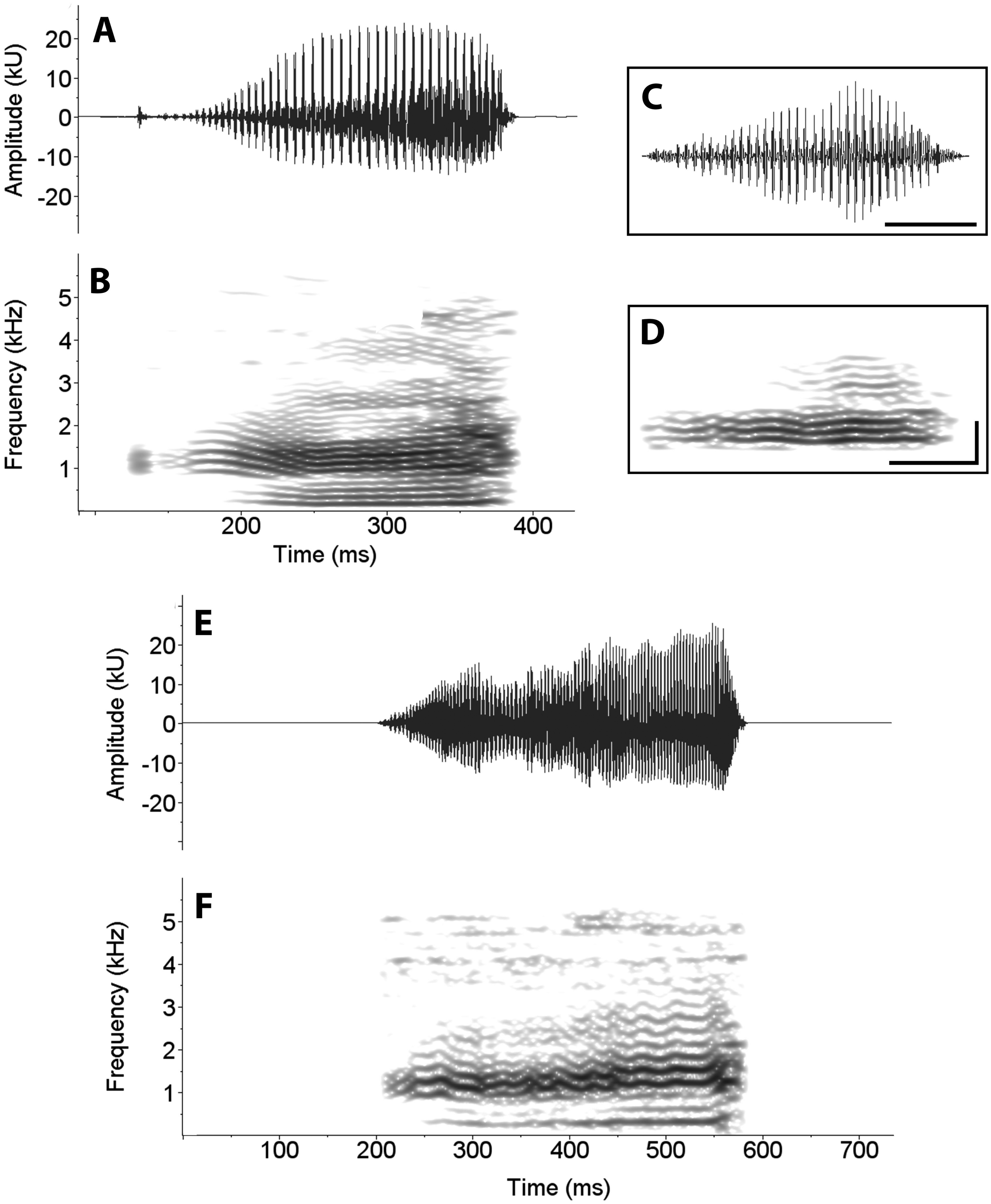

FIGURE 5. Call types A and B of *Physalaemus maculiventris*. Oscillograms (A, C, and E) and audiospectrograms (B, D, and F). A single typical call A (A and B). A single call A with a variant envelope and modulations (C and D). A single call B (E and F). Horizontal scale bars have 0.05 s; vertical scale bars have 1 KHz. Filter bandwidth (Hz): 84.6 (D); 61.4 (B); 78.9 (F).

Call B (Fig. 5E–F and 6A). We examined one recording, a total of one minute, with six calls from two males. Only some of these calls were measured (see Table 2). Call duration varies from 0.375 to 0.675 s. The call rise is longer than the fall with a long regular sustain or shallow valley separating them; the shallow valley yields two amplitude peaks at the beginning and end of the call. The amplitude peak is at around the end of the first two thirds of the call duration (*i.e.*, second amplitude peak). Depending on the slope of the sustain and the difference between the peaks, the envelope of the call can vary from rectangular to triangular (pointed left; Fig. 5E). More than 50 % of the call energy is concentrated in 34 % of the call duration around the amplitude peak. The call has a slight PAM (there is no silence interval between the peaks; Fig. 5E). The rate of the PAM is *ca.* 32 Hz, forming *ca.* 13 amplitude peaks throughout the call. The call is composed of harmonics (Fig. 6A). Usually the harmonics are clear, however, eventual decreases of the wave periodicity make the harmonics less clear. Audiospectrograms with relatively broad filter bandwidths (*e.g.*, above 100 Hz) can show wave peaks, of some parts of the call with low fundamental frequencies (minimum 123 Hz; see Table 2), as broadband pulses (instantaneously high sound-pressure effect; see Littlejohn 2001). The fundamental frequency is usually *ca.* 240 Hz and it can be present with low energy or absent in the audiospectrograms. The dominant frequency varies from *ca.* 1030 to 1310 Hz (Fig. 5F). The dominant harmonic varies from the third to the eighth, but it is usually the fourth or the fifth harmonic. There is no clear shift in the relative energy among the bands throughout the call. Most of the call energy is between 800 and 1600 Hz (*ca.* three harmonics). The frequency bands have a general upward FM throughout the call with a up-downward FM segment at the beginning forming arc-shaped bands in this part of the call and a short downward FM segment at the end (Fig. 5F). There are irregular PFM segments throughout the entire call; these segments are usually synchronic and directly proportional to the PAM (Fig. 5E, F).

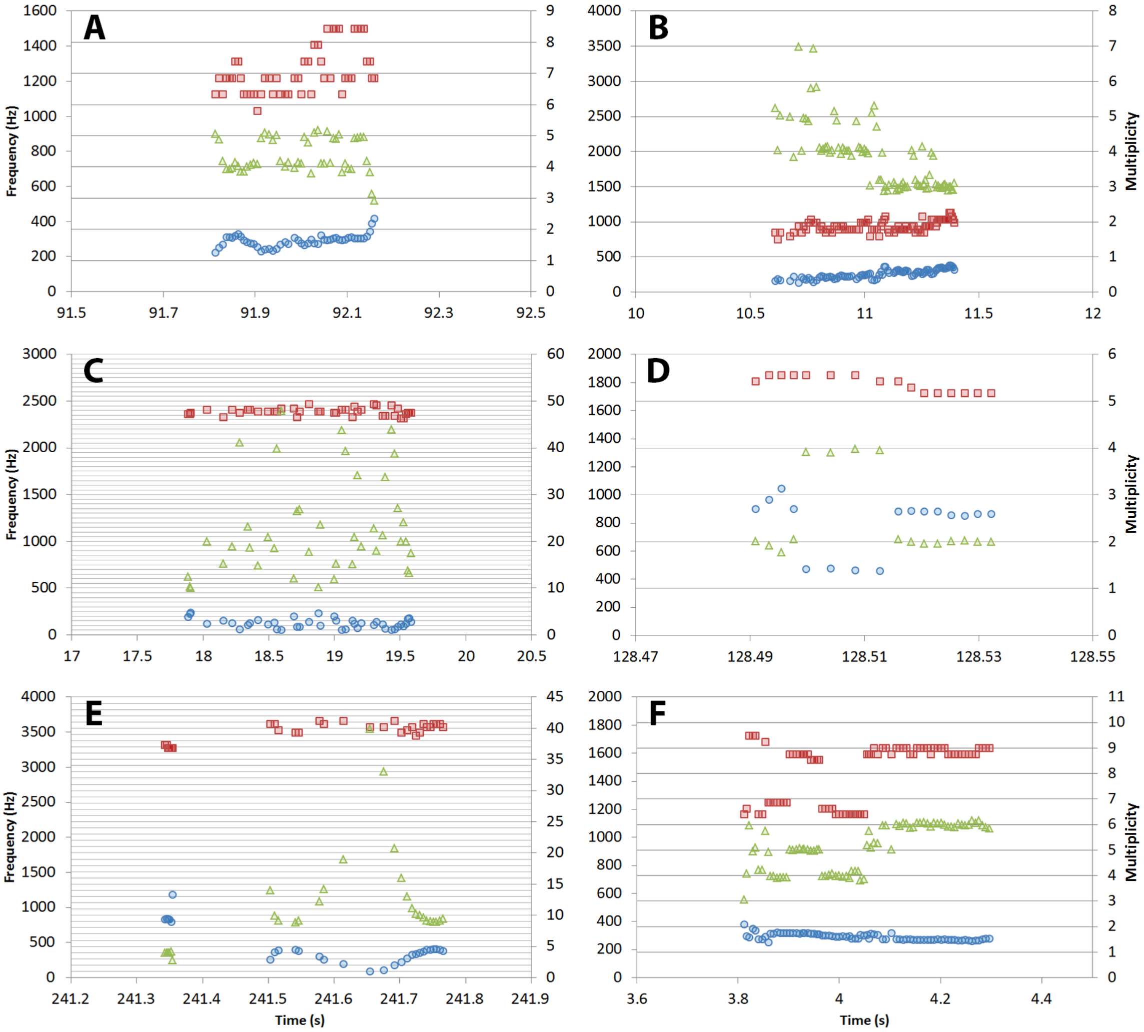

FIGURE 6. Multiplicity relationship between "instantaneous" dominant frequency and *w* of calls B and C of six *Physalaemus* species. Each graph shows a single call. Call B of *P. maculiventris* (A), call B of *P. erythros* (B), call B of *P. ruspestris* (C), call B of *P. nanus* (D), call C of *P. nanus* (E), and call B of *P. spiniger* (F). Grid corresponds to the harmonic values (right y-axis). Red squares are the values of "instantaneous" dominant frequency; blue circles are the values of the reciprocal of *w*; green triangles are the factor values of the ratio "instantaneous" dominant frequency / *w* reciprocal per delta time. Delta time corresponds to the duration of one period of the measured acoustic oscillation. Note that factors around integer values suggest harmonic relationship between the frequency calculated (*w* reciprocal) and the dominant frequency.

Physalaemus deimaticus species group

The two species analyzed have a call A with low fundamental frequency (< 300 Hz) and short duration (< 0.2 s). Calls are usually emitted in long series with short and regular intercall intervals. Frequency bands of the calls are not clear due to the signal aperiodicity (deterministic chaos).

Physalaemus erythros Caramaschi, Feio & Guimarães, 2003

We found two different calls, referred to as call A and B. B calls were common in recordings in which several males were active and calling close to each other. B calls were commonly observed after overlapping periods of calls A. Call B differs from call A by its longer duration, higher fundamental frequency, presence of pulse-PAM and PFM. Additionally, the envelope of A calls is elliptic whereas that of the B calls is triangular or rectangular.

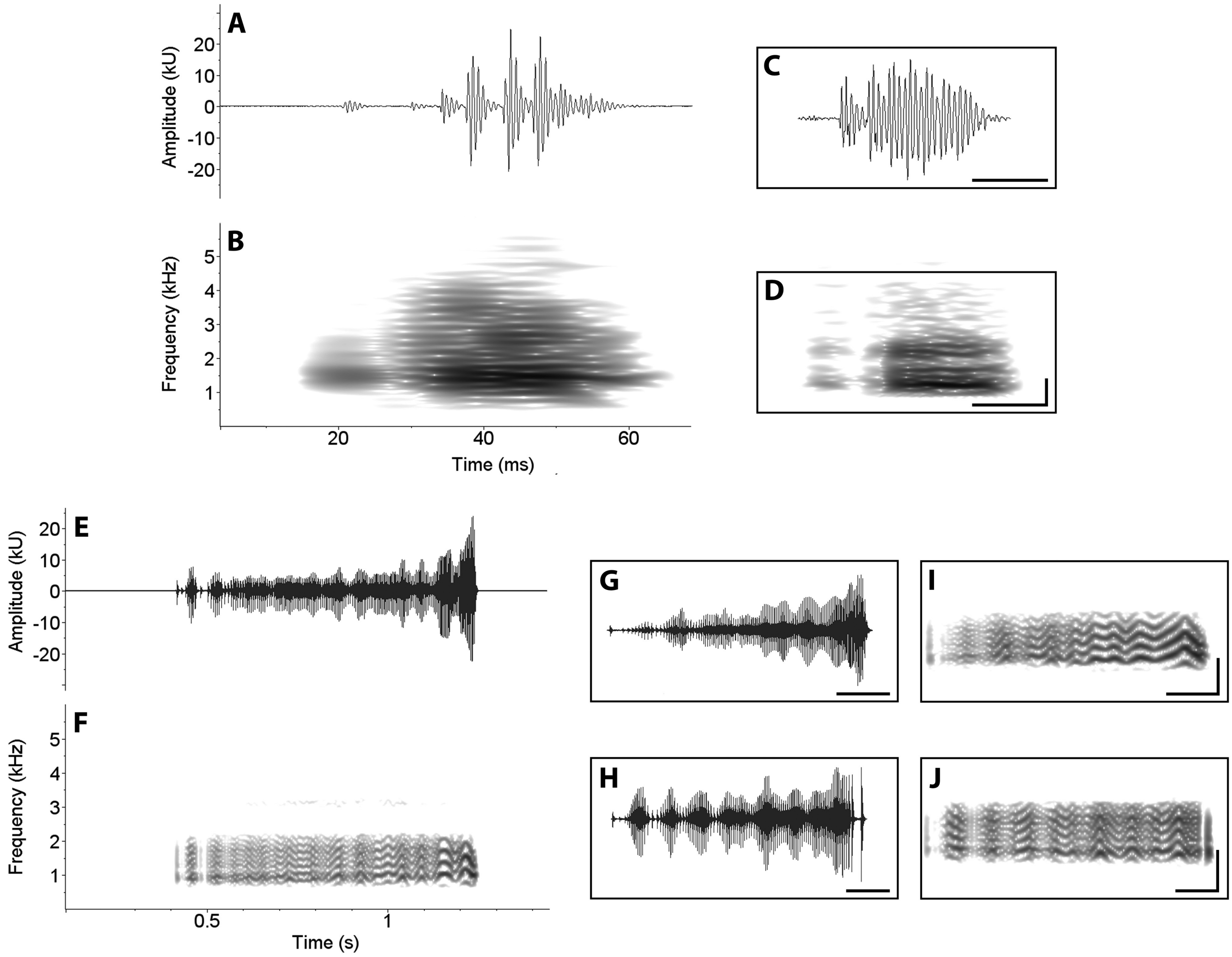

FIGURE 7. Calls A and B of *Physalaemus erythros*. Oscillograms (A, C, E, G, and H) and audiospectrograms (B, D, F, I, and J). A single typical call A (A and B). A variant call A (C and D). A single Call B (E and F). Two calls B with variant envelopes and spectral patterns (G–J). Horizontal scale bars have 0.02 s (C–D) and 0.1 s (G–J); vertical scale bars have 1 kHz. Filter bandwidth (Hz): 92.1 (B and D); 67.4 (F, I, and J).

Call A (Fig. 7A–D and 4D). We examined 21 recordings, a total of 56 minutes, with *ca*. 4900 calls from 15 males. Only some of these calls were measured (see Table 2). Call duration varies from 0.041 to 0.077 s. The call rise and fall are similar in duration, rendering an elliptic call envelope; the call fall is gradual, whereas the call rise is steeper. The amplitude peak is at around the middle of the call duration (Fig. 7A, C). More than 50 % of the call energy is concentrated in 39 % of the call duration around the amplitude peak. The call has no PAM. The call is composed of harmonics (Fig. 4D). The harmonics are very close to each other and hardly distinguished due to the low fundamental frequency and the lack of the wave periodicity throughout the call. The fundamental frequency is approximately 250 Hz and this band can be present with low energy or absent in the audiospectrograms. The dominant frequency varies from *ca*. 1020 to 1160 Hz (Fig. 7B, D). The dominant harmonic varies from the second to the tenth, but it is usually the third. There is no clear shift in the relative energy among the bands throughout the call. Most of the call energy is between 300 and 2000 Hz (*ca.* seven harmonics). There is no clear general FM in the call but there are subtle irregular FM segments throughout the entire call.

Call B (Fig. 7E–J and 6B). We examined eight recordings, a total of 26 minutes, with 93 calls from eight males. Only some of these calls were measured (see Table 2). Call duration varies from 0.200 to 0.875 s. The call rise is abrupt and a little shorter than the fall, which is also very short but gradual. The call has a long sustain. The amplitude is usually regular throughout the call (Fig. 7H). However, in some calls, the amplitude increases gradually toward the end of the call (Fig. 7E, G). The amplitude peak is at the very end of the call duration (Fig. 7E, G, H). Depending on the slope of the sustain and the difference between the amplitude peaks, the envelope of the call can vary from rectangular (Fig. 7H) to triangular (pointed left; Fig. 7E, G). More than 50 % of the call energy is concentrated in 29 % of the call duration around the amplitude peak. The call has a weak to intermediate PAM (there is no silence interval between the peaks; Fig. 7E, G, H). The rate of the PAM is *ca.* 27 Hz, forming *ca.* 13 amplitude peaks throughout the call. The envelope of this PAM cycles is variable but the amplitude peak is at the middle of the cycle. The call is composed of harmonics (Fig. 6B). Usually the harmonics are clear, however, eventual decrease in the wave periodicity makes the harmonics less clear with deterministic chaos regimes. Audiospectrograms with relatively broad filter bandwidths (*e.g.*, above 100 Hz) can show wave peaks in some parts of the call with low fundamental frequencies (minimum 107 Hz; see Table 2), as broadband pulses (instantaneously high sound-pressure effect; see Littlejohn 2001). The fundamental frequency is around 250 Hz and it is usually absent in the audiospectrograms. The dominant frequency varies from *ca*. 840 to 1780 Hz (Fig. 7F, I, J). The dominant harmonic varies from the third to the ninth, but it is usually the third and fourth harmonic. There is no clear shift in the relative energy among the bands throughout the call. Most of the call energy is between 800 and 1600 Hz (three to four harmonics). The frequency bands have a general upward FM throughout the call and a short downward FM at the end (Fig. 7F, I, J). There are irregular PFM segments throughout the entire call; these segments are usually synchronic and directly proportional to the PAM (Fig. 7E–J).

Physalaemus rupestris Caramaschi, Carcerelli & Feio, 1991

We found two different calls, referred to as call A and B. Call B differs from call A by its longer duration and pulse-PAM with irregular silence intervals. Additionally, the envelope of call A is elliptic or triangular whereas that of call B is triangular or rectangular.

Call A (Fig. 8A–D and 4D). We examined three recordings, a total of one minute, with 18 calls from one male. All these calls were measured (see Table 2). Call duration ranges from 0.057 to 0.149 s. The call rise is similar in duration or shorter than the fall; the call fall is gradual, whereas the call rise has an exponential shape. The amplitude peak is usually at around the end of the first sixth of the call duration. The envelope of the call varies from elliptic to triangular (pointed right; Fig. 8A, C, D). More than 50 % of the call energy is concentrated in 28 % of the call duration around the amplitude peak. Some calls have a strong PAM (with silence intervals present between pulses; Fig. 8D). In those calls the rate of this PAM is *ca.* 15 Hz, always forming two pulses. The envelope of these pulses is usually elliptic with the amplitude peak at the middle of the pulse. The last pulse is usually *ca.* 1.5 times longer than the first (Fig. 8C). The call is composed of harmonics (Fig. 4D). The harmonics are very close to each other and not very clear due to the low fundamental frequency and the lack of the wave periodicity throughout the call. The fundamental frequency is approximately 225 Hz and this band can be present with low energy or absent in the audiospectrograms. The dominant frequency varies from *ca*. 1890 to 2550 Hz (Fig. 8B). The dominant harmonic varies from the fifth to the 38th harmonic, but it is usually the eighth. There is no clear shift in the relative energy among the bands throughout the call. Most of the call energy is between 1200 and 2800 Hz (*ca.* six harmonics). There is no clear general FM in the call but there are subtle irregular FM segments throughout the entire call.

Call B (Fig. 8E–F and 6C). We examined three recordings, a total of one minute, with *ca*. 10 calls from one male. All these calls were measured (see Table 2). Call duration ranges from 1.269 to 1.727 s. Both call rise and fall are very short and abrupt. There is a long sustain in the call. Usually the amplitude decreases gradually throughout this segment, from the amplitude peak until the end of it. The amplitude peak is at the very beginning of the call duration. The slope of the sustain makes the envelope of the call triangular (pointed right; Fig. 8E). More than 50

% of the call energy is concentrated in 45 % of the call duration around the amplitude peak. The call has a strong PAM (with silence intervals present between pulses; Fig. 8E, F). The rate of the PAM is considerably irregular with an average of *ca.* 19 Hz, forming *ca.* 30 pulses throughout the call. The envelope of the pulses is variable but it is usually elliptic with the amplitude peak at the middle of the pulse. The last pulse is usually *ca.* 3.5 times longer than the others. The call is composed of harmonics (Fig. 6C). The harmonics are very close to each other and not very clear due to the low fundamental frequency, short pulse duration, and the lack of the wave periodicity throughout the call (deterministic chaos regimes). Audiospectrograms with relatively broad filter bandwidths (*e.g.*, above 100 Hz) can show wave peaks, of some parts of the call with low fundamental frequencies (minimum 107 Hz; see Table 2), as broadband pulses (instantaneously high sound-pressure effect; see Littlejohn 2001). The fundamental frequency is around 130 Hz and it is usually absent in the audiospectrograms. The dominant frequency varies from *ca*. 2060 to 2560 Hz (Fig. 8F). The dominant harmonic varies from the seventh to the 57th, but it is usually around the 15th harmonic. There is no clear shift in the relative energy among the bands throughout the call. Most of the call energy is between 1700 and 4100 Hz (up to 20 harmonics). There is no clear general FM in the call but there are subtle irregular FM segments throughout the entire call (Fig. 8F).

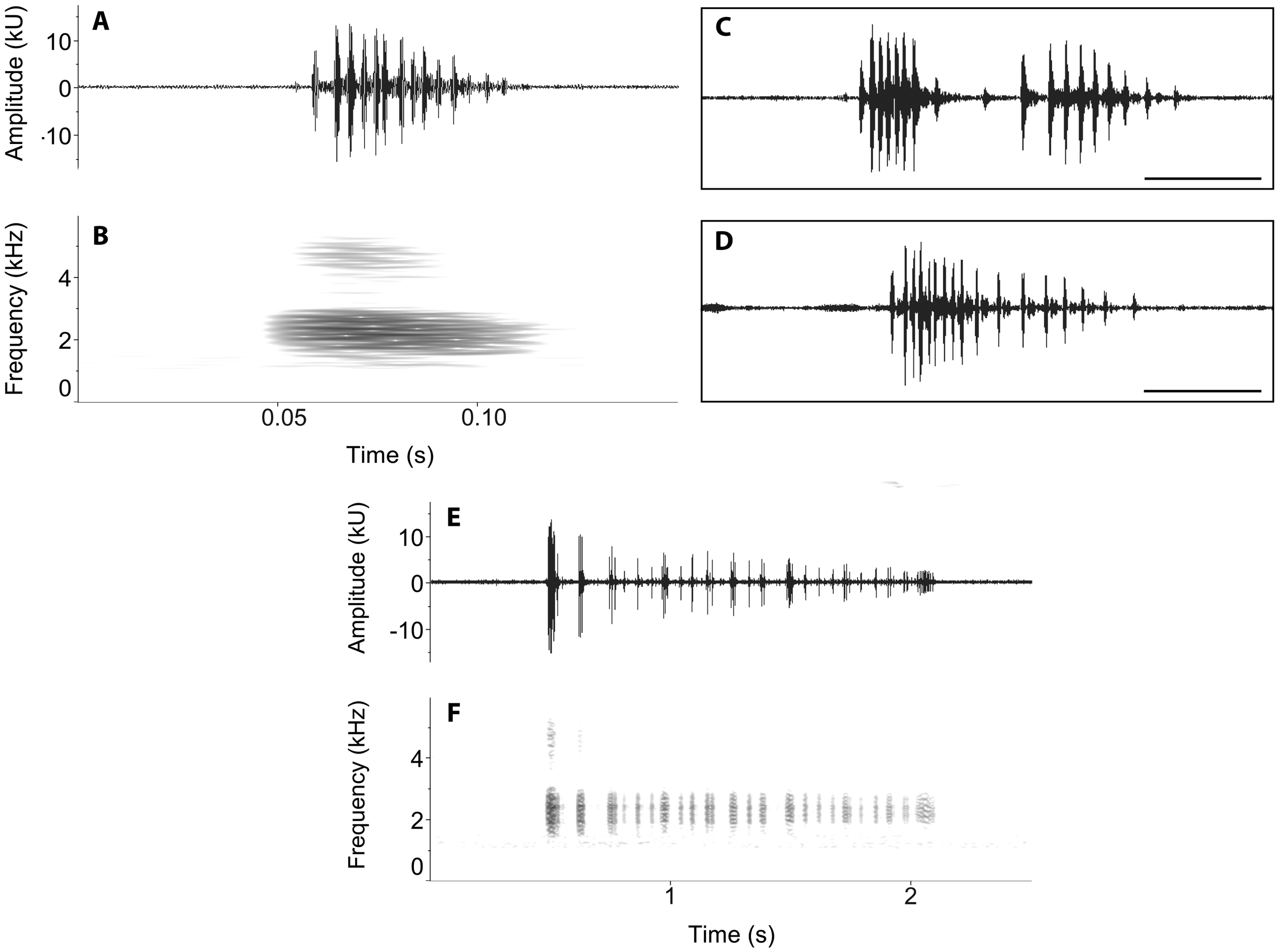

FIGURE 8. Calls A and B of *Physalaemus rupestris*. Oscillograms (A, C, D, and E) and audiospectrograms (B and F). A single typical call A (A and B). Variant A calls (C and D). Note the amplitude modulation resulting in two pulses (C). A single B call (E and F). Horizontal scale bars have 0.05 s (C–D). Filter bandwidth (Hz): 44.9 (B and F).

Physalaemus signifer species group

Several species in this group have pulsed call (*P. angrensis*, *P. atlanticus*, *P. bokermanni*, *P. crombiei*, *P. irroratus*, *P. moreirae*, *P. nanus*, and *P. obtectus*) and show nonlinear regimes (acoustic features more complex than usually expected for simple oscillators; see Material and Methods above) such as subharmonics, deterministic chaos, and frequency jumps (*P. angrensis*, *P. atlanticus*, *P. bokermanni*, *P. camacan*, *P. crombiei*, *P. irroratus*, *P. moreirae*, *P.*

nanus, *P. obtectus*, *P. signifer*, and *P. spiniger*). All species, except *P. bokermanni*, have at least one call with structures long enough to make them sound, to the human ear, as nasal-like whines with high timbre; due to the energy concentrated in higher and dense harmonics.

Physalaemus camacan Pimenta, Cruz & Silvano, 2005

We found a single call type for the species, referred to as call A. The call has a single harmonic note with a slight PAM. It is spectrally polymorphic with clear harmonics, sidebands, and deterministic-chaos regime.

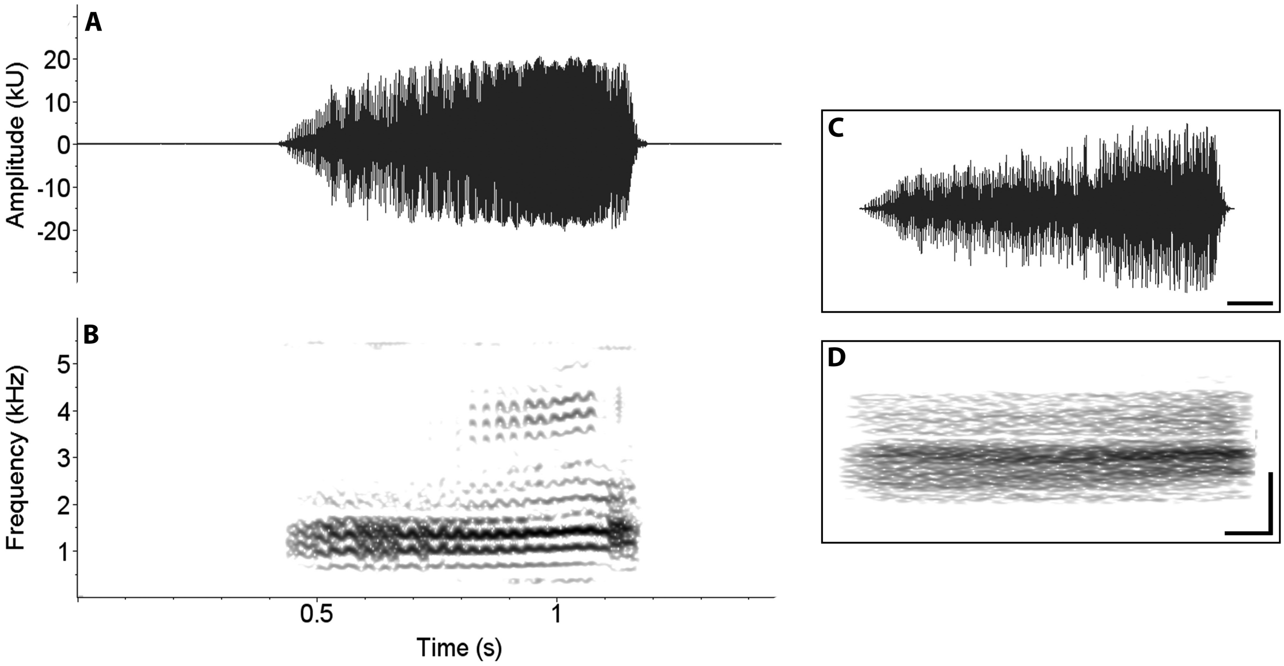

FIGURE 9. Call A of *Physalaemus camacan*. Oscillograms (A and C) and audiospectrograms (B and D). A single typical call with emphasized harmonics (A and B). A variant call (C and D). A single noisy call with high level of deterministic chaos (C and D). Horizontal scale bars have 0.1 s; vertical scale bars have 1 kHz. Filter bandwidth (Hz): 61.9 (B); 31.0 (D).

Call A (Fig. 9A–D and 4E–F). We examined two recordings, a total of five minutes, with *ca*. 130 calls from two males. Only some of these calls were measured (see Table 2). Call duration varies from 0.676 to 0.980 s. The call rise is gradual and longer than the call fall, which is more abrupt. There is a long sustain in the call. Usually the amplitude of the call is regular throughout the call (Fig. 9A). However, in some calls, the amplitude increases gradually toward the amplitude peak at the end of the call (Fig. 9C). The amplitude peak is at around four fifths of the call duration. Depending on the slope of the sustain and the difference between the amplitude peaks the envelope of the call can vary from rectangular (Fig. 9A) to triangular (pointed left; Fig. 9C). More than 50 % of the call energy is concentrated in 38 % of the call duration around the amplitude peak. The call has a slight PAM (with no silence interval between peaks; Fig. 9A, C). The rate of the PAM is *ca.* 13 Hz, forming *ca.* 10 amplitude peaks throughout the call. The calls can have two different spectral patterns (Fig. 4E, F). The bands of one of these patterns (Fig. 9B) are multiple of each other and were considered harmonics. The fundamental frequency of this series is *ca.* 400 Hz (Fig. 9B). In the other spectral pattern (Fig. 9D), there is a series of bands with fundamental frequency of *ca.* 100 Hz, which varies continuously and the bands are not integral multiple of each other. The bands of this 100 Hz series seem to be sidebands (*i.e.*, 100 Hz wave as the modulating signal) with the 410 Hz series as the carrier signal (Fig. 9D). In most calls, the sidebands are the only bands noticeable. In these calls, the bands are not very clear since there is considerably deterministic chaos (Fig. 9D) due to the irregularity of the wave periods of the 100 Hz signal. In the calls where the 400 Hz series are evident, the harmonics are clear due to the higher fundamental frequency and the more regularity (periodicity) of the wave periods. The dominant frequency varies from *ca*. 1380 to 1660 Hz (Fig. 9B). Considering the 400 Hz series, the dominant harmonic varies from the second to the sixth, but it is usually the fourth. There is no clear shift in the relative energy between the bands throughout the call. Most of the call energy is between 1100 and 1800 Hz. This bandwidth corresponds to two harmonics of the 400-Hz series. The frequency bands have a general upward FM throughout the call with a short downward FM at the end (Fig. 9B). There is a PFM in the parts of the call where the bands are clear (Fig. 9B). This PFM is synchronic and directly proportional to the PAM (Fig. 9A, B).

Physalaemus obtectus Bokermann, 1966

We found a single call type for the species, referred to as call A. The call is composed of a sequence of pulses. There are clear harmonics, however deterministic-chaos regimes can be present at the beginning of the pulses where jumps of the fundamental frequency are common.

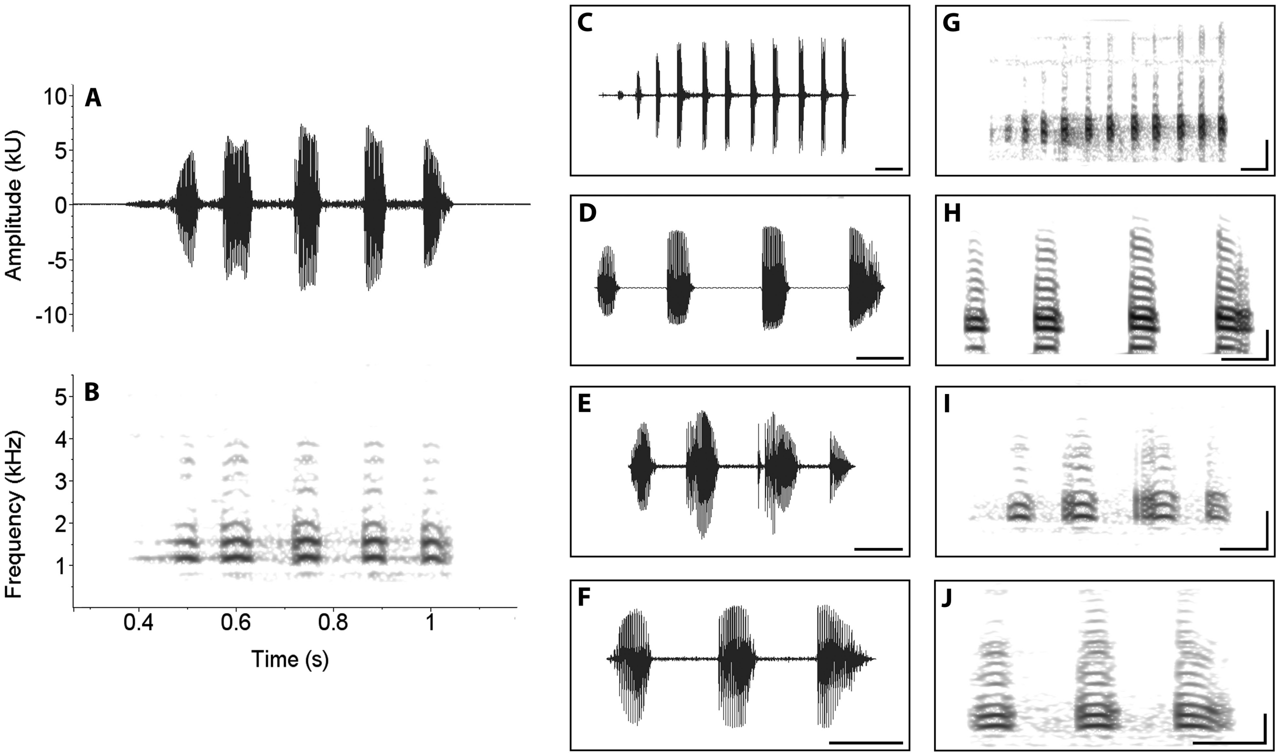

FIGURE 10. Call A of *Physalaemus obtectus*. Oscillograms (A, C, D, E, and F) and audiospectrograms (B, G, H, I, and J). A single typical call (A and B). Variant calls with different envelopes, number of pulses, pulse durations, and interpulse intervals (C–J). Horizontal scale bars have 0.1 s; vertical scale bars have 1 kHz. Filter bandwidth (Hz): 67.4 (G, I, and J); 78.9 (H); 61.9 (B).

Call A (Fig. 10A–J and 4G). We examined seven recordings, a total of eight minutes, with *ca*. 280 calls from eight males. Only some of these calls were measured (see Table 2). Call duration varies from 0.415 to 0.553 s. Usually, call rise and fall durations are similar, both resembling logarithmic shape; the amplitude peak is at around (usually just before) the middle of the call duration (Fig. 10A, D, E, F). However, some calls have an exponential or linear rise, followed by a long sustain and an abrupt fall (Fig. 10C). In calls with rise and fall similar in slope and duration, the envelope of the call is symmetric (Fig. 10A, D, E, F), whereas in calls with sustain the envelope is rectangular or triangular (pointed left; Fig. 10C). More than 50 % of the call energy is concentrated in 35 % of the call duration around the amplitude peak. The call has pulse-PAM (with silence intervals present between pulses; Fig. 10A–J). The rate of the PAM is *ca.* 9 Hz, forming *ca.* four pulses throughout the call. The pulses of the first half of the call have rise similar to fall and the amplitude peak is at the middle of the pulse. On the other hand, the pulses of the second half have rises sharper and shorter than falls, which are more gradual, with amplitude peaks at the beginning of the pulses (Fig. 10A, D, E, F). In some calls, the last pulse is clearly shorter than the others (Fig. 10E). There is a long silence interval between the pulses, equivalent to *ca.* 1.5 times the pulse duration. The call has a harmonic series (Fig. 4G). The fundamental frequency is *ca.* 380 Hz and this band can be present with low energy or absent in the audiospectrograms. Most of the wave periods are regular and the harmonics are clear throughout the call. However, subharmoncis, deterministic chaos, and jumps of the fundamental frequency are observed at the beginning and end of the pulses (Fig. 10H, I). At the same parts of the pulse, the low fundamental frequency can lead to the wave peaks to be shown as broadband clicks (instantaneously high sound-pressure effect; see Littlejohn 2001) in audiospectrograms at broad filter bandwidths. The dominant frequency varies from *ca*. 1210 to 1230 Hz (Fig. 10B). The dominant harmonic varies from the third to the seventh, but it is usually the third or fourth. There is no clear shift in the relative energy among the bands throughout the call. Most of the call energy is between 800 and 1600 Hz (often, two or three harmonics). The frequency bands have a general upward FM throughout the call (Fig. 10B, G, I, J). Additionally, there is PFM throughout the call, which is directly proportional to the synchronic pulse-PAM, *i.e.*, each pulse has an up-downward FM (Fig. 10A, B, D–F, H–J).

Physalaemus irroratus Cruz, Nascimento & Feio, 2007

We found a single call type for the species, referred to as call A. The call is composed of a sequence of pulses. There are clear harmonics, and some pulses have PFM, which is synchronic and directly proportional to the slight PAM.

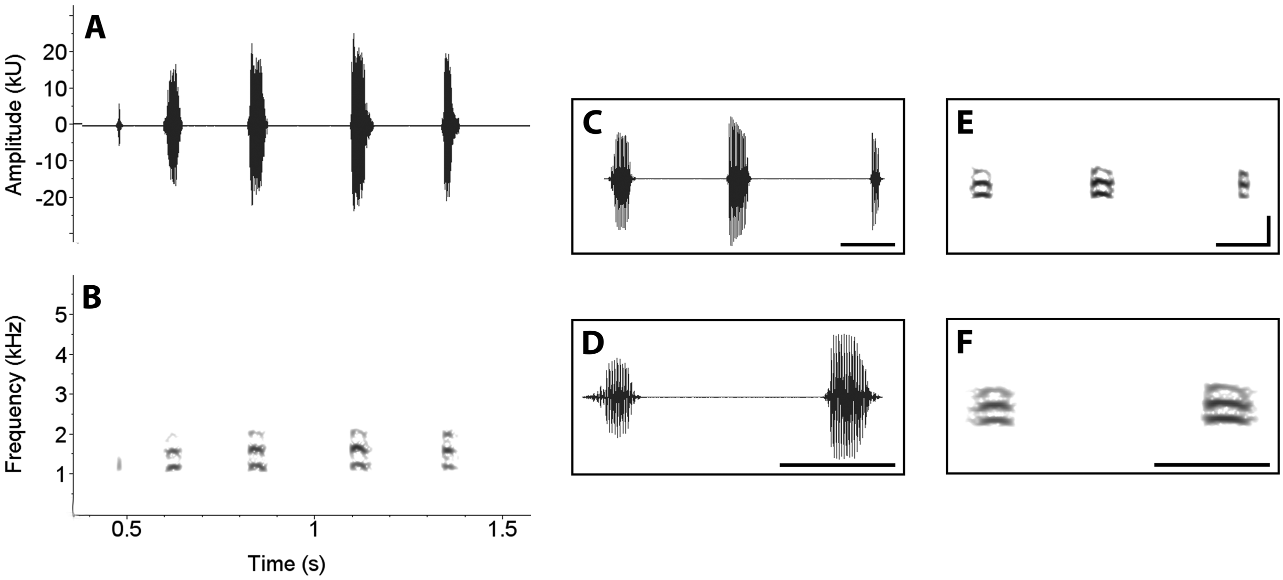

FIGURE 11. Call A of *Physalaemus irroratus*. Oscillograms (A, C, and D) and audiospectrograms (B, E, and F). A single typical call (A and B). Variant calls with different number of pulses, pulse durations and interpulse intervals (C–F). Horizontal scale bars have 0.1 s; vertical scale bars have 1 kHz. Filter bandwidth (Hz): 65.8 (B); 89.9 (E–F).

Call A (Fig. 11A–F and 4H). We examined two recordings, a total of one minute, with 29 calls from two males. Most of these calls were measured (see Table 2). Call duration varies from 0.489 to 0.954 s. The call rise and fall durations are similar; both are usually linear-shaped. In some calls, the rise and/or fall can be more abrupt and have a logarithmic shape. The amplitude peak is at around the middle of the call duration, except in calls with very few pulses (*e.g.*, two pulses). Since both rise and fall are similar in slope and duration, the envelope of the call is fairly elliptic (Fig. 11A, C). More than 50 % of the call energy is concentrated in 38 % of the call duration around the amplitude peak. The call has a strong PAM (with silence intervals present between pulses; Fig. 11A–F). The rate of the PAM is *ca.* 6 Hz, forming *ca.* four pulses throughout the call. Usually, pulses have an abrupt rise, shorter than fall, which is more gradual, with amplitude peak at the beginning of the pulse (Fig. 11A, C, D). However, the first pulses of the longer calls have rises similar to falls and the amplitude peak is at the middle of the pulse. In some calls, the last pulse is clearly shorter than the others. There is a long silence interval between pulses, *ca.* 5.5 times the pulse duration (Fig. 11A, C, D). Some pulses have an internal slight PAM. The call has a harmonic series (Fig. 4H). The fundamental frequency is *ca.* 400 Hz and this band can be present with low energy or absent in the audiospectrograms. The wave periods are regular and then the harmonics are clear throughout the call. However, subharmonics, deterministic chaos, and jumps of the fundamental frequency are observed at the beginning and at the end of the pulses, or even in the entire pulse (usually the last one). Short pulses can be shown as broadband clicks (instantaneously high sound-pressure effect; see Littlejohn 2001) in audiospectrograms at broad filter bandwidth (first pulse in Fig. 11A). The dominant frequency varies from *ca*. 1250 to 1720 Hz (Fig. 11B). The dominant harmonic varies from the second to the ninth, but it is usually the third or fourth. There is no clear shift in the relative energy among the bands throughout the call. Most of the call energy is between 1300 and 2000 Hz (often, three harmonics). The frequency bands have a general upward FM throughout the call (Fig. 11B). There is PFM throughout the call, which is directly proportional to the synchronic pulse-PAM, *i.e.*, each pulse has an up-downward FM (Fig. 11F). Additionally, another PFM is present within some pulses and it is directly proportional to the synchronic slight PAM within the pulses.

Physalaemus nanus (Boulenger, 1888)

We found three different calls, referred to as call A, B, and C (Fig. 12). Calls B and C were common in recordings in which several males were active and calling close to each other. Calls A and B are composed of harmonics and a single note each. Call B is shorter than Call A with a lower fundamental frequency, irregular FM segments, and absence of pulse-PAM. Call C is composed of two notes, the first and the second notes are similar to those of calls A and B, respectively.

Call A (Fig. 12E–H and 13A). We examined 20 recordings, a total of 77 minutes, with *ca*. 3500 calls from 33 males. Only some of these calls were measured (see Table 2). Call duration varies from 0.178 to 0.218 s. The call envelope is variable; however, calls often have rise, a regular sustain (or shallow valley), and falls sections. Call rise and fall are usually gradual and linear but they can have different durations, being long or abrupt. The amplitude peak of the calls measured here is at around the end of the first fourth of the call duration (Fig. 12A, C, D, E). The envelope of the call can be elliptic (Fig. 12A, D), rectangular (Fig. 12E), or triangular (Fig. 12C). More than 50 % of the energy is concentrated in 42 % of the call duration around the amplitude peak. This call has a strong PAM (with silence intervals present between pulses; Fig. 12A–H). The rate of the PAM is *ca.* 28 Hz, forming *ca.* five pulses throughout the call. The envelope of the pulses is also highly variable; however, the middle pulses tend to have amplitude peak at the middle of the pulse with similar rise and fall. Often, the first pulse has very little amplitude and the last pulse is the longest one (Fig. 12C, D, F, G). Silence intervals are present between pulses, slightly shorter than pulse duration (Fig. 12A–H). Some pulses have a down-upward AM at the middle of their durations, yielding two amplitude peaks per pulse. The call has a harmonic series (Fig. 13A). The fundamental frequency varies from 620 to 1100 Hz and the band can be present with low energy or absent in the audiospectrograms. The wave periods are regular and then the harmonics are clear throughout the call. Subharmonics can be present at the beginning and end of the pulses and jumps of the fundamental frequency can happen at the end of the call (fourth pulse in Fig. 12B). The dominant frequency varies from *ca*. 2240 to 2540 Hz (Fig. 12B). The dominant harmonic varies from the second to the fourth one, but it is usually the second. There is no clear shift in the relative energy among the bands throughout the call. Most of the energy is concentrated between 1800 and 2800 Hz (*ca.* two harmonics). The frequency bands have a general and slight downward FM throughout the call (Fig. 12B). Additionally, there is PFM throughout the call, which is directly proportional to the synchronic pulse-PAM (Fig. 12A–H).

Call B (Fig. 12 I–N and 6D). We examined five recordings, a total of 27 minutes, with *ca*. 40 calls from 13 males. Only some of these calls were measured (see Table 2). Call duration varies from 0.027 to 0.090 s. Often, the call rise is longer than the fall, both exponential; there is a long regular sustain (or shallow valley) between them. The amplitude peak is at around the end of the first three fourths of the call duration (Fig. 12I, K, L). The envelope of the call varied from rectangular (Fig. 12K) to triangular (pointed left; Fig. 12I, L). More than 50 % of the energy is concentrated in 31 % of the component duration around the amplitude peak. This call has no PAM. The call has a harmonic series (Fig. 6D). The fundamental frequency is *ca.* 300 Hz and this band can be present with low energy or absent in the audiospectrograms. Usually, the wave periods are regular and then the harmonics are clear throughout the call. However, harmonics are not very clear with considerably deterministic chaos in some parts of the call (Fig. 12N). Sudden jumps of the fundamental frequency can be present (usually at the end of the call). Moreover, some calls show subharmonics (Fig. 12N). The dominant frequency varies from *ca*. 1680 to 1850 Hz (Fig. 12J). The dominant harmonic varies from the seventh to the 41st, but it is usually the ninth or tenth. There is no clear shift in the relative energy among the bands throughout the call. Most of the energy is concentrated between 1300 and 2200 Hz (three or four harmonics). The frequency bands can have a general down or upward FM throughout the call with either short down or upward FM at the end (Fig. 12J, M, N). Some calls have no clear general FM. Additionally, some calls have a subtle PFM throughout the call (Fig. 12J, M, N).

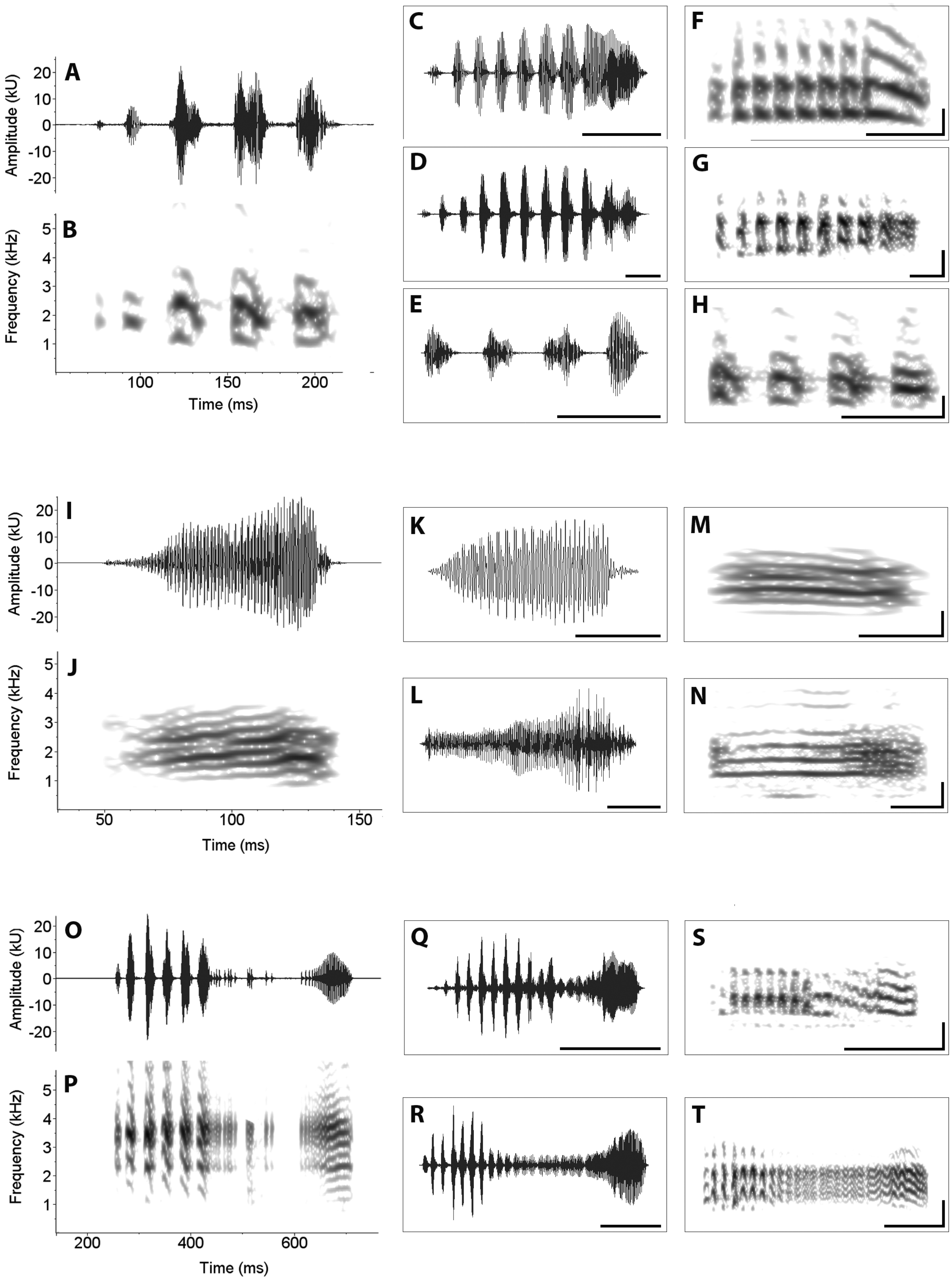

FIGURE 12. Calls A, B, and C of *Physalaemus nanus*. Oscillograms (A, C–E, I, K–L, O, and Q–R) and audiospectrograms (B, F–H, J, M–N, P, and S–T). A single typical call A (A and B). Variant calls A with different envelopes, number of pulses, pulse durations, and interpulse intervals (C–H). Calls B (I–N). Calls C (O–T). Horizontal scale bars have 0.05 s (A–H), 0.02 s (I–N), and 0.2 s (O–T); vertical scale bars have 1 kHz. Filter bandwidth (Hz): 181.0 (B and H); 162.0 (F); 110.0 (G); 124.0 (J, M, and P); 106.0 (N); 84.6 (S); 92.1 (T).

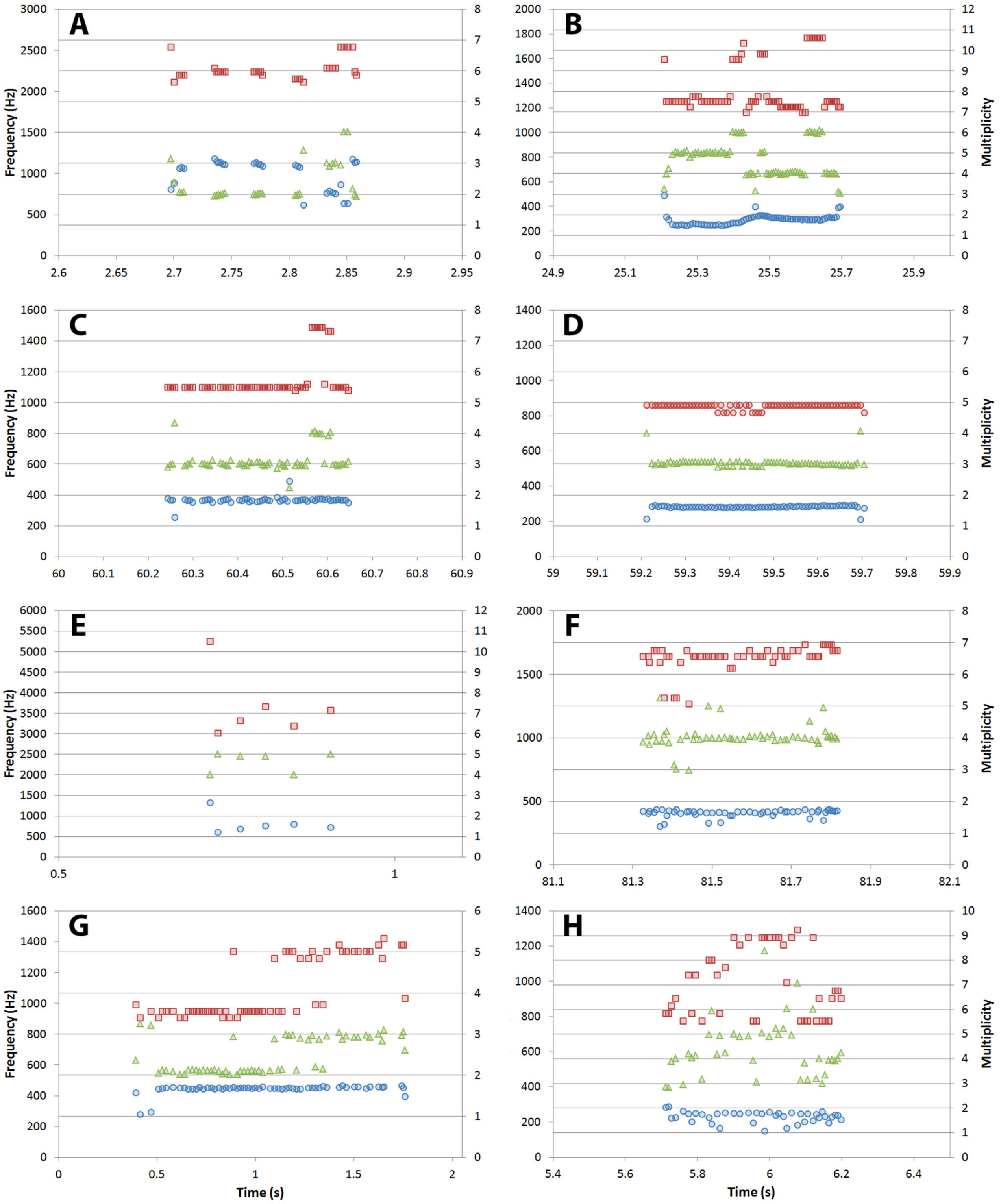

FIGURE 13. Multiplicity relationship between "instantaneous" dominant frequency and *w* of calls A of eight *Physalaemus* species. Each graph shows a single call A of: *P. nanus* (A), *P. spiniger* (B), *P. crombiei* (C), *P. signifer* (D), *P. bokermanni* (E), *P. angrensis* (F), *P. atlanticus* (G), *P. moreirae* (H). Grid corresponds to the harmonic values (right y-axis). Red squares are the values of "instantaneous" dominant frequency; blue circles are the values of the reciprocal of *w*; green triangles are the factor values of the ratio "instantaneous" dominant frequency / *w* reciprocal per delta time. Delta time corresponds to the duration of one period of the measured acoustic oscillation. Note that factors around integer values suggest harmonic relationship between the frequency calculated (*w* reciprocal) and the dominant frequency. Factors multiple of ½ of the fundamental frequency correspond to subharmonics (see *P. nanus*; A).

Call C (Fig. 12 O–T and 6E). We examined 16 recordings, a total of 60 minutes, with *ca*. 200 calls from 28 males. Only some of these calls were measured (see Table 2). Calls are composed of two notes, the first and the second are similar to those of calls A and B, respectively. Call duration varies from 0.188 to 0.311 s. The amplitude, temporal, and spectral traits of the components are similar to those described above. However, the first note can have more pulses and the envelope of the second note has steeper rise and fall in call C (Fig. 12O, Q, R). Although the amplitude decreases at the transition between notes, their limits are not clear (Fig. 12Q, R). At this transition, there is a decrease in the fundamental frequency and wave peaks emitted at low repetition rates (*e.g.*, 90 Hz) are shown as clicks (instantaneously high sound-pressure effect; Fig. 12P) in audiospectrograms at broad filter bandwidths (*e.g.*, above 100 Hz). The bands are observed in audiospectrograms at narrow filter bandwidth (*e.g.*, below 90 Hz). This rate gets faster until the beginning of the center of the second note. In C calls, the harmonics of the second note usually have a general upward FM with a short downward FM at the end of the call (Fig. 12P but see Fig. 12S, T).

Physalaemus spiniger (Miranda-Ribeiro, 1926)

We found two different calls, referred to as call A and B. Calls A and B are composed of harmonics and a single note each. Call B has two very different components. The first component is similar to call A, whereas the second one is composed of nonlinear regimes such as deterministic chaos and subharmonics.

Call A (Fig. 14A–L and 13B). We examined 16 recordings, a total of 43 minutes, with *ca*. 800 calls from 12 males. Only some of these calls were measured (see Table 2). Call duration varies from 0.221 to 0.492 s. The envelope of the call is highly variable (Fig. 14A, C–G). Often, the call rise and fall are similar in duration and vary from linear to exponential shape; there is a long regular sustain or a shallow valley connecting them (Fig. 14A, C). The amplitude peak of the calls is at around the end of the first three fourths of the call duration. The envelope of the call can be elliptic (Fig. 14D, F), rectangular (Fig. 14A, C), or triangular (Fig. 14E, G) depending on the shape of the sustain. There can be a short and deep amplitude valley at the beginning of the call (Fig. 14G). More than 50 % of the call energy is concentrated in 35 % of the call duration around the amplitude peak. The call has no PAM. The call has a harmonic series (Fig. 13B). The fundamental frequency is *ca.* 380 Hz and this band can be present with low energy or absent in the audiospectrograms. The wave periods are regular and the harmonics are clear throughout the call. The dominant frequency of the call varies from 1120 to 1981 Hz (Fig. 14B). The dominant harmonic varies from the second to the sixth, but it is usually the fourth. There is no clear shift in the relative energy between the bands throughout the call. Most of the call energy is between 1100 and 1700 Hz (*ca.* two or three harmonics). The call usually has a general upward FM (Fig. 14I, J, K), a few calls have downward FM (Fig. 14B, H, L). Additionally, many calls have a rapid up-downward FM at their outset, forming arc-shaped bands in this part of the call and a short downward FM at the end (Fig. 14B, J, K, L). In calls with short amplitude valleys the bands have down-upward FM, synchronically to the valley (Fig. 14L). Some calls showed a slight PFM (Fig. 14I, J).

Call B (Fig. 14M–P and 6F). We examined two recordings, a total of five minutes, with seven calls from three males. Most of these calls were measured (see Table 2). Call duration varies from 0.376 to 0.512 s. The call rise and fall are short and similar in duration; there is a long irregular sustain (Fig. 14M, O). The amplitude peak is at around the middle of the call duration. Shallow amplitude valleys are present yielding secondary amplitude peaks at the beginning and end of the call. The envelope of the call is somewhat rectangular (Fig. 14M, O). More than 50 % of the call energy is concentrated in 43 % of the call duration around the amplitude peak. The call has no PAM. The call has a harmonic series (Fig. 6F). The call has two different components. The traits of the first component are similar to those of the call A, whereas in the second component, the harmonics can be not well defined due to deterministic chaos (high irregularity of the wave periods; Fig. 14N, P). Subharmonics are common in the second component of the call (Fig. 14N, P). The fundamental frequency is *ca.* 290 Hz. Although the amplitude often decreases slightly at the transition between components, their limits can be unclear in oscillograms (Fig. 14M). The dominant frequency of the call varies from 1163 to 1723 Hz (Fig. 14N). The dominant harmonic of the second component varies from the third to the 12th, but it is usually the fourth, fifth, or sixth. There is a slight increase in the relative energy of the higher harmonics throughout the call (Fig. 14N, P). Most of the second component's energy is between 1200 and 2000 Hz (*ca.* three harmonics). The general FM is usually downward, with no additional FM at the end (Fig. 14N, P). Some calls have an up-downward FM at the beginning, yielding arc-shaped bands in this part of the call (Fig. 14N). In highly variable calls, and mainly along the second component, there can be several parts with irregular up and downward FM mirroring the AM direction (Fig. 14N, P).

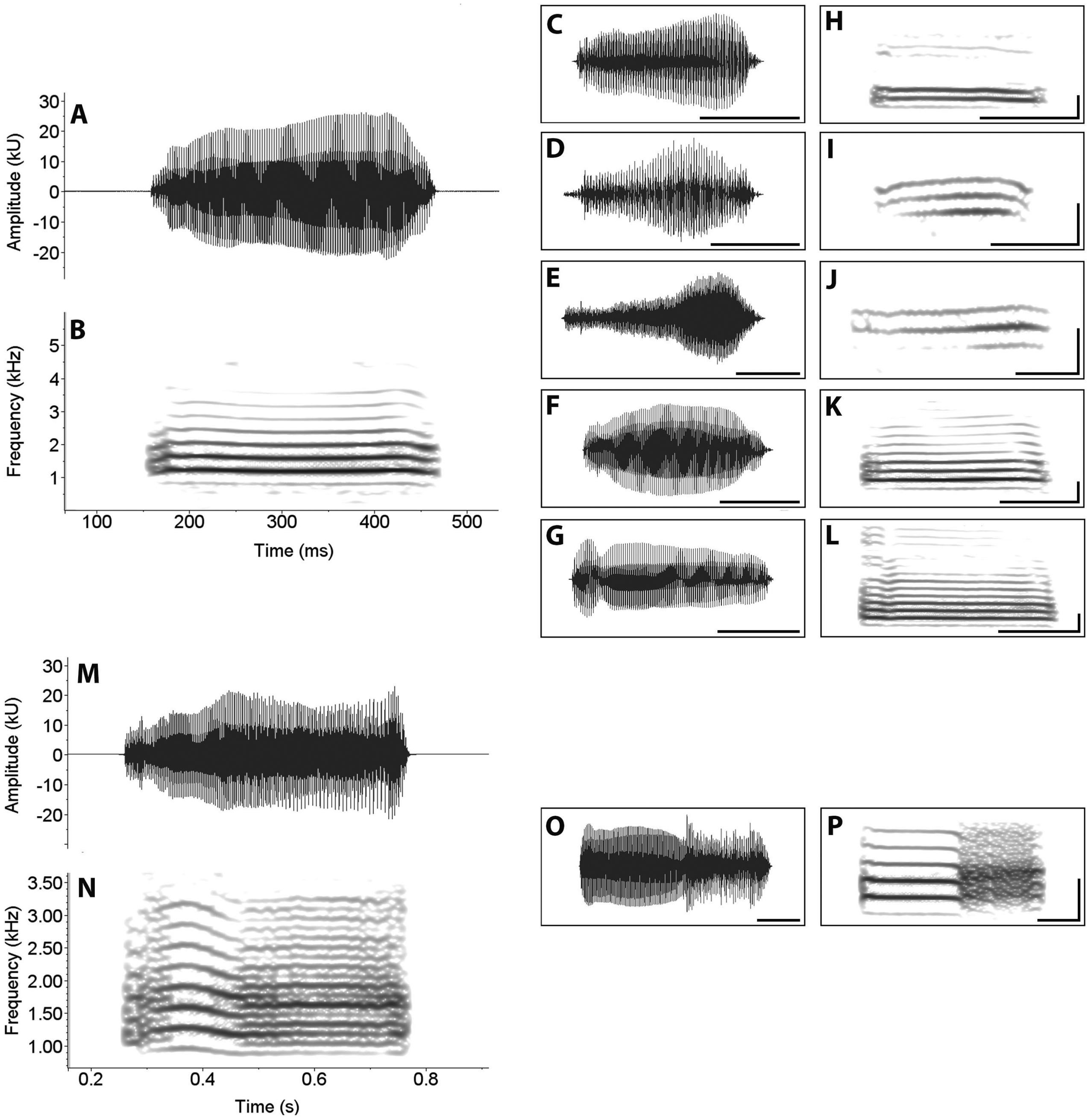

FIGURE 14. Calls A and B of *Physalaemus spiniger*. Oscillograms (A, C–G, M, and O) and audiospectrograms (B, H–L, N, and P). A single typical call A (A and B). Variant calls A with different envelopes and spectral features (C–L). Calls B (M–P). Horizontal scale bars have 0.1 s; vertical scale bars have 1 kHz. Filter bandwidth (Hz): 50.7 (N and P); 61.9 (B); 110.0 (H); 97.6 (I); 74.6 (J and K); 84.6 (L).

Physalaemus crombiei Heyer & Wolf, 1989

We found two different calls, referred to as call A and B. B calls were observed in recordings in which males emitted A calls with very long durations. Calls A and B are composed of harmonics and a single note each. A calls have pulses separated by silence intervals whereas B calls have not. Moreover, B calls have a general upward FM and FM segments (periodic or not) stronger than those of A calls.

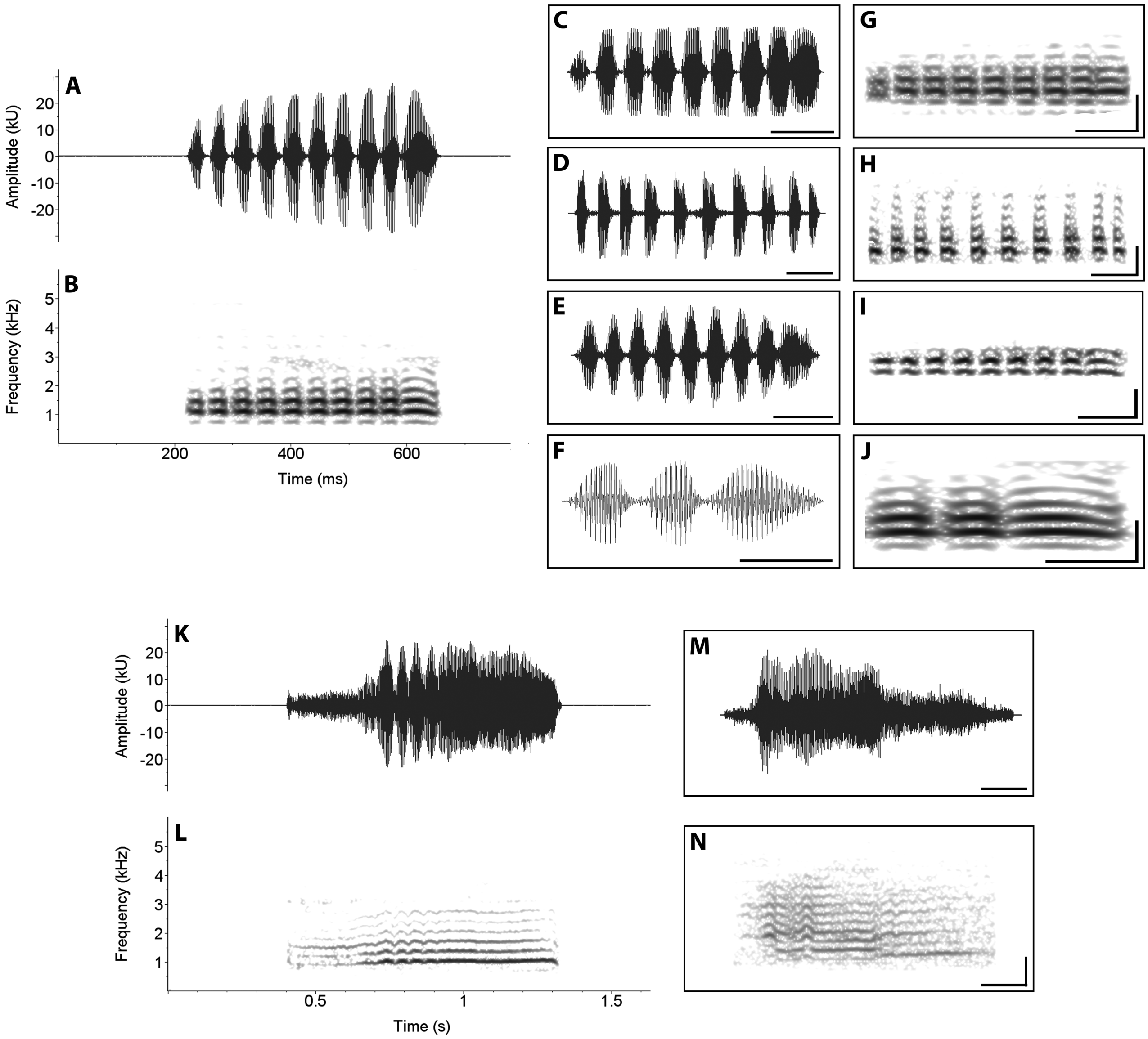

FIGURE 15. Calls A and B of *Physalaemus crombiei*. Oscillograms (A, C, D, E, F, K, and M) and audiospectrograms (B, G, H, I, J, L, and N). A single typical call A (A and B). Variant calls A with different number of pulses, pulse durations, and interpulse intervals (C–I). Last three pulses of the call A (F–J). Two B calls with different envelope and spectral features (K–N). Note that there is no silence intervals within call B (K–N). Horizontal scale bars have 0.1 s (C–E, G–I, M–N) and 0.05 s (F and J); vertical scale bars have 1 kHz. Filter bandwidth (Hz): 90.6 (G and J); 79.3 (B); 84.6 (I); 67.4 (L and N).

Call A (Fig. 15A–J and 13C). We examined nine recordings, a total of 20 minutes, with *ca*. 900 calls from 18 males. Only some of these calls were measured (see Table 2). Call duration varies from 0.319 to 0.774 s. The call rise and fall durations are usually similar to each other and they can be gradual or abrupt, linear or logarithmic; there is a long sustain (Fig. 15A, C, D, E). This segment can be slightly concave or convex (Fig. 15D, E, respectively). The amplitude peak is often at around (usually just after) the middle of the call duration. Since both rise and fall are similar in slope and duration, the envelope of the call is fairly elliptic (Fig. 15E) but can be rectangular (Fig. 15C, D) or triangular (pointed left; Fig. 15A) depending on the shape of sustained segment and the position of the amplitude peak of the call. More than 50 % of the call energy is concentrated in 43 % of the call duration around the amplitude peak. The call has a strong PAM (with silence intervals present between pulses; Fig. 15A–J). The rate of this PAM is *ca.* 25 Hz, forming *ca.* nine pulses throughout the call. Except for the last pulse, the rise of the pulses is longer than the fall and the amplitude peak is at around the end of the first two thirds of the pulse duration (Fig. 15F). The last pulse has the inverse envelope with amplitude peak at its outset (Fig. 15F). In some calls, the last pulse is notably longer than the others (Fig. 15A, B, C, E, F, G, I, J). Silence intervals are present between pulses, *ca.* tenfold shorter than pulse duration (Fig. 15A–J). The call has a harmonic series (Fig. 13C). The fundamental frequency is *ca.* 370 Hz and this band can be present with low energy or absent in the audiospectrograms. The wave periods are very regular and the harmonics are clear throughout the call. Jumps of the fundamental frequency can be present between the first pulses. The dominant frequency varies from *ca*. 1010 to 1380 Hz (Fig. 15B). The dominant harmonic varies from the third to the fourth, but it is usually the third. There is no clear shift in the relative energy between the bands throughout the call. Most of the call energy is between 900 and 1300 Hz (two harmonics). The frequency bands have a general upward FM throughout the call and short downward FM at the end (Fig. 15B, G, H, I). Additionally, there is PFM throughout the call, which is directly proportional to the synchronic pulse-PAM (Fig. 15B, G, H, I, J).

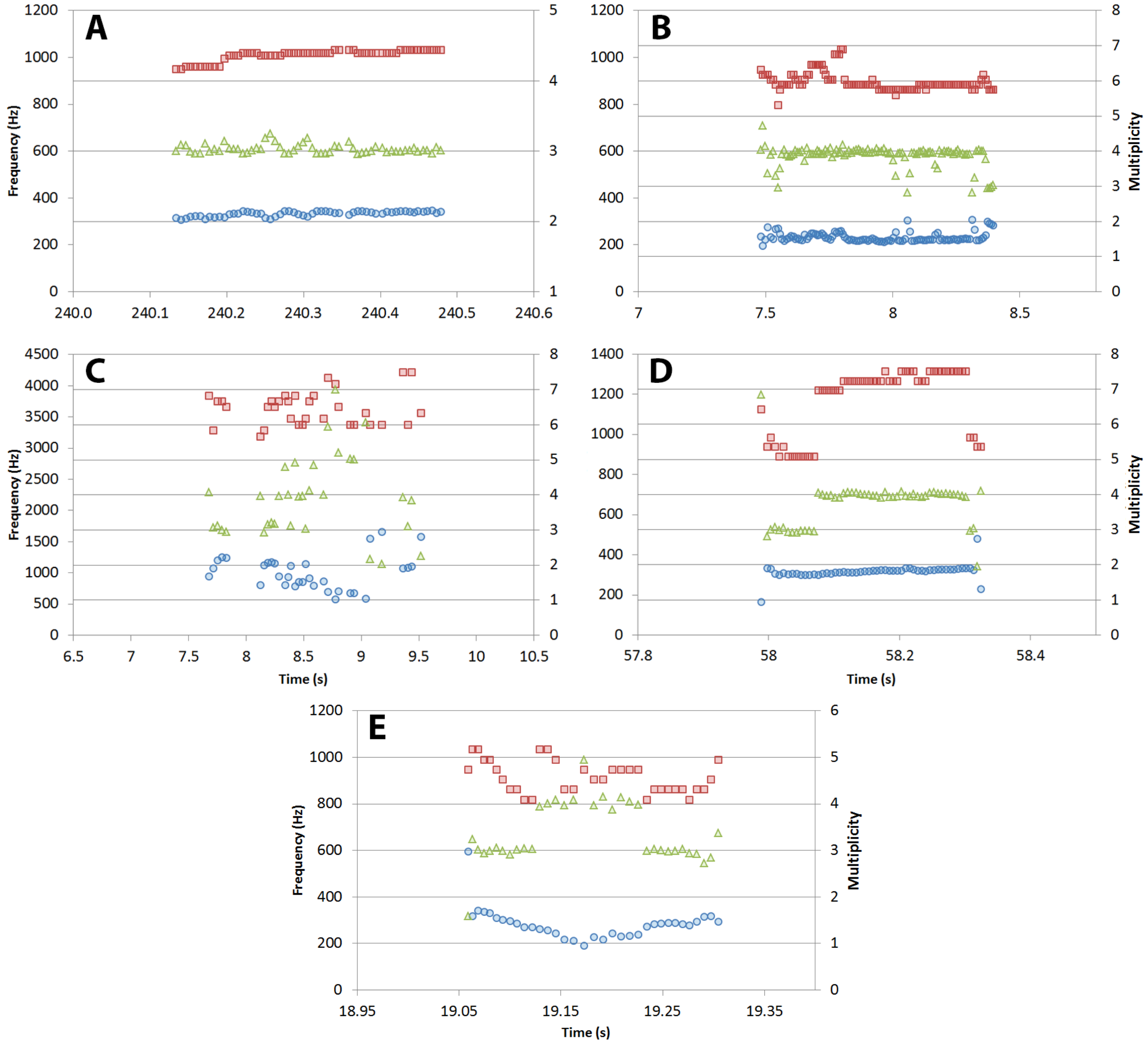

FIGURE 16. Multiplicity relationship between "instantaneous" dominant frequency and *w* of calls B of five *Physalaemus* species. Each graph shows a single call B of: *P. crombiei* (A), *P. signifer* (B), *P. bokermanni* (C), *P. angrensis* (D), and *P. moreirae* (E). Grid corresponds to the harmonic values (right y-axis). Red squares are the values of "instantaneous" dominant frequency; blue circles are the values of the reciprocal of *w*; green triangles are the factor values of the ratio "instantaneous" dominant frequency / *w* reciprocal per delta time. Delta time corresponds to the duration of one period of the measured acoustic oscillation. Note that factors around integer values suggest harmonic relationship between the frequency calculated (*w* reciprocal) and the dominant frequency.

Call B (Fig. 15K–N and 16A). We examined one recording, a total of five minutes, with two calls from one male. Most of these calls were measured (see Table 2). Call duration varies from 0.709 to 0.945 s. The envelope of the call is variable; call rise and fall are short. There can be more than one sustain, with different amplitudes (Fig. 15K, M). Usually, the first has lower amplitude (Fig. 15K). The amplitude peak is at around the middle or beginning of the call duration. The envelope can be classified as elliptic, triangular (pointed right; Fig. 15M) or rectangular

(Fig. 15K). More than 50 % of the call energy is concentrated in 30 % of the call duration around the amplitude peak. One call clearly shows a section with a slight PAM (there is no silence interval between the amplitude peaks; Fig. 15K). The rate of this PAM is *ca.* 19 Hz, forming *ca.* seven emphasized peaks at the middle of the call duration. The call has a harmonic series (Fig. 16A). The fundamental frequency is *ca.* 340 Hz and this band can be present with low energy or absent in the audiospectrograms. One call shows a sudden jump of the fundamental frequency at the end of the call. The wave periods are regular and then the harmonics are clear throughout the call. The dominant frequency varies from *ca*.1020 to 1160 Hz (Fig. 15L). The dominant harmonic is the third. There is no clear shift in the relative energy between the bands throughout the call. Most of the call energy is between 600 and 2000 Hz (*ca.* five harmonics). The frequency bands have a general upward FM throughout the call and short downward FM at the end (Fig. 15L, N). Additionally, there is PFM throughout the call, which is directly proportional to the synchronic pulse-PAM where it is present (15K–N).

Physalaemus signifer **(Girard, 1853)**

We found two different calls, referred to as call A and B. Calls B were recorded in agonistic contexts (M. Bilate, personal communication). Calls A and B are composed of harmonics and a single note each. Call B tends to be longer and with lower fundamental frequency than Call A. Calls B have strong FM segments and nonlinear regimes, such as deterministic chaos and subharmonics.

Call A (Fig. 17A–L and 13D). We examined 68 recordings, a total of 213 minutes, with *ca*. 5800 calls from 135 males. Only some of these calls were measured (see Table 2). Call duration varies from 0.453 to 0.579 s. Call rise and fall are short and usually similar to each other in duration. In some calls, the rise is longer than the fall (Fig. 17A, C, D, F). Both can have a linear or exponential shape. There is a long sustain (Fig. 17A, C, D, E, F, G). Usually it has a convex shape it can be quite irregular with periods of concave (amplitude valley) and convex shapes (Fig. 17E, D, respectively). In some calls the rise and the sustain can be fused. The amplitude peak of the call is at around the end of the first four fifths of the call duration (Fig. 17A, C, E, F). The envelope of the call can be classified as elliptic (Fig. 17D), rectangular (Fig. 17F, G), or triangular (pointed left; Fig. 17A, C, E) depending on the shape of the sustain and position of the amplitude peak in the call. More than 50 % of the call energy is concentrated in 34 % of the call duration around the amplitude peak. Some calls have a slight PAM (there is no silence interval between the amplitude peaks; Fig. 17 C, E, G). The rate of the PAM is *ca.* 50 Hz, forming *ca.* 22 cycles throughout the call. The cycle rise and fall are similar, with amplitude peak at the middle of the cycle. The call has a harmonic series (Fig. 13D). The fundamental frequency is *ca.* 280 Hz and this band can be present with low energy or absent in the audiospectrograms. The wave periods are regular and the harmonics are clear throughout the call. Subharmonics are present at the very end of some calls. The dominant frequency varies from *ca*. 860 to 1550 Hz (Fig. 17B). The dominant harmonic varies from the third to the fifth harmonic, but it is usually the third. There is no clear shift in the relative energy between the bands throughout the call. Most of the call energy is between 700 and 1000 Hz (two harmonics). Usually, the call has a general upward FM with a short downward FM at the end (Fig. 17B, H, I, J, K, L). Some calls have an up-downward FM at the beginning, yielding arc-shaped bands in this part of the call (Fig. 17L). Additionally, there is PFM throughout the call, which is directly proportional to the synchronic PAM (Fig. 17C, E, G, H, J, L).

Call B (Fig. 17M–R and 16B). We examined two recordings, a total of eight minutes, with 64 calls from four males. Only some of these calls were measured (see Table 2). Call duration varies from 0.883 to 1.355 s. Call rise and fall are short and usually similar in duration. In some calls, the rise is longer than the fall. Both can have a linear or exponential shape. There is a long sustain, usually very irregular, with several amplitude peaks (Fig. 17M, O, P). The highest amplitude peak is at around the end of the first nine tenths of the call duration (see below; Fig. 17M, O, P). The envelope of the call can be classified as elliptic, rectangular, or triangular (pointed left; Fig. 17M, O, P) depending on the shape of the sustain and position of the amplitude peak in the call. More than 50 % of the call energy is concentrated in 40 % of the call duration around the amplitude peak. The call has an irregular PAM (there is no silence interval between the amplitude peaks; Fig. 17M). Amplitude peaks are variable in intensity and some of them can show high amplitude. Usually, that is the case of the last peak, where the amplitude peak of the call is. The rate of the PAM is *ca.* 19 Hz even though highly variable, forming *ca.* 14 peaks throughout the call. The cycle ride and fall are usually similar, with amplitude peak at the middle of the cycle. The call has a harmonic series (Fig. 16B). The fundamental frequency is *ca.* 230 Hz and this band can be present with low energy or absent in the audiospectrograms. Usually the wave periods are regular and harmonics are clear throughout the call. However, some parts of the call can have poorly distinguished harmonics, with considerably deterministic chaos due to the high irregularity of the wave periods (Fig. 17Q). Sudden jumps of the fundamental frequency can be present (usually at the end of the call; Fig. 17Q). Moreover, some calls show subharmonics, usually at their ends (Fig. 17N). The dominant frequency varies from *ca*. 840 to 950 Hz (Fig. 17N). The dominant harmonic varies from the third to the fifth harmonic, but it is usually the fourth. There is no clear shift in the relative energy between the bands throughout the call. Most of the call energy is between 600 and 1200 Hz (two or three harmonics). The call has a general upward FM with a short downward FM at the end (Fig. 17N, Q, R). Additionally, there is a remarkable PFM throughout the call, which is directly proportional to the synchronic PAM where the latter is present (Fig. 17M–R).

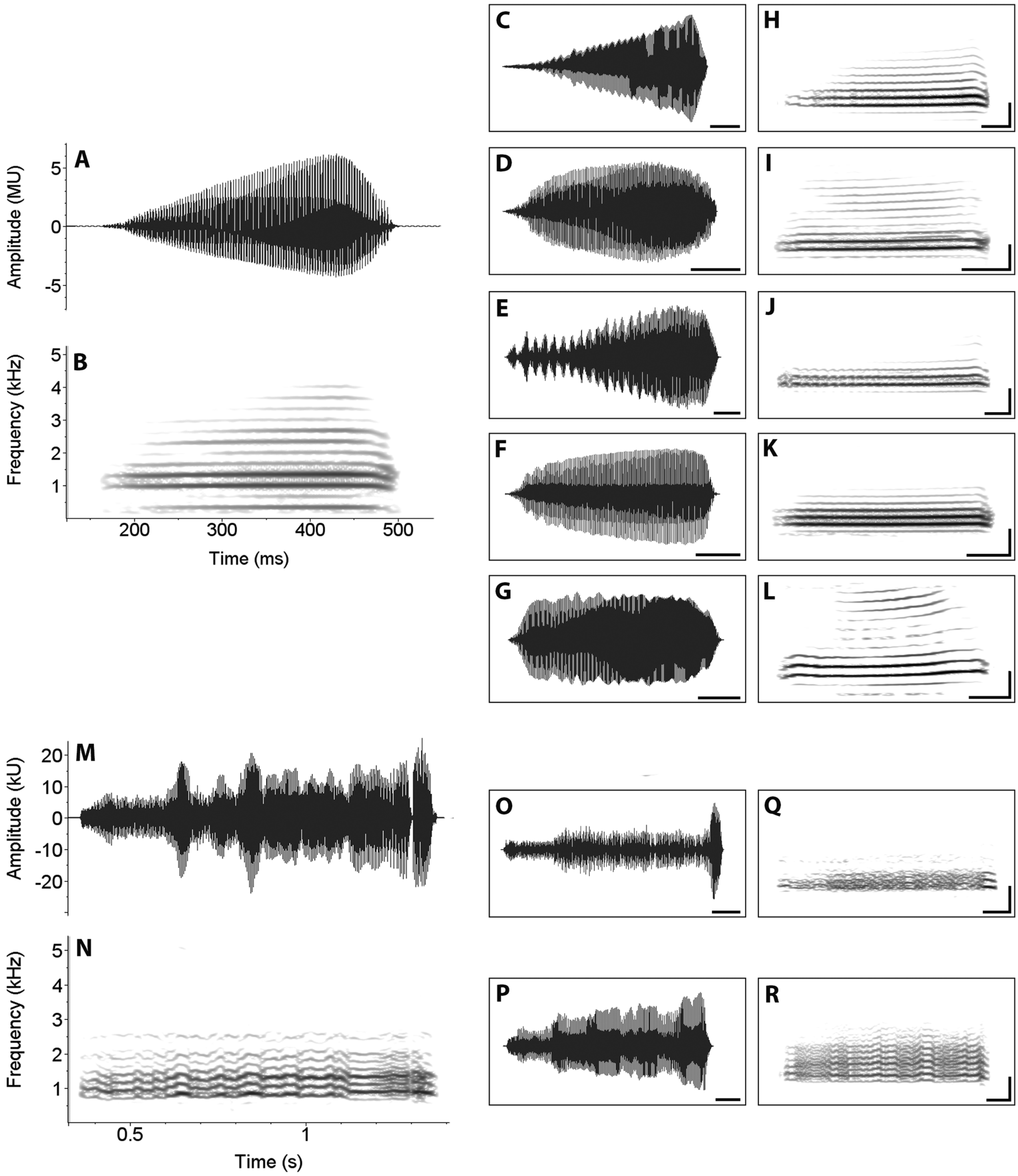

FIGURE 17. Calls A and B of *Physalaemus signifer*. Oscillograms (A, C–G, M, and O–P) and audiospectrograms (B, H–L, N, and Q–R). A single typical call A (A and B). Variant A calls with different envelopes and level of periodic amplitude modulation (C–L). Calls B (M–R). Horizontal scale bars have 0.1 s; vertical scale bars have 1 kHz. Filter bandwidth (Hz): 48.8 (I–H, N, and R); 50.7 (J); 69.0 (B); 55.2 (K); 42.3 (L and Q).

Physalaemus bokermanni Cardoso & Haddad, 1985

We found two different calls, referred to as call A and B. Calls B were common in recordings in which several males were active and calling at the same night. Calls A and B are composed of harmonics and pulses (*i.e.,* pulse-PAM). Call B has two notes while Call A has only one. The first note of call B is similar to that of call A. The second note of call B is much longer than that of call A and has an envelope with a long and gradual rise.

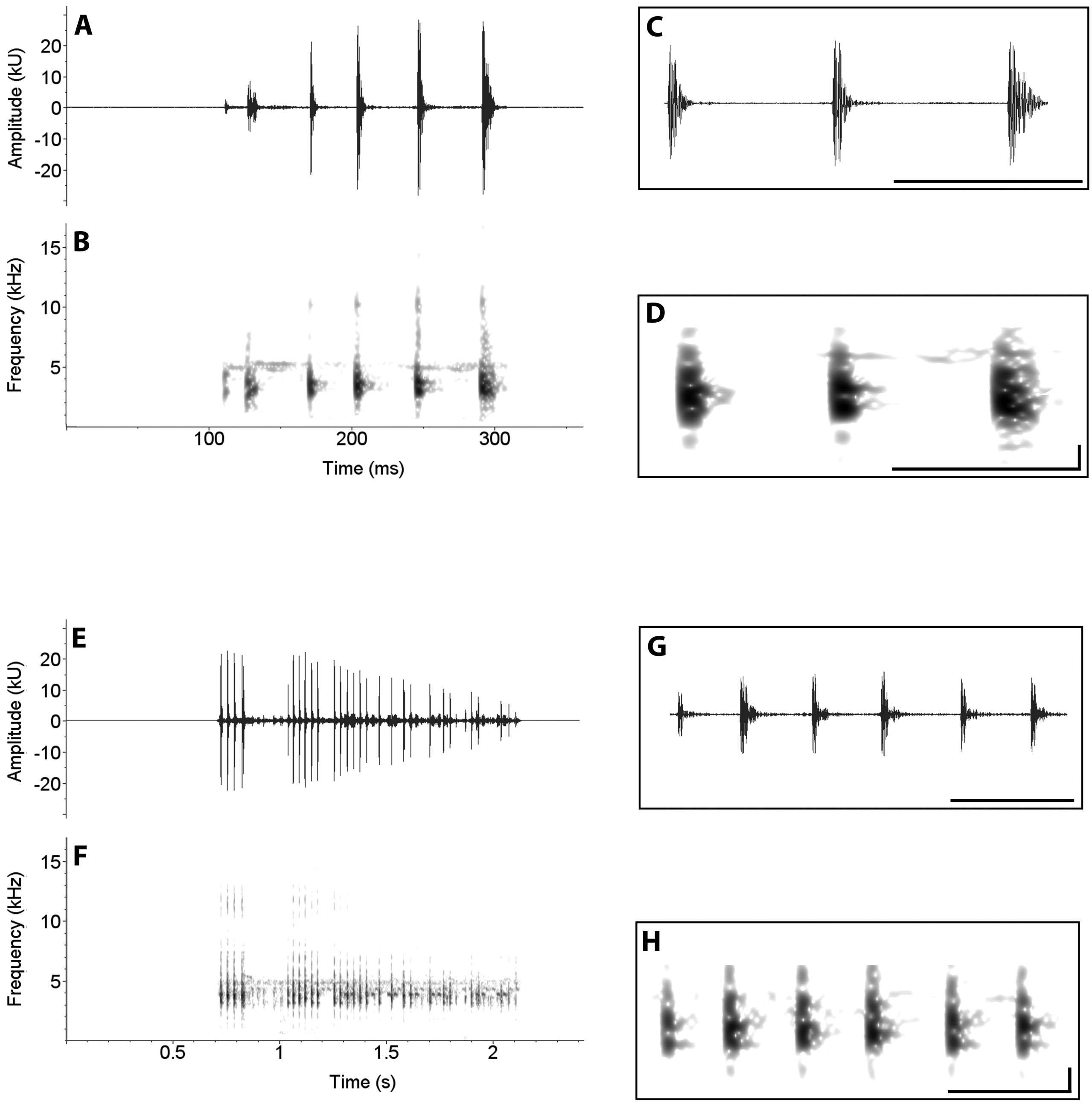

FIGURE 18. Calls A and B of *Physalaemus bokermanni*. Oscillograms (A, C, E, and G) and audiospectrograms (B, D, F, and H). A single typical call A (A and B). Last three pulses of call A (C–D). Single call B (E–F). Six pulses in detail from the middle of a call B (G–H). Horizontal scale bars have 0.1 s; vertical scale bars have 1 kHz. Filter bandwidth (Hz): 212 (H); 181 (D); 400 (B); 500 (F).

Call A (Fig. 18A–D and 13E). We examined eight recordings, a total of 12 minutes, with *ca*. 650 calls from nine males. Only some of these calls were measured (see Table 2). Call duration varies from 0.177 to 0.197 s. The call rise is linear or logarithmic-shaped and longer than the fall, which is usually abrupt and logarithmic-shaped; the amplitude peak is at around the end of the first three fourths of the call duration (Fig. 18A). The envelope of the call is elliptic or triangular (pointed left; Fig. 18A, C). More than 50 % of the energy is concentrated in 41 % of the call duration around the amplitude peak. This call has a strong PAM (with silence intervals present between pulses; Fig. 18A–D). The rate of the PAM is *ca.* 35 Hz, forming *ca.* six pulses throughout the call. The pulse rise is abrupt and much shorter than the fall; the amplitude peak is at the beginning of the pulse (Fig. 18C). The first one or two pulses have much lower amplitude than the others (Fig. 18A). Often, the second and the last pulses are the longest (Fig. 18A, B). Silence intervals are present between pulses, *ca.* fivefold longer than pulse duration. The first interval is usually much shorter than the others (Fig. 18A–D). The call has a harmonic series (Fig. 13E). The fundamental frequency is *ca.* 780 Hz and this band can be present with low energy or absent in the audiospectrograms. The short duration of the pulses makes the bands broad with narrow intervals (Fig. 18B, D). Some pulses can have not very clear harmonics, with considerably deterministic chaos due to the irregularity of the wave periods (Fig. 18B, D). There are jumps of the fundamental frequency between pulses in some calls. The dominant frequency varies from *ca*. 2840 to 3660 Hz (Fig. 18B). The dominant harmonic varies from the second to the 10th, but it is usually the fourth. There is no clear shift in the relative energy among the bands throughout the call. Most of the energy is concentrated between 2600 and 3900 Hz (*ca.* three harmonics). Usually, there is no clear general FM throughout the call, however, in some calls the first two pulses have their energy concentrated in lower frequency bands, making the general FM of the call upward (Fig. 18B).

Call B (Fig. 18E–H and 16C). We examined three recordings, a total of six minutes, with 35 calls from three males. Only some of these calls were measured (see Table 2). Call duration varies from 0.947 to 1.868 s and the call has two different notes. Duration of the second note is *ca.* 1.0 s. The amplitude, temporal and spectral traits of the first note resemble those of call A, although in call B the first note often has more abrupt rise and fall (Fig. 18E). Usually, there is a silence interval between the notes (Fig. 18E, F). However, in some calls, this interval is perceptible only as a decrease in amplitude. The rise of the second note is logarithmic-shaped and shorter than fall, which is gradual, almost linear; the amplitude peak of the note is at the end of the first tenth of the note duration (Fig. 18E). Due to the very short rise and the long and gradual fall, the envelope of the component B is triangular (pointed right; Fig. 18E). More than 50 % of the energy of the compound call is concentrated in *ca.* 34 % of the duration around the amplitude peak. Both notes have a strong PAM (there are silence intervals present between pulses; Fig. 18E–H). The rate of the PAM is similar to that of the call A, *ca.* 30 Hz, yielding 28 pulses throughout the call. The rate of the PAM is less regular in the second note than in the first one. The pulse rise is abrupt and much shorter than the fall; the amplitude peak is at the beginning of the pulse (Fig. 18G). Some pulses can be twofold longer than the others. At the beginning of the second note the ratio between the silence interpulse-interval and pulse duration is similar to that in component A. The interval becomes longer (pulse duration remains the same) towards the end of the call (*i.e.*, pulse-PAM rate decreases), mainly after the first fourth of the second-note duration (Fig. 18E, G). Spectral traits of the second note are similar to those of call A (Fig. 18F, H; see some quantitative differences in Table 2). There is no general FM in component B (Fig. 18F, H).

Physalaemus angrensis **Weber, Gonzaga & Carvalho-e-Silva, 2006**

We found two different calls, referred to as call A and B. Calls A and B are composed of harmonics and a single note each. Call A is composed of pulses whereas Call B has no PAM. Moreover, call B has a stronger general upward FM. Call B can have irregular FM segments and jumps of the fundamental frequency (*vs.* absent in call A).

Call A (Fig. 19A–H and 13F). We examined nine recordings, a total of 32 minutes, with *ca*. 800 calls from 19 males. Only some of these calls were measured (see Table 2). Call duration varies from 0.431 to 0.605 s. In most calls, the limits between the call rise, sustain, and fall are not clear (for example in calls with elliptic envelopes; see below; Fig. 19D). In calls where the limits are perceptible, the call rise and fall are similar in duration and shape, both have a logarithmic or linear shape, and there is a long sustain, which can have shallow valleys and short slopes (concave and convex shapes, respectively; Fig. 19A). The amplitude peak is at around the end of the first three fourths of the call duration. The envelope varies from elliptic (Fig. 19D) to rectangular (Fig. 19A) depending on how emphasized or regular is the sustain. More than 50 % of the energy is concentrated in 37 % of the call duration around the amplitude peak. This call has a strong PAM (there are silence intervals present between pulses; Fig. 19A, B, D, E, G, H). The rate of the PAM is *ca.* 58 Hz, yielding *ca.* 30 pulses throughout the call. Except for the last pulse, the pulse rise is longer than the fall and the amplitude peak is around two thirds of the pulse duration. The last pulse has the opposite envelope with amplitude peak at the beginning (Fig. 19E). The first pulses can have much lower amplitude than the others. The last pulse is the longest. There are short silence intervals between pulses, which can be absent between the first and last pulses (pulses are juxtaposed to neighboring pulses; Fig. 19A, B, D, E, G, H). Intervals are usually eightfold longer than the pulse durations. The call has a harmonic series (Fig. 13F). The fundamental frequency is at *ca.* 410 Hz and this band can be present with low energy or absent in the audiospectrograms. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency varies from *ca.* 1590 to 1780 Hz (Fig. 19B). The dominant harmonic varies from the third to the fifth, but it is usually the fourth. There is no clear shift in the relative energy among the bands throughout the call. Most of the energy is concentrated between 1200 and 1900 Hz (three harmonics). The call has a general upward FM (Fig. 19B, G). Additionally, there is PFM throughout the call, which is usually directly proportional to the synchronic pulse-PAM (Fig. 19E, H). Calls are usually emitted in short sequences with up to ten calls each (Fig. 19C, F).

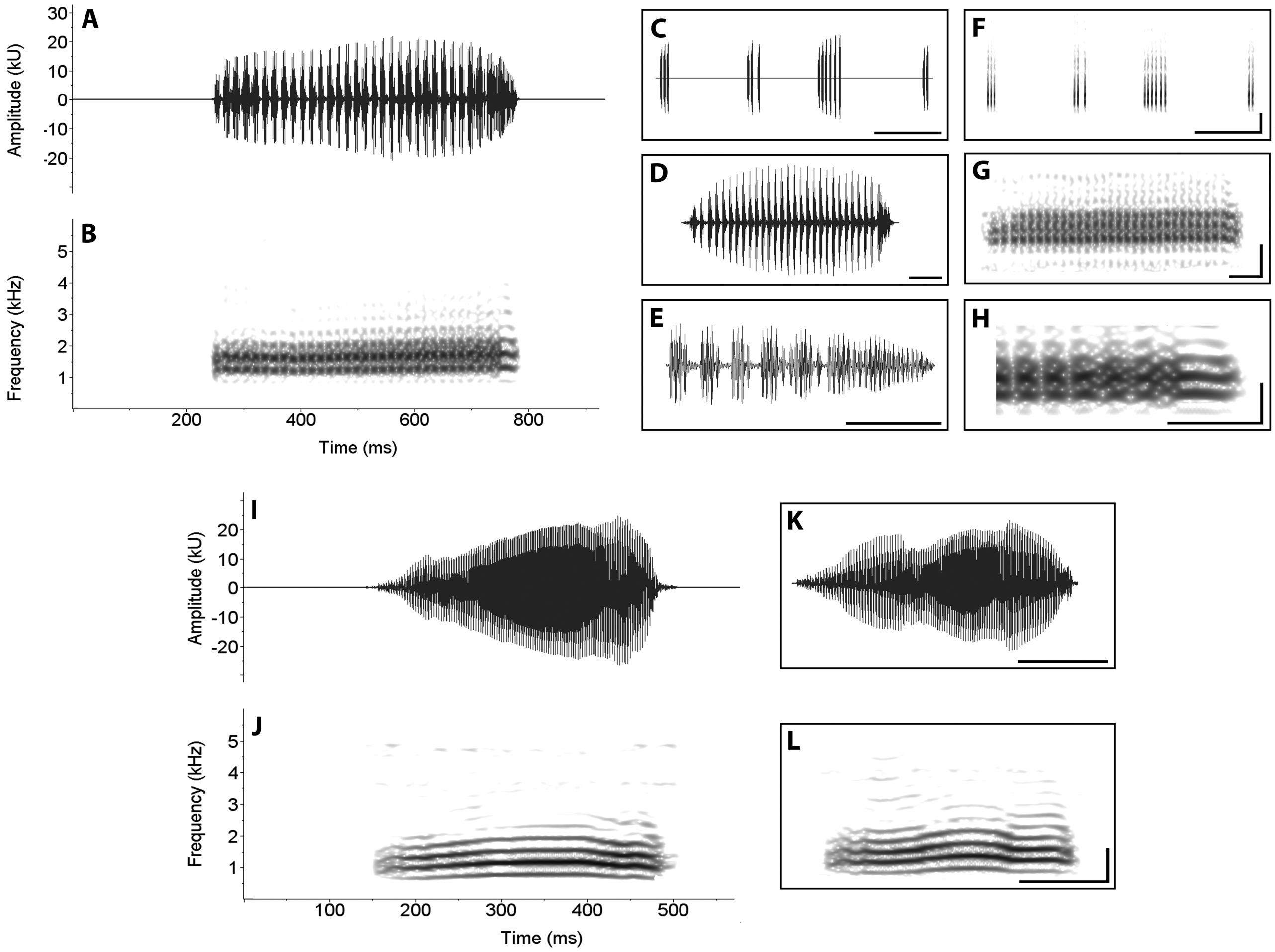

FIGURE 19. Calls A and B of *Physalaemus angrensis*. Oscillograms (A, C, D, E, I, and K) and audiospectrograms (B, F, G, H, J, and L). A single typical call A (A–B). Four groups of call A (C and F). A variant call A with a different envelope (D and G). Last six pulses of the call A (E and H). A single call B (I–J). A single call B with a different envelope (K–L). Horizontal scale bars have 0.1 s (D, H, K, and L), 20 s (C and F), and 0.05 s (E and H); vertical scale bars have 1 kHz. Filter bandwidth (Hz): FFT (points): 550 (H); 750 (B, F and G); 1024 (J and L).

Call B (Fig. 19I–L and 16D). We examined three recordings, a total of 18 minutes, with *ca.* 150 calls from five males. Only some of these calls were measured (see Table 2). Call duration varies from 0.309 to 0.353 s. The call rise and fall are similar in duration and shape (logarithmic-shaped). There is a sustain, which has shallow valleys, usually at its beginning and end (Fig. 19I, K). The amplitude peak of the call is at around the end of the first four fifths of the call duration (Fig. 19I, K). The envelope varies from elliptic to triangular (pointed left; Fig. 19I, K). More than 50 % of the energy is concentrated in 32 % of the call duration around the amplitude peak. This call has no PAM. The call has a harmonic series (Fig. 16D). The fundamental frequency is *ca.* 320 Hz and this band can be present with low energy or absent in the audiospectrograms. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency varies from *ca.* 1080 to 1310 Hz (Fig. 19J). The dominant harmonic varies from the second to the seventh harmonic, but it is usually the fourth. There is no clear shift in the relative energy among the bands throughout the call. Most of the energy is concentrated between 900 and 1400 Hz (two harmonics). The call has a general upward FM with short downward FM at the end (Fig. 19J, L). The sustain has an up-downward FM (Fig. 19J, L). There is clear PFM in some parts of the call. Additionally, several calls have parts with irregular up and downward FM, usually, inversely proportional to the AM directions (Fig. 19I–L).

Physalaemus atlanticus Haddad & Sazima, 2004

We found a single call type for the species, referred to as call A. The call has a single harmonic note with a sequence of pulses (pulse-PAM). Pulses of this call can have subharmonics.

Call A (Fig. 20A–F and 13G). We examined six recordings, a total of 15 minutes, with *ca*. 450 calls from ten males. Only some of these calls were measured (see Table 2). Call duration varies from 1.096 to 1.377 s. In most calls, the limits between the call rise, sustain, and fall are not clear (for example in calls with elliptic envelope; see below). When perceptible, the call rise and fall of the call are similar in duration and shape, both with a logarithmic or linear shape, and there is a long and regular sustain. The amplitude peak is at around the middle of the call duration (Fig. 20A). The envelope varies from elliptic (Fig. 20A) to rectangular (Fig. 20C), depending on how emphasized or regular is the sustain. More than 50 % of the energy is concentrated in 38 % of the call duration around the amplitude peak. This call has a strong PAM (with silence intervals present between pulses; Fig. 20A–F). The rate of the PAM is *ca.* 48 Hz, forming *ca.* 60 pulses throughout the call. The pulse rise is shorter than the fall and the amplitude peak is at their outset (Fig. 20D). In most calls, the last pulse is the longest (*ca.* four times the duration of the other pulses). Silence intervals are present between pulses, which is approximately as long as the pulses (Fig. 20D). The call has a harmonic series (Fig. 13G). The fundamental frequency is *ca.* 440 Hz and is generally absent in the audiospectrograms. The wave periods are regular and harmonics are clear throughout the call. However, the short duration of the pulses makes the bands broad with narrow intervals. Longer pulses have subharmonics (usually $f_0$1/2). The dominant frequency varies from *ca*. 950 to 1380 Hz (Fig. 20B). The dominant harmonics varies between the second and third, but it is usually the second. There is no clear shift in the relative energy among the bands throughout the call. Most of the energy is concentrated between 900 and 1500 Hz (two harmonics). Some calls have a slight upward general FM (Fig. 20B, E). Most calls have neither general FM nor other additional FM in the call.

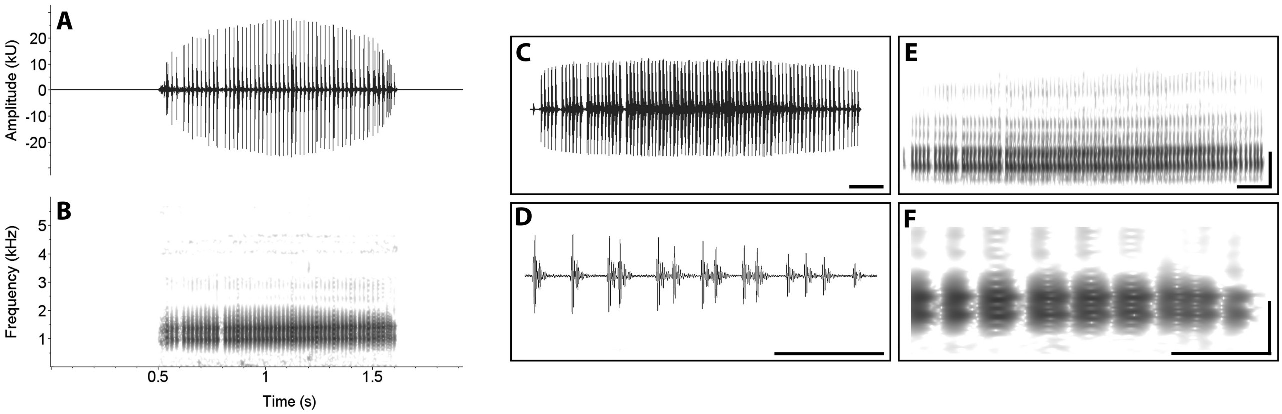

FIGURE 20. Call A of *Physalaemus atlanticus*. Oscillograms (A, C, and D) and audiospectrograms (B, E, and F). A single typical call with elliptic envelope (A and B). Variant call with different envelope and general FM (C and E). Last pulses of the call (D and F). Horizontal scale bars have 0.1 s; vertical scale bars have 1 kHz. FFT (points): 750 (F); 1024 (B and E).

Physalaemus moreirae (Miranda-Ribeiro, 1937)

We found two different calls, referred to as call A and B. Calls A and B are composed of a single harmonic note each. Call A is composed of pulses whereas Call B is not. Moreover, call B has irregular FM segments (*vs.* absent in call A).

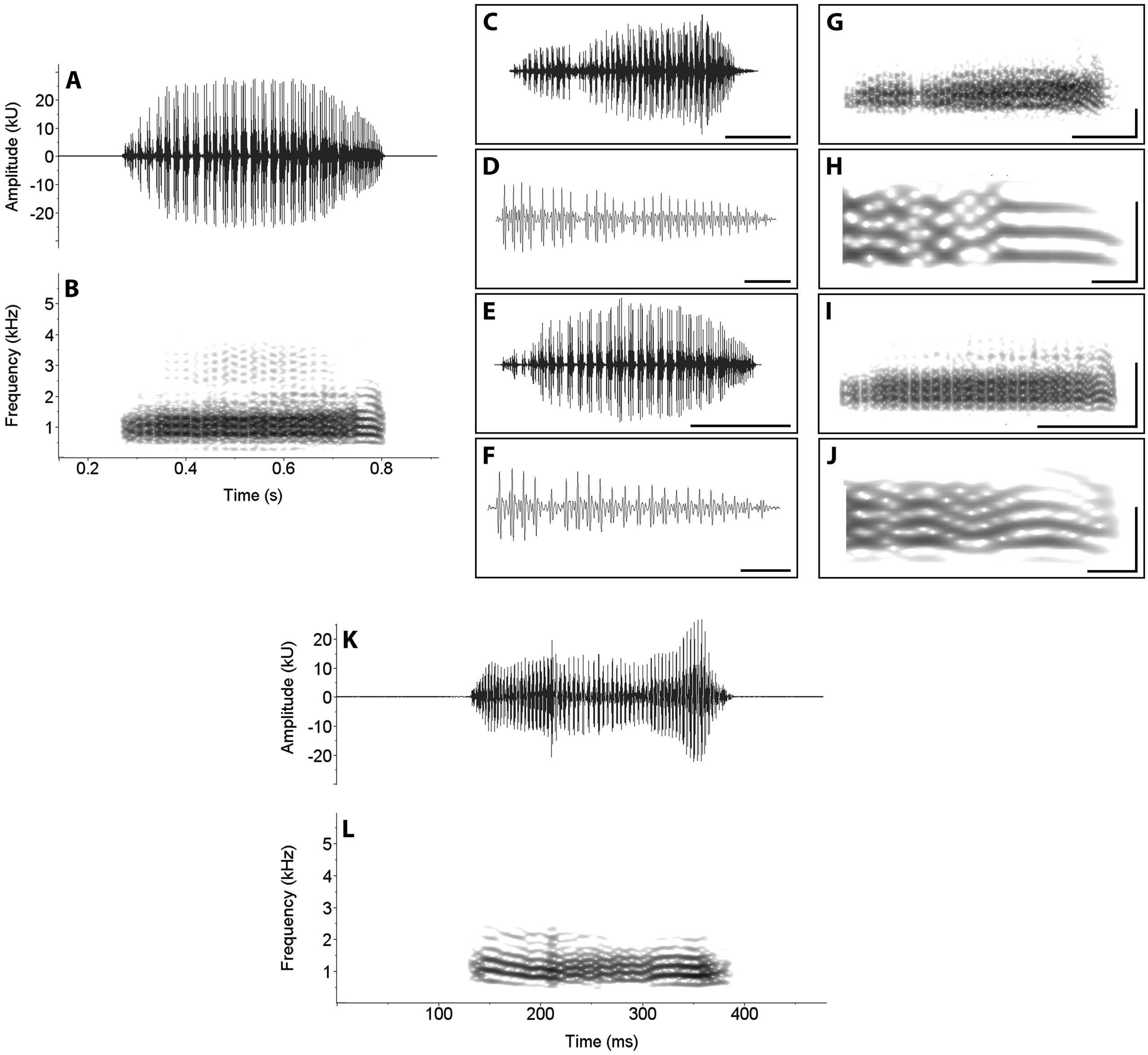

FIGURE 21. Calls A and B of *Physalaemus moreirae*. Oscillograms (A, C, D, E, F, and K) and audiospectrograms (B, G, H, I, J, and L). A single typical call A with elliptic envelope (A and B). Variant calls A with different envelopes (C, G, E, and I). Last pulses of the calls A (D, H, F, and J). Note the longer duration of the last pulse (D, H, F, and J). A single call B (K–L). Note that only the call B has clear FM segments and no pulses. Horizontal scale bars have 0.2 s (C, G, E, and I) and 0.02 s (D, H, F, and J); vertical scale bars have 1 kHz (G, I, and J) and 0.8 kHz (H). Filter bandwidth (Hz): 84.6 (B, H, I, J, and L); 61.9 (G).

Call A (Fig. 21A–J and 13H). We examined three recordings, a total of one minute, with 68 calls from five males. Only some of these calls were measured (see Table 2). Call duration varies from 0.499 to 0.567 s. In most calls, the limits between call rise, sustain, and fall are not clear (for example in calls with elliptic envelope; Fig. 21E). When perceptible, the call rise and fall are similar in duration and shape, both with a linear shape, and there is a long sustain. This segment can be regular and flat (Fig. 21A) or quite irregular with AM segments within it (Fig. 21C). The amplitude peak is usually at around the middle of the call duration. The envelope varies from elliptic (Fig. 21E) to triangular (pointed left; Fig. 21C). More than 50 % of the energy is concentrated in 35 % of the call duration around the amplitude peak. The call has a strong PAM (with silence intervals present between pulses; Fig 21A, C, E). The rate of the PAM is *ca.* 42 Hz, forming *ca.* 23 pulses throughout the call. Most pulses have an elliptic envelope with the amplitude peak around the middle of the pulse. The very first pulses have rise longer than fall, amplitude peak at the end of pulse and the very last pulses have the opposite shape (amplitude peak at the beginning of the pulse; Fig. 21D, F). The last pulse is the longest (Fig. 21A–J). Short silence intervals are present between the pulses, but can be absent between the first and last pulses (pulses are juxtaposed to neighboring pulses; Fig. 21A, C, D, E, F). The call has a harmonic series (Fig. 13H). The fundamental frequency is *ca.* 230 Hz and this band can be present with low energy or absent in the audiospectrograms. Usually, the wave periods are regular and harmonics are clear throughout the call. However, the short duration of the pulses (except the last) make the bands broad with narrow intervals. Where two pulses are juxtaposed, the wave periods are less regular, and the harmonics are less clear with deterministic chaos (Fig. 21B, G, H, I, J). The dominant frequency varies from *ca*. 770 to 1250 Hz (Fig. 21B). The dominant harmonic varies from the third to the eighth, but it is usually the third or fourth. There is no clear shift in the relative energy among the bands throughout the call. Most of the energy is concentrated between 700 and 1300 Hz (three harmonics). A few calls have a slight upward general FM (Fig. 21H, I). Usually, there is no clear general FM (Fig. 21B). Calls have a short downward FM at the end (Fig. 21H, J) and PFM throughout the call without clear relationship with the synchronic pulse-PAM (Fig. 21E, F, I, J).

Call B (Fig. 21K–L and 16E). We examined one recording, a total of one minute, with one call from one male. This call was also measured (see Table 2). A single call was recorded. Call duration is 0.254 s. The call rise and fall are similar in duration and shape (exponential-shaped). There is a long sustain, which is regular until the amplitude peak at the end of the call, around nine tenths of the call duration. The envelope is triangular (pointed left; Fig. 21K). More than 50 % of the energy is concentrated in 54 % of the call duration around the amplitude peak. This call has no PAM. The call has a harmonic series (Fig. 16E). The fundamental frequency is at *ca.* 280 Hz and this band is generally absent in the audiospectrogram. The wave periods are regular and harmonics are clear throughout the call. However, the wave periods are less regular at the middle of the call, with biphonation regime (Fig. 21L). The dominant frequency is *ca.* 860 Hz (Fig. 21L). The dominant harmonic varies from the second to the fifth, but it is usually the third or fourth. There is no clear shift in the relative energy among the bands throughout the call. Most of the energy is concentrated between 800 and 1400 Hz (often, three harmonics). The long downward FM segment at the beginning makes the general FM of the call downward. There is a slight PFM throughout the call. Additionally, the call has parts with irregular up and downward FM (Fig. 21L).

Physalaemus cuvieri clade

Species of this clade typically have one call type (but see *P. cuvieri* in Table 1). Whine-like calls are characteristic emissions in this clade (except in the *P. henselii* group and *P. cicada*). The major aspects of these calls are clear harmonics, high fundamental frequency (> 400 Hz; except *P. olfersii* group and *P. centralis*), high energy in the lower harmonics (except in *P. olfersii* group), downward direction of the general FM (except in the *P. olfersii* group), and an up-downward FM at the beginning of the call, yielding arc-shaped bands in this part of the call and S-shaped bands when considering the entire call (except in *P. henselii* and *P. olfersii* groups). Nonlinear regimes are relatively rare in the clade (present in *P. barrioi*, *P. cuvieri*, *P. ephippifer*, *P. gracilis*, *P. lisei*, and *P. soaresi*).

Physalaemus henselii species group

Only one call type was recorded for this group. Calls with high frequency bands (> 1800 Hz). *Physalaemus fernandezae* is the only species with a single frequency band. *Physalaemus henselli* has two independent band-series, one harmonic series and another composed of sidebands.

Physalaemus fernandezae (Müller, 1926)

We found a single call type for the species, referred to as call A. The call is composed of a single note with a strong PAM without silence interval between the cycles. There is a single frequency band with clear upward FM.

Call A (Fig. 22A–B). We examined two recordings, a total of three minutes, with *ca*. 400 calls from 10 males. Only some of these calls were measured (see Table 2). Call duration varies from 0.339 to 0.969 s. Usually, the limit between the call rise and sustain is not clear. Apparently, the rise is restricted to the very beginning of the call. Most of the segment with amplitude increase was classified as the sustain of the call. Therefore, the call rise and fall are similar in duration and shape (linear or logarithmic). The sustain is long and with an exponential increasing pattern

(Fig. 22A). The amplitude peak is at the very end of the call duration (Fig. 22A). The envelope of the call is triangular (pointed left; Fig. 22A). More than 50 % of the energy is concentrated in 29 % of the call duration around the amplitude peak. The call has a slight PAM (with no silence intervals present between amplitude peaks; Fig. 22A) with rate of *ca.* 31 Hz, yielding *ca.* 21 cycles throughout the call. The cycle rise is similar to the fall, with amplitude peak at the middle of the cycle. A single frequency band is present around 3000 Hz (Fig. 22B). The wave periods are regular and the band is narrow and clear throughout the call. The dominant frequency varies from *ca*. 2880 to 3230 Hz (Fig. 22B). Most of the energy is concentrated between 2700 and 3200 Hz. The call has upward FM (Fig. 22B). Additionally, there is a slight PFM, which is directly proportional to the synchronic PAM (Fig. 22A–B).

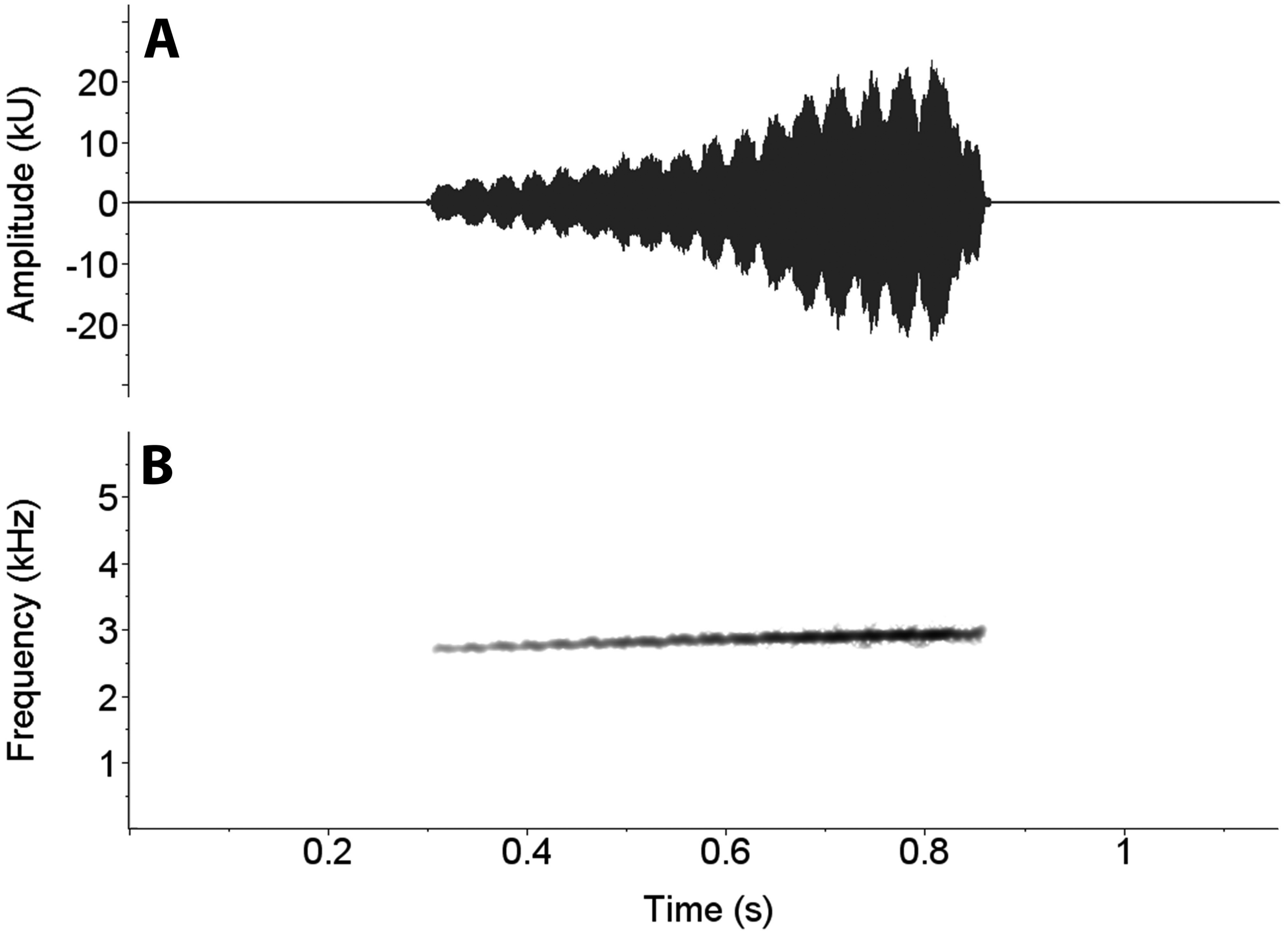

FIGURE 22. Call A of *Physalaemus fernandezae*. Oscillograms (A) and audiospectrograms (B). A single typical call (A and B). Filter bandwidth (Hz): 84.6 (B).

Physalaemus henselii (Peters, 1872)

We found a single call type for the species, referred to as call A. The call is composed of a sequence of pulses (*i.e.*, pulse-PAM). The call is spectrally polymorphic; some calls have pulses with sidebands.

Call A (Fig. 23A–F **and 24A).** We examined two recordings, a total of four minutes, with *ca*. 200 calls from six males. Only some of these calls were measured (see Table 2). Call duration varies from 0.289 to 0.493 s. The call rise is usually very abrupt and shorter than the call fall (Fig. 23C), which has an exponential shape. The call rises are longer and more similar to falls. The sustain varies from flat to very steep in shape. The envelope of the call is elliptic, rectangular (Fig. 23C), or triangular (pointed left; Fig. 23A). More than 50 % of the energy is concentrated in 53 % of the call duration around the amplitude peak. The call has a strong PAM (with silence intervals present between pulses; Fig. 23A–F). The rate of the PAM is *ca.* 54 Hz, forming *ca.* 20 pulses throughout the call. The envelope of the pulses is variable; however, the pulse rise is usually shorter than the fall, with amplitude peak at the beginning of the pulse. Silence intervals are present between pulses, with durations slightly longer than pulse duration except between the first pulses, where the intervals are very short or even absent (pulses are juxtaposed; Fig. 23A, C, D).

The call has a harmonic series (Fig. 24A). The fundamental frequency is at *ca.* 1900 Hz and this band is also the dominant frequency (see below). The wave periods are regular and harmonics are clear throughout the call. The call shows an additional frequency series with bands separated by *ca.* 250 Hz series produced by a PAM present within pulses (Fig. 23E, F). This series is very variable (30 to 550 Hz) and it is not multiple of the harmonic series. Both seem to be independent of each other. Therefore, we called the 250-Hz bands as sidebands. The short duration of the pulses makes the bands broad with narrow intervals. In parts where two pulses are juxtaposed, or at least very close to each other, the wave periods are less regular, the harmonics can be less clear with deterministic chaos (Fig. 23E). The dominant frequency varies from *ca.* 1690 to 2160 Hz (Fig. 23B). The first harmonic is the dominant. There is no clear shift in the relative energy among the bands throughout the call. Most of the energy is concentrated between 650 and 2600 Hz (one harmonic). Most of the call energy is between 1400 and 2400 Hz. There is usually neither a clear general FM nor other shorter FM segment in the call. Some calls, mainly those with juxtaposed pulses, show a slight PFM following the PAM (see beginning of the call in Fig. 23E).

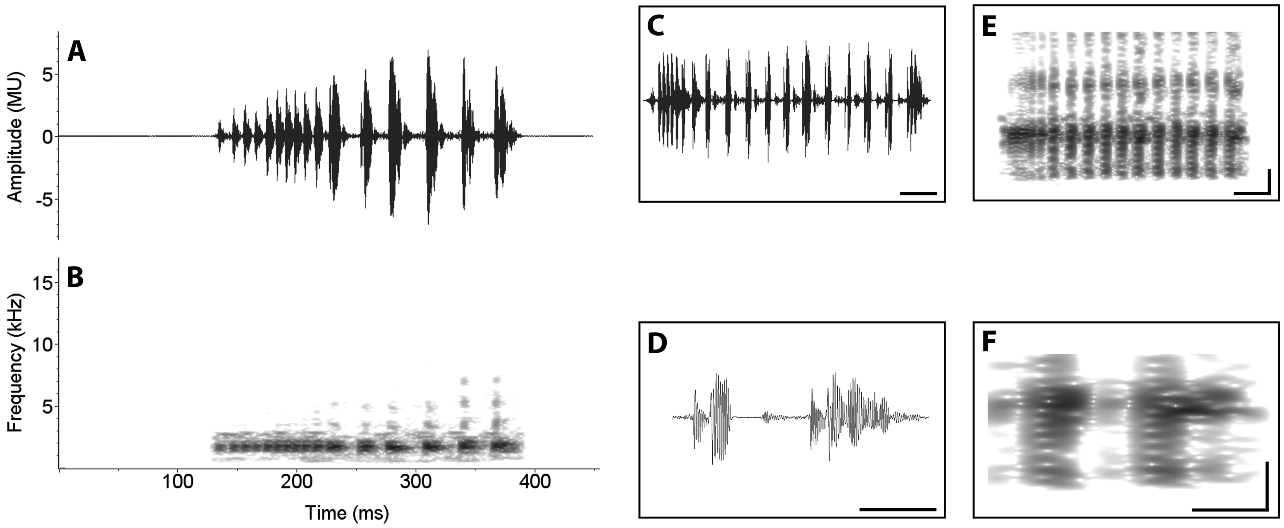

FIGURE 23. Call A of *Physalaemus henselii*. Oscillograms (A, C, and D) and audiospectrograms (B, E, and F). A single typical call (A–B). A variant call with a different envelope (C and E). Last pulses of a call (D and F). Horizontal scale bars have 0.1 s (C and E) and 0.02 s (D and F); vertical scale bars have 1 kHz. Filter bandwidth (Hz): 135 (B); 92.1 (F); 69 (E).

Physalaemus cuvieri **species group**

Only one call type was recorded for this group (but see *P. cuvieri* in Table 1). All species have calls similar, to the human ear, to nasal-like whines with downward FM. Calls have a general downward FM and a subtle up-downward FM at the beginning of the call, yielding arc-shaped bands in this part of the call and S-shaped bands when considering the entire call duration (*e.g.*, *P. erikae* and *P. kroyeri*; this modulation is short and subtle in some species such as *P. albonotatus*, *P. cuqui*, and *P. atim*). A few species (*P. albonotatus*, *P. atim*, *P. cuqui*, and *P. ephippifer*) have weak to intermediate PAM, *i.e.*, silence intervals are absent between pulses. This PAM leads to amplitude cycles throughout the call. Subharmonics are always present in calls of two species in this clade (*P. cuvieri* and *P. ephippifer*).

Physalaemus albonotatus **(Steindachner, 1864)**

We found a single call type for the species, referred to as call A. The call has a single harmonic note with a slight PAM without silence intervals. It has a gradual downward FM throughout the call.

Call A (Fig. 25A–H and 24B). We examined 14 recordings, a total of 24 minutes, with *ca.* 330 calls from 26 males. Only some of these calls were measured (see Table 2). Call duration varies from 1.333 to 1.429 s. In most calls the limits between the call rise, sustain, and call fall are not clear (for example, see elliptic envelope in Fig 25A). In calls where they are perceptible, the call rise and fall can be similar in duration with variable shape (linear, exponential, or logarithmic) or call fall is shorter than the rise. In some calls, there is a long regular sustain (Fig. 25E). The amplitude peak of the calls measured is at around the end of the first three fourths of the call duration. The envelope varies from elliptic (Fig. 25A, C, D) to rectangular (Fig. 25E). More than 50 % of the call energy is

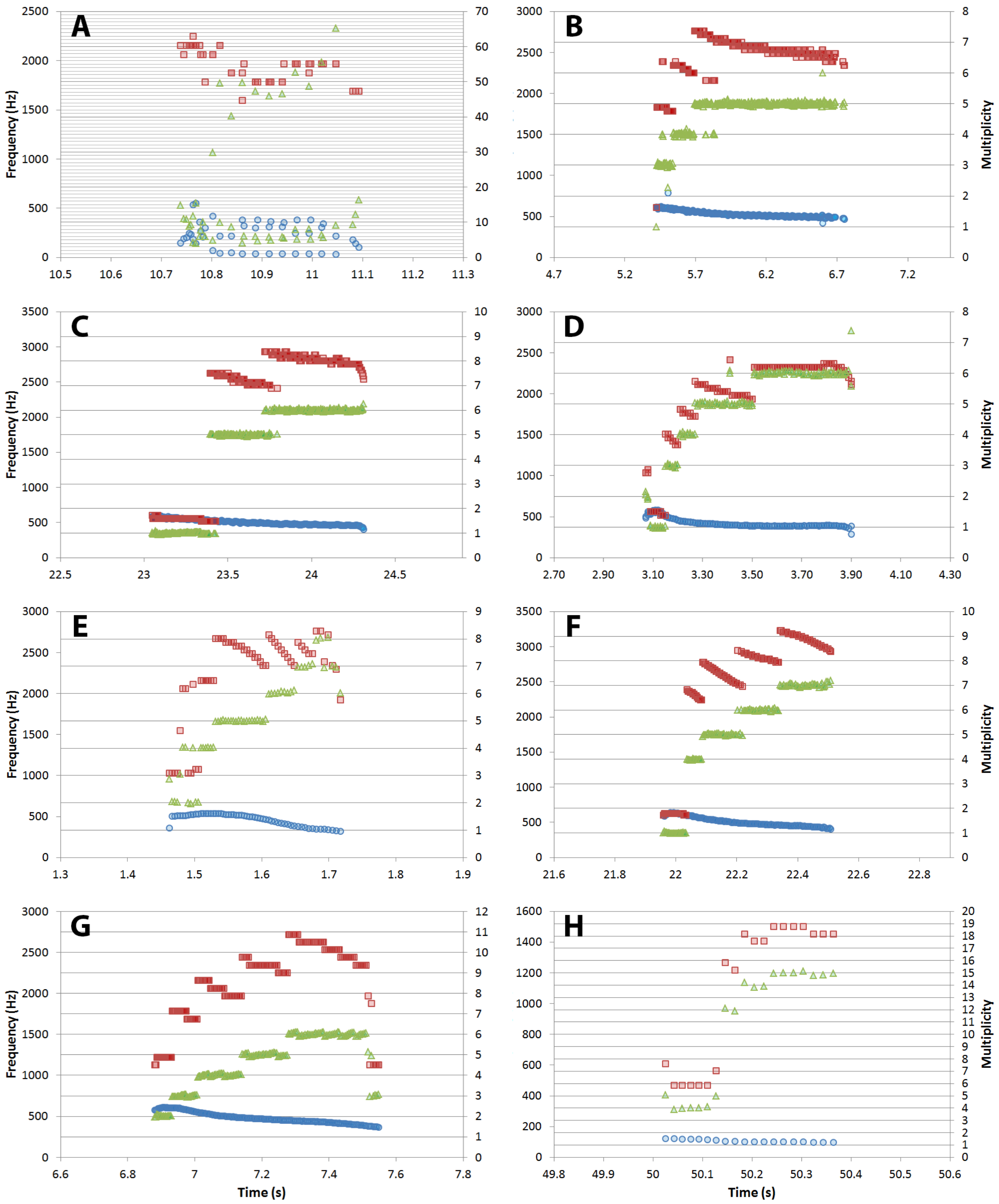

FIGURE 24. Multiplicity relationship between "instantaneous" dominant frequency and *w* of calls A of eight *Physalaemus* species. Each graph shows a single call A of *P. henselii* (A), *P. albonotatus* (B), *P. cuqui* (C), *P. atim* (D), *P. albifrons* (E), *P. erikae* (F), *P. kroyeri* (G), *P. centralis* (H). Grid corresponds to the harmonic values (right y-axis). Red squares are the values of "instantaneous" dominant frequency; blue circles are the values of the reciprocal of *w*; green triangles are the factor values of the ratio "instantaneous" dominant frequency / *w* reciprocal per delta time. Delta time corresponds to the duration of one period of the measured acoustic oscillation. Note that factors around integer values suggest harmonic relationship between the frequency calculated (*w* reciprocal) and the dominant frequency. The heterogeneity of the factors in *P. henselii* (A) suggests sidebands.

concentrated in 42 % of the call duration around the amplitude peak. The call has a slight PAM (there is no silence interval between amplitude peaks; Fig. 25A, C, D, E). The rate of the PAM is *ca.* 25 Hz, forming *ca.* 35 cycles throughout the call. The cycle rise and fall are similar, with amplitude peak at the middle of the cycle. The call has a harmonic series (Fig. 24B). The fundamental frequency is *ca.* 530 Hz and approximately the first six harmonics are emphasized. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency varies from *ca.* 1590 to 2440 Hz (Fig. 25B). The dominant harmonic varies from the first to the sixth, but it is usually the fifth. There is a clear shift in relative energy among the bands; the dominant frequency gets higher toward the end of the call, starting at first harmonic and ending in the fifth or sixth one (Fig. 25B, F, G, H). Most of the call energy is between 450 and 2950 Hz (five to six harmonics). The call has a general downward FM. Additionally the calls have a subtle up-downward FM at the beginning, yielding arc-shaped bands in this part of the call (Fig. 25F, G, H), and a short downward FM at the end (Fig. 25B, F, G, H). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call. The call also has a PFM, which is inversely proportional and synchronic to the PAM (Fig. 25A, B, C, E, F, H). In a few calls, the rate of the PAM is very low and so is the number of cycles (Fig. 25D, G). In those calls, the PFM is equally slow and weak (Fig. 25D, G).

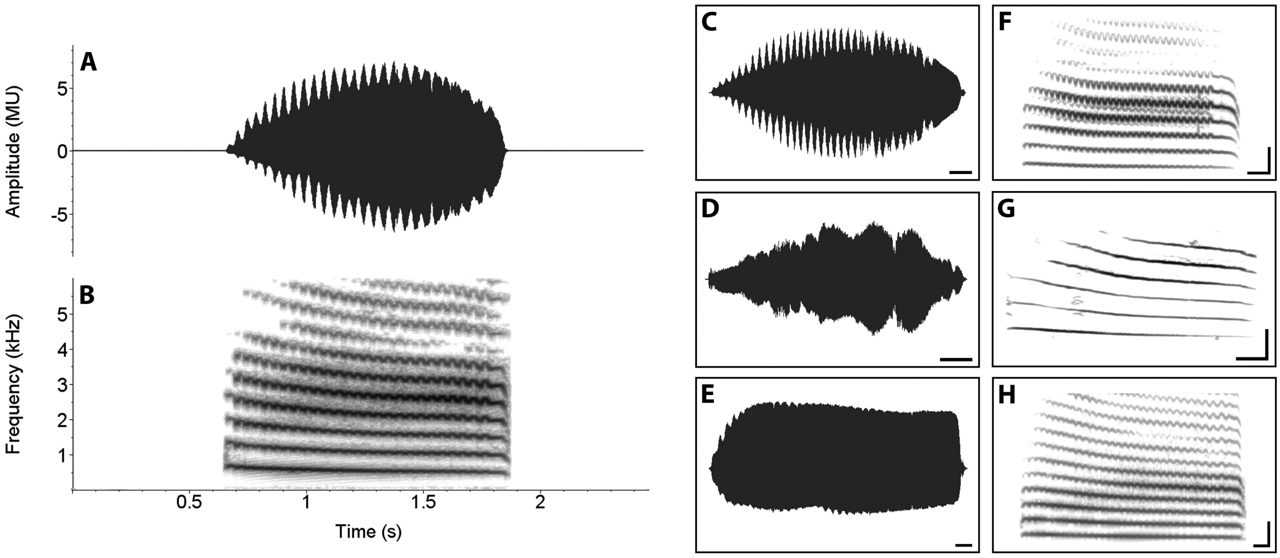

FIGURE 25. Call A of *Physalaemus albonotatus*. Oscillograms (A, C, D, and E) and audiospectrograms (B, F, G, and H). A single typical call with elliptic envelope (A and B). Variant calls with different envelopes (C–H). Note the calls with clear PAM and PFM (A–C, E–F, and H) and that with irregular PAM and slight PFM (D and G). Horizontal scale bars have 0.1 s; vertical scale bars have 1 kHz. FFT (points): 3000 (B and G); 2500 (F); 2000 (H).

Physalaemus cuqui Lobo, 1993

We found a single call type for the species, referred to as call A. The call has a single harmonic note with a slight PAM without silence intervals. It has a gradual downward FM throughout the call.

Call A (Fig. 26A–B and 24C). We examined two recordings, a total of two minutes, with 47 calls from six males. Only some of these calls were measured (see Table 2). Call duration varies from 1.215 to 1.500 s. The limits between the call rise, sustain, and call fall are not clear (see elliptic envelope in Fig. 26A); the envelope is linear- or exponential-shaped until the amplitude peak and logarithmic-shaped from the peak to the end of the call (Fig. 26A). The amplitude peak is at around the end of the first two thirds of the call duration. The envelope is elliptic (Fig. 26A). More than 50 % of the call energy is concentrated in 26 % of the call duration around the amplitude peak. The call has a slight PAM (there is no silence interval between amplitude peaks; Fig. 26A). The rate of the PAM is *ca.* 21 Hz, yielding *ca.* 29 cycles throughout the call. The cycle rise and fall are similar, with amplitude peak at the middle of the cycle. The call has a harmonic series (Fig. 24C). The fundamental frequency is *ca.* 510 Hz and approximately the first seven harmonics are emphasized. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency is *ca.* 2850 Hz (Fig. 26B). The dominant harmonic varies from the first to the sixth, but it is usually the sixth. There is a clear shift in relative energy among the bands; the dominant frequency gets higher toward the end of the call, starting at first harmonic and ending in the sixth one (Fig. 26B). Most of the call energy is between 500 and 3000 Hz (five to six harmonics). The call has a general downward FM. Additionally the calls have a subtle up-downward FM at the beginning, yielding a arc-shaped bands in this part of the call in audiospectrograms, and a short downward FM at the end (Fig. 26B). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call (Fig. 26B). The call also has a PFM, which is inversely proportional and synchronic to the PAM (26A–B).

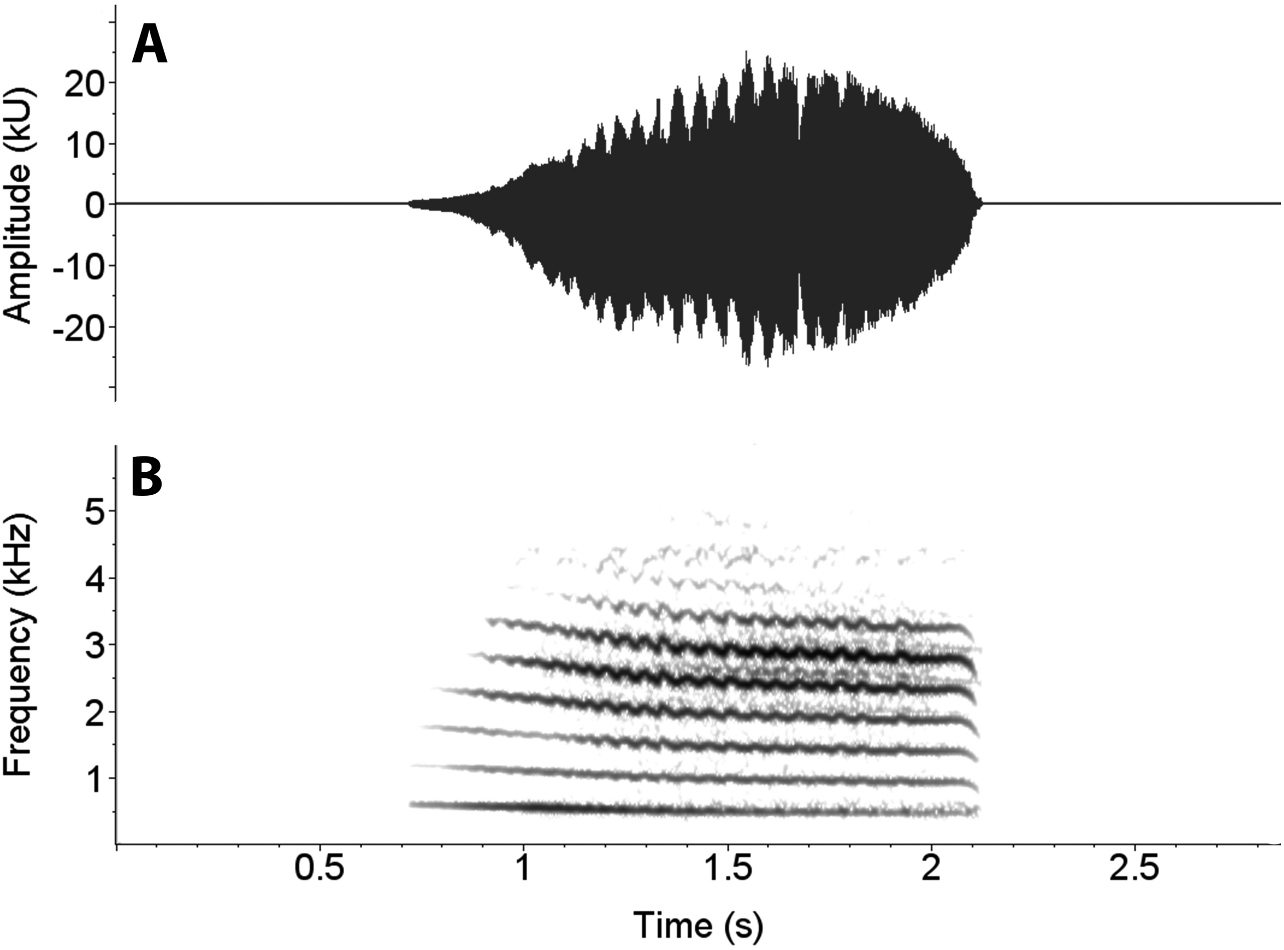

FIGURE 26. Call A of *Physalaemus cuqui*. Oscillogram (A) and audiospectrogram (B). A single call (A and B). Filter bandwidth (Hz): 61.9 (B).

Physalaemus atim Brasileiro & Haddad, 2015

We found a single call type for the species, referred to as call A. The call has a single harmonic note with a gradual downward FM throughout the call.

Call A (Fig. 27A–D and 24D). We examined one recording, a total of 11 seconds, with 11 calls from four males. Most of these calls were measured (see Table 2). Call duration varies from 0.779 to 0.995 s. The limits between the call rise, sustain and call fall are not clear (Fig. 27A). In calls where they are perceptible, the call rise and fall can be similar in duration with variable shape (linear, exponential, or logarithmic) or fall is shorter than rise. The sustain is irregular with short amplitude valleys (Fig. 27A). The amplitude peak is at around the end of the first three fifths of the call duration. The envelope is elliptic (Fig. 27A), rectangular (Fig. 27C) or triangular (pointed left). More than 50 % of the call energy is concentrated in 33 % of the call duration around the amplitude peak. The call has an irregular slight PAM (there is no silence interval between amplitude peaks). The rate of the PAM is *ca.* 45 Hz, forming *ca.* 24 peaks throughout the call. The cycle rise and fall are similar, with amplitude peak at the middle of the cycle. The call has a harmonic series (Fig. 24D). The fundamental frequency is *ca.* 430 Hz and approximately the first eight harmonics are emphasized. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency varies from *ca*. 1980 to 2330 Hz (Fig. 27B). The dominant harmonic varies from the first to the seventh, but it is usually the sixth. There is a clear shift in relative energy among the bands; the dominant frequency gets higher toward the end of the call, starting at the first harmonic and ending at the sixth (Fig. 27D). Most of the call energy is between 700 and 2700 Hz (five to six harmonics). The call has a general downward FM (Fig. 27B, D). Additionally, the calls have a subtle up-downward FM at the beginning, yielding arc-shaped bands in this part of the call (Fig. 27D), and a short downward FM at the end (Fig. 27B, D). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call. There is no clear PFM.

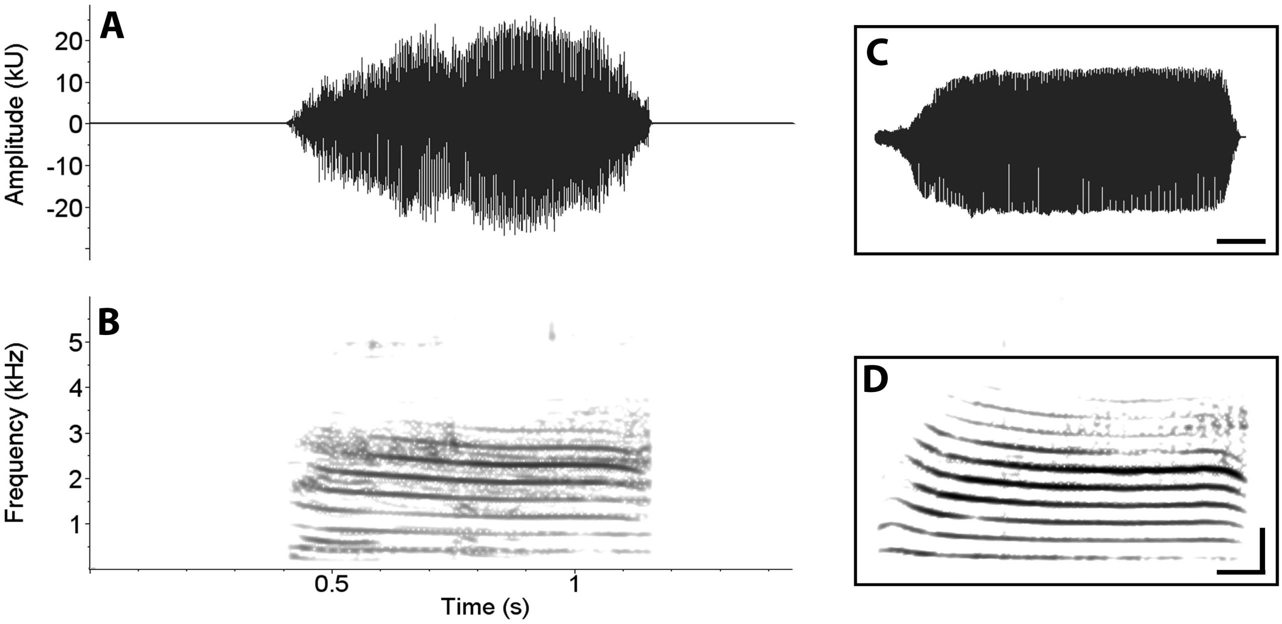

FIGURE 27. Call A of *Physalaemus atim*. Oscillograms (A and C) and audiospectrograms (B and D). A single typical call with elliptic envelope (A and B). A variant call with a different envelope (C and D). Horizontal scale bars have 0.1 s; vertical scale bar has 1 kHz. FFT (points): 1024 (B and D).

Physalaemus albifrons (Spix, 1824)

We found a single call type for the species, referred to as call A. The call is composed of a short single harmonic note with an elliptic envelope. It has a general downward FM throughout the call but with an up-downward FM segment in the first three fourths of the call duration.

Call A (Fig. 28A–F and 24E). We examined two recordings, a total of two minutes, with *ca*. 90 calls from two males. Only some of these calls were measured (see Table 2). Call duration varies from 0.263 to 0.297 s. The call rise and fall durations are similar to each other in duration and shape (linear to exponential). There is a sustain, usually with a concave shape, yielding two amplitude peaks around the middle of the call (Fig. 28A). The amplitude peak is at around the middle of the call duration. The envelope is elliptic (Fig. 28A, C). More than 50 % of the call energy is concentrated in 24 % of the call duration around the amplitude peak. There is no PAM in the call. The call has a harmonic series (Fig. 24E). The fundamental frequency is *ca.* 480 Hz and approximately the first seven harmonics are emphasized. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency varies from *ca*. 2440 to 2670 Hz (Fig. 28B). The dominant harmonic varies from the second to the ninth, but it is usually the fifth. There is a clear shift in the relative energy among the bands; the dominant frequency gets higher toward the end of the call, starting at the second harmonic and ending at the eighth or ninth (Fig. 28B, E, F; 24E). Thenceforth, it gets lower, ending in the seventh or sixth harmonic (Fig. 28B, E, F; 24E). Most of the call energy is between 1100 and 3700 Hz (six to nine harmonics). The call has a general downward FM (Fig. 28B, E, F). Additionally, the calls have an up-downward FM in the first three fourths of the call duration, yielding arc-shaped bands in this part of the call and a short downward FM at the end (Fig. 28B, E, F). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call. There is no PFM.

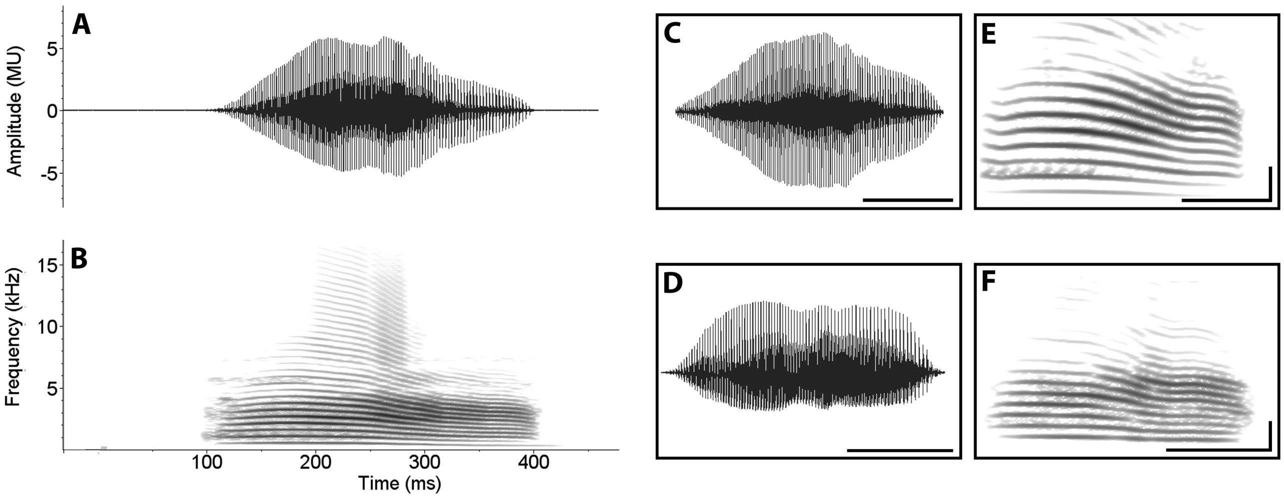

FIGURE 28. Call A of *Physalaemus albifrons*. Oscillograms (A, C, and D) and audiospectrograms (B, E, and F). A single typical call with elliptic envelope (A–B). Variant calls with different envelopes and levels of FM (C–F). Horizontal scale bars have 0.1 s; vertical scale bars have 1 kHz. Filter bandwidth (Hz): 92.1 (B); 81.2 (E); 78.9 (F).

Physalaemus erikae Cruz & Pimenta, 2004

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note. It has a general downward FM throughout the call but with an up-downward FM segment in the first sixth of the call duration.

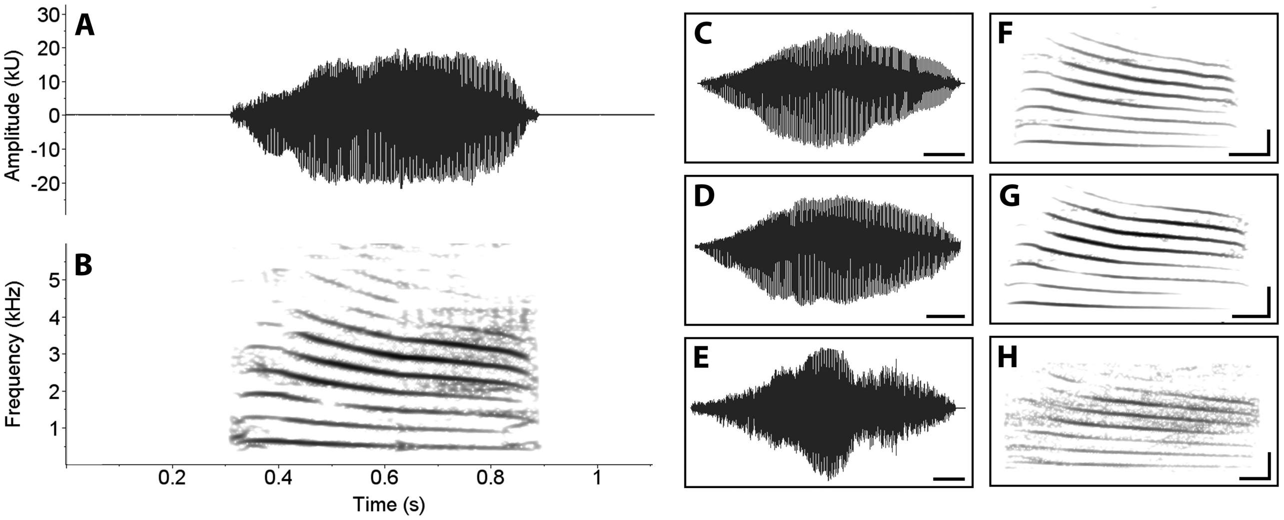

FIGURE 29. Call A of *Physalaemus erikae*. Oscillograms (A, C, D, and E) and audiospectrograms (B, F, G, and H). A single typical call (A and B). Variant calls A with differences in their envelopes (C–H). Horizontal scale bars have 0.1 s; vertical scale bars have 1 kHz. Filter bandwidth (Hz): 61.9 (B, F, and G); 67.4 (H).

Call A (Fig. 29A–H and 24F). We examined two recordings, a total of four minutes, with 37 calls from four males. Only some of these calls were measured (see Table 2). Call duration varies from 0.478 to 0.566 s. The limits between the call rise, sustain, and call fall are not clear (mainly in calls with elliptic envelope, see Fig. 29C, D). When perceptible, the call rise and fall can be similar in duration, or fall shorter than rise. Usually, call rise has an exponential shape, whereas call fall has a logarithmic shape. When present, the sustain is irregular, usually with short and very shallow amplitude valleys (Fig. 29A, E). The amplitude peak is at around the middle of the call duration. The envelope of the call varies from elliptic (Fig. 29C, D, E) to slightly rectangular (when flat sustains are present; Fig. 29A). More than 50 % of the call energy is concentrated in 30 % of the call duration around the amplitude peak. There is no PAM in the call. The call has a harmonic series (Fig. 24F). The fundamental frequency is *ca.*

420 Hz and approximately the first eight harmonics are emphasized. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency varies from *ca*. 2840 to 2890 Hz (Fig. 29B). The dominant harmonic varies from the first to the seventh. There is a clear shift in the relative energy among bands; the dominant frequency gets higher toward the end of the call, starting at the first harmonic and ending at the seventh (Fig. 24F, 29B, F, G, H). Most of the call energy is between 650 and 3450 Hz (five to six harmonics). The call has a general downward FM (Fig. 29B, F, G, H). Additionally, the calls have an up-downward FM in the first sixth of the call duration, yielding arc-shaped bands in this part of the call, and a short downward FM at the end (Fig. 29B, F, G, H). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call. There is no PFM.

Physalaemus kroyeri (Reinhardt & Lütken, 1862)

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note with a general downward FM throughout the call and an up-downward FM segment in the first fifth of the call duration.

Call A (Fig. 30A–F and 24G). We examined four recordings, a total of six minutes, with *ca*. 190 calls from eight males. Only some of these calls were measured (see Table 2). Call duration varies from 0.673 to 0.759 s. In some calls the limits between the call rise, sustain and call fall is not very clear (mainly in calls with elliptic envelope, Fig. 30A). The call rise and fall are similar in duration. Usually, the call rise has a short logarithmic-shaped section followed by an exponential shape, whereas call fall has an exponential shape only. The sustain is irregular, usually with short or long shallow valleys (Fig. 30D). The amplitude peak is usually before the middle of the call duration. The envelope varies from elliptic (Fig. 30A, C) to almost rectangular (when flat sustains are present; Fig. 30D). More than 50 % of the call energy is concentrated in 34 % of the call duration around the amplitude peak. There is no PAM in the call. The call has a harmonic series (Fig. 24G). The fundamental frequency is *ca.* 480 Hz and approximately the first seven harmonics are emphasized. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency varies from *ca*. 2060 to 2160 Hz (Fig. 30B). The dominant harmonic varies from the second to the sixth (Fig. 24G, 30E, F). There is a clear shift in the relative energy between the bands; the dominant frequency gets higher until three fourths of the call duration, starting at the second harmonic and ending at the sixth; thenceforth, it gets lower, ending at the third harmonic (Fig. 24G, 30E, F). Most of the call energy is between 450 and 2700 Hz (four to seven harmonics). The call has a general downward FM (Fig. 30B, E, F). Additionally, the calls have an up-downward FM in the first fifth of the call duration, yielding arc-shaped bands in this part of the call, and a short downward FM at the end (Fig. 30B, E, F). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call. There is no PFM.

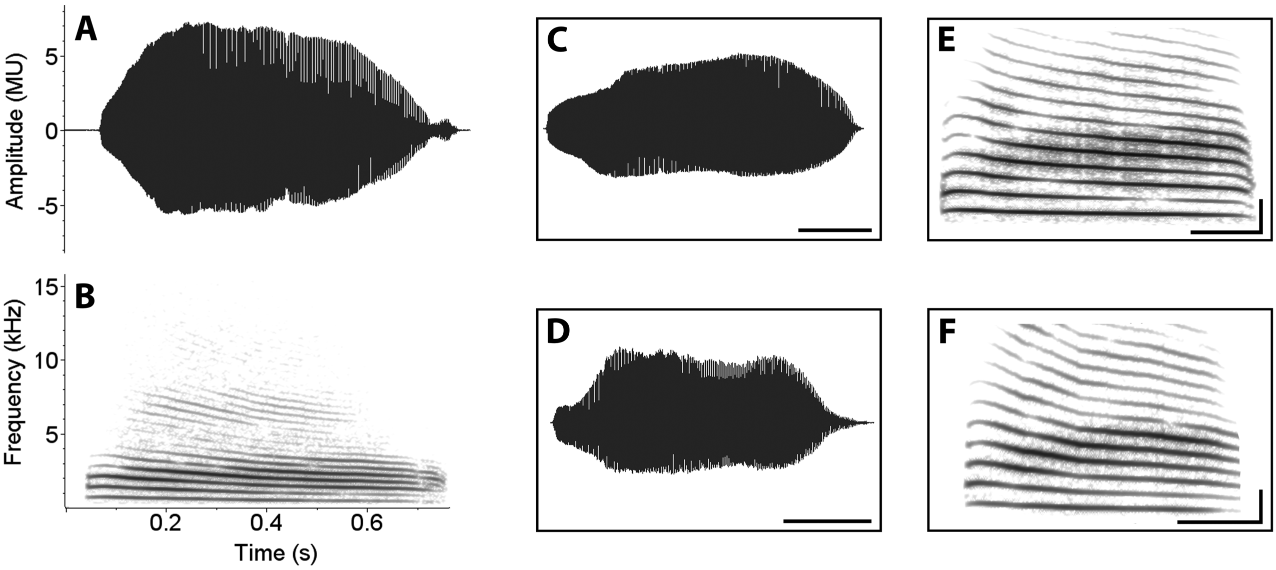

FIGURE 30. Call A of *Physalaemus kroyeri*. Oscillograms (A, C, and D) and audiospectrograms (B, E, and F). A single typical call with elliptic envelope (A–C). Variant calls A with different envelopes (C–F). Horizontal scale bars have 0.2 s; vertical scale bars have 1 kHz. Filter bandwidth (Hz): 78.9 (F); 55.2 (E); 110 (B).

Physalaemus centralis Bokermann, 1962

We found a single call type for the species, referred to as call A. The call is composed of single harmonic note with a very low fundamental frequency. Frequency modulations are subtle (20 Hz), still the call has a general downward FM, with an up-downward FM segment in the first third of the call duration.

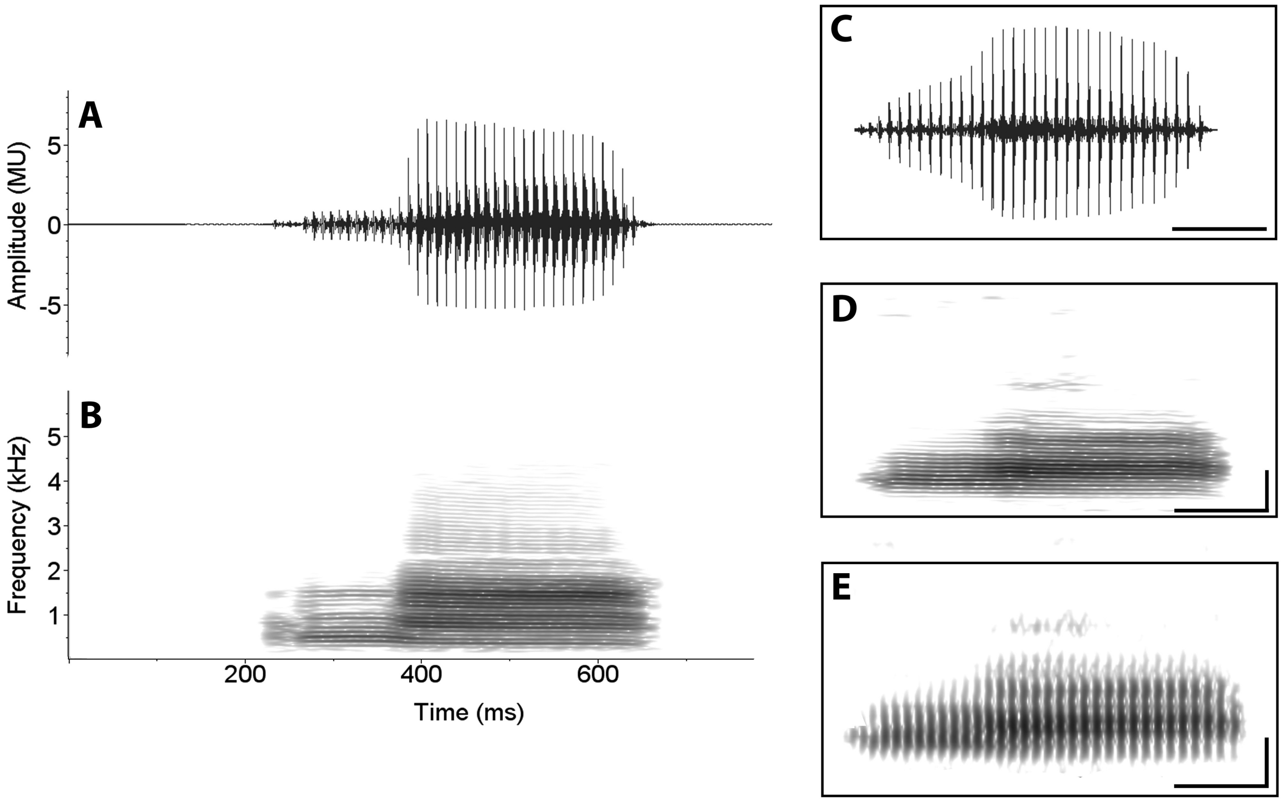

FIGURE 31. Call A of *Physalaemus centralis*. Oscillograms (A and C) and audiospectrograms (B, D, and E). A single typical call (A–B). A variant call with a different envelope (C). Audiospectrograms with apparent bands at a narrow filter (B) and bands not visible at wide filter (D; see filter values below). Sequence with three calls (E); note the frequency modulations (see text). Horizontal scale bars have 0.1 s (C and D) and 0.5 s (E); vertical scale bars have 1 kHz (D) and 0.5 kHz (E). Filter bandwidth (Hz): 34.5 (B and E); 135 (D).

Call A (Fig. 31A–E and 24H). We examined 16 recordings, a total of 36 minutes, with *ca*. 1880 calls from 25 males. Only some of these calls were measured (see Table 2). Call duration varies from 0.404 to 0.550 s. The call rise is much longer than call fall. Call rise has a short gradual increase followed by a long exponential part (Fig. 31C). In some calls the rise remains with very low amplitude until the limit with the sustain, where the amplitude increases abruptly (Fig. 31A). The sustain is regular, slightly decreasing towards the end of the call. The call fall is proportionally short and with logarithmic shape. The amplitude peak is at around the middle of the call duration. The envelope varies from elliptic (Fig. 31C) to almost rectangular (in calls in which the rise is not gradual; Fig. 31A). More than 50 % of the call energy is concentrated in 25 % of the call duration around the amplitude peak. There is no PAM in the call. The call has a harmonic series (Fig. 24H). However, due to the low fundamental frequency (see below), the wave peaks are shown as pulses in audiospectrograms at broad filter bandwidth (*e.g.,* above 100 Hz; Fig. 31E). The bands are observed in audiospectrograms at narrow filter bandwidth (*e.g.,* below 90 Hz; Fig. 31B, D). The fundamental frequency is *ca.* 90 Hz. This band and the next harmonic are generally absent in audiospectrograms. There are *ca.* 20 emphasized harmonics. The wave periods are regular and harmonics clear throughout the call. The dominant frequency varies from *ca*. 1410 to 1500 Hz (Fig. 31B). The dominant harmonic varies from the fourth to the 21st, but it is usually between the 15th and 18th. There is a clear shift in the relative energy among bands; the dominant frequency gets higher toward the end of the call, starting at the fourth, fifth or sixth harmonic and ending at the 15th, 19th, 20th, or 21st (Fig. 24H, 31B, D). Most of the call energy is between 600 and 1650 Hz (eight to twelve harmonics). Frequency modulations are subtle and better perceptible in audiospectrograms with wide filter bandwidths (*e.g.*, Fig. 31E). The call has a general downward FM. Additionally, the calls have an up-downward FM in the first third of the call duration, yielding arc-shaped bands in this part of the call, and a short downward FM at the end (Fig. 31B, D). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call. There is no PFM.

Physalaemus cuvieri Fitzinger, 1826

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note, usually with a triangular envelope that resembles an arrow-like shape. It has a general downward FM, with an up-downward FM segment in the first half of the call and a short upward FM segment at the end. Subharmonics are always present in the first half of the call.

Call A (Fig. 32A–V and 33A). We examined 75 recordings, a total of 94 minutes, with *ca*. 10200 calls from 228 males. Only some of these calls were measured (see Table 2). Call duration varies from 0.257 to 0.311 s. The envelope is very variable (Fig. 32A, C–G, M–Q). In most calls, the limits between the call rise, sustain and call fall are not clear. The ratio between call rise and fall duration, and their shape, are highly variable. Most calls have a fall longer than rise, or both have the same duration. Their shape varies from exponential to linear or logarithmic. The call rise has two consecutive exponential parts, the first shorter than the second. The sustain, when present, is irregular, usually composed of a shallow or deep valley (*i.e.*, with a concave shape; Fig. 32A, C, D, G, M, Q). The amplitude peak is usually before the middle of the call duration. The envelope varies from elliptic (Fig. 32A, C, D, N, O, P, Q) to triangular (pointed right; Fig. 32E, M). Due to the concave shape of the sustain, the triangular envelope of some calls resembles an arrow. More than 50 % of the call energy is concentrated in 20 % of the call duration around the amplitude peak. There is no PAM in the call. The call has a harmonic series (Fig. 33A). The fundamental frequency is *ca.* 650 Hz and approximately the first seven harmonics are emphasized. The wave periods are regular and harmonics are clear throughout the call. Subharmonics ($f_0 1/2$) are present in *ca.* the first half of all calls examined (this part can be shorter or longer than one half of the call duration; Fig. 32B, H–L, R–V). The dominant frequency varies from *ca*. 690 to 780 Hz (Fig. 32B). The dominant harmonic is the first or second (at the very end of the call), but it is usually the first. There is a clear shift in the relative energy among bands. Although there is no shift in the dominant frequency, the higher bands get more energy toward the end of the call (Fig. 32K, L, T, V). Most of the call energy is between 500 and 1300 Hz (one or two harmonics). The call has a general downward FM (Fig. 32B, H–L, R–V). Additionally, the calls have an up-downward FM in the first half of the call duration, forming arc-shaped bands in this part of the call, and a short upward FM at the end (Fig. 32B, H–L, R–V). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call. There is no PFM.

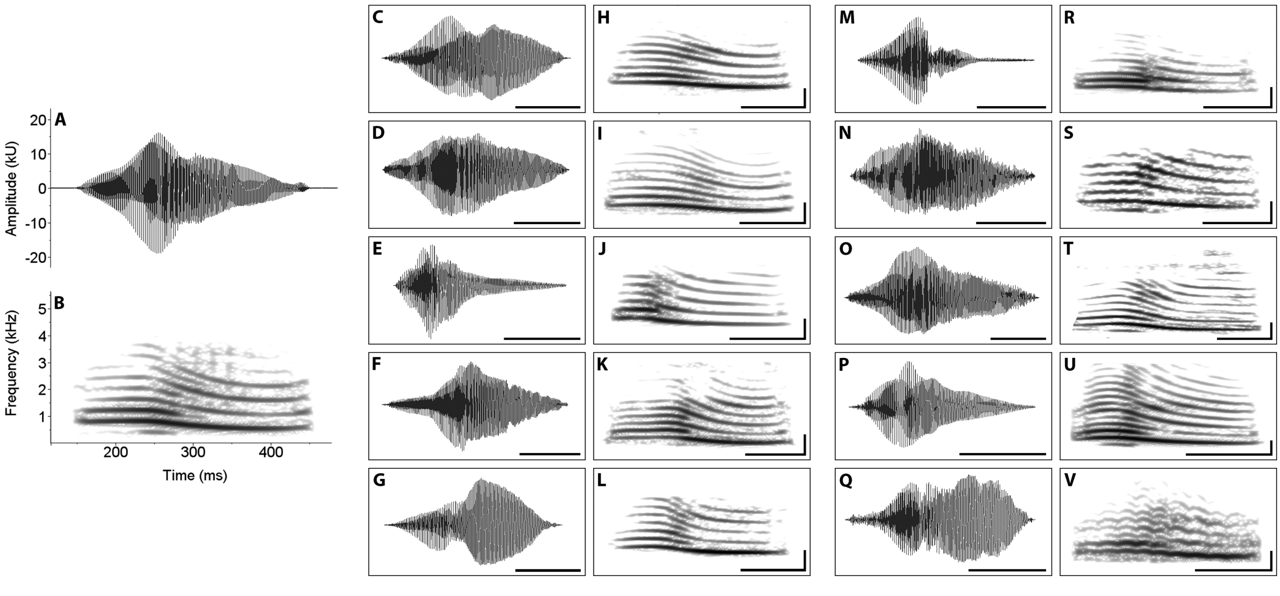

FIGURE 32. Call A of *Physalaemus cuvieri*. Oscillograms (A, C–G, and M–Q) and audiospectrograms (B, H–L, and R–V). A single typical call A (A and B). Variant calls A with different envelopes and spectral features (C–V). Horizontal scale bars have 0.1 s; vertical scale bars have 1 kHz. Filter bandwidth (Hz): 106.0 (U); 69.0 (T); 115.0 (V); 84.6 (B and I); 78.9 (L and R); 92.1 (J, K, S, and H).

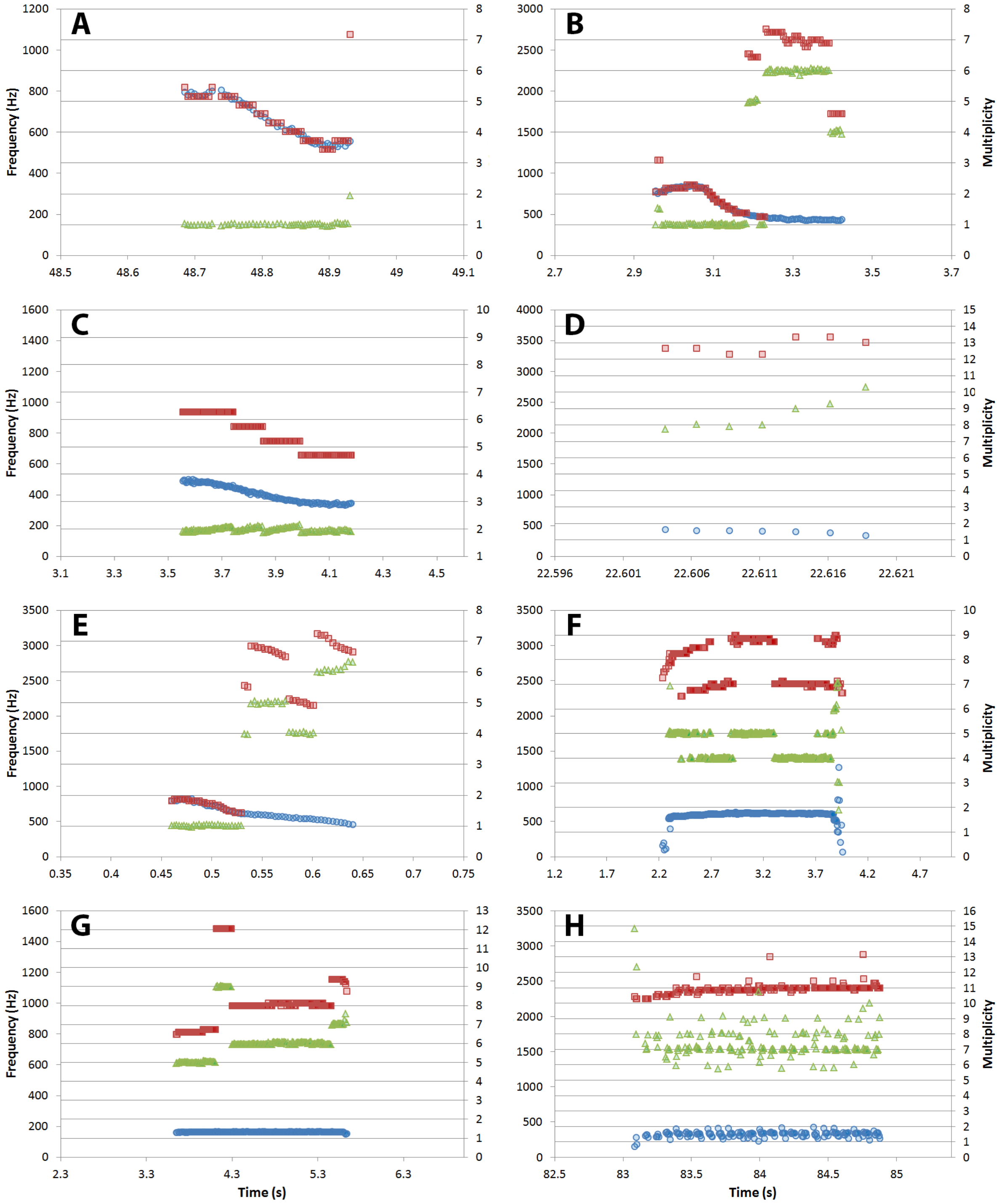

FIGURE 33. Multiplicity relationship between "instantaneous" dominant frequency and *w* of calls A of eight *Physalaemus* species. Each graph shows a single call A of *P. cuvieri* (A), *P. ephippifer* (B), *P. fischeri* (C), *P. cicada* (D), *P. aguirrei* (E), *P. soaresi* (F), *P. maximus* (G), *P. feioi* (H). Grid corresponds to the harmonic values (right y-axis). Red squares are the values of "instantaneous" dominant frequency; blue circles are the values of the reciprocal of *w*; green triangles are the factor values of the ratio "instantaneous" dominant frequency / *w* reciprocal per delta time. Delta time corresponds to the duration of one period of the measured acoustic oscillation. Note that factors around integer values suggest harmonic relationship between the frequency calculated (*w* reciprocal) and the dominant frequency. Factors multiple of ½ of the fundamental frequency correspond to subharmonics (see *P. ephippifer*; B).

Physalaemus ephippifer (Steindachner, 1864)

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note with a triangular envelope that resembles an arrow-like shape. There is usually a slight PAM (without silence intervals) in the final three fourths of the call duration. The call has a general downward FM, with an up-downward FM segment in the first third or first half of the call duration. Subharmonics are always present in the first half of the call.

Call A (Fig. 34A–F and 33B). We examined two recordings, a total of one minute, with *ca*. 130 calls from six males. Only some of these calls were measured (see Table 2). Call duration varies from 0.466 to 0.523 s. The call rise and fall are similar in duration and shape (exponential). The sustain is composed of a long and deep valley (*i.e.*, with a concave shape; Fig. 34A, C). The envelope varies from elliptic to triangular (pointed right). Due to the concave shape of the sustain, the triangular shape of some calls resembles an arrow (Fig. 34A). The amplitude peak is at the end of the first fourth of the call duration. More than 50 % of the call energy is concentrated in 38 % of the call duration around the amplitude peak. Some calls have an intermediate PAM only in the final three fourths of the call duration (there is no silence interval between amplitude peaks; Fig. 34A). The rate of the PAM is *ca.* 26 Hz, forming *ca.* eight cycles throughout part of the call where the PAM is present. The cycle rise and fall are similar, with amplitude peak at the middle of the cycle. The call has a harmonic series (Fig. 33B). The fundamental frequency is *ca.* 590 Hz and approximately the first eight harmonics are emphasized. The wave periods are regular and harmonics are clear throughout the call. Subharmonics ($f_0 1/2$) are present in *ca.* the first third or half of all calls examined (Fig. 34B, E, F). The dominant frequency varies from *ca*. 820 to 2630 Hz. The dominant harmonics are the first, third, fourth, fifth or sixth (usually the first or sixth; Fig. 33B, 34B). At the beginning of the call the subharmonic 1.5 is the dominant band (Fig. 34B, F). There is a clear shift in the relative energy among the bands in the second half of the call; the dominant frequency gets higher toward the end of the call, starting at the first harmonic, moving to the fifth, and ending at the sixth; thenceforth, it dominant frequency gets lower, moving to the fourth or third harmonic (Fig. 33B, 34B). Most of the call energy is between 550 and 2750 Hz (three to five harmonics). The call has a general downward FM (Fig. 34B, E). Additionally, calls have an up-downward FM in the first third or half of the call duration, yielding arc-shaped bands in this part of the call and a short downward FM at the end (Fig. 34B, E). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call. Calls have a PFM throughout the second half of the call, which is inversely proportional and synchronic to the PAM (Fig. 34A, B).

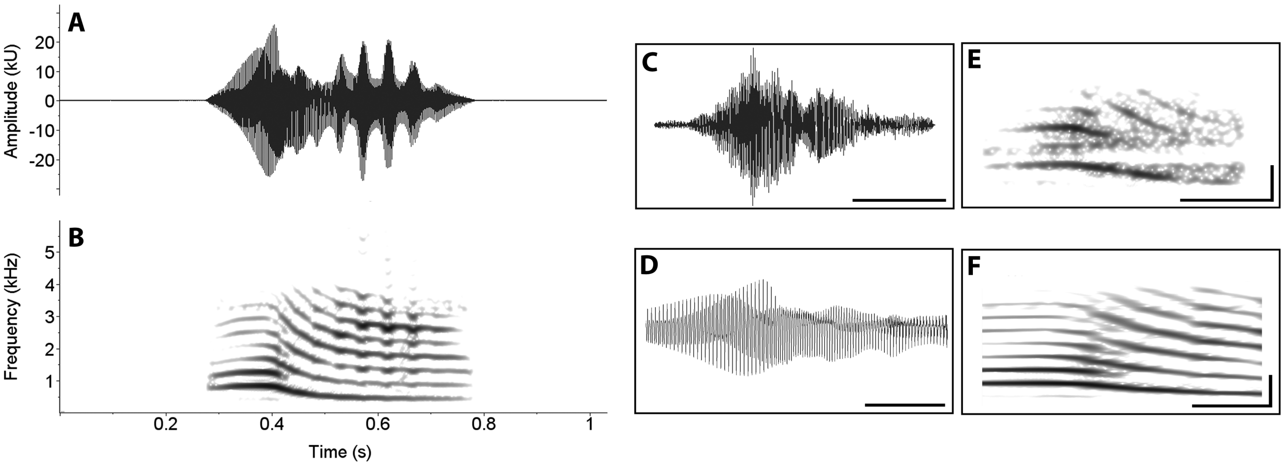

FIGURE 34. Call A of *Physalaemus ephippifer*. Oscillograms (A, C, and D) and audiospectrograms (B, E, and F). A single typical call with PAM and PFM (A–B). A variant call with a different envelope without clear PAM or PFM (C–E). Middle of the call with the transition moment between the segments with and without subharmonics (D–F). Horizontal scale bars have 0.1 s (C and E) and 0.05 s (D and F); vertical scale bars have 1 kHz. Filter bandwidth (Hz): 84.6 (B); 90.6 (E); 61.9 (F).

Physalaemus fischeri (Boulenger, 1890)

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note with an envelope varying from elliptic to almost triangular, resembling an arrow-like shape. It has a general downward FM, with a slight up-downward FM segment in the first half of the call duration and a short upward FM at the end.

Call A (Fig. 35A–B and 33C). We examined three recordings, a total of five minutes, with *ca*. 60 calls from five males. Only some of these calls were measured (see Table 2). Call duration varies from 0.795 to 0.850 s. The call rise and fall are similar in duration and shape (exponential). The sustain is usually composed of a long and deep valley (*i.e.,* with a concave shape). The envelope varies from elliptic to triangular (pointed right; Fig. 35A). Due to the concave shape of the sustain, the triangular shape of some calls resembles an arrow. The amplitude peak is at around the end of the first two fifths of the call duration. More than 50 % of the call energy is concentrated in 18 % of the call duration around the amplitude peak. There is no PAM in the call. The call has a harmonic series (Fig. 33C). The fundamental frequency is *ca.* 410 Hz, and this band can be present with low energy or absent in the audiospectrograms. There are *ca.* six emphasized harmonics. The wave periods are regular and harmonics are clear throughout the call. However, jumps of the fundamental frequency, subharmonics and deterministic chaos can be present at the end of the call (Fig. 35B). The dominant frequency is *ca.* 850 Hz (Fig. 35B). The dominant harmonic is the second. There is a clear shift in the relative energy among bands, higher bands getting more energy toward the end of the call (Fig. 33C, 35B). Most of the call energy is between 650 and 1800 Hz (two to four harmonics). The call has a general downward FM (Fig. 35B). Additionally, calls have a slight up-downward FM in the first half of the call duration, yielding arc-shaped bands in this part of the call and a short upward FM at the end (Fig. 35B). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call. There is no PFM.

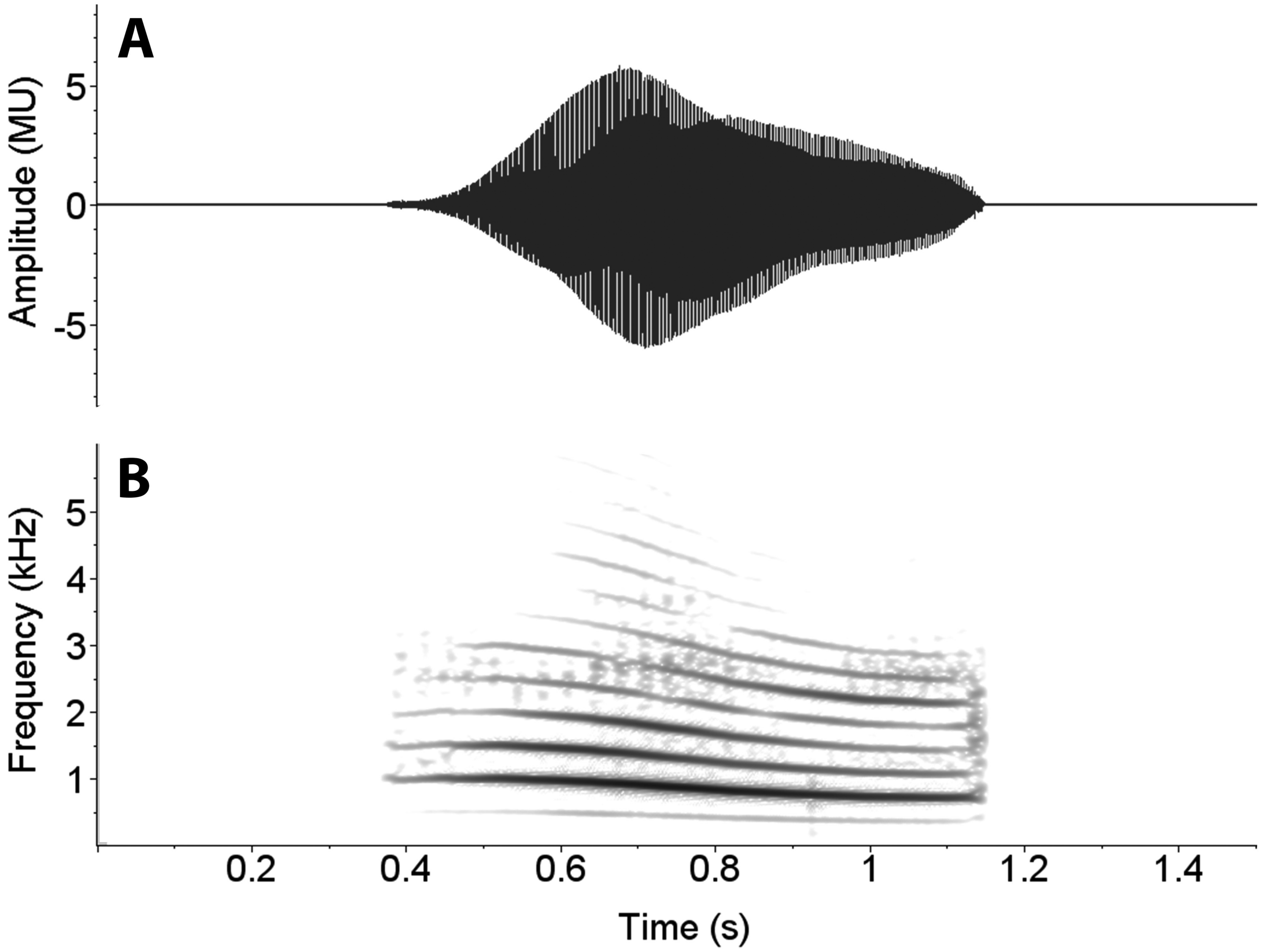

FIGURE 35. Call A of *Physalaemus fischeri*. Oscillogram (A) and audiospectrogram (B). A single call (A and B). Filter bandwidth (Hz): 55.2 (B).

No species group assigned

Physalaemus cicada Bokermann, 1966

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note with an elliptic envelope and very short duration. It has a general downward FM, with an up-downward FM segment in the first half of the call (Fig. 36B, F). Calls are emitted in long sequences (more than 300 calls per sequence; Fig. 36C, D).

Call A (Fig. 36A–G and 33D). We examined six recordings, a total of 13 minutes, with *ca*. 12500 calls from eight males. Only some of these calls were measured (see Table 2). Call duration varies from 0.004 to 0.047 s. The call rise and fall are similar in duration and shape (exponential). The sustain is short or absent. The envelope is elliptic (Fig. 36A. E). The amplitude peak is at around the end of the first two fifths of the call duration. More than 50 % of the call energy is concentrated in 24 % of the call duration around the amplitude peak. There is no PAM in the call. The call has a harmonic series (Fig. 33D). The fundamental frequency is *ca.* 410 Hz and approximately the first ten harmonics (except the first one) are emphasized. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency varies from *ca*. 1410 to 3560 Hz (Fig. 33D, 36B). The dominant harmonic varies from the seventh to the 10th, but it is usually the eighth. There is a clear shift in relative energy between bands; the dominant frequency gets higher toward the end of the call, starting at the seventh or eighth harmonic and ending at the eighth, ninth or 10th (Fig. 33D, 36F). Most of the call energy is between 950 and 3850 Hz (eight harmonics). The call has a general downward FM (Fig. 36B, F). Additionally, calls have an up-downward FM in the first half of the call duration, yielding arc-shaped bands in this part of the call, and a short downward FM at the end (Fig. 36B, F). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call (Fig. 36F). There is no PFM. Calls are usually emitted in series, resulting in long call sequences of *ca.* 400 calls in each sequence (Fig. 36C, D, E, F).

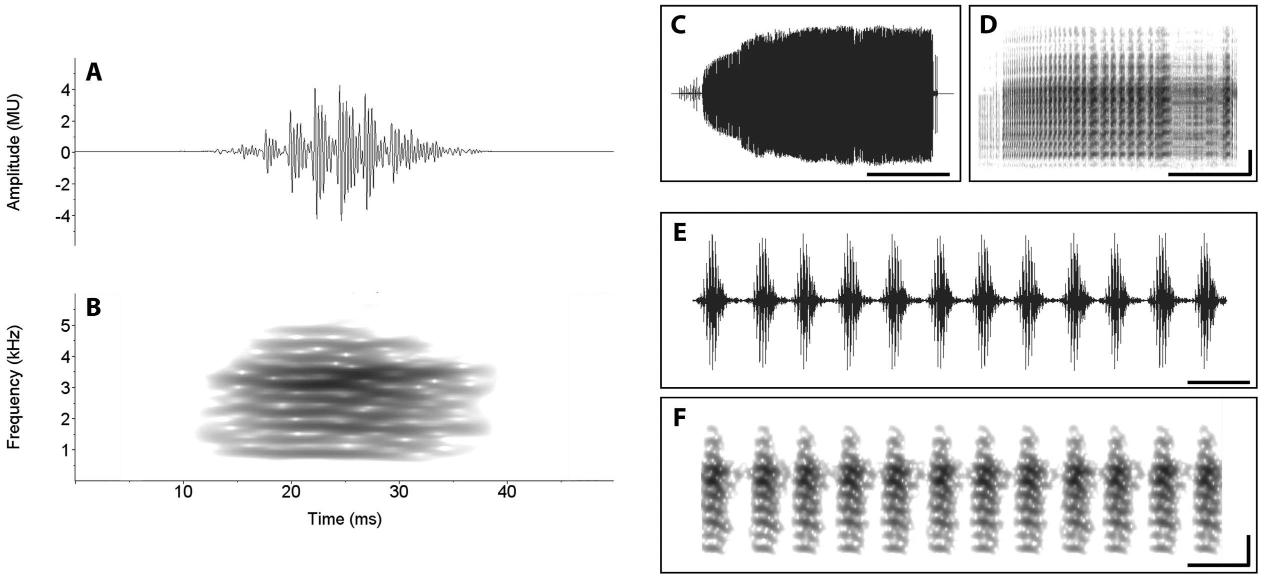

FIGURE 36. Call A of *Physalaemus cicada*. Oscillograms (A, C, and E) and audiospectrograms (B, D, and F). A single call A (A and B). A long sequence with hundreds of calls (C–D). Sequence with 12 calls A (E–F). Horizontal scale bars have 0.025 s (C and D) and 0.05 s (E and F); vertical scale bars have 1 kHz. Filter bandwidth (Hz): 173 (B); 67.4 (D); 135 (F).

Physalaemus aguirrei Bokermann, 1966

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note with an elliptic or trapezium-like envelope. It has a general downward FM, with an up-downward FM segment in the first third of the call.

Call A (Fig. 37A–D and 33E). We examined seven recordings, a total of 11 minutes, with *ca*. 400 calls from 10 males. Only some of these calls were measured (see Table 2). Call duration varies from 0.179 to 0.237 s. Usually, call rise and fall are similar in duration and shape. The call rise is usually composed of two consecutive exponential- or linear-shaped segments, whereas the call fall has an exponential or logarithmic shape (Fig. 37A). The sustain can be irregular with short and shallow valleys, composed of a single deep valley (concave shape), or regular without internal AM segments (Fig. 37A, C). In some calls, the rise is much longer than fall and it remains with very low amplitude until the limit with the sustain, where the amplitude increases abruptly. The amplitude peak is around the middle of the call duration. The envelope varies from elliptic (Fig. 37C) to slightly rectangular (in calls in which the rise is not gradual; Fig. 37A). More than 50 % of the call energy is concentrated in 34 % of the call duration around the amplitude peak. There is no PAM in the call. The call has a harmonic series (Fig. 33E). The fundamental frequency is *ca.* 640 Hz and approximately the first eight harmonics are emphasized. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency varies from *ca*. 770 to 3380 Hz (Fig. 37B). The dominant harmonic varies from the first to the sixth (except the second and third). There is a clear shift in relative energy between the bands; the dominant frequency gets higher until three fourths of the call duration, starting at the first harmonic, moving to the fourth and fifth, and ending at the sixth (Fig. 33E). Most of the call energy is between 700 and 3950 Hz (five to six harmonics). The call has a general downward FM (Fig. 37B, D). Additionally, the calls have an up-downward FM in the first third of the call duration, yielding arc-shaped bands in this part of the call (Fig. 37B), and a short downward FM at the end (Fig. 37B, D). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call. There is no PFM.

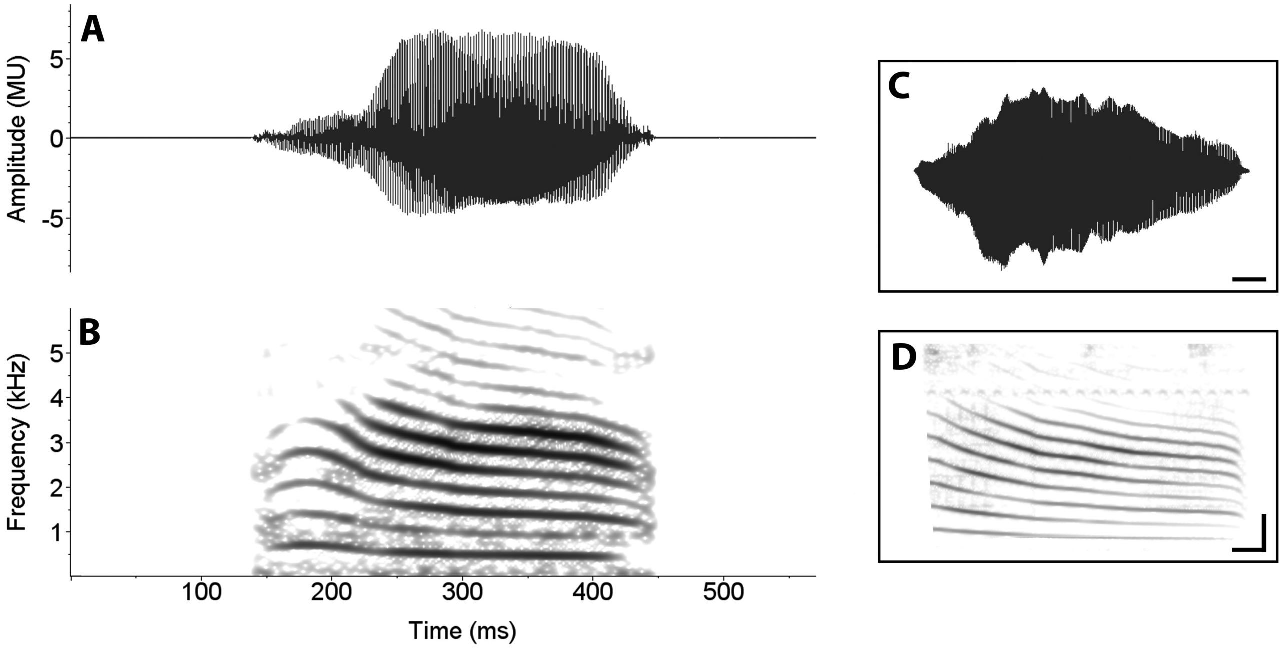

FIGURE 37. Call A of *Physalaemus aguirrei*. Oscillograms (A and C) and audiospectrograms (B and D). A typical call A (A–B). A variant call A with a different envelope and initial FM segment (C–D). Horizontal scale bars have 0.1 s; vertical scale bars have 1 kHz. FFT (points): 1500 (B); 1024 (D).

Physalaemus olfersii species group

Only one call type was recorded for this group. Calls have long durations, varying from 1 to 5 s (higher durations observed in *P. feioi*, *P. orophilus*, and *P. olfersii*). Several species of this clade emit calls with rectangular-shaped envelopes (*e.g.*, *P. feioi*, *P. orophilus*, *P. lateristriga*, and *P. olfersii*). Slight PAM is perceptible in calls of most species (*P. soaresi*, *P. maximus*, *P. lateristriga*, and *P. olfersii*), but two species have calls with pulse-PAM (*P. feioi* and *P. orophilus*). In some species (*P. maximus*, *P. lateristriga*, and *P. olfersii*), the fundamental frequency is lower than 200 Hz, resulting in several close harmonics visible in audiospectrograms. All species have calls with PFM and most species (except for *P. lateristriga* and *P. olfersii*) have a clear general up-downward FM, yielding arc-shaped bands in audiospectrogram when considering the entire call. Fundamental frequency is lower than 400 Hz, except for *P. soaresi* which has call with fundamental frequency of *ca.* 600 Hz. Call energy is concentrated in many higher harmonics. This feature results in a high-pitched timbre for the calls. The long duration, large number of close harmonics (low fundamental frequency and dense-harmonic calls) and high-pitched timbre make the calls sound like human infant cries.

Physalaemus soaresi Izecksohn, 1965

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note with long duration, PFM, and a slight PAM, with no silence intervals. Bands have a general upward FM and a downward FM at the end, yielding arc-shaped bands in audiospectrogram when considering the entire call. Subharmonics, shifts of the fundamental frequency and deterministic chaos are common at the beginning and end of the calls.

Call A (Fig. 38A–J and 33F). We examined three recordings, a total of five minutes, with 40 calls from five males. Only some of these calls were measured (see Table 2). Call duration varies from 1.597 to 1.748 s. In most calls, the limits between the call rise, sustain, and fall are not clear. Usually, call rise and fall are similar in duration and shape (logarithmic). In some calls, the rise is longer than fall. There is a long sustain. It is usually regular, with a convex shape, but it can be almost flat (Fig. 38A, C), or have irregular AM segments, yielding amplitude peaks and valleys over the segment (Fig. 38D, E, F). The amplitude peak is usually at around the middle of the call duration. The envelope of the call varies between elliptic (Fig. 38A, C), rectangular (Fig. E, F), or triangular (pointed left; Fig. 38D), depending on the shape and steepness of the sustain. More than 50 % of the call energy is concentrated in 39 % of the call duration around the amplitude peak. Some calls have a slight PAM (there is no silence interval between peaks; Fig. 38F). The rate of the PAM is *ca.* 16 Hz, forming *ca.* 22 amplitude peaks throughout the call. The call has a harmonic series (Fig. 33F). The fundamental frequency is *ca.* 600 Hz. This band and the next harmonic are absent in the audiospectrogram. There are usually *ca.* six emphasized harmonics. Generally, the wave periods are regular and harmonics are clear throughout the call. However, subharmonics ($f_0 1/2$), jumps of the fundamental frequency, and deterministic chaos are common at the beginning and end of the call (Fig. 38B, G, H, I, J). The dominant frequency varies from *ca*. 2450 to 3060 Hz. The dominant harmonic varies from the second to the seventh, but it is usually the fourth or fifth (Fig. 33F). There is no clear shift in the relative energy between the bands throughout the call (Fig. 33F). Most of the call energy is between 2250 and 3750 Hz (three harmonics). The call has a general upward FM and a short downward FM at the end, yielding an arc-shaped bands in audiospectrogram when considering the entire call (Fig. 38B, G, H, I, J). Additionally, there is clear PFM throughout the call, which is usually independent from the PAM or can be directly proportional and synchronic to some parts of the PAM (Fig. 38A–J).

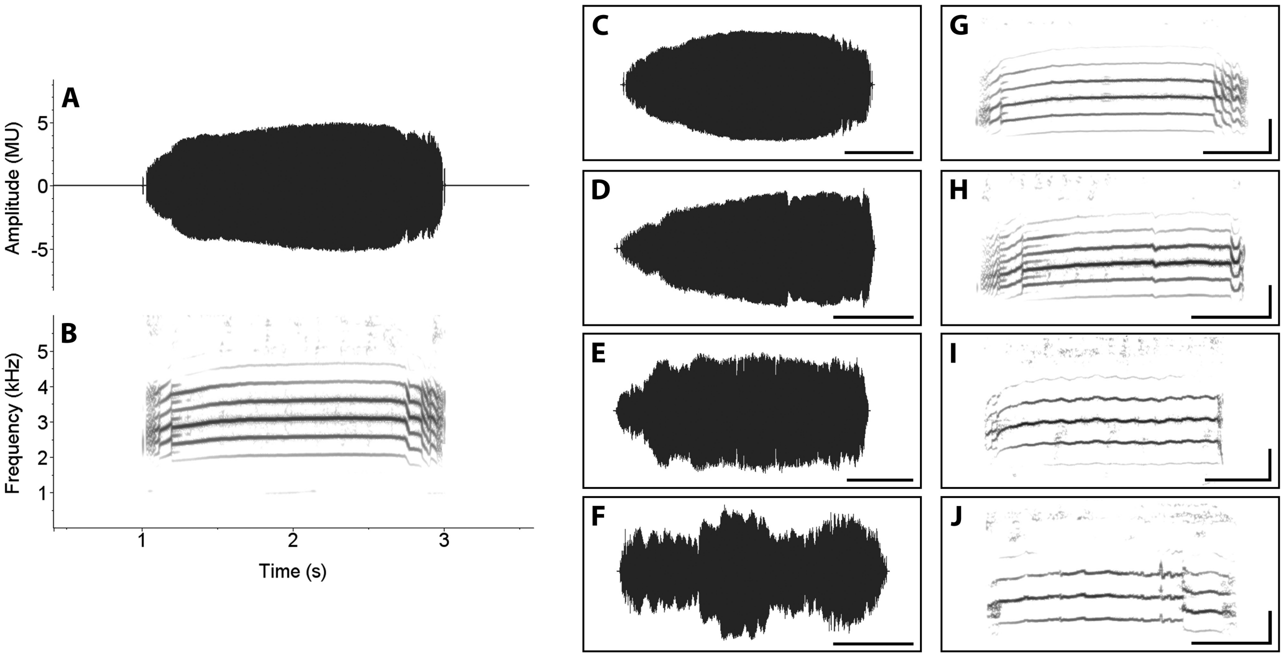

FIGURE 38. Call A of *Physalaemus soaresi*. Oscillograms (A, C–F) and audiospectrograms (B, G–J). A typical call (A–B). Variant calls with different envelopes and spectral features (C–J). Note the frequency jumps, deterministic chaos, and subharmoncis at the beginning and or end of the calls (B, G–J). Horizontal scale bars have 0.5 s; vertical scale bars have 1 kHz. Filter bandwidth (Hz): 55.2 (B and H); 39.5 (G); 42.3 (I); 50.7 (J).

Physalaemus maximus Feio, Pombal & Caramaschi, 1999

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note with a subtle PAM, with no silence intervals. It has a long duration and a very low fundamental frequency with subtle PFM throughout the call. The bands have a slight general upward FM and a downward FM at the end, yielding a slight arc shape in the audiospectrogram when considering the entire call.

Call A (Fig. 39A–D and 33G). We examined seven recordings, a total of five minutes, with *ca*. 90 calls from 11 males. Only some of these calls were measured (see Table 2). Call duration varies from 1.887 to 2.446 s. The call rise is longer than call fall or both are similar in duration. Call rise and fall have exponential, linear or logarithmic shape. There is a long sustain. It is usually almost flat but slightly irregular (Fig. 39A). However, in some calls, the beginning of this segment has low amplitude, which gradually increases towards the end of the call (Fig 39C). The amplitude peak is usually at the end of the first two thirds the call duration. The amplitude of the call is usually at three fifths of the call duration. The envelope varies from elliptic, rectangular (Fig. 39A) to triangular (pointed left; Fig. 39C) depending on the steepness of the sustain and position of the amplitude peak of the call. More than 50 % of the call energy is concentrated in 36 % of the call duration around the amplitude peak. The call can have a slight PAM (silence intervals absent between peaks). The rate of the PAM is *ca.* 10 Hz, forming *ca.* 22 amplitude peaks throughout the call. The call has a harmonic series (Fig. 33G). The fundamental frequency is *ca.* 170 Hz. This band and the next harmonic are absent in audiospectrograms. There are usually *ca.* seven emphasized harmonics. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency varies from *ca*. 1000 to 1030 Hz (Fig. 39B). The dominant harmonic varies from the third to the ninth, but it is usually the sixth (Fig. 33G). There is no clear shift in the relative energy between the bands throughout the call. Most of the call energy is between 850 and 1550 Hz (five harmonics). The call has a general FM slightly upward and a short downward FM at the end, yielding a slight arc shape in the audiospectrogram when considering the entire call (Fig. 39B, D). Additionally, there can be a slight PFM throughout the call, which is usually independent of PAM or can be directly proportional and synchronic to some parts of the PAM.

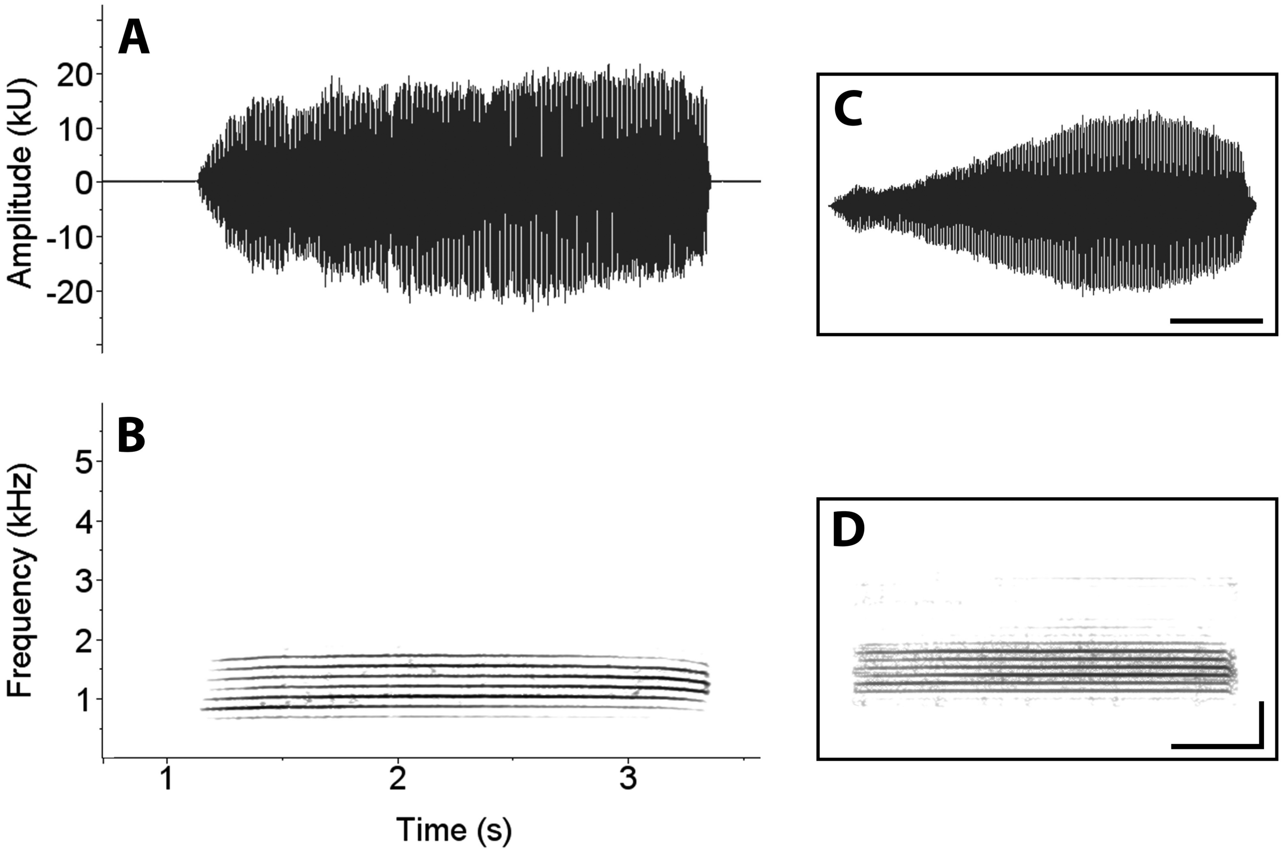

FIGURE 39. Call A of *Physalaemus maximus*. Oscillograms (A and C) and audiospectrograms (B and D). A typical call (A–B). A variant call with different envelope and less frequency-modulated (C–D). Horizontal scale bars have 0.5 s; vertical scale bars have 1 kHz. Filter bandwidth (Hz): 30.7 (B); 38.4 (D).

Physalaemus feioi Cassini, Cruz & Caramaschi, 2010

We found a single call type for the species, referred to as call A. The call has long duration and is composed of a single harmonic note with a sequence of pulses with interpulse silence intervals. The bands have a general upward FM and a downward FM at the end, yielding a slight arc shape in the audiospectrogram when considering the entire call.

Call A (Fig. 40A–H and 33H). We examined seven recordings, a total of eight minutes, with 52 calls from nine males. Only some of these calls were measured (see Table 2). Call duration varies from 3.854 to 4.920 s. Call rise and fall are very short and similar to each other in duration. There is a long sustain. This segment is usually regular and almost flat but some calls have sustains with a convex shape (Fig. 40A, D). The amplitude peak is often at the end of the first seven tenths of the call duration. The envelope of the call is rectangular (Fig. 40A, D). More than 50 % of the call energy is concentrated in 45 % of the call duration around the amplitude peak. The call has a strong PAM (there are silence intervals between pulses; Fig. 40A, D). The rate of the PAM is *ca.* 15 Hz, forming *ca.* 55 pulses throughout the call. The pulse rise is longer than fall, with amplitude peak of the pulse at *ca.* two thirds of the pulse duration (Fig. 40C). The amplitude peak of the last pulse is at the beginning or middle of the pulse. Interval durations are similar to pulse duration (Fig. 40C). The last pulse is usually the longest (*ca.* 1.5 times longer than the other pulses; Fig. 40E). In some calls, the last pulse is the shortest (Fig. 40A). The call has a harmonic series (Fig. 33H). The fundamental frequency is *ca.* 330 Hz. The first five harmonics are usually absent in the audiospectrogram. There are *ca.* four adjacent emphasized harmonics. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency varies from *ca*. 2340 to 2470 Hz. The dominant harmonic varies from the sixth to the 15th, but it is usually the seventh (Fig. 33H). There is no clear shift in the relative energy between the bands throughout the call. Most of the call energy is between 2100 and 2950 Hz (three harmonics). The call has a general upward FM and a short downward FM at the end, yielding a slight arc shape in the audiospectrogram when considering the entire call (Fig. 40B, G). There is a slight PFM throughout the call, which is directly proportional to the synchronic pulse-PAM, *i.e.* up-downward FM in each pulse (Fig. 40A, B, C, F). Additionally, there is another PFM, which is perceptible within the pulses (Fig. 40H).

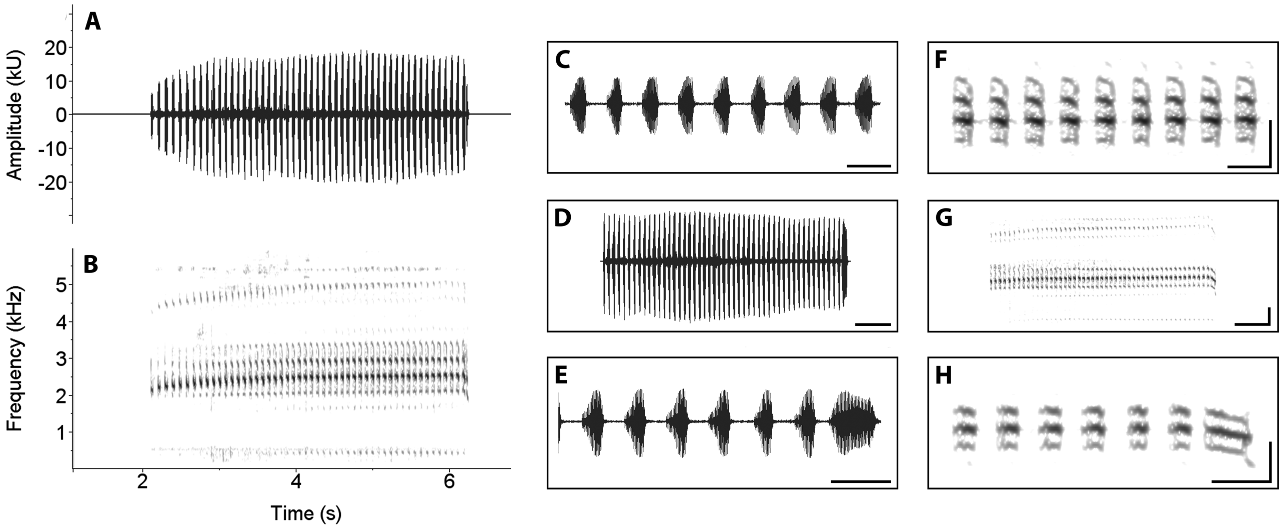

FIGURE 40. Call A of *Physalaemus feioi*. Oscillograms (A, C–E) and audiospectrograms (B, F–H). A typical call (A–B). Segment with nine pulses (C and F). A variant call A with different envelope (D and G). Segment with the last seven pulses of a call (E and H). Note the longer duration of the final pulse (E and H). Horizontal scale bars have 0.5 s (D and G) and 0.1 s (C, F, E, and H); vertical scale bars have 1 kHz. Filter bandwidth (Hz): 61.4 (F); 44.9 (B and G); 92.1 (H).

Physalaemus orophilus Cassini, Cruz & Caramaschi, 2010

We found a single call type for the species, referred to as call A. The call has long duration and is composed of a single harmonic note with a sequence of pulses with interpulse silence intervals. The bands have a general upward FM but with a subtle downward FM at the end, yielding slightly arc-shaped bands in the audiospectrogram of some calls when considering the entire call duration.

Call A (Fig. 41A–H and 42A). We examined 10 recordings, a total of 26 minutes, with *ca*. 270 calls from 16 males. Only some of these calls were measured (see Table 2). Call duration varies from 3.724 to 5.432 s. Call rise and fall are very short and similar to each other in duration. There is a long sustain. This segment is usually regular and almost flat (Fig. 41A, D), but convex in some calls (Fig. 41E). The amplitude peak of these calls is at the end of the first two thirds of the call duration. The envelope of the call varies from elliptic (Fig. 41E) to rectangular (Fig. 41A, D). More than 50 % of the call energy is concentrated in 43 % of the call duration around the amplitude peak. The call has a strong PAM (silence intervals are present between peaks; Fig. 41A–H). The rate of the PAM is *ca.* 11 Hz, forming *ca.* 57 pulses throughout the call. The pulse rise is longer than fall, with amplitude peak of the pulse at *ca.* two thirds of the pulse duration. The amplitude peak of the last pulse is at the beginning or middle of the pulse (Fig. 41C). Duration of silence intervals is similar to pulse duration. The last pulse is usually the longest (*ca.* 1.5 times longer than the other pulses). In some calls, the last pulse is the shortest. The call has a harmonic series (Fig. 42A). The fundamental frequency is *ca.* 290 Hz. The first five harmonics are usually absent in audiospectrograms (Fig. 41B). There are *ca.* four adjacent emphasized harmonics. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency varies from *ca*. 2630 to 2910 Hz (Fig. 41B). The dominant harmonic varies from the seven to the 29th, but it is usually the ninth (Fig. 42A). There is no shift in the relative energy between the bands throughout the call. Most of the call energy is between 2500 and 3350 Hz (three harmonics; Fig. 41F). The call has a slight general upward FM and a short downward FM at the end, leading to arc-shaped bands in audiospectrograms when considering the entire call (Fig. 41B, G, H). Additionally, there can be a slight PFM throughout the call, which is directly proportional to the synchronic pulse-PAM, *i.e.* up-downward FM in each pulse.

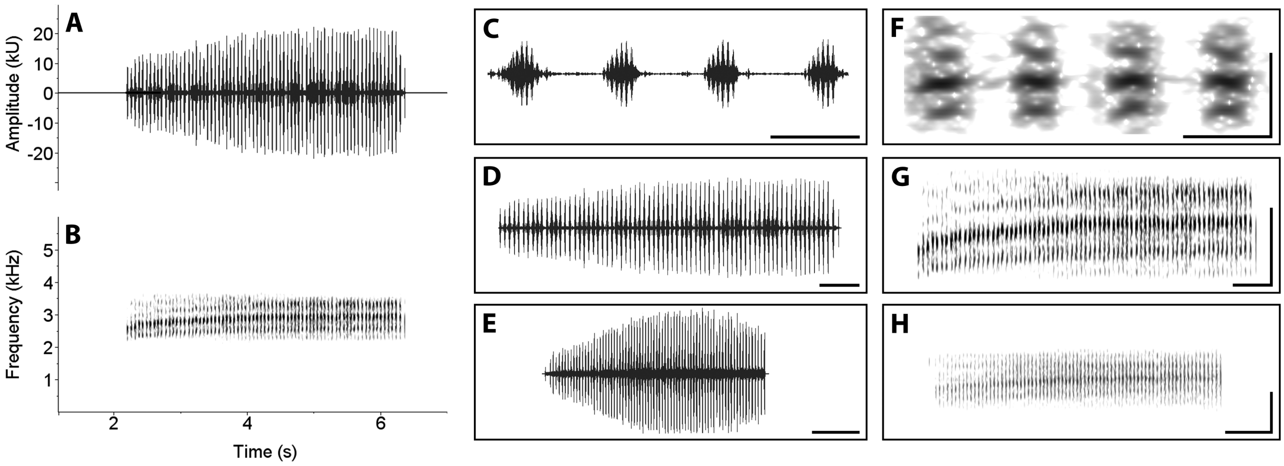

FIGURE 41. Call A of *Physalaemus orophilus*. Oscillograms (A, C–E) and audiospectrograms (B, F–H). A typical call (A–B). Segment with four pulses (C and F). Variant calls with different envelopes (D–H). Horizontal scale bars have 0.05 s (C and F) and 0.5 s (D–H); vertical scale bars have 1 kHz. Filter bandwidth (Hz): 67.4 (B, F, and H); 46 (G).

Physalaemus lateristriga **(Steindachner, 1864)**

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note with a long duration and a slight PAM (no silence intervals between pulses). It has irregular and strong PFM throughout the call. The bands have no general FM or only slight general FM, which is usually upward.

Call A (Fig. 43A–F and 42B). We examined seven recordings, a total of 20 minutes, with *ca*. 160 calls from 16 males. Only some of these calls were measured (see Table 2). Call duration varies from 1.330 to 3.746 s. The call rise is restricted to the very beginning of the call, most of the call corresponding to the sustain (Fig. 43C). Call rise and fall are very short and similar to each other in duration. Sustain usually regular and almost flat (Fig. 43C), but some calls have convex or inclined segments, with amplitude gradually increasing towards its end (Fig. 43A, D). In some calls, there is a shallow valley at the beginning of the sustain (Fig. 43A, C). The amplitude peak is at around the middle or at the end of the call duration. The envelope of the call varies from rectangular (Fig. 43C) to triangular (pointed left; Fig. 43A, D). More than 50 % of the call energy is concentrated in 39 % of the call duration around the amplitude peak. The call has a slight PAM (silence intervals absent between peaks; Fig. 43A, D). The rate of the PAM is *ca.* 8 Hz, forming *ca.* 29 cycles throughout the call. The cycle rise and fall are similar and the amplitude peak is at the middle of the cycle duration. The call has a harmonic series (Fig. 42B). The fundamental frequency is *ca.* 170 Hz. The first five harmonics are usually absent in the audiospectrogram or with very low energy. There are

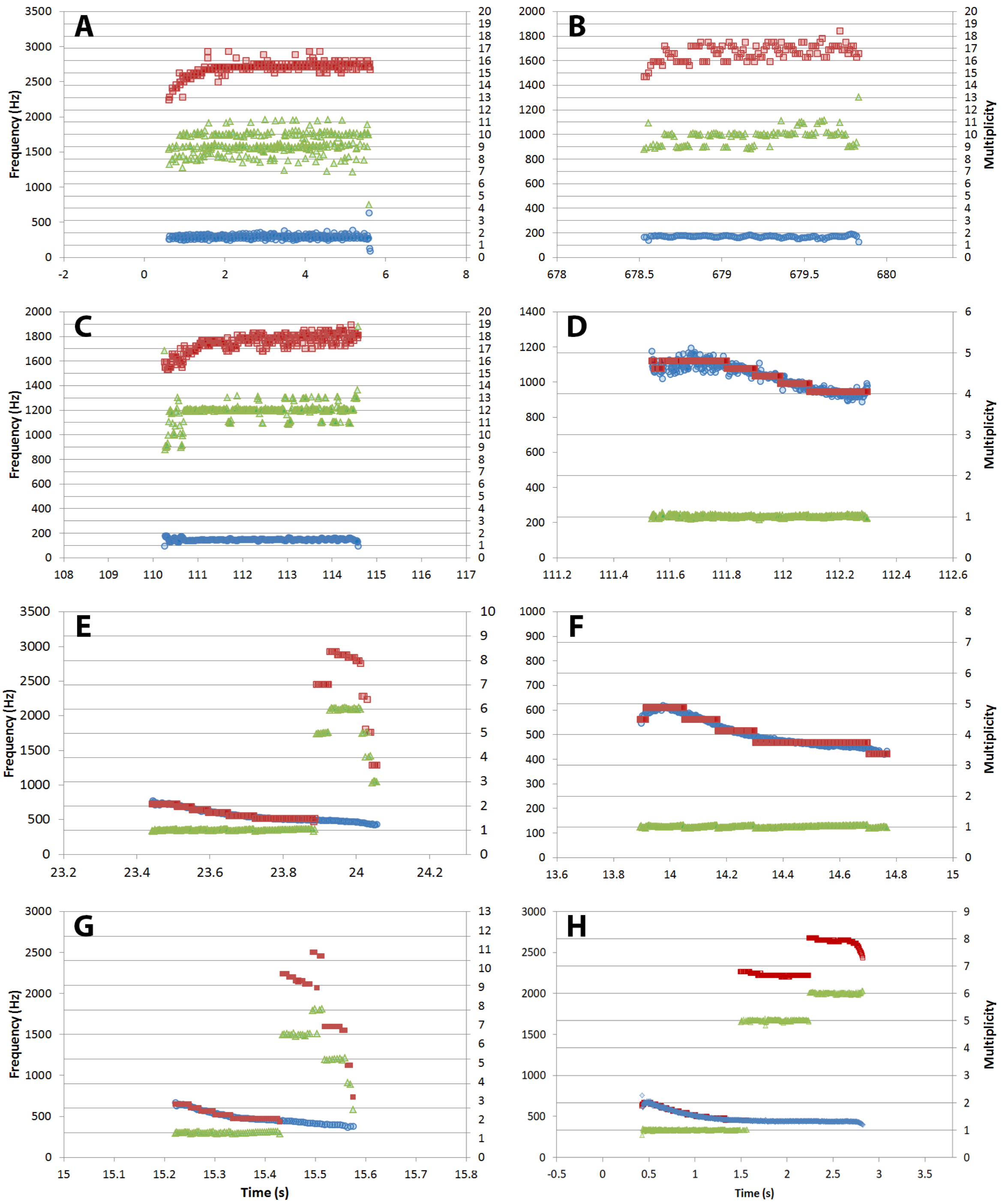

FIGURE 42. Multiplicity relationship between "instantaneous" dominant frequency and *w* of calls A of eight *Physalaemus* species. Each graph shows a single call A of *P. orophilus* (A), *P. lateristriga* (B), *P. olfersii* (C), *P. riograndensis* (D), *P. biligonigerus* (E), *P. marmoratus* (F), *P. santafecinus* (G), *P. carrizorum* (H). Grid corresponds to the harmonic values (right y-axis). Red squares are the values of "instantaneous" dominant frequency; blue circles are the values of the reciprocal of *w*; green triangles are the factor values of the ratio "instantaneous" dominant frequency / *w* reciprocal per delta time. Delta time corresponds to the duration of one period of the measured acoustic oscillation. Note that factors around integer values suggest harmonic relationship between the frequency calculated (*w* reciprocal) and the dominant frequency. Factors multiple of ½ of the fundamental frequency correspond to subharmonics (see call B of *P. ephippifer*).

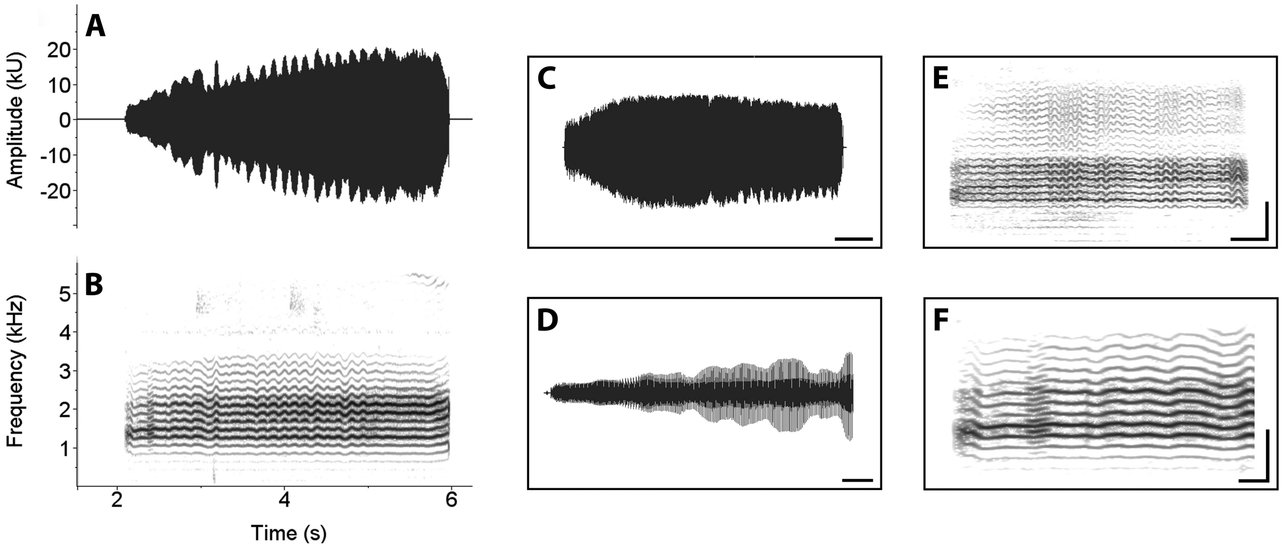

FIGURE 43. Call A of *Physalaemus lateristriga*. Oscillograms (A, C, and D) and audiospectrograms (B, E, and F). A typical call (A–B). Variant calls with different envelopes and different spectral features (C–F). Horizontal scale bars have 0.5 s (C and E) and 0.1 s (D and F); vertical scale bars have 1 kHz. Filter bandwidth (Hz): 18.4 (E); 42.3 (B); 31.7 (F).

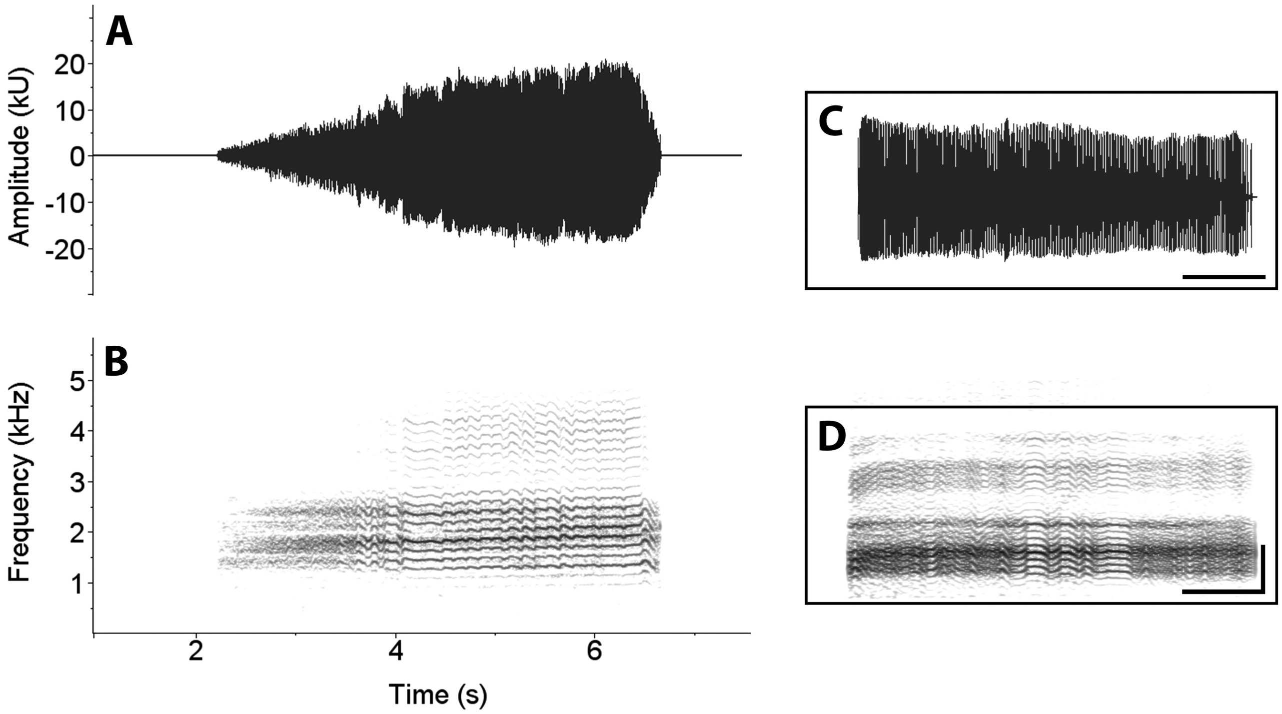

FIGURE 44. Call A of *Physalaemus olfersii*. Oscillograms (A and C) and audiospectrograms (B and D). A typical call (A–B). A variant call with a different envelope and spectral features (C–D). Note the deterministic chaos at the beginning of the call (B). Note the higher noise level in the call and the irregular PFM (D). Horizontal scale bars have 0.5 s; vertical scale bars have 1 kHz. Filter bandwidth (Hz): 25.4 (B and D).

ca. eight adjacent emphasized harmonics. The wave periods are regular and harmonics are clear throughout the call. Subharmonics ($f_0$1/2) are present at the beginning of some calls (Fig. 43B, F). The dominant frequency varies from *ca*. 1590 to 1840 Hz (Fig. 43B). The dominant harmonic varies from the ninth to the 13th, but it is usually the ninth or 10th (Fig. 42B). There is no clear shift in the relative energy between bands throughout the call. Most of the call energy is between 1100 and 2150 Hz (seven harmonics). Calls usually lack a clear general FM (Fig. 43B, E). In some calls, a slight up or downward general FM is observed, usually upward. A short downward FM is frequently present at the end of the call (Fig. 43E). Additionally, there is a strong PFM throughout the call, which is usually independent (Fig. 43C, E), but it is directly proportional and synchronic to PAM when it is present (Fig. 43A, B).

Physalaemus olfersii (Lichtenstein & Martens, 1856)

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note with a very long duration and a slight PAM (no silence intervals between pulses). It has an irregular and strong PFM throughout the call. The bands have no general FM or have only a slight FM, which is usually upward.

Call A (Fig. 44A–D and 42C). We examined 13 recordings, a total of 35 minutes, with 332 calls from 31 males. Only some of these calls were measured (see Table 2). Call duration varies from 3.530 to 4.837 s. Call rise and fall are very short and similar to each other in duration. The limit between the call rise and sustain is not clear in calls with triangular envelope (Fig. 44A). There is a long sustain. This segment is usually regular and almost flat (slightly decreasing towards end of the segment – Fig. 44C), but some calls have very inclined sustains, where the beginning of the segment has low amplitude and gradually increases towards its end (Fig. 44A). The amplitude peak is at around the end of the first tenth or at the very end of the call duration. The envelope of the call varies from rectangular (Fig. 44C) to triangular (pointed left; Fig. 44A). More than 50 % of the call energy is concentrated in 46 % of the call duration around the amplitude peak. The call can have a slight PAM (silence intervals are absent between peaks). The rate of the PAM is *ca.* 11 Hz, forming *ca.* 50 cycles throughout the call. The cycle rise and fall are similar and the amplitude peak is at the middle of the cycle duration. The call has a harmonic series (Fig. 42C). The fundamental frequency is *ca.* 150 Hz. The first seven harmonics have very low energy or are absent in the audiospectrogram. There are *ca.* 12 adjacent emphasized harmonics. The wave periods are usually regular and harmonics are clear throughout the call. However, some calls have deterministic chaos regimes in several parts, mainly at their outset (Fig. 44B). The dominant frequency varies from *ca*. 1570 to 1870 Hz (Fig. 44B). The dominant harmonic varies from the ninth to the 19th, but it is usually between the ninth and 12th (Fig. 42C). There is no clear shift in the relative energy between the bands throughout the call. Most of the call energy is between 1100 and 2150 Hz (12 harmonics). Calls have no general FM (Fig. 44D), or have only a slight general FM, usually upward (Fig. 44B), but sometimes downward. There is usually a short downward FM at the end of the call (Fig. 44B). Additionally, there is a strong PFM throughout the call, which is usually independent, but it is directly proportional and synchronic to PAM when it is present (Fig. 44B, D).

Physalaemus biligonigerus species group

Only one call type was recorded for this group. All species have calls composed of a single harmonic note. The fundamental frequency is usually around 500 Hz, except for *P. riograndensis* whose calls have a fundamental frequency at *ca.* 1000 Hz. All species have calls with S-shaped harmonics, resulting from a general downward FM with an up-downward FM segment in the beginning of the call. The call envelope is considerably variable within the species of this group.

Physalaemus riograndensis Milstead, 1960

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note with high fundamental frequency (*ca.* 1000 Hz). It has a general downward FM throughout the call, with an up-downward FM segment in the its first third.

Call A (Fig. 45A–F and 42D). We examined 14 recordings, a total of 31 minutes, with *ca*. 820 calls from 50 males. Only some of these calls were measured (see Table 2). Call duration varies from 0.691 to 0.835 s. The envelope of the call is variable (Fig. 45A, C, D). In most calls, the limits between the call rise, sustain, and call fall are not clear. Calls usually have a short segment with very low amplitude at the beginning of the call, separated from the rest of the call by an abrupt change in amplitude. The shape of the call rise and fall is usually exponential. The sustain is irregular, usually composed of a shallow or deep valley (*i.e.*, with a concave shape; Fig. 45D). The amplitude peak is often at around the middle or after one third of the call duration. The envelope varies from elliptic (Fig. 45A, D) to triangular (pointed right; Fig. 45C). Due to the concave shape of the sustain, the triangular shape of some calls resembles an arrow. More than 50 % of the call energy is concentrated in 27 % of the call duration around the amplitude peak. There is no PAM in the call. The call has a harmonic series (Fig. 42D). The fundamental frequency is *ca.* 1020 Hz and the first six harmonics are generally emphasized. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency varies from *ca*. 950 to 1030 Hz (Fig. 42D). The first harmonic is the dominant (Fig. 42D, 45B, E, F). There is a clear shift in relative energy among bands. Although, usually, there is no shift in the dominant frequency, the higher bands get more energy towards the end of the call (Fig. 42D). Most of the call energy is between 850 and 1150 Hz (one harmonic). The call has a general downward FM (45B, E, F). Additionally, calls have an up-downward FM in the first third of the call duration, leading to arc-shaped bands in this part of the call, and a short upward FM at the end (45B, E, F). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call. There is no PFM.

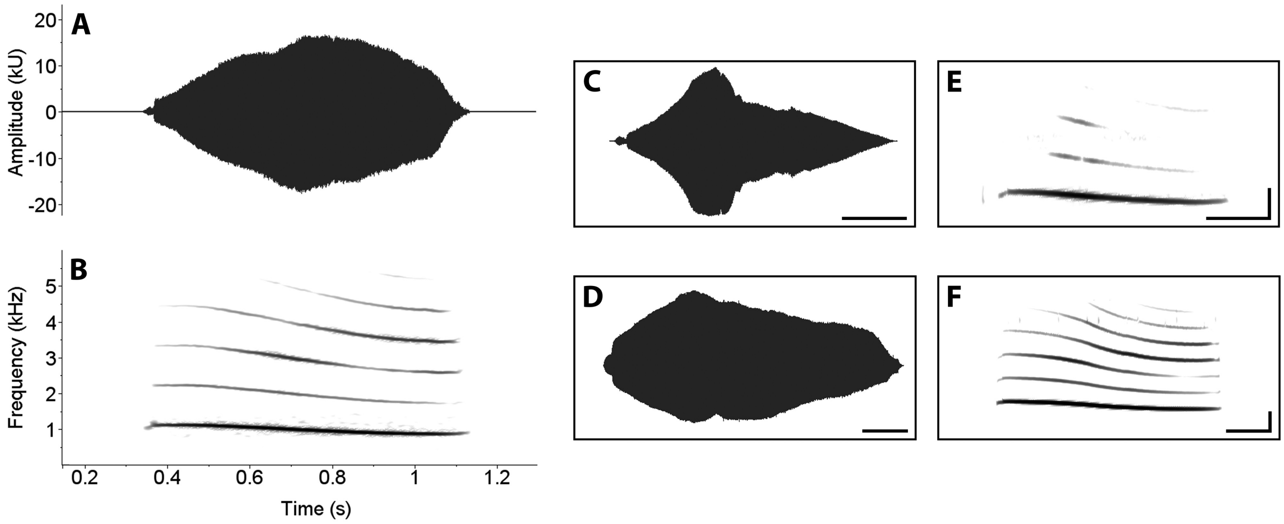

FIGURE 45. Call A of *Physalaemus riograndensis*. Oscillograms (A, C, and D) and audiospectrograms (B, E, and F). A typical call (A–B). Variant calls with different envelopes (C–F). Horizontal scale bars have 0.2 s; vertical scale bars have 1 kHz. Filter bandwidth (Hz): 92.1 (E and F); 42.3 (B).

Physalaemus biligonigerus **(Cope, 1861)**

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note. It has a general downward FM throughout the call but with an up-downward FM segment in the first fifth of the call.

Call A (Fig. 46A–F and 42E). We examined 29 recordings, a total of 65 minutes, with *ca*. 2140 calls from 105 males. Only some of these calls were measured (see Table 2). Call duration varies from 0.546 to 0.640 s. The envelope of the call is variable (Fig. 46A, C, D). In most calls, the limits between the call rise, sustain, and call fall are not clear. The ratio between call rise and fall duration, and their shapes, are highly variable. Most calls have rise and fall similar in duration, or the former longer than the fall. The shape of the envelopes varies from exponential or linear to logarithmic. The call rise can have two consecutive exponential parts, the first shorter than the second. The sustain is usually irregular, composed of shallow valleys and small peaks (Fig. 46A, C, D). In some calls, the call rise remains with very low amplitude until the limit with the sustain, where the amplitude increases abruptly (Fig. 46D). The amplitude peak is at around the end of the first third or two thirds of the call duration. The envelope varies from rectangular (Fig. 46C) to triangular (pointed left or right; Fig. 46D, A, respectively). Due to the asymmetry of some triangular envelopes, the shape resembles an arrow. More than 50 % of the call energy is concentrated in 30 % of the call duration around the amplitude peak. There is no PAM in the call. The call has a harmonic series (Fig. 42E). The fundamental frequency is *ca.* 570 Hz and approximately the first eight harmonics are emphasized. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency varies from *ca*. 600 to 650 Hz (Fig. 46B). The dominant harmonic varies from the first to the sixth (except the second), but it is usually the first (Fig. 42E, 46B, E, F). There is a clear shift in relative energy between the bands; the dominant frequency gets higher toward the end of the call, starting at the first harmonic, moving to the fifth, and ending at the sixth; thenceforth it decreases, ending at the third harmonic (sometimes skipping the fourth harmonic; Fig. 42E, 46B, E, F). Most of the call energy is between 450 and 2950 Hz (four to six harmonics). The call has a general downward FM (Fig. 46B, E, F). Additionally, the calls have an up-downward FM in the first fifth of the call duration, leading to a arc-shaped bands in this part of the call, and a short downward FM at the end (Fig. 46B, E, F). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call. There is no PFM.

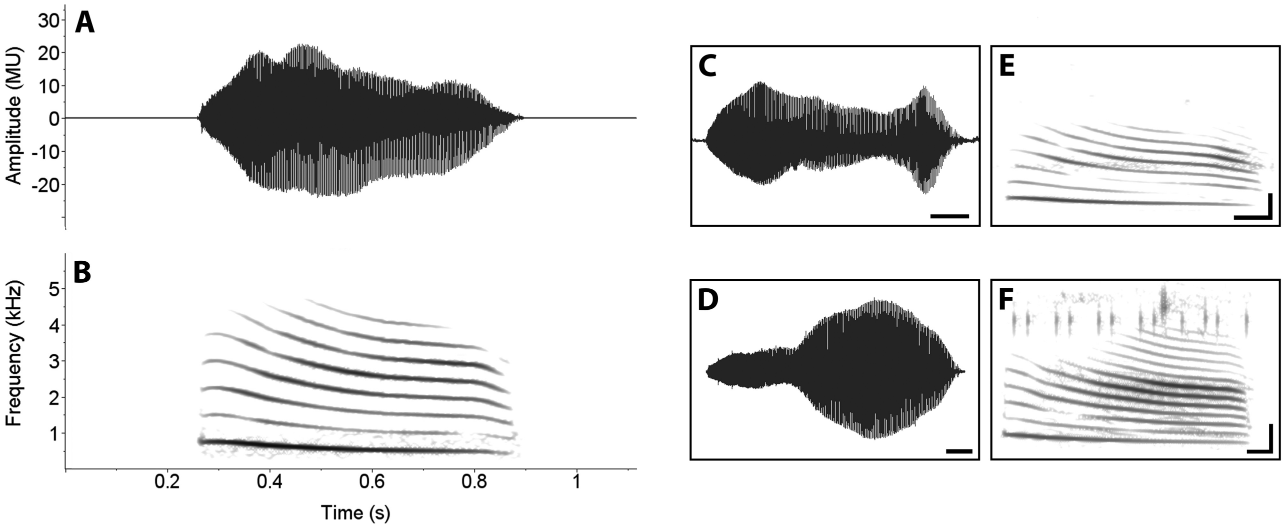

FIGURE 46. Call A of *Physalaemus biligonigerus*. Oscillograms (A, C, and D) and audiospectrograms (B, E, and F). A typical call (A–B). Variant calls with different envelopes and spectral features (C–F). Note the shorter duration of the initial FM segment (F). Horizontal scale bars have 0.1 s; vertical scale bars have 1 kHz. Filter bandwidth (Hz): 61.9 (B); 62.8 (E); 69.0 (F). Pulses of high frequency in the background in (F) correspond to calls of *Pseudopaludicola* sp.

Physalaemus marmoratus (Reinhardt & Lütken, 1862)

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note. It has a general downward FM, with an up-downward FM segment in the first third of the call.

Call A (Fig. 47A–J and 42F). We examined 15 recordings, a total of 31 minutes, with *ca.* 1100 calls from 44 males. Only some of these calls were measured (see Table 2). Call duration varies from 0.614 to 0.938 s. The envelope of the call is highly variable (Fig. 47A, C–F). In most calls, the limits between the call rise, sustain, and call fall are not clear. The ratio between durations of call rise and fall, and their shapes, are highly variable. The sustain is usually irregular, composed of shallow valleys and small peaks (Fig. 47A, C–F). In some calls the rise remains with very low amplitude until the limit with the sustain, where the amplitude increases abruptly (Fig. 47D). In other calls, the call fall has this same pattern, with an abruptly amplitude decrease after the sustain and thenceforth with low and constant amplitude until the end of the call (Fig. 47C). The amplitude peak is usually at around the end of the first third of the call duration. The envelope of the calls varies from rectangular (Fig. 47E, F) to triangular (pointed left or right; Fig. 47D, A, respectively). Due to the asymmetry of some triangular envelopes, the shape resembles an arrow. More than 50 % of the call energy is concentrated in 29 % of the call duration around the amplitude peak. There is no PAM in the call. The call has a harmonic series (Fig. 42F). The fundamental frequency is *ca.* 510 Hz and the first six harmonics are generally emphasized. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency is *ca.* 500 Hz (Fig. 47B). The first is dominant harmonic (Fig. 42F). There is a clear shift in relative energy between bands; although there is no shift in dominant frequency, the higher bands get more energy toward the end of the call (Fig. 47G–J). Most of the call energy is between 400 and 2100 Hz (three to five harmonics). The call has a general downward FM (Fig. 47B, G–J). Additionally, the calls have an up-downward FM in the first third of the call duration, leading to slightly arc-shaped bands in this part of the call, and short downward FM at the end (Fig. 47B, G–J). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call. There is no PFM.

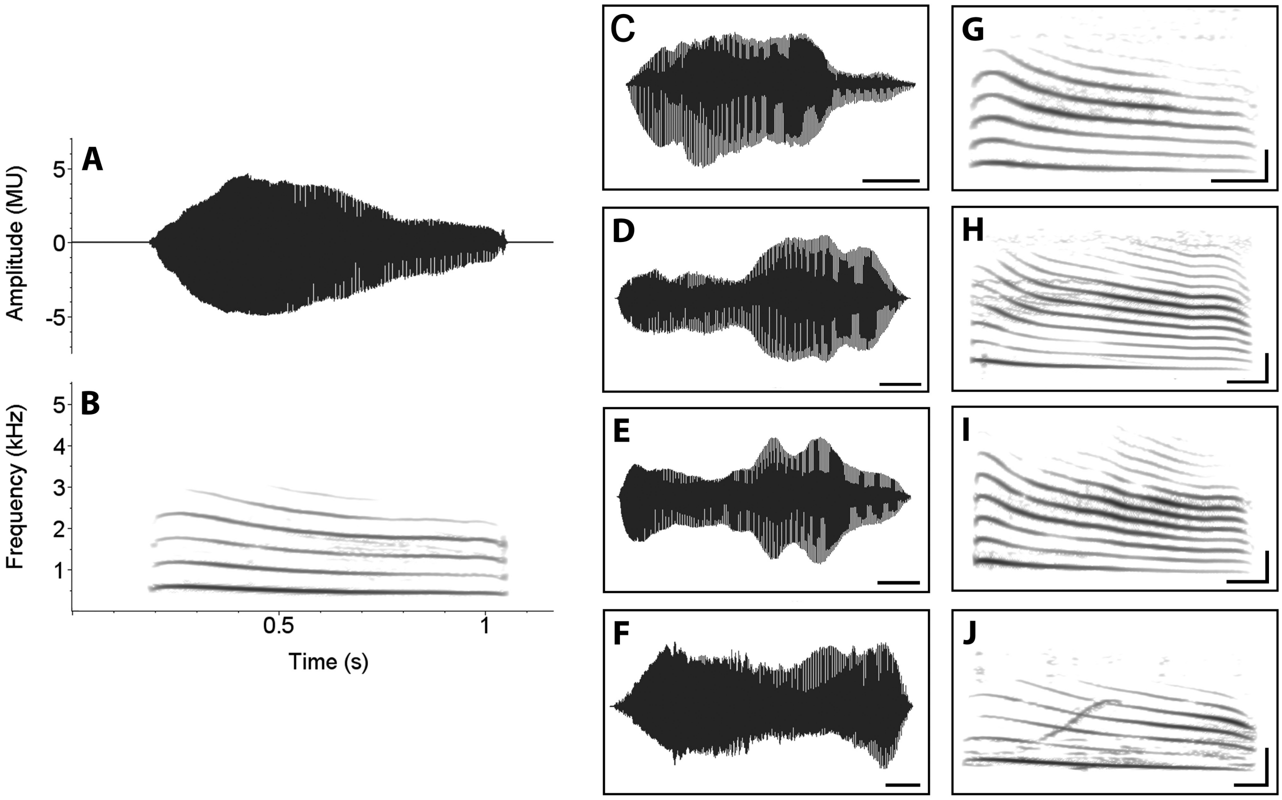

FIGURE 47. Call A of *Physalaemus marmoratus*. Oscillograms (A, C–F) and audiospectrograms (B, G–J). A typical call (A–B). Variant calls with different envelopes and spectral features (C–J). Note the different slopes in the FM segments (G–J). Horizontal scale bars have 0.1 s; vertical scale bars have 1 kHz. Filter bandwidth (Hz): 67.4 (G); 55.2 (H); 67.4 (I); 46 (B and J).

Physalaemus santafecinus Barrio, 1965

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note. It has a general downward FM, with an up-downward FM segment in the first third of the call.

Call A (Fig. 48A–D and 42G). We examined two recordings, a total of three minutes, with 61 calls from two males. Only some of these calls were measured (see Table 2). Call duration varies from 0.330 to 0.375 s. The envelope of the call is variable. In most calls, the rise and fall are similar in duration and shape (exponential). In some calls, the limits between call rise, sustain, and call fall are not clear, with linear or logarithmic-shaped rise and fall and the sustain with a convex shape (calls with elliptic envelope; Fig. 48C). The amplitude peak is usually at around the end of the first seven tenths of the call duration or at the middle of the call. The envelope varies from elliptic (Fig. 48C) to triangular (pointed left; Fig. 48A). Due to the concave shape of the sustain, the triangular envelope of some calls resembles an arrow (Fig. 48A). More than 50 % of the call energy is concentrated in 36 % of the call duration around the amplitude peak. There is no PAM in the call. The call has a harmonic series (Fig. 42G). The fundamental frequency is *ca.* 490 Hz and approximately the first seven harmonics are emphasized. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency varies from *ca.* 474 to 2627 Hz (fig. 48B). The dominant harmonic varies from the first to sixth (rarely the second harmonic), but it is usually the first (Fig. 42G, 48B, D). There is a clear shift in relative energy between the bands; the dominant frequency gets higher toward the end of the call, starting at the first harmonic, moving to the fifth and ending at the sixth; thenceforth it decreases, usually skipping the fifth and ending at the third or second harmonic (Fig. 42G, 48B, D). Most of the call energy is between 450 and 2650 Hz (four to six harmonics). The call has a general downward FM (Fig. 48B, D). Additionally, calls have an up-downward FM in the first third of the call duration, leading to slightly arc-shaped bands in this part of the call (Fig. 48B), and a short downward FM at the end (Fig. 48B, D). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call. There is no PFM.

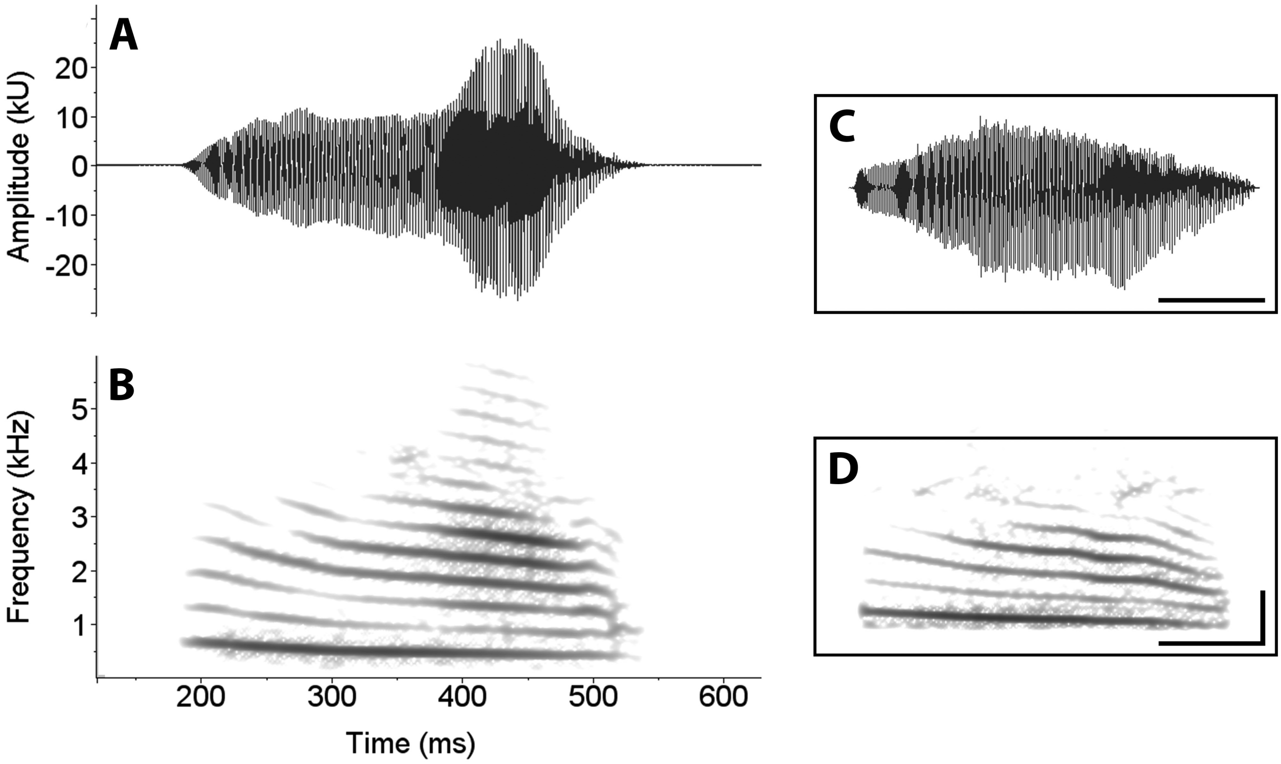

FIGURE 48. Call A of *Physalaemus santafecinus*. Oscillograms (A and C) and audiospectrograms (B and D). A typical call (A–B). A variant call with a different envelope and spectral features (C–D). Note the different slopes in the FM segments (D). Horizontal scale bars have 0.1 s; vertical scale bars have 1 kHz. Filter bandwidth (Hz): 84.6 (B and D).

Physalaemus gracilis species group

Only one call type was recorded for this group. All species have calls composed of a single harmonic note, with fundamental frequency around 500 Hz. All species have calls with S-shaped harmonics, resulting from a general downward FM with an up-downward FM segment in the beginning of the call. This pattern is less clear in *P. lisei* and *P. jordanensis* due to less defined initial FM in the former, and to discontinuity of harmonics as a result of pulse-PAM in the latter. *Physalaemus jordanensis* is the only species of the group with pulse-PAM and PFM in its call. The call envelope is considerably variable within the species of this group.

Physalaemus carrizorum Cardozo & Pereyra, 2018

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note, with general downward FM, but with an up-downward FM segment in the first fourth of the call.

Call A (Fig. 49A–D and 42H). We examined one recording, a total of four minutes, with 44 calls from three males. Only some of these calls were measured (see Table 2). Call duration varies from 2.360 to 4.118 s. The envelope of the call is variable. In most calls, rise and fall are similar in duration and shape (exponential) and the sustain is long. Some sustains are regular (Fig. 49C) and others are irregular (Fig. 49A), with short and shallow valleys. In some calls, the limits between the call rise, sustain, and call fall are not clear. Usually, the envelope is divided into two parts with different amplitude levels (Fig. 49A). The amplitude peak is usually at the end of the first seven tenths of the call duration. The envelope varies from elliptic or rectangular (Fig. 49C), to triangular (pointed left; Fig. 49A; rarely pointed right). Due to the asymmetry of some triangular envelopes, the shape resembles an arrow. More than 50 % of the call energy is concentrated in 36 % of the call duration around the amplitude peak. There is no PAM in the call. The call has a harmonic series (Fig. 42H). The fundamental frequency is *ca.* 460 Hz and approximately the first seven harmonics are emphasized. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency varies from *ca.* 410 to 2630 Hz (Fig. 49B). The dominant harmonic is the first, fifth, or sixth (Fig. 42H). There is a clear shift in relative energy between the bands; the dominant frequency gets higher toward the end of the call, starting at the first harmonic, moving to the fifth, and ending at the sixth (Fig. 42H, 49B). Most of the call energy is between 350 and 3500 Hz (eight to nine harmonics). The call has a general downward FM (Fig. 49B, D). Additionally, calls have an up-downward FM in the first fourth of the call duration, leading to slightly arc-shaped bands in this part of the call (Fig. 49B, D), and a short downward FM at the end (Fig. 49B). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call. Some calls have a slight PFM.

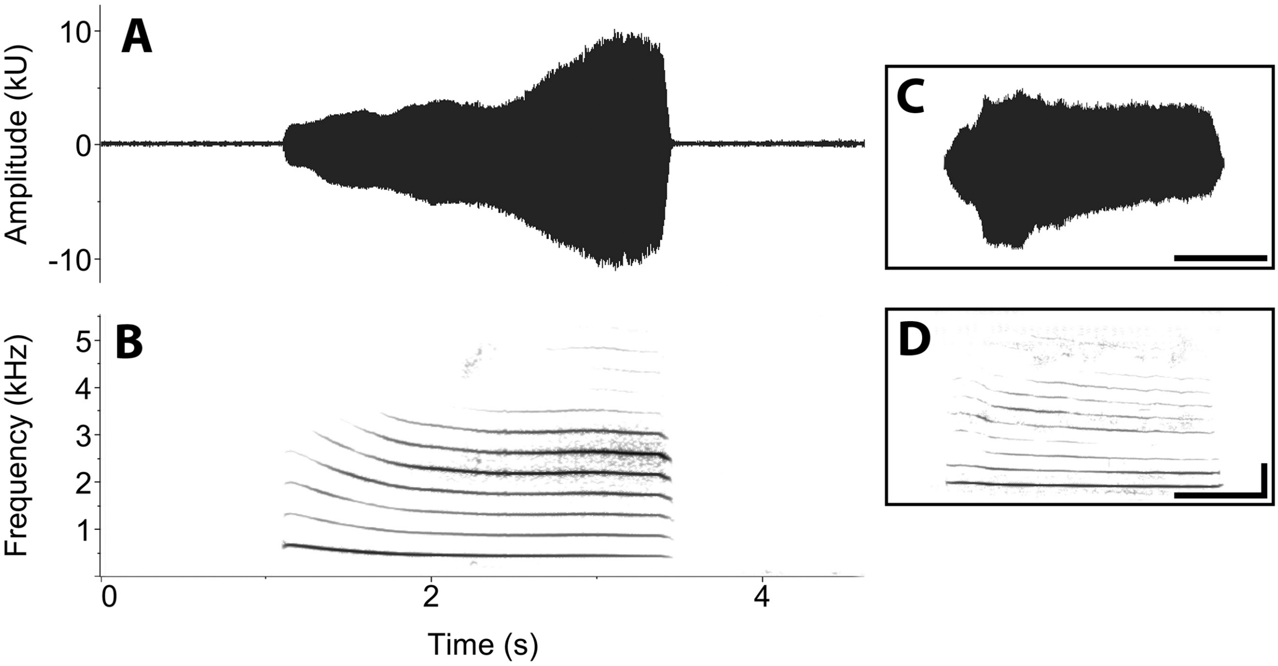

FIGURE 49. Call A of *Physalaemus carrizorum*. Oscillograms (A and C) and audiospectrograms (B and D). A typical call A (A–B). Variant calls A with different envelopes and spectral features (C–D). Horizontal scale bars have 1 s (C–D); vertical scale bar has 1 kHz. Filter bandwidth (Hz): 31.7 (B and D).

Physalaemus gracilis **(Boulenger, 1883)**

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note, with general downward FM, but with an up-downward FM segment in the first sixth of the call.

Call A (Fig. 50A–T and 52A). We examined 40 recordings, a total of 158 minutes, with *ca*. 2480 calls from 106 males. Only some of these calls were measured (see Table 2). Call duration varies from 0.451 to 0.565 s. The envelope of the call is variable (Fig. 50A, C–G, M–P). In most calls, rise and fall are similar in duration and shape (exponential) and the sustain is long. Some sustains are regular (Fig. 50A, G, M, N, O) and others are irregular, with short and shallow valleys, mainly at the beginning of the segment (Fig. 50D, F, P). In several calls, the sustain has a convex shape and the limits between the call rise, sustain, and call fall are not clear. Usually, the envelope is divided into two parts with different amplitude levels (Fig. 50C). The amplitude peak is usually at the end of the first seven tenths of the call duration. The envelope varies from elliptic or rectangular (Fig. 50A, D, F, G, M, N, O) to triangular (pointed left; Fig. 50C, E, P). Due to the asymmetry of some triangular envelopes, the shape resembles an arrow. More than 50 % of the call energy is concentrated in 32 % of the call duration around the amplitude peak. There is no PAM in the call. The call has a harmonic series (Fig. 52A). The fundamental frequency is *ca.* 510 Hz and approximately the first seven harmonics are emphasized. The wave periods are regular and harmonics are clear throughout the call. Subharmonics ($f_0$1/2 and $f_0$1/3) are common at the beginning and middle of the call (Fig. 50I, L, Q, R). The dominant frequency varies from *ca*. 2110 to 2760 Hz (Fig. 50B). The dominant harmonic varies from the first to the seventh (except the second), but it is usually the fourth, fifth, or sixth (Fig. 52A). There is a clear shift in relative energy between the bands; the dominant frequency gets higher toward the end of the call, starting at the first harmonic, moving to the third, fourth, fifth and sixth, and ending at the sixth or seventh; thenceforth, the dominant frequency decreases in some calls, moving to the fourth harmonic (Fig. 52A, 50B). Most of the call energy is between 950 and 3050 Hz (four to five harmonics). The call has a general downward FM (Fig. 50B, H–L, Q–T).

Additionally, calls have an up-downward FM in the first sixth of the call duration, leading to slightly arc-shaped bands in this part of the call, and a short downward FM at the end (Fig. 50B, H–L, Q–T). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call. Some calls have a slight PFM (Fig. 50H, I, L).

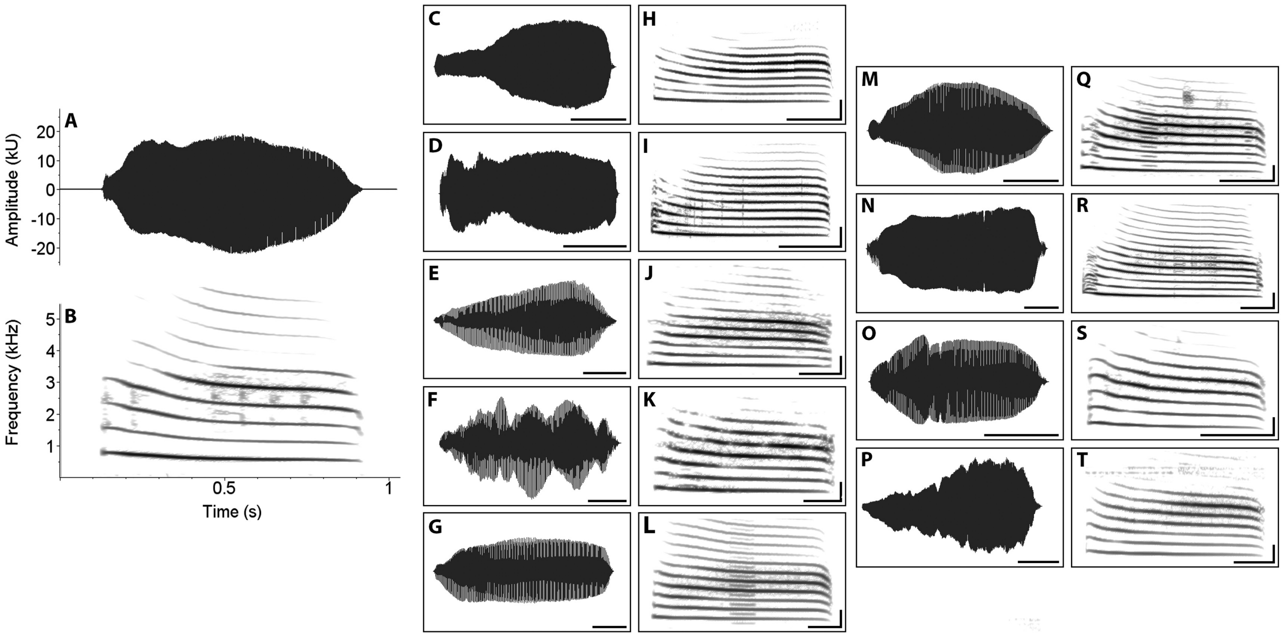

FIGURE 50. Call A of *Physalaemus gracilis*. Oscillograms (A, C–G, and M–P) and audiospectrograms (B, H–L, and Q–T). A typical call A (A–B). Variant calls A with different envelopes and spectral features (C–T). Note the presence of subharmonics at the beginning or middle of the call (I, L, Q, and R). Horizontal scale bars have 0.5 s (C–L) and 0.2 s (M–T); vertical scale bars have 1 kHz. Filter bandwidth (Hz): 42.3 (B); 84.6 (K, L, and T); 74.6 (J); 55.2 (I and R); 69.0 (H and S); 61.4 (Q).

Physalaemus lisei **Braun & Braun, 1977**

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note with a long duration, slight PAM (no silence intervals between peaks) and irregular PFM. The bands have a general downward FM and a short upward FM segment at the end. Calls usually have nonlinear regimes such as deterministic chaos and subharmonics.

Call A (Fig. 51A–N and 52B). We examined 19 recordings, a total of 89 minutes, with *ca*. 915 calls from 50 males. Only some of these calls were measured (see Table 2). Call duration varies from 0.967 to 1.997 s. The envelope of the call is variable; durations of call rise and fall are usually short and similar in duration, with a long sustain in between; the rise and fall shapes vary from logarithmic to almost linear or exponential. The sustain is flat (Fig. 51E, F, H, I) or gradually ascending (Fig. 51C, G). Some calls have a final part with higher amplitude (Fig. 51C, G, I). Shallow and short amplitude valleys can be present, mainly at the beginning and end of the call (Fig. 51C, I). The amplitude peak is usually at the very end of the call duration. Depending on the slope of the sustain, the envelope varies from rectangular (Fig. 51E, F, H, I) to triangular (pointed left; Fig. 51C, G). More than 50 % of the call energy is concentrated in 47 % of the call duration around the amplitude peak. The call can have a slight PAM (there is no silence interval between peaks; Fig. 51E, G, H). The rate of the PAM is *ca.* 26 Hz, forming *ca.* 25 cycles throughout the call. The call has a harmonic series (Fig. 52B). The fundamental frequency is *ca.* 480 Hz and this band can be present with low energy or absent in audiospectrograms. Six adjacent harmonics are emphasized (first seven except the fundamental). Usually, the wave periods are regular and harmonics are clear throughout the call. However, several calls show nonlinear regimes such as subharmonics ($f_0$1/2, $f_0$1/3, $f_0$1/4, or $f_0$1/5), biphonation, and deterministic chaos (Fig. 51D, J, K, M). These phenomena can occur over the entire call. The dominant frequency varies from *ca.* 2330 to 2460 Hz (Fig. 51D). The dominant harmonic varies from the first to the fifth (except the second), but it is usually the fourth or fifth along the first half of the call (Fig. 52B). There is a clear shift in relative energy between the bands. Although there is no shift in the dominant frequency, higher bands get more energy towards the end of the call (Fig. 51D, L, N). Most of the call energy is between 950 and 3350 Hz (five to six harmonics). The call has

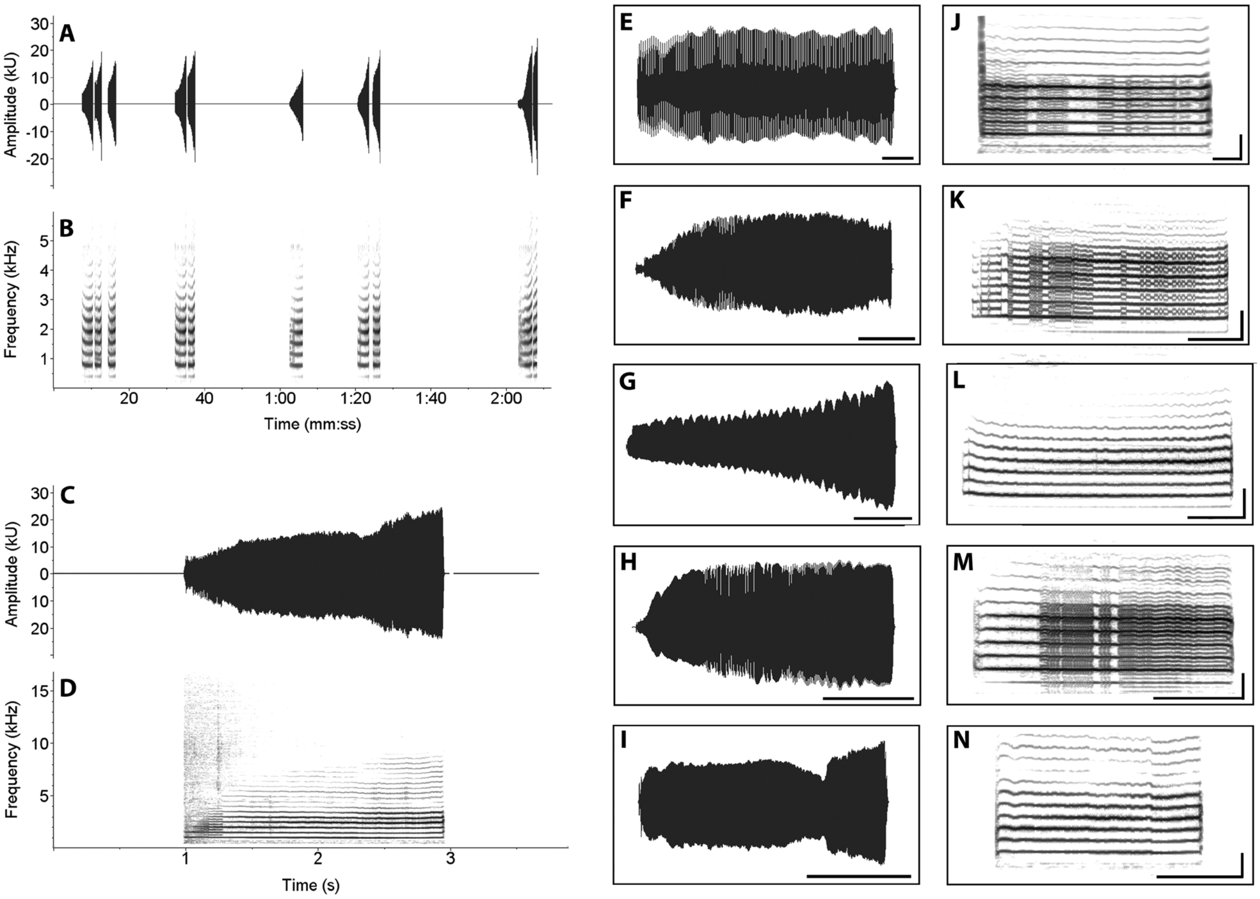

FIGURE 51. Call A of *Physalaemus lisei*. Oscillograms (A, C, E–I) and audiospectrograms (B, D, J–N). Ten calls gathered in groups (A–B). A typical call (C–D). Variant calls with different envelopes and spectral features (E–N). Note PFM and the subharmonics in the calls (J, K, L, M, and N). Horizontal scale bars have 0.5 s; vertical scale bars have 1 kHz. Filter bandwidth (Hz): 61.9 (D and P); 46 (K, L, N, and O); 69 (B); 55.2 (M).

a slight general downward FM (Fig. 51D, L, N). Additionally, calls have a very short and slight up-downward FM at their outset, leading to slightly arc-shaped bands in this part of the call, and a short upward FM at the end (Fig. 51L, N). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call. Some calls show clear PFM (Fig. 51L, N). Calls are usually emitted in irregular sequences, with two or three calls (Fig. 51A–B).

Physalaemus evangelistai Bokermann, 1967

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note, with a general downward FM and an up-downward FM segment in the first sixth of the call duration. Calls usually have intermediate PAM (with no silence intervals between peaks) and PFM throughout their duration.

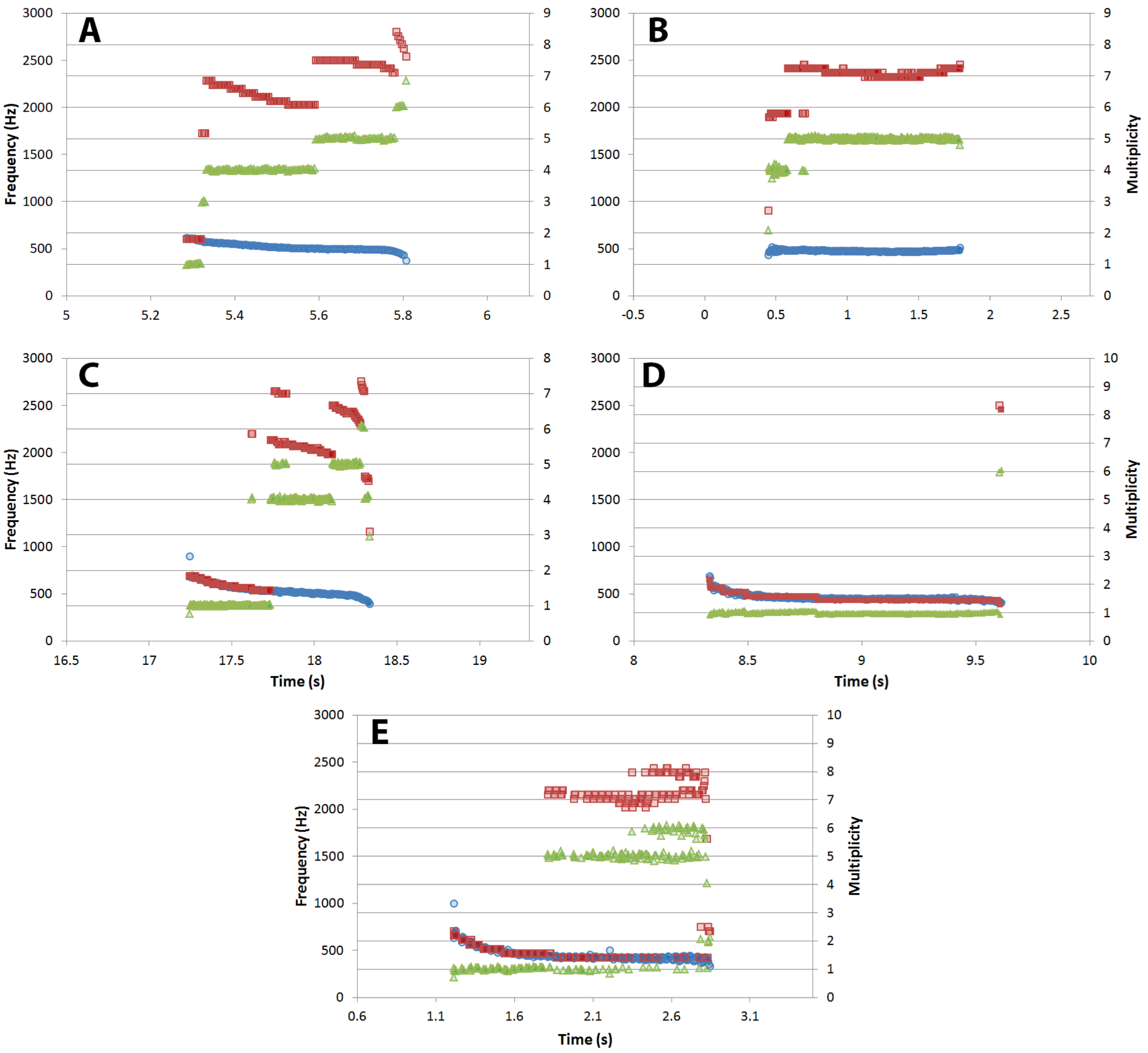

FIGURE 52. Multiplicity relationship between "instantaneous" dominant frequency and *w* of calls A of four *Physalaemus* species. Each graph shows a single call A of *P. gracilis* (A), *P. lisei* (B), *P. evangelistai* (C), *P. barrioi* (D), *P. jordanensis* (E). Grid corresponds to the harmonic values (right y-axis). Red squares are the values of "instantaneous" dominant frequency; blue circles are the values of the reciprocal of *w*; green triangles are the factor values of the ratio "instantaneous" dominant frequency / *w* reciprocal per delta time. Delta time corresponds to the duration of one period of the measured acoustic oscillation. Note that factors around integer values suggest harmonic relationship between the frequency calculated (*w* reciprocal) and the dominant frequency.

Call A (Fig. 53A–F and 52C). We examined eight recordings, a total of 27 minutes, with *ca*. 340 calls from 20 males. Only some of these calls were measured (see Table 2). Call duration varies from 0.976 to 1.358 s. Call rise duration is very short and similar to call fall duration; the call rise and fall shapes vary from logarithmic to almost linear or exponential. The sustain is flat or gradually ascending (Fig. 53D, C). There is a long shallow valley at the beginning of the sustain (Fig. A, C, D). The amplitude peak is usually at the end of the first seven tenths of the call duration. The envelope varies from rectangular (Fig. 53A, D) to triangular (pointed left; Fig. 53C). More than 50 % of the call energy is concentrated in 36 % of the call duration around the amplitude peak. Some calls show an intermediate PAM only in the final two fourths of the call duration. This PAM yields emphasized cycles (with no silence intervals between peaks; Fig. 53A, C). The rate of the PAM is *ca.* 9 Hz, forming *ca.* 10 cycles throughout the call. The cycle rise and fall are similar, with amplitude peak at the middle of the cycle. The call has a harmonic series (Fig. 52C). The fundamental frequency at *ca.* 540 Hz and approximately the first six harmonics are emphasized. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency varies from *ca.* 670 to 2910 Hz (Fig. 53B). The dominant harmonic varies from the first to sixth (except the second), but it is usually the first or fourth (Fig. 52C). There is a clear shift in relative energy between the bands; the dominant frequency increases towards the end of the call, starting at the first harmonic, moving to the fourth and fifth, and ending at the sixth; thenceforth, it decreases, ending at the third (Fig. 52C, 53E, F). Most of the call energy is between 550 and 3100 Hz (three to four harmonics). The call has a general downward FM, with a short up-downward FM at the first sixth of the call duration, leading to slightly arc-shaped bands in this part of the call, and a short downward FM at the end (Fig. 53B, E, F). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call. Some calls have a PFM during the entire call independent of the PAM. Other calls have PFM inversely proportional and synchronic to the PAM.

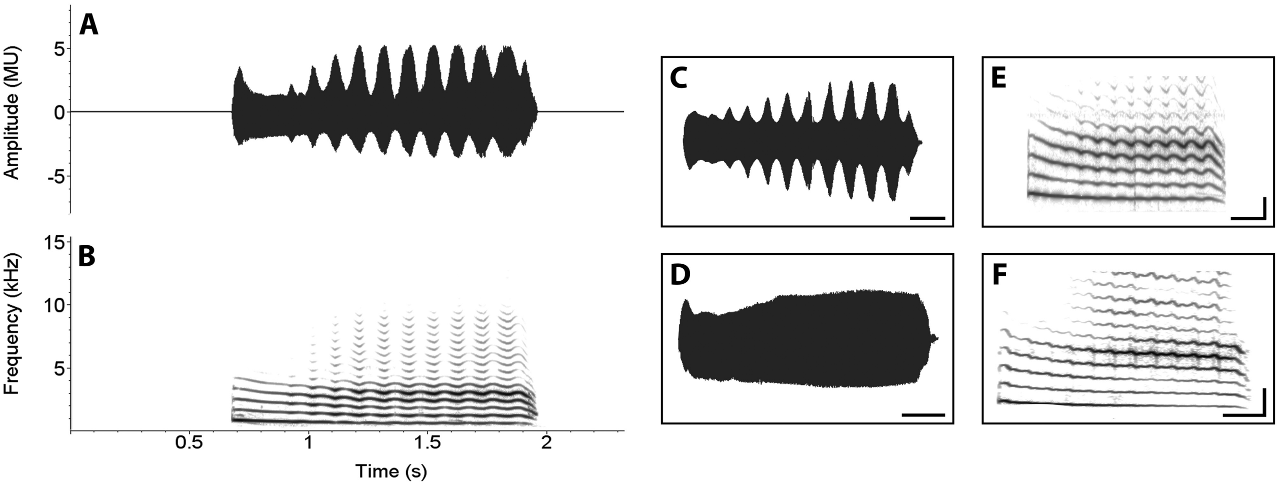

FIGURE 53. Call A of *Physalaemus evangelistai*. Oscillograms (A, C, and D) and audiospectrograms (B, E, and F). A typical call (A–B). Variant calls with different envelopes (C–F). Note the absence of PAM in the call (D–F). Horizontal scale bars have 0.2 s; vertical scale bars have 1 kHz. Filter bandwidth (Hz): 110 (B); 69 (E); 42.3 (F).

Physalaemus barrioi Bokermann, 1967

We found a single call type for the species, referred to as call A. The call has a single harmonic note with a long duration and general downward FM, with an up-downward FM segment in the first seventh of the call.

Call A (Fig. 54A–L and 52D). We examined eight recordings, a total of 13 minutes, with *ca*. 70 calls from eight males. Only some of these calls were measured (see Table 2). Call duration varies from 1.323 to 2.038 s. Call rise duration is short and similar to call fall duration; the call rise and fall shapes vary from logarithmic to almost linear or exponential. The sustain is irregular, generally flat (Fig. 54A, E, F) or ascending (Fig. C, D, G). In this latter case, the amplitude gets higher towards the end of the call. There is usually a long shallow valley at the beginning or at the middle of the sustain (Fig. 54A, C, D, E, G). The amplitude peak is usually at the end of the first three fifths of the call duration. The envelope varies from elliptic (Fig. 54F), rectangular (Fig. 54A, E, G) to triangular (usually pointed left; Fig. C, D). More than 50 % of the call energy is concentrated in 39 % of the call duration around the amplitude peak. There is no PAM in the call. The call has a harmonic series (Fig. 52D). The fundamental frequency is *ca.* 460 Hz and the first seven harmonics are generally emphasized. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency varies from *ca.* 470 to 2580 Hz. The dominant harmonic is the first or the sixth, but usually the first (Fig. 52D, 54B, H–L). There is a clear shift in relative energy between the bands; the dominant frequency increases towards the end of the call, starting at the first harmonic and moving to the sixth at the very end of the call (Fig. 52D, 54B, H–L). Most of the call energy is between 450 and 2700 Hz (four to six harmonics). The call has a general downward FM. Additionally, the calls have an up-downward FM at the first seventh of call duration, leading to slightly arc-shaped bands in this part of the call, and a short downward FM at the end (Fig. 54B, H–L). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call. There is no PFM.

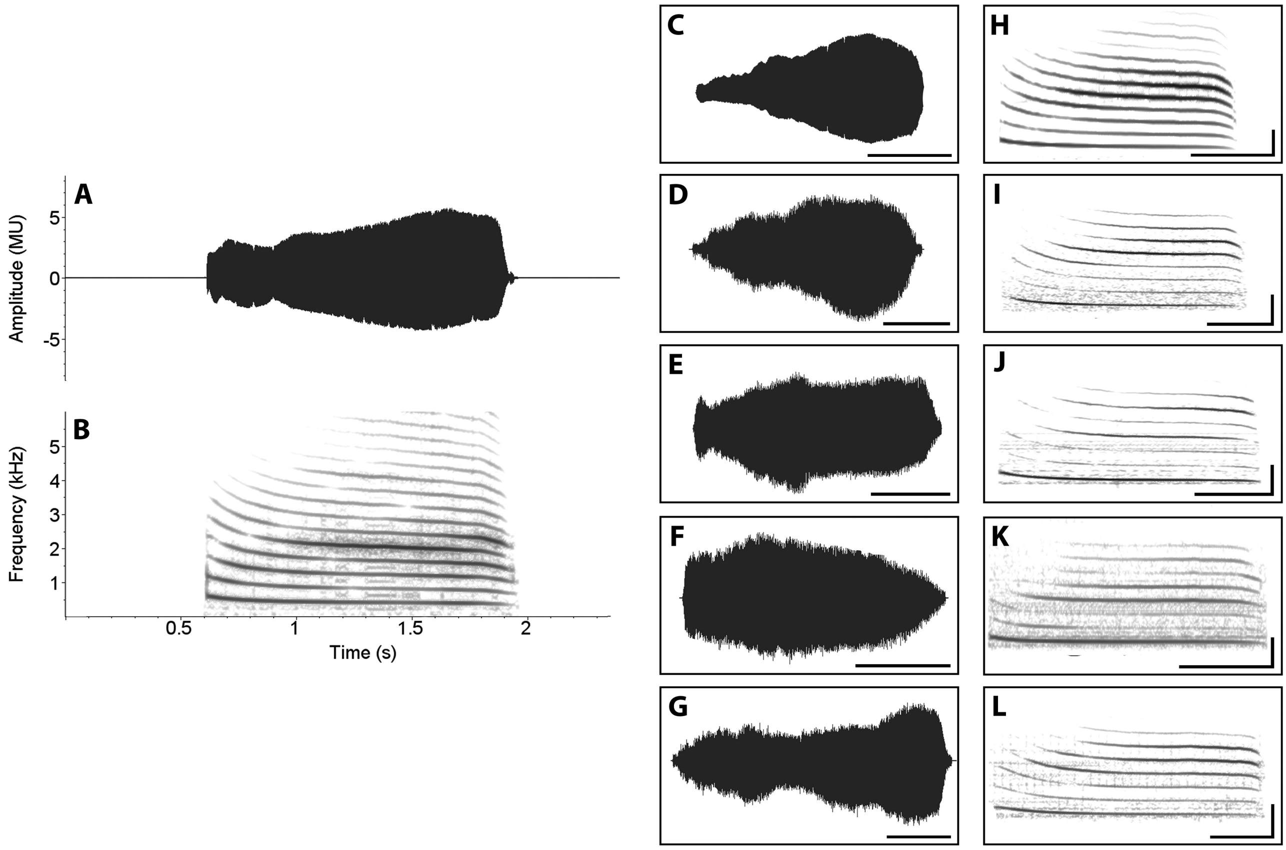

FIGURE 54. Call A of *Physalaemus barrioi*. Oscillograms (A, C–G) and audiospectrograms (B, H–L). A typical call (A–B). Variant calls with different envelopes (C–L). Note the subharmonics at the middle of the call (B). Horizontal scale bars have 0.5 s; vertical scale bars have 1 kHz. FFT (points): 2000 (H, J, and I); 2500 (B); 1024 (K); 1500 (L).

Physalaemus jordanensis Bokermann, 1967

We found a single call type for the species, referred to as call A. The call is composed of a single harmonic note with an elliptic or triangular envelope. The call is composed of a sequence of pulses (pulse-PAM) with silence intervals between pulses. It has a general downward FM throughout the call but with a short and slight up-downward FM segment in the first seventh of the call duration.

Call A (Fig. 55A–N and 52E). We examined 20 recordings, a total of 47 minutes, with *ca*. 1100 calls from 55 males. Only some of these calls were measured (see Table 2). Call duration varies from 0.980 to 1.961 s. The envelope of the call is variable. The call rise and fall are very short and similar to each other. The sustain is irregular (Fig. 55G), generally flat (Fig. 55A, C, F) or ascending (Fig. 55E, H). There is usually a long shallow valley at the beginning or at the middle of the sustain. In several calls, the first half of the envelope has lower amplitude than the second half. The amplitude peak is usually at around the end of the first four fifths of the call duration. The envelope of the calls varies from elliptic (Fig. 54A) to rectangular (Fig. 55C, F) or triangular (pointed left; Fig. 54E, G, H). More than 50 % of the call energy is concentrated in 45 % of the call duration around the amplitude peak. The call has a strong PAM (silence intervals are present between pulses; Fig. 55A–N). The rate of the PAM is *ca.* 20 Hz, forming *ca.* 31 pulses throughout the call. The interpulse intervals are variable but they are usually fourfold longer than the pulse duration. Silence intervals are absent between the last pulses of the call (pulses are juxtaposed; Fig.55D, J)). The last pulse longer than the others (Fig. 55A, B, C, D, E, I, J, K). The call has a harmonic series (Fig. 52E). The fundamental frequency is *ca.* 450 Hz and approximately the first seven harmonics are emphasized. The wave periods are regular and harmonics are clear throughout the call. The dominant frequency varies from *ca.* 560 to 2440 Hz (Fig. 55B). The dominant harmonic varies from the first to the sixth (except the third), but during the first half of the call, it is usually the first (Fig. 52E; 55B, I–N). There is a clear shift in relative energy among the bands; the dominant frequency increases towards the end of the call, starting at the first harmonic, moving to the fifth and

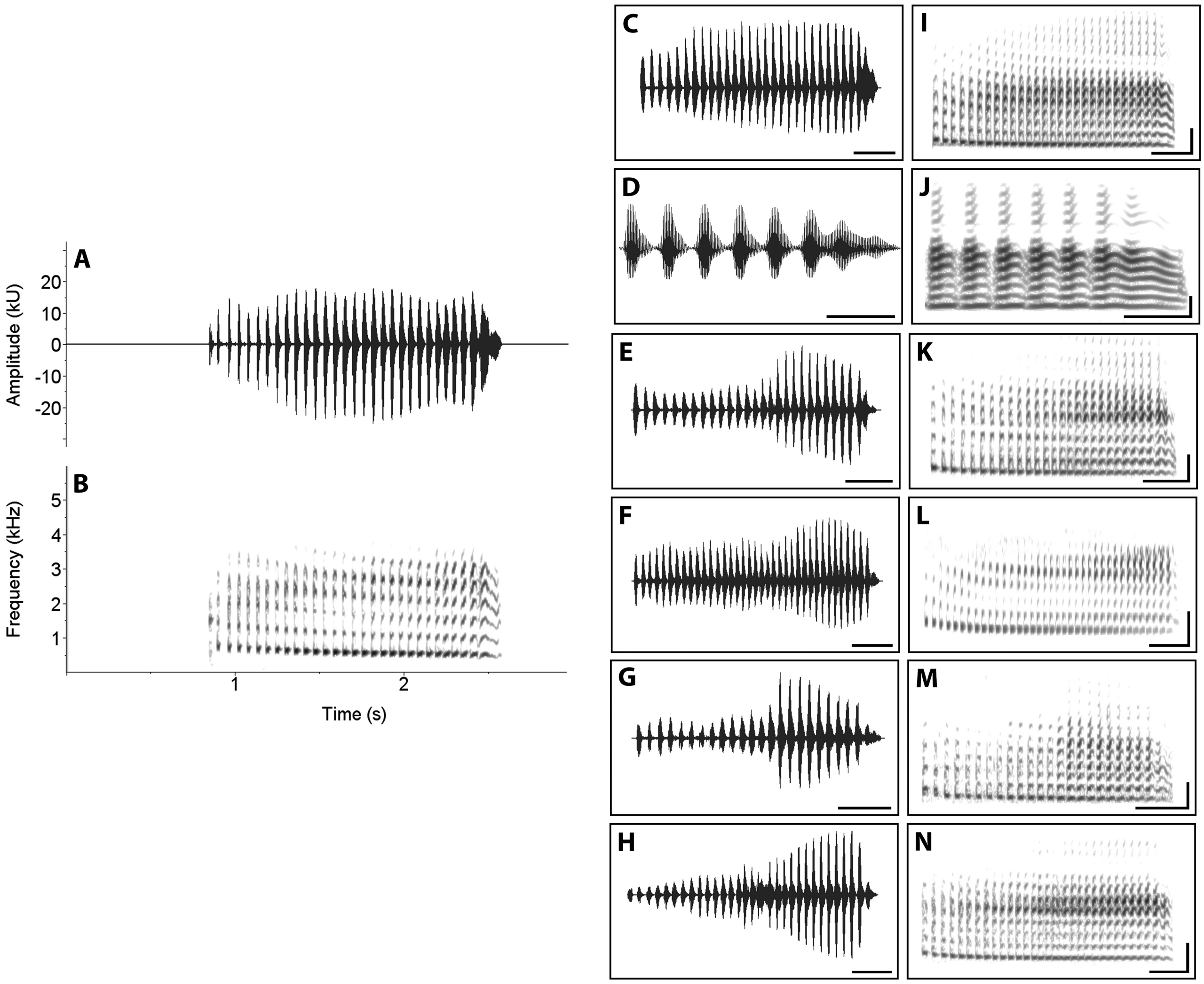

FIGURE 55. Call A of *Physalaemus jordanensis*. Oscillograms (A, C–H) and audiospectrograms (B, I–N). A typical call (A–B). Variant calls with different envelopes (C and I; E–H, K–N). Final pulses of a call (D and J). Note the longer duration of the final pulse (D and J). Horizontal scale bars have 0.3 s (C and I; E–H, K–N) and 0.1 s (D and J); vertical scale bars have 1 kHz. Filter bandwidth (Hz): 135 (L); 78.9 (M); 110 (J); 61.4 (N); 69 (I and K); 61.9 (B).

ending at the sixth; at the end of the call, the dominant frequency jumps among the first, fourth, fifth and sixth harmonics (Fig. 52E; 55B, I–N). Most of the call energy is between 400 and 3700 Hz (five to six harmonics). The call has a general downward FM, a short and slight up-downward FM in the first seventh of the call duration, leading to slightly arc-shaped bands in this part of the call, and usually a short upward FM at the end (Fig. 55B, I–N). The general downward FM and the initial up-downward FM result in S-shaped harmonics when considering the entire call. Additionally, there is PFM throughout the call, which is directly proportional and synchronic with the pulse-PAM (Fig. 55D, J, G, M).

Quantitative comparisons among the species and species groups

The first two components extracted from the PCA account for 54 % of the total variation. The first and second components correspond to 29.3 and 24.7 %, respectively. The biplot of these components shows a clear discrimination of two clusters (Fig. 56A, B), one containing most taxa of the *P. signifer* clade, *i.e.*, species of the *P. signifer* (except *P. nanus*) and *P. deimaticus* species groups plus two species with no group assigned, *P. nattereri* and *P. maculiventris* (Fig. 56A, Table 1). Additionally, species of the *P. henselii* and *P. olfersii* species groups and a single species of the *P. cuvieri* species group (*P. centralis*), which belong to *P. cuvieri* clade, were also found in this cluster (Fig. 56A, Table 1).

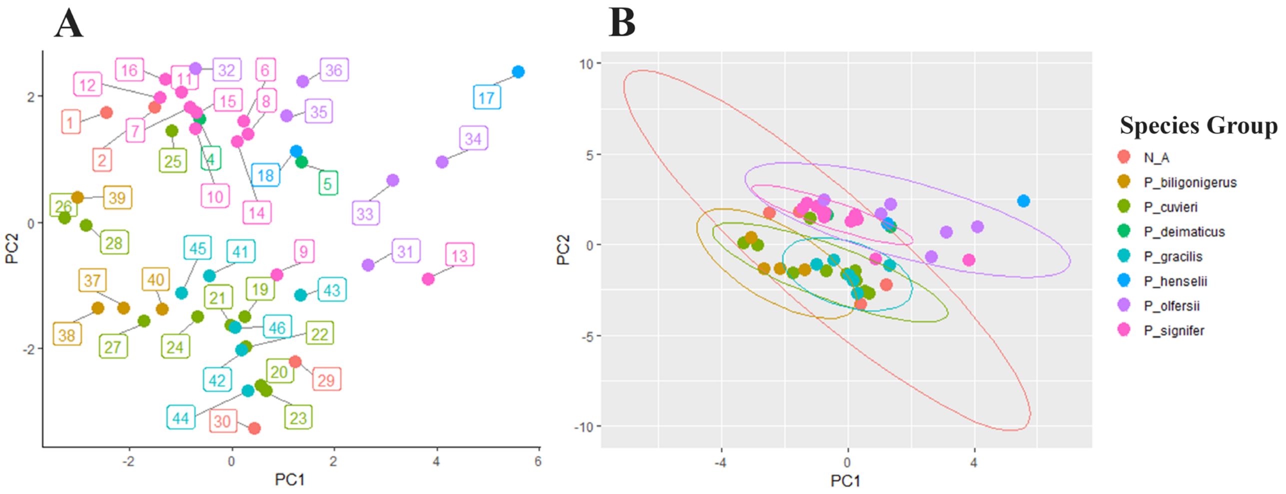

FIGURE 56. Distribution of 45 species (= samples) of *Physalaemus* along the first and second components of a Principal Component Analysis (PCA) generated from 12 acoustical variables (A–B). Number labels in (A) indicate which species is each dot on graph. The species' numbers follow those in Table 1. Ellipses in (B) correspond to confidence interval of 95 %. Colors indicate the species groups to which the species belong (see caption in the figure). "N_A" means "no species group assigned" (see Table 1). Note that there are two groups, one basically composed of *P. deimaticus*, *P. henselii*, *P. olfersii*, and *P. signifer* species groups and the other composed of *P. biligonigerus*, *P. cuvieri* (except *P. centralis*; see text), and *P. gracilis* species groups.

The other cluster contains most taxa of the *P. cuvieri* clade, *i.e.*, species of *P. biligonigerus*, *P. cuvieri* (except *P. centralis*), and *P. gracilis* species groups plus two species with no group assigned, *P. cicada* and *P. aguirrei*. *Physalaemus nanus*, which belong to *P. signifer* clade, was also found in this cluster (Fig. 56A, Table 1).

The most explanatory variables were the frequency delta, fundamental frequency, bandwidth, and dominant frequencies at the beginning and end of the call along the second component (Fig. 57). The variation found for the first component mainly correspond to within-cluster variation (Fig. 57A, C), while most of the separation between the two clusters is explained by the variation along the second component (Fig. 57B, C).

Discussion

Descriptive terminology and acoustic homology

The terminology used in acoustic descriptions of *Physalaemus* is highly variable. Similar and apparently homologous structures have been referred to under different names. This variation apparently stems from two main reasons. One is the application of terms without concern for homology. This nomenclature usually followed arbitrary applications of bioacoustic terms (see Littlejohn 2001), focusing only on describing differences between calls instead of also properly identifying acoustic correspondences (Robillard *et al.* 2006a; Köhler *et al*. 2017).

In cases when comparisons took into account acoustic similarities, the absence of important key taxa (intermediate taxa criterion of Remane [1952]) might have jumbled the puzzle, making it difficult to evaluate homology among structures and features. That seems to be the case in descriptions of calls emitted in sequences (*P. nattereri*, *P. cicada*, and *P. lisei*). These sequences have been described as entire calls composed of notes (Bokermann 1966a; 1966b; Morais & Kweet 2012). In those cases, a "call" (= call series) seems not to be homologous to what is usually referred to as call for other congeners (*e.g.*, *P. atim*, *P. albifrons*, *P. cuvieri*, *P. riograndensis*, *P. gracilis*, see references in Table 1). That seems to be the case of the call of *P. rupestris* which was described as a sequence of notes (= sequence of calls A, see *P. erythros* and *P. rupestris* in the present study and Nascimento *et al.* [2001]).

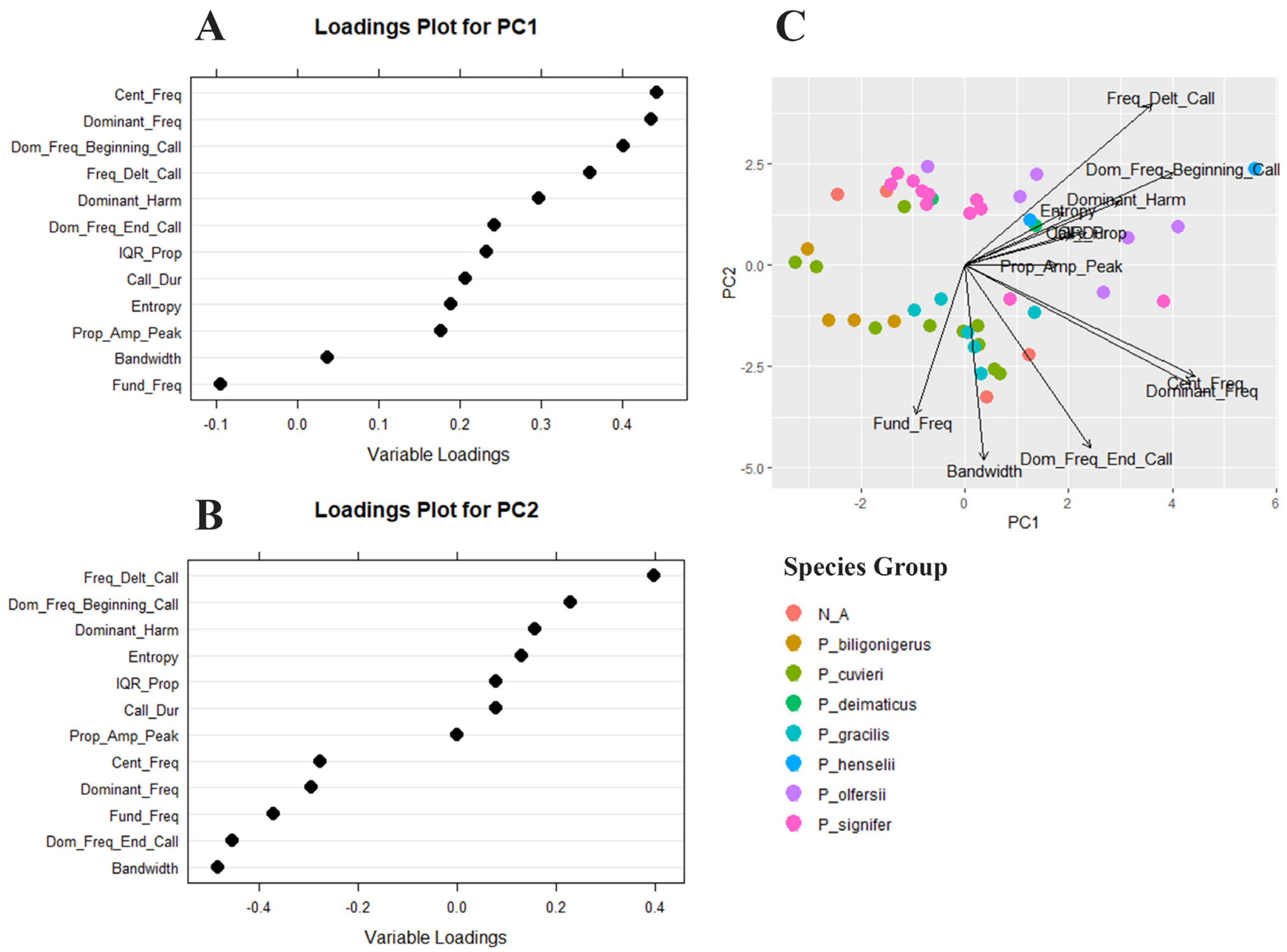

FIGURE 57. Loadings plots of 12 acoustical variables for the first two components of a Principal Compoment Analysis (PCA) based on 45 species (= samples) of *Physalaemus* (A–C). Plots with the ordered variable loadings for first (A) and second (B) components. Distribution of the samples along the first and second components with the variable loadings depicted as vectors on the biplot (C). Colors indicate the species groups to which the species belong (see caption in the figure). "N_A" means "no species group assigned" (see Table 1). Note that the two groups are mainly separated by the frequency delta, fundamental frequency, bandwidth, and dominant frequencies at the beginning and end of the call along the second component (see text). The variable variances were scaled in order to equalize their influence in the PCA.

The second reason for this nomenclatural instability is related to the difficulty in establishing homology among acoustic structures (Atz 1970; Cannatella *et al.* 1998). Even though some studies have improved our comprehension on the homology of behavior (Wenzel 1992; de Queiroz & Wimberger 1993; Rendall & Di Fiore 2007), the application of the suggested criteria on acoustic traits is not easy. The less complex the structure, the less amount of available information to be compared and used under homology criteria (Remane 1952). Since bioaoustical signals are considerably simpler than other phenotypical structures such as anatomical ones, a deep understanding of the signals is imperative to extract the maximum of information while comparing their traits to establish homologies. Errors like clear convergent structures and/or traits not recognized as such but rather considered homologous and *vice-versa* are frequent in the literature as a result of superficial knowledge about the signal's traits. This issue can be exemplified by the several attempts in classifying correctly the frequency bands in *Physalaemus* as sidebands or harmonics (*e.g.*, bands of *P. olfersii* in Bokermann 1966a; Heyer *et al*. 1990; Giaretta *et al*. 2009; Cassini *et al*. 2010; see also subharmonics above). Several studies have addressed the issue and allowed identification of these bands by methods that verify the behavior of the bands and the mathematical relationship among each other to estimate the number of vibrating sources and their dependency degree (see Bradbury & Vehrencamp 1998: 58; Greenewalt 1968: 88–100; Gerhardt & Huber 2002: 425–430). The correct band identification means a deeper comprehension of the likely processes responsible for producing the observed bands. In other words, it means a better comprehension with larger and more accurate information about the bioacoustical structures studied. Although physiological experiments on vocal activity will certainly contribute with more reliable evidence for these questions (*e.g.*, Martin 1972; Suthers *et al.* 2006), those methods are more affordable because they allow this kind of assessment by analyzing the signals only.

Usually, sidebands are observed as low energy bands flanking the carrier (dominant) frequency (Bradbury & Vehrencamp 1998; see Watkins 1967 for other patterns). The pattern of the frequency bands in several *Physalaemus* species resembles that of sidebands (all species in the *P. signifer* clade and *P. olfersii* group). Probably, this is the reason why many studies have described sidebands for some species such as *P. maximus*, *P. soaresi*, *P. angrensis*, and *P. lateristriga* (Weber *et al*. 2005; Weber *et al*. 2006; Cassini *et al*. 2010; Santanna & Moura 2011; Peres & Simon 2012). Here, we combined the criteria given by Greenewalt (1968) and the known behavior of sidebands and harmonics in frequency-modulated calls (Bradbury & Vehrencamp 1998; Gerhardt & Huber 2002; see Material and Methods in the present study) to propose a more objective method for identification of the process responsible for the observed bands. For instance, the harmonic behavior of the bands can be exemplified by the figures 33F (*cf.* Fig. 38B) and 42B (*cf.* Fig. 43B) for *P. soaresi* and *P. lateristriga*, respectively. The modulation of the calculated frequency [reciprocal values of the periods (w) of the structure responsible for the bands] clearly follows the modulation of the "instantaneous" dominant frequency. This modulation is also followed by the other bands observed at the same time span. Moreover, the factors found dividing "instantaneous" dominant frequency by the calculated frequency were always very close to integer values. All these results are expected for harmonic-related bands. Sidebands could be integer multiples of the carrier frequency (usually the dominant band) by chance. However, since the real modulations that produce sidebands are usually produced by independent oscillators, this coincidence is unlikely. Even so, if the bands were sidebands, variations of the calculated frequency of the responsible modulation would instantaneously change the distance between the sidebands and the carrier frequency instead of all the bands change together at the same distance among each other.

The use of several complex traits such as S-shaped harmonics and arrow-shaped envelopes were indispensable to recognize homology among calls in *Physalaemus*, however, the case harmonic *vs*. sideband was emblematic. By assessing, at least in part, how the observed bands are produced and underpinning their harmonic or sideband relationship, we were also able to use this information to support or refute homology among the observed bands of different species and species groups and consequently among the bioacoustical structures to which these bands are associated as well.

Call function

We described the calls here using letters as labels. We avoided the traditional terms applied in call descriptions such as "advertisement", "aggressive", "territorial", etc. (Wells 1977; Duellman & Trueb 1986). Most of the recordings were obtained from acoustic collections (Appendix I) and the behavioral context in which males were recorded was not directly observed (but see inferences on number and relative distance of active males in Material and Methods). Therefore, we avoided spurious connections between acoustic traits and functions of calls (Hepp *et al.* 2017). Even when contexts are informed, associated call functions are usually highly speculative in the absence of more reliable evidence such as those from playback experiments (Martin 1972; see Bastos *et al.* 2011 as an example with proper playback experiments).

Nonetheless, some clues may be present in the acoustic recordings and they can lead to possible functions of the signals which have to be tested in further studies. The calls A described here were the most frequently emitted by the species recorded. That observation usually leads to an association between the signal and mating function, *i.e.*, males advertising themselves to gravid females (Bogert 1960). Since this signal can have the function of advertising females and rival males, it has been termed "advertisement call" (Duellman & Trueb 1986; Wells 1977; 2007). Moreover, several A calls described here resemble the advertisement call reported for *Engystomops* species (Ron 2008). The A calls of the *P. cuvieri* group, *P. biligonigerus* group, and *P. gracilis* group (except the long calls of *P. lisei* and the pulse-PAM in calls of *P. jornadensis*) are very similar to the whine-like note of *Engystomops pustulosus* (Ryan & Guerra 2014). The A calls of species in the *P. deimaticus* group resemble the chuck-like note of that species (both have several frequency bands close to each other). Whine- and chuck-like notes compose the well-known advertisement call of *E. pustulosus* and both play important roles in the mating process (Ryan 1985). Type A calls of the other *Physalaemus* species seem to share traits with both notes and there is no clear correspondence to a single structure, *i.e.*, to whine- or chuck-like note of *Engystomops* calls.

Calls B and C were often recorded after apparently agonistic interactions or, at least, in highly intrasexual competitive contexts, such as several active males calling at high call rates close to each other in the same chorus (see Material and Methods). Usually, calls B and C were followed by the same call type emitted by other neighboring males, suggesting an aggressive and/or territorial function. In species with more than one call type and nonpulsed A calls (*P. maculiventris*, *P. erythros*, *P. signifer*, and *P. spiniger*), B calls are longer than A calls. This difference is expected for aggressive calls in species with narrowly-tuned calls (Gerhardt & Huber 2002). The call B tends to be more tone-like than call A in all species, even in those with pulsed A calls (*P. nanus*, *P. angrensis*, *P. moreirae*, and *P. crombiei*). A similar pattern has been found for aggressive calls in relation to advertisement calls, such as in *Colostethus panamensis* (Wells 2007 and references within).

Additionally, B calls of some species have lower fundamental frequencies than calls A (*P. crombiei*, *P. spiniger*, *P. nanus*, and *P. rupestris*). Decreasing fundamental frequency is one way to make voice pitch lower. Lowering the voice pitch has been an important strategy in transmitting dishonest signals of size-related information in sexual selection contexts (*e.g.*, Bee *et al.* 2000). The subharmonics regimes, common in calls B and C, might be acting in the same way. The existence of subharmonics would provide means of lowering apparent voice pitch without having an oscillator large enough to emit such low-frequency signal (Fitch *et al.* 2002). This could explain the motivation behind the female preference for chuck-like notes in *Engystomops*, since this note has emphasized subharmonics (Kime *et al.* 2013). Female preference for calls with lower fundamental frequencies and/or subharmonics is still untested in *Physalaemus* species.

Repertoire recognition

We recognized and described for the first time additional calls for *P. maculiventris*, *P. erythros*, *P. nanus*, *P. crombiei*, *P. bokermanni*, *P. angrensis*, and *P. moreirae* (Table 1). Nonetheless, we did not recognize some calls of *P. spiniger*, *P. signifer*, and *P. cuvieri* (Table 1; *cf.* "fight call" in Wogel *et al*. 2002; "fight call", "release call", and "amplexus call" in Costa & Toledo 2013; "courtship call" in Gambale & Bastos 2014). The "courtship call" of *P. cuvieri* has very low amplitude (P. Gambale pers. comm.) and it is apparently very difficult to record. Therefore, it is likely uncommon in sound collections and, even though we have analyzed a large number of recordings for the species (see Appendix I), it is possible that we have examined any "courtship call".

Alternatively, we might have examined some of these calls but not recognized them as a different call type. That seems to be the case for the calls of *P. spiniger* and *P. signifer*, which are very similar to other calls in acoustic traits but differ significantly in social context. Since we were not able to assess the precise context in which the calls were emitted, this missing data might be key traits for differentiation in these cases. Moreover, we have examined several recordings used in some of these studies (see Appendix I; Wogel *et al*. 2002; Costa & Toledo 2013; Gambale & Bastos 2014), which corroborates this latter explanation for fewer recognized calls in the present study for these three species.

Application in systematics

The acoustic traits of *Physalaemus* species have been intensely used to clarify their taxonomy (*e.g.*, Bokermann 1966b; 1967; Heyer & Wolf 1989; Haddad & Pombal 1998; Pimenta *et al.* 2005; Weber *et al.* 2006; Cardozo & Pereyra 2018). The stereotypy of the species' calls, the high availability of recordings, and acoustic diversity observed in the genus contribute to the historical usefulness of bioacoustical features in these studies. The diversity of acoustic traits is especially true for the *P. signifer* clade, where A calls with or without pulses, different pulse and interpulse durations, and different timbres (*i.e.*, different frequency bandwidths and energy patterns of the bands) are observed. That explains why acoustic features are part of the diagnostic traits of so many species in this clade (see discussion in Heyer & Wolf 1989; Haddad & Pombal 1998; Haddad & Sazima 2004).

Besides the diversity among A calls, species in the *P. signifer* clade are the only species to have a repertoire formed by calls A and B, which can be quite distinct from each other. For instance, *P. angrensis*, *P. moreirae*, and *P. nanus* have calls in their repertoires with and without pulse-PAM (calls A and B, respectively). The capacity of many species to produce different calls (calls A, B, and C), and the remarkable differences found among calls A of different species and between calls A and B in a same species indicate a propensity of this clade to acoustic diversification (perhaps a consequence of the vocal apparatus' complexity, see below).

On the other hand, species in the same clade tend to share many similar acoustic traits. For instance, species of

P. olfersii group have a relatively long call duration, usually upward general FM, low fundamental frequency, and only higher harmonics emphasized. Moreover, species of this group (*P. feioi*, *P. lateristriga*, *P. maximus*, *P. olfersii*, and *P. soaresi*) have PFM throughout the entire call. As stated above, species of the *P. signifer* clade have energy concentrated in adjacent higher harmonics and usually more than one call type. Within this clade, species in the *P. deimaticus* group have relatively short A calls with low fundamental frequency and broad bandwidth. *Physalaemus cuvieri* and *P. ephippifer* are closely related within the *P. cuvieri* group (see Lourenço *et al*. 2015), and both have subharmonics present in all calls. Nevertheless, one of the most remarkable call similarities in the genus is the whine-like call with a single harmonic note, the first harmonics carrying most of the sound energy, and S-shaped bands (consequence of the FM pattern). This kind of call is shared by 21 species, including all species in the *P. cuvieri* clade, except those in the *P. henselii* and *P. olfersii* groups and, apparently, it is plesiomorphic for the genus (Hepp & Pombal *in prep*).

Barrio (1965) described calls of eight *Physalaemus* species and classified calls of 13 species of the genus into four call types referred to as type A, B, C, and D. Barrio's (1965) categories focused on the taxonomic differences. In this case, distinct call types mean distinct call features, but, different from here, do not mean that the calls are or are not homologous or even that the species in question have their repertoires composed of a single or more calls. Barrio has claimed for a possible phylogenetic correspondence of the proposed phenetic classes, however the species groups with different call types do not agree with the clades found by recent phylogenetic studies (Lourenço *et al.* 2015; Hepp & Pombal *in prep*; but see species with type B below). His types A and B seem to be the only classes that are defined based on fixed acoustic similarities. Type C was assigned for calls with sequences of short notes (= call series here, see section "Descriptive terminology and acoustic homology" below) and included species such as *P. cuvieri*, *P. signifer*, *P. santafecinus*, and *P. aguirrei*. A few species really emit calls in series (see "call series" in Köhler *et al*. 2017). Some of them have almost all calls grouped in sequences (*e.g., P. cicada* and *P. lisei*). On the other hand, such call series seem to be facultative in other species (*e.g., P. angrensis* and *P. nattereri*) depending on the social environment (*e.g.,* number of calling males in the chorus) and abiotic conditions (*e.g.*, temperature; pers. obs.). Barrio (1965) defined type D as calls with no harmonic series and assigned for *P. henselii*, *P. centralis*, *P maculiventris*, *P. nattereri*, and *P. obtectus* (and possibly also *Pleurodema* spp.). The unique species that could be considered without harmonic series is *P. fernandezae* (type B *sensu* Barrio 1965; see below) which has a single perceptible frequency band (but see Cei 1980). Some of the species with type C calls, such as *P. centralis* and *P. maculiventris*, have a very low fundamental frequency and the bands are not shown in audiospectrograms with wide filter bandwidth. That could be the reason which led Barrio (1965) to that class definition.

Type A calls (*sensu* Barrio 1965) were defined as calls with many harmonics, sounding to human ear as a meow or as an infant cry. Indeed, calls classified as type A (*sensu* Barrio 1965; those of *P. biligonigerus*, *P. albonotatus*, *P. riograndensis*, and *P. gracilis*) have common traits such as clear harmonics, emphasized first harmonics, downward general FM, and arc-like FM at the outset of the call (plesiomorphic traits described above; Hepp & Pombal *in prep*). Even though, *P. henselii* had been classified as having call type D by Barrio (1965), its call has the same traits used to define his type B (lack of clear harmonics and higher fundamental frequency). Indeed, the Barrio's definition of type B calls could be used to classify the calls of the current *P. henselii* species group (*P. fernandezae* and *P. henselii*).

Barrio's (1965) classification was the first to use calls to define species groups in *Physalaemus*. Since then, species have been described (Bokermann 1966b; 1967; Heyer & Wolf 1989; Haddad & Pombal 1998; Pimenta *et al.* 2005; Weber *et al.* 2006; Cardozo & Pereyra 2018) and phylogenetic relationships are being assessed based on call traits (Hepp & Pombal *in prep*). Still, it should be noted that some traits must be carefully interpreted, as they can be polymorphic. For instance, slight PAM and/or PFM are present in some calls of *P. albonotatus*, *P. ephippifer*, *P. evangelistai*, *P. gracilis*, and *P. kroyeri* (see Bokermann 1966b), whereas most calls lack such modulations. Depending on the character in question, an extensive sampling is necessary to make sure whether the feature is fixed (see discussion in Köhler *et al*. 2017).

Part of the fixed acoustic differences may be due to fixed anatomical differences in the vocal apparatus (Drewry *et al.* 1982). Even the pulse-PAM might be produced passively (Martin 1972). Therefore, further comparative anatomical studies on the vocal apparatus of the genus may bring some light on this issue.

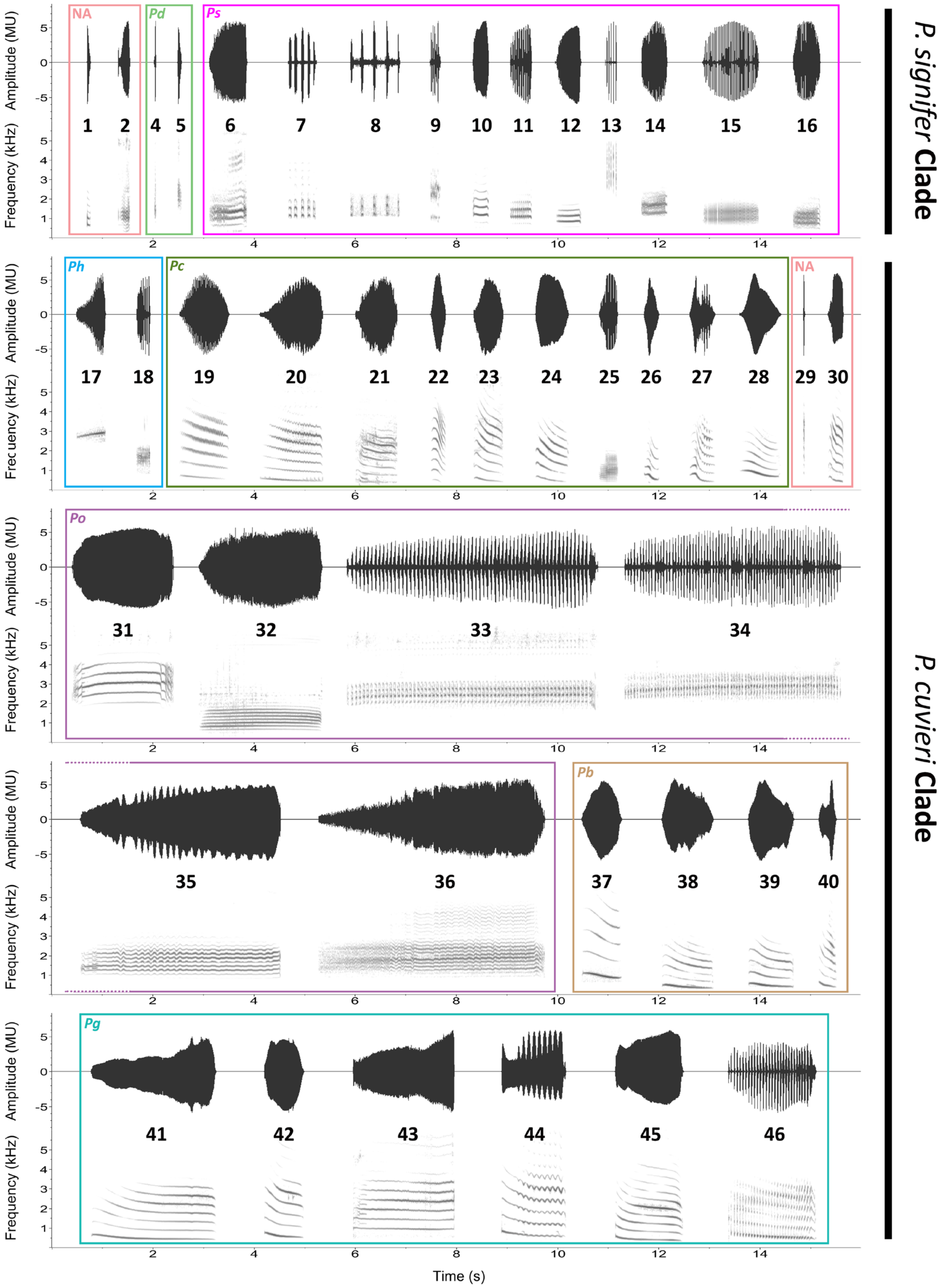

FIGURE 58. Calls A of 45 species of *Physalaemus* organized into five tracks. All tracks have the same duration of 16 seconds and each one has oscillograms above and audiospectrograms below. All audiospectrgrams with filter bandwidth = 46 Hz and varying from 0 to 6 KHz. The species' numbers follow those in Table 1 (number 3, *i.e.*, *P. deimaticus*, was not analyzed in the present study). First track with the species of the *P. signifer* clade; the other four tracks with the species of the *P. cuvieri* clade. Colors indicate the species groups to which the species belong: NA = no species group assigned; *Pd* = *Physalaemus deimaticus* group; *Ps* = *Physalaemus signifer* group; *Ph* = *Physalaemus henselii* group; *Pc* = *Physalaemus cuvieri* group; *Po* = *Physalaemus olfersii* group; *Pb* = *Physalaemus biligonigerus* group; and *Pg* = *Physalaemus gracilis* group (see Table 1).

Quantitative comparisons among the species and species groups

We found two clusters in the PCA and they substantially represent the two major clades found by Lourenço *et al.* (2015). Considering the most explanatory variables (see Fig. 57), the cluster mostly composed of taxa of *P. signifer* clade has lower fundamental frequency, bandwidth and dominant frequency at the end of the call and higher frequency delta and dominant frequency at the end of the call than the cluster with most taxa of the *P. cuvieri* clade (Fig. 58). *Physalaemus nanus* was the only species of the *P. signifer* clade that did not cluster with the rest this taxon. One of the main reasons was the atypical high fundamental frequency of the call A of *P. nanus* for the *P. signifer* clade, a possible convergence with the species of the *P. cuvieri* clade (Hepp & Pombal *in prep*). Regarding the species of this latter clade, only *P. centralis* and the species of the *P. henselii* and *P. olfersii* species groups did not cluster with the other taxa of this clade (see Fig. 56). Instead, they clustered with those of the *P. signifer* clade. This configuration seems to be mainly a consequence of the low fundamental frequency (except *P. henselii* species group) and low values of frequency delta or high values of positive frequency delta of the calls in these species, common features for species of the *P. signifer* clade (Fig. 58). As well as for *P. nanus*, preliminary phylogenetic analyses indicate that these acoustic resemblances are convergence rather than plesiomorphies (Hepp & Pombal *in prep*).

Energy concentration in higher harmonics

Several *Physalaemus* species have the energy concentrated in adjacent harmonics above the fundamental frequency. Usually, harmonic sounds have most energy concentrated in the fundamental frequency and successive harmonics showing decreasing amplitudes (*i.e.*, Dirichlet conditions; Bradbury & Vehrencamp 1998). There are two major processes to keep higher harmonics with more energy than the lower ones: by directly producing this pattern in the sound source or modulator; or by filtering the sound after its production (Bradbury & Vehrencamp 1998). Rand & Dudley (1993) addressed the issue by recording males of four species (including *E. pustulosus*) calling in regular air atmosphere and in an artificial, helium impregnated, atmosphere. If acoustic filtering was important to the final acoustic outcome, one would expect different sounds coming from the two different environments. However, these authors did not find differences among the trials. They concluded that acoustic filtering is not relevant to the production of the acoustic signals of those species (Rand & Dudley 1993).

Most of the species with energy concentrated in the higher harmonics belong to the *P. signifer* clade and to the *P. olfersii* species group. If all vocal sacs are made of the same material, smaller vocal sacs will tend to have higher resonance frequencies, and then we can expect that species with small sacs would have energy concentrated in higher harmonics by filtering. Although some species of those taxa have relatively small to medium, not expanded laterally, vocal sacs (*e.g.*, *P. bokermanni* and *P. deimaticus* group; Nascimento *et al.* 2005), most species of the *P. olfersii* group have significantly large vocal sacs (except *P. soaresi*; see Cassini *et al.* 2010; but also see Drewry *et al.* 1982). This indicates that the relationship between the size of the vocal sacs and the energy pattern of the frequency bands is not a likely explanation to this energy pattern in *Physalaemus*.

Studies on *E. pustulosus* have showed that the lower the fundamental frequency, the higher is the dominant one (Ryan 1985). In fact, this hypothesis could be an alternative explanation for the energy concentration in higher harmonics in species with medium or large vocal sacs. However, some species such as *P. nattereri*, *P. signifer*, and *P. moreirae*, which emit calls with low fundamental frequencies do not show such energy differences between higher and lower harmonics. Other species, such as *P. lisei* and *P. cicada,* have relatively regular fundamental frequency values and their fundamental bands have little energy or are not visible in audiospectrograms. Perhaps a combination of after-production filtering and source-produced signal may be acting together in order to generate this high-pitched, nasal-like timbre.

Nonlinear regimes

Nonlinear phenomena are common in the repertories of animals with complex neuromuscular machinery involved in the phonation such as mammals (Wilden *et al.* 1998). In humans, nonlinear phenomena are associated to pathologies in the vocal folds or they can be achieved by intentional phonation (Herzel *et al.* 1994; 1995). To produce some of those phenomena, mammals can use projections of the apparatus, such as vocal membrane or "vocal lip", as an extra oscillator, which vibrates at different frequencies from those of the main vocal folds (Mergel *et al.* 1999). In birds, nonlinear vibrations are claimed to be emitted by a similar two-mass model consisting of a heavy medial labium coupled to a flexible medial tympaniform membrane (Fee *et al.* 1998). Similarly, fibrous projections (commonly named as fibrous masses) in the vocal apparatus of species of *Engystomops* and *Physalaemus* (Martin 1972; Drewry *et al.* 1982; Gridi-Papp *et al.* 2006) have been evoked as being the structures responsible for vibrations at lower frequencies and for producing subharmonics (Drewry *et al.* 1982; Ryan & Drewes 1990; Gridi-Papp *et al.* 2006).

The phonatory organ of anurans, referred to as vocal apparatus, is admittedly simple and supposedly unable to oscillate in complex regimes such nonlinear ones (Suthers *et al.* 2006). However, a few studies have recorded and/or stimulated nonlinear signals in anuran species (*e.g.*, Feng *et al.* 2002; Narins *et al.* 2004, Suthers *et al.* 2006). For instance, nonlinear phenomena are prominent in the repertoire of the ranid *Odorrana tormota* (Feng *et al.* 2002; Narins *et al.* 2004). The complex morphology of the T-like vocal cords of this species might be related to this phonetic ability (Suthers *et al.* 2006).

Twenty-three *Physalaemus* species presented calls with nonlinear regimes. Interestingly, nonlinear phenomena have never been described in the genus so far. In calls of some species, such as *P. camacan*, *P. lisei*, *P. spiniger*, and *P. soaresi*, deterministic chaos and subharmonics regimes are quite common or even predominant. In *P. cuvieri* and *P. ephippifer*, subharmonics are present in all the calls examined. In these species, subharmonics have been described as possible harmonics or sidebands (Heyer *et al.* 1990), or been apparently just ignored (Barrio 1965; Kaefer *et al.* 2011; Gambale & Bastos 2014). The term "subharmonics" was only briefly cited (once) in a figure caption of a single study with *Engystomops pustulosus* (Kime *et al.* 2013).

Apparently, species of *Physalaemus* have vocal apparatuses that are highly prone to produce nonlinear regimes such as subharmonics and deterministic chaos. All nonlinear phenomena are usually related to exceeding the limit of energy that the apparatus can still vibrate linearly (Wilden *et al.* 1998; Suthers *et al.* 2006). Indeed, species that showed subharmonics tended to show deterministic chaos as well (*e.g., P. lisei*, *P. spiniger*, *P. soaresi*) suggesting that both phenomena may be caused by similar processes.

Morphological source

Recent studies suggest that some species of *Engystomops* are able to emit two-voiced calls by vibrating the vocal cords and the fibrous masses somehow independently (review in Ryan & Guerra 2016). Drewry *et al.* (1982) have described relatively large fibrous masses in *P. lateristriga* (= *P. olfersii* in Drewry *et al.* 1982; see Cassini *et al*. 2010 for specimens referred as *P. olfersii* from the state of Paraná), a species that has a very low fundamental frequency. Additionally, they noticed that *E. pustulosus* has fibrous masses distributed in a longer projection and apparently more mobile than that of *P. lateristriga* and *P. gracilis*. This suggests that the fibrous masses could be occasionally moved towards the path of the air flow while males are calling. That could explain why the specie is able to produce two very different notes, one containing only true harmonics ("whine") and other containing additional subharmonics ("chuck") (Drewry *et al.* 1982; Kime *et al.* 2013).

Future studies should be conducted in order to evaluate whether species with calls with low fundamental frequencies, such as those in the *P. signifer* clade (and especially in the *P. deimaticus* species group) and in the *P. cuvieri* clade (*P. olfersii* species group) have larger and well-developed fibrous masses in their vocal apparatus. Moreover, species of *P. deimaticus* group, *P. maculiventris* and *P. nattereri* (both in the *P. signifer* clade, but with no species group assigned), and *P. maximus* (*P. olfersii* group) show a single vibrational regime. This suggests that, in some species, the fibrous masses may not vibrate independently, as in *P. olfersii* (Drewry *et al.* 1982). Fibrous masses in these species are probably firmly attached to the vocal cords, allowing the species to always emit very nasal-like calls, with low fundamental frequencies.

Final remarks

In the present study we have analyzed as many calls as available in public and particular archives in order to achieve a better comprehension of the acoustic variation in the genus *Physalaemus*. This assessment allowed us to find possible natural acoustic similarity patterns among species and species groups and then establish more robust primary homology hypotheses (*sensu* de Pinna 1991) for the acoustic structures and features. Recently we have codified these similarities into characters, which have been tested in further analyses in a phylogenetic context and some of them have been found to be secondary homologs indeed (see de Pinna 1991; Hepp & Pombal *in prep*). These outcomes highlight the importance of wide interspecific comparisons in order to correctly apply acoustic features to comparative studies such as those on taxonomic and phylogenetic subjects (Hepp *et al*. 2015; 2017; Forti *et al*. 2018).

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APPENDIX I: Recordings examined in the present study. See Material and Methods for collection acronyms. Several recordings were kindly given by recordists and researchers. These files were kept without acronym and number since they were not deposited in official collections yet. In these cases, we used the initials of the researchers' names when the files were cited. We also give the name of the recordist for each recording, when this information was available. The initials of the names are AAG (Ariovaldo A. Giaretta), AB (Avelino Barrio), ACCL (Ana Carolina Calijorne Lourenço), AJC (Adão J. Cardoso), AK (Axel Kwet), BL (Bertha Lutz), BVSP (Bruno V.S. Pimenta), CAB (Cinthia A. Brasileiro), CFBH (Célio F. B. Haddad), CLD (Cyro Luna-Dias), CSC (Carla S. Cassini), DB (Diego Baldo), DEC (Dario E. Cardozo), DPB (Délio P. Baêta), DS (Diego Santana), GVA (Gilda V. Andrade), HTA (Hans T. Andrade), HW (Henrique Wogel), IJR (Igor J. Roberto), IS (Ivan Sazima), JP (José P. Pombal), JRM (José Carlos R. de Magalhães), JV (Jacques Vielliard), LBN (Luciana B. Nascimento), LD (Leandro Drummond), LFS (Luís F. Silveira), LFT (Luis Felipe Toledo), LG (Luiz Giasson), LNW (Luiz N. Weber), LPG (Luiz P. Gonzaga), MAM (Marcos A. Melo), MAP (Michel de Aguiar Passos), MB (Marcos Bilate), MGP (Marcos Gridi-Papp), MM (Marcio Martins), MVG (Michel V. Garey), MWC (Manoela W. Cardoso), PCR (Pedro C. Rocha), PGG (Priscilla G. Gambale), PPGT (Pedro P.G. Taucce), RH (Ronald Heyer), RT (Rodrigo Tinoco), RR (Romulo Ribon), SPCS (Sergio P. Carvalho-e-Silva), TC (Thais Costa), TLP (Tiago L. Pezzuti), and WCAB (Werner C.A. Bokermann). "A.t." = air temperature; "rec." = recordist; "w.t." = water temperature.

Pleurodema brachyops. **Brazil**: Roraima: *Boa Vista*: Lagoa Embrapa (FNJV 0011023, rec. MM, a.t. 30ºC); **Venezuela**: Barinas: *Barrancas*: Estação Experimental El Irel, da ULA (FNJV 0031292, rec. AJC, a.t. 26ºC, w.t. 26ºC).

Engystomops freibergi. Unknown locality (CENBAM 0505).

Engystomops petersi. **Brazil**: Acre: *Xapuri* (FNJV 0004594, rec. AJC); *Marechal Thaumaturgo* (FNJV 0031648, rec. AJC, a.t. 25ºC, w.t. 22ºC); Pará: *Altamira* (FNJV 0004595, rec. AJC).

Engystomops pustulosus. **Venezuela**: Barinas: *Barrancas*: Estação Experimental El Irel, da ULA (FNJV 0031267, rec. AJC, a.t. 23, w.t. 25; FNJV 0031268, rec. AJC, a.t. 26, w.t. 26); Fazenda Cucuchica – Tovar-ME (FNJV 0007660–62).

Physalaemus aguirrei. **Brazil**: Espírito Santo: *Linhares*, Reserva Biológica CURD (FNJV 0031167, rec. AJC, a.t. 21ºC, w.t. 22ºC); Sooretama (FNJV 0031776, rec. WCAB, a.t. 20ºC); Minas Gerais: Carlos Chagas (CBUFMG 043, rec. PCR, a.t. 19ºC; CBUFMG 044, rec. PCR, a.t. 19ºC; CBUFMG 045, rec. PCR, a.t. 19ºC; CBUFMG 046, rec. PCR, a.t. 18ºC); Bahia: *Prado*: Parque Nacional Descobrimento (undeposited file #11-04 given by Bruno Pimenta, rec. BVSP).

Physalaemus albifrons. **Brazil**: Bahia: *Maracás*: Brocotó (FNJV 0031943, rec. WCAB, a.t. 20ºC, w.t. 24ºC); Ceará: *Jaguaripe* (AAGARDA 10254, rec. DS).

Physalaemus albonotatus. **Argentina**: Helvetia: *Santa Fé* (FNJV 0031169, rec. AJC, a.t. 23.5ºC, w.t. 23ºC; FNJV 0031170, rec. AJC, a.t. 21ºC, w.t. 20ºC); **Brazil**: Mato Grosso: Cáceres (FNJV 0031171, rec. AJC, a.t. 30ºC, w.t. 28ºC, FNJV 0031175, rec. AJC, a.t. 26ºC, w.t. 26ºC); Baia da Caiçara (FNJV 0031172, rec. AJC, a.t. 28ºC, w.t. 26.6ºC; FNJV 0031173, rec. AJC, a.t. 28ºC, w.t. 26.6ºC); Baia do Sovaco (FNJV 0031174, rec. AJC, a.t. 26ºC, w.t. 26ºC, FNJV 0031176, a.t. 25ºC, w.t. 28ºC); *Cuiabá* (FNJV 0031877, rec. WCAB, a.t. 25ºC); *Jaciara* (FNJV 0031863, rec. WCAB, a.t. 28ºC); unkown locality (one undeposited file, RT; one undeposited file in Guia Interativo dos Anfíbios Anuros do Cerrado, Campo Rupestre & Pantanal); **Paraguay**: Alto Paraná: *Hernandarias*: Mbaracayú Biosphere Reserve (FPANF119RE; available on http://www.faunaparaguay.com/physalaemusalbonotatus.html).

Physalaemus angrensis. **Brazil**: Rio de Janeiro: *Angra dos Reis*: Rio Florestão (ASEC 12679–80, rec. LPG, ASEC 17136–37, rec. LNW).

Physalaemus atim. **Brazil**: Goiás: *Campo Limpo de Goiás*: Fazenda Conceição (undeposited file used in Brasileiro & Haddad, 2015, rec. CAB, a.t. 20ºC).

Physalaemus atlanticus. **Brazil**: São Paulo: *Ubatuba*: Praia Domingas Dias (FNJV 0032013, rec. IS, a.t. 20ºC, w.t. 20ºC; FNJV 0032014, rec. IS, a.t. 19ºC, w.t. 18.5ºC); Picinguaba (CFBH 43.4, rec. CFBH, a.t. 22ºC; CFBH 53.10, rec. CFBH, a.t. 28ºC, w.t. 27ºC; CFBH 53.11, rec. CFBH, a.t. 28ºC, w.t. 27ºC).

Physalaemus barrioi. **Brazil**: São Paulo: *São José do Barreiro*: Parque Nacional Serra da Bocaina (FNJV 0031177, rec. AJC, a.t. 17ºC, w.t. 16ºC, FNJV 0031564, rec. AJC, a.t. 21ºC, w.t. 23ºC; five undeposited used in Provete *et al.*, 2012, rec. MVG); fazenda de fruticultura (FNJV 0031933, rec. WCAB, a.t. 10ºC, w.t. 15ºC).

Physalaemus biligonigerus. **Brazil**: Rio Grande do Sul: *Osório* (FNJV 0031178–79, rec. AJC, a.t. 22ºC, w.t. 22ºC; FNJV 0031682, rec. AJC, a.t. 22ºC, w.t. 23.5ºC; FNJV 0031683–84, rec. AJC, a.t. 23ºC, w.t. 23.5ºC; FNJV 0031685, rec. AJC, a.t. 23.5ºC, w.t. 23.5ºC; FNJV 0031686, rec. AJC, a.t. 24ºC, w.t. 23.5ºC; FNJV 0031687, rec. AJC; FNJV 0031688, rec. AJC, a.t. 24.5ºC, w.t. 23.5ºC; FNJV 0031689–91, rec. AJC); *Viamão*: Parque Estadual de Itapuã (FNJV 0031180, rec. AJC, a.t. 24ºC, w.t. 25ºC); *São lourenço do Sul* (FNJV 0031181, rec. AJC, a.t. 22ºC, w.t. 20ºC); *General Camara* (Fonozoo 6219–21, rec. AK, a.t. 21.5ºC; Fonozoo 6223, rec. AK, a.t. 21.5ºC); *São Jerônimo* (Fonozoo 6047, rec. AK, a.t. 23.5ºC; Fonozoo 6118, rec. AK, a.t. 23.5ºC); *Candiota* (Fonozoo 6068–69, rec. AK, a.t. 20.5ºC; Fonozoo 6075–76, rec. AK, a.t. 20.5ºC); *Caçapava do Sul* (Fonozoo 5841, rec. AK, a.t. 21ºC; Fonozoo 5843, rec. AK, a.t. 21ºC); *Porto Alegre* (Fonozoo 5723, rec. AK, a.t. 16ºC; Fonozoo 5962, rec AK, a.t. 16ºC; Fonozoo 6022, rec. AK, a.t. 20ºC); *Cidreira* (Fonozoo 5976, rec. AK, a.t. 21ºC).

Physalaemus bokermanni. **Brazil**: São Paulo: *Santo André*: Campo Grande (FNJV 0031182, rec. AJC, a.t. 19ºC, w.t. 18ºC;

FNJV 0031183, rec. AJC, a.t. 18ºC, w.t. 18ºC; FNJV 0031184, rec. AJC, a.t. 18ºC); Paranpiacaba (CFBH 01-03, rec. CFBH, a.t. 19ºC, w.t. 20ºC); *São Paulo*: Parque Natural Municipal da Cratera de Colonia (FNJV 0012046, rec. MAM); *Santos* (undeposited file, rec. AAG, a.t. 21ºC, w.t. 22ºC); unknown locality (one undeposited file, JP; one undeposited file in Guia Sonoro da Mata Atlântica).

Physalaemus carrizorum. **Argentina**: Missiones: *San Pedro*: Parque Provincial el Piñalito (one undeposited file used in Cardozo & Pereyra, rec. DEC, a.t. 18ºC, w.t. 13ºC).

Physalaemus camacan. **Brazil**: Bahia: *Itacaré*: Fazenda Capitão (undeposited file given by PB, rec. PB); *Camamu*: PA Zumbi dos Palmares (undeposited file given by PB, rec. PB); *Una*: ReBio de Una (undeposited file given by PB, rec. PB, a.t. 24.3ºC). All these recordings were used in Pimenta *et al.* (2005).

Physalaemus centralis. **Brazil**: Mato Grosso: *Cáceres* (FNJV 0031189, rec. AJC, a.t. 25ºC; FNJV 0031234, rec. AJC, a.t. 26ºC, w.t. 29ºC); *Barra do Bugres* (FNJV 0031235, rec. AJC, a.t. 24ºC, w.t. 25ºC); *Rosário Oeste* (FNJV 0031883, rec. WCAB, a.t. 29ºC); *São Félix do Araguaia* (FNJV 0031186, rec. AJC, a.t. 26ºC, w.t. 27ºC); *Guimarães* (CBUFMG 233, rec. PCR); Mato Grosso do Sul: *Três Lagoas* (FNJV 0013013, rec. LFT, a.t. 27ºC); Minas Gerais: *Pedro Leopoldo* (FNJV 0031922, rec. WCAB, a.t. 21.5ºC, w.t. 23.5ºC); *Mateus Leme* (two undeposited files given by LD, rec. LD) Santa Catarina: *São Bento do Sul* (FNJV 0031187, rec. AJC, a.t. 26ºC, w.t. 25ºC); São Paulo: *Itipirina*: Lagoa da Ponte (FNJV 0012973, rec. LFT, a.t. 23ºC); *Luis Antonio*: Fazenda Santa Helena (FNJV 0031190, rec. AJC, a.t. 22ºC, w.t. 24ºC, FNJV 0031629, rec. AJC, a.t. 22.5ºC, w.t. 22.5ºC); *Paulínia*: João Aranha (FNJV 0031185, rec. IS, a.t. 24ºC, w.t. 28ºC); Tocantins: *Formoso do Araguaia* (FNJV 0031188, rec. AJC, a.t. 25ºC, w.t. 24ºC).

Physalaemus cicada. **Brazil**: Bahia: *Maracás*: Brocotó (FNJV 0031942, rec. WCAB, a.t. 20ºC, w.t. 24ºC); Ceará: *Jaguaripe* (AAGARDA 10376, rec. DS); Paraíba: *Patos* (FNJV 0031191, rec. AJC, a.t. 23ºC, w.t. 25ºC); Minas Gerais: *Mocambinho* (CBUFMG 417–418, rec. TLP, a.t. 20ºC); Rio Grande do Norte: *Guamaré* (MNVOC 035.1, rec. IJR).

Physalaemus crombiei. **Brazil**: Espírito Santo: *Santa Teresa*: Reserva Biológica de Santa Lúcia (MNVOC 012.3, rec. HW; MNVOC 013.13, rec. JP, a.t. 26ºC; MNVOC 015.14, rec. JP, a.t. 21.5ºC, w.t. 21.5ºC; three undeposited files given by BVSP, rec. BVSP, a.t. 20.8ºC); sítio do Boza (MNVOC 013.9, rec. JP, a.t. 21ºC); Aracruz (CFBH 46.2, rec. CFBH, a.t. 24ºC, w.t. 26ºC; 48.6, a.t. 23.5ºC).

Physalaemus cuqui. **Agentina** (two undeposited, rec. DB).

Physalaemus cuvieri. **Brazil**: Alagoas: *São Miguel dos Campos*: Fazenda Varrela (MNVOC 016.9, rec. JP, a.t. 22ºC) Bahia: Piatã (AAGARDA 10132, rec. DS, a.t. 18.6ºC; one undeposited file, rec. LD); Minas Gerais: *Catas Altas*: RPPN Santuário do Caraça (MNVOC 030.2–3, rec. JP, a.t. 24.5ºC; MNVOC 031.12–13, rec. MWC, a.t. 20ºC, MNVOC 031.15, rec. MWC, a.t. 20ºC); *Santa Cruz do Escalvado* (ASEC 9895–96, rec. RR); *Araponga*: Parque Estadual Serra do Brigadeiro (ASEC 9897, rec. RR); *Itabira*: Ipoema (three undeposited files, rec. LD); *Perdões*: Pedra Negra (two undeposited files, rec. BVSP, a.t. 28.1ºC for one of the [unknown for the other]); *Itumirim*: Mata da Curva (one undeposited file, rec. BVSP, a.t. 22.5ºC); *São Roque de Minas*: Parque Nacional da Serra da Canastra (FNJV 0007703, rec. AJC; FNJV 0031205, rec. AJC, a.t. 18ºC, w.t. 19ºC; FNJV 0031211, rec. AJC, a.t. 22ºC, w.t. 20ºC); *Poços de Caldas* (FNJV 0031194, rec. AB): Morro do Ferro (FNJV 0031199, rec. AJC, a.t. 18ºC, w.t. 17ºC; FNJV 0031201, rec. AJC, a.t. 20ºC, w.t. 19ºC; FNJV 0031210, rec. AJC, a.t. 13ºC, w.t. 17ºC; FNJV 0031215, rec. AJC, a.t. 18ºC, w.t. 18ºC); *Monte Verde* (FNJV 0031229, rec. MGP, a.t. 16ºC; FNJV 0031230, rec. MGP, a.t. 17ºC, w.t. 19.5ºC); *Carlos Chagas* (CBUFMG 142, rec. PCR, a.t. 20ºC); *Grão Mongol* (CBUFMG 664, rec. HTA, a.t. 20ºC; CBUFMG 665, rec. HTA, a.t. 22ºC); *Nova Lima*: Água Limpa (FNJV 0031204, rec. AJC, a.t. 23ºC, w.t. 26ºC); Vargem Bonita (FNJV 0031206, rec. AJC, a.t. 22ºC, w.t. 19ºC); *Alpinópolis*: Fazenda Salto (FNJV 0031207, rec. AJC, a.t. 24ºC, w.t. 21ºC); Várzea Bonita (FNJV 0031209, rec. AJC, a.t. 19ºC, w.t. 24ºC); *Munhoz*: Serraria (FNJV 0031212, rec. AJC, a.t. 18ºC, w.t. 17ºC); *Jaboticatubas* (FNJV 0031213, rec. IS, a.t. 16ºC, w.t. 17ºC); Goiás (one undeposited file, rec. PGG): *Niquelândia* (three undeposited files, rec. LD); *Mineiros*: Parque Nacional das Emas (FNJV 0031223, rec. AJC, a.t. 26ºC, w.t. 25ºC); *Moçamedes* (FNJV 0031226, rec. AJC, a.t. 28ºC, w.t. 25ºC); Piauí: *São Raimundo Nonato* (ASEC 10845, rec. LFS); Parque Nacional Serra da Capivara (FNJV 0031228, rec. AJC, a.t. 27.5ºC, w.t. 27ºC); *Bom Jesus*: Estação Ecológica de Uruçuí-Uma (ASEC 3160, rec. LFS); *Amarente* (one undeposited file, rec. LD); São Paulo: *Anhembi*: Fazenda Barreiro Rico (FNJV 0010325, rec. JRM); *Ribeirão Branco*: Fazenda São Luiz (CFBH 33.7, rec. CFBH, a.t. 19ºC, w.t. 23ºC; CFBH 36.5, rec. CFBH, a.t. 14ºC, w.t. 20ºC); Fazenda Mathedi (CFBH 18.4, rec. CFBH, a.t. 23ºC, w.t. 26ºC); *Cabreúva*: Fazenda da Cava (FNJV 0031193, rec. GVA, a.t. 21ºC, w.t. 25ºC); *Jundiaí*: Serra do Japí (FNJV 0031195, rec. CFBH, a.t. 21ºC, w.t. 21ºC); *Jaguariúna* (FNJV 0031202, rec. JV); *Campinas*: Estrada Observatório Capricórnio (MNVOC 036.1, a.t. 20ºC, w.t. 25.5ºC); Brejo Taubaté (FNJV 0031203, rec. AJC, a.t. 22ºC, w.t. 21ºC); *São José dos Campos* (CBUFMG 195–196, rec. PCR, a.t. 22ºC); *Santo André*: Reserva de Paranapiacaba (FNJV 0031216, rec. AJC, a.t. 17ºC, w.t. 17ºC; FNJV 0031224, rec. AJC, a.t. 20ºC, w.t. 22ºC); Campo Grande (FNJV 0031217, rec. AJC, a.t. 19ºC, w.t. 18ºC); *São Paulo*: Cidade Universitária (FNJV 0032009, rec. WCAB, a.t. 21ºC, w.t. 22ºC); *Campo Grande* (FNJV 0031773, rec. WCAB, w.t. 19ºC; FNJV 0031812, rec. WCAB, a.t. 20ºC; FNJV 0031872–73, rec. WCAB, a.t. 20ºC); Rio Grande do Sul: *Santa Maria* (CFBH 50.2, rec. CFBH, a.t. 23ºC, w.t. 22ºC); *Santo Ângelo* (Fonozoo 5786, rec. AK, a.t. 17ºC); *Caçapava do Sul*: Guaritas (Fonozoo 5822, rec. AK, a.t. 26ºC; Fonozoo 5841, rec. AK, a.t. 21ºC; Fonozoo, rec. AK, 5882–83, a.t. 21ºC); *Viamão* (Fonozoo 5863, rec. AK, a.t. 21ºC; Fonozoo 5865, rec. AK, a.t. 20ºC; Fonozoo 6020, rec. AK, a.t. 23.5ºC); *Derrubadas*: Parque Turvo (Fonozoo 5901, rec. AK, a.t. 21ºC; Fonozoo 5905, rec. AK, a.t. 23ºC; Fonozoo 5918, rec. AK, a.t. 21.5ºC; Fonozoo 6086, rec. AK, a.t. 21.5ºC); *Torres* (Fonozoo 6023, rec. AK, a.t. 23ºC); *Porto Alegre* (Fonozoo 6038–40, rec. AK, a.t. 17ºC); *Santa Cruz do Sul*: Rio Pardinho (Fonozoo 6093–94, rec. AK, a.t. 23.5ºC; Fonozoo 6096, rec. AK, a.t. 23.5ºC; Fonozoo 6097, rec. AK, a.t. 23ºC; Fonozoo

6113, rec. AK, a.t. 25ºC); Campos universitário Santa Cruz do Sul (Fonozoo 6225, rec. AK, a.t. 22.5ºC); *Mata* (Fonozoo 6099, rec. AK, a.t. 24ºC); *Herveiras* (Fonozoo 6247–48, rec. AK, a.t. 20.5ºC); Lauro Müller (Fonozoo 6366, rec. AK, a.t. 20ºC); *Seara* (Fonozoo 6371, rec. AK, a.t. 24ºC; Fonozoo 6376, rec. AK, a.t. 20ºC; Fonozoo 6380, rec. AK, a.t. 20ºC); *Àrvorezinha*: Peral de Janeiro (Fonozoo 6450–51, rec. AK, a.t. 20.6ºC); *Taquara* (FNJV 0031198, rec. AJC, a.t. 23ºC, w.t. 25ºC); Santa Catarina: *São Martinho* (Fonozoo 6145, rec. AK, a.t. 21ºC; Fonozoo 6148–49, rec. AK, a.t. 22ºC); *Lebon Réges*: Fazenda Serra de Esperança (Fonozoo 6460, rec. AK, a.t. 18ºC); *Florianópolis* (Fonozoo 6183, rec. AK, a.t. 21ºC; Fonozoo 6288, rec. AK, a.t. 18ºC): Unidade de Conservação Ambiental Desterro (Fonozoo 6151, rec. AK, a.t. 20ºC); Lagoa do Perí (Fonozoo 6197, rec. AK, a.t. 21.5ºC; Fonozoo 6410, rec. AK, a.t. 21–22ºC); Praia dos Naufragados (Fonozoo 6203, rec. AK, a.t. 21.5ºC; Fonozoo 6205, rec. AK, a.t. 21.5ºC; Fonozoo 6295, rec. AK, a.t. 21ºC); Praia da Joaquina (Fonozoo 6289, rec. AK, a.t. 22.5ºC; Fonozoo 6291, rec. AK, a.t. 22.5ºC; Fonozoo 6292, rec. AK, a.t. 18.5ºC; Fonozoo 6414, rec. AK, a.t. 22ºC); *Corupá* (Fonozoo 6470, rec. AK, a.t. 18.9ºC; Fonozoo 6471–72, rec. AK, a.t. 19.7ºC); *Blumenau*: Três Peixinhos (FNJV 0031196, rec. AJC, a.t. 21ºC, w.t. 23ºC); *Lages* (FNJV 0031197, rec. AJC, a.t. 17ºC, w.t. 20ºC); *Itapema*: Praia de Itapema (FNJV 0031214, rec. IS, a.t. 27ºC, w.t. 29ºC); Mato Grosso: *Chapada dos Guimarães* (CBUFMG 240, rec. PCR, a.t. 24ºC); Colégio do Buriti (FNJV 0031200, rec. AJC, a.t. 22ºC, w.t. 22ºC); Paraná: *Engenheiro Beltrão* (FNJV 0031225, rec. AJC, a.t. 20ºC, w.t. 22ºC); Paraíba: *Teixeira*: Maturéia (FNJV 0031227, rec. AJC, a.t. 19ºC, w.t. 20ºC); Tocantins: *Formoso do Araguaia* (FNJV 0031221–22, rec. AJC, a.t. 25ºC, w.t. 24ºC). Unknown locality (Fonozoo 5944, rec. AK, a.t. 20ºC; CFBH 14.12, rec. CFBH; one undeposited file, rec. PGG).

Physalaemus ephippifer. **Brazil**: Pará: *Xingú*: Serra do Jaguar (one undeposited file, rec. LD); unknown locality (unamed file, CENCAM).

Physalaemus erikae. **Brazil**: Bahia: *Alagoinha*: Bairro de Areia Funda (FNJV 0012239, rec. MAP); *Porto Seguro*: RPPN Estação Vera Cruz (one undeposited file, rec. BVSP, used in Cruz & Pimenta, 2004, a.t. 24.4ºC).

Physalaemus erythros. **Brazil**: Minas Gerais: *Barão dos Cocais* (CBUFMG 117–124, rec. PCR, a.t. 22ºC); *Itacolomi* (CBUFMG 150–154, rec. PCR, a.t. 20ºC; CBUFMG 155–158, rec. PCR, a.t. 19ºC); *Ouro Preto*: Parque Estadual do Itacolomi, Lagoa Seca (one undeposited file, rec. DPB ; three undeposited files, rec. LD).

Physalaemus evangelistai. **Brazil**: Minas Gerais: Serra do Cipó (FNJV 0031900, rec. WCAB, a.t. 19ºC); *Jaboticatubas* (FNJV 0031208, rec. IS, a.t. 16ºC, w.t. 17ºC); *Santana do Riacho* (FNJV 0031631, rec. AJC, a.t. 21ºC, w.t. 22ºC; FNJV 0031634–36, rec. AJC a.t. 16.5ºC, w.t. 21ºC); *Santa Bárbara*: RPPN Santuário do Caraça (MNVOC 030.1, rec. ACCL, w.t. 18ºC); unknown locality ("Serra de OB-brejão", one undeposited file, rec. LD).

Physalaemus feioi. **Brazil**: Minas Gerais: *Viçosa* (five undeposited files used in Cassini *et al.*, 2010, rec. CSC, a.t. 21.8ºC); *Muriaé* (two undeposited files, rec. PPGT, a.t. 25.4ºC).

Physalaemus fernandezae. **Agentina** (one undeposited file in Catalogo de Voces de Anfibios Argentinos); *Buenos Aires*: General Lavalle (FNJV 0031236, rec. JV).

Physalaemus fischeri. **Venezuela**: Apuri: *Mantecal* (FNJV 0031231, rec. AJC, a.t. 25ºC, w.t. 26ºC; FNJV 0031232, rec. AJC, a.t. 23ºC, w.t. 25ºC); Bolívar: *Guasipato* (FNJV 0031233, rec. AJC, a.t. 28ºC, w.t. 26ºC).

Physalaemus gracilis. **Brazil**: Bahia: *Itabuna* (FNJV 0031270, rec. AJC, a.t. 26ºC, w.t. 27.5ºC); Santa Catarina: *Lages* (FNJV 0031237, rec. AJC, a.t. 17ºC, w.t. 20ºC); *São Bento do Sul* (FNJV 0031240, rec. AJC, a.t. 20ºC, w.t. 22ºC); Paraná: *São Luis do Purunã* (FNJV 0031529, rec. AJC, a.t. 15ºC, w.t. 17ºC; FNJV 0031674, rec. AJC, a.t. 17.5ºC, w.t. 21.5ºC; FNJV 0031675–76, rec. AJC; FNJV 0031677–79, rec. AJC, a.t. 16ºC, w.t. 18.5ºC; FNJV 0031680, rec. AJC, a.t. 15.5ºC, w.t. 18.5ºC; FNJV 0031681, rec. AJC, a.t. 15.5ºC, w.t. 16ºC); Rio Grande do Sul: *Taquara* (FNJV 0031238, rec. AJC, a.t. 23ºC, w.t. 25ºC; FNJV 0032019, rec. WCAB, a.t. 20ºC, w.t. 22ºC); *Rio Grande*: Balneário Cassino (FNJV 0031239, rec. AJC, a.t. 21ºC, w.t. 22ºC); Taim (Fonozoo 5725, rec. AK, a.t. 17ºC; Fonozoo 5952, rec. AK, a.t. 17ºC); *Torres* (Fonozoo 6023, rec. AK, a.t. 23ºC): Parque Estadual da Guarita (FNJV 0031577, rec. AJC, a.t. 18ºC, w.t. 17ºC; FNJV 0031582–83, rec. AJC, a.t. 17.5ºC, w.t. 18ºC); *Viamão* (FNJV 0031584, rec. AJC, a.t. 18ºC, w.t. 16.5ºC; FNJV 0031586, rec. AJC, a.t. 18ºC, w.t. 16.5ºC; Fonozoo 5832, rec. AK, a.t. 19ºC; Fonozoo 6019–20, rec. AK, a.t. 23.5ºC); *Porto Alegre* (Fonozoo 6038, rec. AK, a.t. 17ºC; Fonozoo 6040, rec. AK, a.t. 17ºC): Campus da Universidade Federal do Rio Grande do Sul (FNJV 0031587, rec. AJC, a.t. 23ºC, w.t. 21ºC; FNJV 0031607, rec. AJC, a.t. 12ºC, w.t. 16ºC; FNJV 0031609, rec. AJC, a.t. 19ºC, w.t. 23ºC); *Sapucaí do Sul* (FNJV 0032021, rec. WCAB); *Caçapava do Sul*: Guaritas (Fonozoo 5845, rec. AK, a.t. 21ºC); *Cidreira*: Balneário Pinhal (Fonozoo 5975, rec. AK, a.t. 21ºC; Fonozoo 5977, rec. AK, a.t. 21ºC); *Osório* (Fonozoo 6006, rec. AK, a.t. 25.5ºC); *Candiota* (Fonozoo 6072, rec. AK, a.t. 15ºC; Fonozoo 6081, rec. AK, a.t. 14ºC); *Santa Cruz do Sul*: Rio Pardinho (Fonozoo 6092, rec. AK, a.t. 24ºC; Fonozoo 6093–94, rec. AK, a.t. 23.5ºC, Fonozoo 6096, rec. AK, a.t. 23.5ºC; Fonozoo 6097, rec. AK, a.t. 23ºC; Fonozoo 6110, rec. AK, a.t. 25ºC; Fonozoo 6113, rec. AK, a.t. 25ºC).

Physalaemus henselii. **Brazil**: Rio Grande do Sul: *Porto Alegre* (FNJV 0031578, rec. AJC, a.t. 12ºC): Córrego Sabão (FNJV 0031579, rec. AJC, a.t. 16ºC).

Physalaemus irroratus. **Brazil**: Minas Gerais: *Santa Maria do Salto*: Fazenda Talismã (two undeposited files, used in Cruz *et al.*, 2007, rec. LBN, a.t. 22ºC).

Physalaemus jordanensis. **Brazil**: Minas Gerais: *Wenceslau Braz*: Charco (three undeposited files, rec. CLD, a.t. 17ºC); *Poços de Caldas* (one undeposited file, rec. AAG, a.t. 18.3ºC, w.t. 19.2ºC): Morro do Ferro (FNJV 0031241, rec. AJC, a.t. 15ºC, w.t. 19.5ºC; FNJV 0031242, rec. AJC, a.t. 19ºC, w.t. 21ºC; FNJV 0031243, rec. AJC, a.t. 20ºC, w.t. 19ºC; FNJV 0031244, rec. AJC, a.t. 17ºC, w.t. 18ºC; FNJV 0031245, rec. AJC, a.t. 21ºC, w.t. 19ºC); São Paulo: *Campos do Jordão* (FNJV 0031661–67, rec. AJC, a.t. 13ºC, w.t. 17ºC; FNJV 0031668, rec. AJC, a.t. 13.5ºC, w.t. 16ºC); Usina do Fojo (FNJV 0031660, rec. AJC, a.t. 11.5ºC, w.t. 14ºC); Lagoa da Serra (FNJV 0031787, rec. WCAB, a.t. 15ºC); unknown locality (one undeposited file, rec. JP).

Physalaemus kroyeri. **Brazil**: Piauí: *Amarante* (one undeposited file, rec. LD); Minas Gerais: *Teófilo Otoni* (FNJV 0031800, rec. WCAB, a.t. 24ºC, w.t. 24ºC); Bahia: *Maracás*: Santo Onofri (FNJV 0031939, WCAB, a.t. 20ºC, w.t. 21ºC); *Ilhéus*: CEPEC (FNJV 0032047, rec. WCAB, a.t. 24ºC, w.t. 21ºC).

Physalaemus lateristriga. **Brazil**: São Paulo: *Ribeirão Branco*: Fazenda Mathedi (CFBH 018.5, rec. CFBH, a.t. 21.5ºC, w.t. 28ºC; CFBH 019.7, rec. CFBH, a.t. 26ºC, w.t. 24ºC); Fazenda São Luiz (CFBH 035.3, rec. CFBH, a.t. 18.5ºC, w.t. 21ºC); Santa Catarina: *São Bento do Sul* (CFBH 052.8, rec. CFBH, a.t. 17ºC, w.t. 18.5ºC; CFBH 054.2, rec. CFBH, a.t. 18ºC, apparently used in Cassini *et al.*, 2010); *Ilhota*: Morro do Baú (Fonozoo 6211, rec. AK, a.t. 17ºC); *Blumenau*: Parque das Nascente (Fonozoo 6433, rec. AK, a.t. 19ºC; Fonozoo 6489–90, a.t. 22ºC); *Pirabeiraba*: Serra de Dona Francisca (Fonozoo 6480, rec. AK, a.t. 20.8ºC); *Corupá* (Fonozoo 6470, rec. AK, a.t. 18.9ºC; Fonozoo 6473, rec. AK, a.t. 25ºC); Paraná: *Morretes* (one undeposited file used in Cassini *et al.*, 2010, rec. CSC, a.t. 20.8ºC); *São José dos Pinhais* (two undeposited files used in Cassini *et al.*, 2010, rec. CSC, a.t. 20.8ºC); *Guaratuba* (Fonozoo 6306–08, rec. AK, a.t. 19ºC).

Physalaemus lisei. **Brazil**: Rio Grande do Sul: *Porto Alegre* (FNJV 0031248, rec. AJC, a.t. 25ºC); *São Francisco de Paula* (FNJV 0031249, rec. AJC, a.t. 22ºC, w.t. 18ºC; FNJV 0031250, rec. AJC, a.t. 22ºC, w.t. 19ºC, FNJV 0031623, rec. AJC, a.t. 18ºC, w.t. 22ºC; FNJV 0031624, rec. AJC, a.t. 18ºC, w.t. 21ºC; FNJV 0031625, rec. AJC, a.t. 18ºC, w.t. 20ºC; FNJV 0031645, rec. AJC): Pro-Mata (Fonozoo 5807, rec. AK, a.t. 17ºC; Fonozoo 5850, rec. AK, a.t. 15ºC, w.t. 13ºC; Fonozoo 5927, rec. AK, a.t. 15ºC; Fonozoo 5929–30, rec. AK, a.t. 16ºC; Fonozoo 5934, rec. AK, a.t. 17.5ºC; Fonozoo 5936, rec. AK, a.t. 19ºC); *Canela*: Parque Estadual Caracol (FNJV 0031602, rec. AJC, a.t. 17ºC, w.t. 18ºC; FNJV 0031603, rec. AJC, a.t. 18ºC, w.t. 17ºC; FNJV 0031604, rec. AJC, a.t. 13ºC, w.t. 19ºC; FNJV 0031605, rec. AJC; Fonozoo 5775, rec. AK, a.t. 17ºC); *Terra de Areia* (Fonozoo 6011, rec. AK, a.t. 23ºC, 6016–17, a.t. 21ºC).

Physalaemus maculiventris. **Brazil**: São Paulo: *Paranapiacaba* (FNJV 0031815, rec. WCAB, a.t. 18ºC); Paraná: *Guaratuba* (Fonozoo 6317, rec. AK, a.t. 24ºC).

Physalaemus marmoratus. **Brazil**: Minas Gerais: *Uberlândia* (one undeposited file, rec. AAG, a.t. 21.5ºC, w.t. 23.5ºC); *Jeceaba* (two undeposited files, rec. PPGT); São Paulo: *Botucatu* (FNJV 0031826, rec. WCAB, a.t. 21ºC): Lageado (FNJV 0004584, rec. IS); *Luis Antônio*: Fazenda Santa Helena (FNJV 0004590–93, rec. AJC); Santa Catarina: *Araçatuba* (FNJV 0004585, rec. IS); Mato Grosso: *Cáceres*: Baia da Caiçara (FNJV 0004586, rec. AJC); Baia do Sovaco (FNJV 0004587–89, rec. AJC).

Physalaemus maximus. **Brazil**: Minas Gerais: *Araponga*: Parque Estadual Serra do Brigadeiro (ASEC 9898–99, rec. RR; three undeposited files, rec. DS, used in Santana & Moura 2011, a.t. 21ºC); *Ouro Branco*: Serra de Ouro Branco, Sítio Seu Mariano (one undeposited file, rec. LD).

Physalaemus moreirae. **Brazil:** São Paulo: *Salesópolis*: Estação Biológica de Boraceia (one undeposited file, rec. RH); *Santo André*: Paranapiacaba (one undeposited file, rec. AAG, a.t. 21ºC, w.t. 22.5ºC; one undeposited file, rec. PPGT);

Physalaemus nanus. **Brazil**: Rio Grande do Sul: *São Francisco de Paula* (Fonozoo 5937, rec. AK, a.t. 18ºC; Fonozoo 6085, rec. AK, a.t. 21.5ºC); Santa Catarina: *Treviso* (FNJV 0012929, rec. LFT); *São José*: Cubatão (FNJV 0031251, rec. AJC, a.t. 24ºC, w.t. 25ºC); *Florianópolis*: Naufragados (Fonozoo 6175, rec. AK, a.t. 23ºC); Morro do Perí (Fonozoo 6182, rec. AK, a.t. 21ºC); Reserve UCAD (Fonozoo 6153, rec. AK, a.t. 20ºC); Córrego Grande (FNJV 0031592, rec. AJC, a.t. 20ºC, w.t. 18ºC); São João do Rio Vermelho (CFBH 050.4, rec. CFBH, a.t. 23.5ºC, w.t. 22ºC); Trilha do Poção (five undeposited files, rec. MWC, a.t. 18.5 and 19.5ºC); *Rancho Queimado*: Sítio Fernando (FNJV 0031597, rec. AJC); *Urubici* (FNJV 0031601, rec. AJC, a.t. 17.5ºC, w.t. 16ºC); *São Benedito*: Serra do Tabuleiro (two undeposited files, rec. LD); *Santo Amaro da Imperatriz*: Serra do Tabuleiro (one undeposited file, rec. LD); *Ilhota*: Morro da Baú (Fonozoo 6213, rec. AK, a.t. 14ºC); unknown locality (one undeposited file, JP).

Physalaemus nattereri. **Brazil**: São Paulo: *Botucatu*: Lageado (FNJV 0031252, rec. JP, a.t. 21.5ºC, w.t. 26ºC); *Luis Antônio*: Fazenda Santa Helena (FNJV 0031628, rec. AJC, a.t. 23.5ºC, w.t. 25ºC); Mato Grosso: *Cáceres* (FNJV 0031253, rec. AJC, a.t. 26ºC, w.t. 29ºC); *Água Boa* (FNJV 0031254, rec. AJC, a.t. 27ºC, w.t. 28ºC); *Rio Claro*: Itapé (CFBH 057.3, rec. CFBH, a.t. 24ºC, w.t. 26ºC); *Cuiabá* (FNJV 0031878, rec. WCAB, a.t. 18ºC, w.t. 16.5ºC); *Chapada dos Guimarães* (CBUFMG 218–219, rec. PCR, a.t. 24ºC); Tocantins: *Formoso do Araguaia* (FNJV 0031255–56, rec. AJC, a.t. 23ºC, w.t. 24ºC; FNJV 0031257, rec. AJC, a.t. 25ºC, w.t. 26ºC); Goiás (one undeposited file, rec. PGG): *Pontalina*: Fazenda Lagoa Grande (CFBH 53.5, rec. CFBH, a.t. 22.5ºC, w.t. 24ºC); Minas Gerais: *Uberlândia* (one undeposited file, rec. AAG, a.t. 23.2ºC, w.t. 24.3ºC); unknown locality (one unnnamed file in Guia Interativo dos Anfíbios Anuros do Cerrado, Campo Rupestre & Pantanal).

Physalaemus obtectus. **Brazil**: Espírito Santo: *Sooretama* (FNJV 0031774, rec. WCAB, a.t. 19.5ºC): Reserva Biológica de Sooretama (four undeposited files, rec. BVSP, a.t. 23.6ºC); *Guaçuí*: Fazenda Oliveira (two undeposited files, rec. BVSP).

Physalaemus olfersii. **Brazil**: São Paulo: Serra da Bocaina: Sítio do Aguinaldo (MNVOC 036.5); *Socorro*: Rio do Peixe (FNJV 0031259, rec. AJC, a.t. 20ºC, w.t. 20ºC; FNJV 0031260–61, rec. AJC, a.t. 22.5ºC, w.t. 21ºC); *São José do Barreiro*: Parque Nacional Serra da Bocaina: Fazenda da Barreira (FNJV 0031263, rec. AJC, a.t. 19ºC, w.t. 23ºC); *Campo Grande* (FNJV 0031811, rec. WCAB, a.t. 20ºC); *Atibaia* (one undeposited file, rec. AAG, a.t. 19ºC, w.t. 25ºC); *São Luiz de Paratinga* (two undeposited files, rec. CSC); Rio de Janeiro: *Teresópolis* (four undeposited files, rec. CSC, used in Cassini *et al*. 2010, a.t. 23ºC).

Physalaemus orophilus. **Brazil**: Minas Gerais: *Catas Altas*: RPPN Santuário do Caraça (MNVOC 031.8–9, rec. JP, MNVOC 031.25, rec. ACCL and MWC, a.t. 19ºC; one undeposited file, rec. CSC, used in Cassini *et al*. 2010); *Itabira*: Ipoema (three undeposited files, rec. LD); *Mariana* (three undeposited files, rec. CSC, used in Cassini *et al*. 2010).

Physalaemus riograndensis. **Argentina**: Província Entre Ríos: *Gualeguaicho* (FNJV 0031281–83, rec. AJC, a.t. 21ºC, w.t.

19ºC; FNJV 0031284, rec. AJC, a.t. 21ºC, w.t. 18ºC); **Brazil**: Rio Grande do Sul: *Guaíba* (Fonozoo 5993, rec. AK, a.t. 19ºC); *São Lourenço do Sul* (FNJV 0031280, rec. AJC); *Osório* (FNJV 0031285, rec. AJC, a.t. 22ºC, w.t. 21.6ºC); *El Dorado do Sul* (FNJV 0031610, rec. AJC, a.t. 19ºC, w.t. 23ºC; FNJV 0031640–42, rec. AJC, a.t. 19ºC, w.t. 23ºC; FNJV 0031643, rec. AJC, a.t. 16ºC, w.t. 22ºC); *Torres*: Arroio do Sal (Fonozoo 6025, rec. AK, a.t. 23ºC); *Itapeva* (Fonozoo 6494, rec. AK, a.t. 23ºC); *Candiota* (Fonozoo 6067–68, rec. AK, a.t. 20.5ºC; Fonozoo 6070, rec. AK, a.t. 20.5ºC; Fonozoo 6073, rec. AK, a.t. 14ºC; Fonozoo 6079, rec. AK, a.t. 20ºC); *Rosário do Sul* (Fonozoo 6131, rec. AK, a.t. 22.5ºC); **Uruguay**: *Rocha* (Fonozoo 6270, rec. AK, a.t. 21.5ºC).

Physalaemus rupestris. **Brazil**: Minas Gerais: Serra do Ibitipoca (three undeposited files, rec. LBN, used in Nascimento *et al*. 2001, a.t. 16ºC).

Physalaemus santafecinus. **Argentina** (two undeposited files, rec. DB, a.t. 18 and 19.8ºC, w.t. 19.6 and 21.6ºC).

Physalaemus signifer. **Brazil**: Rio de Janeiro: *Itaguaí*: Porto Florestal Santa Cruz (FNJV 0031273–75, rec. AJC, a.t. 23ºC, w.t. 24ºC; FNJV 0031276, rec. AJC, a.t. 23ºC, w.t. 22ºC; FNJV 0031919, rec. WCAB, a.t. 23.5ºC, w.t. 23.5ºC); *Teresópolis* (FNJV 0032138, rec. BL, a.t. 22.5ºC): Vale da Revolta (16 undeposited files, rec. MB, a.t. 19.5 to 20ºC, w.t. 18.5ºC); *Bom Jesus do Itabapoana*: Calheiros (one undeposited file, rec. BVSP); *Rio das Ostras*: Reserva Biológica União (MNVOC 015.4, rec. JP, a.t. 24.5ºC); *Cachoeira de Macacu*: Reserva de Guapiaçu (two undeposited files, rec. LD); *Niterói*: Parque Estadual da Serra da Tiririca (four undeposited files, rec. MB, a.t. 18 to 24ºC, w.t. 19ºC); *Duque de Caxias*: Parque Municipal daTaquara (11 undeposited files, rec. MB, a.t. 25.5 to 27ºC); *Angra dos Reis*: Ilha Grande (five undeposited files, rec. MB, a.t. 21 to 23.5ºC, w.t. 21 and 22.5ºC); *Magé*: Campo Escola dos Escoteiros Geraldo Hugo Nunes (15 undeposited files, rec. MB, a.t. 19ºC, w.t. 20ºC); Minas Gerais: *Viçosa*: Campus da Universidade Federal (FNJV 0031277–78, rec. AJC, a.t. 25ºC, w.t. 24ºC; FNJV 0031279, rec. AJC, a.t. 24ºC, w.t. 19ºC); Bahia: *Canavieiras*: Fazenda Santa Clara (one undeposited file, rec. BVSP); *Porto Seguro*: RPPN Estação Vera Cruz (three unnnamed files, rec. BVSP); *Prado*: Parque Nacional do Descobrimento (one undeposited file, rec. BVSP); unknown locality (one undeposited file, rec. RT).

Physalaemus soaresi. **Brazil**: Rio de Janeiro: *Seropédica*: Floresta Nacional Mário Xavier (FNJV 0031272, rec. AJC, a.t. 23ºC, w.t. 22ºC; two undeposited file, rec. SPCS).

Physalaemus spiniger. **Brazil**: São Paulo: *Iporanga*: Parque Estadual Turistico de Alto Ribeira: Núcleo Ouro Grosso (FNJV 0012968–69, rec. LG, a.t. 18ºC; FNJV 0013117, rec. LFT, FNJV 0013119, rec. LFT); *Caraguatatuba*: Loteamento Parque Imperial (FNJV 0031570, rec. AJC, a.t. 23ºC, w.t. 22.5ºC; FNJV 0031571, rec. AJC, a.t. 23.5ºC, w.t. 24ºC); *Jacupiranga* (FNJV 0031790, rec. WCAB, a.t. 20ºC); *Cananéia*: Ilha do Cardoso (CFBH 016.3, rec. CFBH, a.t. 15.5ºC); Paraná: *Guaraqueçaba*: Reserva Natural Salto Morato (FNJV 0013111–16, rec. TC, FNJV 0013118, rec. TC, FNJV 0013120, rec. TC); unknown locality (one undeposited file, JP; one undeposited file in Guia Sonoro da Mata Atlântica).