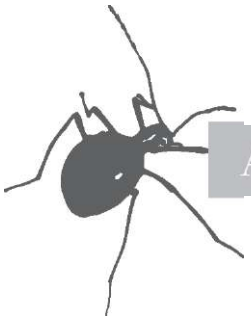

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*TETTIGETTA CARAYONI*BOULARD (HEMIPTERA: CICADIDAE) FROM CRETE, FAUNISTIC DATA AND FIRST DESCRIPTION OF ITS SONG

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Abstract - Using recording equipment for sonic and ultrasonic range we recorded the calling song of *Tettigetta carayoni* Boulard 1982, which is endemic to the Greek island of Crete (Kriti). It is widely distributed and common species from the sea coast to the mountains up to 1500 m above sea level. Nevertheless, the song of this species has not been described until now. The calling song structure is characteristic and easily distinguishable from the songs of related cicadas. Typical for the calling song is very fast repetition rate with 7 to 11 echemes per second. It consists of two parts, together forming a complete song with usual duration of many minutes. The monotonous part is a regular repetition of echemes with medium length, while rhythmic part consists of series with 2 to 4 very short echemes followed by one longer echeme. The monotonous part and rhythmic part can exchange either on a regular basis either one part is very long and can be randomly interrupted with a few echemes from opposite part. Studied was also the microstructure of the song, which shows 4-click units and consequently the stepwise distribution of the echeme duration. The song contains frequencies from 6 to 20 kHz with a maximum between 10.8 and 14.7 kHz. This species specific calling song pattern is compared with songs of other European cicadas.

KEY WORDS: *Tettigetta carayoni,* Cicadidae, bioacoustics, singing cicadas

Izvleček - *TETTIGETTA CARAYONI* BOULARD (HEMIPTERA: CICADIDAE) S KRETE, FAVNISTČNI PODATKI IN OPIS POZIVNEGA NAPEVA

S pomočjo snemalne opreme za slušno in ultrazvočno območje smo posneli pozivni napev škržada vrste *Tettigetta carayoni* Boulard 1982, ki je endemičen na

grškem otoku Kreta. Vrsta je splošno razširjena in pogosta od morske obale do nadmorske višine 1500 metrov. Kljub temu oglašanje te vrste še ni bilo opisano. Struktura napeva je vrstno značilna in jo po pozivnem napevu zlahka ločimo od napevov sorodnih pojočih škržadov. Značilna za pozivni napev je zelo velika ponavljalna frekvenca s 7 do 11 ehemi v sekundi. Napev, ki je sestavljen iz dveh delov, običajno traja več minut. Monotoni del je enakomerno ponavljanje srednje dolgih ehemov, medtem ko je ritmični del sestavljen iz serij z 2 do 4 zelo kratkimi ehemi, ki jim sledi en daljši ehem. Monotoni in ritmični del se bodisi izmenjujeta enakomerno ali pa en del traja zelo dolgo in je le naključno prekinjen z nekaj ehemi iz drugega dela. Mikrostrukturo napeva sestavljajo enote iz 4 klikov in zato je časovna razporeditev dolžin ehemov stopničasta. Frekvenčni obseg napeva je med 6 in 20 kHz z maksimumom med 10,8 and 14,7 kHz. Vrstno značilni pozivni napev sva primerjala tudi z drugimi evropskimi pojočimi škržadi.

KLJUČNE BESEDE: *Tettigetta carayoni,* Cicadidae, bioakustika, pojoči škržadi

Introduction

There is still no comprehensive paper on the singing cicadas (Cicadidae, sensu Moulds 2005) of Greece. Recently, we published the description and the song of three new species of "mountain cicadas" *Cicadetta hannekeae* Gogala, Drosopoulos et Trilar 2008, *Cicadetta olympica* Gogala, Drosopoulos et Trilar 2009 and *Cicadetta kissavi* Gogala, Drosopoulos et Trilar 2009, which are endemic to Greece.

Also on the biggest Greek island of Crete (Kriti) three endemic singing cicadas are present: *Cicada cretensis* Quartau & Simöes 2005, *Tettigetta carayoni* Boulard 1982 and *Pagiphora aschei* Kartal 1978. *Cicada cretensis* has been described only recently, together with its song characteristics. The songs of *T. carayoni* and *P. aschei,* however, had not been previously investigated (Sueur 2001) and were not described yet.

Tettigetta carayoni was described on the basis of two males from the monastery Arkadion (Moni Arkadiou) near Rethymno collected by the late J. Carayon and deposited in the Muséum national d'Histoire naturelle de Paris (Boulard 1982).

In this paper we give faunistic data and describe song characteristics of *T. carayoni* from the Greek island of Crete. The term "song" is used here in a broad sense, although tymbalisation (according to i.e. Boulard 2006, Leroy 1979) or simply sound emission may be more appropriate for cicadas.

Materials and Methods

In the year 2006 we investigated singing cicadas (Hemiptera: Cicadidae) of the Greek island of Crete (Kriti) with the use of classical and bioacoustic methods. From May 27th to June 3rd, 2006 we visited Rethymno and Lasithi Counties (Nomos Rethymnis, Nomos Lasithiou). For sound recordings we used microphones, sensitive

in sonic range (Telinga Pro 6 stereo - parabola diameter 57 cm) and in ultrasonic range (ultrasonic detector Pettersson D-200) in combination with solid state recorders Marantz PMD660 and PMD670. Computer program for the analysis of acoustic data was Raven 1.2 and 1.3 (Cornell Lab of Ornithology) and for graphical representation of the sounds Seewave package (Sueur et al. 2008) as a part of R software platform (R Development Core Team 2008).

The specimens collected are preserved in the collections of the Slovenian Museum of Natural History (PMSL) in Ljubljana, Slovenia; all sound recordings are stored in the Slovenian Wildlife Sound Archive housed in PMSL. Representative sound samples mentioned in this paper are available also on the web pages "Songs of the European singing cicadas" <http://www.cicadasong.eu/>.

Results

Faunistic data

Faunistic data from the Greek island of Crete (Kriti) from June 27th to July 3rd, 2006 are presented below. All recordings, observations and collecting have been made by the authors.

Rethymno: Adele, Mesi; 35°20'16.2" N, 24°34'31.7" E; 210 m; 27. 5. 2006; recorded and collected
Rethymno: Adele, Harkia; 35°18'23.5" N, 24°34'47.5" E; 460 m; 27. 5. 2006; recorded and collected
Rethymno: Moni Arkadiou; 35°18'23.5" N, 24°37'50.0" E; 495 m; 27. 5. 2006; song heard
Rethymno: Adele, Adelianos Kambos, hotel Adele Mare; 35°22'17.7" N, 24°33'04.9" E; 2 m; 28. 5. 2006; collected
Rethymno: Armeni, Somatas; 35°19'11.5" N, 24°27'50.5" E; 345 m; 28. 5. 2006; recorded and collected
Rethymno: Armeni, Late Minoan Cemetery; 35°19'04.5" N, 24°27'48.1" E; 355 m; 28. 5. 2006; song heard
Rethymno: Spili; 35°13'12.8" N, 24°32'03.0" E; 470 m; 28. 5. 2006; recorded
Rethymno: Spili, Kato Hadika; 35°13'46.6" N, 24°32'42.2" E; 655 m; 28. 5. 2006; recorded and collected
Rethymno: Aghia Fotini, Patsos, Kato Hadika; 35°13'47.3" N, 24°33'12.9" E; 655 m; 28. 5. 2006; recorded
Rethymno: Aghia Fotini, Pantanassa; 35°16'12.9" N, 24°35'08.7" E; 285 m; 28. 5. 2006; recorded
Rethymno: Adele, Pigi; 35°21'30.4" N, 24°35'57.5" E; 41 m; 29. 5. 2006; song heard
Rethymno: Adele, Loutra; 35°21'11.7" N, 24°35'9.84" E; 100 m; 29. 5. 2006; song heard

Rethymno: Perama, Aghia; 35°22'09.2" N, 24°45'44.4" E; 140 m; 29. 5. 2006; recorded
Rethymno: Anoghia, Vathias; 35°16'07.3" N, 24°53'18.9" E; 960 m; 29. 5. 2006; recorded and collected
Rethymno: Anoghia, Tsounia; 35°13'28.4" N, 24°52'52.7" E; 1410 m; 29. 5. 2006; recorded
Rethymno: Nida Plateau, pred jamo Ideo Andro; 35°12'18.5" N, 24°49'57.0" E; 1475 m; 29. 5. 2006; recorded
Rethymno: Platanias; 35°21'54.0" N, 24°31'2.1" E; 458 m; 30. 5. 2006; collected
Lasithi: Aghios Nikolaos, Kritsa, pod vrhom Lato; 35°10'10.8" N, 25°39'21.7" E; 315 m; 31. 5. 2006; recorded
Lasithi: Aghios Nikolaos, Ellounda; 35°15'27.0" N, 25°43'37.8" E; 24 m; 31. 5. 2006; song heard
Lasithi: Neapoli, Drasi; 35°13'16.1" N, 25°36'17.3" E; 340 m; 1. 6. 2006; recorded
Lasithi: Neapoli, Tzermiadhon; 35°12'22.9" N, 25°31'13.4" E; 920 m; 1. 6. 2006; recorded
Lasithi: Lasithi Plateau, Mesa Lasithi; 35°11'29.8" N, 25°31'31.7" E; 995 m; 1. 6. 2006; collected
Lasithi: Lasithi Plateau, Aghios Georgios; 35°09'56.4" N, 25°29'30.7" E; 820 m; 1. 6. 2006; recorded and collected
Lasithi: Lasithi Plateau, Psychro, in front of the cave Dikteo Andro; 35°09'44.9" N, 25°26'46.8" E; 950 m; 1. 6. 2006; song heard
Lasithi: Lasithi Plateau, Aghios Haralambos; 35°10'16.0" N, 25°26'20.5" E; 850 m; 1. 6. 2006; recorded
Lasithi: Lasithi Plateau, Moni Vidianis; 35°11'31.4" N, 25°26'; 35.3" E; 810 m; 1. 6. 2006; collected
Lasithi: Katharo Plateau, Katharo Tsivi; 35°10'27.1" N, 25°32'49.9" E; 1135 m; 1. 6. 2006; recorded and collected
Lasithi: Katharo Plateau, Kopraki; 35°09'50.0" N, 25°32'36.7" E; 1180 m; 1. 6. 2006; recorded and collected
Lasithi: Aghios Nikolaos, Kritsa, Panaghia Kera; 35°09'23.9" N, 25°39'19.2"E; 225 m; 2. 6. 2006; song heard
Lasithi: Aghios Nikolaos, Kritsa, Lato; 35°10'23.3" N, 25°39'13.9" E; 313 m; 2. 6. 2006; song heard

Description of the song pattern

TIME PARAMETERS. In all localities we detected many males with the same song pattern, made many recordings and collected 19 males previously recorded. Analysed were 21 recordings (27. 5. 2006: Adele, Harkia - 3 recordings; 28. 5. 2006: Armeni, Late Minoan Cemetery - 3, Armeni, Somatas - 2, Spili - 7, Spili, Kato Hadika - 1, Aghia Fotini, Pantanassa - 2; 1. 6. 2006: Lasithi Plateau, Aghios Haralambos - 3 recordings). The measurements were performed either on the original channels from Telinga microphone (4 recordings), either on the original channel

Table 1. Temporal parameters of the calling song of *Tettigetta carayoni.*
EA - medium long echeme; EA Dur - EA duration; EA CarFrMax - carrier frequency maximum of EA; EA int - interval before EA; RepRateA - repetition rate of echemes in segment A; N(EA)/s - number of EA per second; EB1 - very short echeme; EB 1 Dur - EB1 duration; Double EB 1 Dur - duration of double very short echeme (DEB1); EB2 - longer echeme; EB2 Dur - EB2 duration; EB2 CarFrMax - carrier frequency maximum of EB2; EB1 / DEB1 Int = interval before EB1 and double EB1; EB2 Int - interval before EB2; RepRateB = repetition rate of echemes in segment B.

S	Parameter	Unit	Count	Mean	St. Dev	Min	Max
A	EA Dur	ms	8955	21.9	4.5	14.0	37.9
A	EA CarFrMax	kHz	88	12.8	0.7	11.4	14.2
A	EA Int	ms	8847	91.6	14.3	50.7	147.3
A	RepRateA	N(EA)/s	140	8.9	1.0	7.3	11.1
B	EB1 Dur	ms	4064	6.3	1.2	3.2	9.0
B	Double EB1 Dur	ms	755	11.6	1.5	9.1	14.0
B	EB2 Dur	ms	1628	44.2	5.3	32.6	58.6
B	EA CarFrMax	kHz	76	12.9	0.6	11.7	14.3
B	EB1 / DEB1 Int	ms	4932	113.1	21.4	66.8	249.1
B	EB2 Int	ms	1200	39.9	4.9	23.9	49.9
B	RepRateB	N(EB)/s	136	9.3	1.0	7.3	11.5
C	EB2 Dur	ms	46	43.9	5.7	31.0	54.9
C	EB2 Int	ms	41	544.7	210.5	290.5	995.2

of ultrasonic detector (13 recordings) or on the transposed signal of ultrasonic detector (4 recordings).

The characteristic of the calling song of *T. carayoni* is very fast repetition rate of echemes - average repetition rate of the whole song is 8.9 ± 1.0 (7 - 11) echemes per second.

It consist of three types of echemes characterised by duration: very short echeme of 6.3 ± 1.2 ms duration (EB1), medium long echeme of 21.9 ± 4.5 ms (EA) and longer echeme of 44.2 ± 5.3 ms duration (EB2). In 18.5% EB1 is prolonged to double length (double EB1; 11.6 ± 1.5 ms) (Table 1, Figs. 3, 4, 5 and 6).

The microstructure of EB1 shows a basic pattern of 4 tymbal clicks (Fig. 7). Looking at this pattern even in more details can be recognised 4 double clicks, where the inward movement of tymbal produces a very soft click and the outward a loud one (Fig. 7a). All three types of echemes comprise multiple values of 4-click units: EB 1 one 4-click unit, double EB 1 two, EA three and EB2 from 6-8 4-click units (Fig. 7b) and therefore, the duration of echemes is distributed stepwise (Figs. 8).

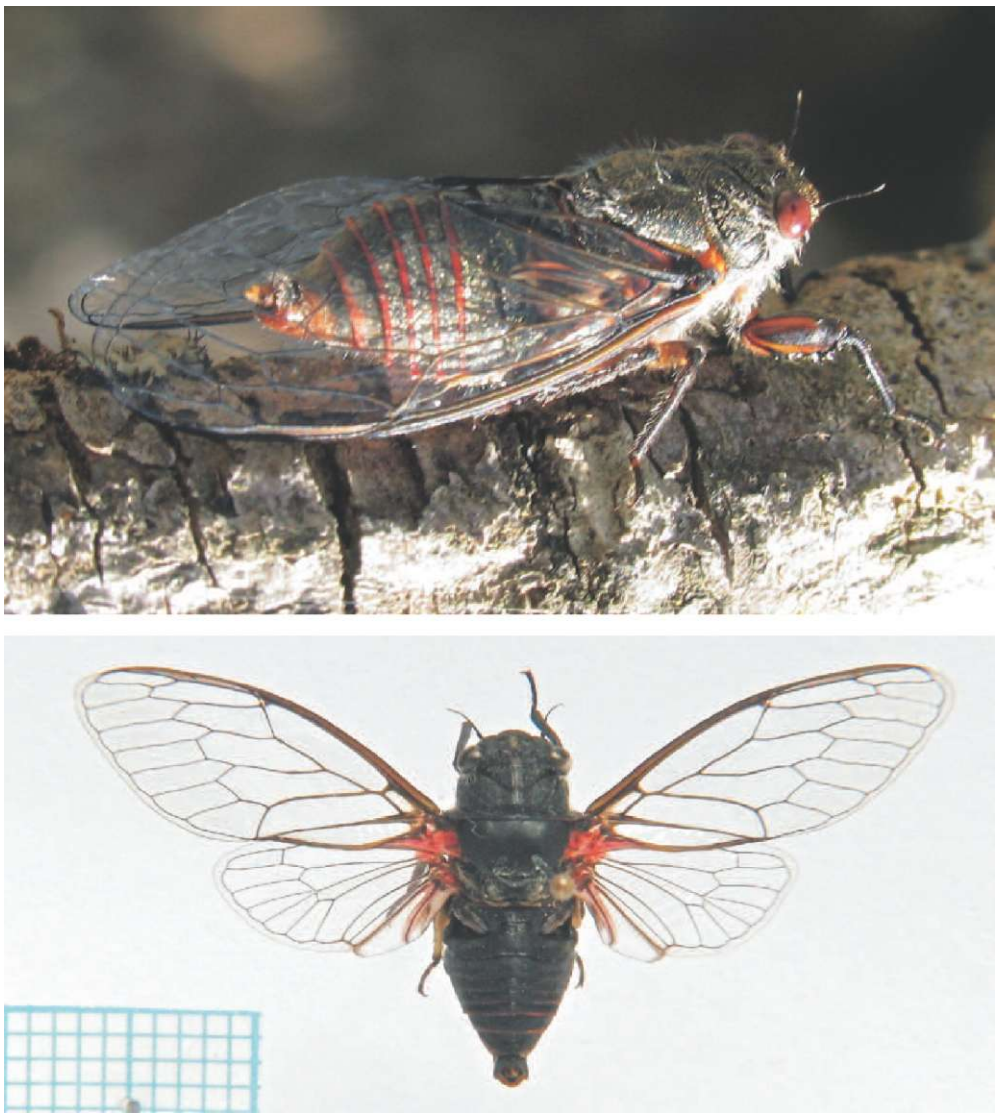

Fig. 1: *Tettigetta carayoni.* Live animal from Kopraki, Katharo Plateau (above) and prepared male specimen (below).

The calling song consists of two segments, together forming a complete song with typical duration of many minutes. The shortest song recorded lasted 21 s and the longest one 3 min 55 s. Altogether we measured 44 min 59 s of recordings.

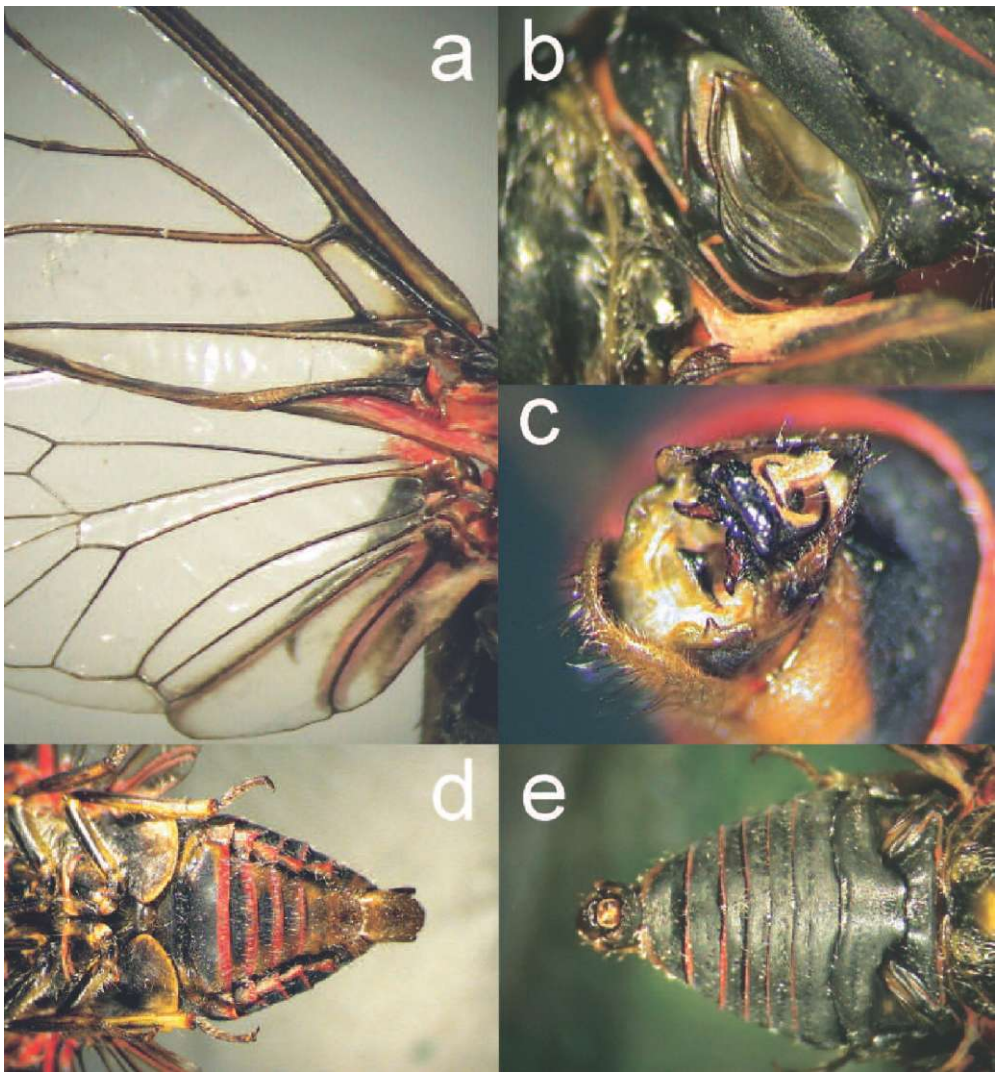

Fig. 2: Morphology of *Tettigetta carayoni.* a - left wing detail with common root of the Median and Cubitus Anterior veins; b - left tymbal; c - view of male genital capsule from behind, pygopher basal lobe with inner tooth, dark base of aedeagus, claspers pointing anterolaterad and black uncus can be seen; d - ventral view of opercula and male abdomen; e - dorsal view of tymbals and male abdomen.

The song starts with long lasting segment A, which is a monotonous repetition of EA (Figs. 3 and 4, for statistic parameters see Table 1) with repetition rate 9.3 ± 1.0

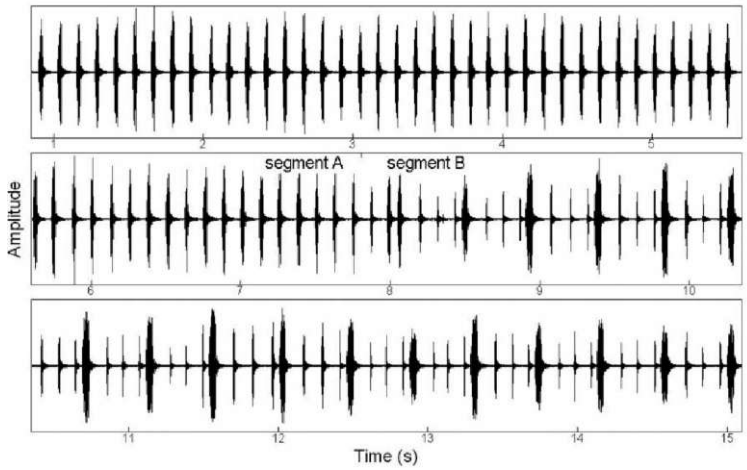

Fig. 3: Oscillogram of the calling song of *Tettigetta carayoni.*

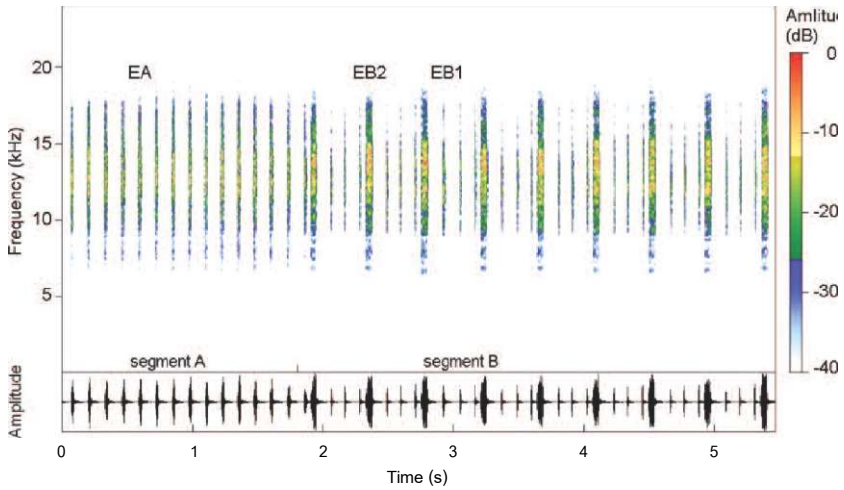

Fig. 4: Spectrogram and oscillogram (below) of the calling song of *Tettigetta carayoni.* EA - medium long echeme; EB2 - longer echeme; EB1 - very short echeme.

(7 - 11) echemes per second. The interval between echemes is 91.6 ± 14.3 ms (Table 1). Segment A lasts from only 0.6 s (5 echemes) to 113 s (1043 echemes).

After this first monotonous part of the song appears without interruption the rhythmic part or segment B (Figs. 3 and 4, for statistic parameters see Table 1), which consists of series with 2 to 4 EB1 followed by one EB2. In one series can be

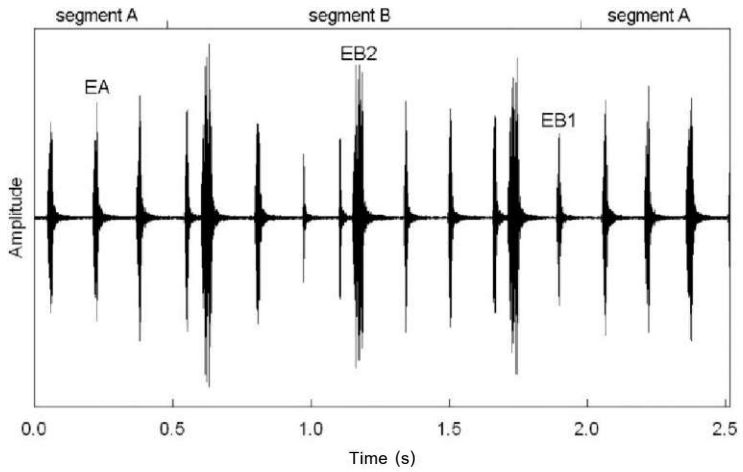

Fig. 5: Oscillogram of the transition from segment A to segment B and after two series back to segment A of the calling song of *Tettigetta carayoni.* EA - medium long echeme; EB2 - longer echeme; EB1 - very short echeme.

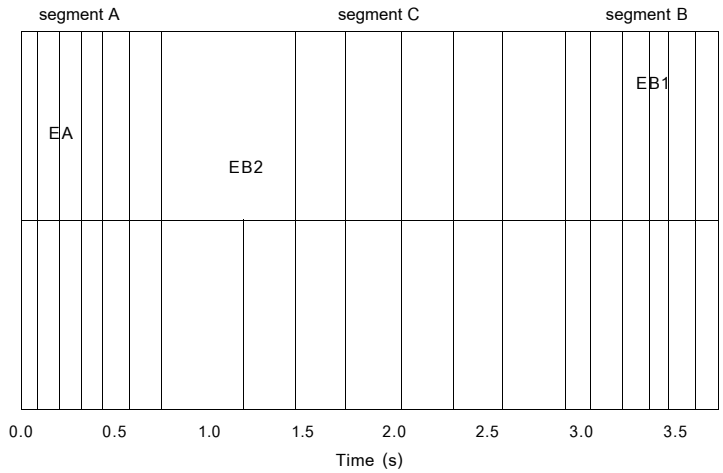

Fig. 6: Oscillogram of the series of longer echemes (segment C) of the calling song of *Tettigetta carayoni.* Segment C is preceded by segment A and followed by segment B. EA - medium long echeme; EB2 - longer echeme; EB1 - very short echeme.

2 (11.5%), 3 (72.6%) or 4 EB1 (13.0 %) always followed by one EB2. We noticed also series with 1, 5, 6, 7 or 8 EB1 followed by one EB2, but it occurred in less then 1%. The repetition rate of segment B is 9.1 ± 1.0 (7 - 11) echemes per second. The interval between EB2 and first EB1 and interval between EB1-EB1 is 113.1 ± 21.4

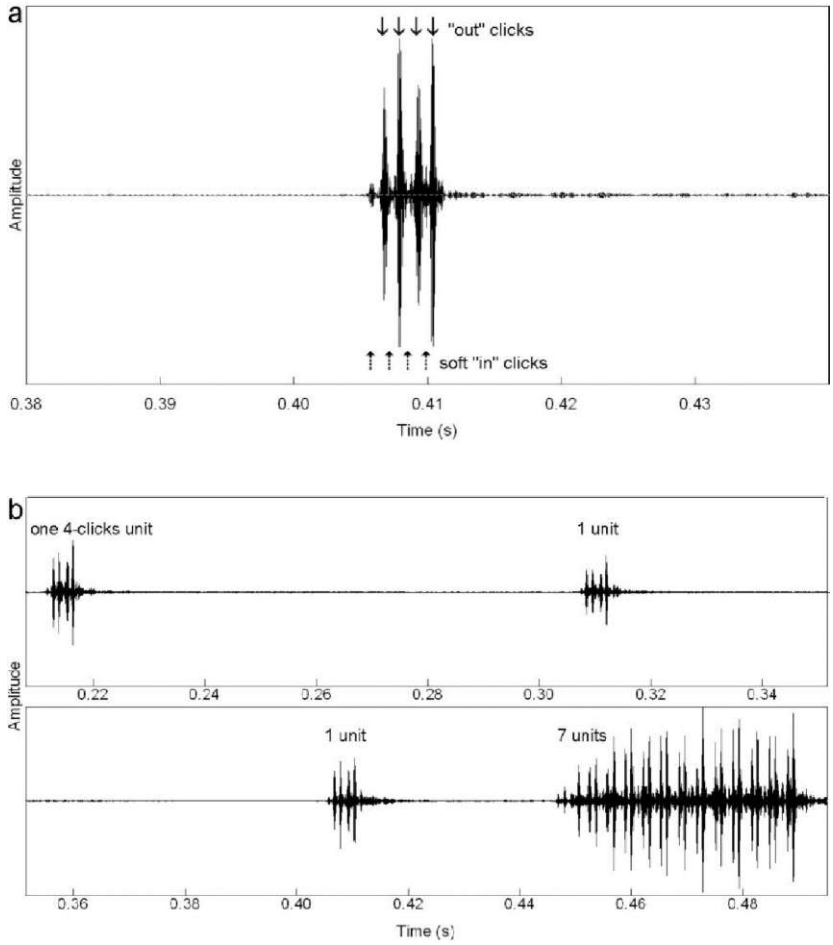

Fig. 7: Oscillograms showing pulse structures of the segment B of the calling song of *Tettigetta carayoni:* a - sample of the shortest echeme with 4 double pulses, soft "in" and loud "out" clicks representing the basic "4-click unit"; b - 3 very short echemes (EB1) comprising 1 "4-click units" and 1 longer echeme (EB2) comprising 7 units.
Note a different time scale in Fig. 7b!

ms, while the interval between the last EB1 and EB2 is 39.9 ± 4.9 ms. Segment B lasts from only one series (3-5 echemes) to 35 s (131 echemes).

The segment A (monotonous part) and segment B (rhythmic part) can exchange either on a regular basis either one segment is very long and can be randomly interrupted with a few echemes from opposite segment. The transition from segment A to segment B consist either of one double EB1 or of one EA, usually shorter then the

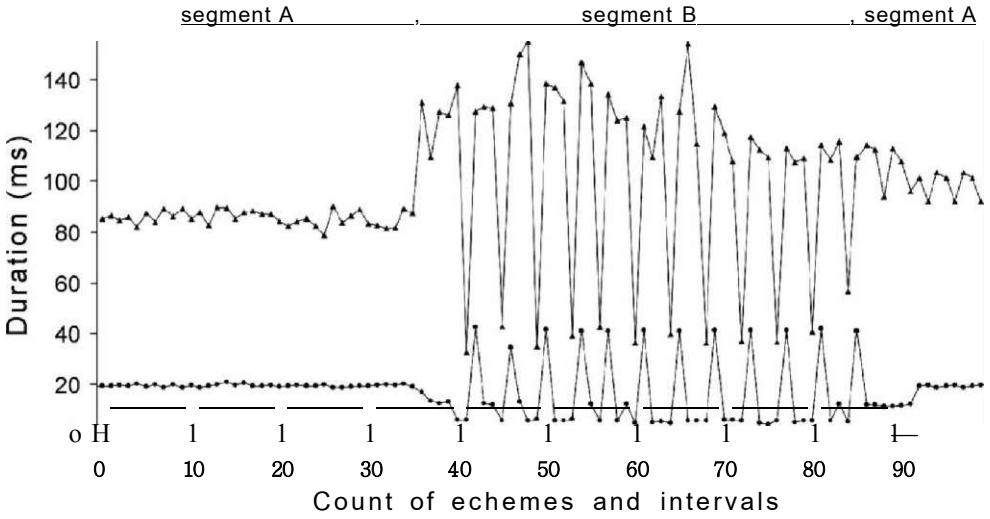

Fig. 8: Graph showing echeme durations (diamond, below) and following interval durations (triangles, above) during segment A and B of the calling song of *Tettigetta carayoni.* Duration of shortest echemes (EB1) is 6 to 7 ms, higher values of very short echeme durations are two times higher than the "4-click unit" (double EB1). Longer echemes (EB2) in segment B are in this recording composed by 6 to 7 basic units and medium long echemes (EB2) in segment A from 3 basic units.

average in the preceding sequence, followed by one or two EB1 and one EB2 (Fig. 5). The transition from segment B to segment A consist of one to three EB1 and either one double EB1 or one EA, usually shorter then the average in the sequence that follows (Fig. 5).

Very occasionally there is a sequence of slow repeating EB2 (segment C) (Fig. 6). The duration of EB2 is in range with the duration of EB2 from segment B, while the interval is 544.7 ± 210.5 ms (Tab. 1). We recorded four songs with included segment C with 8, 9, 13 and 17 EB2.

FREQUENCY RANGE. The frequency spectrum of the calling song shows broad frequency range between 6 and 20 kHz (Fig. 4). Carrier frequency maximum is between 10.8 and 14.7 kHz. The -20 dB range covers the frequencies between 9.5 and 16.0 kHz. Such frequency characteristics can be expected from the size of these singing cicadas (Bennet-Clark & Young 1994).

Due to the high frequency content of this song it makes sense to use the ultrasonic or "bat" detector for listening, detecting and recording these cicadas in the field.

ECOLOGY. As mentioned before we found this species in localities from the sea-coast to the mountains up to 1500 m above see level. They usually sit and sing on shrubs or small trees either in macchia or olive tree plantations at lower elevations and at higher elevations on grass or other green plants. They are active at daytime. A single male is singing at the same spot for one or a few minutes, then flies away and immediately starts singing at a new spot. Due to the cryptic coloration and high pitched song it is not easy to spot singing males in the field.

Discussion

In recent years it has been shown that singing cicadas (Cicadidae, sensu Moulds 2005) of Europe are not known to such extent as supposed previously. Bioacoustic investigations, combined with morphological and molecular approaches shed new light on the taxonomy of this group of insects. By acoustic methods it is much easier to single out singing animals in vegetation and recognize their identity. This is true also for the fauna of Cicadidae of Greece.

Also the song characteristics of *T. carayoni,* endemic for the Greek island of Crete (Kriti), has not been previously investigated (Sueur 2001). However, this cicada is widely distributed and common species on Crete from the sea coast to the mountains up to 1500 m above sea level.

The main characteristics of the calling song of *T. carayoni* are very short echemes and very high repetition rate. The same song characteristics can be observed also in *Cicadetta flaveola* Brullé 1832 (Gogala & Drosopoulos 2006), *Cicadetta mediterranea* Fieber 1876 (Gogala & Popov 1997) and *Euryphara contentei* Boulard, 1982 (Quartau & Simöes 2004, Sueur et al. 2004) from the Mediterranean basin, which have also similar eco-ethology since all are singing on grass or herbaceous plants. These song characteristics could be an adaptation to the acoustic conditions in such habitats (Gogala & Drosopoulos 2006) but the hypothesis should be supported by exact acoustic measurements.

A song pattern closest to the one of *T. carayoni* is the calling song of *C. flaveola* (Gogala & Drosopoulos 2006). Also in microstructure of *C. flaveola* calling song 4-click units can be observed, with a very soft click during the inward tymbal movement and the loud outward movement. Therefore, the duration of echemes is distributed stepwise. The duration of very short echeme is 8 ± 0.9 ms (one 4-clicks unit), double very short echeme 16.5 ± 1 ms (2 units), medium long echeme 24.6 ± 1 ms (3 units) and longer echeme 51.3 ± 1.5 ms and 59.6 ± 1.5 ms (6 and 8 4-clicks units) (calculation from the original measurements of Gogala & Drosopoulos 2006). The song consists of monotonous part with repetition of medium long echemes and of two different rhythmic parts with more or less regular sequences of two very short echemes followed by one longer echeme or one very short echeme followed by one longer echeme. The repetition rate of echemes in monotonous part is typically 7 - 11 echemes per second (Gogala & Drosopoulos 2006).

On the basis of the composition of the calling song, very fast repetition rate of echemes, echeme duration in the same time range, microstructure with 4-clicks units

and consequently the stepwise distribution of the echemes duration *T. carayoni* and *C. flaveola* can be acoustically placed in the same group. They have in common also some morphological characteristics, like a short common root of the Median (M) and Cubitus Anterior (CuA) veins, sternite VIII slightly shorter or as long as sternite VII, pygopher basal lobe in ventral view showing inner tooth present, tymbal with 4 long ribs. The single major morphological difference beside colouration is the number of apical cells on hind wings, which is usually 6 in *T. carayoni* and 5 in *C. flaveola,* but it can vary even between the left and right wing of the same specimen. According to S. Puissant (personal communication) these two species belong to the same genus.

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