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Temperature effect on the advertisement call of *Pleurodema tucumanum* (Anura: Leiuperidae)

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Abstract

Temperature effect on the advertisement call of *Pleurodema tucumanum* (Anura: Leiuperidae). The advertisement call represents an important character to discriminate species, mainly between sibling species. The genus *Pleurodema* has cryptic species, therefore its acoustical characteristics could represent an useful tool to solve taxonomic problems. It is expected that the advertisement call acoustic properties of the amphibian anurans will vary with the temperature because the frogs are ectotherms. We evaluated the effect of temperature in the acoustic variables of the advertisement call of *Pleurodema tucumanum.* The inter-call interval, number of pulses per call, inter-pulse interval and pulse rate showed covariation with temperature, whereas the call duration, pulse duration and dominant frequency were temperature-independent. The advertisement call of *P. tucumanum* corresponds to a single periodic pulse train. The call showed an average duration of 289 ms, dominant frequency of 2552 Hz and 35 pulses of 2.38 ms at 22°C. The number of pulses increased with temperature. The discrimination of exogenous variability from the acoustic components allows one to analyze the intrinsic variability of the advertisement calls.

Keywords: bioacoustic analysis, linear regression model, single periodic pulse train.

Resumen

Efecto de la temperatura en el canto de advertencia de *Pleurodema tucumanum* (Anura: Leiuperidae). El canto de advertencia es un carácter importante que permite discriminar especies, principalmente entre especies simpátricas. El género *Pleurodema* poseen especies crípticas y por lo tanto, sus características acústicas podrían representar una herramienta útil para resolver problemas taxonómicos. Es esperado que las propiedades acústicas del canto de advertencia de los anfibios anuros varíen con la temperatura debido a su condición ectotérmica. Nosotros evaluamos el efecto de la temperatura en las variables acústicas del canto de advertencia de *Pleurodema tucumanum.* Las variables intervalo entre cantos, número de pulsos por canto, intervalo entre pulsos y tasa de pulsos mostraron covariación con la temperatura, mientras que las variables duración del canto, duración del pulso y frecuencia dominante resultaron temperatura-independientes. El canto de advertencia de *P.*

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tucumanum corresponde a un canto simple (tren de pulsos periódico simple). El canto tuvo una duración promedio de 289 ms, una frecuencia dominante de 2552 Hz y 35 pulsos de 2.38 ms a 22˚C. El número de pulsos incrementó junto con la temperatura. La discriminación de la variabilidad exógena a los componentes acústicos permite analizar la variabilidad intrínseca de los cantos de advertencia.

Palabras Clave: análisis bioacústico, canto simple, modelo de regresión lineal.

Resumo

Efeito da temperatura sobre o canto de advertência de *Pleurodema tucumanum* (Anura: Leiuperidae). O canto de advertência representa um caráter importante para discriminar espécies, principalmente entre espécies aparentadas. O gênero *Pleurodema* possui espécies crípticas, portanto suas características acústicas poderiam representar uma ferramenta útil para resolver problemas taxonômicos. É esperado que as propriedades acústicas do canto de advertência dos anfíbios anuros variem com a temperatura, devido à sua ectotermia. Avaliamos o efeito da temperatura sobre as variáveis acústicas do canto de advertência de *Pleurodema tucumanum.* O intervalo entre cantos, o número de pulsos por canto, o intervalo entre pulsos e a taxa de pulsos mostraram covariação com a temperatura, enquanto a duração do canto, a duração do pulso e a frequência dominante foram independentes da temperatura. O canto de advertência de *P. tucumanum* corresponde a uma sequência de pulsos periódicos. O canto teve uma duração média de 289 ms, frequência dominante de 2552 Hz e 35 pulsos de 2.38 ms a 22ºC. O número de impulsos aumentou com a temperatura. A discriminação da variabilidade exógena a partir de componentes acústicos permite analisar a variabilidade intrínseca dos cantos de advertência.

Palavras-chave: análise bioacústica, modelo de regressão linear, sequência de pulsos periódicos.

Introduction

The advertisement call plays an important role in the life history of anuran amphibians, mainly during the breeding season (Bogert 1960). These sound emissions are very effective to assure or reinforce genetic incompatibility, especially in the case of sibling species (Cei 1980). This last fact is because these acoustic signals have a genetic base which can be recognized by means of analyses of calls that produce the interspecific hybrids (Duellman and Trueb 1994). Therefore, the acoustic variables represent an important character to discriminate species (Schneider and Sinsch 1992, Schneider *et al.* 1993, Márquez and Bosch 1995, Schneider and Sinsch 1999, Martino and Sinsch 2002, Valetti *et al.* 2009). However, given that frogs are ectotherms, it is expected that acoustic properties of their calls will vary with temperature (Duellman and Trueb 1994). Moreover, several authors already have demonstrated the correlation of the temporal parameters of the call with the temperature (e.g., Blair 1958, Zweifel 1959, Gerhardt, 1978, Gayou 1984, Schneider and Sinsch 1992, Schneider *et al.* 1993, Márquez and Bosch 1995, Navas 1996b, Schneider and Sinsch 1999, Esteban *et al.* 2002, Martino and Sinsch 2002, Heyer and Reid 2003), mainly in species with energetic calling (Navas 1996a). Hence, the bioacoustic analyses of anuran calls requires considering temperature, so that this factor does not mask intrinsic differences or generate variations in otherwise similar calls.

The genus *Pleurodema* Tschudi, 1838, currently contains fifteen species and between them there are cryptic species (Frost 2011, Kolenc *et al.* 2011, Faivovich *et al.* 2012). For these reasons, bioacoustic analyses would represent a useful tool to help solving taxonomic problems in this genus (Barrio 1964, Valetti *et al.* 2009). For example, Barrio (1964), Duellman and Veloso (1977) and McLister *et al.* (1991) described and compared calls of different species of genus *Pleurodema,* but they did not consider the temperature effect. Herein, we evaluate the effect of temperature in the acoustic variables of the advertisement call of *Pleurodema tucumanum* Parker, 1927, and we describe this call type considering the effect of this environmental variable.

Materials and Methods

Field Work

We recorded advertisement calls of *Pleurodema tucumanum* in the central west area of Córdoba province, Argentina (Figure 1) during years 2005, 2006 and 2007 using a DAT record Sony™ TCD-100 with stereo microphone ECM-MS907 Sony™ and tape TDK™ DAT-RGX 60. The males emit their calls floating in temporary ponds. Therefore, after advertisement call recordings, we registered water temperatures with digital thermometer TES 1300 (±0.1˚C).

Sound Analyses

We analyzed 264 calls from 87 males in a temperature range of 11.1˚C (18.4–29.5˚C) using the Canary™ 1.2.1 software (Charif *et al.* 1995) at a sampling frequency of 44.1 kHz and sample size of 16 bits. We measured the temporal variables of each advertisement call using oscillograms and sonograms. According to Valetti *et al.* (2009) we performed the analyses of dominant frequency using a spectrogram with the following settings: filter bandwidth 649.4 Hz, frame length 256 points, grid resolution 128 points, overlap 50%, frequency 43.07 Hz, FFT size 1024 points; window function hamming; amplitude logarithmic; clipping level –95 dB. We measured seven call parameters: (1) call duration [ms]; (2) inter-call interval [ms]; (3) number of pulses per call; (4) pulse duration [ms]; (5) inter-pulse interval [ms]; (6) pulse rate [pulses/s]; (7) dominant frequency [Hz]. We calculated and used for further analyses the arithmetic means of these call parameters for each series (Martino and Sinsch 2002).

Statistical Analyses

We examined the overall thermal dependency of temporal parameters via principal component analysis (PCA) to understand the interaction between sound variables and the correlations of component scores of these variables with temperature. Then, we used multiple correlation analysis to identify the temperature-dependent acoustic variables and quantified temperature effect on these variables using linear regression

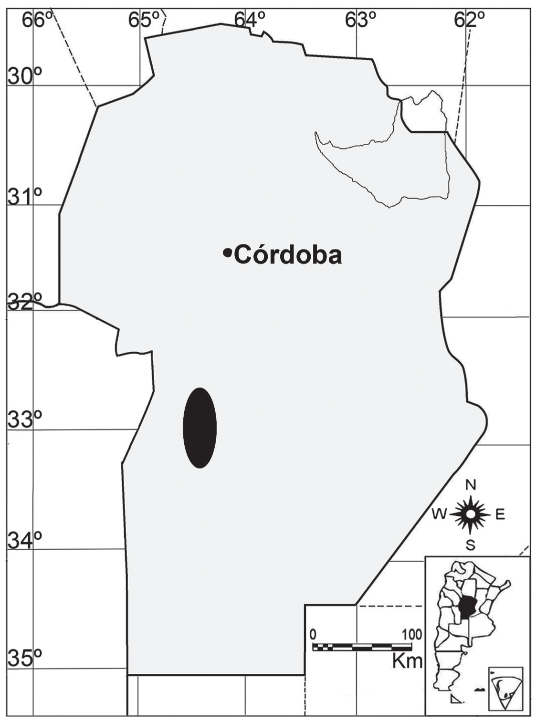

Figure 1. Geographical position of the location where the advertisement call records of the present study were obtained. Córdoba province, Argentina.

analyses (Heyer and Reid 2003). We standardized the temperature-dependent acoustic variables to 22˚C (average temperature of recorded calls) and calculated the position and dispersion statistics. We performed all calculations using the program package STATGRAPHICS for Windows, version 5.0 and we deposited the recordings of advertisement calls used in this works in the Fonoteca of Ecology, Department of Natural Science National University of Río Cuarto, Argentina.

Results

The results of PCA indicate that the first three principal components explain 79.4% of the variation in the original variables and each subsequent component explains a decreasing proportion of variance (Table 1). The factor loading of variables in each principal component (Table 2) and the projection of variables onto the plane defined by the first two principal components showed in the Figure 2 indicate that the variable Temperature has a little positive correlation with PC2 and a high correlation with PC1. Moreover, the variables Inter-call interval, Inter-pulse interval and Pulse rate also loaded in PC1 with Temperature. Therefore, the PC1 represents temperature-related features. The correlation analyses confirm that Inter-call interval, Number of pulses per call, Inter-pulse interval and Pulse rate are temperature-dependent variables (Table 3).

The linear regression model for each temperature-dependent acoustic variable and the variability percentage attributed to temperature were obtained using the water temperature (Table 4, Figure 3), with a range from 18.4 to 29.5˚C. The temperature-dependent variables standardized to 22˚C are characterized by the arithmetic mean, standard deviation and range. Likewise are presented the data to temperature-independent variables (Table 5). In addition, the Table 6 shows the confidence interval of the mean of the temperature-dependent variables at 22˚C.

The advertisement call of *Pleurodema tucumanum* is a simple call with only one pulse train (Figure 4). The calls show an average duration of 289 ms, dominant frequency of 2,552 Hz and 35 pulses. Each pulse has duration of 2.38 ms at 22˚C, showing an increase in the number of pulses when the temperature increases.

Discussion

The advertisement call of *Pleurodema tucumanum* corresponds to a single periodic pulse train according to its temporal pattern (Littlejohn 2001). The call duration agrees with the data enumerated by Barrio (1964) to temperature of 25.2˚C (0.28–0.33 seconds) to *P. tucumanum* from Patquía, La Rioja province, whereas the dominant frequency is lower than the range of 2,600–3,200 Hz presented by this author. Barrio (1964) did not contribute data referred to the number and duration of the pulses in *P. tucumanum*. Therefore, this is the first and only work in reporting this information for this species.

In the present study, we have observed that the pulse rate and the number of pulses per call are positively correlated with water temperature, whereas the call interval is negatively correlated with water temperature. Call duration and pulse duration are not considerably correlated with water temperature. These results indicate that the

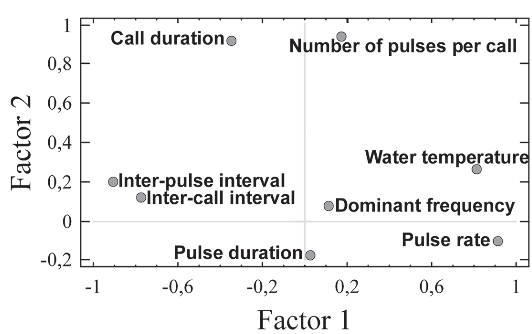

Figure 2. Projection of variables onto the plane defined by the first two principal components.

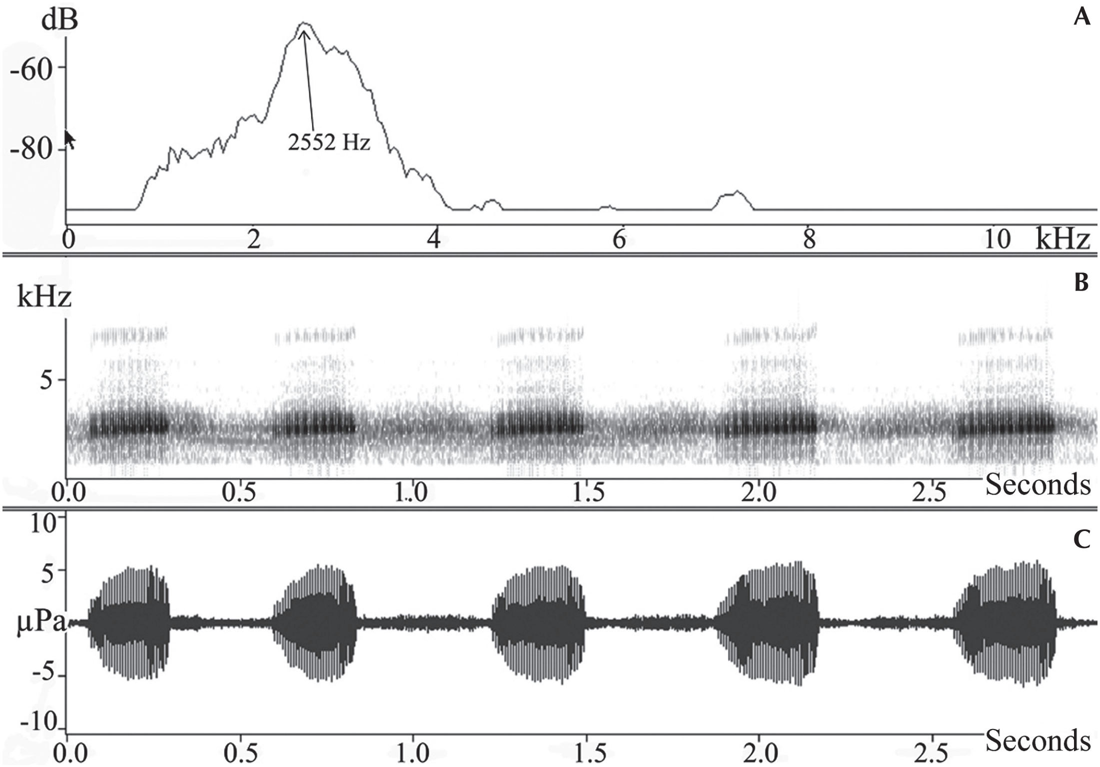

Figure 3. Linear regressions of the temperature-dependent acoustic variables versus water temperature and corresponding 95% confidence and prediction intervals. (**A**) Inter-call interval, (**B**) number of pulses per call, (**C**) inter-pulse interval, (**D**) pulse rate.

increase in the pulse rate regarding the temperature is due to the decrease of pulse interval and not to decrease of the pulse duration. Therefore, the number of pulses per call increases without affecting the duration of the call.

Given that amphibian anurans are ectothermic, their body temperature is heavily influenced by environmental temperature, with effects on behaviour and physiology (Wells 2007). In this study, the acoustic variables that were correlated with the water temperature are the variables whose emissions depend on laryngeal muscles (Schmidt 1965, Martin and Gans 1972, Schneider 1977, Schneider 1988, Pough *et al.* 1992). In hylids, which have calls consisting of a series of repeated pulses, laryngeal muscles actively open and close the larynx in synchrony with trunk muscles to produce the highly stereotyped and regularly spaced pulses which often are important for species recognition (Gerhardt 1991, Girgenrath and Marsh 1997). Martin (1972), Manz (1975) and Wells and Taigen (1992) demonstrated temperature constraints on the contractile properties of the trunk and laryngeal muscles involved in the production of the call. This last fact could explain the positive relationship of pulse rate with temperature.

In contrast with the acoustic variables discussed above, the dominant frequency did not relate to temperature. Several researchers have demonstrated a lack of association between the

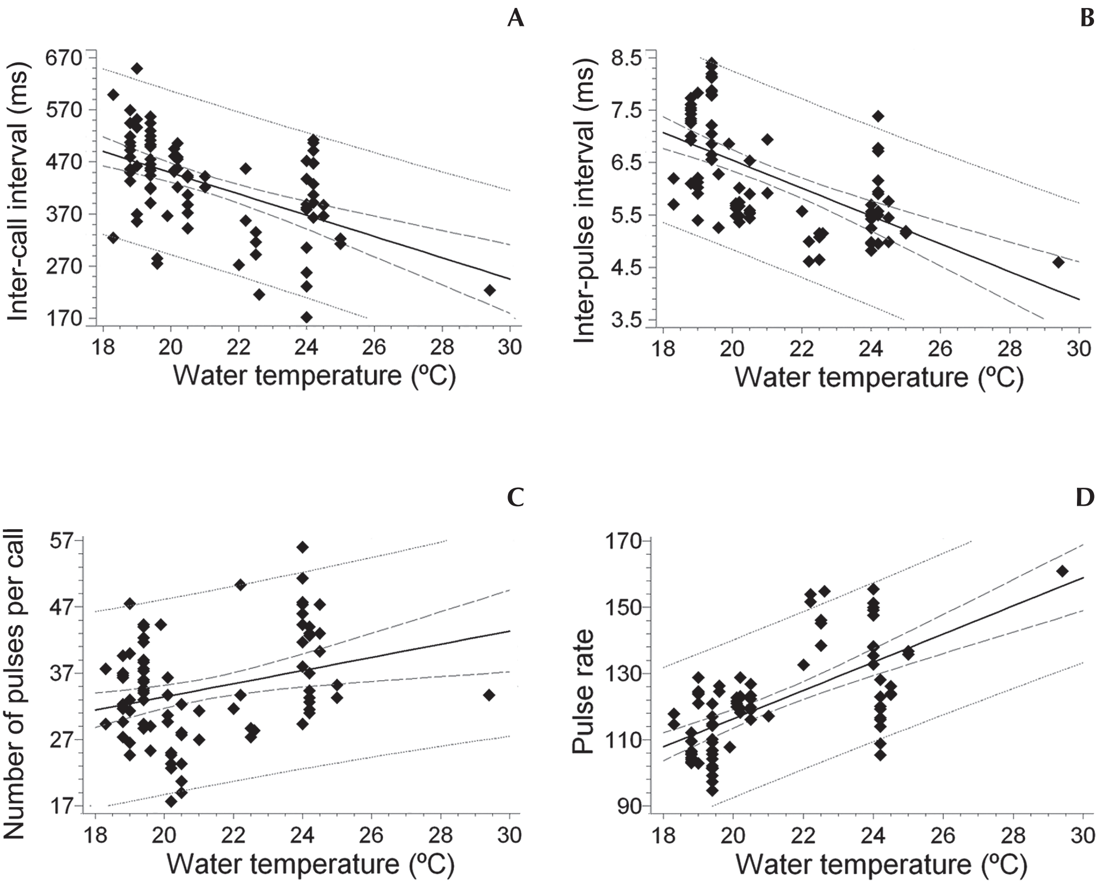

Figure 4. Components of a typical *Pleurodema tucumanum* advertisement call: power spectrum (call intensity vs. frequency); (**A**) sonogram (frequency vs. time); (**B**) and oscillogram (call intensity vs. time); (**C**) Water temperature: 25°C.

Table 1. Principal component analysis. Eigenvalues and percentage of variance for the components

PC	Eigenvalue	% Variance	% Cumulative
1	3,16474	39,559	39,559
2	2,16986	27,123	66,683
3	1,01430	12,679	79,361
4	0,83290	10,411	89,772
5	0,43063	5,383	95,155
6	0,36759	4,595	99,750
7	0,01469	0,184	99,934
8	0,00529	0,066	100,000

Table 2. Principal component analysis. Factor loading matrix in the first three components.

Variable	PC 1	PC 2	PC 3
Call duration	–0,34531	**0,91972**	0,11014
Inter-call interval	**-0,77539**	0,11982	–0,20883
Pulses per call	0,17346	**0,94296**	0,21122
Dominant frequency	0,11492	0,07274	**0,70542**
Pulse duration	0,02591	–0,17489	**-0,81838**
Inter-pulse interval	**-0,90526**	0,19892	0,23139
Pulse rate	**0,91497**	–0,10615	0,18817
Water temperature	**0,81632**	0,26187	0,00410

Table 3. Correlation of acoustic variables with air and water temperature, *N* = 87. Level of significance: *ns* not significant, **p* < 0.05, ***p* < 0.01, ****p* < 0.001.

	Call duration	Inter-call interval	Number of pulses per call	Dominant frequency	Pulse duration	Inter-pulse interval	Pulse rate
Water temperature	-0.0726^{ns}	–0.5175***	0.3040**	0.1405^{ns}	-0.0430^{ns}	–0.55927***	0.6453***

Table 4. Linear regression analyses between temperature-dependent variables and water temperature. Level of significance: *ns* not significant, **p* < 0.05, ***p* < 0.01, ****p* < 0.001.

Parameter	Correlation coefficient r	Regression coefficient R^2	Regression formula
Inter-call interval	–0.522052***	26.3980	y = 857.185 – 20.3975x
Number of pulses per call	0.304011*	8.1746	y = 13.5411 + 0.994053x
Inter-pulse interval	–0.592714***	34.3678	y = 11.855 + 0.265636x
Pulse rate	0.645259**	40.9493	y = 31.3312 + 4.25386x

Table 5. Means and corresponding standard deviations of the temperature-independent call parameters (TI) and means and corresponding standard deviations of the temperature-dependent call parameters (TD) standardized to 22°C. *N* = sample size (Individuals/calls/pulses).

Variables		*N*	Mean ± SD (Range)
Call duration [ms]	TI	87/264	288.7 ± 68.5 (144.0–467.7)
Inter-call interval [ms]	TD	87/260	408.4 ± 78.4 (211.6–588.5)
Number of pulses per call	TD	87/264	35.4 ± 7.3 (19–54)
Dominant frequency [Hz]	TI	87/264	2552.4 ± 104.9 (2239–2761.7)
Pulse duration [ms]	TI	87/264/792	2.38 ± 0.45 (1.47–3.37)
Inter-pulse interval [ms]	TD	87/264/792	6.01 ± 0.85 (4.60–7.97)
Pulse rate [pulses/s]	TD	87/264	125.0 ± 11.8 (96.1–153.1)

Table 6. Temperature-adjusted features of the advertisement call of *Pleurodema tucumanum*. Means and corresponding 95% confidence intervals. Water temperature of 22°C. *N* = sample size (individuals/calls/pulses)

Variables	*N*	Mean (confidence interval)
Inter-call interval [ms]	87/264	408.4 (391.7; 425.2)
Number of pulses per call	87/264	35.4 (33.8; 37.0)
Inter-pulse interval [ms]	87/264/792	6.01 (5.83; 6.19)
Pulse rate [pulses/s]	87/264	125.0 (122.3; 127.7)

call dominant frequency and the temperature, although this variable appears to depend of the body size of individuals (e.g., Nevo and Schneider 1976, Ryan 1986, Ryan 1988, Giacoma *et al.* 1997, Castellano and Giacoma 1998, Castellano *et al.* 1999, Márquez and Bosch 2001). Unfortunately, the sampling design and the elusive behaviour of individuals studied precluded us to capture recorded individuals. Therefore, future work is necessary to elucidate size effects on the calling traits of this species, including possible size-temperature interactions.

Our results indicate that temperature explains an important fraction of the variability in some acoustic variables (40% in the pulse rate) in *Pleurodema tucumanum.* The inter-pulse interval showed variability attributed to the temperature higher than 34% and it explains the increase of the pulse rate respect to the temperature. The inter-call interval also showed a high variability attributed to the temperature, but this variable could be related to several exogenous factors. Giacoma and Castellano (2001) demonstrated that the variation in the inter-call interval among individuals is lesser than within individuals, therefore should be less likely to exhibit an evolutionary response to selection, although can convey information relevant to the intraespecific mate choice. Dole and Durant (1974) demonstrated that the inter-call interval in *Colostethus collaris* diminishes when the conspecific female approaches to less than 5 cm.

Some researchers have characterized the advertisement calls of different species without considering the temperature effect. In these works, the acoustic variables are described using position and dispersion statistics (e.g., Barrio 1964, Duellman and Veloso 1977, McLister *et al.* 1991, Salas *et al.* 1998, Heyer and Carvalho 2000). In other cases, temperature-dependent variables are fitted to linear regression models (e.g., Schneider and Sinsch 1992, Schneider *et al.* 1993, Márquez and Bosch 1997, Stöck 1998, Schneider and Sinsch 1999, Esteban *et al.* 2002, Martino and Sinsch 2002, Heyer and Reid 2003). In this study, we characterized the acoustic variables using position and dispersion statistics. Before to this, we standardized the temperature-dependent variables at a fixed temperature. This methodology allows us to evaluate the acoustic variables of individuals at different temperatures, as was made by Heyer and Reid (2003) for *Leptodactylus fuscus* and as was made here by us regarding to data of Barrio (1964). In addition, we provide a linear regression model encompassing temperature effects and their confidence intervals. These models allow one to infer the value of the acoustic variables for another temperature of interest. For these reasons, it is very important that results of future investigations are expressed as in this study so that researchers can compare data from different studies.

Numerous studies have emphasized the importance of bioacoustics as an element of high taxonomic value (e.g., Blair 1958, Bogert 1960, Barrio 1964, Bogart and Wasserman 1972, Schiotz 1973, Littlejohn 1977, Duellman and Pyles 1983, Martino and Sinsch 2002). The results presented here demonstrate the importance of considering the temperature effect on the acoustic components. In this study, we present an approach allowing to consider the exogenous variability on the acoustic components and to analyze the intrinsic variability of the advertisement calls among individuals within a population, among populations and among individuals of different species.

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