**THE SONG STRUCTURE OF *CICADETTA PODOLICA* (EICHWALD 1830)
(HEMIPTERA: CICADIDAE)**Tomi TRILAR¹ and Matija GOGALA²

¹ Slovenian Museum of Natural History, Prešernova 20, P.O.Box 290, SI-1001
Ljubljana, Slovenia; e-mail: ttrilar@pms-lj.si

² Slovenian Academy of Sciences and Arts, Novi trg 3, SI-1000 Ljubljana,
Slovenia; e-mail: matija.gogala@guest.arnes.si

Abstract – Using recording equipment for sonic and ultrasonic range we recorded the calling and the courtship songs of *Cicadetta podolica* (Eichwald 1830) in Krzyżanowice Dolne near Pińczów in Poland. *Cicadetta podolica* is a steppe species and belongs to the *Cicadetta montana* species complex. The calling song structure of *C. podolica* is characteristic and easily distinguishable from the songs of related cicadas. The whole phrase of calling song can be as short as 1.2 s or longer than 5.2 seconds but the typical phrase duration is 3.3 ± 0.9 seconds. The next phrase begins after a three quarters of a second long pause. Each phrase consists typically of a long sequence of short echemes (duration 1.6 ± 0.6 s) repeated about 12 ± 1 times per second and ending with one long echeme (duration 1.6 ± 0.6 s). The song contains frequencies from 7.5 to 20.5 kHz with a maximum between 9.9 and 14.1 kHz. We also observed courtship, where females produce in response to male courtship song short clicks associated with wing flipping. This species specific calling and courtship song patterns are compared with songs of other cicadas of the *C. montana* complex.

KEY WORDS: *Cicadetta podolica* calling and courtship song, *Cicadetta montana* complex, cicadas, Cicadidae, bioacoustics

Izvleček – STRUKTURA NAPEVA STEPSKEGA ŠKRŽADA (*CICADETTA PODOLICA* (EICHWALD 1830)) (HEMIPTERA: CICADIDAE)

S snemalno opremo za človeku slišni in neslišni del zvočnega spektra sva na območju Krzyżanowice dolne pri Pińczówu na Poljskem posnela pozivni in paritveni napev stepskega škržada (*Cicadetta podolica* (Eichwald 1830)). To je stepska vrsta, ki je ozko sorodna pojočim škržadom iz kompleksa vrst gorskega škržada (*Cicadetta montana*). Struktura pozivnega napeva stepskega škržada je zelo značilna in jo brez

težav razlikujemo od napevov drugih sorodnih pojočih škržadov. Celotna fraza pozivnega napeva je lahko krajša kot 1,2 s ali daljša od 5,2 s, vendar je značilna dolžina fraze $3,3 \pm 0,9$ s. Naslednja fraza se začne po tričetrt sekunde dolgem premoru. Vsako frazo sestavljajo dolgi nizi kratkih ehmov (dolžina $1,6 \pm 0,6$ s), ki se ponavljajo približno 12 ± 1 krat na sekundo. Fraza se konča z enim dolgim ehmom (dolžina $1,6 \pm 0,6$ s). Napev vsebuje frekvence od 7,5 do 20,5 kHz z največjo energijo med 9,9 in 14,1 kHz. Opazovala sva tudi dvorjenje, kjer samica odgovarja samcu s kratkimi poki, ki so v zvezi z utripanjem kril. Vzorce pozivnega in paritvenega napeva te vrste primerjava z napevi ostalih pojočih škržadov iz kompleksa vrst gorskega škržada.

KLJUČNE BESEDE: *Cicadetta podolica* pozivni and paritveni napev, kompleks vrst *Cicadetta montana*, škržadi, Cicadidae, bioakustika

Introduction

Cicadetta podolica (Eichwald 1830) (Hemiptera, Cicadidae) belongs to the *Cicadetta montana* species complex. While *Cicadetta montana* Scopoli 1772 s. str., *C. brevipennis* (Fieber 1876), *C. macedonica* (Schedl 1999), *C. fangoana* Boulard 1976, *C. cerdaniensis* Puissant & Boulard 2000, and *C. cantilatrix* Sueur & Puissant 2007 of the *Cicadetta montana* complex can be separated with certainty only by bioacoustic and/or molecular characters (Gogala & Trilar 2004, Gogala 2006, Sueur & Puissant 2007b), *C. podolica* is the only species of this complex that can easily be distinguished also on the basis of morphological characters by the dark brown infuscations at the apex of the fore wing (Schedl 1986).

The calling song was briefly described by Gogala and Trilar (2004) and Gogala (2006). In this paper we describe the calling and courtship songs of male *C. podolica* in more details and the response of female and compare their calling and courtship songs with those of closely related cicadas.

Material and Methods

In the years 2003 and 2005 we investigated, with the use of classical and bioacoustic methods, together with our colleague Jacek Szwedo from the Museum and Institute of Zoology of the Polish Academy of Sciences, the cicadas (Hemiptera: Cicadidae) of Poland (Trilar et al. 2006b). On June 24th and 25th, 2003 and on the same date in 2005 we visited the entomological Nature Reserve »Krzyżanowice« [Rezerwat stepowo-entomologiczny »Krzyżanowice«], an 18 ha large steppe area near Krzyżanowice Dolne village between Pińczów and Busko-Zdrój in district Kielce [UTM DA69], the known locality for *C. podolica* (Kostrowicki & Nast 1952, Kostrowicki 1954 – both under the synonym *Cicadetta adusta* Hagen 1856). It is located on the gypsum and limestone height, rising between the Nida valley and Gacki village. The height has a form of a platform, which is wide in the eastern part, and is narrowed sharply toward the west. Both edges are very steep, with inclination up to 75 degrees. The top of the height and northern slope is covered with a dry

pasture, while the southern slope is covered with remnants of steppe vegetation of the pontic type. The xerothermic vegetation is differentiated into five communities: *Koelerio-Festucetum sulcatae*, *Sisymbrio-Stipetum capillatae*, *Thalictro-Salvietum pratensis*, *Scorzonero-Seslerietum* and *Inuletum ensifoliae*; some characteristic plants are *Stipa pennata*, *Adonis vernalis*, *Linum hirsutum*, *Brunella grandiflora*, *Salvia* sp. and *Teucrium* sp. (Kostrowicki & Nast 1952, Kostrowicki 1954).

We detected and recorded songs of *C. podolica* by various methods. For sensitive detection of high pitched sounds we used in this study an ultrasonic microphone (Pettersson) mounted on a Telinga parabola (parabola diameter 57 cm) and connected to the ultrasonic detector Pettersson D-200 in combination with a DAT recorder Sony TCD-D10 and a Solid State recorder Marantz PMD670.

The standard recordings in the human sonic range were made using two Telinga microphones, a Telinga Pro 5 stereo and a Telinga Pro Science (parabola diameter 57 cm) in connection with a DAT recorder Sony TCD-D10 and a Solid State recorder Marantz PMD670.

The recordings were transferred to the hard disk of a G4 Macintosh computer. Software used for viewing, editing and analyzing the song signals was Raven 1.2.1 (Cornell Lab of Ornithology).

For statistical evaluation we used the MS Excel program.

The collected specimens are preserved in the collections of the Museum and Institute of Zoology of the Polish Academy of Sciences (MZPW), Poland and in the collection of the Slovenian Museum of Natural History (PMSL), Ljubljana, Slovenia. All sound recordings are stored in the Sound archive of the Slovenian Museum of Natural History. Selected samples are available also on the web pages »Songs of the European singing cicadas«: <http://www2.pms-lj.si/european-cicadas/>.

Results

The habitus of a male and a female of *C. podolica* is shown in Fig. 1a. The opercula and tymbal structure are presented in Figs. 1b and 1c. The hatching female with exuvia and male and female in copulation are shown in Figs. 1d and 1e. Fig. 1f shows a typical habitat in Krzyżanowice Dolne.

The calling song consists of sequences of one type of phrase (Figs. 2, 5a). The duration of the phrases is 3.3 ± 0.9 s (Table 1, Fig. 3a). Each phrase is formed from two subphrases, which are on average of equal duration. First subphrase consists of a series of short echemes (SE subphrase), followed by one long echeme (LE subphrase). The duration of SE subphrase is 1.6 ± 0.6 s (Fig. 3b) and consists of a fast repetition of SE with median count of 19 and interquartile distance of 10 (Fig. 3d). The repetition frequency of SE is approximately 12 ± 1 Hz. The duration of SE is 16.9 ± 3.5 ms (Fig. 3e), and the mean interval between them is 69.6 ± 10.1 ms (Fig. 3g). The first SE in a phrase is shorter (duration 10.5 ± 3.9 ms, Fig. 3f) and

the following interval is longer (72.7 ± 9.8 ms, Fig. 3h), while the last SE in a subphrase preceding LE is longer (20.4 ± 4.0 ms, Fig. 3f), and the interval preceding last SE is shorter (42.7 ± 11.1 ms), and the interval between last SE and LE is even shorter (22.7 ± 9.3 ms; Fig. 3h). The duration of LE is 1.6 ± 0.6 s (Fig. 3c). A new phrase begins after a pause lasting 641 ± 574 ms.

In front of a regular phrase of the calling song there is occasionally an introductory phrase with a long sequence of SE (duration up to 10 s), which goes over into a regular phrase without a significant pause.

The spectrum of these acoustic signals includes frequencies from about 7.5 to 20.5 kHz with 3 to 5 more or less prominent peaks (between 9.4 and 15.3 kHz). Most of the rest of the energy is in a broad band from 9.1 ± 0.7 to 15.9 ± 0.9 kHz at -20 dB.

Songs are not easily detectable by the unaided human ear unless at close distance of up to a few meters. Therefore, we used ultrasonic detectors in the field.

The animals sing during daylight from morning till dusk in the grass and other low vegetation.

Altogether we evaluated eight recordings of songs of different animals. The duration of selected sequences for evaluation was from 16 s to 2 min.

At the same locality we also observed courtship, where females produce short clicks (Fig. 4) associated with wing flipping. We evaluated two recordings of songs of different animals. Time parameters of calling and courtship songs are compared in Table 1. The structure of the male courtship song is very similar to the calling song. The phrase period duration is approximately the same (3.3 ± 2.1 s) as in the calling song, but the ratio between SE subphrase and LE subphrase is different. The courtship song SE subphrase is longer (duration 2.1 ± 1.2 s), while the LE subphrase is shorter (1.2 ± 1.1 s) than in the calling song. The repetition frequency of the last 10 SE preceding LE is also higher (14 ± 1 Hz). The male LE subphrase is followed with 1 to 12 female short clicks (Fig. 4). The delay of female response is 686 ± 250 ms (range 312-1006 ms, N=28) from the beginning of male LE and 147 ± 48 ms (range 24-244 ms, N=28) from the end of male LE. A new male phrase begins after a pause lasting 641 ± 329 ms.

In general the phrases in the male song are longer (longer SE subphrase and longer LE subphrase) in the presence of the female. If the male song is followed by female response (after male LE subphrase), the phrases can be dramatically shortened (Fig. 4). If there is no female response, the phrases are prolonged again.

Unfortunately, we could not study in detail the click production of females, but there is no doubt that it is in synchrony with wing movements.

Discussion

Cicadetta podolica is a steppe pontic species, which has been described from south Podolia (= west Ukraine) by Eichwald (1830). The morphological characteristics, ecology and geographical distribution were reviewed recently by Schedl (1986).

On June 24th and 25th, 2003 and on the same dates in 2005 we visited the steppe area near Krzyżanowice Dolne, known locality for *C. podolica* (Kostrowicki & Nast 1952, Kostrowicki 1954, Schedl 1986). In the year 2003 we recorded only a song of one animal (June 24th), due to unsuitable weather conditions and very strong wind. On June 24th and 25th, 2005 we registered a population of *C. podolica* on the southern slope of the area. We collected both males and females, recorded male calling and courtship songs, as well as female response, found the exuviae and observed hatching female (Fig. 1d) and copulating pairs (Fig. 1e).

On June 25th, 2005 we also visited some neighbouring xerothermic steppe localities (i.e. steppe Nature Reserves »Przêclin« and »Góry Wschodnie« [rezerwat stepowy »Przêclin« and rezerwat stepowy »Góry Wschodnie«] near the village Chotel Czerwony near Wičlica) from where *C. podolica* was also reported, but we did not detect any cicada.

According to morphological, bioacoustic and genetic characteristics *C. podolica* belongs to the *C. montana* complex (Gogala & Trilar 2004, Gogala 2006). All other species of this complex, i.e. *C. montana* s. str., *C. brevipennis*, *C. macedonica*, *C. fangoana*, *C. cerdaniensis* and *C. cantilatrix*, are morphologically very similar and can be distinguished with certainty only by the species-specific song patterns or/and molecular characters (Gogala & Trilar 2004, Gogala 2006, Sueur & Puissant 2007b). *Cicadetta podolica* is the only species of this complex, which can easily be separated from the others on the basis of morphological characters (i.e. dark brown infuscations on the apex of front wings; Fig. 1a), as well as song characteristics (Fig. 5).

Characteristics of the calling song of *C. montana* s. str. are the long phrases of buzzing sound, slowly increasing in intensity, which rapidly stops after about a minute (Fig. 5g, Gogala 2002, Gogala & Trilar 1999, 2004, Trilar & Holzinger 2004, Gogala 2006, Sueur & Puissant 2007a).

The calling song of *C. brevipennis* is characterized by a repeated pattern of one long echeme followed by a short one (Fig. 5f, Boulard 1995 – under the name *C. montana*, Gogala & Trilar 1999, 2004, Trilar & Holzinger 2004, Gogala 2006, Trilar et al. 2006a).

The calling song of *C. fangoana* from Corsica starts with a series of a few pulses followed by one long echeme and ends with a series of a few pulses. This pattern is repeated after a short pause (Fig. 5e, Boulard 1976).

The typical calling sequence of *C. cerdaniensis* from Pyrénées includes three phrases. The short echemes in the first and third phrase are pulse like, the second phrase comprises double echemes with the initial low intensity part and ending with the short high intensity pulse. The repetition rates of short echemes in first and second phrase are approximately the same, while in the third phrase the repetition rate of short echemes is five times higher (Fig. 5d, Puissant & Boulard 2000, Sueur & Puissant 2007b).

The calling song of *C. cantilatrix* consists of similar sequences following each other, lasting from less than a minute to a few minutes. The sequence comprises double echemes like *C. cerdaniensis* with the initial low intensity part and ending with the short high intensity pulse. At the beginning of the sequence the low intensity

part of echeme is missing or the low intensity part and the high intensity pulse are of equal duration. Later, the duration of low intensity part constantly increases and is longest at the end of the sequence (Fig. 5c, Gogala & Trilar 2004, Hertach 2004, Trilar & Holzinger 2004, Gogala et. al. 2005, Trilar et. al. 2006 - all under the name *C. cerdaniensis*, Sueur & Puissant 2007b).

Recent results of analysis of molecular characters (Chris Simon, Dan Vanderpool & Elizabeth Jacobsen, personal communication) support splitting of *C. cerdaniensis* and *C. cantilatrix* into two species, but on the other hand according to Hertach (2007) in southern Switzerland (Valais and Jura Mountains) males sing similar calling song to *C. cerdaniensis* (sensu Puissant & Boulard 2000). Therefore additional studies are needed.

The calling song of *C. macedonica* comprises phrases formed from two subphrases. The first subphrase consists of a series of short echemes, followed by one long echeme (Fig. 5b, Gogala & Trilar 1999). This looks similar to the *C. podolica* calling song (Figs. 2, 5a), but the time parameters are distinctly different. Details are given in Table 2. *Cicadetta macedonica* inhabits mainly oak forests. Males sing in the trees on prominent branches, but also on isolated smaller trees or bushes or even in the grass of forest clearings, where females gather to find mating partners. *Cicadetta podolica* can be found in steppe habitats, as described before, and the males sing in the grass and other low vegetation, where also females can be found.

Males of *C. podolica* do not have a distinct courtship song, but females produce short clicks during courtship by wing flipping. We can conclude the same from the Jim Grant's recordings of the courtship of *C. montana* s. str. from England (Gogala & Trilar 2004, Gogala 2006). Similar observations were made of courtship in *C. cantilatrix* in »Polana Polichno« Nature Reserve (Poland) (Gogala & Trilar 2004, Trilar et al. 2006b - all under the name *C. cerdaniensis*). Distinct courtship song is described in males of *C. brevipennis* by Puissant (2001 - under the name of *C. montana*). Similar courtship song patterns of the same species have also been recorded in Slovenia (Gogala & Trilar 2004). Courtship song and courtship behaviour of *Cicadetta macedonica* have not been observed yet, despite intensive recording at many localities in Macedonia and northern Greece. Exact observations are needed to clarify this behaviour in all species of *C. montana* group.

During the field work in Krzyżanowice we noticed that *C. podolica* was responding to the male display song of Corn Bunting (*Miliaria calandra* (Linnaeus 1758)) (Fig. 6). The male of this bird was usually singing at a solitary bush at the lower edge of southern slope with steppe vegetation. The two seconds long display song of *Miliaria calandra* is very characteristic and starts with a few short repeating whistles, which are accelerating in multipart, dissonant squeaky, and ending jingling. After a 10 to 15 seconds long interval the strophe is repeated again. In the radius of 30 meters around singing *Miliaria calandra* the males of *C. podolica* stopped singing in the response to the bird song. After two to four times longer pause between the phrases as usual, the males of *C. podolica* started singing again in usual rhythm.

After a few such disturbances males of *C. podolica* stopped singing and flew away to another singing position.

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Table 1: Time parameters of calling and courtship song of *Cicadetta podolica* (Eichwald 1830). In each parameter means, standard deviations, minimum and maximum are shown.

	Calling song	Courtship song
Phrase duration	3.3 ± 0.9 s (range 1.2-5.2 s, N=75)	3.3 ± 2.1 s (range 1.0-7.9 s, N=39)
SE subphrase duration	1.6 ± 0.6 s (range 0.7-2.9 s, N=75)	2.1 ± 1.2 s (range 0.4-4.7 s, N=39)
LE subphrase duration	1.6 ± 0.6 s (range 0.4-2.6 s, N=91)	1.2 ± 1.1 s (range 0.2-3.4 s, N=44)
No. SE in a phrase	median 19, interquartile distance 10 (range 9, 1 st quartile 14, 3 rd quartile 24, max. 35, N=75)	median 32, interquartile distance 34.5 (range 6, 1 st quartile 17.75, 3 rd quartile 52.25, max. 278, N=44)
SE repetition frequency	12 ± 1 Hz (range 10-14 Hz, N=82)	14 ± 1 Hz (range 11-17 Hz, N=45)
1 st SE duration	10.5 ± 3.9 ms (range 4-21 ms, N=91)	10.7 ± 3.4 ms (range 5-15 ms, N=43)
SE duration	16.9 ± 3.5 ms (range 4-28 ms, N=2079)	16.3 ± 3.4 ms (range 6-24 ms, N=1053)
Duration of SE preceding LE	20.4 ± 4.0 ms (range 11-30 ms, N=92)	21.1 ± 5.7 ms (range 11-49 ms, N=43)
Number of female clicks		5 ± 2 (range 1 - 12, N=41)
Intervals after 1 st SE	72.7 ± 9.8 ms (range 50-110 ms, N=90)	95.5 ± 78.6 ms (range 46-389 ms, N=43)
Intervals between SE	69.6 ± 10.1 ms (range 28-165 ms, N=188)	63.6 ± 8.2 ms (range 16-99 ms, N=994)
Interval preceding last SE	42.7 ± 11.1 ms (range 17-89 ms, N=92)	41.4 ± 17.4 ms (range 10-118 ms, N=42)
Interval preceding LE	22.7 ± 9.3 ms (range 6-44 ms, N=92)	20.8 ± 10.9 ms (range 6-64 ms, N=42)
Pause between phrases	641 ± 574 ms (range 201-3168 ms, N=90)	641 ± 329 ms (range 180-1459 ms, N=48)

Table 2: Time parameters of calling song of *Cicadetta macedonica* (Schedl 1999) and *Cicadetta podolica* (Eichwald 1830). In each parameter means and standard deviations are shown.

	<i>Cicadetta macedonica</i>	<i>Cicadetta podolica</i>
phrase duration	1.4 s – 7.1 s (3.3 ± 1.4 s)	1.2 s – 5.2 s (3.3 ± 0.9 s)
SE subphrase duration	3.1 ± 1.4 s	1.6 ± 0.6 s
LE duration	0.19 ± 0.05 s	1.6 ± 0.6 s
SE : LE subphrase duration	15:1	1 : 1
SE duration	29.5 ± 5.4 ms	16.9 ± 3.5 ms
SE-SE intervals duration	72.5 ± 6.8 ms	69.6 ± 10.1 ms
SE-LE interval duration	21.2 ± 9.1 ms	22.7 ± 9.3 ms
Number of SE in a phrase	31 ± 14	19 ± 6.5
SE repetition frequency	11 ± 1 Hz	12 ± 1 Hz

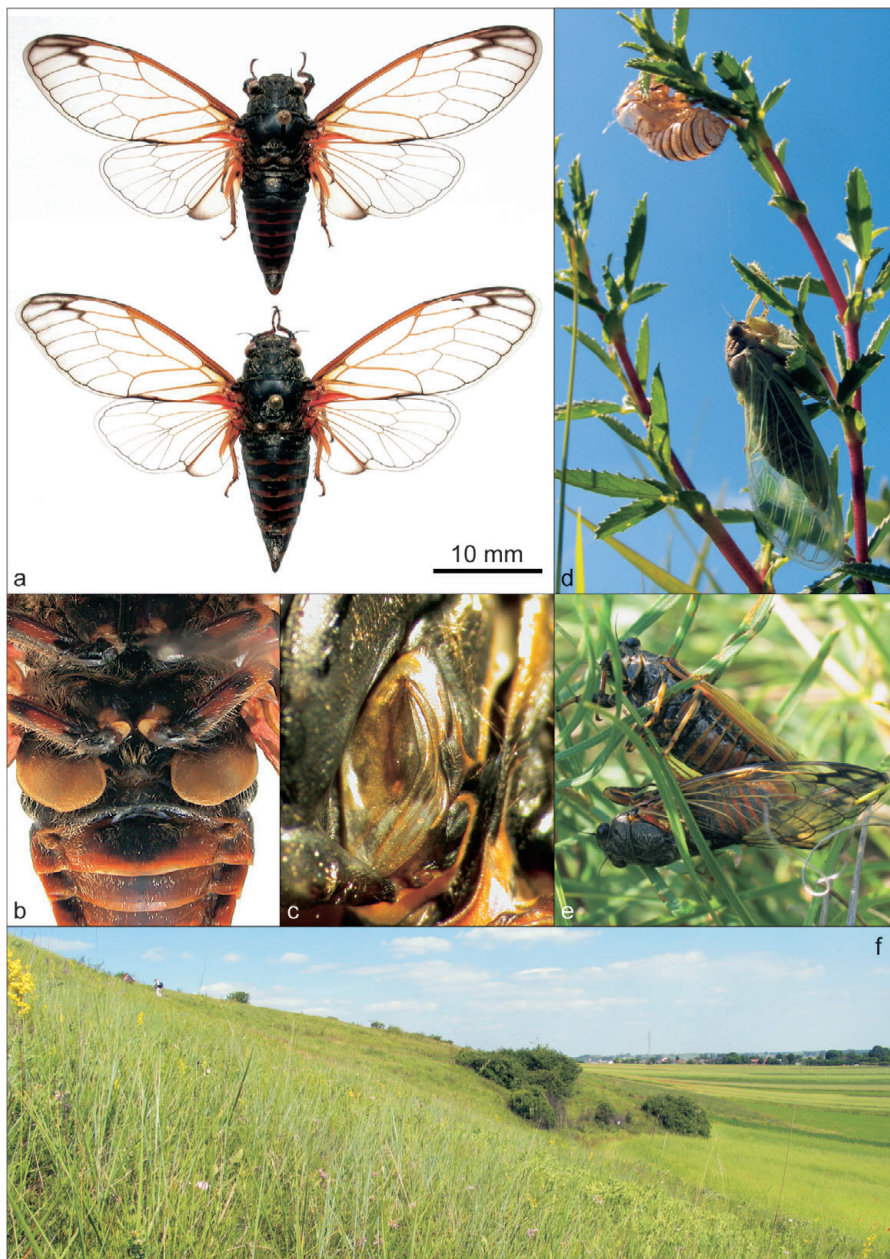


Fig. 1: Some morphological characteristics of *Cicadetta podolica* (Eichwald 1830). a) specimens from the collection, above male, below female; b) opercula; c) right tymbal, right – anterior side, top – dorsal side; d) hatching female with exuvia; e) male and female in copulation; f) typical habitat in Krzyzanowice Dolne.

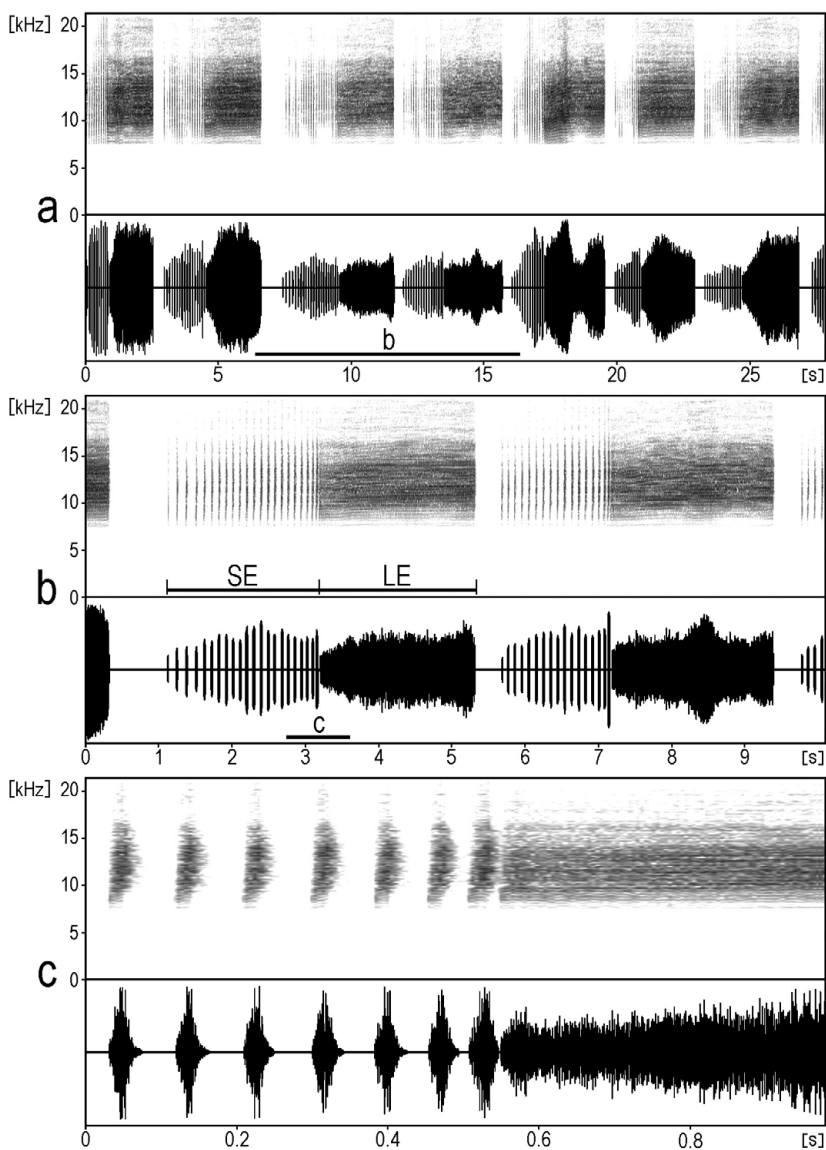


Fig. 2: Calling song of *Cicadetta podolica* from Krzyżanowice Dolne. a) spectrogram and oscillogram of a typical song, b – part enlarged in section *b* of the figure; b) spectrogram and oscillogram of two phrases, SE – series of short echemes (SE subphrase), LE – long echeme (LE subphrase), c – part enlarged in section *c* of the figure; c) spectrogram and oscillogram of the end of SE and beginning of LE. Since the microphone was not calibrated, there is no scale on oscillogram Y-axis (valid also for Figs. 4, 5 and 6).

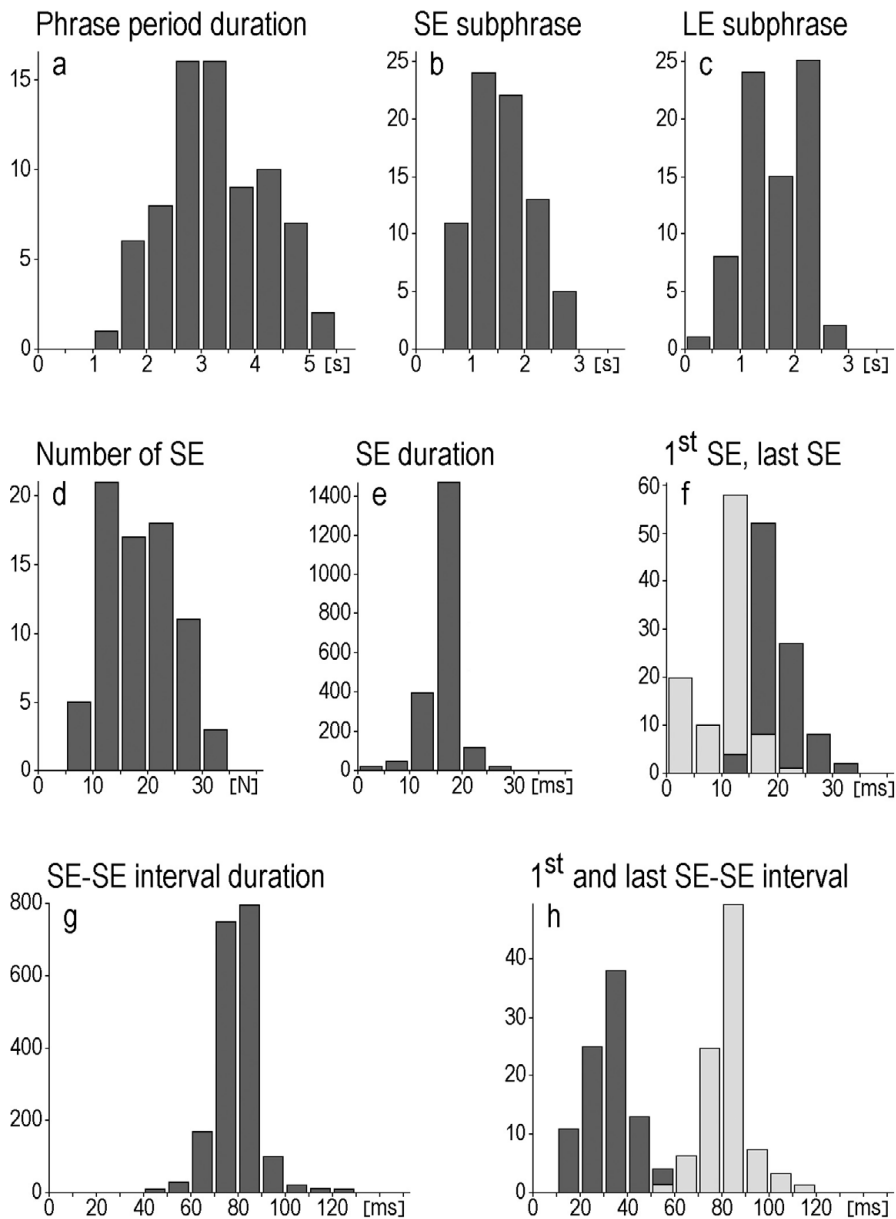


Fig. 3: Time parameters of the calling song of *Cicadetta podolica*: a) phrase duration; b) SE subphrase duration; c) LE subphrase duration; d) number of SE in a phrase; e) SE duration; f) 1st SE duration (light grey) and last SE duration (dark grey); g) duration of interval between SE; h) duration of interval between last SE and LE (dark grey) and the duration of interval after 1st SE (light grey).

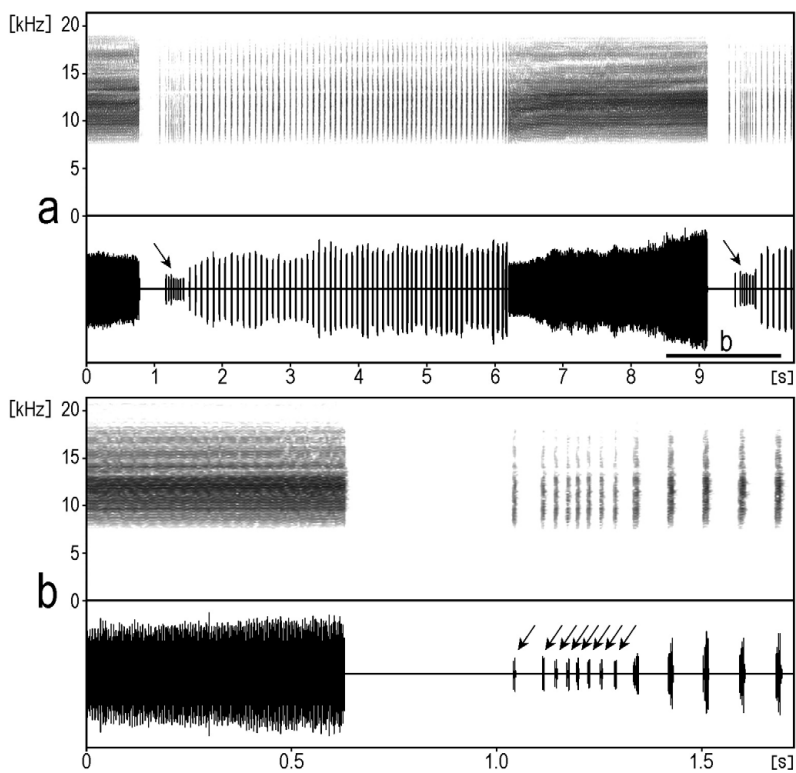


Fig. 4: Courtship song of *Cicadetta podolica* from Krzyżanowice Dolne. a) spectrogram and oscillogram of one phrase with female wing clicks (arrows), b – part enlarged in section *b* of the figure; b) spectrogram and oscillogram of the end of the long echeme (LE subphrase) with female wing clicks (arrows) and beginning of series of short echemes (SE subphrase).

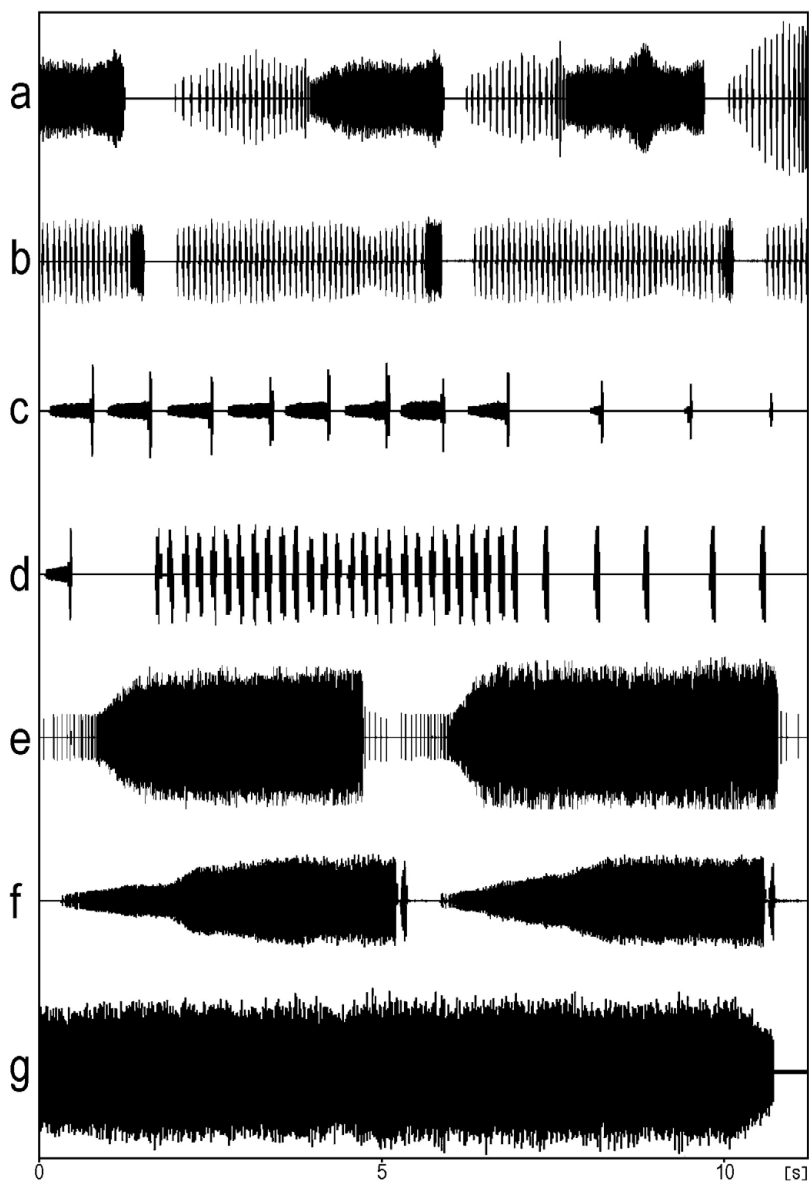


Fig. 5: Comparison of song patterns as oscillograms in the same time scale. a) *Cicadetta podolica* from Krzyżanowice Dolne, Poland; b) *C. macedonica* from Galičica Mountain, Macedonia; c) *C. cantilatrix* from »Polana Polichno« Nature Reserve, Poland; d) *C. cerdaniensis* from Pyrénées, France; e) *C. fangoana* from Corsica, France; f) *C. brevipennis* from Negru Vodă, Romania; g) *C. montana* from Mt. Stražar near Ig, Slovenia.

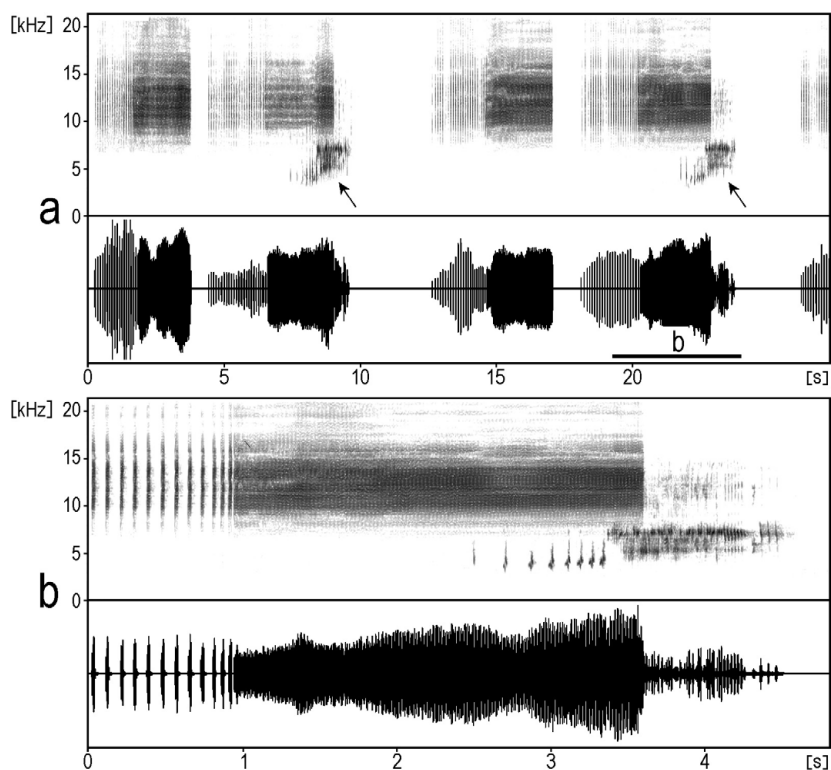


Fig. 6: Acoustic interaction between singing males of *Cicadetta podolica* and the bird *Miliaria calandra*. a) spectrogram and oscillogram of calling song of *Cicadetta podolica* and display song of *Miliaria calandra* (arrow); b – part enlarged in section b of the figure; b) spectrogram and oscillogram of the end of the phrase of singing male of *Cicadetta podolica* and display song of a male of *Miliaria calandra*.