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On the taxonomic status of *Gomphocerus sibiricus turkestanicus* Mistshenko, 1951 (Orthoptera: Acrididae: Gomphocerinae) and on the subspeciation in grasshoppers in the mountains of Central Asia

О таксономическом статусе *Gomphocerus sibiricus turkestanicus* Mistshenko, 1951 (Orthoptera: Acrididae: Gomphocerinae) и о формировании подвидов у саранчовых в горах Средней Азии

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КЛЮЧЕВЫЕ СЛОВА: акустические сигналы, морфология, эволюция, Кыргызстан.

ABSTRACT. Comparative investigation of morphology and the male calling and courtship songs of *Gomphocerus sibiricus sibiricus* (Linnaeus, 1767) and *G. sibiricus turkestanicus* (Mistshenko, 1951) revealed no differences in either characters. Based on this, the synonymy *G. sibiricus sibiricus* = *G. sibiricus turkestanicus*, **syn.n.** is established. Previous studies of Central Asian subspecies of widespread Gomphocerinae species also showed that some of them are synonyms of nominotypical subspecies, while others are good species. No reliable cases of subspeciation in widespread species of Gomphocerinae in the mountains of Central Asia were revealed. It can be assumed that the Central Asian and West Siberian populations of Gomphocerinae are in contact through a continuous chain of mountain ranges of southeastern and eastern Kazakhstan and the adjacent territories of China, which prevents their divergence.

РЕЗЮМЕ. Сравнительное изучение морфологии, призывных сигналов и сигналов ухаживания самцов *Gomphocerus sibiricus sibiricus* (Linnaeus, 1767) и *G. sibiricus turkestanicus* (Mistshenko, 1951) не выявило различий ни по одному из признаков. На основании этого установлена синонимия *G. sibiricus sibiricus* = *G. sibiricus turkestanicus*, **syn.n.** Предыдущие исследования среднеазиатских подвидов широко распространенных видов Gomphocerinae также показали, что одни из них являются синонимами номинативных подвидов, а другие — хорошими видами. Достоверных случаев формирования подвидов у широко распространенных видов Gomphocerinae в горах Средней Азии не выявлено. Можно предположить, что среднеазиатские и западносибирские популяции Gomphocerinae контактируют через непрерывную цепь горных хребтов юго-восточного и восточного Казахстана и сопредельных территорий Китая, что препятствует их дивергенции.

Introduction

Gomphocerus sibiricus (Linnaeus, 1767) (Orthoptera: Acrididae: Gomphocerinae) is a Transpalearctic species occurring in the regions with rather cold climate. In the eastern part of European Russia and in Siberia it can live in the plains, further south it is found only in the mountains. Some mountain populations of *G. sibiricus* were described as subspecies (in particular, by Mistshenko, 1951), but later, based on investigation of both morphological and acoustic traits, they were proved to be good species. For example, in the course of the recent study of the genus *Gomphocerus* Thunberg, 1815 in Turkey, four of five taxa of this genus occurring in Anatolia were raised to the species rank [Mol, 2012; Mol *et al*., 2023]. On the other hand, four subspecific taxa are presently considered synonyms of *G. sibiricus sibiricus* [Cigliano *et al*., 2023] and *G. kudia sachalinensis* Mistshenko, 1951 is synonymized with *G. kudia kudia* Caudell, 1928 [Storozhenko, 1983]. This indicates that all taxa of subspecific rank in this genus require detailed study to clarify their status.

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G. sibiricus turkestanicus Mistshenko, 1951 was briefly described in the key to species and subspecies of *Gomphocerus* based on the material from many mountain ranges of Central Asia with the holotype from the Bolshaya Almatinka River, Zailiyskiy Alatau Range, Northern Tien Shan [Mistshenko, 1951]. According to the key, it differs from *G. sibiricus sibiricus* by proportions of the median antennal segments and the male forewing length. Differences in the pronotum proportions are not adequately described; for *G. sibiricus sibiricus* it is stated that its maximum to minimum width ratio in males is 2.5–3.0 (data on females are not given) and for *G. sibiricus turkestanicus* it is indicated that this ratio in females sometimes reaches 2 (data on males are absent). In almost unchanged form, these data are reproduced in the key to subspecies of *G. sibiricus* in Latchininsky *et al*. [2002].

Earlier we published the song oscillograms and photographs of a male of *G. sibiricus* collected in the Inner Tien Shan, which, according to morphological characters, belongs to the nominotypical subspecies [Tishechkin, 2017]. But since we had only one specimen at our disposal, this did not allow to draw any conclusions about the taxonomic status of *G. sibiricus turkestanicus*. Recently, we collected more material on *G. sibiricus* in the Inner Tien Shan, obtained additional song recordings and also, studied some collection materials on this species from Central Asia. The results of these studies with a discussion of the hypothesis on subspeciation in widespread species of Gomphocerinae in the mountains of Central Asia proposed by Pravdin [1969, 1978] are given below.

Material and methods

Recordings of the songs were made under natural conditions from freely-moving insects with a microphone Spirit IM-01 (frequency response 0.02–20 kHz) and cassette recorder "Elektronika-302-1" (before 2005) or minidisk recorder Sony Walkman MZ-NH900 with a sampling rate of 44.1 kHz (in 2014) or with a Roland R-05 digital audio recorder (frequency response 0.02–40 kHz, flat response 0.02–20 kHz) with a sampling rate of 96 kHz (in 2023). In all cases, manual mode of the recording level control was used. Air temperature was measured during or immediately after recording on the place where the singing insect was sitting. The specimens which songs were recorded were taken for taxonomic identification.

Song terminology is accepted after Ragge & Reynolds [1998]. Calling song is a sound produced by an isolated male for attracting conspecific female. Courtship song is a sound produced by a male when close to female. A syllable is a sound produced by one complete up- and downstroke of the hind leg. Short pauses in the sound resulting from the breaks during up- or downstroke of the leg are referred to as gaps. An echeme is a first-order assemblage of syllables.

Oscillograms of songs were produced with Cool Edit Pro 2.1 software. Measurements of morphological structures were made using a Motic SMZ-171-BP stereomicroscope with a micrometer eyepiece.

All studied materials are deposited in the collection of the Zoological Museum of Moscow State University.

Morphology

For morphological studies, samples of *G. sibiricus sibiricus* from the environs of Kuznetsk (Penza Oblast, European Russia), Nizhniy Tsasuchey (Chita Oblast, Transbaikalia), and Debin (Magadan Oblast, northern part of the Russian Far East) were used; in the population from Nizhniy Tsasuchey song recordings were also made (see below). *G. sibiricus turkestanicus* was studied using samples from the Kekemeren River basin, Terskey Ala-Tau Range, and the Kuylyu River valley (all collection sites are located in Tien Shan Mountains, Kyrgyzstan); in two localities from the Kekemeren River basin song recordings were also made.

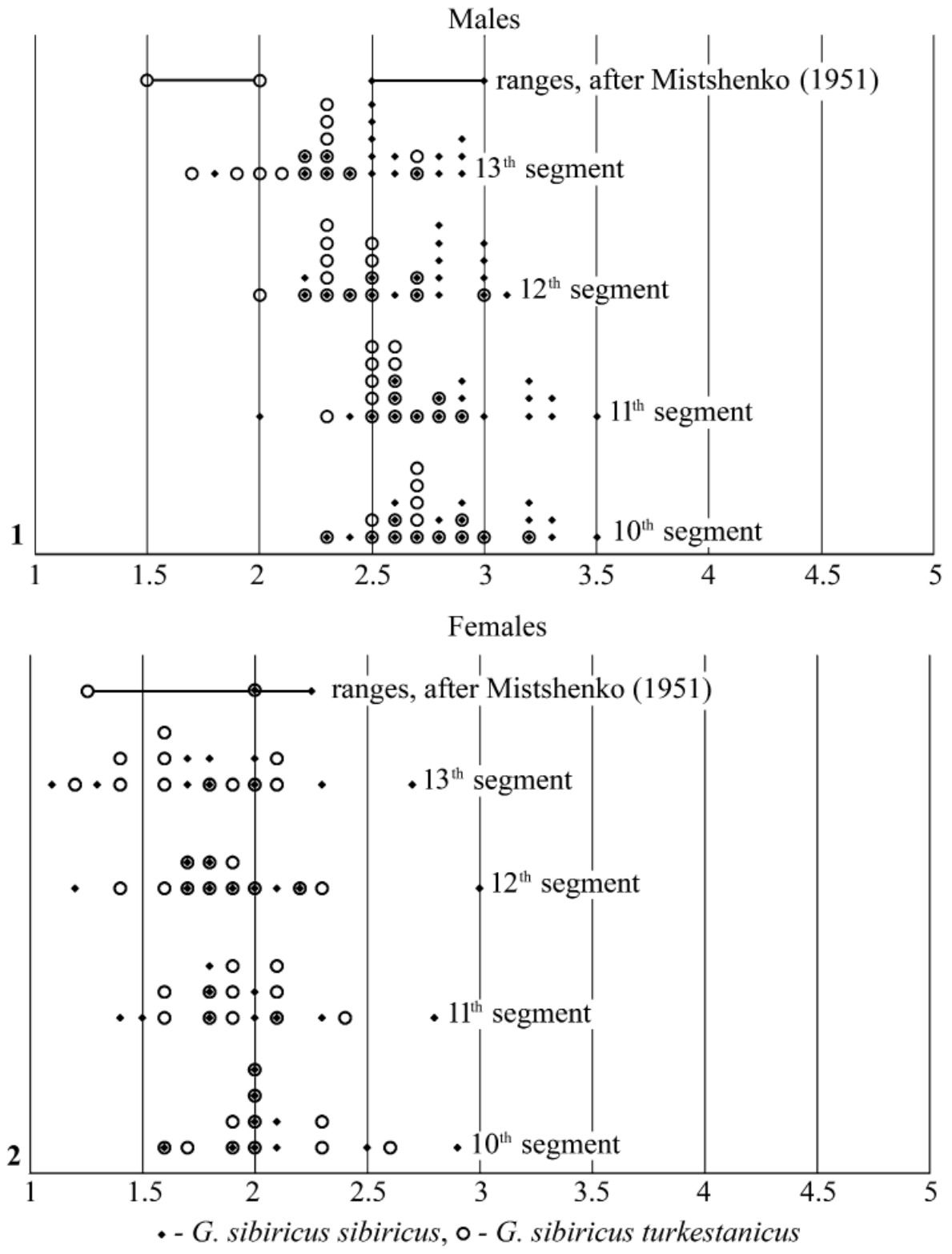
Proportions of the median antennal segments are considered the main character for distinguishing between *G. sibiricus sibiricus* and *G. sibiricus turkestanicus* [Mistshenko, 1951; Latchininsky *et al*., 2002]. According to the original description, the length of an individual median antennal segment in *G. sibiricus sibiricus* exceeds its maximum width by 2.5–3 times in male and by 2–2.25 times in female, while in *G. sibiricus turkestanicus* this ratio is 1.5–2 and 1.25–1.5, respectively.

Antennae of *G. sibiricus* normally are 24- or 23-segmented; sometimes the boundaries between any two segments are indistinguishable. In the present study, we measured the proportions of 10^{th}–13^{th} segments counting from the base. Since the antennal segments in *G. sibiricus* are somewhat flattened, for measurement they were placed in the broadest aspect.

Based on our material, it was impossible to reveal any differences between the two subspecies in this parameter. On the contrary, the ranges of the length-to-width ratio of each of the measured segments overlap almost completely both in males and in females (Figs 1–2). One can also easily verify this by measuring the antennal segments of specimens from different localities shown in the photos (cf. Figs 3–8, *G. sibiricus sibiricus*, and 9–14, *G. sibiricus turkestanicus*). In addition, the length-to-width ratio decreases from the 10^{th} to the 13^{th} segment in both sexes. Only in 3 of 15 studied males from Central Asia a length-to-width ratio of the 12^{th} and/or 13^{th} segments was less than or equal to 2, that is, consistent with the values given in the original description of *G. sibiricus turkestanicus* (Fig. 1). But even in these specimens, a length-to-width ratio of the 10^{th} and 11^{th} segments was higher i.e. as in *G. sibiricus sibiricus*.

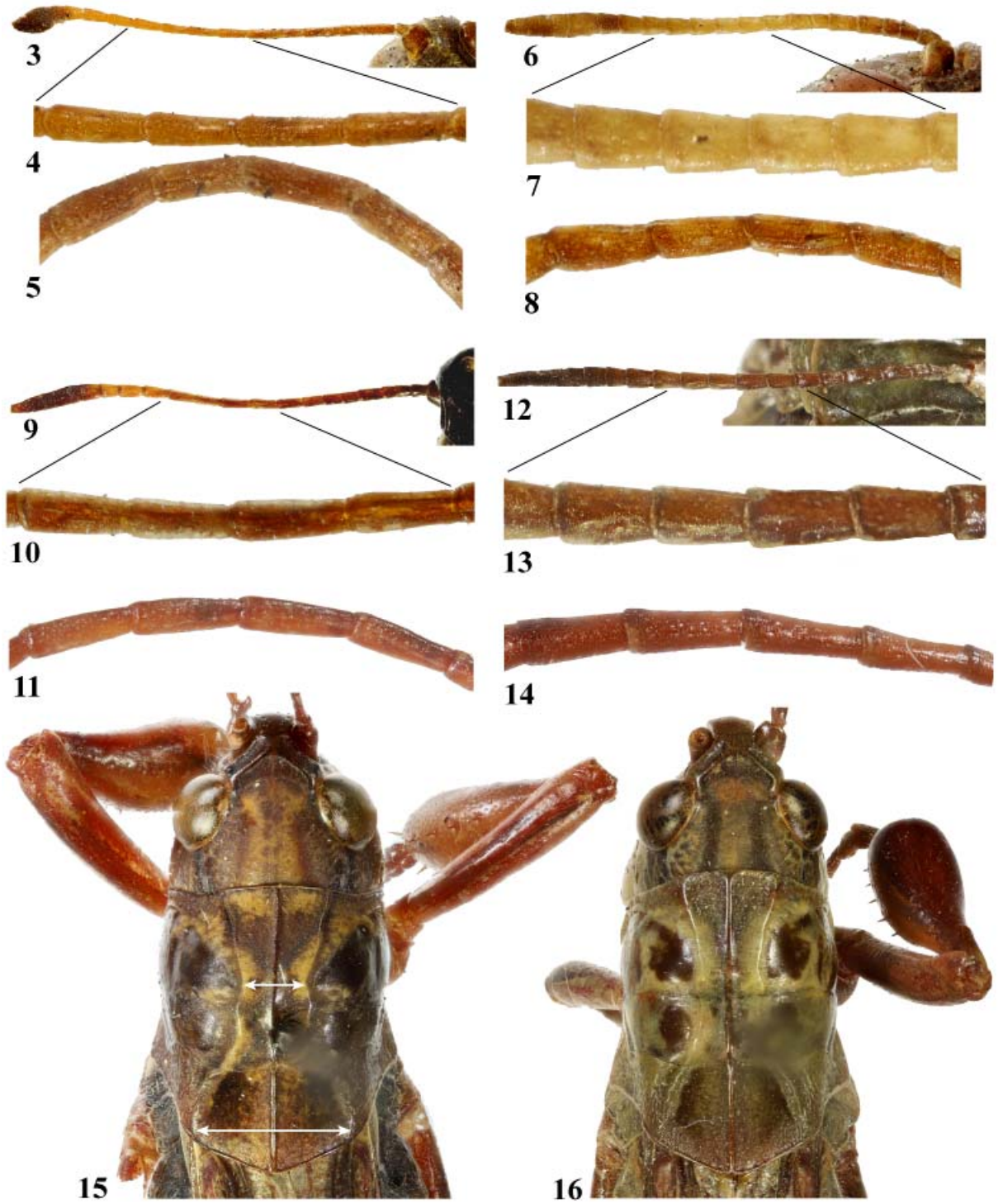
As mentioned above, data on proportions of the pronotum in the original description are incomplete. However, we measured the maximum-to-minimum length ratio in both subspecies. In *G. sibiricus sibiricus* it is on average higher than in *G. sibiricus turkestanicus*, but there is significant overlap between these taxa in this parameter, which can be seen both in the photos of specimens from Siberia and Kyrgyzstan (Figs 15–16) and on the diagram (Fig. 17).

Females of the two subspecies are indistinguishable in the length of forewings. In males of *G. sibiricus sibiricus* forewing are on average longer than in *G. sibiricus turkestanicus*. Still, there is also considerable overlap between them in this parameter; such distinct differences in the length of forewings, which were pointed out by Mistshenko [1951] were not found (Fig. 18).



Figs 1–2. Length-to-width ratio of the median antennal segments in two subspecies of *Gomphocerus sibiricus*. 1 — males, 2 — females. Each point on the diagram represents a measurement of one specimen; the parameter ranges given in the original description are shown above the diagrams as lines bounded by the corresponding marks.

Рис. 1–2. Соотношение длины и ширины средних сегментов антенн двух подвидов *Gomphocerus sibiricus*. 1 — самцы, 2 — самки. Каждая точка на диаграмме соответствует промеру одного экземпляра, диапазоны параметров, приведенные в первоописании, показаны над диаграммами в виде линий, ограниченных соответствующими значками.



Figs 3–16. *Gomphocerus sibiricus*. 3, 6, 9, 12 — antenna, 4–5, 7–8, 10–11, 13–14 — 10th–13th antennal segments, 15–16 — head and pronotum. 3–8 — specimens from European Russia, 9–14, 16 — specimens from Kyrgyzstan, 15 — specimen from Chita Oblast. 3–5, 9–11, 15–16 — males, 6–8, 12–14 — females. Scheme of measurements of minimum and maximum width of pronotum is shown by arrows on the Fig. 15.
Рис. 3–16. *Gomphocerus sibiricus*. 3, 6, 9, 12 — антенна, 4–5, 7–8, 10–11, 13–14 — 10–13-й антеннальные сегменты, 15–16 — голова и переднеспинка. 3–8 — экземпляры из европейской России, 9–14, 16 — экземпляры из Кыргызстана, 15 — экземпляр из Читинской области. 3–5, 9–11, 15–16 — самцы, 6–8, 12–14 — самки. Схема промеров минимальной и максимальной ширины переднеспинки показана стрелками на рис. 15.

Male songs

Song recordings were made in the following localities.

1. Russia, Irkutsk Oblast, 16–17 km north of Nizhneudinsk, the bank of the Uda River near the Uk River mouth, 1.VII.2003, calling songs of one male recorded at 35 °C (Figs 19, 25, 31, 37).

2. Russia, Buryatia, 10 km east of Onokhoy (about 60 km east of Ulan-Ude), the valley of the Bryanka River, 1. VII. 2006, calling songs of one male recorded at 36 °C (Figs 20, 26, 32, 38).

3. Russia, Chita Oblast, the valley of the Onon River 5–6 km west of Nizhniy Tsasuchey Village, 18–19. VI.1995, calling songs of two males recorded at 31–32 °C (Figs 21, 27, 33, 39).

4. Kyrgyzstan, Inner Tien Shan Mts., the Kekemeren River 8–9 km downstream from Kozhomkul village, mountain steppes on the left bank, 27.VI.2014, calling songs of one male recorded at 36 °C (Figs 22, 28, 34, 40).

5. Kyrgyzstan, Inner Tien Shan Mts., the Kekemeren River basin, steppe slope on the southern bank of the Western Karakol River ca 8 km from the mouth (ca 8 km east of the Suusamyr Village), 13.VII.2023, calling songs of one male (Figs 23, 29, 35, 41) and the courtship song of one male (Figs 24, 30, 36) recorded at 36 °C.

The calling and courtship songs of *G. sibiricus* were described by many authors; a complete list of references can be found in Vedenina *et al*. [2020]. The main part of the calling song is an echeme lasting from 10–15 up to 40–50 s (Figs 19–23). It begins quietly and usually reaches maximum intensity at about one third or a half of its duration. Each syllable consists of a longer lower-amplitude initial part with many gaps of variable duration and a shorter higher-amplitude end part. The first two thirds or one half of an end part usually includes 4–6 gaps (Figs 25–29, 31–35). Syllables follow each other at the rate of 5–6/s at 31–36 °C. At the end (Figs 20–23) and, more rarely, also at the beginning of an echeme (Fig. 19), syllables of lower intensity repeated at the rate of about 4/s can follow (Figs 37–41). Duration of this part and the shape of syllables vary greatly; sometimes it is almost reduced and includes only several low-amplitude syllables (Fig. 22).

The courtship song is similar to the calling, but its duration varies within wider limits (Figs 24, 30, 36; see also, Vedenina *et al*., 2020). The sequence of the low-amplitude syllables at the end of the courtship song can be strongly reduced or absent (Fig. 24).

Conclusions

Within the subfamily Gomphocerinae, subspecies differ in morphological characters, although not to the same extent as good species. In addition, they can differ in the song patterns while retaining species-specific features important for recognition by a conspecific female, such as the overall structure of the song (single echeme or an echeme-sequence), the general scheme of the syllable temporal pattern, and the syllable repetition rate; *Mongolotettix japonicus japonicus* (I. Bolivar, 1898) and *M. japonicus vittatus* (Uvarov, 1914) or *Chorthippus apricarius apricarius* (Linnaeus, 1758) and *Ch. apricarius major* (Pylnov, 1914) can be mentioned as examples [Vedenina, Bukhvalova, 2001; Tishechkin, 2017].

However, even in our very limited material, *G. sibiricus sibiricus* and *G. sibiricus turkestanicus* do not differ in any of the morphological characters used in the original description. The study of additional specimens from other parts of the range will undoubtedly only expand the revealed ranges of variability, due to which the overlap in morphometric parameters between these two taxa will become wider.

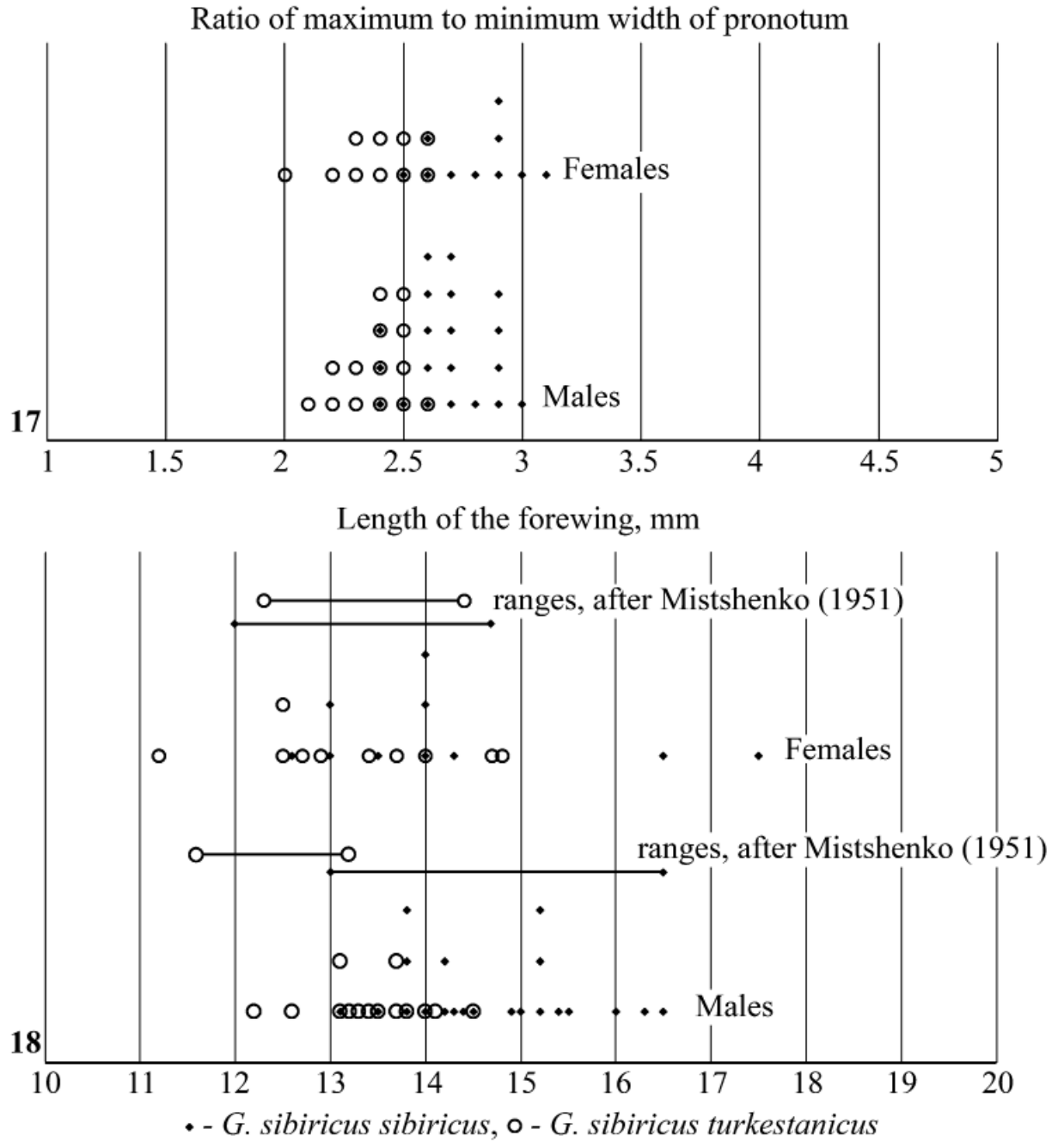
Male calling songs of different *Gomphocerus* species have the same general scheme of the temporal pattern and differ in the syllable patterns, including the number of gaps, and in the syllable repetition rate [Mol *et al*., 2023]. Based on these data, it can be argued that all calling songs we studied undoubtedly belong to the same species. Moreover, we revealed no differences between the songs of males from Central Asian and Siberian populations. We have only one recording of the courtship song of *G. sibiricus turkestanicus*, however, no differences were revealed between it and songs of this type in *G. sibiricus sibiricus* described by Vedenina *et al*. [2020].

Based on this, we establish the synonymy *G. sibiricus sibiricus* (Linnaeus, 1767) = *G. sibiricus turkestanicus* (Mistshenko, 1951), **syn.n.**

The mountain insect fauna of Central Asia is known to be characterized by high endemism on the generic and species levels. In Acridomorpha (Orthoptera), Pravdin [1969, 1978] distinguishes two groups of endemic Central Asian taxa. The first group includes mountain species with rather narrow ranges. The emergence of endemic taxa in this group is usually related to the disintegration of a mountain system into several orographic units; populations, thus being isolated by intermountain valleys, may evolve into separate subspecies or species. The isolation of different populations is also facilitated by the fact that most of such species are short-winged or wingless. A similar phenomenon is also known in Central Asian short-winged species of Tettigoniidae (Orthoptera) [Korsunovskaya, 2023].

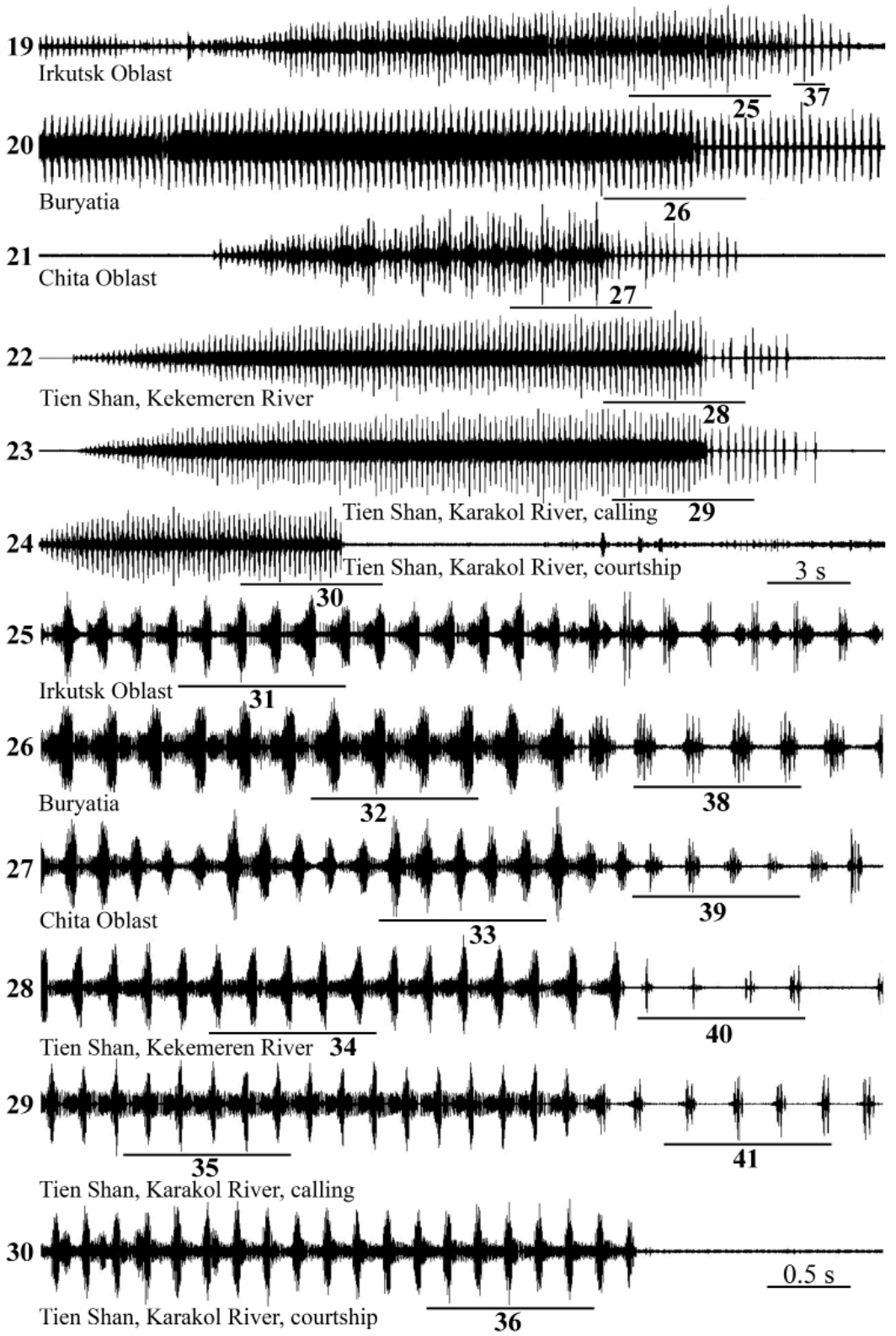
The second group is formed by widespread, long-winged, good flying species, at least part of whose ranges cover the temperate plains of the Palearctic, and whose Central Asian populations were described as separate subspecies. According to Pravdin [1969], this group includes the following species of Gomphocerinae: *Arcyptera microptera* (Fischer von Waldheim, 1833), *Dociostaurus kraussi* (Ingenitzky, 1897), *Notostaurus albicornis* (Eversmann, 1848), *G. sibiricus*, *Chorthippus biguttulus* (Linnaeus, 1758), *Ch. apricarius*, and *Ch. parallelus* (Zetterstedt, 1821). We have not conducted detailed studies of the first three species in Central Asia. A study of four other species showed that the taxonomic rank of their Central Asian populations was mis-

interpreted. Central Asian subspecies of *Ch. apricarius* and *G. sibiricus* are synonyms of nominotypical subspecies [Tishechkin, 2017 and the present paper]. *Ch. biguttulus meridionalis* Mistshenko, 1951 is a junior synonym of a Transpalearctic *Ch. maritimus* Mistshenko, 1951 [Bukhvalova, 1993, 1998; Tarasova *et al*., 2021]. The exact taxonomic status of *Ch. pamiricus* (Ramme, 1930), which is sometimes considered as a subspecies of



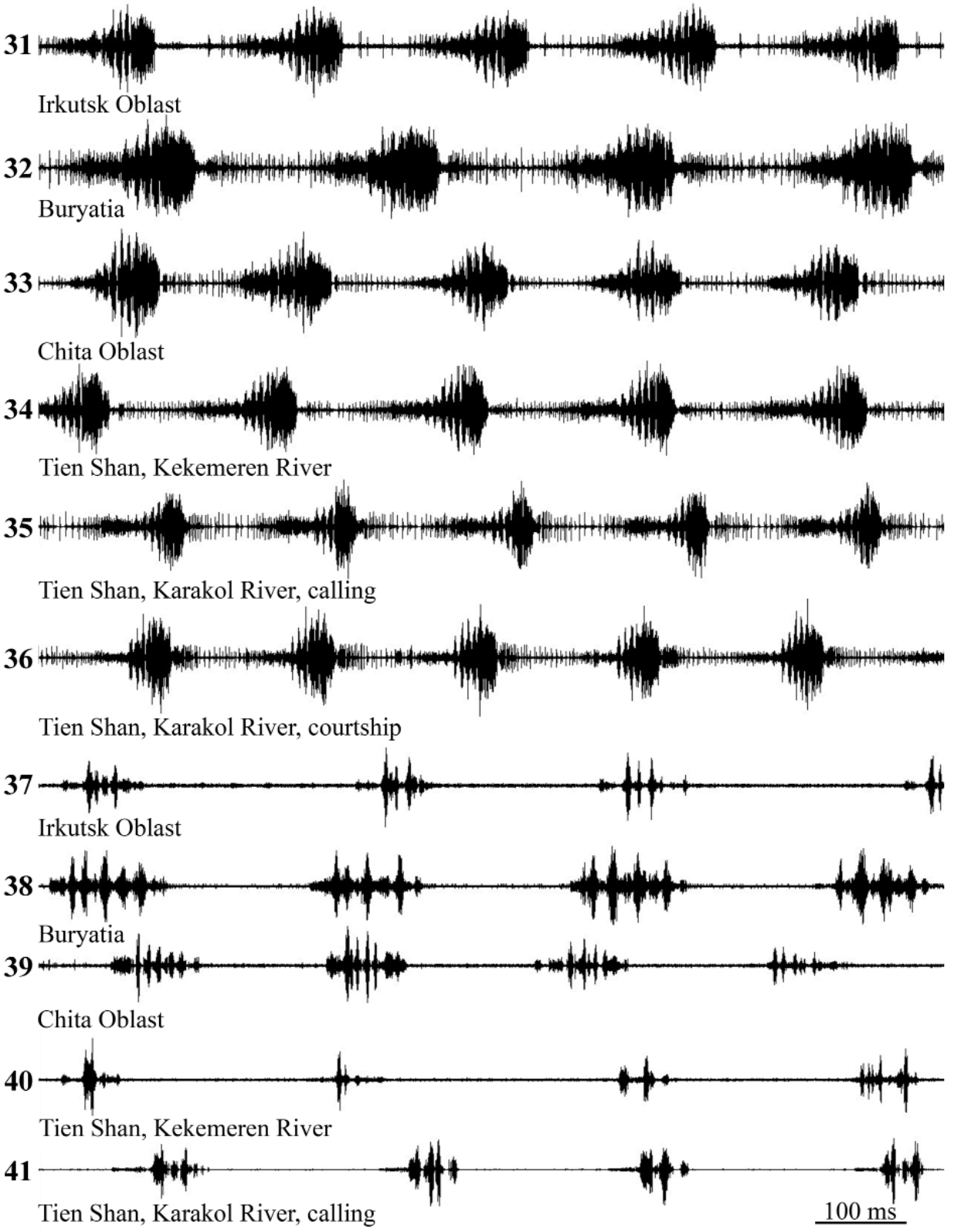
Figs 17–18. Morphometric parameters of two subspecies of *Gomphocerus sibiricus*. 17 — ratio of maximum to minimum width of pronotum, 18 — forewing length. Each point on the diagram represents a measurement of one specimen; the parameter ranges given in the original description are shown above the diagrams as lines bounded by the corresponding marks.

Рис. 17–18. Морфометрические параметры двух подвидов *Gomphocerus sibiricus*. 17 — соотношение максимальной и минимальной ширины переднеспинки, 18 — длина переднего крыла. Каждая точка на диаграмме соответствует промеру одного экземпляра, диапазоны параметров, приведенные в первоописании, показаны над диаграммами в виде линий, ограниченных соответствующими значками.



Figs 19–30. Oscillograms of male songs of *Gomphocerus sibiricus* from different localities. 19–23, 25–29 — calling song, 24, 30 — courtship song. Faster oscillograms of the parts of signals indicated as "25–41" are given under the same numbers. Scale mark "3 s" — for oscillograms 19–24, "0.5 s" — for oscillograms 25–30.

Рис. 19–30. Осциллограммы сигналов самцов *Gomphocerus sibiricus* из разных местонахождений. 19–23, 25–29 — призывный сигнал, 24, 30 — сигнал ухаживания. Фрагменты сигналов, помеченные цифрами "25–41", представлены на осциллограммах под соответствующими номерами. Отметка времени "3 s" — для осциллограмм 19–24, отметка времени "0.5 s" — для осциллограмм 25–30.



Figs 31–41. Oscillograms of male songs of *Gomphocerus sibiricus* from different localities. 31–35, 37–41 — calling song, 36 — courtship song. Scale mark at the bottom is the same for all oscillograms.
Рис. 31–41. Осциллограммы сигналов самцов *Gomphocerus sibiricus* из разных местонахождений. 31–35, 37–41 — призывный сигнал, 36 — сигнал ухаживания. Отметка времени внизу – общая для всех осциллограмм.

Ch. biguttulus [Mistshenko, 1951; Pravdin, 1969, 1978] is unclear. Still, it is extremely unlikely that it could be a subspecies of *Ch. biguttulus*, since the latter species penetrates south no further than the steppes of northern and eastern Kazakhstan [Bukhvalova, 1993]. *Ch. geminus* Mistshenko, 1951 originally described as a subspecies of *Ch. parallelus* was shown to be a good species, distinctly different from *Ch. parallelus* s.str. in a song pattern [Tishechkin, 2024].

Thus, no reliable cases of subspeciation in widespread species of Gomphocerinae in the mountains of Central Asia were revealed so far. This fact can be explained as follows. In the north, the mountains of Central Asia are separated from the steppe and forest zones by the deserts of Kazakhstan; this may lead to an erroneous conclusion about the geographic isolation of the Central Asian mountain populations of grasshoppers from these located to the north in the plains. However, the mountain systems of Central Asia are connected with the forest-steppe and mountainous regions of Western Siberia by an almost continuous chain of mountain ranges in southeastern and eastern Kazakhstan and in the adjacent regions of China. Gaps in this chain (for example, the so-called Dzhungarian Gate at the eastern end of the Dzhungarian Alatau) do not exceed several tens of kilometers and cannot serve as an effective barrier for well-flying insects. It can be assumed that it is through this pathway that genes are exchanged between the Siberian and Central Asian populations, which prevents the formation of subspecies in the mountains of Central Asia.

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