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Articles

# Endemic grasshoppers (Orthoptera, Acridoidea) of the steppes of West Siberia and North-East Kazakhstan: how can we estimate their future?

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The distribution patterns of 3 rare acridid species, namely *Asiotmethis jubatus* (Uvarov, 1926) (Pamphagidae), *Aeropedellus baliolus* Mistshenko, 1951 and *Mesasippus arenosus* (Bey-Bienko, 1930), are described and compared. In the region, there are the type localities of these species. *A. jubatus* and *M. arenosus* are very rare and mainly associated with the dry steppes and the semi-deserts of the region, while *A. baliolus* are more or less common and distributed over the steppes from their northern boundary up to the southern one. The ecologo-geographic modelling based on the Maxent approach allows to reveal the potential distribution patterns of habitats applicable for each species to forecast possible shifts of species distributions relative to feasible climatic changes according the Shared Socioeconomic Pathway 3-7.0 and the global climate model CNRM-ESM2-1. The comparative analysis of the species distributions, the predicted distributions of suitable conditions and the forecasts of their possible shifts showed that predictions for the endemic steppe species can be quite different. The fore-casts for *A. jubatus* and *M. arenosus* based on the species distribution models and the predictions of high greenhouse gas emissions show that they may become relatively prosperous in the middle of the 21st century and the northern boundaries of the optimal parts of their ranges may shift northward. The predictions for *A. baliolus* show that the species optimal territories may catastrophically reduce in the future (from 265,000 km$^2$ now up to about 18,000 km$^2$ in the middle of the 21st century). As a result, the conservation status of *A. baliolus* may significantly change, because it will explicitly meet the IUCN criteria of the Vulnerable species.

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# Keywords

Caelifera, Acrididae, Pamphagidae, rare species, Russia, modelling, forecast

# Introduction

Many grasshoppers (Acridoidea) are characterized by wide distribution and very abundant populations. Some of them are known as harmful insects, especially across grasslands and agricultural fields. Nevertheless, this superfamily includes numerous endemic and rare species meriting conservation efforts, especially in mountains (Uvarov 1928; Sergeev 1992, 1998; Samways and Lockwood 1998; Lockwood and Sergeev 2000; Steck et al. 2007). The actual version of the IUCN Red List of Threatened Species (IUCN 2024) includes more than 460 grasshopper species. Many taxa are on regional Red Lists/Books as well (Kleukers and Felix 2020). In the grassland areas, local endemics and rare forms often occur either in the same habitats as possible pests or in the adjacent ecosystems (Sergeev 1996, 1998, 2021a, 2021b). This is why the pest population management, especially insecticide treatments, may strongly affect some local populations of rare species. Besides, the last ones can also fall prey to some ecosystem transformation processes, especially ploughing and overgrazing. Moreover, the global warming may cause significant changes in the rare species distributions as well.

In the steppes of the southern parts of West Siberia and in North-East Kazakhstan (including the so-called Kazakh Uplands or Saryarka), there are 3 endemic acridid species, namely *Asiotmethis jubatus* (Uvarov, 1926) (Pamphagidae), *Mesasippus arenosus* (Bey-Bienko, 1930), and *Aeropedellus baliolus* Mistshenko, 1951 (Acrididae). The type localities of *A. jubatus* and *M. arenosus* are in the Kulunda steppe between the Irtysh and Ob Rivers. *A.baliolus* was described from the central part of the Kazakh Uplands. All species are distributed over the steppe landscapes, their ranges overlap, however, their ecological preferences are similar, but particular. This means the modern conservation statuses and the future of these 3 grasshoppers may be quite different. The aim of this publication is to reveal distribution patterns of 3 endemic acridid species of West Siberia and north-east Kazakhstan and to model possible shifts in these patterns in the future.

# Materials and methods

Original data were collected from 1976 until 2023 in the southern parts of West Siberia and in the northern, north-eastern and central parts of Kazakhstan. The main part of local steppes was converted into agricultural lands (fields and pastures) in the beginning of the last century and especially in the 1950–1960s during the socalled Virgin Land campaign, when enormous steppe territories have been transformed into wheat fields and, consequently, many steppe remnants have become overgrazed.

The peculiarities of acridid ecological and geographical distribution were characterized by quantitative and qualitative samples from natural and transformed eco-systems, usually in the middle of summer when adults commonly occurred. Samples captured during a fixed period of time were made in each habitat investigated (Gause 1930; Sergeev 1986, 1992). Using this method, insects were caught with a standard net over a period of 10-30 minutes. Results for a habitat were recalculated for an hour. In many habitats, grasshopper densities were also counted on 25-100 arbitrarily placed plots 0.25 x 0.25 $m^2$ (in some cases 0.5 x 0.5 $m^2$). After that, the average density was estimated. Some old materials, mainly from the field trips of Novosibirsk State University (1972-1980), were also used, but previous identifications were checked and corrected. We used the Glonass/GPS handheld navigators to determine geographical coordinates. For localities studied until the end of 20th century, we used Google Earth Pro (©Google, 2020) to get the same parameters. The studied specimens are mainly in the collections of Novosibirsk State University and the Institute of Systematics and Ecology of Animals (Novosibirsk). We obtained some data on general distribution of the species from several publications as well (Tarbinskij 1925; Bey-Bienko 1930a, 1930b; Bey-Bienko and Mistshenko 1951; Berezhkov 1956). The electronic table with the geographic coordinates of known localities of the model species may be found in the Suppl. material 1: Table S1.

Maps of species distribution were generated with QGIS 3.18.3 (QGIS, 2024). They were based on a Lambert conformal conic projection. The species distribution models were developed by the maximum entropy approach, namely Maxent *3.4.4* (Phillips et al. 2006, 2017; Elith et al. 2011). It is based only on presence data. To generate the Maxent models we used the full sets of the applicable bioclimatic variables at the 30 arcsecond spatial resolution (Fick and Hijmans 2017; WorldClim 2022) to equate results for the same territory, but for different species and periods. We assessed accuracy of these models by using the AUC (the area under the receiver operating characteristic curve) values for sets of replicates with cross-validation. Significance of climatic variables was determined on the basis of their predictive contributions. To forecast some possible shifts in the species distribution the "Future climate data" for 2021-2040 and 2041-2060 downscaled from the global climate model CNRM-ESM2-1 (Séférian 2018) at the 30 arcsecond spatial resolution and for the Shared Socioeconomic Pathway 3-7.0 (Meinshausen et al. 2020) were used.

Our database included 24 occurrence records for *A. baliolus*, 14 – for *A. jubatus*, and 7 – for *M. arenosus* (See supplementary file: Table 1). However, the modelling of the last species distribution explicitly overestimated areas with the optimal conditions. This is why to avoid such overrating we added several pseudo-occurrence records randomly distributed inside the known species range and limited by sandy soils (cf. Hengl and MacMillan 2019). In June, 2024, we organized the special field trip to find some additional species localities and used new findings of *A. jubatus* and *M. arenosus* in this article to validate the models.

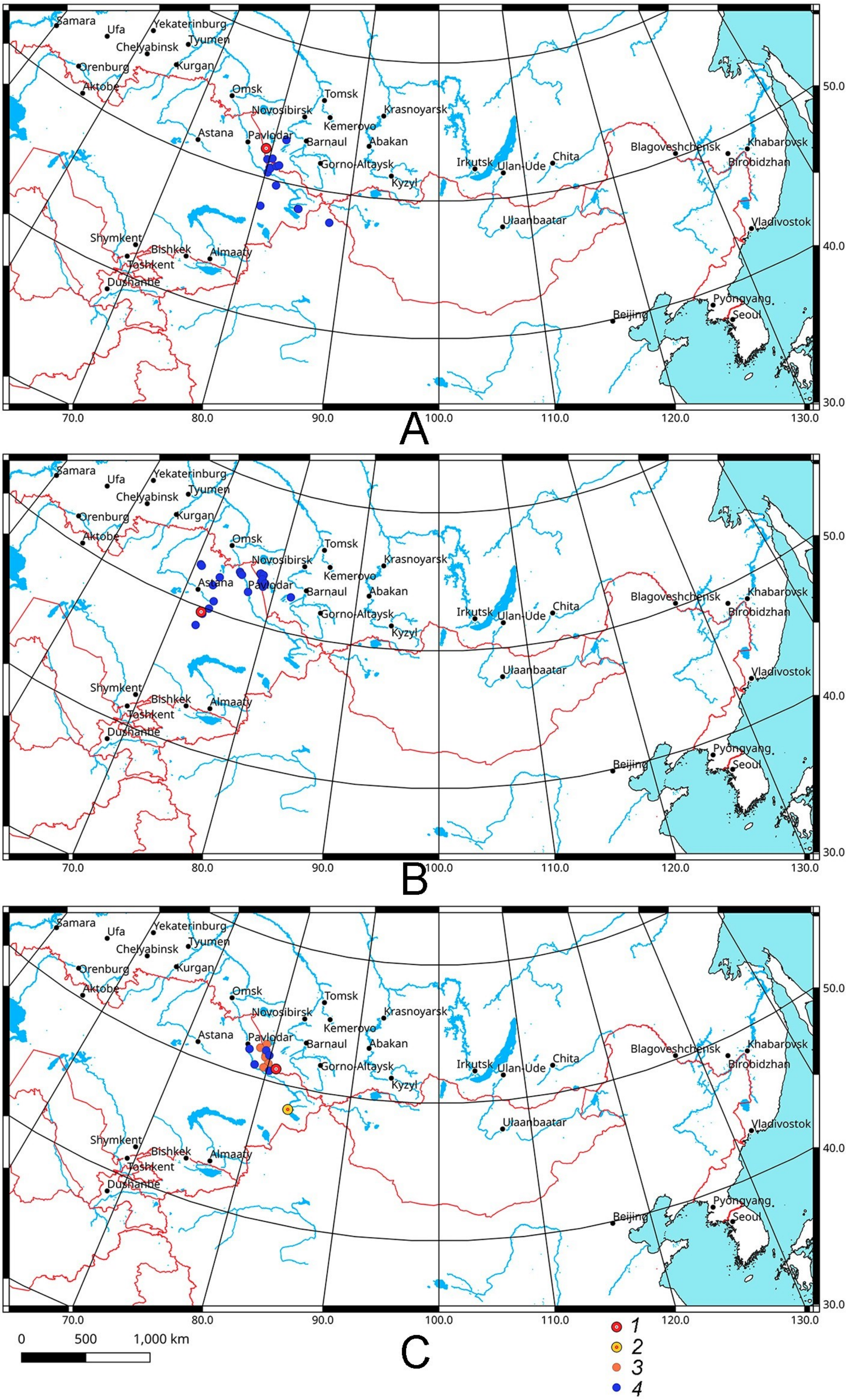
# Results and discussion

### Ecologo-geographic peculiarities of the model species

The ranges of the model species are mainly limited by the steppes and the semi-deserts of the south-eastern parts of West Siberian Plain, the Kazakh Uplands (except their westernmost areas), and the south-western slopes of South and Mongolian Altai Mts. *A. jubatus* (Uvarov) was described as *Tmethis jubatus* Uvarov from the vicinities of the Severnaya settlement, Slavgorod District, Omsk Province (now the Severka settlement, Klyuchevsky District, Altai Krai (Altaj Region), Russia) (Uvarov 1926) (Figure 1A). In the first half of the 20th century, *A. jubatus* was relatively common in the southern part of the Kulunda steppe between the Irtysh and Ob Rivers (Berezhkov 1956). Bey-Bienko (1930b) noted that the species was found in the dry steppes with gravelly soil, but its abundance was very low. In the end of the last century, we could not collect this species in south Siberia (Popova et al. 2020, 2021). The species occurred also in the semi-deserts of East Kazakhstan. *A. jubatus* usually prefers plain habitats with scanty vegetation, often with *Artemisia* spp. and halo- phytes, and some similar stony mountain slopes. Many characteristic habitats of this species could be seriously transformed during the so-called Virgin Land campaign in the middle of the 20th century. Besides, the species is an early hatching grasshopper (Berezhkov 1956), e.g. in the beginning of June, 2024, we observed mainly the 3rd and 4th instars of the species. This is why it may be missed during field trips in the middle and end of a summer. However, in the beginning of June, 2024, we found its dense population in the Uzkaya Steppe (Altai

Krai).

*A. baliolus* Mistshenko was described from the vicinities of Karagandy (Dolinskoye settlement, now Dolinka) in the central part of the Kazakh Uplands (Bey-Bienko and Mistshenko 1951). The type series also includes specimens from the central and north-eastern parts of the Kazakh Uplands and from the vicinities of Slavgorod in the Kulunda steppe (Altai Krai (Altaj Region), Russia). The species is distributed over the steppes of north-east Kazakhstan and the south-eastern parts of West Siberia (Sergeev et al. 2023a) (Figure 1B). Some mentions of this species for Mongolia (Steimann 1971) look like based on misidentification [see (Chogsomzhav 1972)]. *A. baliolus* occupies different dry steppe habitats, usually with short and scanty grass vegetation. It may be also observed on plots with halophytes. *A. baliolus* colonizes different transformed habitats as well, from the old fields of the crested wheat grass (*Agropyron cristatum* (L.) Gaertn.) up to verges. Our data show that its abundance is usually low (commonly between 4 and 18 adults per hour) (Sergeev 2019). The similar values were published for the steppes of Kazakhstan (Kadyrbekov et al. 2017). However, sometimes the species may be very abundant, e.g. in 1985, we found the huge amount of *A. baliolus* (up to 152 per hour) on the abandoned field and the verge near Karasuk in the south-western part of the Novosibirsk Region (Oblast) and near the northern boundary of the species range. The first ecologo-geographic models for this species were published recently (Sergeev et al. 2023a), but they were based on the selected sets of variables and the limited number of occurrence records.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Kemerovo
Astana
Pavlodar
Barnaul
Abakan
Gorno-Altaysk
Kyzyl
Irkutsk
Ulan-Ude
Chita
Blagoveshchensk
Khabarovsk
Birobidzhan
Ulaanbaatar
Vladivostok
Shymkent
Bishkek
Almaaty
Toshkent
Dushanbe
Beijing
Pyongyang
Seoul
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40.0
30.0
70.0
80.0
90.0
100.0
110.0
120.0
130.0
A
B
C
0
500
1,000 km
1
2
3
4

**Figure 1.** *Distribution of Asiotmethis jubatus (**A**), Aeropedellus baliolus (**B**), and Mesasippus arenosus (**C**): 1 – type locality of each species; 2 – possible position of the type locality of Mesasippus arenosus zaisanicus; 3 – pseudo-occurrences of Mesasippus arenosus; 4 – all other localities.*

*M. arenosus* (Bey-Bienko) was described as *Chorthippus kozhevnikovi arenosus* Bey-Bienko, 1930 from the vicinities of the Kurort Aul settlement, Semipalatinskij District (now in the Abai Oblast (Region), Kazakhstan) (Bey-Bienko 1930a) (Figure 1C). Later, Mistshenko (Bey-Bienko and Mistshenko 1951) described *Mesasippus arenosus zaisanicus* Mistshenko, 1951 from the coastal area of Zaysan Lake, however, the exact type locality of this taxon remained unknown. Besides, the local populations of this subspecies could become extinct after the construction of the Bukhtarma Dam and subsequent flooding of the lake coastal areas. The populations of *M. arenosus arenosus* are insular, because it occurs almost only in the dry sandy steppe habitats, including openings in the steppe pine forests. Bey-Bienko (1930b) found some very abundant colonies of *M. arenosus* in the very dry sandy habitats with scarce grass vegetation just near the steppe pine forests or across their openings. In 2004-2006, we counted the average density of its population near the Rakity settlement in the Altai Krai. It fluctuated between 0.16 and 1.32/m$^2$ (Popova et al. 2020). In 2024, we found the species population in the open and dry pine forest near the Uglovskoye settlement (Altai Krai).

Therefore, according the distribution data the populations of *A. baliolus* look like stable, maybe more or less flourishing. However, the populations of two other species may be estimated as insular and problematic. As a result, *A. jubatus* and *M. arenosus* may be qualified for inclusion in the regional Red Books.

## Ecological models of the species distribution

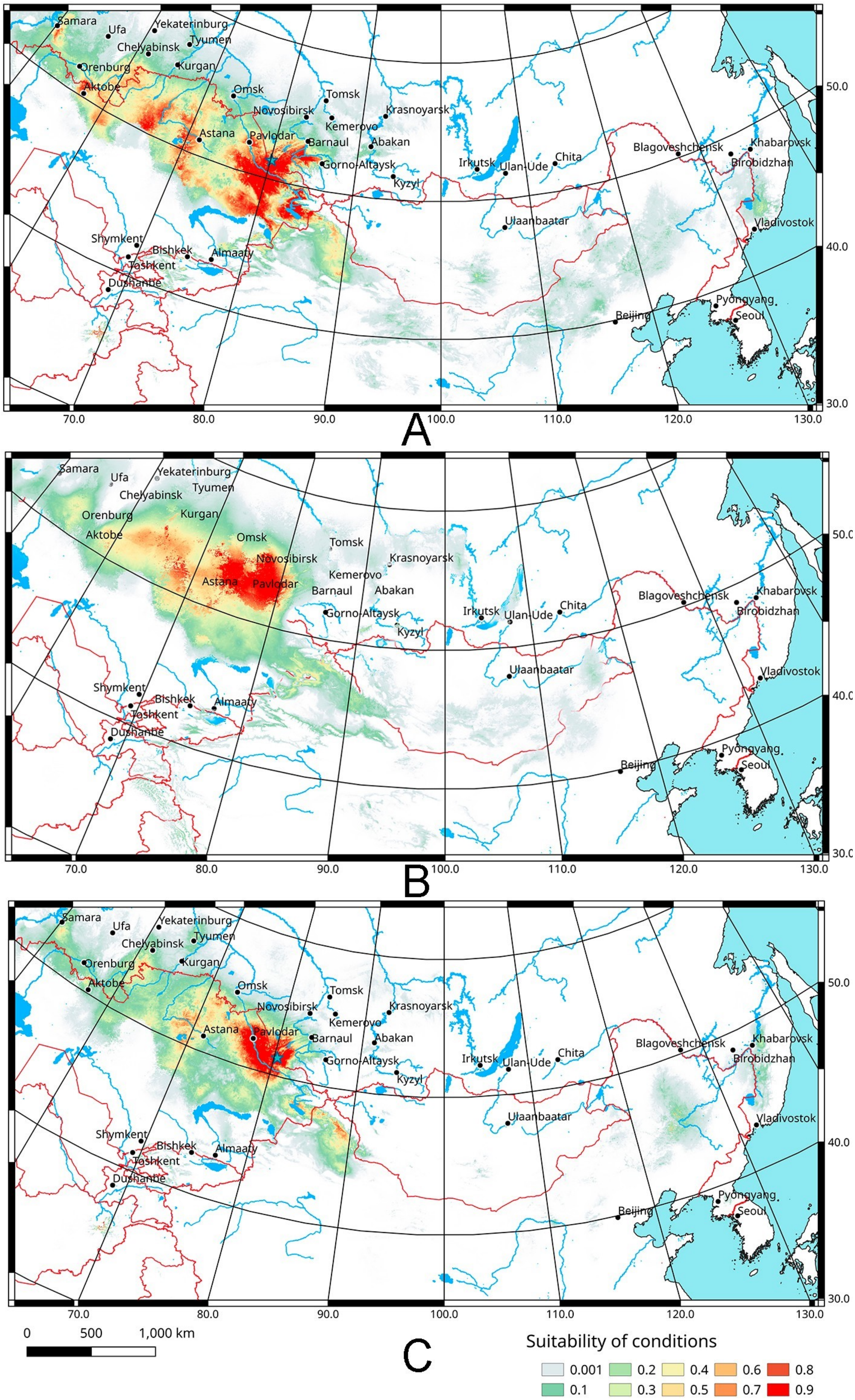
A comparative analysis of modelling results for the contemporary conditions shows each species may occur outside its known range (Figure 2). Very suitable areas for *A. jubatus* are in steppes of the southeasternmost parts of East European Plain, the southeastern slopes of the Ural Mts. and in the western parts of the Kazakh Uplands, where another species from this genus, namely *A. muricatus* (Pallas, 1771), is distributed. Besides, the Tarbagatai Mts. and the steppes of North Altai may be applicable for *A. jubatus* as well. In the case of *A. baliolus*, the superb areas are revealed not only inside its known range, but also in the north-west Kazakhstan and in Tarbagatai, Saur, and Dzungarian Alatau (cf. Sergeev et al. 2023a), however, they look like the very isolated and small. Very suitable territories for *M. arenosus* are on the left (western) side of the Irtysh River and locally across the south-western slopes of South and Mongolian Altai Mts. (Figure 2C). All models are well supported with the AUC > 0.98 (Table 1). New findings of *A. jubatus* and *M. arenosus* in 2024 validate perfectly the corresponding models (Figure 2). The new localities of these two species fall in the pixels with the predicted suitability conditions higher than 0.95 (0.956 and 0.964 respectively).

Two model species, namely *A. jubatus* and *M. arenosus*, both mainly associated with the dry steppes and the semi-deserts, are similar relative to the distribution of significant bioclimatic variables (Table 1). Annual mean temperatures and precipitation seasonality are the most important parameters. Mean temperatures of the wettest quarter are significant as well. However, mean diurnal ranges are also important for *A. jubatus*. The evident ecologo-geographic similarity of these species is confirmed by the Spearman's correlation analysis (Table 2). *A. baliolus* distributed mainly over the steppes and reaching their northern boundary looks like quite different. The most significant variable for this species is precipitations of the driest quarter (Table 1). Annual precipitation amounts, temperature seasonality, minimal temperatures of the coldest month, and annual mean temperatures may be added as well. This set of the most important variables does not match with already published results for the species (Sergeev et al. 2023a). Such difference may be explained both by some preliminary selection of the bioclimatic variables and variables characterizing altitudes, solar radiation, and vegetation cover during the previous stage of the project and by the fewer number of localities analyzed.

| Bioclimatic | *Asiotmethis jubatus* | *Aeropedellus baliolus* | *Mesasippus arenosus* |
|---|---|---|---|

| variable | Percent contribution | Permutation importance | Percent contribution | Permutation importance | Percent contribution | Permutation importance |
|---|---|---|---|---|---|---|
| 1 – Annual mean temperature | **23.7** | 6.9 | **10.3** | 38 | **26.2** | 29.4 |
| 2 – Mean diurnal range | **14.9** | 6.8 | 0.5 | 0.8 | 5.5 | 0 |
| 3 – Isothermality | 0.1 | 0 | 0 | 0 | 0.2 | 1 |
| 4 – Temperature seasonality | 2.3 | 19.6 | **14.4** | 5.5 | 1.8 | 0.4 |
| 5 – Max temperature of warmest month | 0.8 | 0.1 | 0 | 0 | 3.3 | 10.1 |
| 6 – Min temperature of coldest month | 7.3 | 23 | **10.7** | 0 | 2.4 | 0.4 |
| 7 – Temperature annual range | 0 | 0 | 0.1 | 4.7 | 0 | 0 |
| 8 – Mean temperature of wettest quarter | **14.1** | 0.1 | 8.1 | 1.3 | **17.2** | 0.5 |
| 9 – Mean temperature of driest quarter | 4.8 | 4 | 6.2 | 11.1 | 7.8 | 0.4 |
| 10 – Mean temperature of warmest quarter | 0.1 | 0 | 0 | 1.8 | 0.6 | 4.8 |
| 11 – Mean temperature of coldest quarter | 0.3 | 13 | 0 | 0 | 0.2 | 0 |
| 12 – Annual precipitation | 0 | 0.2 | **15.8** | 26.1 | 4.7 | 0 |
| 13 – Precipitation of wettest month | 2.7 | 4.3 | 0.1 | 0 | 4.9 | 17.3 |
| 14 – Precipitation of driest month | 0 | 0 | 0.9 | 0.1 | 0 | 0 |
| 15 – Precipitation seasonality | **27** | 10.2 | 4.4 | 8.2 | **21.3** | 4.5 |
| 16 – Precipitation of wettest quarter | 0 | 0 | 5.5 | 2.4 | 1.8 | 28.5 |
| 17 – Precipitation of driest quarter | 0 | 0 | **21.5** | 0 | 0.2 | 0 |
| 18 – Precipitation of warmest quarter | 1.9 | 11.9 | 1.4 | 0 | 2 | 2.7 |
| 19 – Precipitation of coldest quarter | 0 | 0 | 0 | 0 | 0 | 0 |
| AUC | 0.988 | | 0.987 | | 0.995 | |

**Table 1.** *Predictive contributions for all data and the area under the receiver operating characteristic curve values (AUC) (in bold – the most significant variables for each species)*



Samara
Ufa
Yekaterinburg
Chelyabinsk
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Kurgan
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Kemerovo
Astana
Pavlodar
Barnaul
Abakan
Gorno-Altaysk
Kyzyl
Irkutsk
Ulan-Ude
Chita
Blagoveshchensk
Khabarovsk
Birobidzhan
Ulaanbaatar
Vladivostok
Shymkent
Bishkek
Almaaty
Toshkent
Dushanbe
Beijing
Pyongyang
Seoul
50.0
40.0
30.0
70.0
80.0
90.0
100.0
110.0
120.0
130.0
A
B
C
0
500
1,000 km
Suitability of conditions
0.001
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

**Figure 2.** *Predicted probabilities of suitable conditions for Asiotmethis jubatus (**A**), Aeropedellus baliolus (**B**), and Mesasippus arenosus (**C**) (all bioclimatic variables for 1970-2000; point-wise means for replicates with cross-validation). Asterisks – validation points for Asiothemthis jubatus and Mesasippus arenosus in 2024.*

| Species | Spearman's correlation, $r_s$ | p-value |
|---|---|---|
| *Asiotmethis jubatus – Aeropedellus baliolus* | 0.178 | 0.471 |
| *Asiotmethis jubatus – Mesasippus arenosus* | **0.828** | **$1.192x10^{-5}$** |
| *Aeropedellus baliolus – Mesasippus arenosus* | 0.383 | 0.105 |

**Table 2.** *Spearman's rank correlations between predictive contributions' distribution of all bioclimatic variables*

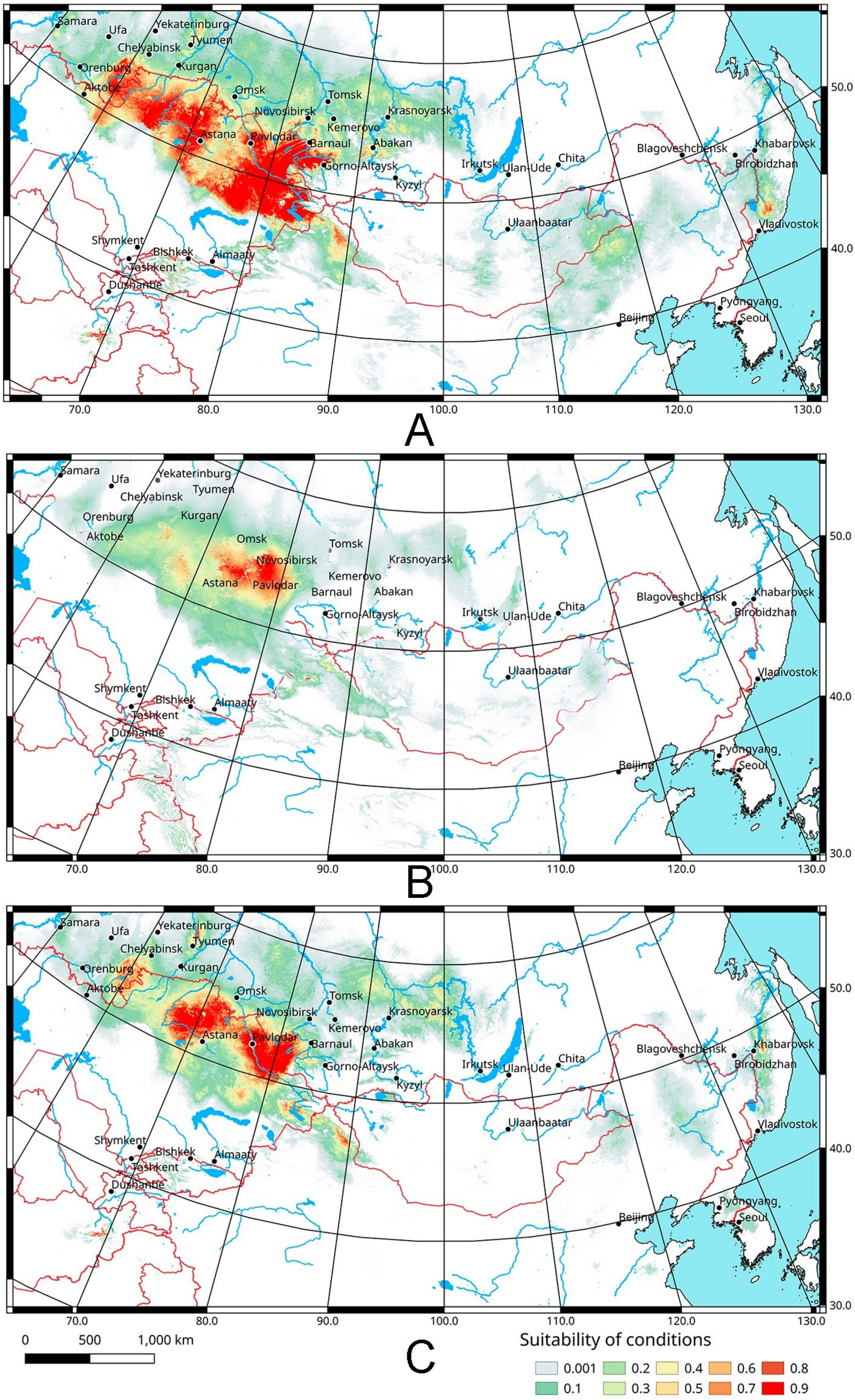
The models produced for 2021-2040 and 2041-2060 predict again very similar shifts in the species distributions of *A. jubatus* and *M. arenosus* (Figure 3A, C, Figure 4A, C; Table 3). The areas optimal for each species may significantly increase until 2040, after that, they will decrease, but, in any case, will remain more than now. The models forecast very weak changes in the southern parts of the modern ranges, however, the northern boundaries of the areas with the very suitable conditions for these two grasshoppers may shift northward, up to 56-57°N (Figure 3A, C, Figure 4A, C). Besides, several territories suitable for these species may appear far outside their modern ranges, e.g. in the western parts of West Siberian Plain, in East Siberia (mainly across the Angara River basin), and in the southern parts of the Russian Far East. Very small plots with high levels of suitability are forecasted also for the mountains of Tien Shan and Hindukush and across high grassland plains of Inner Mongolia (China). The models for *M. arenosus* predict its possible dispersal over the northern and north-western parts of the Kazakh Uplands. Besides, the small areas applicable for the species may emerge in intermountain basins of the central parts of the Altai-Sayan Mts. where some sandy soils are distributed.

The absolutely another trend is revealed for the third endemic acridid species, *A. baliolus* (Figure 3B, Figure 4B; Table 3). While now this species is relatively abundant and often, the models for the future periods show the significant depletion of the area with suitable conditions (about 15 times less).

Therefore, in the region, the species distribution modelling allows to differ explicitly two groups of the rare acridid species. The first group includes only *A. baliolus* mainly associated with the local steppes. The second one contains *A. jubatus* and *M. arenosus* primarily distributed across the dry steppes and the northern semi-deserts. The predicted contemporary distributions of the suitable conditions confirm the distributions of the known localities and let us, first, to estimate the real ranges of the model species, second, to evaluate some possible areas for species dispersal, and, third, to reveal some potential shifts of their ranges in the future.

| Period | *Asiotmethis jubatus* | *Aeropedellus baliolus* | *Mesasippus arenosus* |
|---|---|---|---|
| Current | 414 700 | 265 000 | 176 900 |
| 2021–2040 | 847 800 | 138 900 | 365 000 |
| 2041–2060 | 605 000 | 18 100 | 277 900 |

**Table 3.** *Possible changes of the species range areas ($km^2$) based on forecasts of suitability conditions more than 0.6.*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Krasnoyarsk
Kemerovo
Astana
Pavlodar
Barnaul
Abakan
Gorno-Altaysk
Kyzyl
Irkutsk
Ulan-Ude
Chita
Blagoveshchensk
Khabarovsk
Birobidzhan
Vladivostok
Ulaanbaatar
Shymkent
Bishkek
Almaaty
Toshkent
Dushanbe
Beijing
Pyongyang
Seoul
70.0
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50.0
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Suitability of conditions
0.001
0.1
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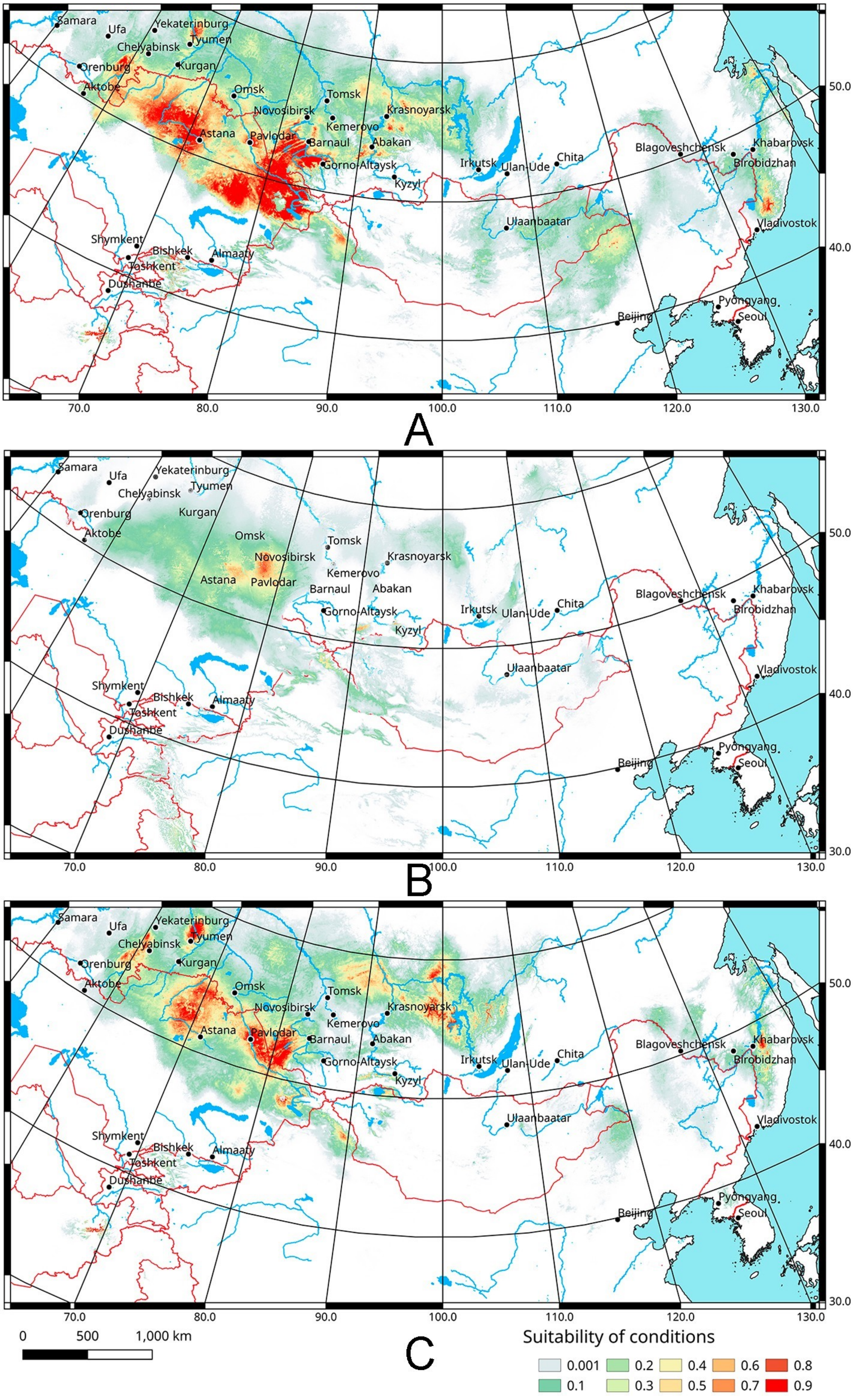
0.3
0.4
0.5
0.6
0.7
0.8
0.9

**Figure 3.** *Predicted probabilities of suitable conditions for Asiotmethis jubatus (**A**), Aeropedellus baliolus (**B**), and Mesasippus arenosus (**C**) (forecasts of bioclimatic variables for 2021- 2040 according the global climate model CNRM-ESM2-1 (Séférian 2018); point-wise means for replicates with cross-validation) and the 3-7.0 Shared Socioeconomic Pathway based on high greenhouse gas emissions (Meinshausen et al. 2020).*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Irkutsk
Ulan-Ude
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Shymkent
Bishkek
Almaaty
Toshkent
Dushanbe
Beijing
Pyongyang
Seoul
70.0
80.0
90.0
100.0
110.0
120.0
130.0
30.0
40.0
50.0
0
500
1,000 km
Suitability of conditions
0.001
0.2
0.4
0.6
0.8
0.1
0.3
0.5
0.7
0.9

**Figure 4.** *Predicted probabilities of suitable conditions for Asiotmethis jubatus (**A**), Aeropedellus baliolus (**B**), and Mesasippus arenosus (**C**) (forecasts of bioclimatic variables for 2041- 2060 according the global climate model CNRM-ESM2-1 (Séférian 2018); point-wise means for replicates with cross-validation) and the 3-7.0 Shared Socioeconomic Pathway based on high greenhouse gas emissions (Meinshausen et al. 2020).*

# Conclusions

In the steppes of West Siberia and North-East Kazakhstan, the rare species of grass-hoppers comprise about quarter of the local acridid fauna (Berezhkov 1956; Sergeev 1986, 2021a; Popova et al. 2020, 2021). Besides, there are some rare species of bush-crickets (Tettigoniidae) (Sergeev 1986, 2021a; Storozhenko 2004; Sergeev, Molodtsov 2022, 2024). However, all known local endemics are exclusively the grasshoppers from the superfamily Acridoidea. All endemics are known from the limited number of localities. This is why the species distribution modelling can help to estimate modern distribution patterns of habitats applicable for each form and to reveal some unknown local populations. As for rare Orthoptera, the maps of the contemporary suitability conditions' distributions were produced for the several steppe species, e.g. the bush-crickets *Onconotus servillei* Fischer de Waldheim, 1846 near the westernmost boundary of its range (Chobanov et al. 2021), *Miramiola pusilla* (Miram, 1927) (Sergeev, Molodtsov 2024) and *Montana striata* (Kittary, 1849) (Sergeev, Molodtsov 2022) in the Asian parts of their ranges. Furthermore, some similar maps were produced for the blackish bush-cricket *Decticus nigrescens* Serg. Tarbinsky, 1930 (Sergeev et al. 2023b) and the Amurian grig *Paracyphoderris erebeus* Storozhenko, 1980 (Storozhenko et al. 2023) distributed in the Far East and the mountain endemic grasshopper *Stenobothrus newskii* Zubovsky, 1899 (Sergeev et al. 2023a). The recent findings of the local populations of *A. jubatus* and *M. arenosus* verify the models generated earlier.

Moreover, some approaches of such modelling allow to forecast possible shifts of species distributions relative to feasible climatic changes. As for Orthoptera, a few results of predictions were published, but mainly for the pest species (Popova et al. 2022; Çıplak, Uluar 2024). However, the ecologo-geographic modelling may help to estimate statuses of rare species and (or) their populations (cf. Dey et al. 2021). Our analysis showed that predictions for such species can be quite different. Two of them, namely *A. jubatus* and *M. arenosus*, are associated with the dry steppes and the semi-deserts and now are very rare. However, the forecasts based on the species distribution models and the predictions of high greenhouse gas emissions show that they may become relatively prosperous in the middle of the 21st century and the northern boundaries of the optimal parts of their ranges may shift northward. The similar pattern was described for the steppe bush-crickets *M. pusilla* (Sergeev, Molodtsov 2024) and *M. striata* (Sergeev, Molodtsov 2022). The third species, *A. baliolus*, is distributed over the steppes of the south-eastern parts of West Siberia and North-East Kazakhstan. Their populations are more or less common now. However, our forecasts show that the species optimal territories may catastrophically reduce in the future. This means if these predictions will come true the conservation status of *A. baliolus* will significantly change, because it will explicitly meet the criteria of the Vulnerable species (IUCN, 2001).

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# References

Berezhkov RP (1956) The grasshoppers of West Siberia. Tomsk University Publ., Tomsk, 175 pp. [In Russian]

Bey-Bienko GYa (1930a) Materials concerning the Orthoptera of the District of Semipalatinsk. News of West-Siberian Branch of the Russian Geographic Society 7: 189–214. [In Russian]

Bey-Bienko GYa (1930b) The zonal and ecological distribution of Acrididae in West Siberian and Zaisan Plains. Bulletin of Plant Protection. Entomology 1(1): 51–90. [In Russian]

Bey-Bienko GYa, Mistshenko LL (1951) Locusts and grasshoppers of the USSR and adjacent countries. Vol.1–2. USSR Academy of Science Publ., Moscow-Leningrad, 667 pp. [In Russian]

Çıplak B, Uluar O (2024) Anatolian short-horned grasshoppers unveiled: integrating biogeography and pest potential. Insects 15(1): 55. https://doi.org/10.3390/insects15010055

Chobanov DP, Aneva IY, Iorgu IS, Ivković S, Borissov SB (2021) Distribution and habitat of *Onconotus servillei* (Orthoptera: Tettigoniidae) within its westernmost range (Bulgaria, Romania, Serbia): models and perspectives. Macedonian Journal of Ecology and Environment 23(1): 37–49.

Chogsomzhav L (1972) Acridoidea and Tettigonioidea of the Mongolian People’s Republic. Nasekomje Mongolii 1: 151–198. [In Russian]

Dey LS, Simões MVP, Hawlitschek O, Sergeev MG, Xu S, Lkhagvasuren D, Husemann M (2021) Analysis of geographic centrality and genetic diversity in the declining grass-hopper species *Bryodemella tuberculata* (Orthoptera: Oedipodinae). Biodiversity and Conservation 30: 2773–2796. https://doi.org/10.1007/s10531-021-02221-8

Elith J, Phillips SJ, Hastie T, Dudík M, Chee YE, Yates CJ (2011) A statistical explanation of MaxEnt for ecologists. Diversity and Distributions 17: 43–57. https://doi.org/10.1111/j.1472-4642.2010.00725.x

Fick SE, Hijmans RJ (2017) WorldClim 2: New 1 km spatial resolution climate surfaces for global land areas. International Journal of Climatology 37: 4302–4315. https://doi.org/10.1002/joc.5086

Gause GF (1930) Studies on the ecology of the Orthoptera. Ecology 11: 307–325. https://doi.org/10.2307/1930266

Hengl T, MacMillan RA (2019) Predictive soil mapping with R. OpenGeoHub foundation, Wageningen, 370 pp. https://soilmapper.org/

International Union for Conservation of Nature (2001) IUCN Red List Categories and Criteria: Version 3.1. IUCN Species Survival Commission, Gland–Cambridge, 30 pp.

International Union for Conservation of Nature (2024) The IUCN Red List of Threatened Species. Version 2023-1. https://www.iucnredlist.org/

Kadyrbekov RH, Childebaev MK, Zhdanko AB, Tleppaeva AM, Kolov SV (2017) Impact of anthropogenic and abiotic factors on the structure of the insect fauna of the steppe life zone of Kazakhstan in contemporary environments. Almaty, 460 pp. [In Russian]

Kleukers R, Felix R (Eds) (2020) Grasshopper conservation in Europe. EIS Kenniscentrum Insecten & Naturalis Biodiversity Center, Leiden, 85 pp.

Lockwood JA, Sergeev MG (2000) Comparative biogeography of grasshoppers (Orthoptera: Acrididae) in North America and Siberia: Application to the conservation of biodiversity. Journal of

Insect Conservation 4(3): 161–172. https://doi.org/0.1023/A:1009618425473

Meinshausen M, Nicholls ZRJ, Lewis J, Gidden MJ, Vogel E, Freund M, Beyerle U, Gessner C, Nauels A, Bauer N, Canadell JG, Daniel JS, John A, Krummel PB, Luderer G, Meinshausen N, Montzka SA, Rayner PJ, Reimann S, Smith SJ, van den Berg M, Velders GJM., Vollmer MK, Wang RHJ (2020) The shared socioeconomic pathway (SSP) green-house gas concentrations and their extensions to 2500. Geoscientific Model Development 13: 3571–3605. https://doi.org/10.5194/gmd-13-3571-2020

Phillips SJ, Anderson RP, Schapire RE (2006) Maximum entropy modeling of species geographic distributions. Ecological Modelling 190: 231–259. https://doi.org/10.1016/j.ecolmodel.2005.03.026

Phillips SJ, Anderson RP, Dudík M, Schapire RE, Blair B (2017) Opening the black box: An open-source release of Maxent. Ecography 40: 887–893. https://doi.org/10.1111/ecog.03049

Popova KV, Molodtsov VV, Sergeev MG (2020) Rare grasshoppers (Orthoptera, Acridoidea) of the Baraba and Kulunda steppes (South Siberia). Acta Biologica Sibirica 6: 595–609. https://doi.org/10.3897/abs.6.e59519

Popova KV, Molodtsov VV, Efremova OV, Sergeev MG (2021) Grasshoppers in steppe areas of the south-eastern West Siberian Plain: Centennial transformations of biodiversity. IOP Conference Series: Earth and Environmental Science 817: 012088. https://doi.org/10.1088/1755-1315/817/1/012088

Popova KV, Baturina NS, Molodtsov VV, Yefremova OV, Zharkov VD, Sergeev MG (2022) The handsome cross grasshopper *Oedaleus decorus* (Germar, 1825) (Orthoptera: Acrididae) as a neglected pest in the south-eastern part of West Siberian Plain. Insects 13: 49. https://doi.org/10.3390/insects13010049

QGIS (2024) QGIS. A free and open source geographic information system. https://www.qgis.org

Samways MJ, Lockwood JA (1998) Orthoptera conservation: pests and paradoxes. Journal of Insect Conservation 2: 143–149. https://doi.org/10.1023/A:1009652016332

Séférian R (2018) CNRM-CERFACS CNRM-ESM2-1 Model Output Prepared for CMIP6 CMIP Amip. Version 20211010. Earth System Grid Federation. https://doi.org/10.22033/ESGF/CMIP6.3924

Sergeev MG (1986) Distribution patterns of Orthoptera in North Asia. Nauka Publ., Novosibirsk, 237 pp. [In Russian]

Sergeev MG (1992) Distribution patterns of Orthoptera in North and Central Asia. Journal of Orthoptera Research 1: 14–24. https://doi.org/10.2307/3503557

Sergeev MG (1996) La sécheresse et les schémas de distribution des criquets en Asie centrale et septentrionale. Sécheresse 7(2): 129–132.

Sergeev MG (1998) Conservation of orthopteran biological diversity relative to landscape change in temperate Eurasia. Journal of Insect Conservation 2: 247–252. https://doi.org/10.1023/A:1009620519058

Sergeev MG (2019) The assemblages of Orthoptera in the south-eastern part of West Siberian Plain (the Karasuk River Basin), Russia. Euroasian Entomological Journal 18(4): 255–264. https://doi.org/10.15298/euroasentj.18.4.04 [In Russian]

Sergeev MG (2021a) Distribution patterns of grasshoppers and their kin over the Eurasian steppes.

Insects 12: 77. https://doi.org/10.3390/insects12010077

Sergeev MG (2021b) Ups and downs of the Italian locust (*Calliptamus italicus* L.) populations in the Siberian steppes: On the horns of dilemmas. Agronomy 11: 746. https://doi.org/10.3390/agronomy11040746

Sergeev MG, Molodtsov VV (2022) New data on distribution of *Montana striata* (Kittary, 1849) (Orthoptera: Tettigoniidae: Platycleidini) in the eastern part of the range. Far Eastern Entomologist 465: 6–11. https://doi.org/10.25221/fee.465.2

Sergeev MG, Molodtsov VV (2024) New data on distribution of *Miramiola pusilla* (Miram, 1927) (Orthoptera: Tettigoniidae). Far Eastern Entomologist 496: 16–24. https://doi.org/10.25221/fee.496.4

Sergeev MG, Kim-Kashmenskaya MN, Molodtsov VV, Yefremova OV, Popova KV, Sokolova (Baturina) NS (2023a) Mapping and ecomodeling of the distribution of rare insect species in the south of Siberia and in neighboring regions (a case study of the superfamily Acridoidea). Geography and Natural Resources 5: 129–135. https://doi.org/10.15372/GIPR20230516[In Russian]

Sergeev MG, Molodtsov VV, Storozhenko SYu (2023b) New data on distribution of *Decticus nigrescens* Tarbinsky, 1930 (Orthoptera: Tettigoniidae) in Russia. Far Eastern Entomologist 487: 21–28. https://doi.org/10.25221/fee.487.2

Steck CE, Bürgi M, Bolliger J, Kienast F, Lehmann A, Gonseth Y (2007) Conservation of grasshopper diversity in a changing environment. Biological Conservation 138: 360– 370. https://doi.org/10.1016/j.biocon.2007.05.001

Steinmann H (1971) Tetricidae und Acrididae. Ergebnisse der zoologischen Forschungen von Dr. Z. Kaszab in der Mongolei (Orthoptera). 209. Faunistische Abhandlungen – Staatliches Museum für Tierkunde Dresden 3(14): 145–157.

Storozhenko SYu (2004) Long-horned orthopterans (Orthoptera: Ensifera) of the Asiatic part of Russia. Dalnauka, Vladivostok, 280 pp. [In Russian]

Storozhenko SYu, Molodtsov VV, Sergeev MG (2023) The mysterious Amurian grig *Para cyphoderris erebeus* Storozhenko, 1980 (Orthoptera: Prophalangopsidae): new data on its distribution, ecology and biology. Insects 14: 789. https://doi.org/10.3390/insects14100789

Tarbinskij SP (1925) Materials concerning the Orthopterous fauna of the Province of Altai. Revue Russe d'Entomologie 19: 176–195. [In Russian]

Uvarov BP (1926) A preliminary key to the Central-Asiatic species of the genus *Tmethis* Fieb. (Orth. Acrid.). Konowia 5(3): 179–186.

Uvarov BP (1928) Orthoptera of the mountains of Palaearctic region. Mémoires de la Société de Biogéographie 2: 135–141.

WorldClim (2022) WorldClim https://worldclim.org/data/index.html

# Supplementary material 1

**Table S1. The geographic coordinates of known localities of the model species**

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