First evidence of sound production in the genus *Iberolacerta* ARRIBAS, 1997
(Squamata: Sauria: Lacertidae)

Erster Nachweis einer Lautäußerung bei der Gattung *Iberolacerta* ARRIBAS, 1997
(Squamata: Sauria: Lacertidae)

ROBERTO GARCÍA-ROA & DIEGO LLUSIA
& PILAR LÓPEZ & JOSÉ MARTÍN

KURZFASSUNG

Lautäußerungen spielen eine Schlüsselrolle in einer Vielzahl von Interaktionen zwischen artgleichen und -verschiedenen Individuen. Doch im Vergleich mit anderen Sinnesleistungen wird der Akustik bei Reptilien nur wenig Aufmerksamkeit geschenkt. Innerhalb der Lacertidae wird Fehlen und Vorhandensein von Lautäußerungen als ein Unterscheidungsmerkmal zwischen den Unterfamilien Gallotinae und Lacertinae angesehen, wobei letztere, höchst diverse Unterfamilie als mehrheitlich nicht stimmbegabt betrachtet wird.

Mit Hilfe von Bild- und Tonaufzeichnungen berichten die Autoren erstmals über die Lautäußerungen bei *Iberolacerta cyreni* (MÜLLER & HELLMICH, 1937), einer europäischen Felseidechsenart. Tonaufnahmen eines Exemplars im Freiland geben kurze nasale quietschende Laute wieder, die hinsichtlich des Mechanismus der Schallproduktion und der akustischen Merkmale Ähnlichkeit mit den Lauten nahe verwandter Lacertidenarten zeigen. Die funktionale Bedeutung derartiger Lautäußerungen ist unklar, doch weisen die akustischen Merkmale und der Verhaltenskontext auf die Möglichkeit eines bei Gefahr abgegebenen Schreckrufs hin. Die vorliegenden Beobachtungen lassen vermuten, daß sich die Fähigkeit zur Lautproduktion bei verschiedenen systematischen Gruppen der Halsbandeidechsen entwickelt hat und, auch wenn selten eingesetzt, weiter verbreitet ist als erwartet.

ABSTRACT

Sound production plays a key role in a broad range of animal interactions among both conspecifics and heterospecifics. Yet less attention has been paid to acoustic communication in reptiles than to other sensorial modalities. Within Lacertidae, the presence or absence of vocal behavior has been referred as a distinctive trait between their two subfamilies Gallotinae and Lacertinae, being the latter the most diverse group of lacertid lizards and considered to be mainly silent.

Using image and sound recordings, the authors report for the first time the ability to sound production in a European rock lizard species. Recorded sounds of a free-ranging female of the Carpetan Rock Lizard *Iberolacerta cyreni* (MÜLLER & HELLMICH, 1937), were short nasal squeak-like sounds showing a similar production mechanism and acoustic characteristics to sounds emitted by closely related lacertid species. Functional significance of such a sound activity is unclear, although its acoustic characteristics and behavioral context point out that these sounds might function as distress calls. The present findings suggest that the ability to sound production might have evolved at different systematic groups across lacertid lizards and, even if sporadically used, is more widespread than previously expected.

KEY WORDS

Reptilia: Squamata. Sauria: Lacertidae; *Iberolacerta cyreni*; behavior, acoustic communication; distress calls; lizard vocalization; Iberian Peninsula

INTRODUCTION

Sound enables animals to convey information to conspecifics and heterospecifics in a wide array of social interactions and encounters, including mate choice, territorial defense, or antipredator responses (SEARCY & NOWICKI 2005). In some conditions, acoustic cues are more efficiently propagated and detected than those from other sensorial modalities (ROSENTHAL & RYAN 2000). Moreover, they are also used together with other cues in multimodal signaling, particularly in agonistic or aggressive behavior, to enhance receivers' responsiveness (Narins et al. 2003).

In reptiles, less attention has been paid to acoustic communication than in other groups or to other sensorial modalities, such as visual and chemical communication (Frankenberg & Werner 1992; Martín & López 2014; Willis et al. 2014). Crocodiles, geckos, and some species of lizards are known to vocalize during reproductive season, aggressive interactions or distress behavior (Frankenberg & Werner 1984; Hibbitts et al. 2007; Vergne et al. 2009). Within lacertid lizards (Lacertidae), the ability to sound production has traditionally been referred as one of the behavioral traits separating its two subfamilies (Salvador & Pleguezuelos 2013). Lizards belonging to the subfamily Gallotiinae, which comprises two genera and 16 species (Pyron et al. 2013), are able to produce sounds in inter- and intra-specific interactions (Böhme et al. 1985). However, vocalizations in the subfamily Lacertinae, the most diverse group of lacertid lizards, with 19 genera and approximately 100 species, have been scarcely recorded, and correspond to only a few species (Böhme et al. 1985; Ouboter 1990).

Here, the authors report the first evidence of sound production in the *Archaeolacerta* group *sensu lato*, one of the historical species groups within Lacertinae. Image and sound recordings, provide a detailed acoustic characterization of sounds emitted by a free-ranging Carpetan Rock Lizard *Iberolacerta cyreni* (Müller & Hellmich, 1937), as well as a description of sound production mechanism, behavior, and context. The functional significance of such a sound activity is discussed. To the best of the authors' knowledge, no recordings of European rock lizards (*Iberolacerta* spp.) nor lizards within the *Archaeolacerta* group *s. lat.* are available to date, despite of the increasing interest aroused in their behavioral ecology and evolution (Martín 2015).

MATERIALS AND METHODS

Iberolacerta cyreni is a medium-sized lizard, endemic of Sistema Central, the central mountain range of the Iberian Peninsula, where it inhabits rocky highlands near the treeline (> 1,700 m a.s.l.). This species belongs to European rock lizards, which were historically included in *Archaeolacerta* group *s. lat.* (Carranza et al. 2004).

In May to September 2014, adult individuals were captured in the "Cerro Del Telégrafo" (23°10'12"N, 102°53'19"W, Sierra de Guadarrama, Spain) to gain behavior and morphology data. During subsequent release of individuals (August 7, 2014), a free-ranging female basking on a rock immediately began to emit serial sounds upon the observer's approach. After three series of sound production, the specimen fled and hid in an underground refuge. During this activity, images of the focal individual were taken (Canon 450D, lens 18-55 mm) and a 22 second digital film recording (MPG4 format, Sony Xperia Miro ST23i, Tokyo, Japan) was obtained at a distance of around 1.5-2 m from the subject. Subsequently, an audio file (48 kHz, 16-bit) was extracted from this recording with VLC 2.0.6 (Video LAN, Paris, France) and analyzed with Raven 1.4 (Cornell University, Ithaca, USA). For each sound, a total of 10 acoustic parameters were measured using both oscillogram and spectrogram: 5 in the temporal domain and 5 in the spectral domain (Table 1). Spectral parameters were calculated through a fast short-term Fourier transform (FFT) set at a length of 512 points with 90 % overlap between successive Hanning windows, providing a resolution of 135 Hz and 10.6 ms. Band-stop frequency filter (0-0.3 kHz) and peak normalization (100 %) were applied with Raven 1.4 to the audio recordings before parameter measurements. The R package "seewave" was used to create visual representations of a characteristic sound (Sueur et al. 2008).

Table 1: Description of acoustic parameters measured in a vocalizing female of *Iberolacerta cyreni* (Müller & Hellmich, 1937). Hz – Hertz, s – seconds.

Tab. 1: Beschreibung der bei den Lautäußerungen eines Weibchens von *Iberolacerta cyreni* (Müller & Hellmich, 1937) untersuchten akustischen Meßgrößen. Hz – Hertz, s – Sekunden.

Parameter	Description of the measurement / Meßwertdefinition
Note duration (s) / Rufdauer (s)	Time (s) from the onset to the end of one sound, as shown in an oscillogram Zeit (s) vom Beginn bis zum Ende des Rufs wie im Oszillogramm angezeigt
Inter-note interval (s) / Rufintervall (s)	Time (s) from the end of one sound to the onset of the next sound Zeit (s) vom Ende eines Rufs bis zum Beginn des folgenden Rufs
Rise duration / Anstiegszeit (s)	Time (s) from the onset to the point of the maximum amplitude of one sound Zeit (s) vom Rufbeginn bis zum Zeitpunkt der maximalen Rufamplitude
Fall duration (s) / Abfallzeit (s)	Time (s) from the point of the maximum amplitude to the end of one sound Zeit (s) vom Zeitpunkt der maximalen Rufamplitude bis zum Rufende
Rise ratio (%) / Anstiegsverhältnis (%)	Percentage (%) of rise duration relative to note duration Anteil (%) der Anstiegszeit an der Rufdauer
Dominant frequency (Hz) / Dominante Frequenz (Hz)	Frequency (Hz) at which sound energy of one sound is maximum Jene Frequenz (Hz) eines Rufs mit der maximalen Schallenergie
Fundamental frequency (Hz) / Grundfrequenz (Hz)	Frequency (Hz) of the lowest harmonic of one sound Die tiefste Frequenz (Hz) im harmonischen Frequenzgemisch eines Rufs
Maximum frequency (Hz) / Maximalfrequenz (Hz)	Frequency (Hz) of the highest harmonic of one sound Die höchste Frequenz (Hz) im harmonischen Frequenzgemisch eines Rufs
Number of frequency bands / Frequenzbandzahl	Total number of frequency bands in one sound Die Gesamtzahl der Frequenzbänder eines Rufs
Frequency modulation (Hz) / Modulation der dominanten Frequenz (Hz)	Difference in dominant frequency (Hz) between the first and the last 10 % section of one sound / Differenz in der dominanten Frequenz der ersten und letzten 10 % des Rufs

RESULTS

The sound emitted by the *I. cyreni* female was produced with open mouth and comprised two major phases, according to video analysis: (i) abrupt air expiration by rapid thoracic compression of lungs at the time of mouth opening, followed by an (ii) up and backward movement of the head at right angle to the ground, thorax relaxation, and mouth closure (Fig. 1). Sounds consisted of series of short nasal squeaks emitted in bouts of 3-7 notes. These squeaks were single pulsed notes with a mean duration of 122 ms that were repeated each 6.4 s on average (Table 2 and Fig. 2). Most of the sound energy was produced at the very beginning of the note and then progressively decreased across the emission. Thereby, sound amplitude peaked after only an aver-

Table 2: Descriptive statistics including mean ± standard deviation, ranges and sample size of ten parameters of the sounds produced by a female of *Iberolacerta cyreni* (Müller & Hellmich, 1937). Hz – Hertz, s – seconds.

Tab. 2: Beschreibende Statistiken (Mean – Mittelwert, SD – Standardabweichung, range – Spannweite, *N* – Stichprobenumfang) von 10 Kenngrößen jener Laute, die von einem Weibchen von *Iberolacerta cyreni* (Müller & Hellmich, 1937) produziert wurden. Hz – Hertz, s – Sekunden.

Parameter	Mean ± SD (range, *N*)
Note duration (s) / Rufdauer (s)	0.122 ± 0.035 (0.163-0.096, 3)
Inter-note interval (s) / Rufintervall (s)	6.415 ± 1.022 (7.138-5.692, 2)
Rise duration (s) / Anstiegszeit (s)	0.011 ± 0.007 (0.02-0.005, 3)
Fall duration (s) / Abfallzeit (s)	0.111 ± 0.029 (0.143-0.086, 3)
Rise ratio (%) / Anstiegsverhältnis (%)	9.091 ± 4.009 (12.269-4.587, 3)
Dominant frequency (Hz) / Dominante Frequenz (Hz)	2937.5 ± 471.864 (3375.0-2437.5, 3)
Fundamental frequency (Hz) / Grundfrequenz (Hz)	1000 ± 286.410 (1312.5-750.0, 3)
Maximum frequency (Hz) / Maximalfrequenz (Hz)	9563.9 ± 879.958 (10485.0-8732.4, 3)
Number of frequency bands / Anzahl der Frequenzbänder	5
Frequency modulation (Hz) / Modulation der dominanten Frequenz (Hz)	1000 ± 943.729 (1875.0-0.0, 3)

Fig. 1: Sound production in a female of *Iberolacerta cyreni* (Müller & Hellmich, 1937), from the Sierra de Guadarrama, Madrid, Spain. Three consecutive phases are represented: A – relaxation phase before sound emission; B – abrupt air expiration by rapid thoracic compression of lungs at the time of mouth opening; and C – up and backward movement of the head at right angle to the ground, thorax relaxation, and mouth closure.

age of 11 ms (< 10 % of rise ratio). The spectral structure of the vocal sound is characterized by the presence of several frequency bands, starting at 1.0 kHz, a discrete frequency modulation, and 3.0 kHz of dominant frequency. Sound activity lasted around two min during which three series of squeaks were uttered. Inter-series interval was longer than duration of the series and the subject allocated such pauses to change its position before restarting sound production.

DISCUSSION

This study provides the first evidence of sound production in a species belonging to the genus *Iberolacerta*. Image and sound recordings of a free-ranging female of *I. cyreni* suggest that the ability to sound production might have evolved at different taxonomic groups across lacertid lizards and is more widespread than previously expected. Vocal behavior had hitherto been observed and reported in four genera of the subfamily Lacertinae, namely *Meroles*, *Zootoca*, *Lacerta*, and *Podarcis* (Böhme et al. 1985; Ouboter 1990), in addition to *Gallotia* and *Psammodromus* within the subfamily Gallotiinae. Nevertheless, acoustic communication seems to be sporadic in Lacertinae, while it is a well-established behavioral trait in Gallotiinae.

Sounds emitted by *I. cyreni* were squeak-like sounds showing similar acoustic features to sounds emitted by several closely related lacertid species. For instance, *Podarcis siculus* (Rafinesque-Schmaltz, 1810) has been found to also produce brief squeaks, slightly shorter (0.07 s) and lower in frequency (0.2-2.2 kHz kHz) than those

---

Abb. 1 (linke Spalte): Schallproduktion bei einem Weibchen von *Iberolacerta cyreni* (Müller & Hellmich, 1937) aus der Sierra de Guadarrama, Madrid, Spanien. Drei aufeinanderfolgende Phasen sind dargestellt: A – Entspannungsphase vor der Lautabgabe; B – plötzlicher Luftausstoß aus den Lungen durch rasche Kontraktion des Brustkorbs bei geöffnetem Maul; C – Aufwärts- und Rückwärtsbewegung des Kopfes, rechtwinkelig zur Unterlage, Entspannung des Brustkorbs, Schließen des Maules.

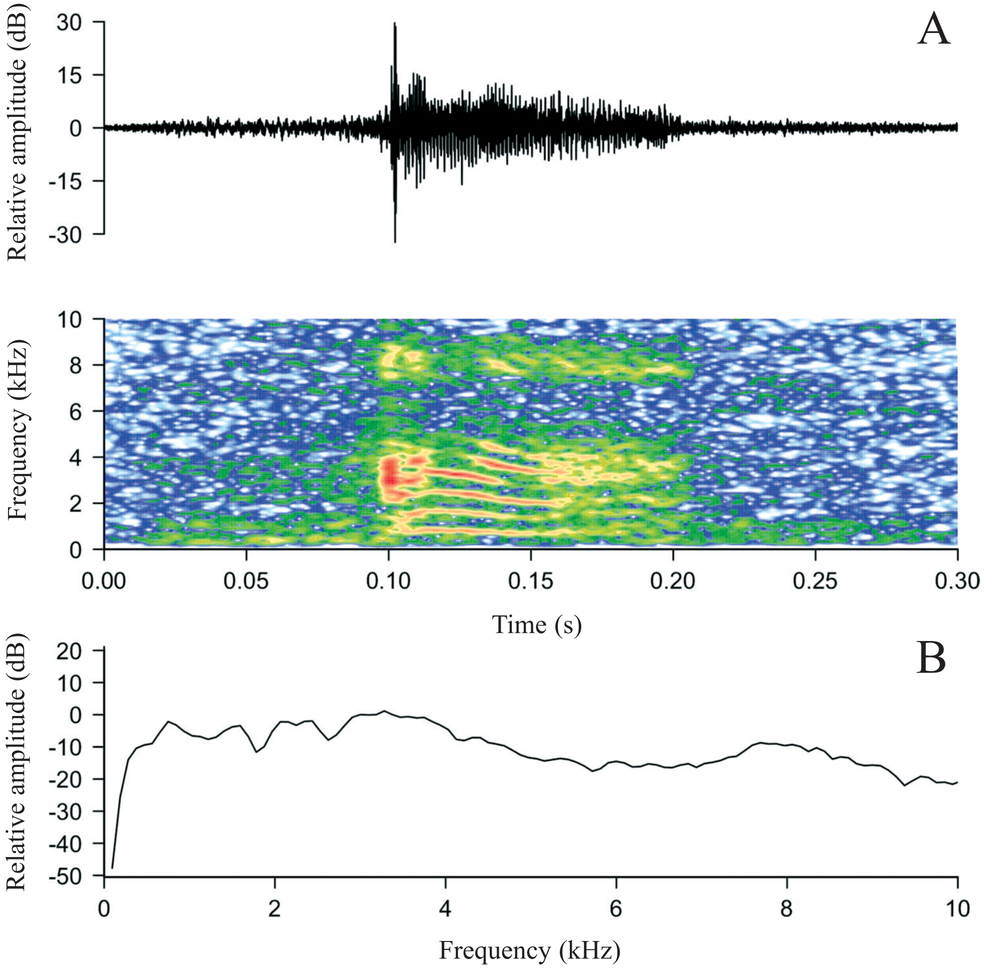

Fig. 2: A – Oscillogram (above) and sound spectrogram (below), and B – power spectrum (512 points of FFT size, 135 Hz bandwidth, 90 % overlap, and Hanning window) of a sound uttered by a female of *Iberolacerta cyreni* (MÜLLER & HELLMICH, 1937).

Abb. 2: A – Oszillogramm (oben) und Audiospektrogramm (unten) sowie C – Energiespektrum (Länge der schnellen Fourier-Transformation: 512 Stützstellen, Bandbreite 135 Hz, 90 % Überlappung, Hanning Fenster) der Lautäußerung eines Weibchens von *Iberolacerta cyreni* (MÜLLER & HELLMICH, 1937).

of *I. cyreni* (OUBOTER 1990). In contrast, most of the species of the subfamily Gallotiinae, e.g., *Psammodromus algirus* (LINNAEUS, 1758), *P. hispanicus* FITZINGER, 1826, and several *Gallotia* species exhibit markedly longer notes (0.1-1.8 s), often reaching high and broad-banded frequencies (up to 16 kHz), in comparison to the recorded squeaks of *I. cyreni* (BÖHME et al. 1985). Among the variety of sounds uttered by lizards, these from *I. cyreni* and other squeak-like sounds, such as those of some *Anolis* species (CHRISTENSEN-DALSGAARD & MANLEY 2005; MILTON & JENSSEN 1979), largely converge in acoustic properties. Moreover, the sound production mechanism in *I. cyreni* seems to be closely associated with that described in other lizards (Gans & Maderson 1973).

Specific investigations are required to conclusively determine the functional significance of the observed sound activity, although some insights may be gained by examining its characteristics and behavioral context. On the one hand, sounds produced by *I. cyreni* might correspond to vocalizations or communication signals directed to, for instance, a potential predator. Their temporal and spectral structure, characterized by short rise time and one-way frequency modulation, is consistent with a widespread acoustic pattern of animal alarm and distress calls (Willis et al. 2014). Since they were recorded in close proximity of a human observer after animal manipulation, these sounds might be ascribed to distress calls. Individuals of the study species are typically solitary and rarely form into social groups (Martín 2015) and hence these sounds were unlikely alarm calls addressed to off-guard conspecifics. Many sounds produced by other lacertids have been interpreted as antipredator responses aimed at deterring aggression or warning risk. *Podarcis siculus* emits squeaks when handled, although also in free-ranging conditions (Ouboter 1990). Moreover, species of the subfamily Gallotiinae have been observed to produce acoustic signals in agonistic encounters with both conspecifics and heterospecifics, even though their functions are poorly known. On the other hand, sounds produced by *I. cyreni* might also correspond to non-communicative airborne sounds emitted as by-products of other biophysical phenomena. It cannot be excluded that a pathological condition in the respiratory tract was responsible for the sound activity in the observed Carpetan Rock Lizard.

ACKNOWLEDGMENTS

Roberto García-Roa benefited from an FPI (Formación Personal Investigador) grant from the Ministerio de Ciencia e Innovación (research projects MICIINCGL 2011-24150/BOS and CGL2014-53523-P/BOS). Diego Llusia was supported by the Fondation Fyssen (Postdoctoral Study Grant, 2014-2016, France).

REFERENCES

Böhme, W. & Hutterer, R. & Bings, W. (1985): Die Stimme der Lacertidae, speziell der Kanareneidechsen (Reptilia: Sauria).- Bonner Zoologische Beiträge, Bonn; 36 (3/4): 337-354.

Carranza, S. & Arnold, E. & Amat, F. (2004): DNA phylogeny of *Lacerta* (*Iberolacerta*) and other lacertine lizards (Reptilia: Lacertidae): did competition cause long-term mountain restriction?- Systematics and Biodiversity, Abingdon; 2 (01): 57-77.

Christensen-Dalsgaard, J. & Manley, G. A. (2005): Directionality of the lizard ear.- Journal of Experimental Biology, Cambridge; 208 (6): 1209-1217.

Frankenberg, E. & Werner, Y. (1984): The defensive vocal «distress» repertoire of gekkonid Lizards: intra-and inter-specific variation.- Amphibia-Reptilia, Leiden; 5 (2): 109-124.

Frankenberg, E. & Werner, Y. (1992): Vocal communication in the reptilia – facts and questions.- Acta Zoologica Lilloana, Tucumán; 41: 45-62.

Gans, C. & Maderson, P. F. (1973): Sound producing mechanisms in recent reptiles: review and comment.- American Zoologist, Lawrence; 13 (4): 1195-1203.

Hibbitts, T. J. & Whiting, M. J. & Stuart-Fox, D. M. (2007): Shouting the odds: vocalization signals status in a lizard.- Behavioral Ecology and Sociobiology, Berlin, Heidelberg etc.; 61 (8): 1169-1176.

Martín, J. (2015): Lagartija carpetana - *Iberolacerta cyreni* (Müller & Hellmich, 1937); pp. 1-20. In: Salvador, A. & Marco, A. (Eds.): Enciclopedia virtual de los vertebrados españoles. Ver. 1-09-2015. Madrid (Museo Nacional de Ciencias Naturales), WWW document available at < http://www.vertebradosibericos.org/reptiles/ibecyr.html > [last accessed: November 14, 2016].

Martín, J. & López, P. (2014): Pheromones and chemical communication in lizards; pp. 43-75. In: Rheubert, J. L. & Siegel, D. S. & Trauth, S. E. (Eds.): Reproductive biology and phylogeny of lizards and tuatara. Boca Raton (CRC Press).

Milton, T. H. & Jenssen, T. A. (1979): Description and significance of vocalizations by *Anolis grahami* (Sauria: Iguanidae).- Copeia, Washington: 1979: 481-489.

Narins, P. M. & Hödl, W. & Grabul, D. S. (2003): Bimodal signal requisite for agonistic behavior in a dart-poison frog, *Epipedobates femoralis*.- Proceedings of the National Academy of Sciences, Washington; 100 (2): 577-580.

Ouboter, P. E. (1990): Vocalization in *Podarcis sicula salfii*.- Amphibia-Reptilia, Leiden; 11 (4): 419-421.

Pyron, R. A. & Burbrink, F. T. & Wiens, J. J. (2013): A phylogeny and revised classification of

Squamata, including 4161 species of lizards and snakes.- BMC Evolutionary Biology, London, Berlin, Heidelberg; 13 (1): 93 [pp. 53].

Rosenthal, G. G. & Ryan, M. J. (2000): Visual and acoustic communication in non-human animals: a comparison.- Journal of Biosciences, Bangalore; 25 (3): 285-290.

Salvador, A. & Pleguezuelos, J. M. (2013): Guía de Reptiles de España. Identificación, historia natural y distribución. Talavera de la Reina (Canseco Editores), pp. 464.

Searcy, W. A. & Nowicki, S. (2005): The evolution of animal communication: reliability and deception in signaling systems. Princeton (Princeton University Press), pp. XII, 270.

Sueur, J. & Aubin, T. & Simonis, C. (2008): Equipment review: seewave, a free modular tool for sound analysis and synthesis.- Bioacoustics, Berkhamsted, 18 (2): 213-226.

Vergne, A. & Pritz, M. & Mathevon, N. (2009): Acoustic communication in crocodilians: from behaviour to brain.- Biological Reviews, Oxford; 84 (3): 391-411.

Willis, K. L. & Christensen-Dalsgaard, J. & Carr, C. E. (2014): Auditory brain stem processing in reptiles and amphibians: roles of coupled ears; pp. 193-225. In: Köppl, C. & Manley, G. A. & Popper, A. N. & Fay, R. R. (Eds.): Insights from comparative hearing research. New York (Springer).

DATE OF SUBMISSION: April 20, 2016 Corresponding editor: Heinz Grillitsch

AUTHORS: Roberto García-Roa (Corresponding author < r.garcia-roa@mncn.csic.es >) [1], Diego Llusia [2, 3], Pilar López [1] & José Martín [1]

[1] Department of Evolutionary Ecology. National Museum of Natural Sciences - Spanish Research Council (MNCN-CSIC). José Gutiérrez Abascal, 2, 28006, Madrid, Spain.

[2] Department of Biodiversity and Evolutionary Biology, Fonoteca Zoológica. National Museum of Natural Sciences - Spanish Research Council (MNCN-CSIC). José Gutiérrez Abascal, 2, 28006, Madrid, Spain.

[3] Institut de Systématique, Évolution, Biodiversité, ISYEB - UMR 7205 - CNRS, MNHN, UPMC, EPHE; Muséum national d’Histoire naturelle, Sorbonne Universités, 57 rue Cuvier, CP 50, F-75005, Paris, France.