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Acoustic signals of the bush-crickets of tribe Barbitistini (Orthoptera, Tettigoniidae, Phaneropterinae) from Eastern Europe and Caucasus. II. *Leptophyes* Fieber, 1853, *Euconocercus* Bey-Bienko, 1950, *Barbitistes* Charpentier, 1825, *Polysarcus* Fieber, 1853

Акустические сигналы кузнечиков трибы Barbitistini (Orthoptera, Tettigoniidae, Phaneropterinae) восточной Европы и Кавказа. II. *Leptophyes* Fieber, 1853, *Euconocercus* Bey-Bienko, 1950, *Barbitistes* Charpentier, 1825, *Polysarcus* Fieber, 1853

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KEY WORDS. Tettigoniidae, Barbitistini, *Leptophyes, Euconocercus, Barbitistes, Polysarcus*, acoustic signals.

КЛЮЧЕВЫЕ СЛОВА. Tettigoniidae, Barbitistini, *Leptophyes, Euconocercus, Barbitistes, Polysarcus,* акустические сигналы.

ABSTRACT. Temporal pattern and frequency spectra of the songs and stridulatory files of species belonging to genera of *Leptophyes, Euconocercus*, *Barbitistes* and *Polysarcus* of phaneropterine bush-crickets of the tribe Barbitistini from Eastern Europe and Caucasus are given. Acoustic signals of eastern European and Caucasian species with other European species of *Barbitistes*, *Polysarcus* and *Leptophyes* are compared.

РЕЗЮМЕ. Приводятся данные об амплитудно-временных и частотных характеристиках звуковых сигналов и стридуляционных жилках листовых кузнечиков трибы Barbitistini из родов *Leptophyes, Euconocercus*, *Barbitistes* и *Polysarcus* из Восточной Европы и с Кавказа. Проводится сравнение их сигналов со звуками других европейских видов.

Phaneropterinae including more than 2000 species is the largest subfamily of Tettigoniidae. Sometimes this taxon is considered as family. Most of species are distributed in the Palaearctic. The high biodiversity of these bush-crickets is observed in the Mediterranean region. Males of all known Phaneropterinae species produce calling songs and females in many species are capable to respond with sounds. The results of the first investigations of acoustic communication of the palaearctic species were published in 1977–1981 [Zhantiev & Dubrovin, 1977; Zhantiev, 1981]. Since then acoustic signals of many Mediterranean species are carefully studied [e.g. Heller, 1988; Heller, 1990; Ragge & Reynolds, 1998; Sevgili et al., 2010; Chobanov et al., 2013], but songs of species from the South of the East Europe, Caucasus and Transcaucasia are less known. Sound signals of only a few phaneropterine bush-crickets are described [op. cit.; Zhantiev & Korsunovskaya, 1986, 1990, Korsunovskaya, 2015]. We suppose that it is interesting and useful to compare the comprehensive studied songs of specimens from West European populations (e.g. *Leptophyes albovittata* (Kollar, 1833) and *Barbitistes constrictus* Brunner von Wattenwyl, 1878) with corresponding data concerning eastern European specimens of these species. Songs of *Euconocercus iris* Bey-Bienko, 1950 and *Polysarcus zacharovi* (Stshelkanovtzev, 1910) were investigated at the first.

Material and methods

Laboratory tape-recordings of the songs of captured insects were made with use 1/4 *inch* Bruel&Kjaer 4135 or MK 301 RFT microphones with linear characteristics in the range 0.02–100 kHz, microphone ampliphier 2604 Bruel&Kjaer or 00 017 RFT and modified tape recorder "Yupiter-202 Stereo" with linear characteristic in the range 0.063–70 kHz. Songs of several species were recorded with the use of the mentioned microphone amplifiers connected with A-D converter E14–440 (L-card, Russia) of computer. Most of songs were stored on magnetic tape and then were digitized (sampling rate are 30.3; 58.8; 142.8 or 200 kHz) and analyzed using the computer program TurboLab 2.4. All power spectra were obtained with linear amplitude scale.

All laboratory experiments were made in anechoic chamber in darkness at 22–27°C. Microphone was positioned at 8–10 cm of singing male. Recordists — O.Korsunovskaya and R.Zhantiev.

Electronograms of stridulatory files (*pars stridens*) were obtained by use of scanning electron microscopes S-405A and CamScan S-2.

Terminology

For the description of songs the following terminology is used:

pulse — sound produced by closing forewing-strokes at stridulation [= *hemisyllable* of Ragge & Reynolds, 1998; Heller et al., 2004];

series [= *echemes* of Ragge & Reynolds, 1998] — the first order assemblage of pulses;

click — very fast sound impulse sometimes following pulse. In some species it is the obligatory second component of the song.

tooth-impact [= *impulse* of Heller et al., 2004] — fast sound impulse arising during contact of single tooth of *pars stridens* with *plectrum.*

Results and discussion

Leptophyes albovittata (Kollar, 1833)

Distribution area of this species is much wider than that of other congenerics [Kleukers et al., 2010]. Now is known that only *L. albovittata* occurs in Eastern part of Europe and Caucasus.

LOCALITIES: Transcarpatian: Uzhgorod distr., vil. Vyshka; Central Russia, Kursk distr.: Centralno-Chernozemny reserve.; Ciscaucasia, near Grozny.

SONG. Males produce calling song (Figs 1–2, 5) and perhaps aggressive ones (Figs 1–4) when two males are nearby. Females respond to male sounds by short click and stay at the same position as long as male finds it after her sound response. The selectivity of female reaction is low, any relatively short sound is able to elicit female click. It should be noted that the beginning of the male song causes the reply [Zhantiev & Korsunovskaya, 1986].

Calling song of the Eastern European specimens represented by a short pulse containing up to 19 tooth-impacts (Figs 2–3). Sometimes males are able to produce more short sounds with 4–11 tooth-impacts. Such pulses were observed when one male is positioned at the second one (Figs 2–4) and perhaps these sounds can function as an aggressive signal. In some populations male produce two-component song consisting of a simple sound pulse and one (rare two) clicks. The last ones can have different amplitude — very low (Fig. 5) or comparable with main pulse. K.-G. Heller [1988] noticed that very rare in the song of Western European specimens there is distinguishable crescendo series of weak tooth-impacts following the pulse. Such final series in Eastern European and Ciscaucasian specimens did not observed. Duration of the pulse in different studied population is very similar: 27.0±0.5 ms (22°C, SD=2.0; Transcarpatian specimen) and 28±3 ms (SD=11.4, 27°C, Kursk specimen). Pause between pulse and click if present in male song lasts 30.3±0.8 ms (SD=3.2, 22°C, Transcarpatian specimen) and 3.3 to 15 ms (Kursk population, 27 °C). Calling songs of other European congenerics as *Leptophyes punctatissima* (Bosc, 1792), *L. boscii* Fieber, 1853 and *L. discoidalis* (Frivaldszky, 1868) have optional clicks after main fast pulse too [Heller, 1988].

Spectrum of male sounds lies in the band 30–80 kHz. Main peak is near 50 kHz. In some spectra are distinguishable additional periodical peaks (Figs 6–7)

Male *pars stridens* (Fig. 8) contains ca. 60 teeth.

Euconocercus iris Bey-Bienko, 1950

This Caucasian genus is very similar to *Leptophyes* Fieber, 1853 but differs from it by form of base of male cerci and strongly sharpened and elongated genital plate of female.

Only two species in the genus is known. *Euconocercus caucasicus* Bey-Bienko, 1950 occurs in Ciscaucasia (Daghestan), Northern Caucasus (Essentuki), Transcaucasia (Armenia); *E. iris* distributed in SE Azerbaidjan (Lenkoran distr.). The last species is known as a pest subtropical crops.

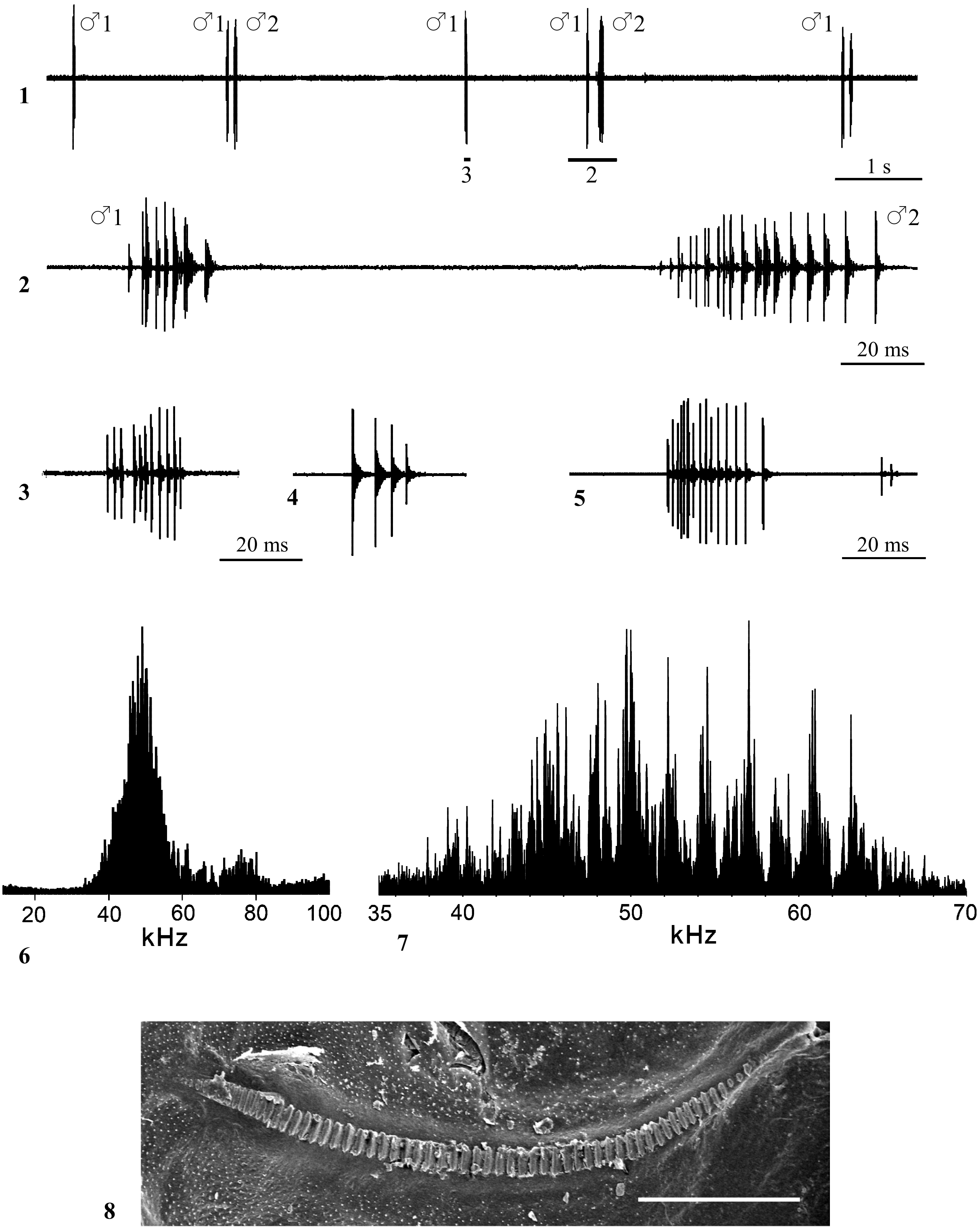
LOCALITY. Males and females were collected in Azerbaidjan, Lenkoran distr., vil. Lerik.

SONG. Males produce two kinds of sounds. The first one is the calling song. It is represented by series followed by one or two clicks (Figs 9–11). Pause between two parts of the song is 111±3 ms (SD=9.8). Each series lasts about 1.4 — 3 sec depending on number of pulses. In our records series contain 30–60 pulses. Calling signals in our experiments were produced irregular or in low rate — about 0.1–0.2 s^{-1}. Pulses last 15–27 ms (mean 20.4±0.5 ms, SD=2.6), intervals between them 24.2±0.5 ms, SD=2.7. Period of pulses increases from the beginning to the end of series from 40 ms to more than 70 ms (mean is 54.4±0.6 ms, SD=5.8). Pulses in the first part of the song consist of 3 to 5–6 tooth-impacts. Second part of the song (clicks) acts as a trigger for female sound reply rare females respond after the first part of the song.

Males during contact with another male produce a song of the second type. These sounds indicate antagonistic relations between males and can be qualified as agressive (or territorial) signals. As a rule these sounds are a pairs (series) of pulses with irregular or more rare regular (with rate about 0.5 s^{-1}) intervals between series (Fig. 12). Duration of pulses is 24.6±0.4 ms (SD=3.4), intervals between pulses last 46.6±0.8 ms (SD=4.3). Periods of tooth-impacts in the pulses of two kind of song are 5.0±0.1 ms and 6.2±0.2 ms, SD=1.2 and 1.6 respectively.

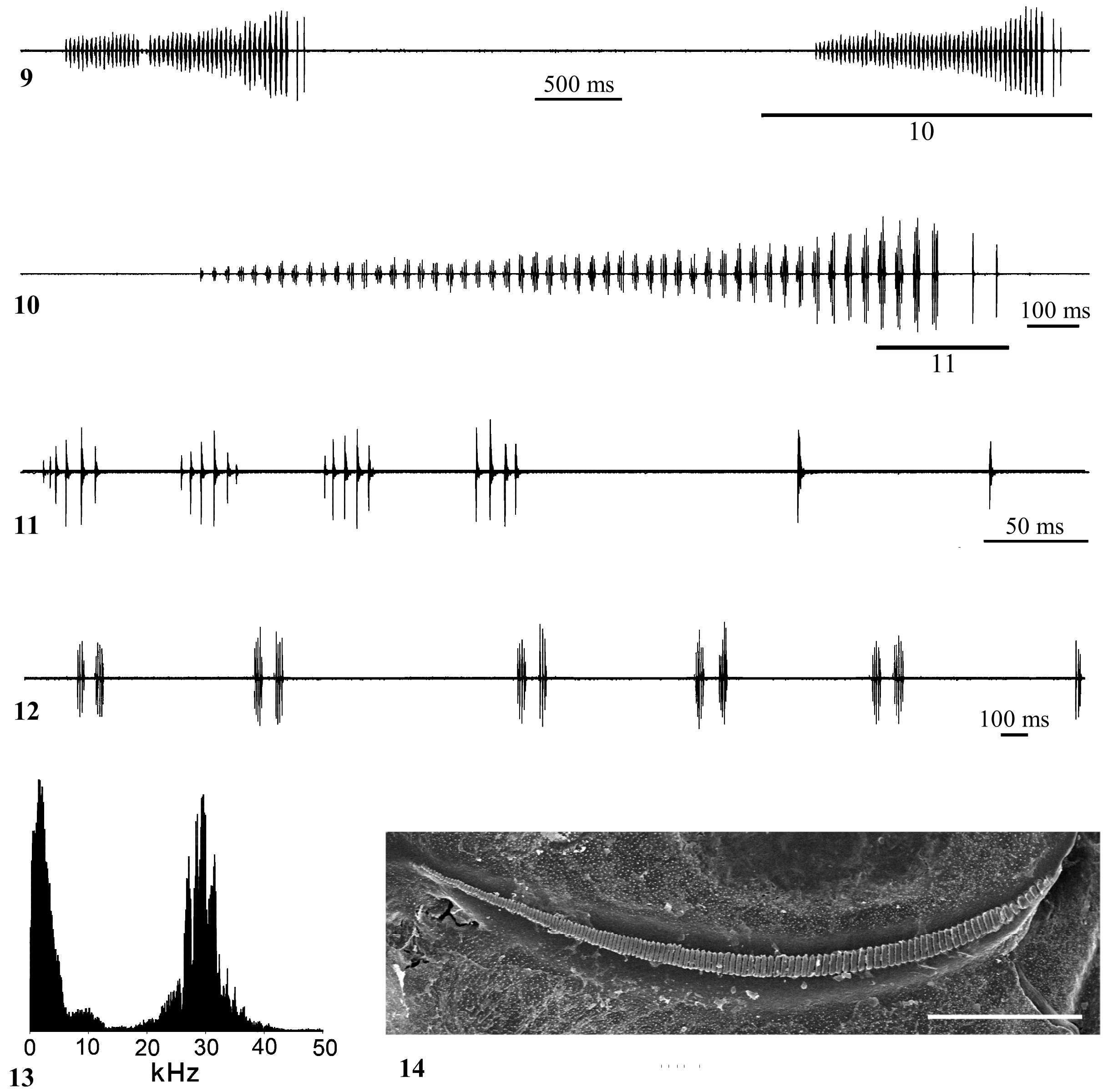
Spectra of the calling song (Fig. 13) and the song of the second type are almost identical — main high frequency components lie in the band 20–40 kHz with dominant amplitudes near 30 kHz.

Stridulatory file is weakly curved and contains numerous teeth of exponentially decreasing size and density to the medial edge (Fig. 14).



Figs 1–8. *Leptophyes albovittata*: 1–5 — oscillogrms of a male songs at different velocities; 6–7 — frequency spectrum of calling song in linear scale; 1–3 — sounds of two alternatively stridulating males (27°C, Kursk distr.); 4 — aggressive sound of a male (22°C, Kursk distr.); 5–6 — calling song (22°C, Uzhgorod distr); 8 — male stridulatory file of *Leptophyes albovittata* (scale 400 mkm).

Рис. 1–8. *Leptophyes albovittata*: 1–5 — осциллограммы акустических сигналов самцов при разных скоростях развёртки; 6–7 — амплитудно-частотный спектр призывного сигнала; 1–3 — звуки двух альтернирующих самцов (27°C, окр. Курска); 4 — звук агрессии самца (22°C, окр. Курска); 5–6 — призывный сигнал (22°C, окр. Ужгорода); 8 — стридуляционная жилка самца (масштаб 400 мкм).



Figs 9–14. *Euconocercus iris*: 9–11 — oscillograms of male calling song at different velocities, 24°C; 12 — oscillogram of male aggressive sounds at 24°C; 13 — frequency spectrum of the male calling song; 14 — stridulatory file of the male (scale 400 mkm).

Рис. 9–14. *Euconocercus iris*: 9–11 — осциллограммы призывного сигнала самца при разных скоростях развёртки, 24°C; 12 — осциллограмма сигнала агрессии самца при 24°C; 13 — амплитудно-частотный спектр призывного сигнала самца; 14 — стридуляционная жилка самца *Euconocercus iris* (масштаб 400 мкм)

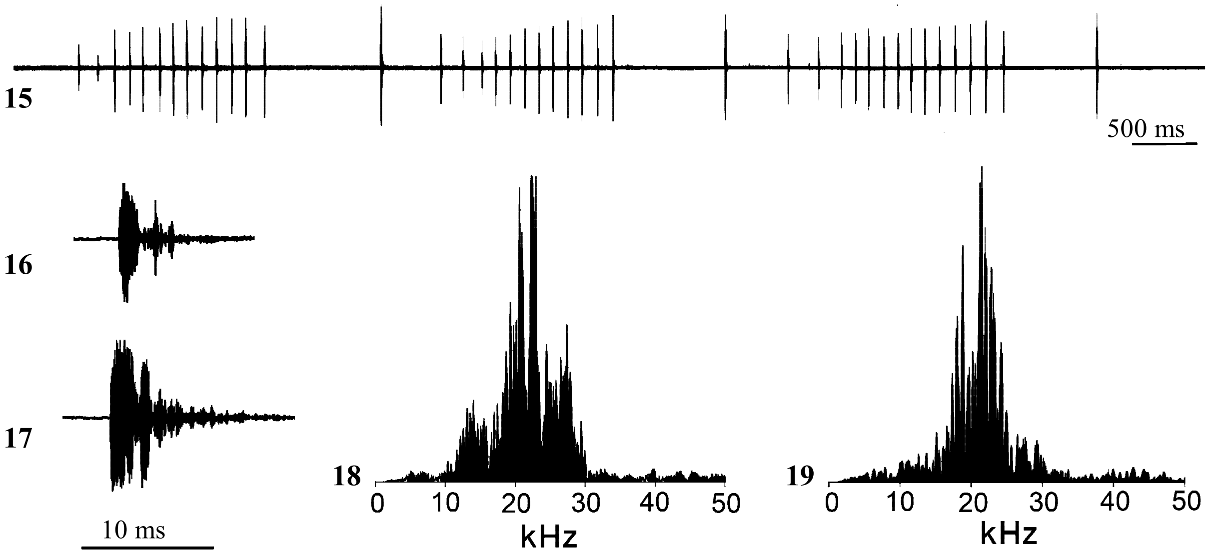
Barbitistes constrictus
Brunner von Wattenwyl, 1878

This species is distributed in Central and Eastern Europe up to Leningrad and Novgorod vicinities in the North.

LOCALITIES. Central Russia, near Moscow: vil. Iljinskoe; vil. Novy Ierusalim.

SONG of males is represented by sequence of 6–14 fast pulses and loud one or two final clicks following after pause of 772±12 ms (SD=40.5) (Figs 15–17). Sometimes after this click there are one or two weak tooth-impacts. Similar temporal pattern is observed in two other European species: *Barbitistes ocskayi* (Charpentier, 1850) and *B. yersini* Brunner von Wattenwyl, 1878 [Heller, 1988; Stumpner & Meyer, 2001]. In *B. constrictus* of Moscow vicinity duration of pulses in the series is 4–8 ms, final click lasts 10–12 ms, period of the pulses in main part of the series is 115±2 ms (SD=18.8), duration of the whole signal is about 2.5 s, repeating rate is about 0.3 s^{-1} at 23°C.

In male calling song main components of the frequency spectrum lie in the band between 10 and 35 kHz. Dominant frequencies of the pulses in the series can



Figs 15–19. *Barbitistes constrictus*: 15–17 — oscillograms of male calling song of at different velocities, 23°C; 18–19 — frequency spectrum; 15 — three series with final clicks; 16 — one of the pulses of the 1st component of the song; 17 –click after series (2nd component of the song); 18 — pulses from series of calling song; 19 — click after series of calling song.

Рис. 15–19. *Barbitistes constrictus*: 15–17 — осциллограммы призывного сигнала самца *Barbitistes constrictus* при разных скоростях развёртки, 23°C; 18–19 — амплитудно-частотный спектр; 15 — три серии с заключительными щелчками; 16 — один из пульсов I компонента сигнала; 17 — заключительный щелчок (II компонент сигнала); 18 — пульсы из серии призывного сигнала; 19 — щелчок после серии призывного сигнала.

slightly shift from 18 to 24 kHz. There are some additional peaks at 14 or 19 kHz (Figs 18–19). These data coincides with frequency spectra of Serbian specimens [Stumpner & Meyer, 2001].

Male *pars stridens* (Figs 20–21) is almost straight in the lateral and middle part of tegmen and curved to its medial edge. Number of teeth is ca. 70. Shape, size and density of most teeth are almost uniform besides some medial and lateral ones.

Female stridulatory apparatus contains 4 main files with dense teeth and 3–4 veins with more rare teeth in the basal and apical end of the upper part of the lower tegmen (Figs 22–23). The plectrum lies on the underside part of the upper tegmen (Figs 24–25).

Earlier the song of *B. constrictus* specimens was described by Zhantiev and Korsunovskaya [1986] and Heller [1988]. Stumpner and Meyer [2001] worked with specimens reared in laboratory (the origin of insects is not specified). Therefore we can compare the songs of the German (Mittelfranken, Muggendorf) and Eastern European specimens only. Their calling sounds are very similar and differences are only in the number of pulses in the first part of the series. In western specimens this song fragment contains 8–10 pulses and eastern ones — 6–14 pulses. This parameter of male song of Western European specimens reared in a laboratory is up to 15. Data of sound recording of Ukrainian (Kanev) males (recordist K.-G.Heller, database DORSA, tape no. S1/1996A) show that they produce calling song with almost identical to Russian specimens temporal parameters. So number of the pulses in the series is more variable character.

Polysarcus zacharovi (Stshelkanovtsev, 1910)

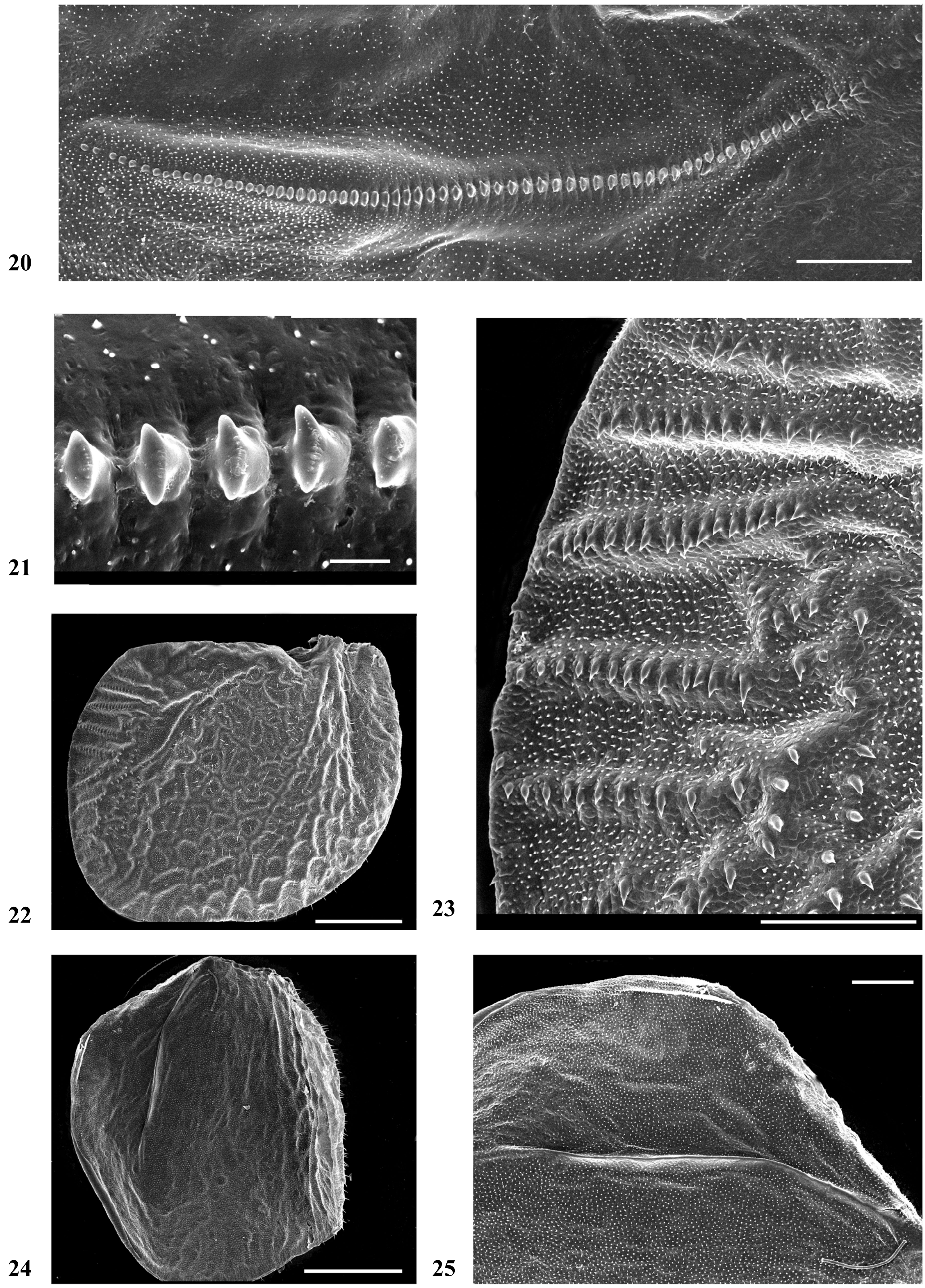
It is one of five known species. Distributed in eastern Ciscaucasia, Caucasus, Transcaucasia, North-Eastern Turkey.

Known outbreaks of this species and correspondingly gregarious and solitary forms. Gregarious form is mostly dark (sometimes almost black) and smaller. During outbreaks *P. zacharovi* can damage mountine pastures and some agricultural crops [Avakian, 1981].

LOCALITY: Northern Ossetia, Northern Ossetian reserve.

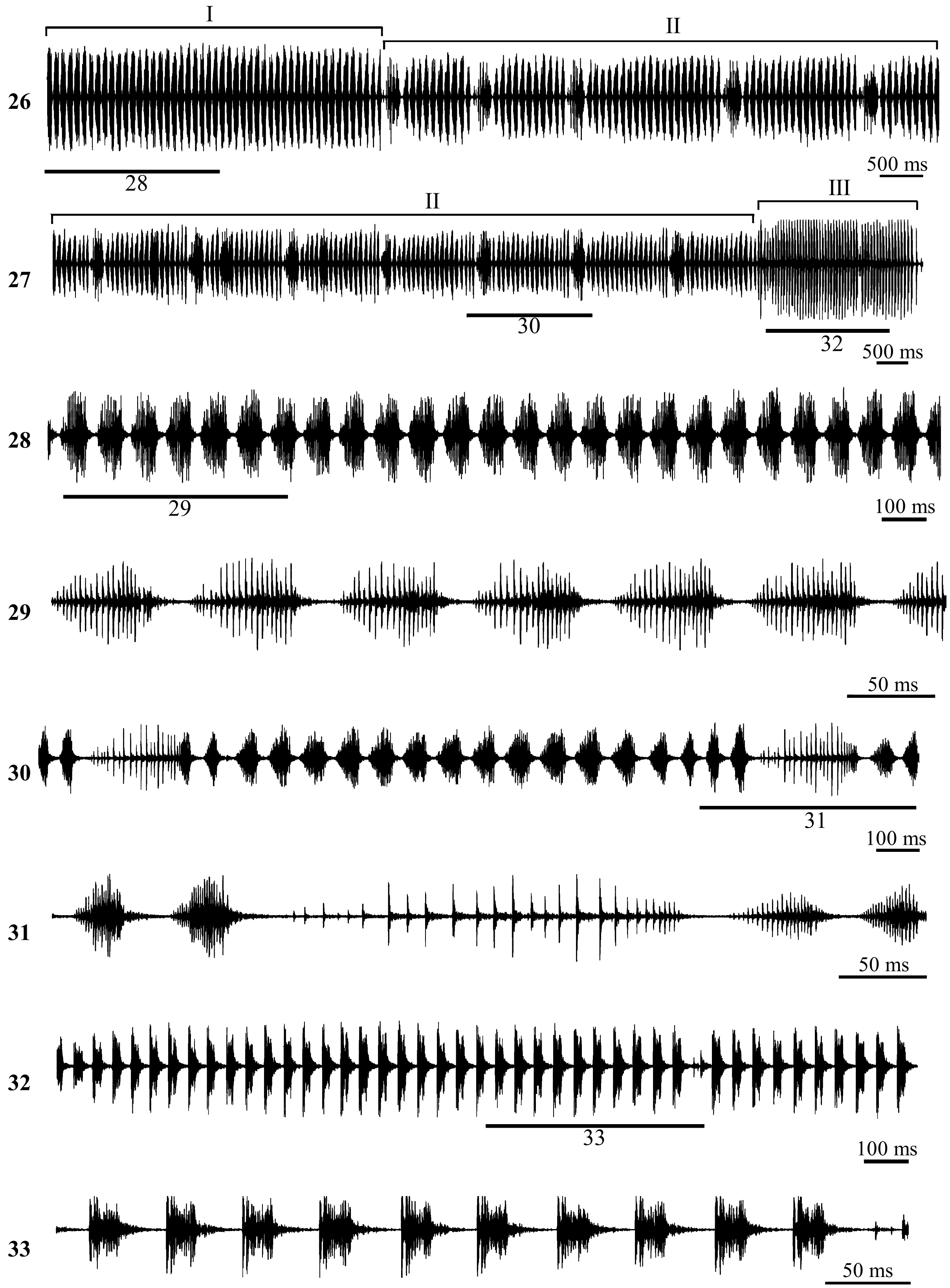
SONG. Males produce very complicated calling sounds (Figs 26–33). That divides into three different alternating parts. The first one is the sequence of the fast pulses. They follow with regular rate (mean period is 42.7±0.2 ms, SD=1.4) and have duration 36.9±0.2 ms (SD=1.5). The second song fragment lasts about 3–4 s That is a sequence of series (of 10–20 pulses) alternating with separate single long pulses. Duration of the fast pulses is 34.7±0.3 ms (SD=2.2), the slow pulses last 116.2±1.8 ms (SD=8). Tooth-impacts rates in the pulses from series and the single ones differ. The third phase of calling song is more loud than the 1st and 2nd parts. It consists of double pulses repeating with period 51.5±0.3 ms (SD=1.4). Mean duration of these pulses is 31.6±0.3 ms (SD=2.3). Definite sequence of different phases in the calling song is absent. Male is able to produce any part of the signal after a silent interval. However males at the initiation of singing as a rule produce calling song in described sequence of its parts.

Temporal pattern of this song is very similar to that of *Polysarcus denticauda* (Charpentier, 1825) described



Figs 20–25. *Barbitistes constrictus*: 20–21 — male stridulatory file; 22 — female right tegmen; 23 — medial veins on the upper surface of the female right tegmen; 24 — female left tegmen with plectrum on the downer surface; 25 — plectrum on the female left tegmen; Sacale bars: 20, 23, 25 — 300 mkm; 21 — 30 mkm; 22, 24 — 1 mm.

Рис. 20–25. *Barbitistes constrictus*: 20–21 — стридуляционная жилка самца; 22 — правое надкрылье самки; 23 — медиальные жилки на верхней поверхности правого надкрылья самки; 24 левое надкрылье самки с плектрумом на нижней поверхности; 25 — плектрум на левом надкрылье самки. Масштаб: 20, 23, 25 — 300 мкм; 21 — 30 мкм; 22, 24 — 1 мм.



Figs 26–33. Oscillograms of calling song of male *Polysarcus zacharovi* at different velocities, 27°C.
Рис. 26–33. Осциллограммы призывного сигнала самца *Polysarcus zacharovi* при разных скоростях развёртки, 27°C.

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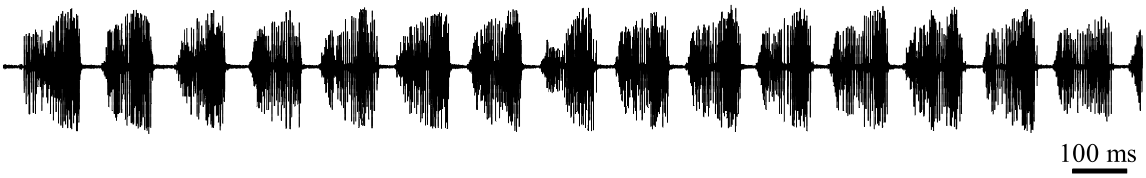

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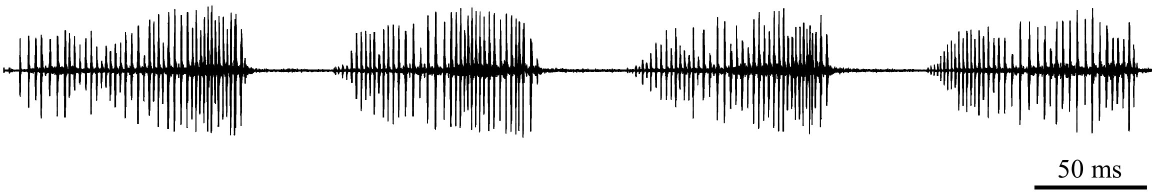
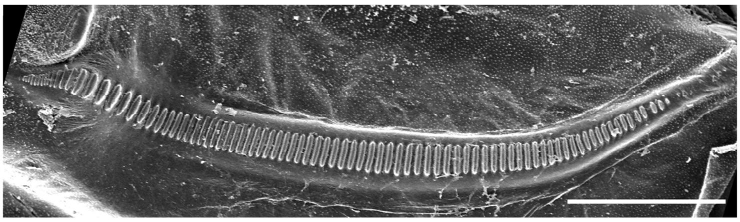


Figs 34–36. Oscillograms of protest sounds of male *Polysarcus zacharovi* at different velocities, 27°C

Рис. 34–36. Осциллограммы сигнала протеста самца *Polysarcus zacharovi* при разных скоростях развёртки, 27°C.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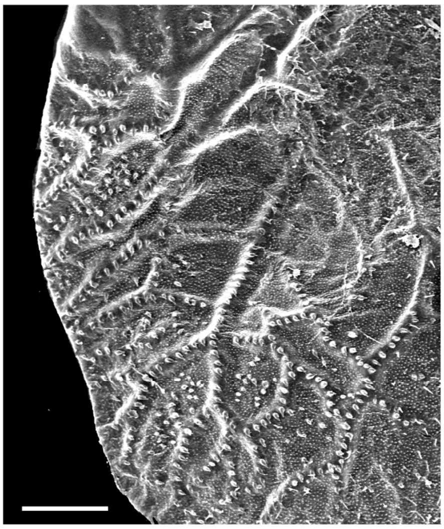
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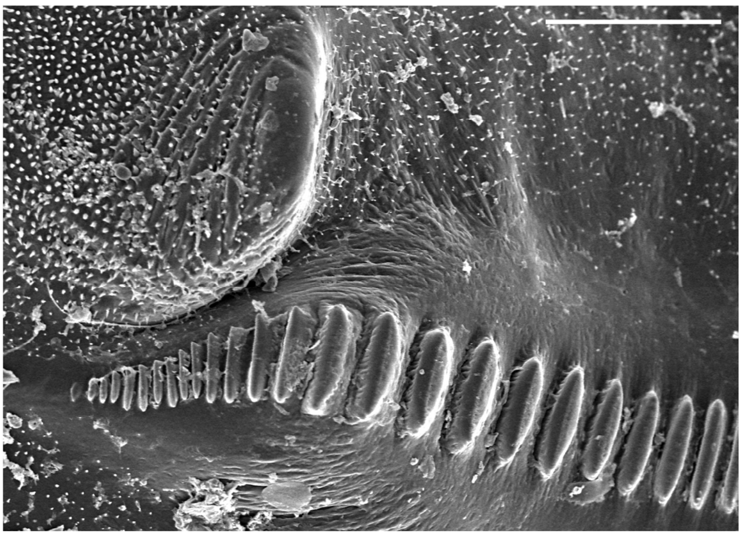
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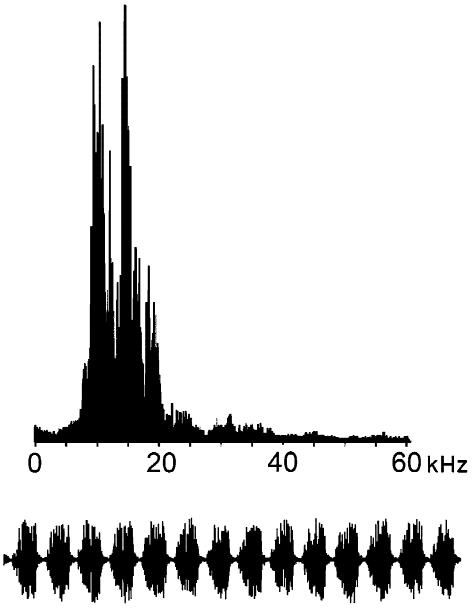
Figs 41–43. *Polysarcus zacharovi*: 41–42 — male stridulatory file; 43 — fragment of the lower female tegmen with stridulatory teeth on the medial veins. Scale bars: 41 — 800 mkm; 42 — 200 mkm; 43 — 500 mkm.

Рис. 41–43. *Polysarcus zacharovi* : 41–42 — стридуляционная жилка самца; 43 — фрагмент нижнего надкрылья самки с зубчиками на медиальных жилках. Масштаб: 41 — 800 мкм; 42 — 200 мкм; 43 — 500 мкм.

from south European populations [Heller, 1988]: calling signal of *P. denticauda* consists of three phases too and the pulses are of the same structure. However pulses in both phases as well as inside of each phase have approximately equal duration and in the first part of the song they have very regular repetition rate. Males of another species (*P. scutatus* (Brunner von Wattenwyl, 1882)) distributed in southern Europe and Northern Africa produce calling song consisting of the 1st and the 2nd phases only [Heller, 1988]. It is known that females of *P. denticauda* can produce similar but less loud complicated song [Faber, 1957].

Besides calling song males *P. zacharovi* produce protest sounds (Figs 34–36). These are trills consisting of uniform pulses with rate 7.5±0.1 s^{-1} (SD=0.4). Duration of the pulses is 102.9±1.4 ms (SD=7.1), intervals



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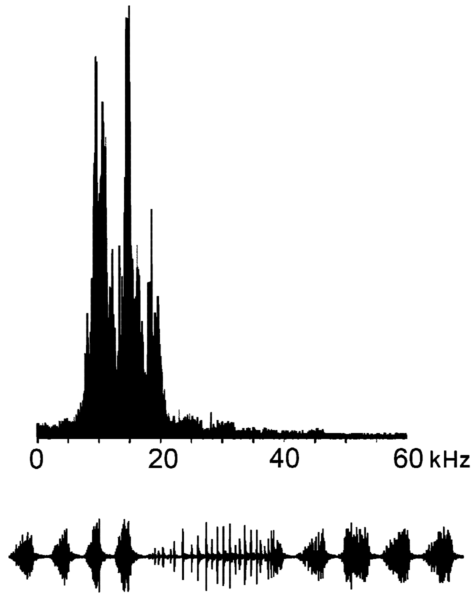

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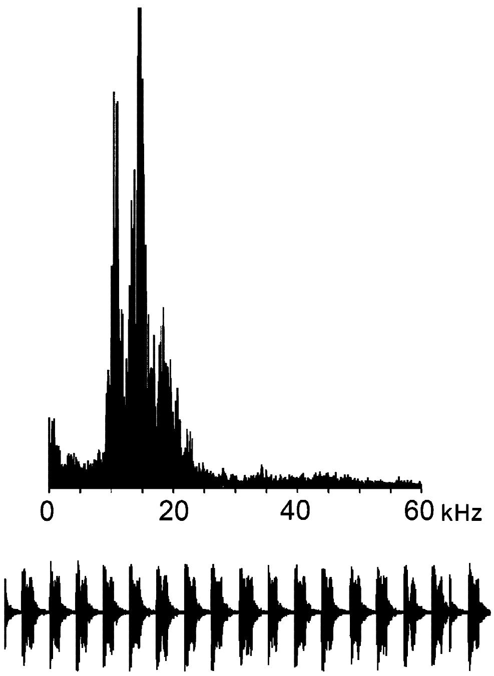

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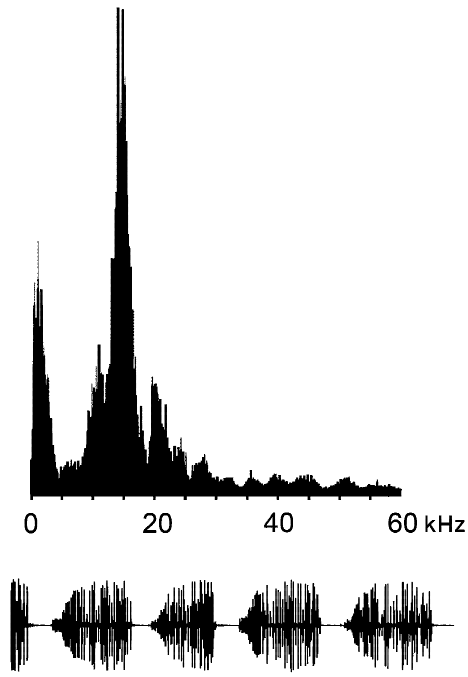

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Figs 37–40. Frequency spectra of different parts of calling song (37–39) and protest sounds (40) of male *Polysarcus zacharovi*. Below different fragments of the songs.

Рис. 37–40. Амплитудно-частотные спектры разных частей призывного сигнала самца (37–39) и звуков протеста (40). Внизу — различные фрагменты сигнала.

between them are 29.6±0.4 ms long (SD=2.1). Duration of these trills depends of disturbance level of the insect.

Frequency spectra of three phases of the calling song are very similar: main components lie between 10 and 20 kHz. Dominant frequencies are at 10 and 15 kHz (Figs 37–39). Spectrum of protest sounds distinguishes from the calling song one by absence of the peak at 10 kHz (Fig. 40).

Weakly curved male *stridulatory file* is shown in Fig. 41. The medial teeth have less density and lie on a concavity. Near there is a big tooth-like structure (Fig. 42). Perhaps it is used in producing of the very loud 3rd phase of the song.

Structure of female *sound apparatus* is similar to the one of another Odonturinae species. Medial parts of a veins on the dorsal surface of the right (lower) tegmen bear teeth (Fig. 43), plectrum lies on the inner surface of the left (upper) tegmen.

Conclusions

The comparison of songs of investigated wide spreading species with known data (op. cit.) concerning other palaearctic phaneropterine bush-crickets shows that temporal characters and frequency spectra in the songs of *B. constrictus* and *L. albovittata* are very similar in different part of distribution area, i.e. its variability is very low. The differentiation of a male song pattern in *Leptophyes* is connected with speed of tegmina closing movement. Additional sound units are the result of pause(s) before final closing of the wings. Appearance of the final click in *L. albovittata*, *L. laticauda* and *L. punctatissima* is optional and we consider that such state of the song is plesiomorphic. However in *L. laticauda* and *L. discoidalis* click or pulses are the result of separate wing movements [Heller, 1988]. The calling song of *E. iris* represented temporal pattern owned *Barbitistes* spp. and *L. discoidalis*. Thus different temporal patterns apparently evolved in different genera repeatedly and independently. Most complicated song in palaearctic Phaneropterinae is produced by *Polysarcus* spp. It is interesting that temporal characters and frequency spectra in congenerics are different but the pattern of the male calling song is very similar in all investigated species.

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