LJUBLJANA, JULY 1997 Vol. 5, No. 1: 11-24

BIOACOUSTICS OF SINGING CICADAS OF THE WESTERN PALAEARCTIC: *CICADETTA MEDITERRANEA* FIEBER 1876 (CICADOIDEA: TIBICINIDAE)

Matija GOGALA, Ljubljana and
Andrej V. POPOV, St. Petersburg

Abstract - *Cicadetta mediterranea* Fieber 1876 is one of the smallest species of palaearctic singing cicadas and is ecologically bound to a narrow coastal zone and to herbaceous plants in this habitat. We investigated the bioacoustics of this cicada species in the coast of Istria (Croatia). The only type of song, the calling song of the solitary male, consists of two phrases with repeated patterns. Typically, the 1.6 s long phrase I consists of a long echeme (0.7 s), followed by 3 to 6 short echemes (60 - 100 ms). Phrase II (1.2 s) again consists of a long echeme (340 ms), followed by a higher number (3 - 32) of very short echemes (10 - 20 ms) (Figs 2,3). Sequences of phrase I can switch to phrase II without any interruption. We present temporal parameters qualitatively and quantitatively. The spectrum of the calling song contains two main frequency bands: a dominant one between 11 and 17 kHz with a maximum at 12 - 15 kHz and a secondary peak between 7 and 9 kHz which is 5 - 10 dB lower in amplitude than the main peak. There is also a third weak spectral band around 20 kHz. The pattern of phrase I and the frequency spectra are similar to the song characteristics of the related species *C. tibialis* but the patterns of phrase II are clearly different in both species.

Izvleček - BIOAKUSTIKA POJOČIH ŠKRŽATOV ZAHODNEGA PALEARKTIKA: *CICADETTA MEDITERRANEA* FIEBER 1876 (CICADOIDEA: TIBICINIDAE)

Cicadetta mediterranea Fieber 1876 je ena najmanjših vrst palearktičnih pojočih škržatov, ekološko vezana na ozek obalni pas in na nizke zelnate rastline tega habitata. Pozivni napev samca te vrste sestoji

iz dveh fraz, ki se ponavljata in lahko prehajata druga v drugo brez vmesne prekinitve. Tipično sestoji 1,6 s dolga fraza I iz dolgega ehema (0,7 s), ki mu sledi zaporedje treh do šestih kratkih ehemov (60 - 100 ms), in ta vzorec se ponavlja. Fraza II, katere ponavljajoči se vzorec v povprečju traja 1,2 s, pa sestoji iz večjega števila (3 - 32) zelo kratkih ehemov (10 - 20 ms) (sl. 2,3). Časovni parametri so prikazani kvalitativno in kvantitativno. Zvočni spekter pozivnega napeva vsebuje dva glavna pasova, enega v območju med 11 in 17 kHz z vrhom med 12 do 15 kHz in drugega med 7 in 9 kHz, ki je po jakosti za 5 - 10 dB nižji od glavnega. Tretje slabotnejše spektralno območje smo ugotovili v območju okoli 20 kHz. Po strukturi prve fraze pozivnega napeva in v emisijskem spektru ugotavljamo precejšnjo podobnost z napevom sorodne vrste *C. tibialis*, medtem ko je struktura druge fraze pri obeh vrstah bistveno različna.

Introduction

Among the small south European singing cicadas producing high-frequency communicative sounds, *Cicadetta mediterranea* has an outstanding position according to its distribution and ecological specialization. According to Schedl (1986) and to our experience, it can only be found in a narrow coastal region on grasses and other low vegetation, not more than about 50 meters from the seacoast.

There is a good reason for continuing our description of acoustic signals of singing cicadas from the western Palaearctic (Gogala et al., 1996) with this smallest species of *Cicadetta*, since its song structure has many similarities to that of the previously described species *C. tibialis*. Besides, to our knowledge, its acoustic signals have not been ever described.

Material and Methods

The acoustic behavior of *Cicadetta mediterranea* Fieber 1876 was investigated on Cape Kamenjak, the most southern part of Istria (Croatia), from the end of June till July 16th, 1995.

The song recordings were made in the field using digital techniques in the sonic range between 20 and 22000 Hz with a Telinga Pro III parabolic stereo microphone (parabola diameter 57 cm) and SONY DAT-recorders TCD-D3 and TCD-D7 (sampling rate 48 kHz, 16 Bit dynamic range).

Alternatively, we used the bat (ultrasonic) detector S-25 from UltraSound Advice with its microphone mounted in a reverse position to another Telinga parabola. The low frequency signal from the detector was recorded with the second DAT recorder. With such equipment we were able to detect the songs and locate the animals much more easily than with normal recording equipment due to the high frequency content of their acoustic emissions.

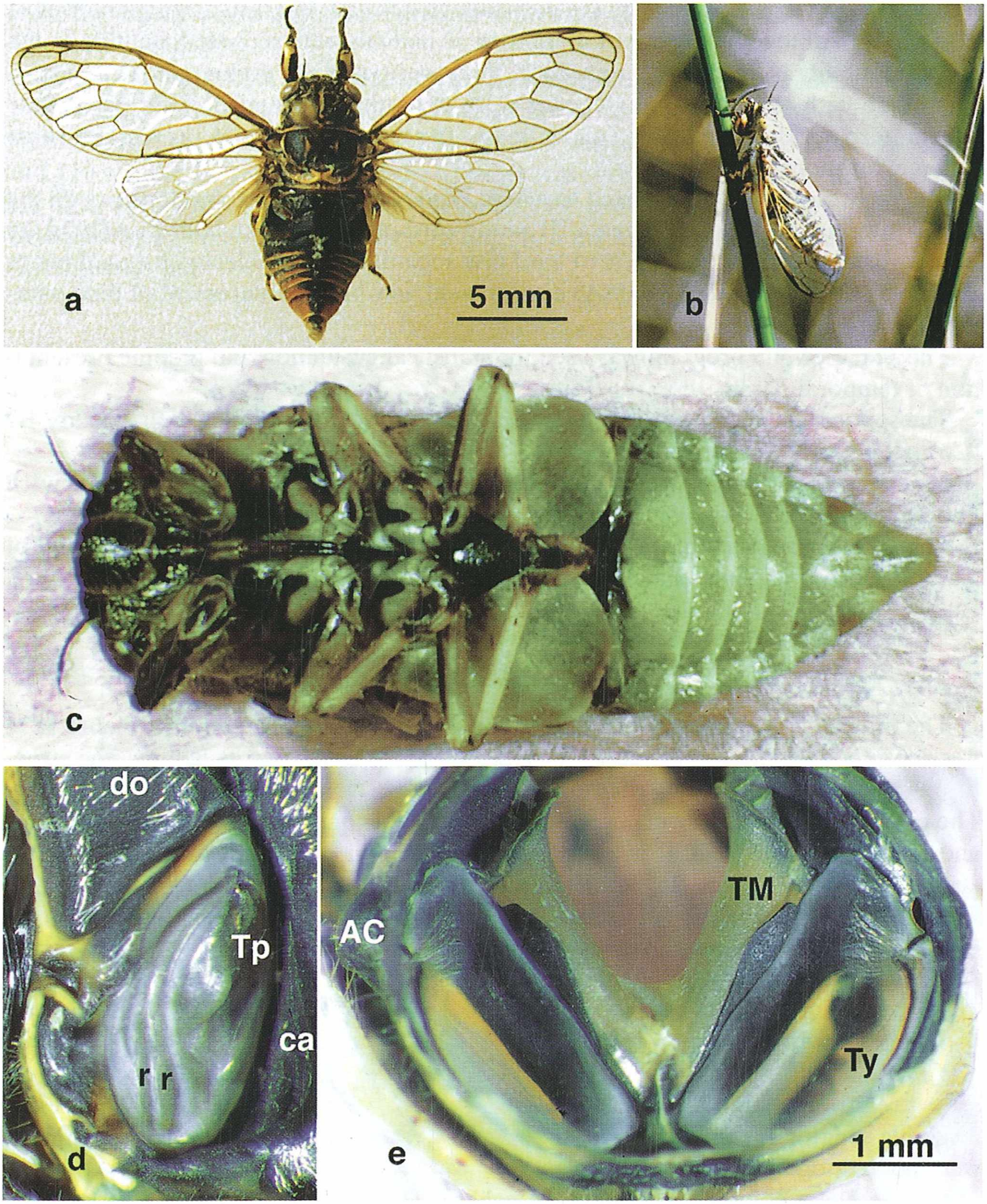

Fig. 1: a) *Cicadetta mediterranea*, male, b) singing animal in its habitat, c)ventral view with opercula, d) left tymbal with two long ribs (r) on the proximal field (do = dorsal, ca = caudal, Tp = tymbal plate), e) tympanal membranes (Ty) and tymbal muscles (TM) - as seen caudally after the abdomen was removed (AC = auditory capsule).

Recordings were made during the day from 10 AM to 6 PM and at temperatures of 25° to 28°C. All together, songs of more than 30 animals were recorded, but due to the different quality of recordings, only 24 of them were used for evaluation. The recordings made with the ultrasonic detector were not suitable for evaluation of all time parameters, as the ultrasonic echoes made the measurements of especially short echeme durations uncertain.

The recordings were transferred to a Mac PowerPC 8500/120 computer through the digital interface in the Audiomedia III sound card or through the built in AD/DA 16 Bit converters. The suitable parts of hard disk recordings were selected for analyses in the Pro Tools III (Digidesign, USA) environment, in which measurement of time parameters were also made.

The StatView 4.5 program was used for statistical evaluation and graphic presentation of temporal parameters.

The sonograms and spectrograms from selected ranges were made with Canary 1.2 (Cornell Univ. USA) software.

Macro photographs were made with a Wild M8 stereomicroscope with Photoautomat. A.V. Popov photograped the singing animals.

The voucher specimens are preserved in the collections of the Slovene Museum of Natural History in Ljubljana, Slovenia, and the Zoological Museum in St.Petersburg, Russia.

Results

The morphology and geographic distribution of *Cicadetta mediterranea* Fieber 1876 was recently described by Schedl (1986), thus here we only show its habitus, the structure of tymbals with two long ribs, the tympana and associated structures (Fig. 1).

The calling song of solitary males was the only type of communicative sound, we heard and recorded in the field. It is a continous sequence of phrases of two distinct types, lasting for minutes (Figs. 2c, 3c). Both phrases are composed of a long echeme (LE) followed by a number of short echemes (SE, see below). The animals switched from one phrase to the other without any interruption, but during our investigations the fast 2nd phrase was emitted by the animals less frequently and for shorter periods of time. We observed many times that the males ended singing with phrase II and then immediately flew away.

For the evaluation of temporal parameters in phrases I, we selected 30 seconds long sequences from each of 16 good recordings, and for analyses of phrases II pieces of available lengths (in most cases also 30 s) of 8 recordings. The data for all animals were pooled together.

Phrase I is a combination of a long echeme (LE1), followed by a series of 3 - 6 (mostly 3-4) short echemes (SE1) (Fig. 2c, 7a). The repetition period of phrases I (=that of LE1) was between 1110 and 2426 ms with the mean value at 1562±220 ms (mean ± standard deviation). Thus, the mean repetition rate is 0.6 Hz. The distribution of period durations (T2) clearly showed double or even triple peaks (Fig. 5b) also in single animals. This was connected with the number of short echemes in a phrase

(Fig. 7b). There is also a positive correlation between the LE1 duration and LE repetition period (Fig 7c).

The duration of LE1 (T1 according to the description of *C. tibialis* in Gogala et al., 1986) varied between 447 and 1064 ms with a mean value of 700±93 ms (Fig. 5a). The duration of short echemes SE1 (T3) in phrase I varied in our recordings between 40 and 116 ms, the first short echeme in a phrase was shorter (64±9 ms) than the following ones (78±10 ms). The intervals between LE1 and the first SE1 in a phrase (T6: 154±26 ms) were not significantly different than the intervals between short echemes (T5: 144±22 ms).

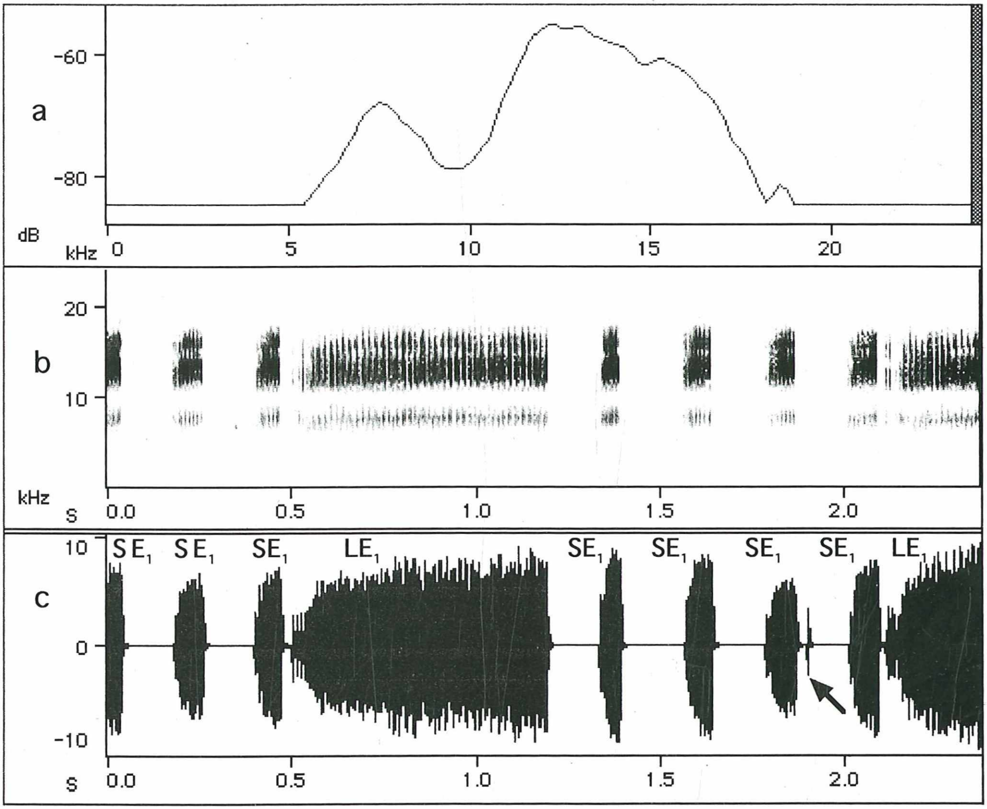

Fig. 2: Phrase I - spectral characteristics (a, b) and temporal structure (c): a) frequency spectrum, b) sonogram, c) oscillogram of the same part of the song; SE1 - short echemes, LE1 - long echemes, arrow points to click, occurring frequently with a short delay during the last SE1 - SE1 intervals (Canary 1.2).

During the interval or intervals between last two or three short echemes in a phrase very often one or a few very short pulses appeared, similar to the beginning of the long echemes LE1 and with a similar delay (arrow in Fig. 2c, cf. Fig. 4a). The last interval (T7) preceding the next long echeme LE1 varied extremely between 3 and a few hundreds of a ms, therefore mean and standard deviation do not make sense. Quantitative data of time parameters of phrase I are presented in Fig. 5 a-f and 7a-c.

The structure of **phrase II** is in principle similar to phrase I of the same species, but the durations of echemes SE2 and LE2 were much shorter (see below) and the number of short echemes in a phrase was higher, varying between 3 and 32 per phrase (11±5, Figs. 3c, 7d). The repetition period of phrases II (=that of LE2) varied widely according to the different number of short echemes in a phrase between 422 and 2932 ms (1176±468 ms)(Fig. 7e). So, their mean repetition rate is 0.85 Hz.

The mean LE2 duration was 343±121 ms (171 - 775 ms, Figs. 3c, 6a) and in both cases, the plotted values did not show any similarity with a Gaussian distribution and had many peaks (Fig. 6a,b). Less variable were the durations of SE2 (T3) with a mean value of 16.7±4.6 ms with clear multiple peaks between 9 and 22 ms (Fig. 6d). This unusual distribution is a consequence of the fine structure of echemes, consisting of three (3d), four (4d), five (5d), or other numbers of double pulses (see below).

The intervals between the short echemes lasted on average 55±21 ms. The first interval after the long echeme (T6) was of similar duration and the last interval in a phrase preceding the next long echeme was much shorter (20±12 ms). This means that the repetition period of short echemes in the fast second phrase is about 72 ms and the repetition rate was 14 Hz. In phrase II most temporal parameters varied to such an extent that a simple statistic giving the mean and standard deviation is irrelevant (Fig. 6 a-f).

Pulse structure of *C. mediterranea* in short and long echemes of both phrases is shown in Fig. 4. The short echemes (SE1 and SE2) had a series of double pulses ("d") in both phrases but the structure of long echemes was different. They also began with some double pulses (Fig. 4a and b), followed by a longer sequences of 4 click patterns ("f"). In the long echemes (LE1 and LE2) the groups of 4 clicks (probably 1 cycle of both tymbals) are clearly separated from each other by longer intervals (Fig. 4a-c), giving a secondary rhythm. At the end of a long echeme, one or more double pulses can again appear (Fig. 4c), but this is not a rule.

The spectral characteristics of the songs of *C. mediterranea* were analyzed in the sonic range up to 22 kHz. As in the species *C. tibialis*, the sound emission of *C. mediterranea* has in both phrases two main spectral bands slightly shifted to the lower frequencies. The dominant band had the most energy between 11 and 17 kHz with a maximum between 12 to 15 kHz. The secondary peak between 7 to 9 kHz was lower by about 5 - 10 dB compared to the maximum (Figs. 2a,b 3a,b). From the bat detector measurements we could expect that the song of *C. mediterranea* also contained frequencies above 22 kHz. Our sonograms and spectrograms showed some sound energy or a weaker side band also in the upper range of around 20 kHz.

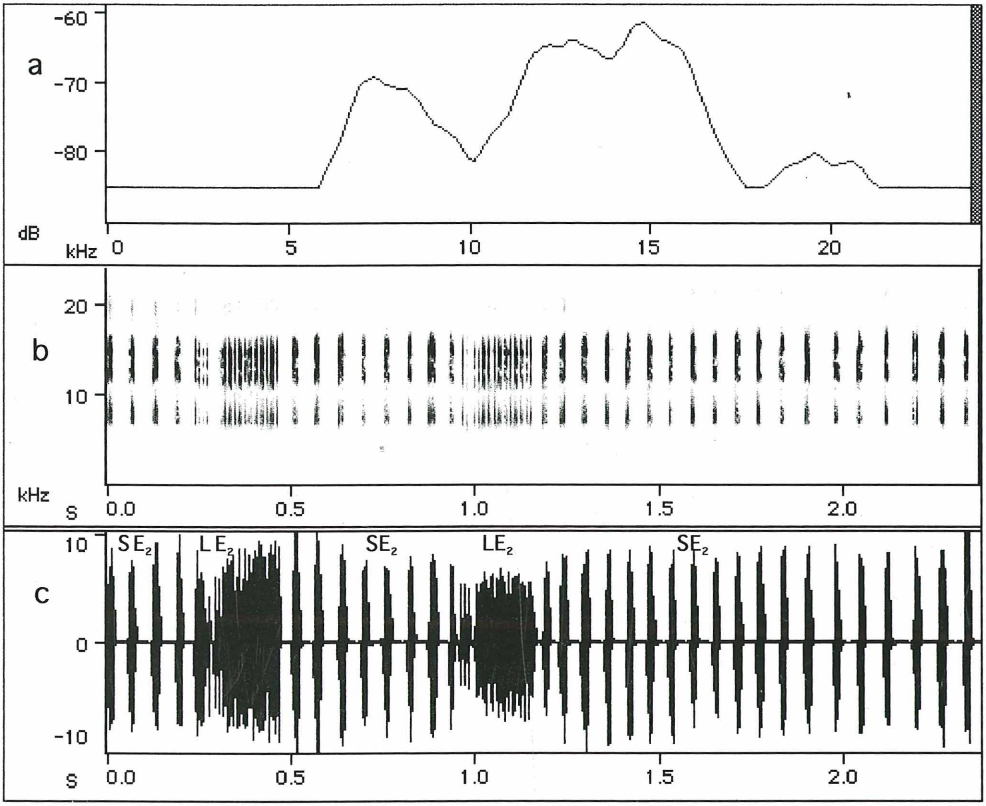

Fig. 3: Phrase II - spectral characteristics (a, b) and temporal structure (c): a) frequency spectrum, b) sonogram, c) oscillogram of the same part of song; SE2 - short echemes, LE 2 - long echemes. The equally long part of the song is shown as in Fig. 2 (Canary 1.2).

Discussion

As mentioned already in the Introduction, there is a close similarity between song structures, or more exactly, between phrases I of *C. mediterranea* and *C. tibialis* described before (Gogala et al., 1996). Both cicada species can be found during the same period of the year, and in some localities (e.g. island Krk: Stara Baška: Gogala, Popov - unpublished data) *C. tibialis* can also be found on grass close to the shore. Therefore, one can expect that both species sympatrically come together at least occasionally. Different structure of the second phrase could be a differential character to prevent cross mating in the field. Nevertheless, even temporal parameters of phrase I in both species is only similar in principle, since the long echeme durations (T1) hardly overlap (C. m.: 700±93 ms and C. t.: 292±50 ms) and the number of short echemes in *C. tibialis* varied between 2 - 15 (Gogala et al., 1996) and in *C. mediterranea* only between 3 - 6 (see above and Fig. 7a).

Actually, we have never observed mixed populations of both species and we do not have any evidence how the calling song of one species influences the specimens of the other taxons. Future observation of *C. mediterranea* should also be extended to other localities and to longer period of their activity.

On the other hand, the similarity between phrase I of both species can also be a sign of a close systematic position of both species, since this acoustic pattern does not appear in the same form in any other palaearctic species investigated up to now (compare: Boulard 1995, Fonseca 1991, Popov 1975). We think, therefore, that the morphological differences, on which the genus *Cicadivetta* for the species *C. tibialis* was established (Boulard, 1982) should be revised.

The ambient temperature during our experiments did not vary substantially (25° - 28°C); this allowed us to pool all data together.

The statistical distribution of time parameters was many times complicated (compare Fig. 6), showing multiple peaks or at least a non-Gaussian distribution. In some cases the reasons for such an abnormal distribution were found. In phrase I and II, the period durations correlate with the number of short echemes in a phrase (Fig. 7b and e) and LE durations are correlated with period durations in both phrases (Figs. 7c and 7f).

In phrase II, the short echeme durations are concentrated in equidistant peaks (Fig. 6d) due to the internal fine structuring of these acoustic signals. One echeme can be composed of 1 to 6 or even more double clicks, probably representing the in and out buckling of the tymbal. Therefore, such a short echeme can most often have 3 double pulses ("3d") = 6 pulses, 4 double pulses ("4d") = 8 pulses or 5 double pulses ("5d") = 10 pulses, but not 5, 7, or 9 pulses (Fig. 4, 6d). The two pulses in a unit follow each other in 1.45 - 1.7 ms but the interval to the next double click is somewhat longer, 1.7 - 3.5 ms and is more variable. Therefore, the usual duration of SE2 with 3 double pulses is about 11 ms, with 4 double pulses usually around 14 ms, and with 5 double pulses around 17 ms (Fig. 6d), varying to some extent from animal to animal.

Therefore, basic statistical description (i.e. mean and standard deviation) are in such cases of limited value. Range limits (minimum, maximum) or frequency histograms represent the measured values much better. The reason for such an unusual statistical distribution may also lie in the incorrect pooling of data, but we had no arguments for grouping the data in a different way.

There are other cases of abnormal statistical distribution of time parameters, as in the case of the last interval preceding the LE1, which could be interpreted by two hypothetical pacemakers - one for the long echeme repetition and the second for the short echeme repetition. They seemed to be synchronized after the offset of LE1 but not at the onset of the next LE1, since SE1 durations and intervals between them were quite stable, but the interval preceeding the next long echeme varied from 0 to values higher than the longest other intervals in a phrase. In the case of phrase II, even this stability in the duration of the first interval after a long echeme (LE2) was lost and only SE2 durations and intervals between them remained stable.

Nevertheless, the general pattern of both phrases of the calling song of *Cicadetta mediterranea* is in practice easy to recognize, and can be distinguished by acoustic signals from any other local species of singing cicadas. Samples of the acoustic signals can be downloaded for comparison from the Internet home page:

http://www2.arnes.si/~ljprirodm3/cikade.html

In the case of *C. mediterranea*, we did not make any measurements of vibrational components due to the unavailability of suitable equipment (very small mass of plant structures on which the animals were sitting and singing), a limited number of animals, and a lack of time available for these investigations.

As in the case of *C. tibialis* we cannot exclude for the species described here the existence of other types of songs in addition to the calling song of solitary males. The calling song described above, at least during the period of our investigation, was the only recognized and recorded sound signal of this cicada species.

Acknowledgements

We are grateful to the Ministry for Science and Technology of the Republic of Slovenia, which supported our joint studies in the years 1994 and 1995. We are also indebted to the Ministry of Science of the Republic of Croatia, which gave us permission to investigate singing cicadas in Croatia. Dr. Tomi Trilar from the Slovene Museum of Natural History kindly took the macro photographs.

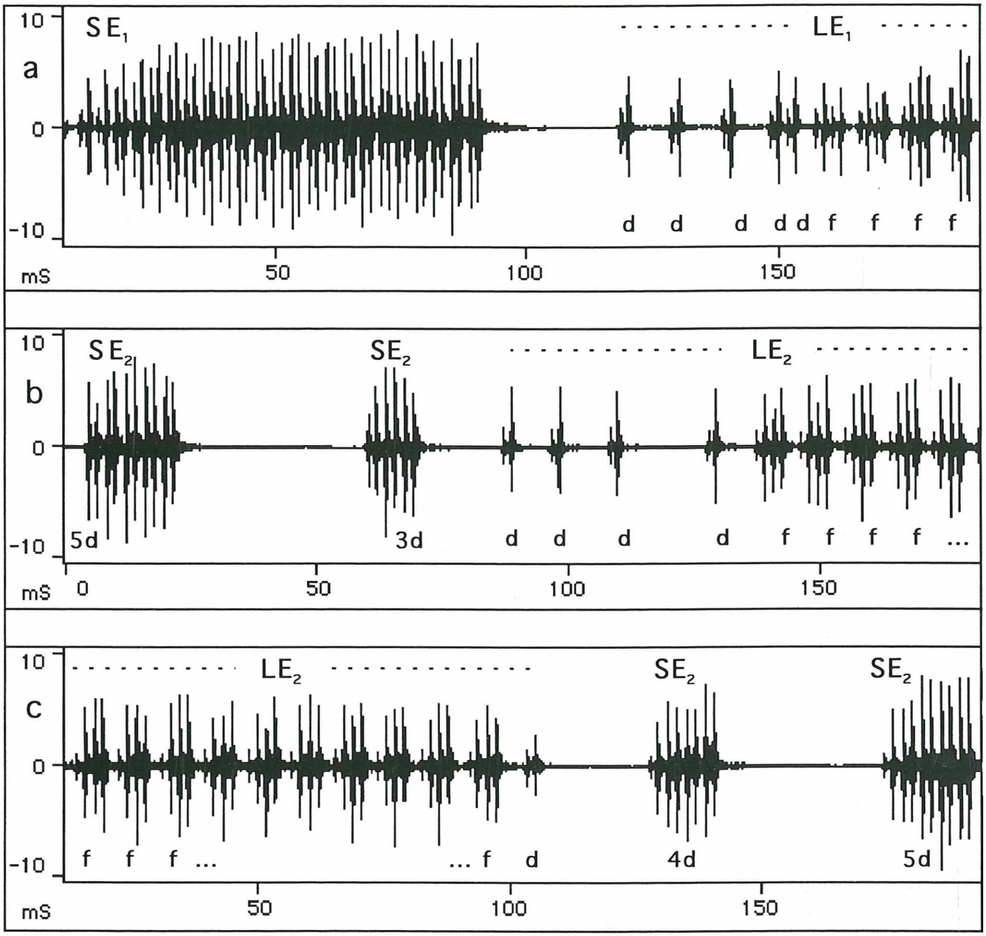

Fig. 4: Pulse structure in phrase I (a) and phrase II (b, c) with double pulse units (d) and four pulse units (f); the latter are characteristic for the main part of long echemes only: SE1 - short echeme of phrase I, LE1 long echeme of phrase I, SE2 - short echeme of phrase II, LE2 - long echeme of phrase II, 3d, 4d, 5d - echemes with 3, 4, and 5 double pulses. For further details see text.

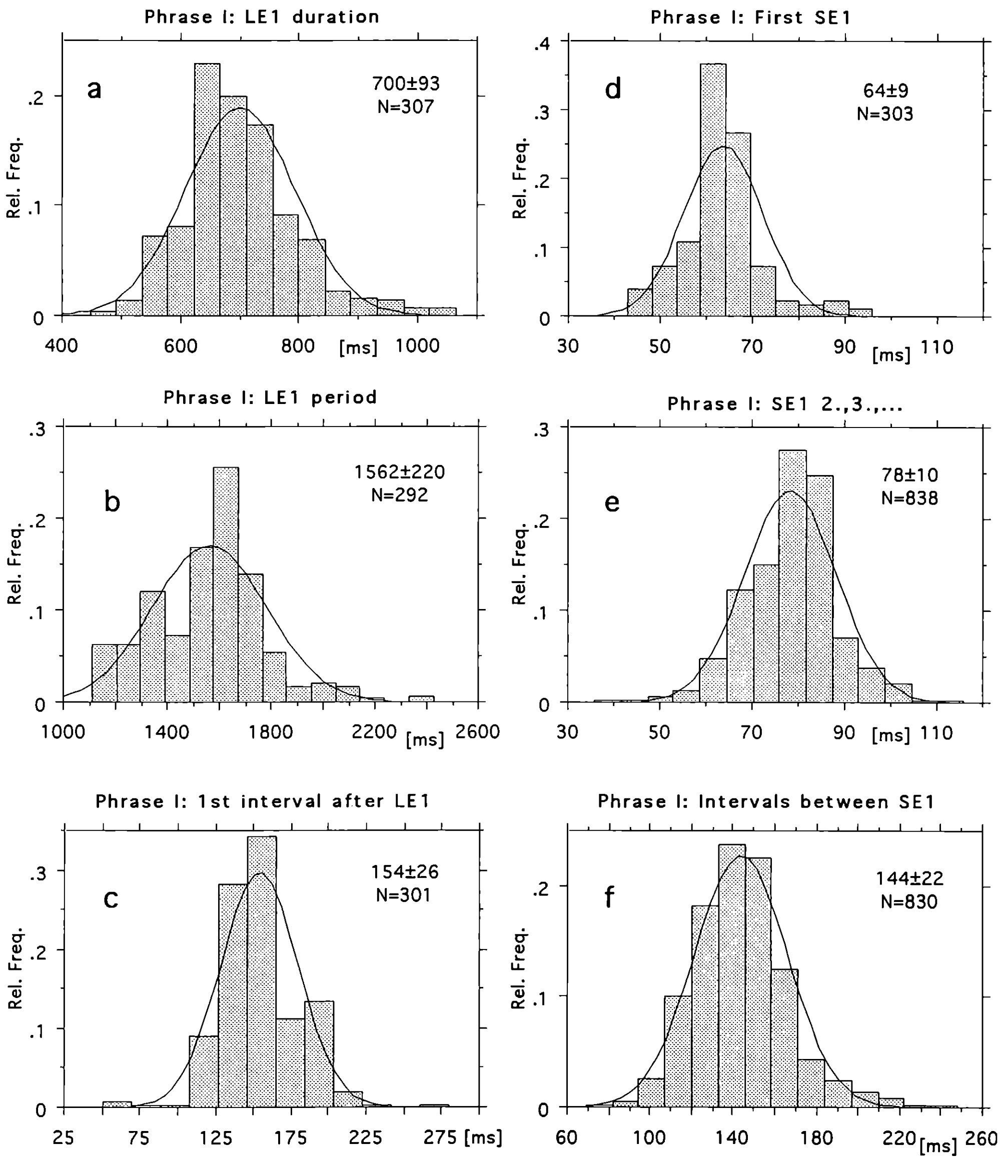

Fig. 5: Phrase I - histograms of temporal parameters and curve fits with normal distribution: a) LE1 duration (T1), b) LE1 period (T2), c) first interval after LE1 (T6), d) duration of the first SE1 in a phrase, e) durations of other SE1 echemes (T3), f) intervals between SE1 echemes. The values for the interval preceding the next LE1 varies between 3 and 420 ms with the highest peak at 25 ms.

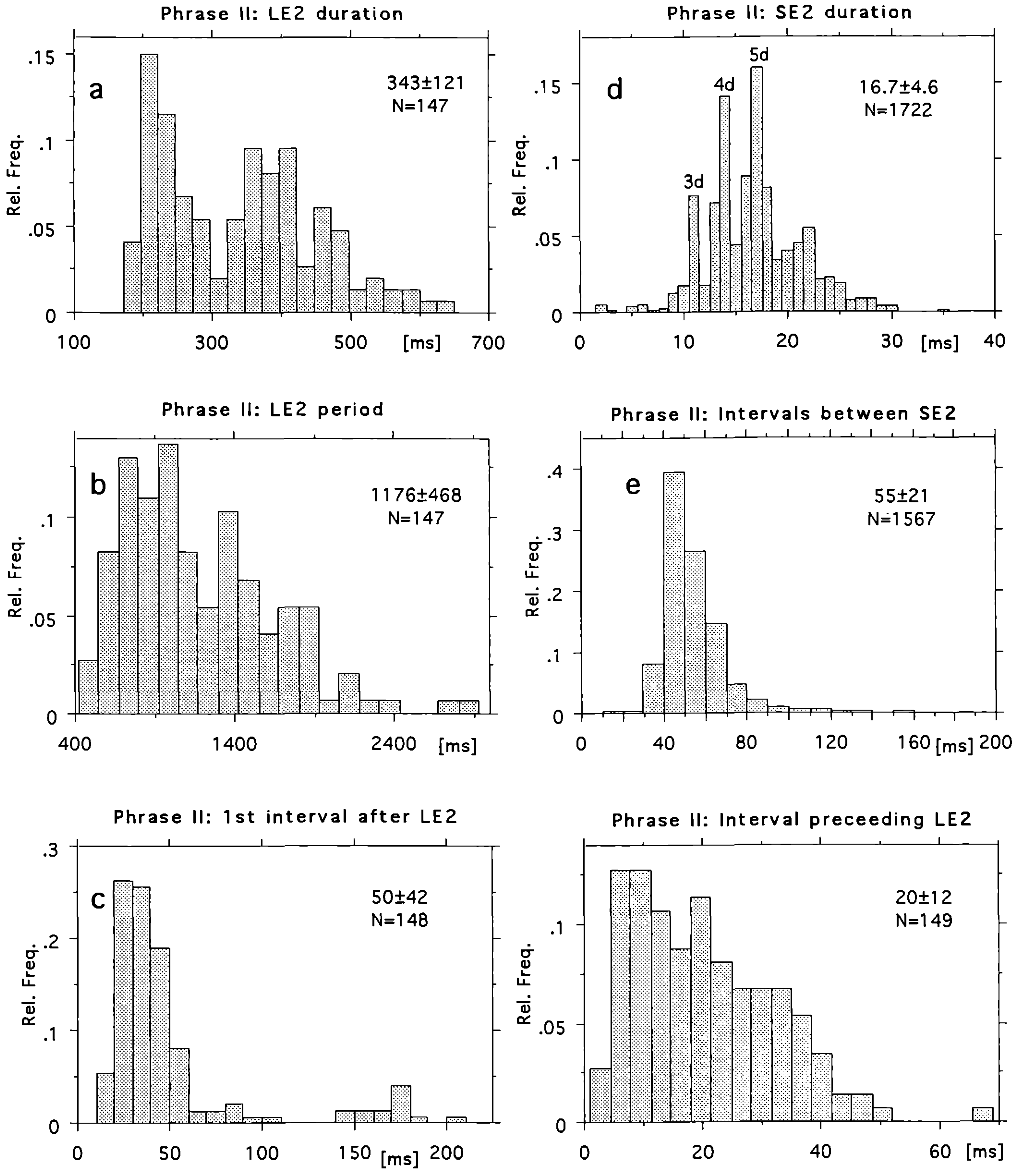

Fig. 6: Phrase II - histograms of temporal parameters - due to the complicated distribution of parameters, the normal distribution curves are not shown but the mean and standard deviation are given in for orientation: a) LE2 duration (T1), b) LE2 period (T2), c) first interval after LE2 (T6), d) duration of the SE2; 3d, 4d, 5d - peaks related to the 3, 4, 5 double pulses in SE2, e) intervals between SE1 echemes, f) interval preceding the next LE2. For further details see text.

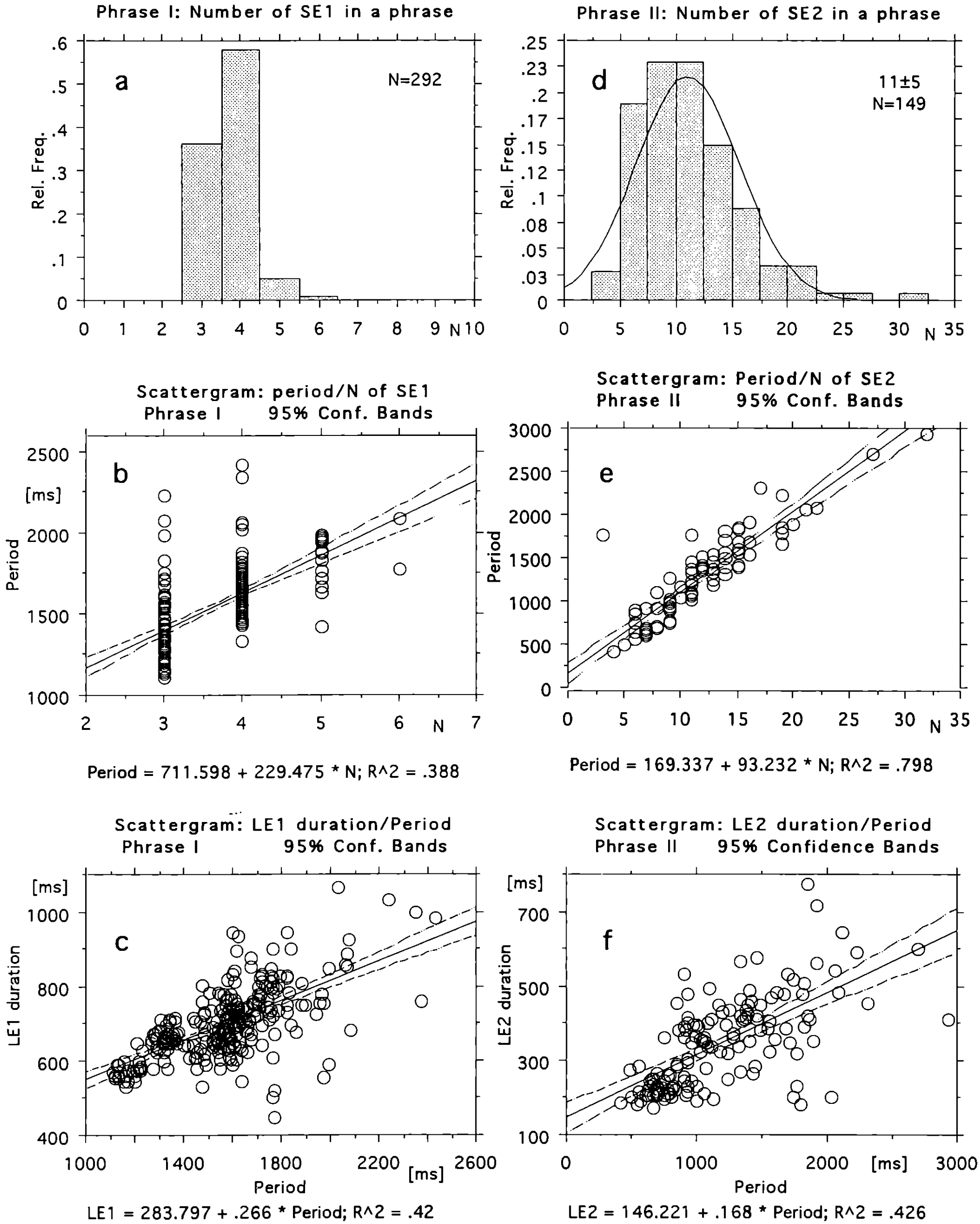

Fig. 7: Number of short echemes in phrase I (a) and II (d), scattergrams showing the relation of the period duration in both phrases to these values (b and e) and scattergrams showing the relation between LE durations and LE periods in both phrases (c and f) with regression lines, coefficients and r^2 values.

References

Boulard M., 1982: Taxa nouveaux pour la faune des Cigales de France (Hom.). *Bull. Soc. ent. France,* **87**: 49-50.

Boulard M., 1995: Postures de cymbalisation, cymbalisations et cartes d'identité acoustique des cigales. 1.- Généralités et espèces méditerranéennes (Homoptera Cicadoidea). *EPHE, Biol. Evol. Insectes*, 7/8, 1994/1995: 1-72.

Fonseca P.J., 1991: Characteristics of the acoustic signals in nine species of cicadas (Homoptera, Cicadidae). *Bioacoustics*, **3**: 173-192.

Gogala M., A.V. Popov, D. Ribarič, 1996: Bioacoustics of singing cicadas of the western Palaearctic: Cicadetta tibialis (Panzer) (Cicadoidea: Tibicinidae). *Acta entomologica slovenica*, **4**: 45-62.

Popov A.V., 1975: The structure of the tymbals and the characteristics of the sound signals in singing cicadas (Homoptera, Cicadidae) in the southern regions of the USSR. *Entomol. Obozr.*, **54**: 258-291.

Schedl W., 1986: Zur Verbreitung, Biologie und Ökologie der Singzikaden von Istrien und dem angrenzendem Küstenland (Homoptera: Cicadidae and Tibicinidae). *Zool. Jb. Syst.*, **113**: 1-27.

Authors' addresses/Naslova avtorjev
Matija GOGALA
Prirodoslovni muzej Slovenije
Prešernova 20, p.p. 290
SI-1001 Ljubljana, Slovenia

Andrej V. POPOV
Sechenov Institute Evol. Physiology and Biochemistry
Russian Academy of Sciences
Thorez pr. 44
194223 St. Petersburg, Russia