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Ultrasound recordings of some Orthoptera from Sardinia (Italy)

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ABSTRACT During August 2013, Ultramic 250 by Dodotronic was field-tested for application in Orthopteran acoustic biodiversity studies. The songs of four species were recorded: *Uromenus brevicollis insularis* Chopard, 1924, *Rhacocleis baccettii* Galvagni, 1976, *Svercus palmetorum palmetorum* (Krauss, 1902) and *Oecanthus dulcisonans* Gorochov, 1993. The recording campaign proved the viability of Ultramic 250 for field use and provided the opportunity to assess the presence in South-Western Sardinia of two less documented species, *Svercus palmetorum palmetorum* (Krauss, 1902) and *Oecanthus dulcisonans* Gorochov, 1993.

KEY WORDS Orthoptera; ultrasound; ecology; taxonomy.

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INTRODUCTION

The Orthoptera fauna of Sardinia is relatively well studied (A. Costa, 1882, 1883, 1884, 1885, 1886; Nadig & Nadig, 1934; Galvagni, 1976, 1978, 1990; Galvagni & Massa, 1980; Ingrisch, 1983; Schmidt & Hermann, 2000; Galvagni et al., 2007; Massa, 2010; Fontana et al., 2011) and summarized in Massa et al. (2012), with information on acoustic emission to date limited to audible frequencies (Massa et al., 2012).

A recent field expedition of the first author to SW Sardinia, Fluminimaggiore (Carbonia-Iglesias Province), resulted in the ultrasound recordings of four species herein reported to improve bioacoustics knowledge on local Orthoptera.

Study of Orthoptera acoustic emission is important for many reasons. The first and maybe most commonly pursued purpose is taxonomy, being songs useful in taxa discrimination. Biodiversity inventories can also benefit from bioacoustics studies, since many taxa that would be very elusive for direct search, are more easily tracked and identified by their song. Other aim is to investigate or better understand behavioral implications in intraspecific communication (reproductive behavior and rivalry behavior), interspecific communication and predator avoidance. We therefore focus here on ultrasound emissions of the surveyed species.

Species identification from the ultrasound recordings, a paramount requirement in biodiversity assessments, was achieved also with the support of the above mentioned audio data from Massa et al. (2012): the dissimilarity between acoustic and ultrasound recording technologies required special cautions summarized in the following section.

MATERIAL AND METHODS

All the species reported were recorded within a 15 km range from Fluminimaggiore (Carbonia-Iglesias Province, Sardinia, Italy) (Fig. 1). All the audio and ultrasound material was obtained by field recording during August 2013. Captured specimens were not recorded in constrained conditions.

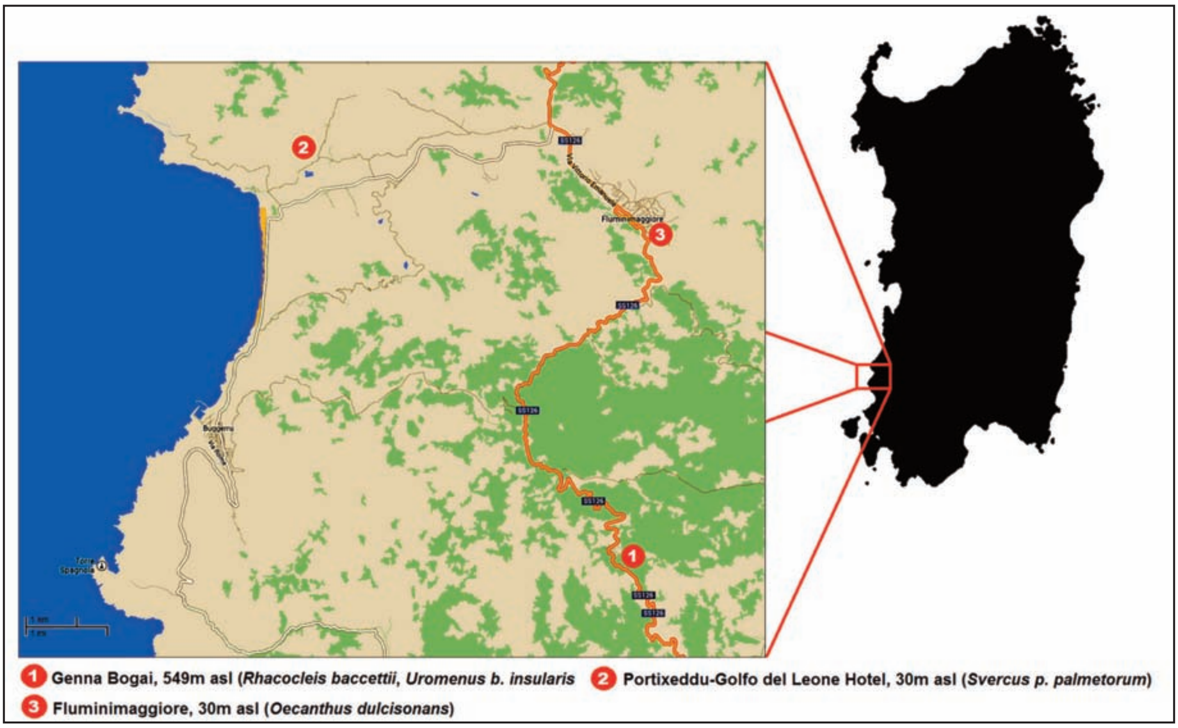


Figure 1. Recording localities: Fluminimaggiore, Carbonia-Iglesias Province, Sardinia, Italy.

Oscillograms, spectrograms and frequency analysis diagrams were produced from 250 kHz recordings by Adobe Audition 1.0 software or by the equivalent Syntrillium Cool Edit Pro version.

Subsidiary stereo, 16 bit, 96kHz sampling frequency recordings, needed to confirm species identification, were obtained by a self-built, stick mounted, stereo microphone using Panasonic WM-64 capsules (obtained from an Edirol R-09 digital recorder), connected to a Zoom H1 handheld digital Micro-SD recorder, using its built-in software.

Monophonic, 16 bit, 250kHz sampling frequency ultrasound recordings where obtained by a Dodotronic Ultramic 250 microphone, connected to an Asus Eee 1225B netbook PC, using SeaWave software by CIBRA (Pavan, 1998-2011). Ultramic is supported also by some tablet PC's (including Android-based models): the use of a Windows-based netbook was preferred for the authors' previous experience with the Windows audio analysis software, installed on the same computer used for recording. The Ultramic was set to medium gain via its special internal set of two dip switches: in about one year of field experience with this device, the authors observed that the sensitivity of the alternative settings (low gain and high gain) is respectively too low and too high to allow a correct representation of the spectral structure of Orthoptera song.

Optimal USB cable length, following several previous tests summarized in figure 2, was found to be under 1m. The short reach of the 45cm cable used for the recordings didn't allow stick-mounting, that would otherwise be ideal to take the Ultramic as near as possible to the recorded specimen, but in turn eliminated the inherent noise that may be generated by Ultramic.When coupled with Asus 1225B Netbook, inherent noise displays a 1kHz fundamental and unitary harmonics up to 12 – 15 kHz, with main audible frequency at 2kHz and secondary audible frequencies at 1kHz, 4 kHz and 7 kHz. From personal communications, the noise spectral pattern is unaltered when Ultramic is coupled with different recording platforms. The 1kHz fundamental was found to be inherent to the Ultramic, and caused by the USB polling/packet transmission on which the communications between microphone and PC (or tablet) are based, at 1000 cycles per second.

As long as the original scope of Ultramic is recording inaudible Chiropteran sounds, noise in the range of the unaided ear was deemed irrelevant.

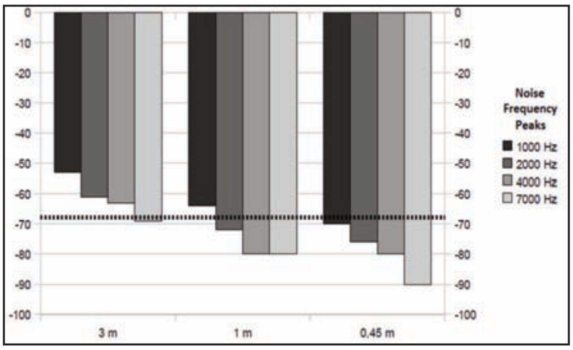


Figure 2. Effect of cable length in the mitigation of Ultramic 250 inherent noise. Vertical axis: sound pressure (dB), horizontal axis: USB cable length (m), dashed line: typical Ultramic 250 noise floor under ideal field recording conditions (-68 dB ref full scale level).

But when recording in the audible range, the whistle at 2kHz becomes definitely undesirable, and the authors investigated how the USB cable length affects inherent noise, testing whether ferrite cores along the cable can mitigate it. The tests allowed to conclude that:

1. Ferrite cores do not mitigate the noise, that originates in the very same device used for recording.

2. USB cable length of less than 1m eliminates the noise bringing it below the level of the background noise present in any field recording.

It should be noted that the recordings obtained by using the Ultramic 250, a device specifically designed to collect ultrasonic frequencies, may not be suitable for specific song pattern recognition by memory and unaided ear, and thus may require sonogram and spectrogram comparisons with existing audio-only recordings, a necessity observed for example in the case of *Rhacocleis baccettii* Galvagni, 1976. Two potential problems, lack of published ultrasound recordings and lack of audible components in the Ultramic recording, may complicate such a comparison. Indeed, the greatest majority of current scientific and popularization works about bioacoustics investigated only the acoustic range: available sonograms, spectrograms, frequency analyses and descriptions almost invariably refer to the audible frequency components.

When field-recording with Ultramic, it's therefore advisable to adopt one or more of the following cautions:

• Visually / photographically identify the singing specimen.

• Collect and identify a specimen.

• Record the same specimen both by Ultramic and by audio microphones, capable of generating audio files whose sonograms, spectrograms, frequency analyses are easily comparable with existing literature.

Subsidiary audio recordings should possibly be taken at 96kHz sampling frequency, so that (depending on the dynamic response of the audio microphone capsules) low ultrasonic frequency may get recorded, allowing an easier bridging of the gap between audio and ultrasound recordings. The first author performed successful simultaneous recordings from the USB and the audio ports of a portable computer, with audio microphone and Ultramic coaxially mounted on the same self-built stick and handle assembly, the drawback of this set being the impossibility to have both microphones at optimal range from the subject without saturating one of the recordings, and the noise induced by the length of the USB cable required for stick mounting. So, in the case of simultaneous recordings, although the handling of two microphones may prove feasible for a single operator, the authors advise to operate in pairs by using two separate portable digital recorders (one of them, obviously, should be compatible with Ultramic, such as a portable PC or one of the supported tablet PC's).

Whether or not the song is audible to the unaided ear, audible components may not be reproduced in the Ultramic recording, depending on hardware gain settings, distance from the subject, song structure.

In particular, it's quite commonplace for the Orthopterans with the smallest stridulatory apparatus, or the highest repetition frequencies, to reach well into the ultrasonic domain, so that it's a routine practice to locate them with the aid of a bat detector, as reported for example by Fontana et al. (2002). For those species, sound pressure at ultrasonic frequencies may be way higher than in the audible range, with the practical consequence that Ultramic 250 may get saturated by the ultrasounds well before reaching the distance at which the audible components may get recorded. Thus, the resulting recording may be both inaudible and unfamiliar, up to the point of being useless without supporting materials such as visual identification, specimen collection or simultaneous audio recording.

Another distinction between audio and ultrasonic recordings stems from the higher sampling frequencies of the latter, that (even for the very same sound source) may result in a different shape of the sonogram, especially when the emission of the louder, dominating ultrasonic elements is not perfectly synchronous with the emission of the potentially audible components. As a consequence, species recognition by listening of an Ultramic recording may prove difficult even in the case of well-known, common species' songs. All these problems were present in the case of *R. baccettii*, a low-Q species delivering a high-pitched call dominated by ultrasounds, whose spectrogram doesn't provide relevant distinctive features and whose Ultramic recording, barely audible, didn't bear any immediate resemblance to the audio recording available for comparison.

To overcome the problem, some saturated (above zero dB) Ultramic recordings were made on purpose, to ease recognition by ear and comparison with available reference material: although counterintuitive, this practice is in fact very useful. In all the cases where ultrasonic pressure outweighs audible frequencies' pressure, after taking unsaturated recordings one may decide to get as close to the subject as needed for grasping the audible components, even though it means making the recording unusable for analytical purposes. Just for the sake of ease of recognition, saturation may be disregarded as long as it occurs in the inaudible range. Obviously, only regular, unsaturated recordings may be used for analyses, while the saturated recording may eventually being low-pass filtered at 21 kHz, and amplified as needed. The preceding practical suggestions outline the protocol illustrated in figure 3.

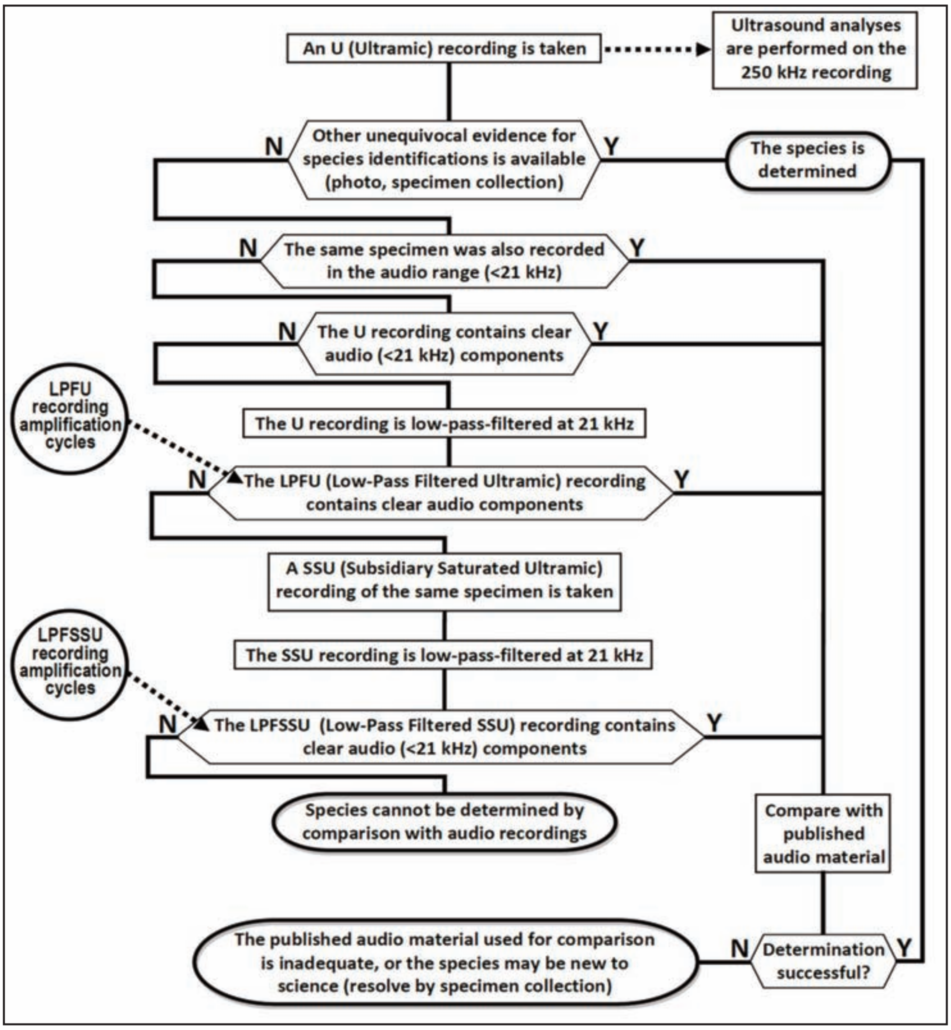


Figure 3. Suggested protocol to allow species identification form Ultramic recordings (flow chart).

DISCUSSION

Terminology on Orthoptera song description may not always be able to convey the sometimes complex structure of sound emission. The song of all the taxa here presented is described in Massa et al. (2012) for their audible range. The authors therefore focused on ultrasounds, frequency analysis and their description. A useful distinction can be made between "high-Q" and "low-Q" spectrum type (Elsner & Popov, 1978; Montealegre & Morris, 1999). High-Q sound results in one or more (e.g. Gryllidae) isolated peaks of frequency, clearly distinguishable from the rest of the frequency emission. On the other hand, "band" or "low-Q" of frequency sound gives a wide bandwidth spectrogram, in which sometimes is possible to distinguish spectral subpeaks (see Table 1).

For what concerns audible sound description we use terminology from Buzzetti & Barrientos (2011), Moore (1989) and Ragge & Reynolds (1998):

• Chirp (or phonatome, syllable): a short, clearly definable sound, produced by a complete opening and closing movements of the tegmina (or upward and downward movements of hind legs).

• Zip: a series of pulses resulting in a short buzz, usually shorter than a chirp.

• Trill: a long series of pulses, in which chirps cannot be recognized.

• Echeme: most basic and simple assemble of syllables.

List of the recorded species

Uromenus brevicollis insularis Chopard, 1923

Examined material. Italy, Sardinia, Genna Bogai (Carbonia-Iglesias Province), N 39° 22' 25.428", E 8° 29' 50.352", 549m asl, 29.VIII.2013, 1 male.

Distribution. *Uromenus brevicollis insularis* is distributed and locally common in Sardinia and Corsica (its type locality).

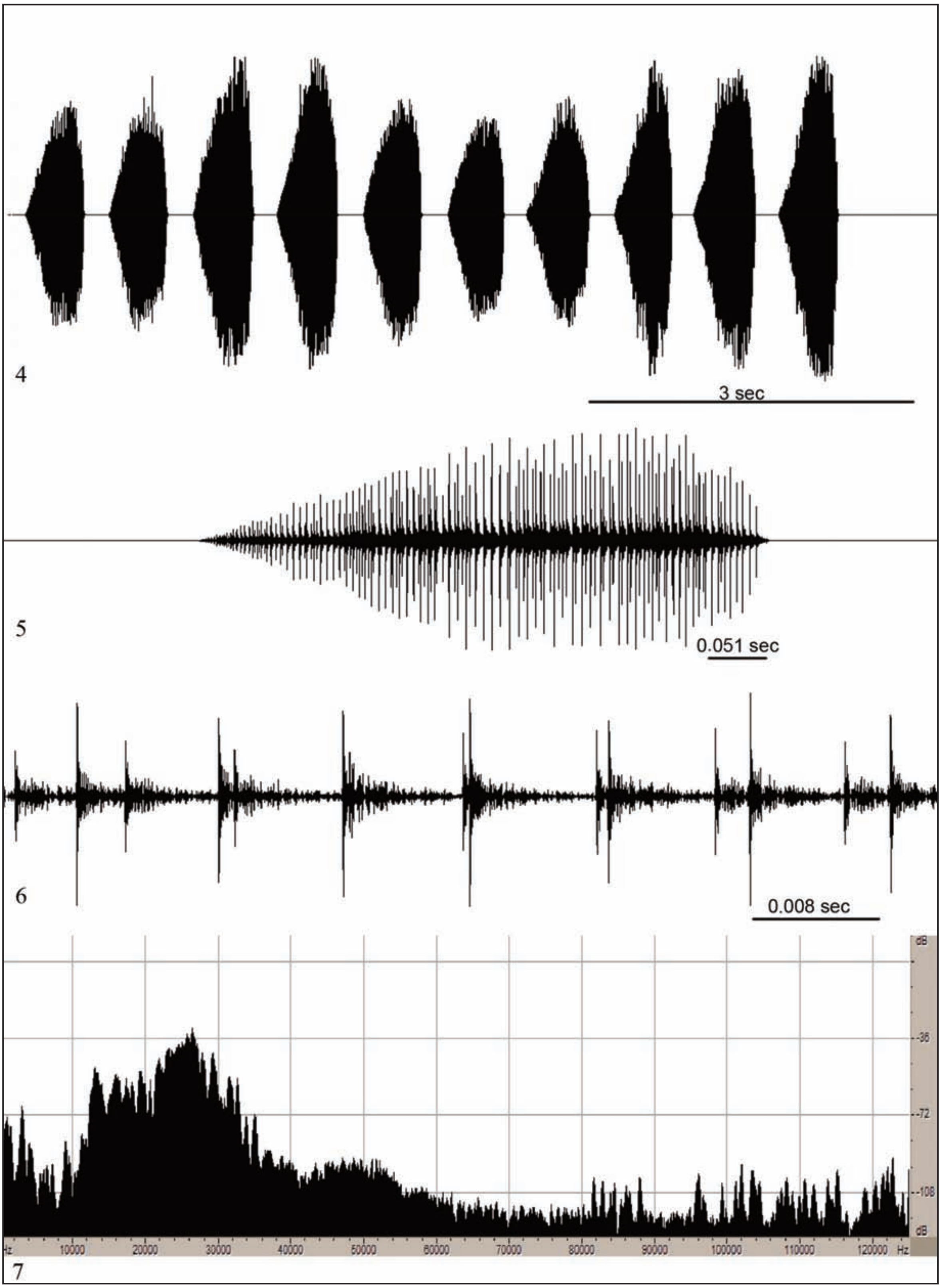
Remarks. This calling song was recorded with air temperatures in the range of 18°C, around midnight, at the Genna Bogai pass. The song could be just faintly perceived by the unaided ear, but proved very easy to locate by the earphones connected to the digital audio recorder. Ultrasound recording didn't meet any particular difficulty, apart the usual tendency to saturate when approaching to the specimen. The male calling song (Fig. 4) consists of a sequence of chirps that are indeed closing hemisyllables. Each hemisyllable (Fig. 5) lasts for about 250-350ms and is composed of about 75-80 tooth-impacts (Fig. 6) (Massa et al., 2012). Comparison between frequency spectrum analysis (Fig. 7) and time-frequency spectrogram (Fig. 8), shows that most energy is emitted from 10 to 40 kHz, with weaker extension to less than 60 kHz. From 10 kHz, the energy rapidly increases to the first maximum peak at 13.45 kHz. A minor energy area, with lower peaks at 16.17, 18.52 and 19.37 kHz, is present between 15 and 21.35 kHz. Then the energy increases to the power peak at a frequency of 26.7 kHz. From here, the energy emitted decreases to 41.25 kHz, with peaks at 29.26, 31.86, 32.83, 33.87 and 35 kHz. A second band of low energy emission is from 41.25 to 58.68 kHz, with a peak at 43.7 kHz

U. brevicollis insularis emits a very wide energy band, reaching ultrasonic frequency, that results in a mostly ultrasonic bandwidth with a ultrasonic range (26.7 kHz) peak.

The song of *U. brevicollis insularis* recorded and here presented, was emitted simultaneously

Species	Principal carrier frequency in kHz	Spectrum type	Most relevant energy emission	Singing rate	Sound unit
Uromenus brevicollis insularis	12 to 41	Low-Q	Sonic	1/sec	Chirp (closing hemisyllable)
Rhacocleis baccettii	28 to 77	Low-Q	Ultrasonic	3-4/sec	Zip
Svercus palmetorum palmetorum	6-12-18-25-(32)	High-Q	Sonic	7-12/sec	Echeme
Oecanthus dulcisonans	3.5-7-10.5	High-Q	Sonic	40/sec	Syllable

Table 1. Main distinctive parameters in the song of the recorded species.



Figures 4–7. Song of *Uromenus brevicollis insularis*. Figure 4: calling song. Figure 5: syllable (closing hemisyllable). Figure 6: tooth-strokes. Figure 7: frequency analysis, FFT size 8192 bytes.

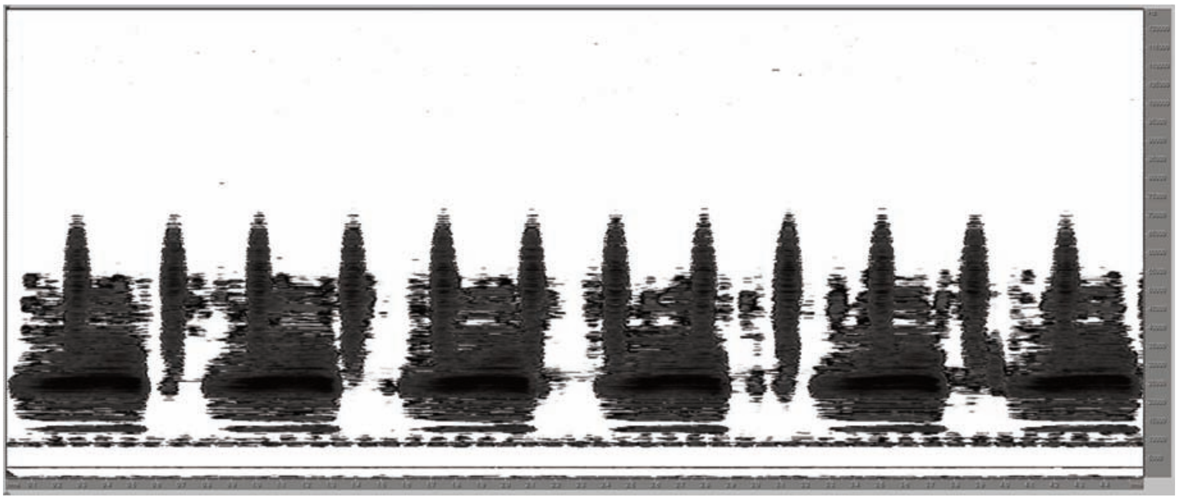


Figure 8. Time-frequency spectrogram of the simultaneous songs of *Uromenus brevicollis insularis* and *Rhacocleis baccettii*.

(Fig. 8) with another calling song by *Rhacocleis baccettii* Galvagni, 1976. A very careful analysis of both the graphs about frequency analysis and temporal frequency spectrum was necessary to discriminate the energy emission of the two taxa. Nevertheless it has become clear (see *R. baccettii* discussion) that these two species share the same sound landscape, with little interference.

Rhacocleis baccettii Galvagni, 1976

EXAMINED MATERIAL. Italy, Sardinia, Genna Bogai (Carbonia-Iglesias Province), N 39° 22' 25.428", E 8° 29' 50.352", 549m asl., 29.VIII.2013, 1 male.

DISTRIBUTION. Endemic of Sardinia (type locality: Monte Ferru, Oristano), is known for whole Sardinia and is the commonest species of the genus in this region.

REMARKS. The song of this species varies among populations from different localities (Massa et al., 2012). The song here presented is very similar to what is presented in Massa et al. (2012) to be the typical song of *R. baccettii*. The calling song of *R. baccettii* (Fig. 9) is made of short zip repeated in sequence at a rate of 3-4/sec. Each zip (Fig. 10) consists of 30-40, up to 50 syllables of different intensity. Frequency spectrum analysis (Fig. 11) shows a low-Q band of energy emission between 28 and 77 kHz, with highest frequency at 50-51 kHz. The song of this species is therefore mostly ultrasonic.

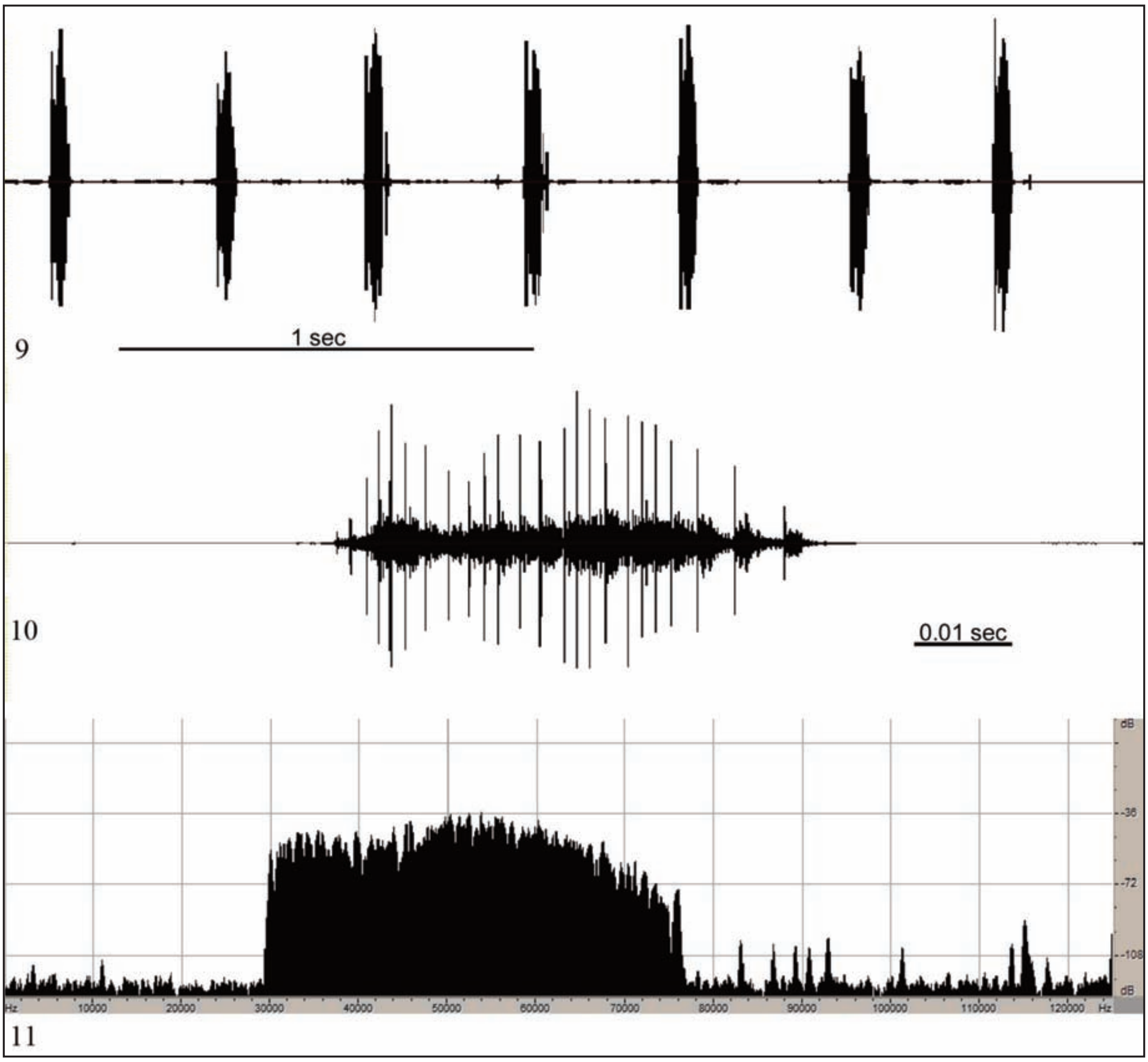
Figure 8 presents the two simultaneous songs of *U. brevicollis insularis* and *R. baccettii*, clearly showing striking differences between the sound emitted by the two species. While *Uromenus* emits a long chirp mostly sonic with main peak at 26 kHz, *Rhacocleis* sings with very short buzz that are mostly ultrasonic. The sound space is therefore shared, with no interference since the sound structure, i.e. temporal parameters and frequency emitted, is completely different in the two species. Such differences are known to be useful in specific mate recognition for sympatric or syntopic species (Zefa et al., 2012), even in "cocktail party" conditions (Siegert et al., 2013).

Svercus palmetorum palmetorum (Krauss, 1902)

EXAMINED MATERIAL. Italy, Sardinia, Fluminimaggiore (Carbonia-Iglesias Province), N 39° 26' 53.232" E 8° 25' 30.18", 30m asl, 8 August 2013, 1 male.

DISTRIBUTION. *Svercus palmetorum* is distributed in North Africa and South West Asia, plus Italy, Spain, Canary Is., Baleares Is., Corsica, Malta and Cyprus. In Italy is known for few localities in Sardinia, Sicily and Calabria.

REMARKS. The song (Fig. 12) is composed by sharp trills that can be continuous or interrupted by a very short pause. Echemes (Figs. 13–14) consist of groups of 7 to 9 syllables lasting on average 0.05 s in which the starting syllables are, each syllable lasting on average 5 ms.

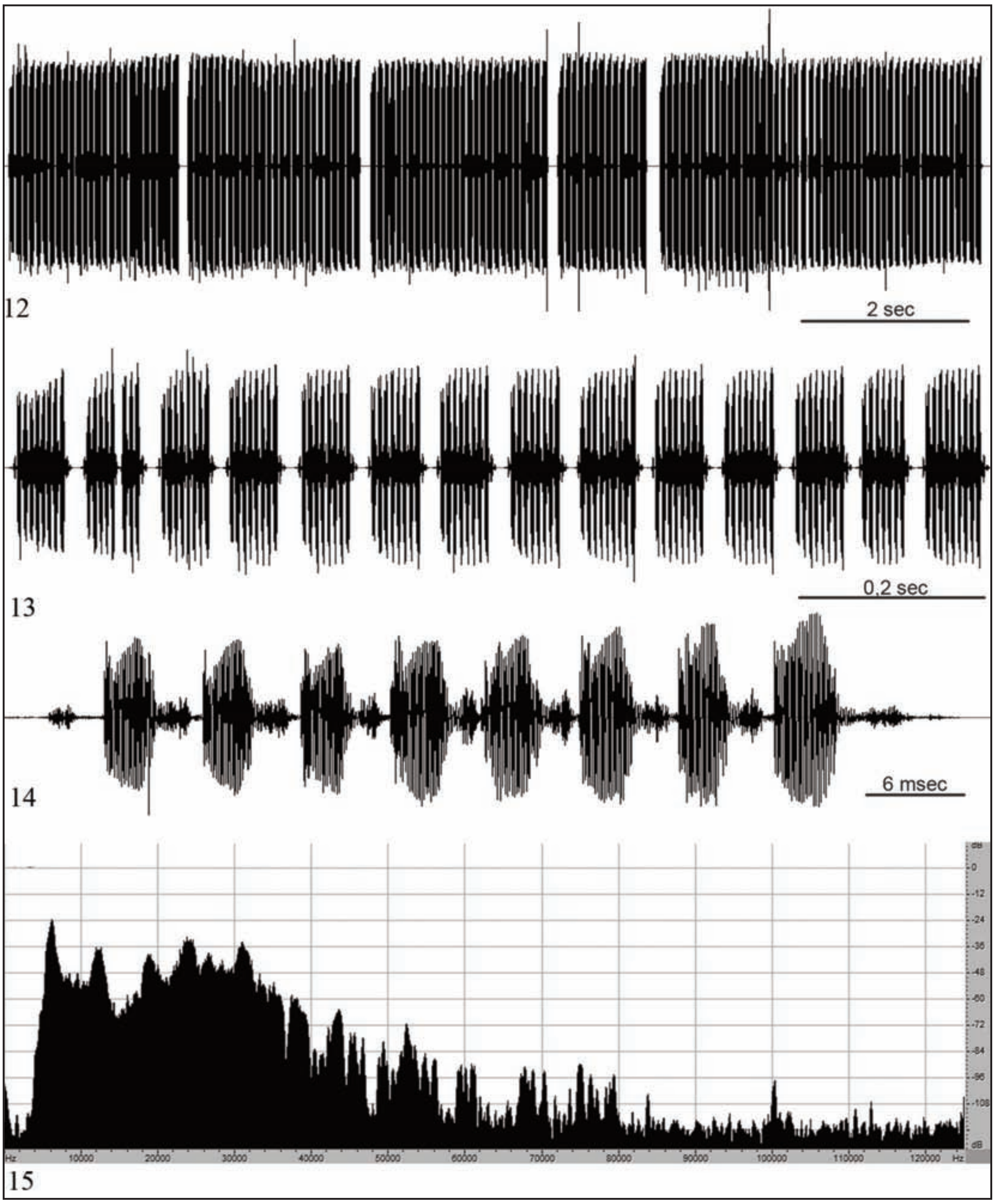


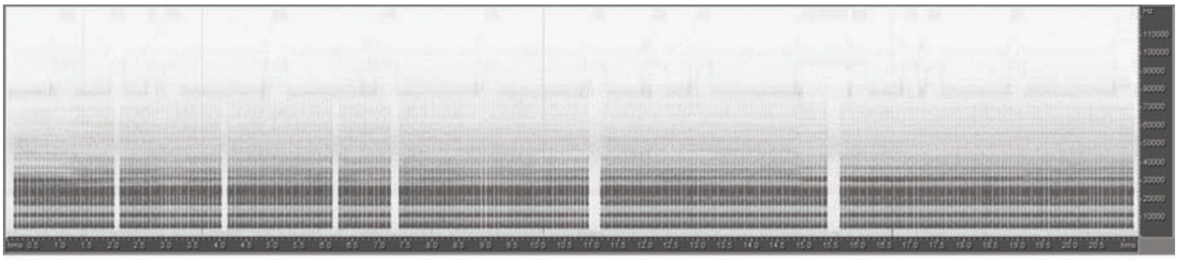
Figures 9–11. Song of *Rhacocleis baccettii*. Figure 9: calling song. Figure 10: sound unit. Figure 11: frequency analysis, FFT size 8192 bytes.

Average silent time between echemes is 0.02 s.

Each trill may include bouts of 8–20 echemes, or may be continuous (>100 echemes without interruption). Song bouts are separated by intervals that may last 0.10 s–0.30 s once the song is initiated, or up to several seconds in the initial or final phases of the song. 250 kHz ultrasound recordings, besides displaying the same pattern described above, allowed a deeper high frequency analysis showing a very elaborated spectral pattern. The strong harmonic structure of the song is revealed by a close up of the spectral analysis in a window between -12 db and -90 db, and for frequencies up to 85 kHz. The pattern of regularly spaced harmonic frequencies can be made out quite clearly. Opening hemisyllable is weaker than closing one, emitting very few energy at a frequency of about 25 kHz. Frequency analysis of closing hemisyllable (Fig. 15) reveals the fundamental at 6.317 kHz, and three harmonics at 12.2 kHz, the weakest at 18.82 kHz and the last at 25.69 kHz. In the first part of each closing hemisyllable an upper harmonic is present at about 32.5 kHz, lasting for 1 msec.

Given the peculiarity of this species, we present here some morphological characters (Figs. 17–19) and the original description (Fig. 18). In the figures are clearly evident the diagnostic characters of this





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Figures 12–15. Song of *Svercus palmetorum palmetorum*. Figures 12–13: calling song. Figure 14: sound unit. Figure 15: frequency analysis, FFT size 8192 bytes. Figure 16. Spectrogram of the 250kHz audio sample from *S. palmetorum palmetorum*, "Golfo del Leone", Portixeddu, 8 August 2013, 23°C.

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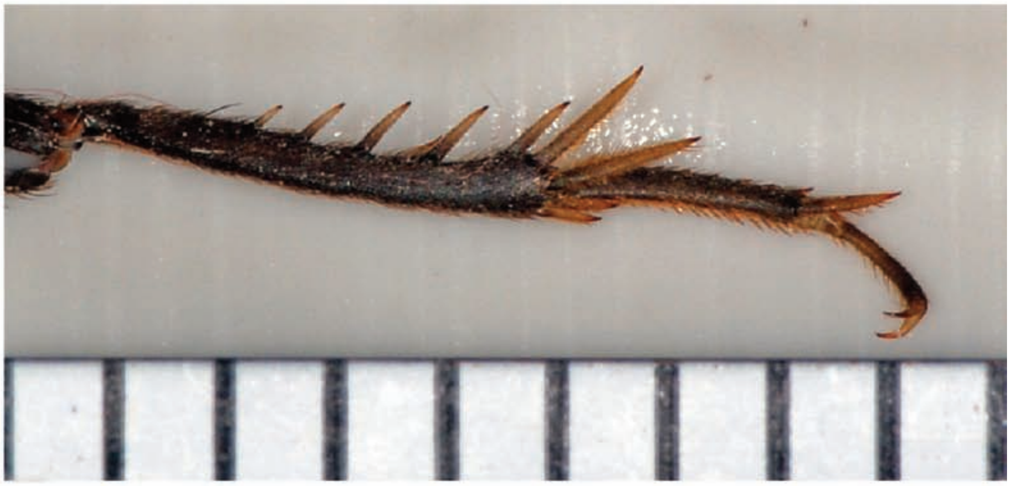

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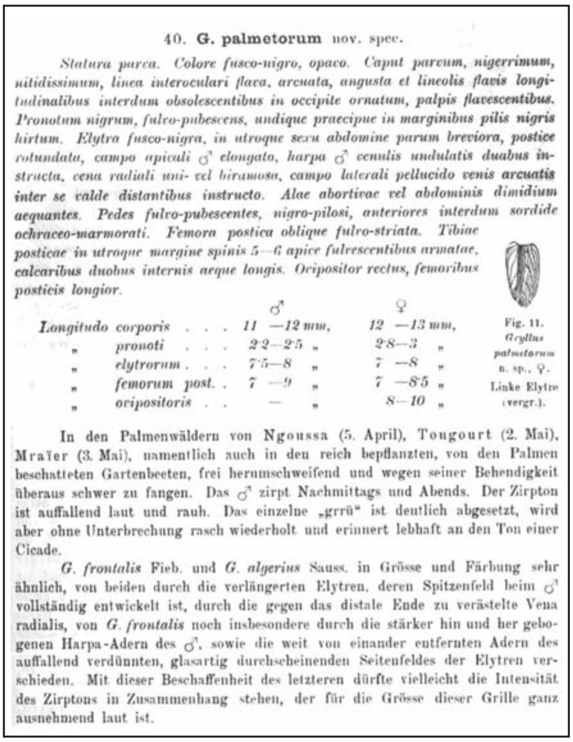
Figures 17–19. *Svercus palmetorum palmetorum*. Figure 17: living male from Fluminimaggiore. Figure 18: male hind tibia, scale 1 mm. Figure 19: male tegmina, scale 1 mm.



40. **G. palmetorum** nov. spec.

Statura parca. Colore fusco-nigro, opaco. Caput parcum, nigerrimum, nitidissimum, linea interoculari flava, arcuata, angusta et lineolis flavis longitudinalibus interdum obsolescentibus in occipite ornatum, palpis flavescentibus. Pronotum nigrum, fulvo-pubescens, undique praecipue in marginibus pilis nigris hirtum. Elytra fusco-nigra, in utroque sexu abdomine parum breviora, postice rotundata, campo apicali ♂ elongato, harpa ♂ venulis undulatis duabus instructa, vena radiali uni- vel biramosa, campo laterali pellucido venis arcuatis inter se valde distantibus instructo. Alae abortivae vel abdominis dimidium aequantes. Pedes fulvo-pubescentes, nigro-pilosi, anteriores interdum sordide ochraceo-marmorati. Femora postica oblique fulvo-striata. Tibiae posticae in utroque margine spinis 5—6 apice fulvescentibus armatae, calcaribus duobus internis aeque longis. Ovipositor rectus, femoribus posticis longior.

	♂	♀
Longitudo corporis . . .	11 —12 mm,	12 —13 mm,
" *pronoti* . . .	2·2—2·5 "	2·8—3 "
" *elytrorum* . . .	7·5—8 "	7 —8 "
" *femorum post.* . .	7 —9 "	7 —8·5 "
" *ovipositoris* . .	— "	8—10 "

Fig. 11. *Gryllus palmetorum* n. sp., ♀. Linke Elytre (vergr.).

In den Palmenwäldern von Ngoussa (5. April), Tougourt (2. Mai), Mraïer (3. Mai), namentlich auch in den reich bepflanzten, von den Palmen beschatteten Gartenbeeten, frei herumschweifend und wegen seiner Behendigkeit überaus schwer zu fangen. Das ♂ zirpt Nachmittags und Abends. Der Zirpton ist auffallend laut und rauh. Das einzelne „grrü" ist deutlich abgesetzt, wird aber ohne Unterbrechung rasch wiederholt und erinnert lebhaft an den Ton einer Cicade.

G. frontalis Fieb. und *G. algerius* Sauss. in Grösse und Färbung sehr ähnlich, von beiden durch die verlängerten Elytren, deren Spitzenfeld beim ♂ vollständig entwickelt ist, durch die gegen das distale Ende zu verästelte Vena radialis, von *G. frontalis* noch insbesondere durch die stärker hin und her gebogenen Harpa-Adern des ♂, sowie die weit von einander entfernten Adern des auffallend verdünnten, glasartig durchscheinenden Seitenfeldes der Elytren verschieden. Mit dieser Beschaffenheit des letzteren dürfte vielleicht die Intensität des Zirptons in Zusammenhang stehen, der für die Grösse dieser Grille ganz ausnehmend laut ist.

Figure 20. *Svercus palmetorum* original description from Krauss (1902).

taxon, i.e. hind tibia spinulation, wing venation pattern and transverse line on the head.

Oecanthus dulcisonans Gorochov, 1993

EXAMINED MATERIAL. Italy, Sardinia, Fluminimaggiore (Carbonia-Iglesias Province), N 39°26' 53.232" E 8° 25' 30.18", 30m asl, 29 August 2013, 1 male.

DISTRIBUTION. *Oecanthus dulcisonans* is known for Canary Is., Spain, Italy and Middle East. Very few localities are known for Sardinia. The presence of this species in Sardinia was ascertained by Schmidt & Herrmann (2000). It is still unreported in the online version of the Fauna d'Italia checklist, but is reported in Massa et al. (2012) with the comment "a few records from Sardinia, central Italy and Sicily, the status in Italy is unclear".

In fact, until Gorochov (1993) description, *O. dulcisonans* wasn't separated from *O. pellucens pellucens* (Scopoli, 1763), so particular care was put in the unequivocal identification of a specimen from the locality where audio recording (both at 96 kHz and at 250 kHz) took place, namely the town of Fluminimaggiore (Carbonia-Iglesias province) under the bridge of Riu Billittu, at an elevation of 80m. Temperature at the moment of recording was 22.1°C. For a quick identification of *O. dulcisonans*, the acoustic and morphological guidelines by Cordero et al. (2009) where applied to the audio sample and to the collected specimen (Figs. 21, 22). The morphological identification didn't pose any doubt, even though the Sardinian specimen, with a tegminal length of 13 mm and a femural length of 8 mm, although obviously larger than *O. pellucens pellucens*, fell slightly below the measurements provided by Cordero et al. (2009) for tegmen length (*dulcisonans* = 14.01 ± 0.26; *pellucens* = 10.80 ± 0.14) (t_{15} = 12.05; $P < 0.0001$) and femur length (*dulcisonans* = 8.60 ± 0.14; *pellucens* = 7.60 ± 0.17) (t_{14}= 4.06; $P < 0.001$) for specimens from Spain and Tunisia.

REMARKS. The calling song (Fig. 23) of *O. dulcisonans* consists of a melodious trill emitted almost continuously. Trills (Fig. 24) consist of syllables emitted at average rate of 40/sec.

Frequency analysis (Fig. 25) shows high-Q pitched emission of energy. Dominant frequency is at 3.295 kHz, with harmonics at 6.286, 9.216 and 12.39 kHz, being therefore strictly in the audio range. Enhanced contrast in time-frequency spectrogram (Fig. 26) show very weak harmonics above 13 kHz.

The song, although somehow different from the data in Cordero et al. (2009) and in Massa et al. (2012), remains clearly discernible from the repetitive but less continuous echemes in concurrent songs by *O. pellucens pellucens*, also living in the same area although not in the same environment. Direct observation of the first author confirmed that *O. pellucens pellucens* sings preferentially from trees while *O. dulcisonans* seems to prefer high grass such as the vegetation growing along small streams.

CONCLUSIONS

Ultrasound songs of four Orthoptera Ensifera from Sardinia have been recorded. Microphones with ultrasonic threshold, such as Ultramic 250 by Dodotronic, proved to be an invaluable device to investigate the ultrasonic components of Orthopteran songs. Some limitations addressed herein do not af-

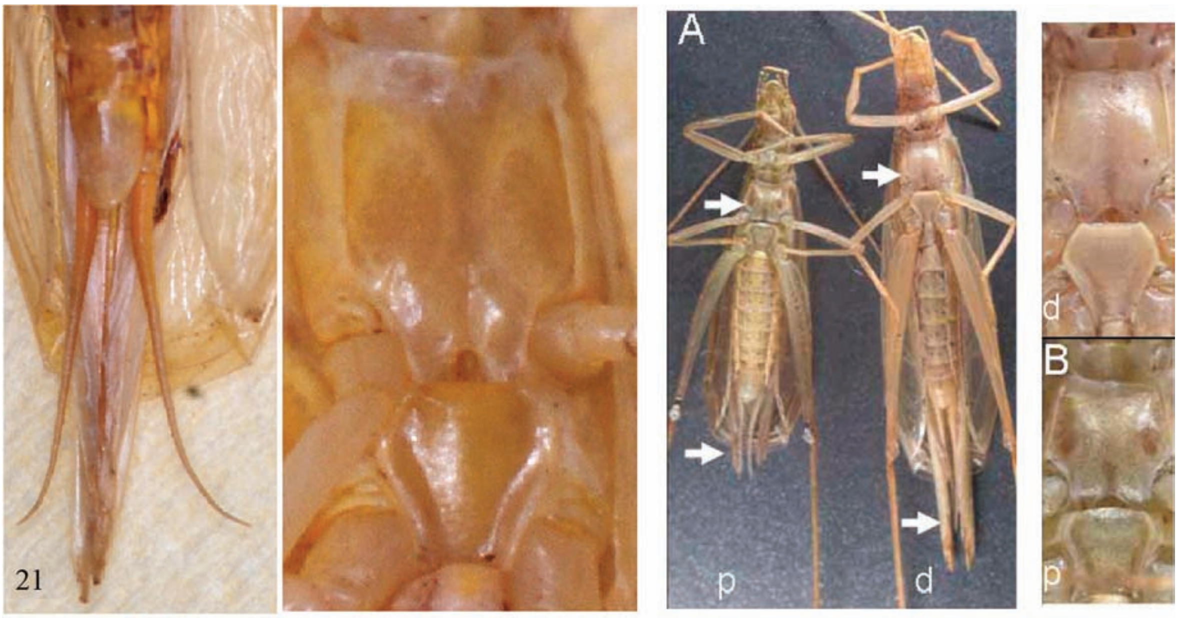
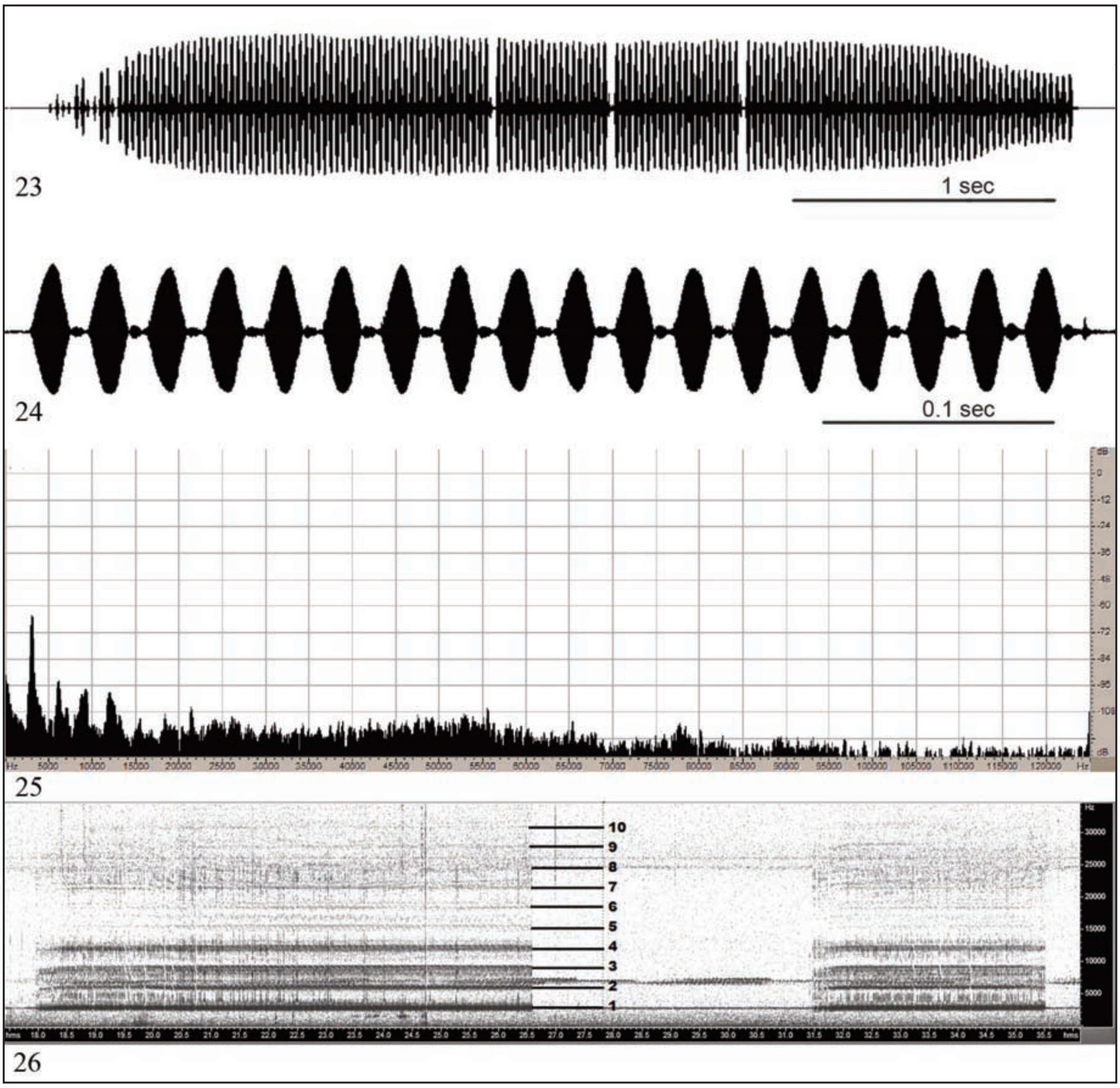


Figure 21. Comparison between the *Oecanthus dulcisonans* from Fluminimaggiore (left) and the guideline illustrations from Cordero et al., 2009 (right), p = *O. p. pellucens*, d = *O. dulcisonans*. Figure 22. Living male from Fluminimaggiore.

fect its high potential as a scientific tool for field research in Orthopteran bioacoustics, in particular if the protocol outlined in the introduction is adopted. Ultramic peculiar features may require specimen collection or subsidiary audio recordings to make it an useful tool for species identification on acoustic evidence. Of the taxa recorded, the only with dominant ultrasonic emission is *R. baccettii*. *U. brevicollis insularis* and *S. palmetorum palmetorum* emit both in audio and ultrasound range, while *O. dulcisonans* appears to emit almost only in the audio range.

The presence of *S. palmetorum palmetorum*, of which to date very few data were available, is confirmed in Sardinia by audio recordings and specimens. *O. dulcisonans* is also confirmed in Sardinia for new localities. Within the limits of a clearly recognizable, more or less continuous stridulation, the song appears more variable than previously reported for the species, in particular for its main audible frequency. Also specimen size variability appears to be higher than previously reported, with a slightly smaller biometry for the Sardinian specimen. The ultrasonic components of *O. dulcisonans* calling



Figures 23–25. Song of *Oecanthus dulcisonans*. Figure 23: calling song. Figure 24: sound unit. Figure 25: frequency analysis, FFT size 8192 bytes. Figure 26. Zoom-in up to 35kHz from the 250 kHz spectrogram of *Oecanthus dulcisonans* song, displaying a main audible frequency of around 3200Hz, Fluminimaggiore, 29 August 2013, numbers show the approximate location of the first ten unitary harmonics.

song do not seem particularly relevant. Nevertheless the weak harmonics above 13 kHz of this species could have some role, the significance of which should be investigated within the frame of heterospecific behavior, though in the same genus. Bioacoustics is here confirmed to be valuable in biodiversity assessment and taxonomic distinction. Sound analysis deeper than simple sonogram illustration, allow to gain more details for sound description, taxonomic discussion and ethological observations.

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