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Bioacoustic evidence of two uncommon crickets from SW Sardinia, including an analysis of the song of *Brachytrupes megacephalus* (Lefèvre, 1827) (Orthoptera Gryllidae) in the ultrasonic range

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ABSTRACT Two elusive species of crickets, *Natula averni* (A. Costa, 1855) (Orthoptera Gryllidae Trigonidiinae), and *Brachytrupes megacephalus* (Lefèvre, 1827) (Orthoptera Gryllidae Gryllinae) are reported from SW Sardinia based on recordings with 96 kHz sample frequency. The song of the latter species, that was observed and photographed during song emission, is also recorded at a sample frequency of 250 kHz, revealing harmonic components up to 100 kHz and above.

KEY WORDS Orthoptera; *Brachytrupes*; *Natula*; Sardinia; Biogeography; Bioacoustics.

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INTRODUCTION

Previous bioacoustics studies by the author in the same geographic area (Brizio & Buzzetti, 2014; Brizio, 2015) have demonstrated the effectiveness on the field of low cost USB microphones capable of recording ultrasounds thanks to high sampling frequency (250 kHz), the consistency of such recordings with those obtained with a 96 kHz audible band digital recorder, and the possibility to identify different species on the basis of their song, as well as to derive novel information from an analysis of high frequency components of the songs, previously unreported in the scientific literature: an observation limited to audible frequencies, or to the 0-48 kHz range provided by 96 kHz recordings, may deliver incomplete or misleading results.

In this short paper, the same techniques cited above are applied to the bioacoustic identification and to the analysis of the song of two elusive species of Orthoptera Gryllidae: *Natula averni* (A. Costa, 1855), also described as "*the most mysterious orthopteran of Europe*" (Odé et al., 2011), and the biggest European cricket, *Brachytrupes megacephalus* (Lefèvre, 1827), capable to emit an exceptionally powerful song. Although lacking field equipment to measure absolute acoustic pressure, based on the direct experience of close contact with both species, the author subjectively feels that the volume of the song of *B. megacephalus* matches or exceeds the volume of the songs by *Gryllotalpa vineae* Bennet-Clark, 1970, the latter species reportedly reaching 80 dB at 2 meters above the burrow (Bennet-Clark, 1970a, b).

In the following pages, the analysis of the song of *B. megacephalus* will reveal a previously unreported, exceptionally rich harmonic structure, extending well into the ultrasonic domain.

MATERIAL AND METHODS

To ensure consistency with previous analyses (Brizio & Buzzetti, 2014; Brizio, 2015), the same methods have been applied here.

All the species reported were recorded within a 10 km range from Fluminimaggiore (Carbonia-Iglesias Province, Sardinia, Italy) (Figs. 1–5).

All the audio material was obtained by field recording. Specimens were not captured nor recorded in constrained conditions.

Recording equipment included a Zoom H1 handheld digital Micro-SD recorder, coupled with a self-built stick stereo microphone using Panasonic WM-64 capsules from an Edirol R-09 digital recorder.

Acoustic recordings were taken in stereo, 16 bit, with a 96 kHz sampling frequency, and thus covering frequencies up to 48 kHz. The audio samples where obtained in the field, in windy conditions. Having observed no meaningful pattern in the lowest frequency range, to improve the clarity of the successive analyses and illustrations, an 18th order Chebychev Type 1 high pass filter was applied, with cut-off frequency at 150 Hz.

Due to atmospheric conditions, the left channel of the stereo microphone recorded a significant amount of noise. To the purpose of the analyses performed, the audio from the right channel was doubled in the left channel with no variation, before merging the two channels in one monophonic recording.

Ultrasound monophonic recording at a 250 kHz sampling frequency was performed via a Dodotronic Ultramic 250 microphone connected via USB cable to an Asus Eee PC 1225B notebook personal computer, using SeaWave software by CIBRA-University of Pavia's "Centro Interdisciplinare di Bioacustica e Ricerche Ambientali". Originally received as amplitude data (mV) by the recording apparatus, software normalized spectral energy is expressed in decibels. Sound pressure is expressed in dB Full Scale.

Oscillograms, spectrograms, and frequency analysis diagrams were generated by Adobe Audition 1.0 software. To give more evidence even to the faintest significant spectral components, or to improve readability of frequency/volume analyses, screenshots were contrast-enhanced with Adobe Photoshop Elements 4.0 by a procedure involving in sequence: color removal, image inversion, brightness and contrast adjustment, shadows/highlights adjustment. Those interventions did not affect the accuracy of rendering.

The illustrations of frequency analyses where generated with a scan of the entire audio sample

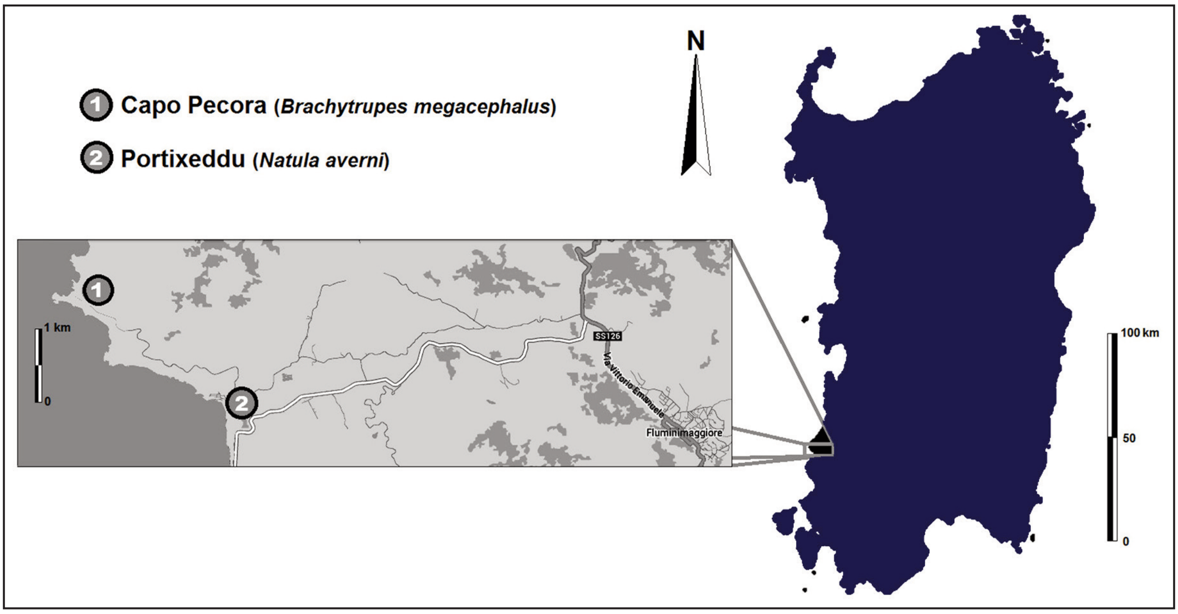

Figure 1. Map of the recording stations of Capo Pecora and Portixeddu, Sardinia.

(Table 1, column "Interval analysed") and with an FFT size of 4096 byte, capable to render a smoother and clearer picture. All the software cited operates under Windows 7 64-bit operating system.

Brizio & Buzzetti, 2014, address in more detail some technical requirements of Ultramic 250 and proposed a specific operating protocol to ensure comparability between Ultramic recordings and audio range recordings available in literature. Brizio (2015) describes in more detail the challenges of ultrasound field recording and the requirement to obtain a recording as near as possible to the singing animal, to avoid the attenuation of faint high-order harmonic components.

RESULTS

Systematics

Ordo ORTHOPTERA Burmeister, 1839
Familia GRYLLIDAE Laicharting, 1871
Subfamilia TRIGONIDIINAE Saussure, 1874
Genus *Natula* Gorochov, 1987

Natula averni (A. Costa, 1855)

EVIDENCE COLLECTED. Bioacoustical.

EXAMINED MATERIAL. Four 96 kHz recordings (Table 1) from Italy, Sardinia, Portixeddu (Carbonia-Iglesias Province), 24.IV.2018, 39°26'21.20"N - 8°24'46.84"E, 0 meter asl.

DISTRIBUTION. General distribution in Italy of this species, as reported by Odé et al. (2011) includes Campania (Averno: Costa, 1855; Targioni-Tozzetti, 1878). Schmidt & Hermann (2000) reported for Sardinia *Anaxipha longipennis* (Audinet-Serville, 1839), a species that, according to Odé et al. (2011), may be a synonym of *N. averni*. Boittier et al. (2006, 2007) reported *N. averni* from Corsica. For other data, see Massa et al. (2012).

REMARKS. Although unaided by visual recognition, due to the elusiveness of this very small species and to its habitat (reed vegetation along rivers near the sea, as confirmed by Odé et al., 2011), posing unsurmountable problems in the localization of this 1 cm long insect, identification poses no doubt, both for its habitat (Fig. 2) and for the unequivocal identification of the pattern and of

Audio samples examined	Duration (mm:ss)	Sampling frequency	Interval Analyzed in figures 6 - 16
B_megacephalus_C_Pecora_20180422-205622.wav	00:37	250 kHz	0:16:87 to 0:19:87
B_megacephalus_C_Pecora_20180422-205757.wav	00:18	250 kHz	not illustrated
B_megacephalus_C_Pecora_20180422-205423.wav	00:53	250 kHz	
B_megacephalus_C_Pecora_20180422-205208.wav	00:34	250 kHz	
B_megacephalus_CapoPecora_21_04_2018_A.WAV	00:35	96 kHz	0:21:00 to 0:26:00
B_megacephalus_CapoPecora_21_04_2018_A.WAV	00:21	96 kHz	not illustrated
Natula averni Portixeddu 24_04_2018 18_30 A.WAV	01:35	96 kHz	0:42:00 to 1:00:00
Natula averni Portixeddu 24_04_2018 18_30 B.WAV	03:19	96 kHz	not illustrated
Natula averni Portixeddu 24_04_2018 18_30 C.WAV	02:02	96 kHz	
Natula averni Portixeddu 24_04_2018 18_30 D.WAV	00:40	96 kHz	

Table 1. List of the audio samples examined in this paper. Also the recording whose analysis is not illustrated, were found consistent with the audio samples deetailed in this paper.

Peak number	Acoustic pressure dBfs	Peak frequency Hz	Theoretical Harmonic Frequency Hz	% difference with the Nth Harmonic
Fundamental	-25.03	6469	--	--
Secondary Peak	-57.95	12350	--	--
2nd Harmonic	-55.43	12980	12938	0.32%
Secondary Peak	-69.86	19170	--	--
3rd Harmonic	-67.69	19450	19407	0.22%
4rd Harmonic	-70.6	25940	25876	0.25%

Table 2. Numeric data from the frequency analysis of a 96 kHz recording of *Natula averni*, Portixeddu, 24.IV.2018.

Sample frequency	96 kHz				250 kHz				
Peak number	Acoustic pressure dBfs	Peak frequency Hz	Theoretical Harmonic Freq. (Hz)	% difference with the Nth Harmonic	Acoustic pressure dBfs	Peak frequency Hz	Theoretical Harmonic Freq. (Hz)	% difference with the Nth Harmonic	% difference with 5800 Hz Harmonics
Fundamental	-19.58	5812	--	--	-15.02	5920	--	--	--
2nd Harmonic	-27.78	11740	11624	0.99%	-19.65	11770	11840	0.59%	1.44%
Secondary peak	-60	~16300	--	--	-43.17	16350	--	--	--
3rd Harmonic	-54.64	17710	17436	1.55%	-43.92	17510	17760	1.43%	0.63%
Secondary peak	--	--	--	--	-40.59	23070	--	--	--
4th Harmonic	-64.85	23250	23248	0.01%	-40.42	24290	23680	2.51%	4.49%
Secondary peak					-58.76	27640			
5th Harmonic	-70.04	29360	29060	1.02%	-56.17	29050	29600	1.89%	0.17%
6th Harmonic	-76.11	35410	34872	1.52%	-61.57	34850	35520	1.92%	0.14%
7th Harmonic	-79.73	41100	40684	1.01%	-63.55	41070	41440	0.90%	1.14%
Secondary peak	-85	~42700	--	--	-64.81	42780	--	--	--
Secondary peak	--	--	--	--	-68.04	44730	--	--	--
8th Harmonic	-82.92	46920	46496	0.90%	-63.04	46560	47360	1.72%	0.34%
9th Harmonic	--	--	--	--	-64.52	52360	53280	1.76%	0.31%
10th Harmonic	--	--	--	--	-67.53	58220	59200	1.68%	0.38%
11th Harmonic	--	--	--	--	-69.28	64080	65120	1.62%	0.44%
12th Harmonic	--	--	--	--	-71.6	69760	71040	1.83%	0.23%
13th Harmonic	--	--	--	--	-74.24	75500	76960	1.93%	0.13%
14th Harmonic	--	--	--	--	-76	81350	82880	1.88%	0.18%
15th Harmonic	--	--	--	--	-77.43	87210	88800	1.82%	0.24%
16th Harmonic	--	--	--	--	-79.63	93200	94720	1.63%	0.43%
17th Harmonic	--	--	--	--	-80.08	98870	100640	1.79%	0.27%
18th Harmonic	--	--	--	--	-80.02	104670	106560	1.81%	0.26%
19th Harmonic	--	--	--	--	-80.41	110650	112480	1.65%	0.41%
20th Harmonic	--	--	--	--	-79.93	116390	118400	1.73%	0.34%
21th Harmonic	--	--	--	--	-77.09	121700	124320	2.15%	0.08%

Table 3. Numeric data from the frequency analysis of 96 kHz and 250 kHz recordings of *Brachytrupes megacephalus*, Capo Pecora, 21–22.IV.2018. Only the most relevant among the secondary peaks are considered in this table.

the harmonic structure well noted for the species and reported by Odé et al. (2011).

Figures 6–8 are self-explanatory and describe clearly the pattern and the structure of the song of *N. averni*, recorded at an air temperature around 22 °C. The song observed consisted of echemes lasting around 250 ms, regularly repeated at the rate of about 2/s. Echemes consist of about 10–20 syllables with a slight volume increase in the first four syllables, then equally loud. Frequency analysis in figure 8 and Table 2 shows the main volume peak at the fundamental frequency of around 6500 Hz, with three well-defined harmonics, the 2nd and the 3rd of which are preceded by a clearly discernible secondary peak.

The particular nature of the habitat, that made very difficult the handling of a portable computer, as well as the complete absence of any hint of high-order harmonic components in the 96 kHz recording, discouraged the attempt to record this species at a 250 kHz sampling frequency.

Subfamilia GRYLLINAE Laicharting, 1871
Genus *Brachytrupes* Serville, 1839

Brachytrupes megacephalus (Lefèvre, 1827)

EVIDENCE COLLECTED. Bioacoustical and photographic.

EXAMINED MATERIAL. Two 96 kHz and four 250 kHz recordings (Table 1) from Italy, Sardinia, Capo

Figure 2. The recording station of *Natula averni*, Portixeddu, 24.IV.2018. Figure 3. The recording station of *Brachytrupes megacephalus*, Capo Pecora, 21–22.IV.2018. Figure 4. A typical burrow of *B. megacephalus*, Capo Pecora, 21–22.IV.2018. Figure 5. Habitus of *B.megacephalus*, Capo Pecora, 22.IV.2018.

Pecora (Medio Campidano Province), 21–22.IV.2018, 39°27'3.27"N - 8°23'46.67"E, 20 meters asl. Air temperature around 19 °C / 20 °C.

Distribution. It's the only Italian representative of the genus. General distribution in Italy of this species, as reported by Odé et al. (2011) includes Sicily as type locality, and Southern Sardinia (Zanardi, 1964; Baccetti, 1991; Schmidt & Hermann, 2000; Galvagni, 2010). However, the species is widespread in North Africa and is reported also from the Maltese islands. For other data see Massa et al. (2012).

Remarks. Both the song and the habitus of this species are unmistakeable. Songs were recorded and specimens were observed on the promontory of Capo Pecora, delimited by granitic cliffs and boulders. In the plateau topping the promontory, the species burrows in the coarse sand resulting from the weathering of granite.

The burrows, the habitus, and the behaviour of the specimen, observed and photographed while singing, corresponded with the description by Odé et al. (2011).

The impressive looks of this cricket have no equal in the Italian fauna. The specimens, that sing during the spring, especially in April, emerge from their burrows at twilight and are very suspicious, ready to re-enter their den if disturbed. Even though the song can be heard from great distance and easily traced, to get the best recording and photographic opportunities, it is better to search for the dens and mark their position for successive visits, considering that the source of such a powerful song, subjectively perceived as reaching 80 dB at around 2m above and behind the animal, is uneasy to locate precisely.

Provided that any noise and rapid movements are avoided, the specimens can be illuminated and observed, in particular during the emission of the song, whose almost unbelievably high volume, with the physical excerption required, apparently saturates the perceptive faculties of the cricket, to the point when it can be lightly touched without escaping.

The pattern described by Odé et al. (2011) was observed: syllables continuously repeated at a rate of around 130/sec.

The recordings at 96 kHz and 250 kHz yielded consistent results, reported in Table 3.

In both the types of recording, the first seven "octaves", delimited by the fundamental frequency and the first seven harmonics, can be clearly made out in both the analyses (Figures 13, 14) and in both the time/frequency spectrograms (Figures 10, 12). Furthermore, as can be expected from an highly stressed sounding apparatus, secondary peaks and clusters of ancillary frequencies are generated.

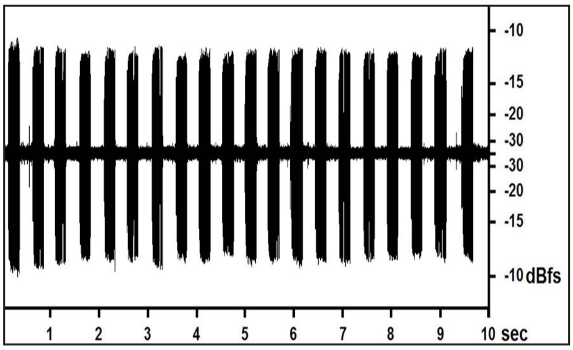

Figure 6. Oscillogram of a 96 kHz audio sample of *Natula averni*, Portixeddu, 24.IV.2018.

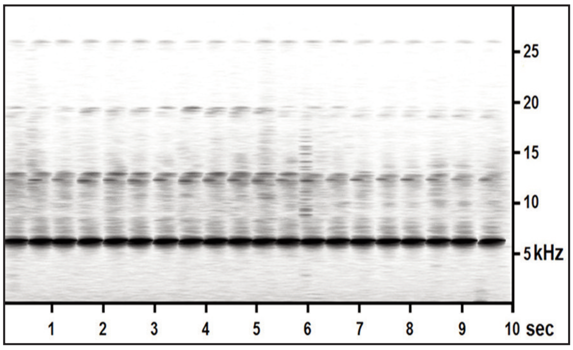

Figure 7. Time/frequency spectrogram of a 96 kHz audio sample of *Natula averni*, Portixeddu, 24.IV.2018.

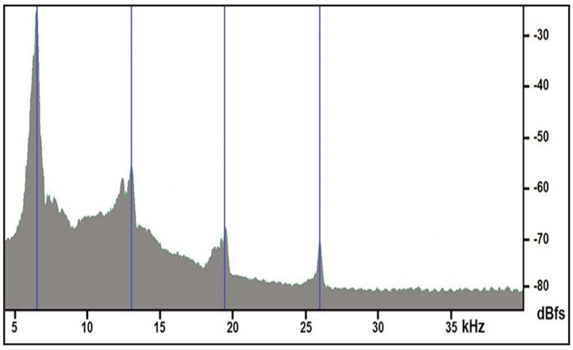

Figure 8. Frequency/volume analysis of a 96 kHz audio sample of *Natula averni*, Portixeddu, 24.IV.2018. Blue lines mark the fundamental frequency and its harmonics.

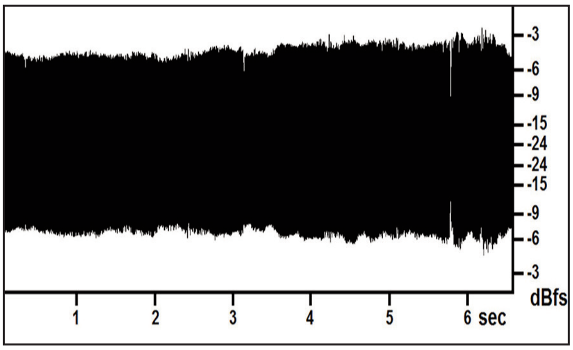

Figure 9. Oscillogram of a 96 kHz audio sample of *Brachytrupes megacephalus*, Capo Pecora, 21.IV.2018.

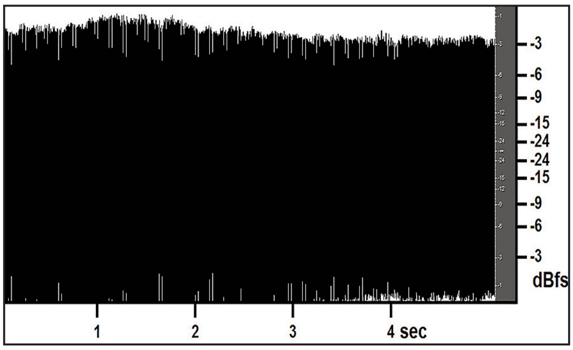

Figure 11. Oscillogram of a 250 kHz audio sample of *Brachytrupes megacephalus*, Capo Pecora, 22.IV.2018.

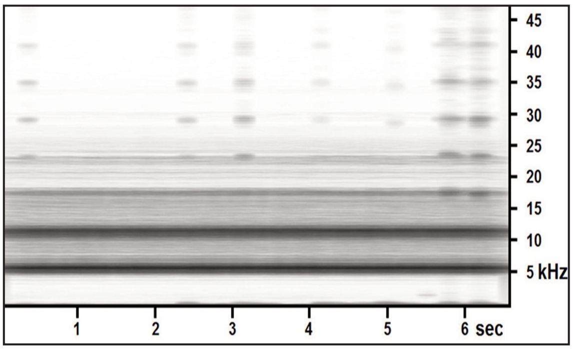

Figure 10. Time/frequency spectrogram of a 96 kHz audio sample of *Brachytrupes megacephalus*, Capo Pecora, 21.IV.2018.

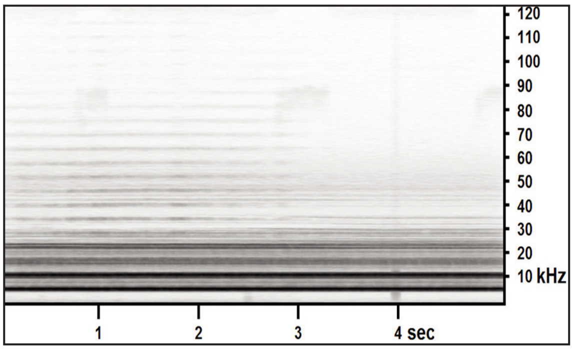

Figure 12. Time/frequency spectrogram of a 250 kHz audio sample of *Brachytrupes megacephalus*, Capo Pecora, 22.IV.2018.

All the main elements are reported in Table 3.

A strong harmonic structure is observed in the frequency/volume analysis of the wide band, 250 kHz sampling frequency recording, with a geometrical progression of octaves delimited by peaks corresponding with the fundamental frequency and its first twenty-one harmonics in geometrically decreasing intensity. All the high order (above 50 kHz) harmonics are in better accordance with a 5800 Hz fundamental, the same observed in the 96 kHz recordings. An accessory cusp can be observed in the 15–50 kHz range, around 1500 kHz below each harmonic frequency, with comparable intensity. A more complex cluster of secondary peaks, among which a two-cusps, regularly repeated pattern, is evident at middle octave in the 5–58 kHz range. Despite the technical differences in microphone sensitivity and recording device, the analysis of the 96 kHz recording reproduces quite faithfully in the 0–48 kHz range the complex pattern described above.

CONCLUSIONS

The songs of two uncommon crickets from Sardinia have been digitally recorded in the field, one of them by a low-cost USB microphone capable of generating 0 to 125 kHz monophonic recordings, including both audible and inaudible frequencies. This device, Ultramic 250, by generating results consistent with other recording methods and by providing useful information about high-frequency components above 20 kHz and up to 125 kHz, allowed to observe a previously unreported high-order harmonic structure for the song of the biggest European cricket, *B. megacephalus*. In addition, the underreported and very elusive, *N. averni*, whose systematic status may need some revision (Odé et al., 2011), was recorded and analysed in the 0–48 kHz range, revealing a well-defined progression of harmonics above its maximum volume frequency.

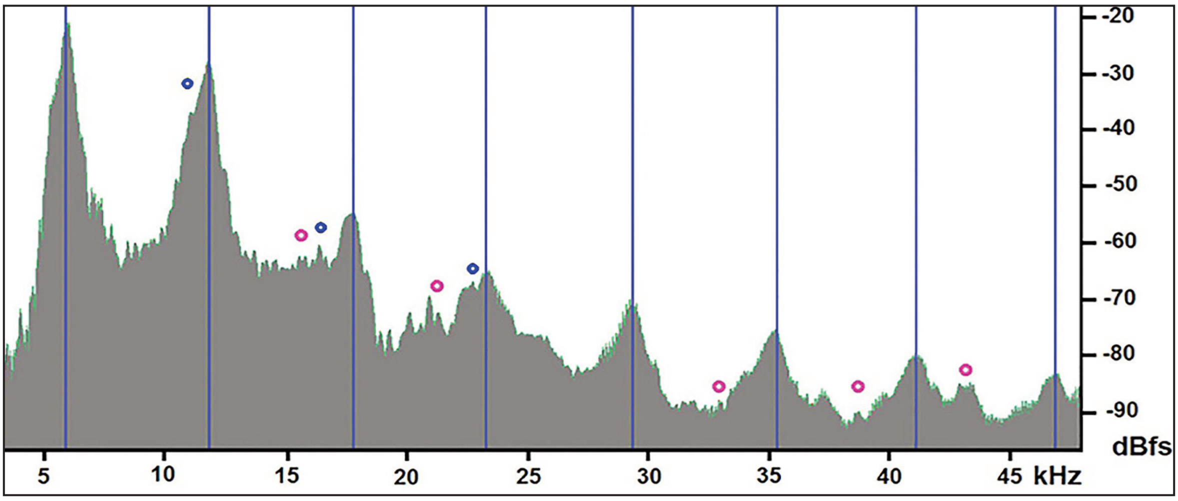

Figure 13. Frequency/volume analysis of a 96 kHz audio sample of *Brachytrupes megacephalus*, Capo Pecora, 21.IV.2018. Blue lines mark the fundamental frequency and its harmonics. Blue circles mark the secondary peaks preceding some harmonics. Magenta circles mark frequency clusters also observed in the 250 kHz recordings.

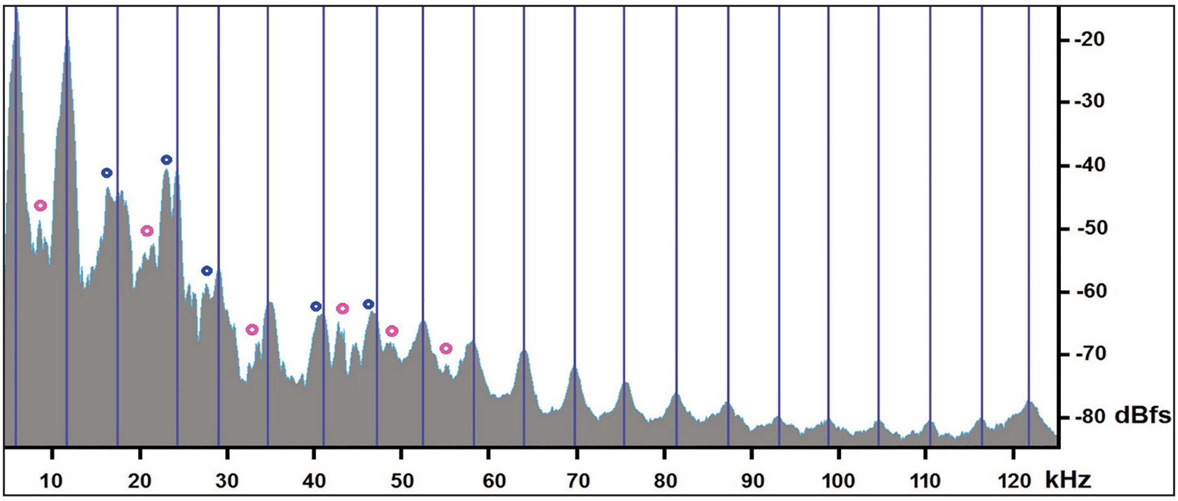

Figure 14. Frequency/volume analysis of a 250 kHz audio sample of *Brachytrupes megacephalus*, Capo Pecora, 22.IV.2018. Blue lines mark the fundamental frequency and its harmonics. Blue circles mark the secondary peaks preceding some harmonics. Magenta circles mark regularly repeated frequency clusters, some of which also observed in the 96 kHz recordings.

Considering the restricted habitat of both the species examined, the value of this report may be regarded both as ecological and biogeographical, as well as bioacoustic.

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