SYSTEMATICS AND PHYLOGENY

Tettigonia balcanica, a new species from the Balkan Peninsula (Orthoptera, Tettigoniidae)

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Abstract

Tettigonia balcanica, sp. n., discovered in the mountainous regions of the Central, Western and North Balkan Peninsula, is described in this paper. This species has many similarities with *T. silana* and *T. cantans*. However, it differs by the song and some morphological characters. Its range differs from that of *T. cantans*, with which it has been confused so far, but the border between their ranges has yet to be specified.

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Introduction

In the Balkan Peninsula, three species of the genus *Tettigonia*, *Tettigonia viridissima* (Linnaeus, 1758), *Tettigonia caudata* (Charpentier, 1842) and a taxon assigned to *Tettigonia cantans* (Fuessly, 1775), have been known (*e.g.*, Heller & de Jong, 2013). The latter has been known from Bulgaria (Frey-Gessner, 1893), Croatia (Padewieth, 1900), Greece (Willemse, 1977), Republic of Macedonia (Lemonnier-Darcemont, 2011) and Serbia (Pančić, 1883). In 2001, two of us (K.-G. Heller, D. Chobanov) observed in the Rila Mountains (Bulgaria) that the song phrases (echemes) of this species are much shorter than the ones known for *T. cantans* (Heller, 1988) and produced even at night, when *T. cantans* sings continuously. The song was similar to the one known for *T. silana*, endemic to Southwestern Italy. Later on, this *silana*-like singing taxon/form has been recognized in many mountain ranges of the Balkan Peninsula. In the present study we have conducted various bioacoustic and morphological analyses, which allowed us to highlight some characters that differentiate this taxon from *T. silana* and *T. cantans* and to describe the Balkan populations as belonging to a new species, *Tettigonia balcanica*, sp. n.

Materials and Methods

Data and depositories

We studied material from the following collections: National Museum of Natural History, Sofia, Bulgaria (NMNHS), Hungarian Natural History Museum, Budapest, Hungary (HNHM), Naturhistorisches Museum Wien, Vienna, Austria (NMW), Collection of D. Chobanov (CC), Collection of M. Lemonnier-Darcemont and C. Darcemont (CLD), Collection of K.-G. Heller (CH), Natural History Department of the Historical Museum in Blagoevgrad, Bulgaria (HMB), Collection of Mladen Karaman kept at the University of Novi Sad (thanks are due to Dr Ivo Karaman), Collection of Gergely Szövényi (Eötvös Loránd University, Budapest), Collection Willemse (Naturalis Biodiversity Center, Leiden). Abbreviations of collectors' names follow alphabetically: DC (D. Chobanov), GP (G. Peščhev), LD (M. Lemonnier-Darcemont and C. Darcemont).

Bioacoustics

Male songs were recorded in different circumstances using various equipment, as follows: i) electret condenser microphone Knowles BT-1759-000 (sensitivity of –60±3 dB re 1 V/μbar at 1 kHz with a frequen-

cy response roll-off about 10 kHz and cut-off at over 45 kHz; data combined from Irie (1995) and W. Schulze, Friedrich-Alexander-Universität Erlangen-Nürnberg, pers. comm.), equipped with a custom-made preamplifier, connected to a PC through an external soundcard (TransitUSB, M-Audio, Cumberland, RI, USA) (48/96 kHz, in captivity); ii) Olympus VN-8400PC digital voice recorder (Olympus, Center Valley, PA, USA) with a Shure BG 4.0 condenser microphone (frequency response: 40-18000 Hz) (in captivity and in nature); iii) Sony MZ-RH10 high density MiniDisc recorder (Sony, Tokyo, Japan) with a Shure BG 4.0 condenser microphone (frequency response: 40-18000 Hz) (in captivity); iv) ZOOM H2 handy recorder (Zoom Corporation, San Francisco, CA, USA) (96 kHz) either directly or connected with Pettersson D500 external microphone (frequency range fits that of the Pettersson D500X recorder being between 1(-6 dB)-2(-3 dB) kHz to 190 kHz (500 kHz sampling rate); Lars Pettersson, pers. comm.) (in captivity and in nature); v) UHER 4200 IC tape recorder with microphone UHER M645 (Uher Werke, Munich, Germany) in the field and later on from the same individual in captivity); vi) Sony FX1000E Videocamera (Sony; 16 bit/48 kHz) (in the field).

Important morphological characters involved in stridulation were studied by Scanning Electron Microscopy.

The bioacoustic terminology used in this study is as follows (modified from Heller *et al*., 2004): calling song – the song produced by an isolated male; echeme or phrase – a group of densely arranged syllables; echeme duration – the time measured from the beginning of the first to the end of the last syllable; echeme period – the span including an echeme and the following interval; syllable – the sound produced by one opening-and-closing movement of the tegmina; syllable duration – the time measured from the beginning of the first to the end of last impulse in a syllable; syllable period – the span including a syllable and the following interval, usually measured between syllable peaks; syllable repetition rate – reciprocal of the syllable period (unit Hz=1/s); hemisyllables – parts of the syllable, produced by part of the sound-producing movement, here – an opening or closing movement of tegmina; pulse – a train of sound waves, resulting from the fusion of several impulses; impulse – an undivided transient train of sound waves produced by the stridulatory tooth striking the plectrum (the anal edge of the opposite tegmen); pulse period – the span including a pulse and the following silent interval until the next pulse starts; duty cycle – during singing activity, proportion of time spend actually singing: echeme duration divided by echeme period.

The following available recordings of *Tettigonia silana* have been used for comparisons (see Differential diagnosis): i) Italy, Calabria, Sila, Fago del Soldato – data from fig. 3 in Fontana & Odé (1999); ii) Italy, Calabria, Sila, Lorica – data from fig. 1 in Fontana & Odé (1999); iii) Italy, Calabria, Sila, Lorica – data from fig. 2 in Fontana & Odé (1999); iv) Italy, Calabria, Sila, M. Botte Donata, studio recording, 26.VI.1999, Calling song, specimen BF, 27.5°C (Massa *et al*., 2012); v) Italy, Calabria, Sra. Castagna, above Corigliano Calabro, 739 m, studio recording, 18.VI.2010, 30°C (Massa *et al*., 2012).

Results: *Tettigonia balcanica* Chobanov and Lemonnier-Darcemont, sp. n.

Examined material and observations

Holotype ♂: Republic of Macedonia, east of Debar, above the village of Gari, 1450 m, 41.48083°N, 20.745°E, 25.VIII.2010 (Figure 1A-C); ♀ paratype: Republic of Macedonia, Mavrovo, Radika riverside, south of Šar Planina, 1244 m, 41.78978°N, 20.63481°E, 22.VIII.2010 (Figure 1E-G), LD; both specimens deposited at the National Museum of Natural History in Paris (France) with specimen reference numbers MNHN-EO-ENSIF3425 (holotype) and MNHN-EO-ENSIF3426 (paratype).

Other paratype material

Republic of Macedonia: south of Brest, under Mount Ramno, 1431 m, 42.19953°N, 21.40269°E, 30.VII.2011, 1 ♂, LD, CLD; Bozovce, 1312 m, 42.05756°N, 20.83264°E, 28.VII.2013, 3 ♂♂, LD, CLD; Korab Mt., 1470 m, 41.80609°N, 20.61857°E, 18.VII.2013, 3 ♂♂, 2 ♀♀, 1 ♂ & 2 ♀♀ nymphs of last instar, DC, CC.

Bulgaria (all references mention *T. cantans*): W Stara Planina Mts, Vratsa, 1300 m (Pešev, 1974a, published as Vrachanksa Planina, above 1000 m), 6.VIII.1957, 11 ♂♂, 1 ♀ GP, NMNHS & 2 ♂♂, 1 ♀, GP, HMB; C Stara Planina Mts, Stara Zagora prov., Gurkovo municipality, NW of Lyava Reka Vill., 42.74652°N, 25.64425°E, 560 m, 16.VIII.2012, males sing from the trees; E Stara Planina Mts, Sliven (Nedelkov, 1908; Buresch & Peschev, 1958), 9.VII.1907, 2 ♂♂, N. Nedelkov, NMNHS; Rila Mts, coll. Br.v.W. | Rilo | Br.v.W.leg., 1 ♂ (specimen No 14.363), NMW; Rila Mts, Eleshnitsa Lodge, 850-950 m, 42.1208°N, 23.2742°E, 25.VII.2001, 1 ♂, 1 ♀, DC, CC (male tegmen and titillators in NMNHS); Rila Mts, Rilski Manastir monastery (Nedelkov, 1908), VII., 1 ♂, N. Nedelkov, NMNHS; same place, 1100-1600 m, 8.-9.VIII.1957, 3 ♂♂, 1 ♂ nymph last instar, GP, NMNHS; same place, 9.VIII.1959, 2 ♂♂, 3 ♀♀, GP, NMNHS & 1 ♀, GP, HMB; Rila, Umg. Rila-Kloster, 42.13°N, 23.23°E, 800 m, 21.VII.2001, 1 ♂, K.-G. & M. Heller, CH5569; Rila Mts, above Rilski Manastir monastery, 1500 m, 10.VIII.1959, 2 ♂♂, 1 ♀, GP, NMNHS; Rila Mts, Dalgiya Rid above Rilski Manastir monastery, 1200-1600 m, mixed forest (*Fagus sylvatica, Pinus peuce, Picea abies, Pinus sylvestris*), 17.VIII.2008, male song observed, DC; Pirin Mts, Predela pass, 1020 m (41.8973°N, 23.3257°E), 12.VII.2008, common, males sing actively about the mid of the day, 2 ♂♂, DC, CC & 1 ♂, DC, HNHM; same place, 8.VIII.2006, males sing from the trees, DC; same place, 8.VII.2013, 2 ♂♂, 1 ♀, DC, CC; Pirin Mts, Predela pass – Kulinoto place, 1200-1450 m (Peščhev & Andreeva, 1986), 17.VII.1984, 3 ♂♂, 4 ♀♀, E. Andreeva, HMB; same place, 20.VII.1983, 4 ♂♂, 1 ♀, E. Andreeva, HMB; same place, 27.VII.1984, 1 ♂ nymph last instar, E. Andreeva, HMB; same place, 4.IX.1983, 4 ♂♂, 1 ♀, E. Andreeva, HMB; Pirin Mts, Pirin peak, 1700 m, 14.VIII.1984, 1 ♂, 3 ♀♀, E. Andreeva, HMB; Pirin Mts, Daoutov Vrukh peak, 21.VII.1983, 2 ♂♂, E. Andreeva, HMB; Pirin Mts, Dzhindzhiritsa cirque, 19.VII.1983, 2 ♂♂, 1 ♂ nymph last instar, E. Andreeva, HMB; Pirin Mts, east of Bansko, 1148 m, 41.84617°N, 23.38844°E, 2.VIII.2013, 3 ♂♂, 1 ♀, LD, CLD; Pirin Mts, Breznitsa vill. – Gotse Delchev Lodge, 1380 m, 41.74635°N, 23.57059°E, 22.VIII.2011, DC, HNHM; same place and date, 1500 m, 41.73992°N, 23.56541°E, male song heard, DC; W Rhodope Mts: Rodopi (Nedelkov, 1908; Buresch & Peschev 1958), 1 ♂, V-VIII.1907, N. Nedelkov, NMNHS; W Rhodope Mts, Chairite place – Gyovren Vill, 1500 m, 41.64164°N, 24.42600°E, 19.X.2012, male singing from a *Picea abies* tree.

Albania: District of Tropojë, Prokletije Mts, Lekbibaj, secondary hornbeam forest at the Vodafone tower, SW of the village, 900 m, 42.27560°N, 19.90475°E, 10.VII.2005 (2005/69), 1 ♀, T. Deli, Z. Eröss, Z. Fehér & D. Murányi, HNHM; District of Tropojë, Prokletije Mts, in the valley of stream Përroi i Motinës above village Dragobi, grazed grassland and *Rubus* shrub, 610 m, 42.42835°N, 19.9705°E, 21.VII.2012, 1 ♂, Z. Barina, G. Puskás, B. Sárospataki & L. Somay, HNHM; District of Tropojë, Prokletije Mts, in the valley of stream Përroi i Motinës above village Dragobi, pasture at an abandoned homestead, 850 m, 42.41993°N, 19.95998°E, 21.VII.2012, 1 ♂, Z. Barina, G. Puskás, B. Sárospataki & L. Somay, HNHM; District of Tropojë, Prokletije Mts, in the valley of stream Përroi i Motinës above village Dragobi, clearing of beech forest, 1780 m, 42.41392°N, 19.9455°E, 25.VII.2012, 1 ♂, Z. Barina, G. Puskás, B. Sárospataki & L. Somay, HNHM & 1 ♂, same collectors, CC; District of Tropojë, Prokletije Mts, southern slope of Mt Maja e Gavnit above village Curraj i Epërm, alpine grassland, 1930 m, N 42.38258° E 19.92573°, 25.VII.2012, 1 ♀, Z. Barina, G. Puskás, B. Sárospataki & L. Somay, HNHM; Skrapar district, Tomor Mts, beech forest and subalpine grassland on the NE slope of Mt. Çuka Partizan, 1280

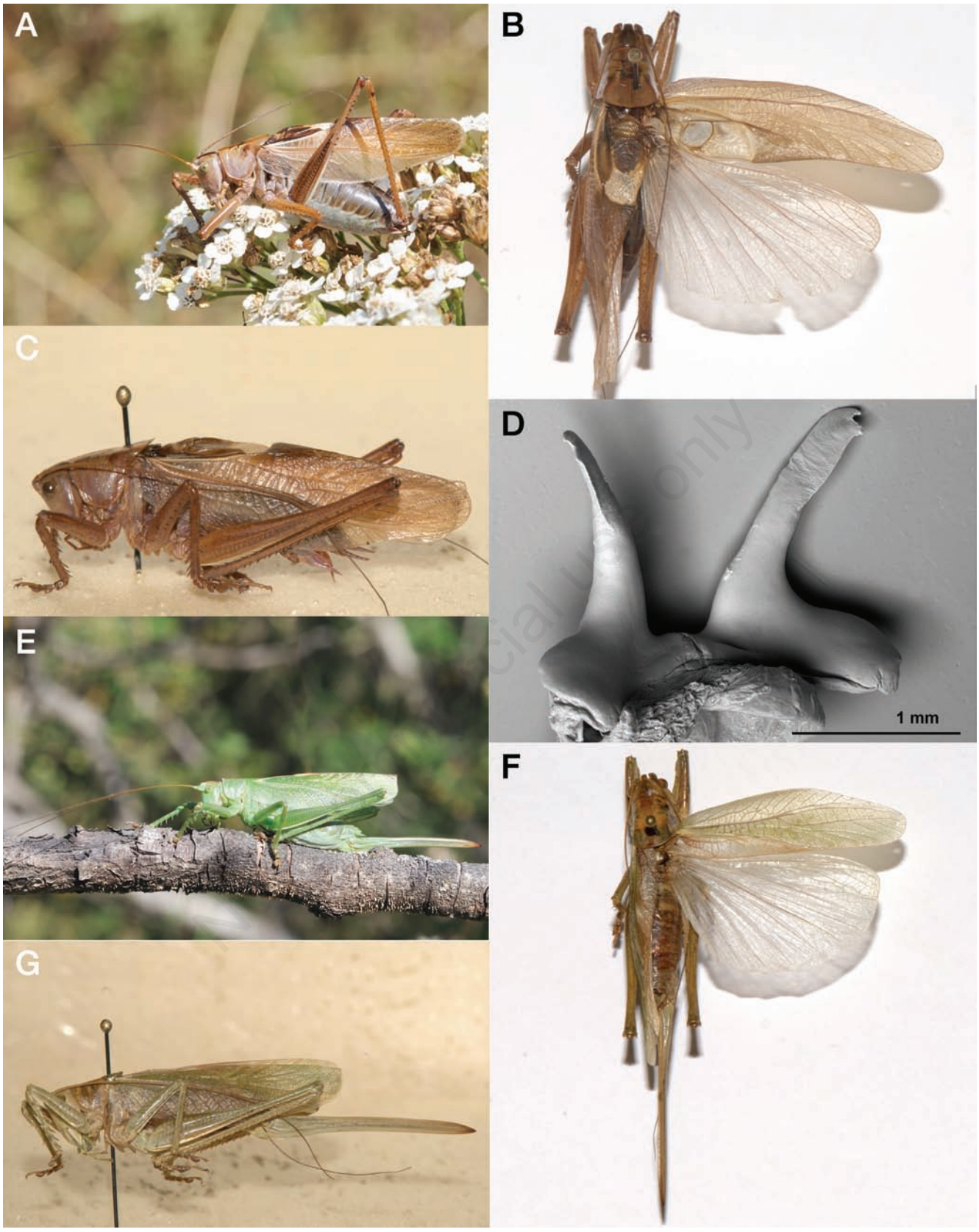

Figure 1. A) ***Tettigonia balcanica*****, sp. n., male holotype in nature; B)** ***Tettigonia balcanica*****, sp. n., male holotype, dorsal view; C)** ***Tettigonia balcanica*****, sp. n., male holotype, lateral view; D)** ***Tettigonia balcanica,*** **sp. n., male titillators, dorso-lateral view (paratype specimen from Albania, Prokletije Mts, Dragobi); E)** ***Tettigonia balcanica*****, sp. n., female paratype in nature; F)** ***Tettigonia balcanica*****, sp. n., female paratype, dorsal view; G)** ***Tettigonia balcanica*****, sp. n., female paratype, lateral view.**

m, 40.71996°N, 20.16943°E, 24.VIII.2006 (2006/154), 1 ♂, 1 ♀ Z. Fehér, A. Hunyadi, T. Huszár & D. Murányi, coll. F. Willemse.

Bosnia-Herzegovina: Dragos Sedlo (Nat. Park Sutjeska), 1000 m, 2.VIII.1968, 3 ♂♂, F. Willemse, coll. F. Willemse.

Croatia: Zadar County, Poštak Mts, meadows, scrub and forest edge of E part of Ljubina poljana, 1070 m, 44.26579°N, 16.14076°E, 23.VII.2013, 7 ♂♂, 2 ♀♀, G. Puskás & G. Szövényi, HNHM & 3 ♂♂, 2 ♀♀, G. Puskás & G. Szövényi, coll. G. Szövényi.

Greece: Hellas (Makedonia, Florina), Polipotamo (Vernous Oros), 1100 m, 19.VII.1969, 1 ♂, F. Willemse, coll. F. Willemse (Willemse, 1977, publ. as Vernon Mt., 6 km SW of Dhrosopiyi).

Other unpublished records

Serbia: Kopaonik Mt., collection of Mladen Karaman at the University of Novi Sad (further details not recorded).

Greece: Epirus, Konitsa, near the Albanian border (Lafranchis, pers. comm.).

Additional literature data related to this species (all references mention *T. cantans*)

Bulgaria: Vitosha Mt. and Sofia surroundings (Nedelkov, 1908); Rila Mts, the slopes above Dupnitsa (Frey-Gessner, 1893); Rila Mts, between Rila and Rilski Manastir monastery (Nedelkov, 1908); Rila Mts, Kirilova Polyana place (Nedelkov, 1908; Uvarov, 1949; Buresch & Peschev, 1958); Rila Mts, Semkovo Resort, 1600 m (Bey-Bienko & Pešchev, 1960); Pirin Mts, Bansko – Demyanitsa Lodge, 1300-1800 m (Bey-Bienko & Pešchev, 1960); W Rhodope Mts, Yundola Vill., 1380 m (Péchev, 1974b; Pechev, 1975).

Montenegro: Šćepan Polje, 400-500 m; Bjelasica Mt. 7 km South of Mojkovac, 900 m (Ingrisch & Pavićević, 2012).

Republic of Macedonia: near Debar and in the south of the Sar Planina (without exact localities) (Lemonnier-Darcemont, 2011).

Male holotype description

Specimen in good condition with just a small tear on the right wing, which is also present on the tegmen. General color light brown with a dark stripe from the top of the head to the prozona of the pronotum where it is bordered by a darker irregular band (Figure 1A-D).

Fastigium of vertex longer than wide, angled at the top and narrower than scapus. Disk of pronotum with rounded posterior margin, smooth prozona and highly wrinkled and punched metazona. Paranota smooth and as wide as high with the inferior-posterior angle slightly curved.

Legs brown, with the exception of the outer portion of hind femur, which is testaceous. Two rows of small black spines present on the underside of hind femur.

Tegmina more or less light brown, short, broad at their base and tapering gradually to the rounded apex. Anterior border convex along its proximal two thirds, then obliquely narrowed at the distal third, and extending beyond the tip of hind femora by about 5.5 mm.

Abdomen brownish. Tenth tergite with two lobes divided by acute deep incision, shaped like an upside U. Cerci long and thin, rather concave at apex and toothed in the basal quarter with a short and somewhat acute internal tooth. Subgenital plate with a large semicircular incision; styles tapered towards the tip, about a quarter shorter than cercus. Titillators (Figure 1D) narrow and elongated, widely separated in their basal part, with diverging arms. Titillators end apically with two strong teeth, the upper one being more robust.

Female paratype description

Specimen in good condition. Uniformly green, except one light brown longitudinal stripe more or less narrowly extending from top of head to over half the length of tegmina. Antennae and tarsi also light brown. No differences from the holotype in the structure of head, pronotum and legs have been noticed (Figure 1E-G).

Tegmina short, reaching beyond hind femora (extending by about 3.5 mm), gradually broadening from their base to beyond the middle and then tapering to form a narrow, rounded apex; their posterior margin straight.

Abdomen green. Last abdominal tergite with two acute lobes divided by a large semicircular notch. Subgenital plate with deep apical incision and broad lobes, rather rounded at their apices. Ovipositor longer than hind femur and slightly down-curved.

General description and variation

Body light green, yellowish to brownish, sometimes slightly violet-brown. A dark brownish stripe passes the middle line of the body from vertex to pronotum and all abdominal tergites, similar to *T. cantans*. Other details as in the holotype and the female paratype. Stridulatory file similar in shape to that of *T. cantans* (Heller, 1988) and bears 104-130 teeth (mean=117, SD=8, n=14). Measurements are presented in Table 1.

Specimens of the only known Croatian population (Poštak Mts, the north-westernmost occurrence of the species) have significantly wider tegmina than measured specimens from all other localities (Figure 2, Table 2). However, no differences were found in song characteristics and other morphological features among the populations.

Bioacoustic analysis

Male calling song (Figure 3, Table 3) consists of short echemes/phrases, lasting between 450 and 2000 ms, depending on temperature (Table 3), spaced by quite variable intervals of the same duration or longer. The echemes involve 17-58 syllables with peak of amplitude at the middle of the syllable. At temperatures above 20°C syllables are lacking clear silent interval in between except for the first 1-2 syllables, that have very low amplitude and variable period of usually 10-30 (up to 117) ms; under that temperature, intervals may be present. The envelope of the echeme shows a rapid rise in 3-4 syllables, over a period of about 100 ms, then a constant level without decrescendo up to the last syllable follows. The temporal parameters of the song differ significantly with temperature (Table 3; Figure 4A). Additional differences may come from specimen's age or be the results of interindividual variation. The average syllable period of the main part of the echeme is fairly constant at similar temperature, but sometimes the last syllable is isolated by a larger interval of up to 40-50 ms (at 25-27ºC).

To the human ear, the general impression given by this species is of a modulated noise spectrum, less high-pitched than of other *Tettigonia*.

The song carrier frequency falls mostly in the range 6-11 kHz, with a weak signal over 20 kHz. Frequency peaks are recorded between 6.4 and 9.4 (sometimes with an additional one at about 13-15 kHz). At –6 dB, the spectrum is centered around 7.5 kHz and has a width of about 3 kHz (6-9 kHz), at –12 dB it widens slightly towards the treble (5.5-10 kHz), then strongly at –18 dB, mainly in the high frequencies, thus covering the range 5 kHz to 17 kHz (Figure 4B).

Differential diagnosis

Morphology

At first, we compared *T. balcanica*, sp. n. to the sympatric species *T. caudata* and *T. viridissima*, the latter one sometimes cohabiting in the least humid microhabitats. *T. balcanica* is easily distinguished from these species by its relatively short tegmina, not extending far beyond the hind femora – at most 5.5 mm for specimens collected. Even when some short-winged forms of *T. viridissima* and *T. caudata* are considered (D. Chobanov, unpublished data), the well expressed differences in the shape of tegmina and other morphological characters (compare *e.g.,* Harz, 1969; Storozhenko, 1994) may easily separate these taxa.

We considered other Western-Palaearctic species such as *T. acutipennis* Ebner, 1946, endemic to Turkey, *T. hispanica* Bolívar, 1893, endemic to Spain, *T. silana* Capra, 1936, endemic to Italy, and the widespread *T. cantans* because of their morphological or bioacoustic affinities.

T. acutipennis differs in the shape of wings and tegmina being more pointed at the apex not surpassing the hind femora (compare Ebner, 1946), as well as in having black spots at the base of ventral spines on hind femora.

In *T. hispanica,* the tegmina are also shorter, the subcostal area is much narrower than in *T. balcanica*, and females have a straight ovipositor (compare Fontana & Odé, 1999).

From general morphology, *T. balcanica* shows closer affinities with *T. silana* and *T. cantans,* with the latter it had hitherto been confused.

T. balcanica differs from *T. cantans* in the shape of male and female wings (Figure 2, compare A with B), by the female ovipositor shape (Figure 5, compare A with B) and length (up to 26 mm in *T. cantans* and usually over 26 mm in *T. balcanica*). However, some unpublished data prove a longer ovipositor in some southern populations of *T. cantans* (from the region of Vienna and from Mehadia, though in the last case the identification is not sure; D. Chobanov, unpublished data). Both species may be differentiated by the shape of the male stridulatory area, in *T. cantans* being wider with usually a larger mirror on the right tegmen than in *balcanica* (Figure 6A-E). In two specimens of *T. cantans* from Austria (specimen CH2084: Kärnten, Obir bei Klagenfurt, N 46.5°, E 14.5°, 900 m, 13.VIII.1980, M. Volleth, CH) and Central Italy (specimen CH2076: Campitello Matese, N 41.47°, E 14.35°, 8.VIII.1978, Heller, CH), the stridulatory area width was 5.5 and 5.3 mm, length of mirror – 3.3 and 3.1 mm (maximal diameter 3.7 and 3.2) and width of mirror – 3.1 and 3 mm, respectively, thus being generally larger than in *T. balcanica* (compare data below). However, the diameter of the mirror in *T. cantans* has been demonstrated to be quite variable according to Latimer & Schatral (1986) measuring 2.9-3.9 mm, while in *T. balcanica* we measured it being 2.7-3.2 with an exception in the holotype reaching 3.5 mm (mean=2.9±0.2). Another morphological difference may be found in the number of stridulatory teeth being usually higher in *T. balcanica* (over 104), while in *T. cantans* it has been reported to be 92-111:92 (Heller, 1988) (Storozhenko, 1994, has reported 54-58 stridulatory teeth in *T. cantans* but as this number largely deviates from ours and other published measurements, *e.g.* Heller, 1988, we regard this data doubtful).

T. balcanica is also closely related to *T. silana*. From the latter it differs by the wider tegmina (compare Figure 2A with C). In a specimen of *T. silana* (male CH5942: Calabria, La Sila, M Botte Donato (da bivio M. Scuro), 39.28°N, 16.45°E, 1750 m, 23.VI.1999, P. Fontana & M. Buzzetti, CH), the ratio length:width of tegmen was found to be 3.04 (25.2:8.3). According to Fontana & Odé (1999), it may be around 2.9 (23-26:7.9-9). In studied male specimens of *T. balcanica* the ratio ranged between 2.11 and 3.00 (mean=2.62±0.27, n=26). Female ovipositor shape differs slightly (compare Figure 5A with C), being longer in *T. balcanica* (up to 26 mm in *T. silana* and usually over 26 mm in *T. balcanica* sp.n.) (see Fontana & Odé, 1999). Some differences in the shape of male stridulatory area exist, in *T. silana* the mirror on the right tegmen (Figure 6A-E) being elongated and at the upper size limit of its diagonal in *T. balcanica* (in the above studied specimen measuring in length 3.2 and in width 2.6 mm, with a maximal diameter of 3.5

Table 1. Morphometrics (mm) of *T. balcanica*, sp. n., (male and female).

Characteristics	Mean±SD	Min-Max	N.
♂			
Pronotum	7.8±0.4	6.6-8.7	53
Tegmen (fore wing) length	28.4±1.2	25.5-30.8	50
Tegmen width	11.0±1.2	9.5-13.6	27
Ratio tegmen length/width	2.62±0.27	2.18-3.00	26
Stridulatory area length (measured as length of MA+CuA1 vein from its base to the approximate merging with the wing margin)*	16.0±0.8	14.3-17.5	28
Stridulatory area width (wider distance between MA+CuA1 and wing anal margin)	5.1±0.2	4.6-5.3	29
Right tegmen mirror diameter**	2.9±0.2	2.7-3.5	31
Right tegmen mirror length	2.8±0.2	2.5-3.0	7
Right tegmen mirror width	2.6±0.1	2.4-2.7	7
Stridulatory file	3.0±0.2	2.7-3.4	16
Hind femur length	21.6±1.3	19.4-24.7	48
Hind femur width	3.3±0.1	3.0-3.5	25
Titillator length	1.7±0.1	1.3-1.8	12
Titillator arms spread at tips (distance between tips of arms)	>1.4		
Titillator arms distance at their base	>0.4		
♀			
Pronotum	7.9±0.4	7.0-8.5	19
Tegmen (fore wing) length	30.2±0.9	28.5-31.7	19
Tegmen width	9.6±0.7	8.0-10.5	13
Ratio tegmen length/width	3.13±0.21	2.80-3.56	13
Hind femur length	23.2±1.2	21.1-25.5	19
Hind femur width	3.4±0.2	3.2-3.7	11
Ovipositor	28.6±1.9	25.0-31.6	18

*According to Gorochov (1995); **according to Latimer & Schatral, 1986.

mm). The stridulatory file was reported to bear a larger number of teeth (135-140 *versus* 104-130 in *T. balcanica*).

Song

The song reveals distinct features that enable easy discrimination *by ear*. Species such as *T. viridissima*, *T. caudata*, *T. hispanica* are distinguished in particular by their high-pitched spectrum and longer echemes (*T. caudata*) or syllables clearly grouped in pairs (*T. viridissima* and *T. hispanica*).

The song of *T. cantans* comprises much longer echemes during the day (Figure 6F-H) or a continuous trill-like sequence of syllables at night, respectively. The temporal song parameters of *T. silana* also differ (Figures 3 and 4). The differences from *T. balcanica* refer to a lower syllable repetition rate, at least at over 15°C (Figure 4A), shorter, more densely arranged echemes, lower number (known range 5-20) of longer, clearly separated syllables, and distinct syllable structure. The song consists of well detached lower- and higher-amplitude syllables that may be referred to opening and closing hemisyllables, respectively. Due to the more densely arranged echemes, the duty cycle in the five available recordings of *T. silana* ranged between 0.63 and 0.72. The frequency spectrum of *T. silana* (Figure 4B, point C) has a slightly higher maximum. Thus, the syllable structure and song carrier frequency result in different sounding of the male song that may be recognized both in nature and laboratory by unaided ear.

Comparison to Asian species

T. balcanica may be compared to the Anatolian-Caucasian species *T. acutipennis*, but those have a quite different song (K.G. Heller and D. Chobanov, unpublished data), as well as to the Eastern Palaearctic continental *Tettigonia* species with short wings, *i.e*. *T. ussuriana* Uvarov, 1939 (data on length of tegmina in Rhee, 2013). *T. ussuriana* has a song structure similar to that of *T. cantans* – a continuous trilling song, but with much lower syllable repetition rate than *T. cantans* (Zhantiev, 1981; Figure 4A), and thus clearly differs from all European species.

We do not consider the *Tettigonia* species endemic to Japan because the taxonomic situation there is quite unclear with several undescribed species (Ichikawa *et al*., 2006), and because it seems very unlikely that Japanese endemics would be conspecific to species confined to parts of Europe.

Etymology

This species seems to be distributed only in the hilly and mountainous regions of the Balkan Peninsula. The name of the new species refers to the latter.

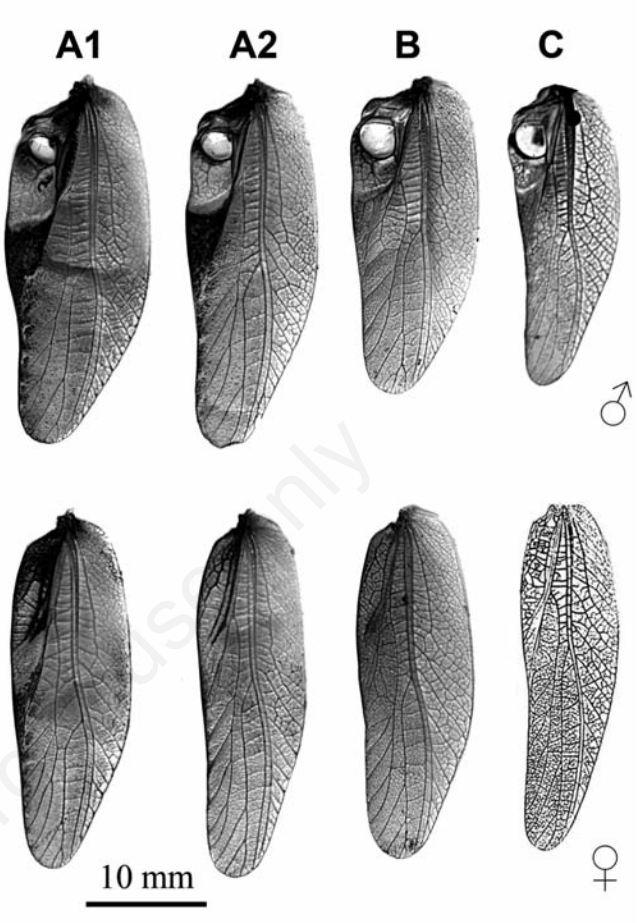

Figure 2. Right tegmina of *Tettigonia balcanica* (A), *Tettigonia cantans* (B), *Tettigonia silana* (C). A1: Croatia, Poštak Mts; A2: Albania, Prokletije Mts, B: Hungary, Börzsöny Mts, C ♂: CH5942: Calabria, La Sila, M Botte Donato (da bivio M. Scuro), N 39.28°, E 16.45°, 1750 m, 23.VI.1999, P. Fontana & M. Buzzetti, C ♀: holotype, from Capra (1936).

Table 2. Tegmen width and ratio of length/width in *Tettigonia balcanica*, sp. n. - differences between population in the Poštak Mts (Croatia) and all other known localities (Bulgaria, Macedonia, Albania).

♂	Tegmen width (mm)	Ratio tegmen length/width
Poštak Mts	12.6±0.63 (12.1-13.6, n=8)	2.30±0.08 (2.2-2.4, n=8)
Other localities	10.2±0.64 (9.5-11.5, n=19)	2.80±0.17 (2.4-3.0, n=17)
Difference	2.4 (24%)	0.5 (18%)
P-value of Student's t-test	0.0000003	0.0000000009
♀		
Poštak Mts	10.3±0.21 (10.0-10.5, n=4)	2.93±0.09 (2.8-3.0, n=4)
Other localities	9.3±0.64 (8.0-10.0, n=9)	3.22±0.18 (3.0-3.6, n=9)
Difference	0.9 (10%)	0.3 (9%)
P-value of Student's t-test	0.001	0.001

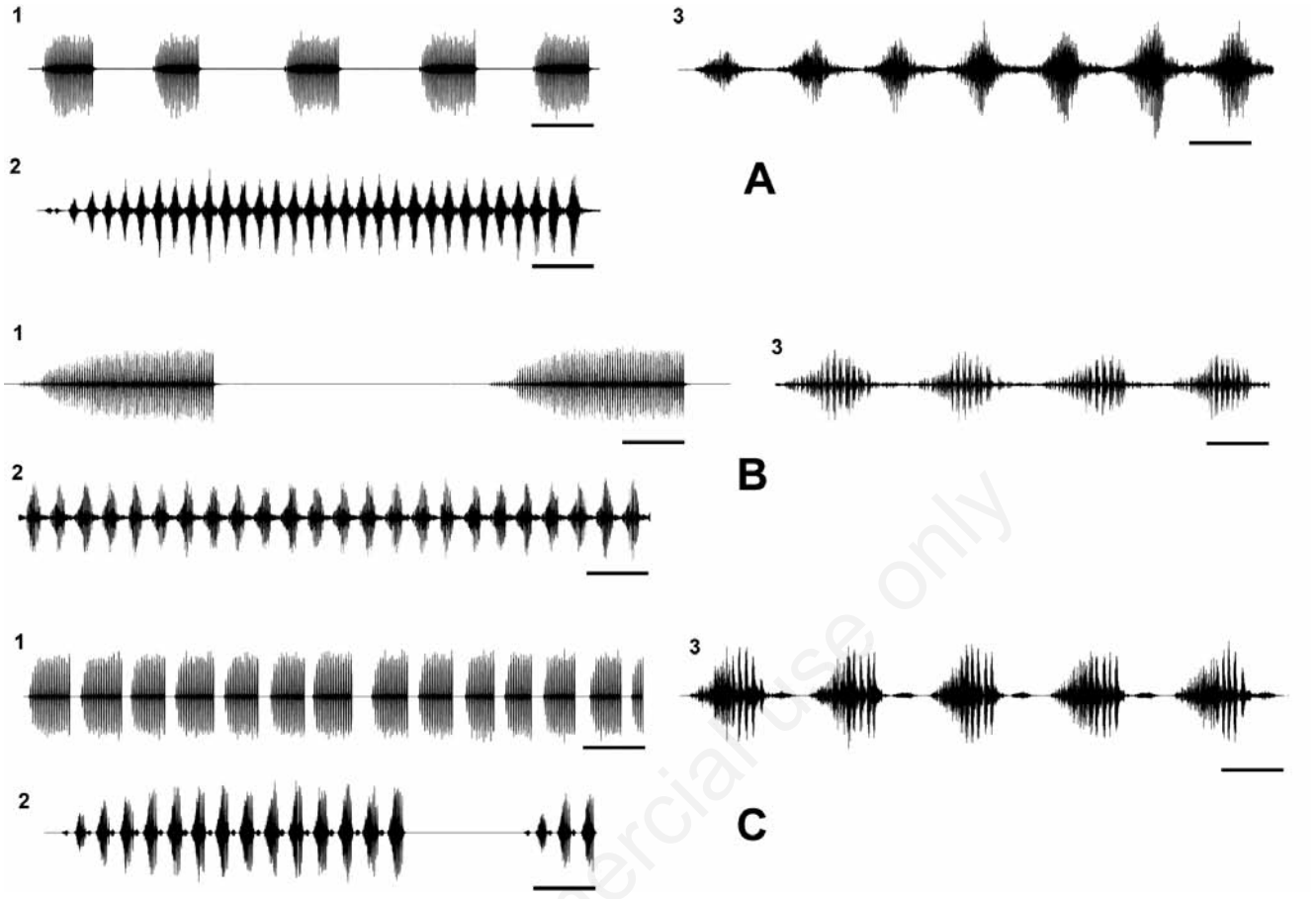

Figure 3. Oscillograms in three different scales of *Tettigonia balcanica* (A), *Tettigonia cantans* (B), *Tettigonia silana* (C). Scale for 1=1 s, for 2=100 ms, for 3=20 ms.

Table 3. Temporal song parameters measured in *T. balcanica*, sp. n. (recordings presented with increasing temperature).

Record	°C	Echeme duration (ms), mean±SD, (range)/n	Syllable period (ms), mean±SD, (range)/n	Syllable number per echeme, mean±SD, (range)/n	Duty cycle
1	16	1394±117 (1206-1576)/19	62.3±2.1 (59-66)/19	23±2 (20-26)/19	0.44
2	19	1136±94 (935-1362)/62	42.9±1.3 (41-45)/62	26±2 (21-31)/62	0.55
3	22	1523 (1270-2026)/7	34.3 (33.9-34.9)/7	46 (38-58)/7	0.47
4	23	1196±174 (958-1441)/12	29.0±1.3 (27.6-31.0)/12	41±6 (34-51)/12	0.58
5	25	808±89 (602-1188)/87	27.5±0.6 (25.8-28.5)/87	30±3 (24-44)/87	0.5
6	25	739±40 (677-827)/42	28.2±0.9 (23.1-29.1)/42	27±1 (24-29)/42	0.5
7	25	1127±167 (906-1660)/29	-	-	0.4
8	26	812±102 (600-1087)/50	31.9±0.8 (29.5-33.3)/50	25±3 (18-34)/50	0.46
9	26	736 (587-1041)/114	26.8 (24-29)/114	25 (20-35)/114	0.37
10	27	556±66 (451-780)/35	26.2±0.3 (25.7-27.2)/34	21±3 (17-30)/34	0.33
11	29	776±66 (616-873)/78	19.9±1.0 (18-22)/78	33±3 (25-39)/78	0.29
12	31	640 (561-714)/10	20.0 (19.9-20.2)/10	32 (28-36)/11	0.45

Data for the recordings: 1. Croatia: Zadar County, Poštak Mts, 23.VII.2013, rec. nature, before sunset. 2. Croatia: Zadar County, Poštak Mts, 23.VII.2013, rec. in nature, afternoon. 3. Bulgaria, Rila Monastery, 21.VII.2001, rec. in captivity, 30.VII-7.VIII.2001, 22-23:00h. 4. Republic of Macedonia, south of Brest, under Mount Ramno, 30.VII.2011, rec. in nature, 15:00h. 5. Bulgaria, Predela, 12.VII.2008, rec. in captivity, 17-18.VII.2008, 23:30-00:25h. 6. Bulgaria, Predela, 8.VII.2013, rec. in captivity, 24.VII.2013, 22:12-22:20h. 7. Republic of Macedonia, Korab Mt., 18.VII.2013, rec. in captivity, 29.VII.2013, 04:50-04:56h. Note: This specimen had an unusually clear song pattern similar to that of *T. silana* due to a bad moulting resulting in injured right-tegmen mirror. 8. Bulgaria, Pirin Mts, near Bansko, 1.VIII.2013, rec. in captivity, 2.VIII.2013, 21:25-21:40h. 9. Albania: Tropojë District, Prokletije Mts, above Dragobi, 25.VII.2012, rec. in captivity 30.VII.2012 night. 10. Republic of Macedonia, Korab Mt., 18.VII.2013, rec. in captivity, 10.VIII.2013, 01:20h. 11. Croatia: Zadar County, Poštak Mts, 23.VII.2013, rec. in captivity, 13.VIII.2013 night. 12. Bulgaria, Rila Monastery, 21.VII.2001, rec. in captivity, 30.VII.-7.VIII.2001, 22-23:00h.

Habitat

The species occurs in the mountainous regions of the Western and Central Balkan Peninsula [Croatia, Bosnia-Herzegovina, Montenegro, Serbia, Macedonia, Albania, Greece, Bulgaria, reaching East Stara Planina in the central part of East Bulgaria (Figure 7)]. Its microhabitats are usually dense herbaceous meadows and wastelands, mesophilous and meso-hygrophilous, with a significant coverage of shrub, located in forest clearings or at the edge of beech forest, of beech-fir or of riparian forest between 500-600 m (Bulgaria, Albania) and 1800-1930 m (Bulgaria, Albania) altitude. In the first half of the summer, adults of *T. balcanica* mostly keep within the herbaceous or woody vegetation, between 0.50 m and 1.20 m above the ground, while adult males frequently get higher in the tree crown from where they sing.

Discussion and Conclusions

According to the habitats and known localities, *T. balcanica*, sp. n., is expected to have a wider range in many mountains in the countries mentioned, and also to be found in Kosovo as the Serbian locality lies at the border of Kosovo. Some specimens from the region of Mehadia in Romania (3 ♂♂, 2 ♀♀, No4241-13.091., NMW) show intermediate characters between *T. cantans* and *T. balcanica* with a wide male wing with a shape similar to that of *T. cantans* and a large mirror but a very long female ovipositor. Yet, their taxonomic affinity needs further bioacoustic study as do the records of *T. cantans* from northern and eastern Serbia (summarized by Adamović, 1975). However, recent data from southern Vojvodina in Serbia proved the occurrence of *T. cantans* in the humid lowland habitats of the territory (Skejo & Stanković, 2014). The three species, *T. balcanica*, *T. cantans* and *T. silana*, seem to be closely related, but differ primarily in the amplitude-temporal characters of the song, and some morphological criteria such as the shape of the wings and ovipositor (Tables 4-6).

Some *intermediate* specimens from southwestern Romania and southern Austria showing common morphological characters of *T. cantans* and *T. balcanica* may represent unusual specimens or transitional populations, thus allowing hypothesizing about close relationships of *T. cantans* and *T. balcanica* (and *T. silana*?).

As *T. cantans* is characterized by a simple song pattern of possibly ancestral state (Schul, 1998) and is weakly selective towards some temporal song parameters (*i.e.* song structure containing echemes is not required by the females of *T. cantans* for tracking the male song phonotactically in contrast to *T. caudata*, for example; Schul, 1998), resulting even in producing hybrids with *T. viridissima* (Schul, 1994), it is possible that in zones of secondary contact *T. cantans* and *T. balcanica* may hybridize. However, without knowing the song pattern of these *transitional* forms, we cannot develop this hypothesis any further.

On the other hand, similarities between *T. balcanica* and *T. silana* include more elaborate song pattern and morphological similarities. Their relationships may be referred to a formerly wider distribution of a supposed ancestor in the Balkans and Apennines (or secondary expansion to any of these territories) or related to the historical movement of the Apulian microplate (*e.g.* Favali *et al*., 1990) that have formerly been separated from the Apennines but due to the collisions of the African and Eurasian plates merged with this territory. Any of the above hypotheses may be supported by the occurrence of some closely related or common species in the western Balkan Peninsula and Apulia or neighboring territories in Italy, *e.g.* some *Metaplastes* species occurring in Italy, whereas the other congenerics occurring in the western Balkans (Fontana *et al*., 2004) or *Eupholidoptera garganica* La Greca, 1959, occurring in Southeastern Italy and Western Greece (Allegrucci *et al*., 2014).

A number of questions remain regarding the status of *T. balcanica* and its phylogenetic relationships and are yet to be studied. Some answers will be likely made at the end of DNA and karyotype studies to be conducted in 2014.

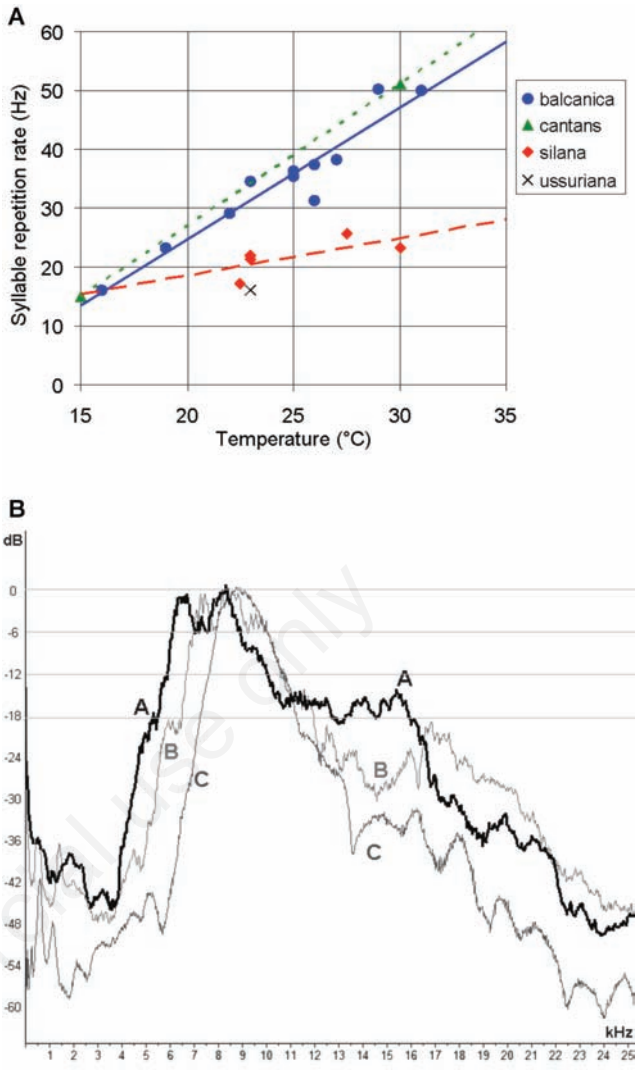

Figure 4. A) Syllable repetition rate according to temperature (line for *T. cantans* based on Heller, 1988, p. 88, Fig. 8; *T. ussuriana* from Zhantiev, 1981). B) Spectrum of *Tettigonia balcanica* (point A), *Tettigonia cantans* (point B), *Tettigonia silana* (point C). The spectrum of *T. silana* has been measured using data by Massa *et al.* (2012).

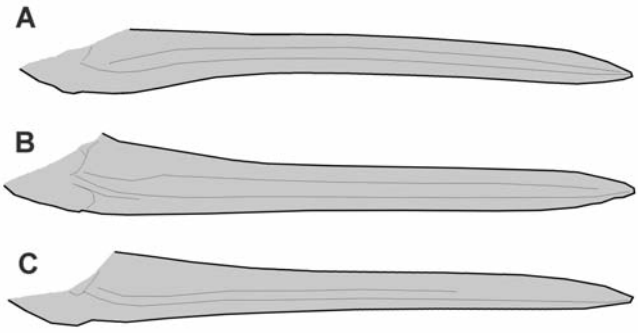

Figure 5. Ovipositor of *Tettigonia balcanica* (A), *Tettigonia cantans* (B), *Tettigonia silana* (C).

Table 4. Comparative bioacoustics analysis of *Tettigonia balcanica*, *T. cantans* and *T. silana*.

Audio criterion	*T. balcanica*	*T. cantans*	*T. silana*
Duration of echeme at 26°C	820 ms, σ=90 ms	2350 ms, σ=850 ms	570 ms, σ=50 ms
Average length of crescendo	100 ms	600 ms	50 ms
Mean syllable period	25 to 35 ms	35 to 50 ms	35 to 45 ms
Spectrum –6dB	6000-9000 Hz	7000-10500 Hz	8000-10000 Hz
Spectrum –12 dB	5500-10000 Hz	6500-11500 Hz	7500-11000 Hz
Spectrum –18 dB	5000-17000 Hz	6000-12500 Hz	7000-12000 Hz

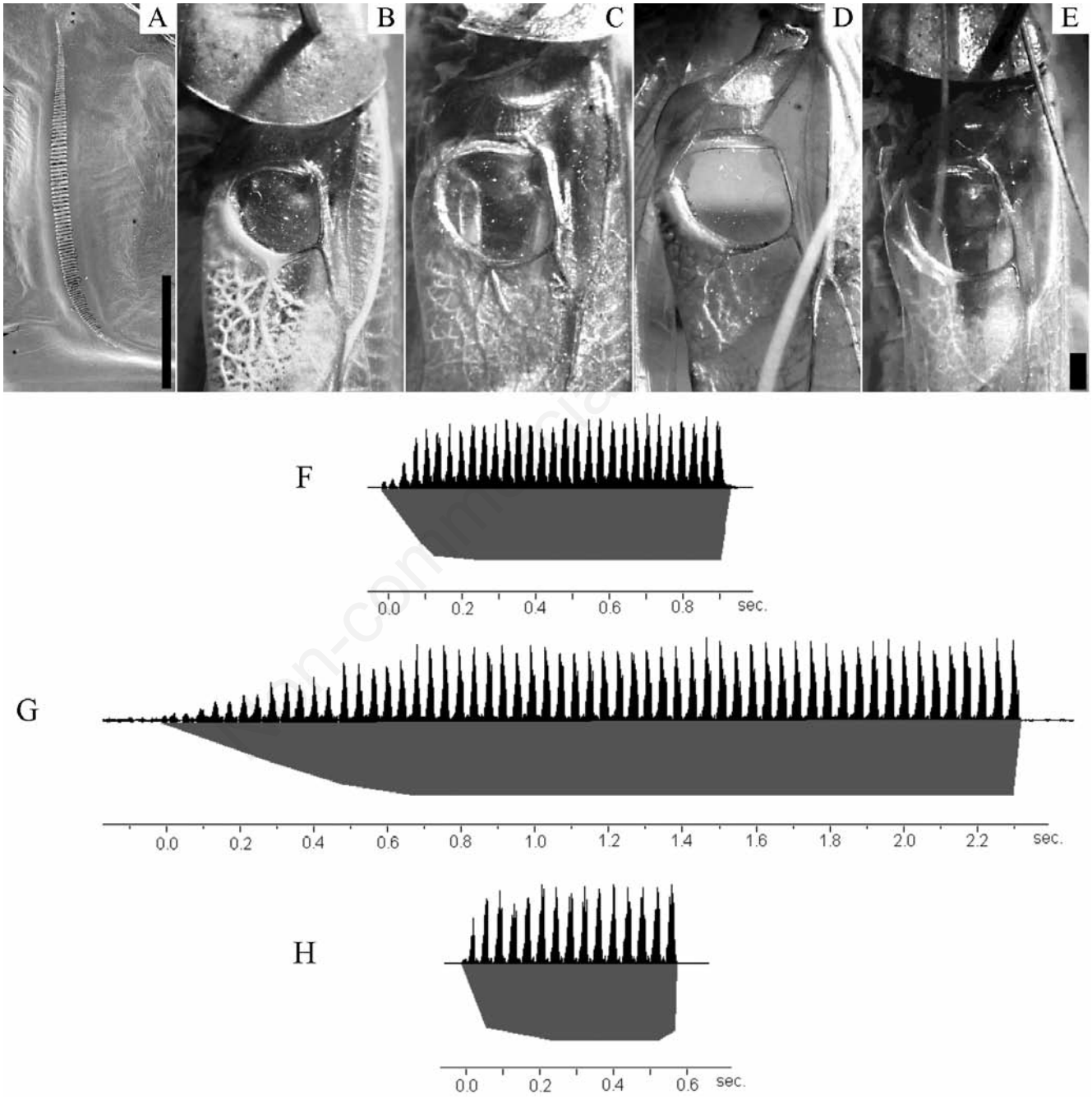

Figure 6. Stridulatory file (A) and stridulatory area of the right tegmen (B-E) in *Tettigonia*: A) *T. balcanica* (Bulgaria, Predela pass), B) *T. balcanica* (CH5569, Bulgaria, near Rila Monastery), C) *T. cantans* (CH 2084, Austria, Obir), D) *T. cantans* (CH 2076, Central Italy), E) *T. silana* (CH5942, Calabria). Scales=1 mm. Echeme of *Tettigonia balcanica* (F), *Tettigonia cantans* (G), *Tettigonia silana* (H).

Table 5. Main morphological and ecological characters distinguishing *Tettigonia balcanica*, *T. cantans*, and *T. silana*.

	Tettigonia balcanica	*Tettigonia cantans*	*Tettigonia silana*
Ovipositor	Figure 5A	Figure 5B	Figure 5C
Ratio length/width of tegmen ♂	2.2-3	2.4-3	2.9-3.5
Ratio length/width of tegmen ♀	3.0-3.6	2.6-2.8	3.1-3.5
Shape of tegmen ♂	Figure 2A	Figure 2B	Figure 2C
Shape of tegmen ♀	Figure 2A	Figure 2B	Figure 2C
Cerci of ♂	Close to *T. silana*	Short and thick	Long and thin
Biotope	Mesophilic to meso-hygrophilous herbaceous formations and forest clearings between 500 and 1930 m altitude (Balkan peninsula)	Rather wet meadows, cold moors, mainly in the mountains (widely distributed in W Palaearctic)	Meadows with shrubs (*Genista* sp., *Rubus* sp., *Rosa* sp.) in forest edges (*Pinus* sp., *Fagus sylvatica*) in the oro-Mediterranean, between 700 and 1800 m altitude (Apennines)*

*According to Fontana & Odé (1999).

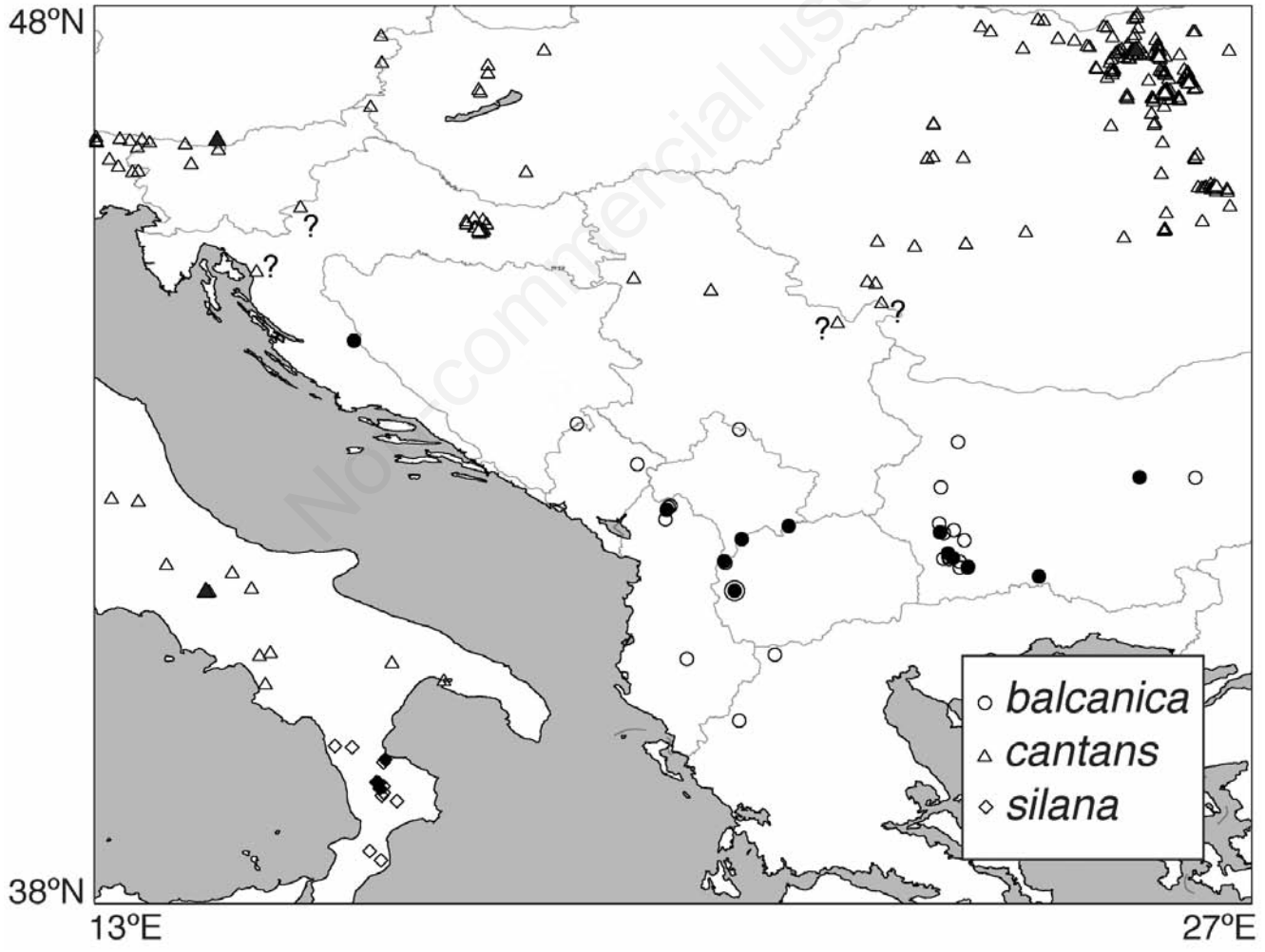

Figure 7. Distribution map of the *T. cantans*-group (excluding Austria for the most part). Black filled symbols: song data available. Italian localities according to Ruffo & Stoch (2005), the Romanian song locality from Iorgu & Pisica (2007).

Table 6. Key measurements (mm) of *Tettigonia balcanica*, *T. cantans* and *T. silana*.

	*T. balcanica Coll.**	*T. cantans*		*T. silana Literature****
		*Coll.***	*Literature****	
Body length ♂	25-29 (28)	24.5-27.5	21-31	20
Body length ♀	27-29 (27)	27.5	29-33	28-30
Pronotum length ♂	6.6-8.7 (7.5)	7-7.5	7-8	6.5-8
Pronotum length ♀	7-8.5 (7)	7-7.5	7-8	6.7-7
Tegmen length ♂	25.5-30.8 (29.5)	24-26.5	24-27 (-30)	23.2-31.5
Tegmen length ♀	28.5-31.7 (28.5)	24.5-26	24-27 (-31)	26-29
Maximum width of tegmen ♂	9.5-11.5 (10)	8.8-10.5	-	7.9-9
Maximum width of tegmen ♀	8-10 (8)	9-10	-	8.3
Hind femur length ♂	19.4-24.7 (20)	19-21	19-23	19.1-25
Hind femur length ♀	21.1-25.5 (21.5)	20-21	19-23	19.9
Ovipositor length	25-31.6 (25)	21.5-23	20-25	21.9-26

*All collected data (several collectors): 53♂ & 19♀; **Collection Lemonnier-Darcemont: 6 ♂, 3 ♀; ***According to Harz (1969); ****According to Fontana & Odé (1999); Capra (1936); La Greca (1948).

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