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Contributions to the study of *Ceraeocercus fuscipennis* Uvarov, 1910 (Orthoptera: Tettigoniidae) in Kazakhstan and Central Asia

К изучению *Ceraeocercus fuscipennis* Uvarov, 1910 (Orthoptera: Tettigoniidae) в Казахстане и Средней Азии

D.Yu. Tishechkin, O.S. Korsunovskaya
Д.Ю. Тишечкин, О.С. Корсуновская

Department of Entomology, Faculty of Biology, Lomonosov Moscow State University, Leninskie Gory, Moscow 119234, Russia. Email: macropsis@yandex.ru; korsuno@mail.ru

Кафедра энтомологии биологического факультета Московского государственного университета имени М.В. Ломоносова, Ленинские горы, Москва 119234, Россия.

KEY WORDS: bush-crickets, subspecies, morphology, acoustic signals, variability, ecology, distribution.

КЛЮЧЕВЫЕ СЛОВА: кузнечики, подвиды, морфология, звуковые сигналы, изменчивость, экология, распространение.

ABSTRACT. Redescriptions and the male calling song oscillograms and frequency spectra of *Ceraeocercus fuscipennis fuscipennis* from southeastern Kazakhstan and *C. fuscipennis hindukushanus* from southern Kyrgyzstan are provided, data on the biology of this species in the localities studied are given. The variability of coloration, morphology, and calling song patterns in males from different localities are discussed. *C. fuscipennis hindukushanus* is recorded from Kyrgyzstan for the first time.

РЕЗЮМЕ. Приведены переописания, а также осциллограммы и частотные спектры призывных сигналов самцов *Ceraeocercus fuscipennis fuscipennis* из юго-восточного Казахстана и *C. fuscipennis hindukushanus* из южного Кыргызстана, представлены данные о биологии этого вида в изученных местонахождениях. Обсуждается изменчивость окраски, морфологии и структуры сигналов у самцов из разных географических точек. *C. fuscipennis hindukushanus* впервые указан для территории Кыргызстана.

Introduction

Ceraeocercus fuscipennis Uvarov, 1910 (Orthoptera: Tettigoniidae) belongs to the monotypical genus of Drymadusini (Orthoptera: Tettigoniidae) and was described from the environs of Lake Inder in northwestern Kazakhstan [Uvarov, 1910]. Later it was shown that this species is widely distributed in the arid plains and low mountains of Central Asia. The range of the nominotypical subspecies, *C. fuscipennis fuscipennis* Uvarov, 1910, includes semi-deserts of the Lower Volga Region of Russia [Pirogovskiy, 2014], Kazakhstan, Turkmenistan, Tajikistan, China (Xinjiang) [Liu et al., 2019], Iran, Uzbekistan [Karabag, 1961], and Kyrgyzstan [Myrzaliev, 1996]; also, it was included in the keys to species of insects of the European Russia, but was recorded in this book only from Kazakhstan and Central Asia [Bei-Bienko, 1964]. *C. fuscipennis hindukushanus* Ramme, 1939 is known from Afghanistan and Tajikistan [Pokivailov, 2017; Liu et al., 2019].

A redescription of *C. fuscipennis fuscipennis*, a description of the male of *C. fuscipennis hindukushanus*, and a key to subspecies was published by Karabag [1961]. Recently, redescription of *C. fuscipennis fuscipennis* based on the material from Xinjiang, China was published by Liu et al. [2019]; in the same paper oscillograms and frequency spectrum of the male calling song from Mangystau District, northwestern Kazakhstan were provided.

Despite its wide distribution, *C. fuscipennis* is considered a rare species and is included in the Red Books of the Astrakhan Oblast (Russia) [Pirogovskiy, 2014] and Kazakhstan [Nasyrova, 2003]. On the other hand, Childebaev and Kazenas [2013] indicate that this species is quite abundant in some regions of Kazakhstan.

In the present article data on morphology, biology, and calling songs of *C. fuscipennis fuscipennis* from southeastern Kazakhstan and of *C. fuscipennis hindukushanus* from southern Kyrgyzstan are given. Both localities are far from the Mangystau District, where the only published song recording of *C. fuscipennis* was

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made (ca 2000 and 1500 km, respectively). Comparison of the morphological and acoustic traits of specimens from these localities will provide new data on the variability of this widespread but sill poorly studied species.

Material collection and field observations were carried out by D. Tishechkin, the study of the material and the analysis of song recordings in the laboratory, as well as the writing of the text, were performed by D. Tishechkin and O. Korsunovskaya.

Material and methods

Insects for song recordings and morphological studies were collected in the following localities.

C. fuscipennis fuscipennis: southeastern Kazakhstan, northwestern part of Dzhungarskiy Alatau Range, the gorge 6 km east of Kyzyl-Agach (45.388°N, 78.814°E), 30.VI.2022, signals of one male were recorded at 22 °C. Songs were recorded under natural conditions from the freely moving insect 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.

C. fuscipennis hindukushanus: southern Kyrgyzstan, Batken Oblast, semi-desert on the slopes of low mountains on the northern shore of the Tortkul Reservoir, ca 10 km southwest of Batken (40.003 N, 70.719 E), 13.VII.2014, signals of one male were recorded at 25 °C. Songs were recorded under natural conditions from the caged freshly captured male with an external microphone Spirit IM-01 (upper frequency range 20 kHz) and minidisc recorder Sony Walkman MZ-NH900 (sampling rate 44.1 kHz).

Acoustic signals were processed using the CoolEdit-Pro 2.1 and PowerGraph 3.3 softwares. For fast Fourier transform, the PowerGraph program was used with FFT size of 8192 lines. If necessary, a band stop filter was used to eliminate 50 Hz background noise.

Most temporal parameters of the sound signals are given as means and standard deviations calculated using $\geq$30 measurements.

To describe sound signals, we mainly follow terminology offered by Baker and Chesmore [2020] and Heller et al. [2021]. **Calling song** is a spontaneous song produced by an isolated male. **Impulse** is a short sound click arising during the contact of a single tooth of a stridulatory file (pars stridens) with a plectrum. **Syllable** is a sound produced during one cycle of the tegmina movements, i.e. opening and closing of the tegmina, producing **opening** and **closing hemisyllables**, respectively. **Syllable repetition rate** is a number of syllables per second. **Echeme** is a first-order assemblage of syllables. **Echeme repetition rate** is a number of echemes per second. **Phrase** is a group of echemes. The main elements of the signal temporal pattern are further marked in the corresponding figures.

Materials studied are deposited in the collections of the Zoological Museum and of the Department of Entomology of Lomonosov Moscow State University.

Results

Coloration and morphology

In terms of coloration, studied males from Kazakhstan do not differ from specimens shown in photographs of other authors from Kazakhstan [Childebaev, Kazenas, 2013; Pirogovskiy, 2014] and China [Liu et al., 2019]. They have smoky black hindwings and thus undoubtedly belong to the nominotypical subspecies, since such wing coloration is one of the main diagnostic traits of *C. fuscipennis fuscipennis* (Figs 1–4).

The only studied male from southern Kyrgyzstan is somewhat slenderer than males from Kazakhstan, distinctly lighter, with hind wings brown with lighter fenestration, and with another shape of the dark pattern on the pronotum (Figs 5–8). In coloration, it fits the description of *C. fuscipennis hindukushanus*. However, in males from both localities, as well as in specimen depicted in Liu et al. [2019], tegmina almost reach hind knee, whereas, according to Karabag [1961], in the nominotypical subspecies tegmina and wings do not reach hind knee, while in *C. fuscipennis hindukushanus* they extend beyond it.

The shape of the mirror on the right tegmen is identical in males of both subspecies (Figs 9–10). The stridulatory file in a male from southeastern Kazakhstan consists of 53 teeth which gradually become smaller towards both ends; approximately the 10th–20th teeth from the costal margin are the largest (Fig. 11). On the whole, the stridulatory apparatus in our specimens does not differ from that described by Liu et al. [2019].

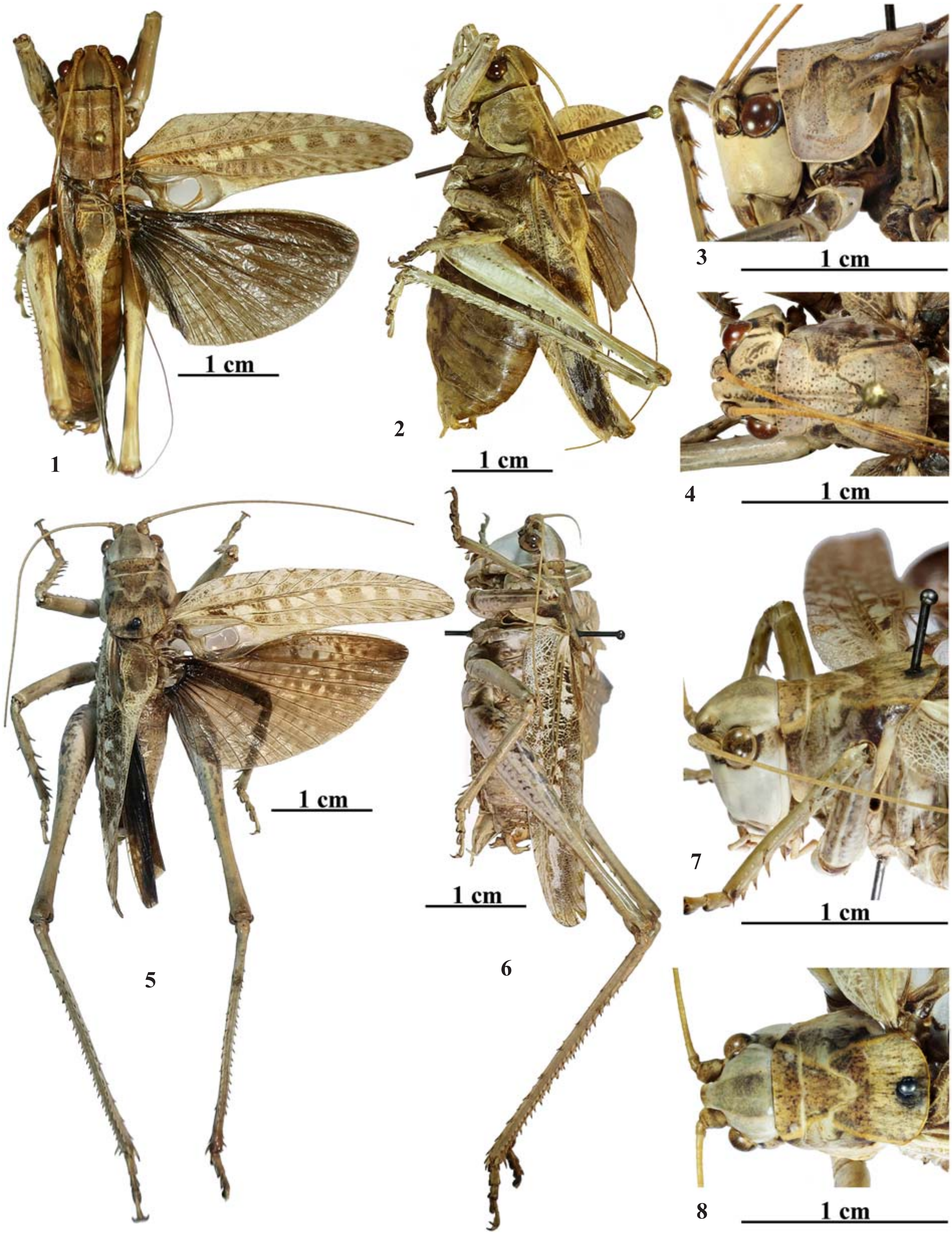
In the figure in the original description [Uvarov, 1910] (Fig. 12) and on photos in Liu et al. [2019] branches of cerci are strongly divergent. In *C. fuscipennis fuscipennis* from southeastern Kazakhstan, branches of cerci are parallel and touching each other or only slightly divergent (Figs 13–15), whereas in *C. fuscipennis hindukushanus* from southern Kyrgyzstan they are strongly divergent (Figs 16–17). In both subspecies cerci do not or only slightly exceed the subgenital plate (Figs. 18–20).

The notch on the back margin of subgenital plate is widely rounded in males from southeastern Kazakhstan (Fig. 19), but angular in male from southern Kyrgyzstan (Fig. 20); in Karabag [1961] and Liu et al. [2019] intermediate variants are depicted for the nominotypical subspecies.

Male calling song

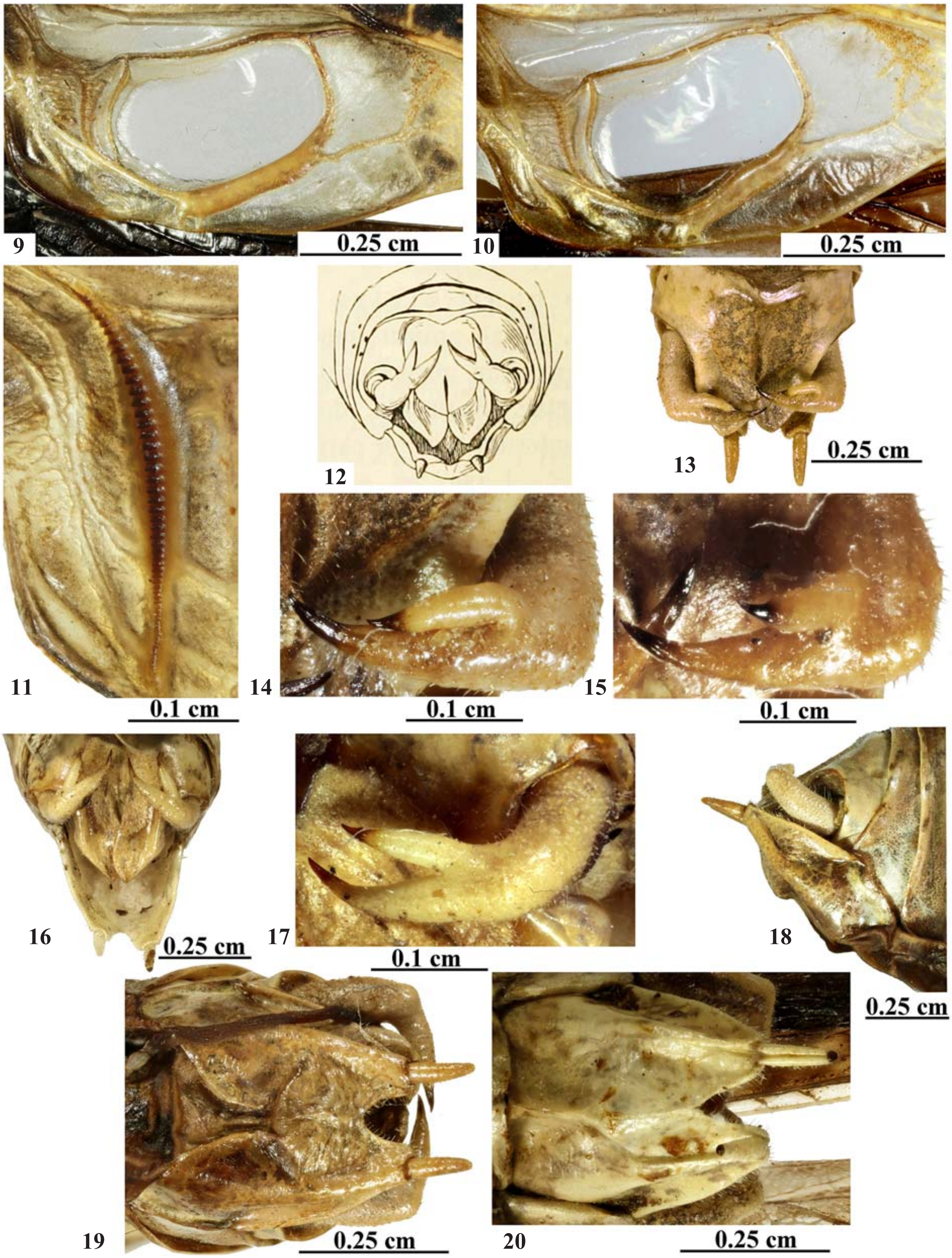
Males of both subspecies produce periodic echeme sequences, i.e. phrases lasting from 2.6 to 10 s in our recordings (Fig. 21). The duration of gaps between the phrases also varies greatly. However, the phrase repetition rate during sustained singing is relatively constant, 0.14 s^{-1} (SD=0.01 s^{-1}, n=10) in *C. fuscipennis fuscipennis* and 0.09 s^{-1} (SD=0.015 s^{-1}, n=9) in *C. fuscipennis hindukushanus*.

Each echeme consists of two syllables, the first one having slightly lower amplitude than the second (Figs 22–27). In *C. fuscipennis fuscipennis* at a temperature



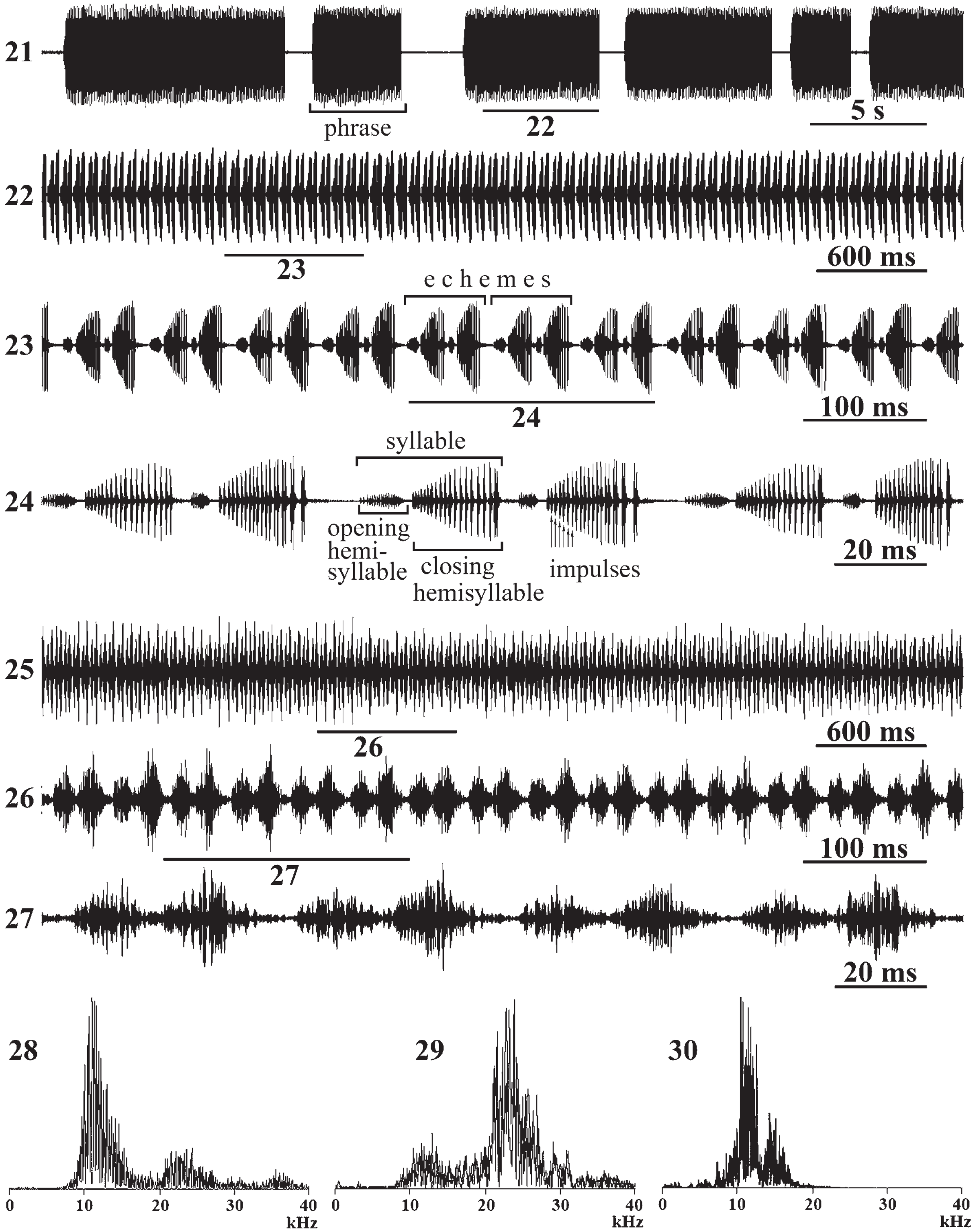
Figs 1–8. *Ceraeocercus fuscipennis*, males: 1–4 — *C. f. fuscipennis*; 5–8 — *C. f. hindukushanus*; 1–2, 5–6 — habitus; 3–4, 7–8 — head and pronotum; 1, 4–5, 8 — dorsal view; 2–3, 6–7 — lateral view.

Рис. 1–8. Самцы *Ceraeocercus fuscipennis*: 1–4 — *C. f. fuscipennis*; 5–8 — *C. f. hindukushanus*; 1–2, 5–6 — внешний вид; 3–4, 7–8 — голова и переднеспинка; 1, 4–5, 8 — сверху; 2–3, 6–7 — сбоку.



Figs 9–20. *Ceraeocercus fuscipennis*, males: 9, 11–15, 18–19 — *C. f. fuscipennis*; 10, 16–17, 20 — *C. f. hindukushanus*; 9–10 — mirror on the right tegmen; 11 — stridulatory file; 12 — end of abdomen, back view; 13, 16 — same, dorsal view; 14–15, 17 — right cercus, 18 — end of abdomen, lateral view; 19–20 — subgenital plate; 12 — after Uvarov [1910].

Рис. 9–20. Самцы *Ceraeocercus fuscipennis*: 9, 11–15, 18–19 — *C. f. fuscipennis*; 10, 16–17, 20 — *C. f. hindukushanus*; 9–10 — зеркальце на правом надкрылье; 11 — стридуляционный файл; 12 — конец брюшка, вид сзади; 13, 16 — то же, сверху; 14–15, 17 — правый церк, 18 — конец брюшка, вид сбоку; 19–20 — субгенитальная пластинка; 12 — по Уварову [1910].



Figs 21–30. Male calling signals of *Ceraeocercus fuscipennis*: 21–24, 28–29 — *C. f. fuscipennis*; 25–27, 30 — *C. f. hindukushanus*; 21–27 — oscillograms; 28, 30 — frequency spectra of syllables in linear scale; 29 — same, opening hemisyllable. Faster oscillograms of the parts of signals indicated as “22–24” and “26–27” are given under the same numbers.

Рис. 21–30. Призывные сигналы самцов *Ceraeocercus fuscipennis*: 21–24, 28–29 — *C. f. fuscipennis*; 25–27, 30 — *C. f. hindukushanus*; 21–27 — осциллограммы; 28, 30 — частотные спектры серий (в линейном масштабе); 29 — то же, интерпульсов (opening hemisyllable). Фрагменты сигналов, помеченные цифрами “22–24” и “26–27”, представлены при большей скорости развёртки на осциллограммах под соответствующими номерами.

of 22 °C, the duration of the first syllable is 30.9 ms (SD = 1.1 ms), of the second one is 27.2 ms (SD = 1.2 ms), the syllable repetition rate in the echeme is 29.6 s^{-1} (SD=0.64 s^{-1}), the duration of the echeme is 60.4 ms (SD = 1.3 ms), and the echeme repetition rate is 14.3 s^{-1} (SD=0.33 s^{-1}). Each syllable is subdivided into opening and closing hemisyllables (Fig. 24). The closing hemisyllables have a higher amplitude than the opening ones and consist of about 20 discrete impulses; the first closing hemisyllable in the echeme usually is somewhat shorter (17–19 ms) than the second one (17–22 ms). The duration of opening hemisyllables lies in the range of 7–10 ms (the first opening hemisyllable) or 3–5 ms (the second opening hemisyllable). Each opening hemisyllable also consists of well-defined impulses.

In the frequency spectrum of an echeme as a whole, the dominant frequencies lie in the range of 10–13 kHz. In addition to the main maximum, there are low-amplitude peaks at ca 23 and 36 kHz (Fig. 28). The opening and closing hemisyllable spectra are distinctly different. The dominant frequencies of the opening hemisyllable are ca 21–26 kHz (Fig. 29). The spectrum of the closing hemisyllable is almost identical to the spectrum of the echeme as a whole, since the amplitude, and, consequently, the energy of the opening hemisyllable is much lower and therefore its components are not visible on the overall spectrum graph.

In *C. fuscipennis hindukushanus* at a temperature of 25 °C, the duration of the first syllable in the echeme is 18.2 ms (SD = 1.2 ms), of the second one is 21.2 ms (SD = 1.6 ms), the syllable repetition rate in the echeme is 50.8 s^{-1} (SD = 2.2 s^{-1}), the duration of the echeme is 42.2 ms (SD = 1.8 ms), and the echeme repetition rate is 20.7 s^{-1} (SD = 0.4 s^{-1}). The opening hemisyllables, as well as discrete impulses in hemisyllables, are indistinguishable on oscillograms (Figs 26–27).

The frequency response of the recording equipment allows us to analyze the frequency spectrum of this signal only in the range of up to 20 kHz. The dominant frequencies in our recording lie in the range of 10–13 kHz (Fig. 30).

Biology

C. fuscipennis has a nocturnal acoustic activity. Males start singing only after the onset of almost complete darkness.

In the northwestern part of Dzhungarskiy Alatau, southeastern Kazakhstan, singing males of *C. fuscipennis fuscipennis* were abundant in a narrow gorge with dense grass vegetation and shrubs, mainly, *Spiraea hypericifolia* L. and *Rosa* sp. (Rosaceae). Males were most numerous in the thickets of *Rosa* sp. under the mountain slope (Fig. 31); here the distance between singing individuals sometimes did not exceed 1.5–2 m. Males usually were singing amid the thorny branches about 0.5–0.7 m above the ground (Fig. 32).

In Batken Oblast, southern Kyrgyzstan, this species was found in semi-desert low mountains among sparse vegetation (Fig. 33). Population density was low; the distance between singing males averaged several tens of meters. Males were mostly located in the bushes of *Capparis spinosa* L. (Capparidaceae) creeping along the ground; males kept for 1–2 days in cages readily fed on the fruits of this plant.


31


32


33

Figs 31–33. Habitats of *Ceraeocercus fuscipennis*: 31 — *C. f. fuscipennis* in southeastern Kazakhstan; singing males concentrated in bush thickets under the rocky slope; 32 — same locality, singing male, photo with a flash lamp; 33 — *C. f. hindukushanus* in southern Kyrgyzstan.

Рис.31–33. Местообитания *Ceraeocercus fuscipennis*: 31 — *C. f. fuscipennis* в юго-восточном Казахстане; поющие самцы концентрировались в зарослях кустарников под каменистым склоном; 32 — там же, поющий самец, фото с лампой-вспышкой; 33 — *C. f. hindukushanus* в южном Кыргызстане.

It should be added that we also found single individuals in the daytime on rocky slopes covered with sparse vegetation in the canyons of the Charyn and Temirlik rivers (a tributary of the Charyn) in southeastern Kazakhstan.

In general, these observations confirm the data of Childebaev and Kazenas [2013: 89] that “the abundance of this species is quite high, at least in the southern low mountains of the Dzhungarskiy Alatau, in the eastern low spurs of the Zailiyskiy Alatau, in the Karatau mountains, and on Mangyshlak”.

Distribution

Information from the literature and our observations indicate that *C. fuscipennis fuscipennis* is widespread in semi-deserts and arid low mountains of the central Palearctic.

C. fuscipennis hindukushanus so far was known only from Afghanistan and Tajikistan. The finding of this subspecies in southern Kyrgyzstan can be explained by the fact that the collection point is located in the foothills of the Turkestan Range belonging to Hissar-Darvaz mountain system. The southern slopes of this range are located on the territory of Tajikistan and the northern ones belong to Kyrgyzstan. Due to this, some Hissar-Darvaz taxa inhabiting the Turkestan Range penetrate to the very south of Kyrgyzstan.

Discussion

The available material is far from sufficient to study the variability of *C. fuscipennis*, but even a comparison of several specimens from remote localities allows us to draw some preliminary conclusions.

Despite distinct differences in coloration between the two subspecies, no differences between them in the shape of the male cerci and the subgenital plate could be revealed. In *C. fuscipennis fuscipennis* from southeastern Kazakhstan, the branches of the cerci are parallel or slightly divergent (Figs 14–15). In *C. fuscipennis fuscipennis* from the type locality [Uvarov, 1910] and from Xinjiang, China as well as in the studied male of *C. fuscipennis hindukushanus*, their branches are strongly divergent (Figs 12, 17). Similarly, *C. fuscipennis fuscipennis* from southeastern Kazakhstan has a widely rounded notch on subgenital plate, while *C. fuscipennis fuscipennis* from Xinjiang and *C. fuscipennis hindukushanus* from southern Kyrgyzstan have a more angular notch (cf. Figs 19 and 20). Thus, different variants of the shape of the cerci and the subgenital plate can be found in males belonging to the same subspecies.

Comparison of the calling songs of males of different subspecies shows that they have a very similar temporal pattern. These are two-syllabic echemes that form repeated phrases. Some differences in the duration of certain song elements are obviously due to the different recording temperatures in the two localities.

Syllable patterns in males from the two localities are also slightly different. First, in *C. fuscipennis fuscipennis*, unlike *C. fuscipennis hindukushanus*, the opening and closing hemisyllables are visible on oscillograms (cf. Figs 24 and 27). We believe that such differences result from the low upper frequency range of the equipment used for signal recording of *C. fuscipennis hindukushanus*. In *C. fuscipennis fuscipennis*, the spectrum of the opening hemisyllable has a higher frequency composition than that of the closing hemisyllable; the same is observed in other species of bush-crickets, for example, in *Lithodusa* spp. [Heller, Korsunovskaya, 2009]. For this reason, using the microphone with low sensitivity to high frequencies, opening hemisyllables will not be recorded, and only low-frequency closing hemisyllables will be visible on the oscillograms.

Second, in the song of *C. fuscipennis hindukushanus* and in the song of *C. fuscipennis fuscipennis* from northwestern Kazakhstan, described by Liu et al. [2019], separate impulses in syllables are indistinguishable, whereas in the song of *C. fuscipennis fuscipennis* from southeastern Kazakhstan they are quite distinct.

Due to differences in the recording equipment, comparison of the frequency spectra in two *C. fuscipennis* subspecies was possible only in the range up to 20 kHz; in both taxa, the dominant frequencies occupy the range of 10–13 kHz.

Comparison of the calling songs of *C. fuscipennis* and other Drymadusini [Korsunovskaya et al., 2002; Heller, Korsunovskaya, 2009; Şirin et al., 2014] showed that the studied species produces signal with a high duty cycle.

In *C. fuscipennis* at 25 °C, the echeme repetition rate somewhat exceeds 20 s^{-1}, and the syllable frequency rate is more than 50 s^{-1}. Such signals are relatively rare in the representatives of this tribe. Similar echeme repetition rate is observed in *Anadrymadusa picta* (Uvarov, 1929) (14.3 s^{-1} at 21 °C), *Pezodrymadusa subinermis* Karabag, 1961, and *P. lata* Karabag, 1961 (15 and 17 s^{-1} at 30 °C, respectively). In terms of syllable repetition rate in the echeme, the song of *C. fuscipennis* is similar to this of *Atlanticus brunneri* (Pylnov, 1914) (45.5 s^{-1}).

The calling song of *C. fuscipennis* belongs to the group of signals with a complex hierarchical temporal pattern. It has three rhythmic levels: the syllable repetition rhythm within an echeme, the echeme repetition rhythm within a phrase, and the phrase repetition rhythm. This indicates that the sound center of this species has rhythm generators of the first, second, and third orders. In representatives of Drymadusini, such signals are known in species from the genera *Anadrymadusa* Karabag, 1961 [Korsunovskaya et al., 2002], *Lithodusa* Bei-Bienko, 1951 [Heller, Korsunovskaya, 2009], and *Pezodrymadusa* Karabag, 1961 [Şirin et al., 2014]. However, the third-order rhythm generator in *C. fuscipennis*, unlike, for example, *Anadrymadusa retowskii* (Adelung, 1907) and *Pezodrymadusa* spp., works less precisely, which is why the duration of phrases and gaps between them varies greatly. Nevertheless, the phrase repetition rate is relatively constant due to the fact that an increase in the duration of a phrase is compensated by a reduction of the subsequent gap. In addition, the phrases of *C. fuscipennis* are significantly longer and their repetition rate is lower than that of species mentioned above.

According to our observations, *C. fuscipennis* has rather broad ecological preferences, since the two studied localities differ greatly in species composition, height, and density of vegetation. Taking into account that the range of this species is very wide, its further findings in Central Asia in the zone of dry steppes and semi-deserts, both in the plains and in the low mountains can be expected. On the northwestern border of its range (in the Astrakhan Oblast of Russia), this species may be rare and needs protection, but in general, at the moment it is not endangered, so its inclusion in the red lists should be more justified.

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Competing interests. The authors declare no competing interests.

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