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# THE *CHORTHIPPUS ALBOMARGINATUS*-GROUP (ORTHOPTERA: ACRIDIDAE: GOMPHOCERINAE) IN THE CARPATHIAN BASIN: TRACES OF HYBRIDIZATION BETWEEN *C. ALBOMARGINATUS* AND *C. OSCHEI* IN SOUTHERN SLOVAKIA

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Specimens of the *Chorthippus albomarginatus*-group were studied from two localities near Ardovo in southern Slovakia. We analyzed the male courtship songs and the stridulatory peg number on the inner side of the hind femora. During recording of courtship songs, the stridulatory movements of the hind legs were also recorded. On the basis of the courtship song analysis and the measurements of the peg number, the specimens from both populations are regarded as *C. oschei pusztaensis.* However, deviations in song and leg movements for some specimens are consistent with hybridization between *C. albomarginatus* and *C. oschei*. Our study provides evidence that *C. albomarginatus* and *C. oschei* hybridize in Slovakia.

Key words: *Chorthippus oschei*, courtship song, hybrid zone

## INTRODUCTION

Grasshopper species of the *Chorthippus albomarginatus*-group represent an interesting species complex with quite similar morphology and similar and simple calling songs, but extremely different and complex courtship songs (HELVERSEN 1986, VEDENINA & HELVERSEN 2003, 2009). To date, five European species of this group have been described: *Chorthippus albomarginatus* (DE GEER, 1773), *C. oschei* HELVERSEN, 1986, *C. karelini* (UVAROV, 1910), *C. lacustris* LA GRECA et MESSINA, 1975, and *C. ferdinandi* VEDENINA et HELVERSEN, 2009. Recently, two subspecies of *C. oschei* have been distinguished: *C. oschei oschei* from northern Greece and *C. oschei pusztaensis* VEDENINA et HELVERSEN, 2009 from the Balkans, Hungary, Moldova and Ukraine (VEDENINA & HELVERSEN 2009). *C. albomarginatus* inhabits northern and central Europe, western Siberia and Yakutia (BEI-BIENKO & MISHCHENKO 1951, KOČÁREK *et al.* 2005). *Chorthippus albomarginatus* and *C. oschei pusztaensis* meet in a contact zone about 200 km wide in

the territory of Ukraine and Moldova, where they hybridize (VEDENINA & HELVERSEN 2003). In this hybrid zone, males singing intermediate courtship songs were in the minority, whereas males singing the song of one or another parental type dominated (VEDENINA & HELVERSEN 2003). The hybrid zone between the two species might also exist in Romania (IORGU 2008). In Hungary, identity of the *Chorthippus albomarginatus*-group has been uncertain, and the possibility exists for hybridization. ORCI (2002) found that most of the Hungarian specimens previously treated as *C. albomarginatus* very likely belong to *C. oschei.* Later, VEDENINA and HELVERSEN (2003, 2009) regarded all specimens of the *C. albomarginatus* group from different Hungarian localities as *C. oschei.* In the northern part of the Carpathian Basin (the Czech Republic and Slovakia) *C. albomarginatus* was found very often (KOČÁREK *et al.* 2005, GAVLAS *et al.* 2007). In contrast, occurrence of *C. oschei* was documented rather poorly in this area: LEHMANN and LEHMANN (2007) found only one male of this species, which was at the village of Ardovo in 2006. At the same time, both species were recorded from the Ukrainian Carpathian Mts (VEDENINA & HELVERSEN 2003, 2009). Therefore, we could also expect the occurrence of both species in Northern Carpathian Mts.

In the current paper, we studied two populations of the *C. albomarginatus* group near Ardovo (Slovakia). Our study of the songs and morphology indicates that the specimens from both populations can be regarded as *C. oschei pusztaensis.* These specimens, however, did not completely match *C. oschei*, because some traces of hybridization between *C. albomarginatus* and *C. oschei* were detected.

## MATERIAL AND METHODS

We collected 25 specimens (13 males and 12 females) of the *C. albomarginatus* group at two localities near Ardovo on 11 August, 2008. The first locality is northeast of Ardovo and is designated NE Ardovo (48°32'11.42"N; 20°25'28.13"E). The second locality, which is southwest of the village and is designated SW Ardovo (48°31'38.71"N; 20°24'38.69"E), is the same one where LEHMANN and LEHMANN (2007) collected a single male.

The NE Ardovo locality (0.5 ha) represented a semi-natural mesophytic grassland (alliance *Cynosurion* R. Tx. 1947) with only a pond without standing water. At NE Ardovo, the species composition of Orthoptera was as follows: *Leptophyes albovittata* (KOLLAR, 1833), *Phaneroptera falcata* (PODA, 1761), *Metrioptera roeselii* (HAGENBACH, 1822), *M. bicolor* (PHILIPPI, 1830), *Pholidoptera griseoaptera* (DE GEER, 1773), *Ephippiger ephippiger* (SERVILLE, 1831), *Decticus verrucivorus* (LINNAEUS, 1758), *Gryllus campestris* LINNAEUS, 1758, *Oecanthus pellucens* (SCOPOLI, 1763), *Chrysochraon dispar* (GERMAR, 1834), *Euthystira brachyptera* (OCSKAY, 1826), *Stenobothrus crassipes* (CHARPENTIER, 1825), *S. lineatus* (PANZER, 1796), *Chorthippus brunneus* (THUNBERG, 1815), *C. dorsatus* (ZETTERSTEDT, 1821), *C. parallelus* (ZETTERSTEDT, 1821).

The SW Ardovo locality (2 ha) is a wetland with *Carex* (*Caricion gracilis* ALMQUIST, 1929) growing ca. 0.5 m high in stream alluvium. The following Orthoptera species were abundant: *Cono-*

**Table 1.** Temporal parameters of the courtship songs (mean and minimum-maximum values, N = 3–5 for each individual) and the number of the stridulatory pegs in the males of *Chorthippus oschei* from two localities in Slovakia. Ambient temperature near a singing male is presented.

| Male | Number of A/B pairs between C elements | Relative B/A sound amplitude | Duration of B element [s] | Rate of leg movements in B element (/s) | Duration of A element (s) | Rate of leg movements in A element [/s] | Duration of B1 element [s] | Duration of A1 element [s] | Rate of leg movements in A1 element [/s] | Duration of C element [s] | Temperature [°C] | The peg number |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 (Figs 2a–4a) | 20.3 | 3.4 | 0.59 | 18.97 | 0.60 | 48.17 | 3.17 | 0.28 | 55.17 | 2.29 | 28 | 159 |
| | 17–23 | 3–3.7 | 0.54–0.66 | 18.5–19.4 | 0.56–0.67 | 46.5–50 | 3–3.4 | 0.27–0.28 | 55–55.5 | 2.28–2.3 | | |
| 2 (Figs 2b–4b) | 8.6 | 2.9 | 0.43 | 18.70 | 0.54 | 42.60 | 2.42 | 0.35 | 51 | 1.6 | 27.5 | 170 |
| | 6–14 | 2.8–3 | 0.39–0.46 | 18–19.5 | 0.52–0.57 | 42–43 | 1.7–4 | 0.33–0.37 | 50–52 | 1.55–1.65 | | |
| 3 (Figs 2c–4c) | 33 | 3.67 | 0.46 | 16.70 | 0.55 | 43.13 | 2.83 | 0.27 | 56.33 | 2.36 | 26 | 160 |
| | 29–40 | 3.3–4 | 0.38–0.51 | 16–17.4 | 0.5–0.59 | 42–44.4 | 2.6–3 | 0.25–0.29 | 56–56.5 | 2.27–2.4 | | |
| 4 (Figs 2d–4d) | 18.25 | 2.47 | 0.68 | 18.73 | 0.68 | 46.47 | 4.05 | 0.27 | 51.33 | 2.02 | 28 | 177 |
| | 8–24 | 2.4–2.6 | 0.65–0.73 | 18–19.7 | 0.65–0.72 | 46–47.3 | 3.8–4.2 | 0.25–0.3 | 50–52 | 1.9–2.15 | | |
| 5 | 16 | 1.77 | 0.28 | 31.13 | 0.36 | 68.17 | 1.70 | 0.13 | 91.00 | 1.30 | 33 | 200 |
| | 14–18 | 1.6–1.9 | 0.25–0.3 | 30–31.8 | 0.34–0.38 | 68–68.5 | 1.6–1.8 | 0.13–0.14 | 90–92 | 1.13–1.6 | | |
| 6 | 20.25 | 3.07 | 0.51 | 23.03 | 0.49 | 60.03 | 2.66 | 0.16 | 70.77 | 1.69 | 32 | 175 |
| | 18–23 | 2.7–3.3 | 0.47–0.53 | 22.7–23.4 | 0.49–0.5 | 57–62.5 | 2.58–2.8 | 0.15–0.16 | 69–71.9 | 1.65–1.72 | | |
| 7 | 18 | 2 | 0.38 | 18.30 | 0.36 | 43.27 | 1.86 | 0.35 | 54.20 | 1.76 | 27 | 157 |
| | 16–20 | 1.8–2.4 | 0.37–0.39 | 17.6–18.9 | 0.32–0.4 | 42.8–44 | 1.74–1.93 | 0.34–0.38 | 51.6–56.2 | 1.76–1.77 | | |
| 8 | 14.25 | 3.9 | 0.50 | 17.83 | 0.53 | 42.50 | 3.19 | 0.24 | 60.67 | 2.12 | 28 | 160 |
| | 13–16 | 3.8–4 | 0.43–0.56 | 17.6–18 | 0.53–0.54 | 41.7–43 | 3.03–3.3 | 0.23–0.25 | 60–61 | 2.02–2.17 | | |
| 9 | 18 | 2.5 | 0.59 | 16.47 | 0.66 | 43.63 | 2.87 | 0.24 | 57.30 | 2.44 | 25.5 | 159 |
| | 15–21 | 2–3 | 0.52–0.64 | 16–16.7 | 0.64–0.68 | 42.5–44.4 | 2.8–3 | 0.24–0.25 | 57–57.9 | 2.1–2.86 | | |
| 10 | 25 | 2.93 | 0.37 | 16.80 | 0.43 | 43.90 | 3.40 | 0.27 | 56.47 | 1.84 | 27 | 156 |
| | 23–26 | 2.8–3 | 0.35–0.41 | 16.7–17 | 0.41–0.44 | 43.3–44.7 | 3.39–3.4 | 0.26–0.28 | 55–57.9 | 1.78–1.89 | | |

*cephalus fuscus* (FABRICIUS, 1793), *Metrioptera roeselii*, *Ruspolia nitidula* (SCOPOLI, 1786), *Chrysochraon dispar*, *Chorthippus dorsatus*, *C. paralellus*.

The living specimens were transferred to the laboratory, where the courtship songs of 10 males were immediately recorded. The courtship song was recorded with a microphone (1/2" Bruel & Kjaer) when a male was sitting near a female, and the ambient temperature near each male was determined (Table 1). Simultaneously with sound recordings, the movements of the hind legs during stridulation were recorded with an optoelectronic device (HELVERSEN & ELSNER 1977). A piece of reflecting foil was glued to the distal part of each hind femur and two opto-electronic cameras were focused on the illuminated reflecting dots. Each camera was equipped with a position-sensitive photodiode that converted the upward and downward movements of the hind legs into voltage signals. These signals, together with the sound recordings, were A/D-converted with a custom-built DSP card and stored as dat files. The recordings were analyzed with the Turbolab program. The sampling rate for recording the stridulatory movements and the sound was 40 kHz. Courtship behaviour was also recorded with a digital video camera (Sony DCR-TRV 900 E); the video signals were transferred to a computer for analysis.

In 13 males, the number of stridulatory pegs was determined. Pegs were observed and counted with a MBS-9 light microscope at 8–56× magnification.

**Fig. 1.** Male (on the left) and female (on the right) of *Chorthippus oschei* from locality Ardovo in southern Slovakia

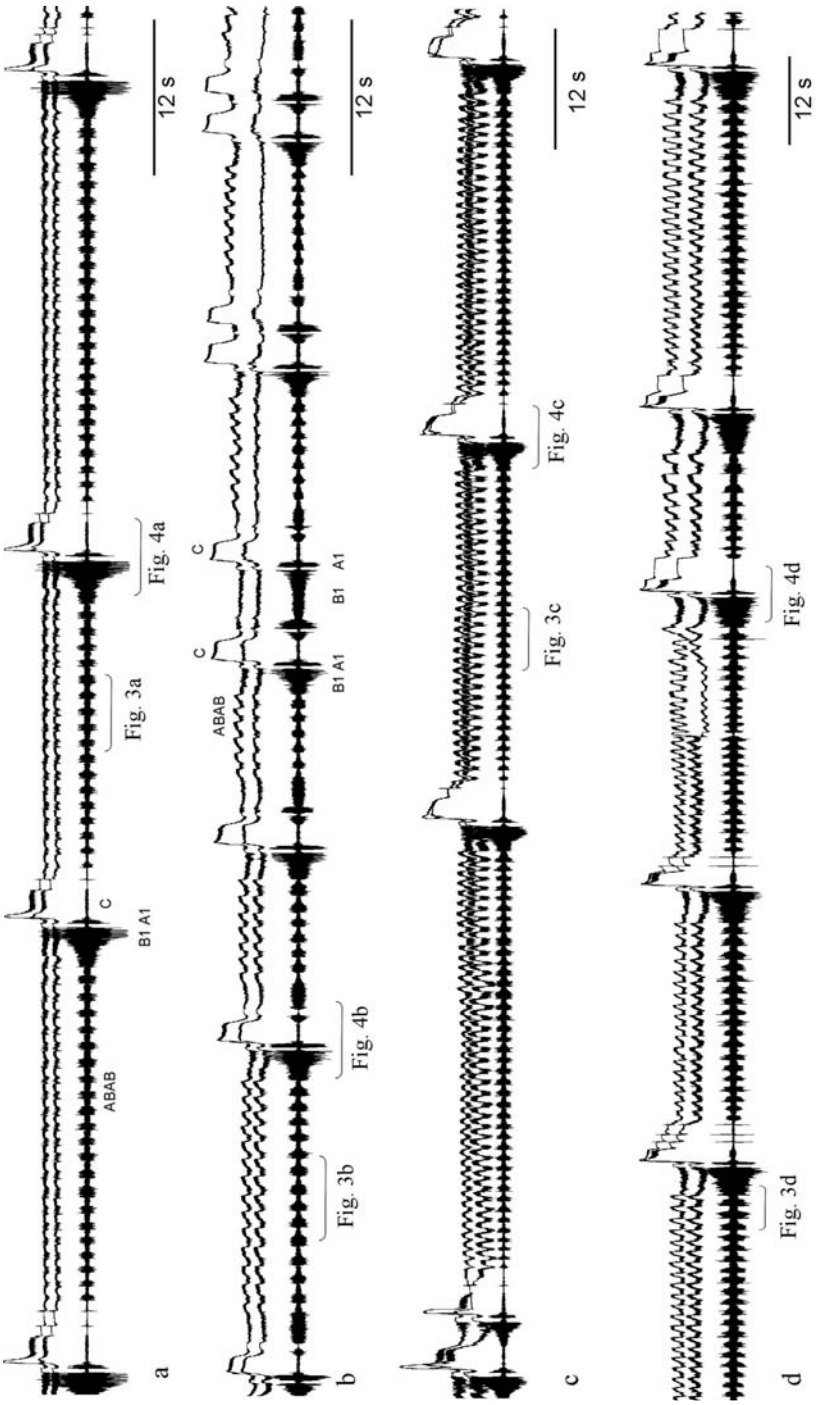


**Fig. 2.** Oscillograms of the courtship song of four males from Slovakia regarded as *Chorthippus oschei* (in each group of three lines, the two upper lines represent leg movements and the third line represents sound). a, b – males no. 1–2 from NE Ardovo, c, d – males no. 3–4 from SW Ardovo. A, B, B1, A1 and C elements are indicated

## RESULTS AND DISCUSSION

All males collected were generally brown with dark or black hind knees and white hind tarsi (Fig. 1). Such coloration is typical for *C. oschei,* whereas in *C. albomarginatus* the hind knees and hind tarsi are green or brown (VEDENINA & HELVERSEN 2009).

The courtship songs of two males from NE Ardovo and eight males from SW Ardovo were studied (Figs 2–4). Their songs generally followed the description of the courtship song of *C. oschei* (VEDENINA & HELVERSEN 2003, 2009, VEDENINA *et al.* 2007). The "pure *oschei* song" started with alternation of two elements, A and B. The A element was produced with legs vibrating rapidly (on average 42–68 vibrations/s) in a high position, and the B element was produced with legs held in a lower position and vibrating much more slowly (on average 16–31 vibrations/s) (Table 1, Fig. 3). A series of alternating A and B elements was followed by a B1-A1-C complex (Fig. 4). The number of A/B pairs between two C elements varied from 8 to 23 pairs on average (Fig. 2). During the B1 element, the amplitude of the leg movements and the sound loudness gradually increased: the B1 element was 3–4 times louder than the B element. The B1 element lasted for 2–4 s on aver-

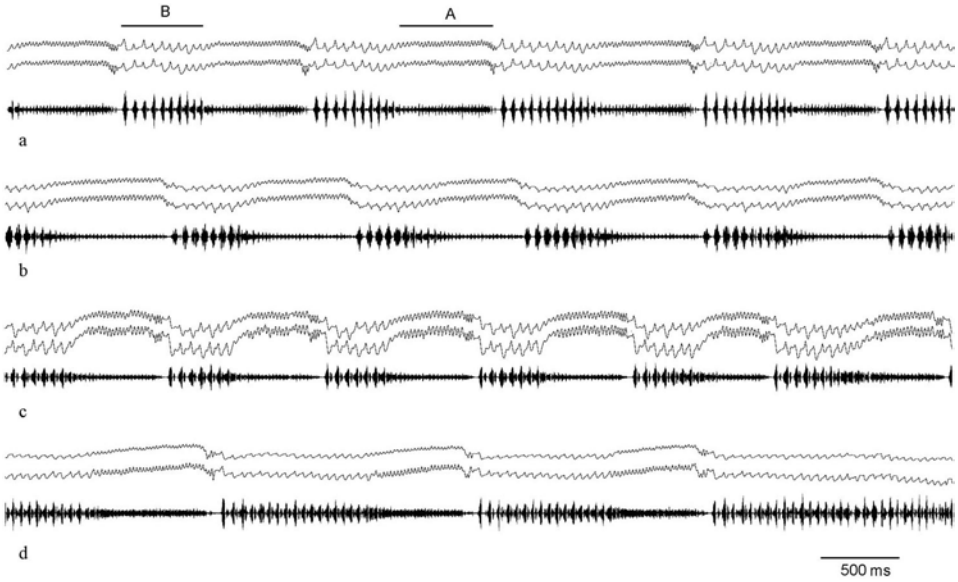


**Fig. 3.** Oscillograms of the courtship song (parts of the songs showed in Fig. 2) of four males of *Chorthippus oschei* from Slovakia (in each group of three lines, the two upper lines represent leg-movements and the third line represents sound). a, b – males no. 1–2 from NE Ardovo, c, d – males no. 3–4 from SW Ardovo. A and B elements are indicated

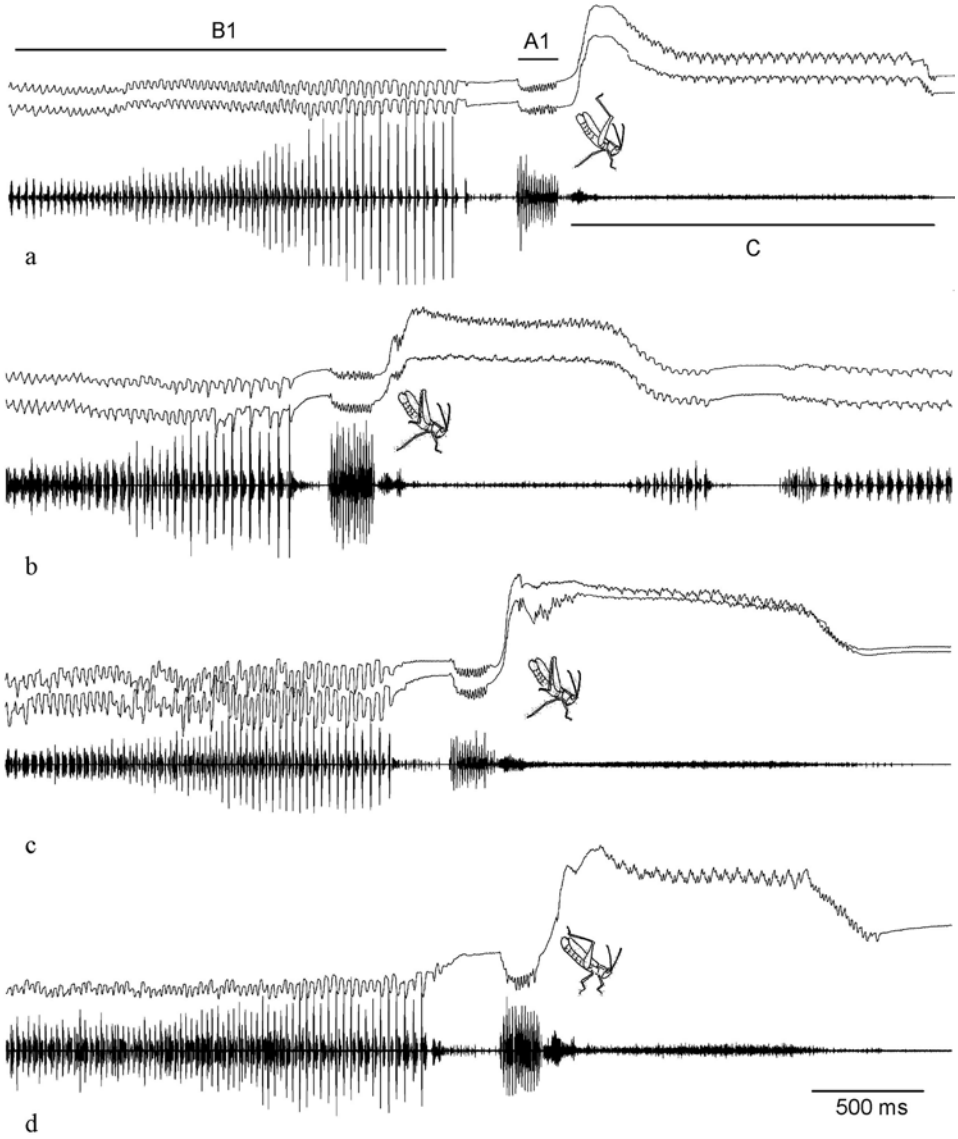


**Fig. 4.** Oscillograms of the courtship song (parts of the songs showed in Fig. 2) of four males of *Chorthippus oschei* from Slovakia (in each group of three lines, the two upper lines represent leg-movements and the third line represents sound). a, b – males no. 1–2 from NE Ardovo, c, d – males 3–4 from SW Ardovo (in d – the recording of only one leg is shown). B1, A1 and C elements are indicated. Drawings show the stroke with the hind tibiae at the beginning of the C element and the maximal angle between femur and tibia in every case

age. After the B1 element, a rapid leg vibration at a rate of about 51–91 vibrations/s produced a very short (about 0.13–0.35 s) element A1 (Table 1). The C element which lasted on average for 1.3–2.44 s, started with the lifting of the abdomen accompanied with a fast movement of the legs into an extra-high position and a very characteristic stroke with the tibiae. After finishing the tibiae stroke, the legs vibrated in a characteristic, complex pattern (Fig. 4a).

The song of some males had several features that differed from the features of the pure *oschei*-song described in the previous paragraph. In one male from NE Ardovo, the number of A/B pairs was too low for the pure *oschei*-song: it varied between seven and 14. Two C-complexes sometimes followed one after another, and the duration of B1 element had a large range: from 1.7 to 4 s (Fig. 2b, Table 1). This male and also one male from SE Ardovo did not produce any stroke with the hind tibiae, even though they lifted the abdomen at the beginning of the C element (Fig. 4 b-c). Because most of courtship elements measured are temperature dependant and temperature varied in a wide range (Table 1), we compared the duration of A, B, B1 and A1 elements relative to the duration of C element. Duration of the C element does not significantly differ in *C. albomarginatus* and *C. oschei* (VEDENINA *et al.* 2007). The B1 element lasted longer in the songs of two males from SE Ardovo (males no. 4 and 10, Table 1), than in the pure *oschei* song. In the song of the male no. 4, the A and B elements also lasted longer than in the pure *oschei*-song.

The only morphological character that can be used to distinguish *C. albomarginatus* and *C. oschei* reliably is the number of stridulatory pegs on the inner side of the hind femora (VEDENINA *et al.* 2007, VEDENINA & HELVERSEN, 2009). The average peg number was 160±9 (SD) in three males from NE Ardovo and 169±13 in 10 males from SW Ardovo. In different populations of pure *C. oschei*, the average peg number ranged from 165 to 186 (VEDENINA & HELVERSEN 2009). According to these data, all the specimens studied from Ardovo could be regarded as *C. oschei.*

Analysis of the courtship songs and morphology for males of the *C. albomarginatus*-group from the two Slovakian localities showed that most of the specimens can be classified as *C. oschei pusztaensis*. However, some courtship songs showed slight deviations from the pure *oschei*-song. Comparison of these recordings with the recordings of the laboratory hybrids between *C. albomarginatus* and *C. oschei* (VEDENINA *et al.* 2007) revealed that some song parameters were similar to those in the hybrid songs. For example, the small number of A/B pairs between C elements, two C elements following each other, or a very long B1 element could be found in the hybrid songs. Absence of the full stroke with the hind tibiae and the lifting of only the abdomen at the beginning of the C element are also typical for the hybrids. However, the songs with some hybrid characteristics recorded from

Ardovo did not otherwise resemble the songs of $F_1$ hybrids between *C. albomarginatus* and *C. oschei* but of backcrosses to *C. oschei*. Therefore, we suggest that some of the recorded specimens could be backcrosses to *C. oschei*, and that populations of *C. albomarginatus* could be situated near the studied localities.

In summary, analysis of the courtship songs and morphology indicates that the populations in the surroundings of Ardovo can be referred to *C. oschei* with some traces of hybridization with *C. albomarginatus*. Our results are consistent with the idea that *C. oschei* hybridizes with *C. albomarginatus* in Slovakia. In the future studies, researchers should investigate more localities containing members of the *C. albomarginatus*-group to describe the hybrid zone in Slovakia in greater details.

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