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The grasshopper *arcyptera (Pararcyptera) meridionalis* ikonnikov (Insecta, orthoptera) as a possible agricultural pest in temperate Asia

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Abstract

The goal of the article is to estimate possible changes of the distribution of *Arcyptera meridionalis* in the contemporary and potential future climatic conditions. The data were collected during field trips. Two packages to produce the species distribution models, namely MaxEnt and ellipsenm, were used. The generated models predict that the status of *A. meridionalis* as the important pest will not change significantly in the nearest future, however, in the middle of this century, its distribution patterns will become more complicated. The areas those will be the most suitable for the species will remain mainly in the western and central parts of its range. The harmful activity of *A. meridionalis* can be especially important due to its early hatching, because hoppers may damage and destroy shoots with first leaves and tillers. The models generated for *A. meridionalis* look like quite different from the models for other steppe acridids. On the contrary, some resemblance between forecasts for two harmful, but quite different grasshopper species, namely Siberian-Mongolian *A. meridionalis* and East-Mediterranean *A. labiata*, are revealed. The models for both species demonstrate some possible significant depletion of the territories with suitable conditions for each one in the second half of the 21st century.

Keywords: Acrididae, Climate change, Ellipsoid envelope model, Forecast, Grasslands, MaxEnt, Modelling, Pest management, Plant protection, Steppe.

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Contents

Contribution of this paper to the literature
This is a first attempt to characterize the main ecologo-geographical peculiarities of the important acridid pest Arcyptera meridionalis. The species distribution over the grasslands of South Siberia, Mongolia and China is described in details, and the several models of this distribution are produced for the contemporary and future climatic conditions.

1. Introduction

The grasshopper *Arcyptera meridionalis* (Figure 1) is the member of the subgenus *Pararcyptera* Serg. Tarbinsky which includes several important pests, such as *A. microptera* (Fischer de Waldheim) and *A. labiata* (Brullè) [1]. All or almost all members of this subgenus prefer grasses and, as result, may significantly damage both different crop fields (e.g. wheat, rye, barley, and oat), pastures, and hayfields, especially in the Eurasian steppe and forest-steppe life zones [1, 2]. *A. meridionalis* per se may be the very serious pest across the eastern parts of the Altai-Sayan Mts. and the southern parts of East Siberia, and also in Mongolia and the northern parts of China [1, 3-5]. Because the species is an early hatching grasshopper, in many regions, the first hoppers can emerge in the end of April and in May and the adults are in June [6]. This means *A. meridionalis* is able to damage seriously shoots of different crops in the end of spring and in the beginning of summer. The current climate change, mainly associated with global warming, may result not only in species range shifts, but also in alteration of species harmful activities relative to some possible changes in agricultural practices. Consequences of such transformations may result, inside the modern range, in both increase of the species devastating effects on agricultural fields, pastures and hayfields, and northward shifts in the species distribution. The goal of this article is to estimate possible changes of the species distribution in the contemporary and potential future climatic conditions.

Figure 1. *Arcyptera meridionalis* (Female) in the typical habitat (Dry steppe) of central Tuva (Republic of Tyva, Russia) (Photo M. G. Sergeev).

2. Materials and Methods

2.1. Territory of Investigations

The southern parts of Siberia and the Russian Far East were studied from 1978 until 2022. In the beginning of the 20th century, forest-steppes, steppes, and semi-deserts covered these vast areas, however, later many habitats were transformed into agricultural lands (fields and pastures) [7]. In the region, mean temperatures of the warmest month vary between 20 °C to 26 °C and the same for the coldest month are from –6 °C to –29 °C. Mean annual precipitations vary between 230 to 950 mm.

2.2. Field Data Acquisition

The data used were collected during field trips. As a rule, different local habitats, particularly natural and semi-natural grasslands and agricultural fields, were surveyed, commonly in the middle of summer. In each habitat, grasshoppers were observed and collected to reveal species richness, and their abundance was normally estimated by one or two methods, namely quantitative sampling during a fixed period of time [8] and/or the standard sweep nettings. Geographic coordinates were evaluated by GPS (Global Positioning System)/Glonass (Globalnaya Navigatsionnaya Sputnikovaya Sistema) hand-held units. The Google Earth Pro (©Google 2022) was used to reveal the geographic coordinates for old collections. The main part of studied specimens is in the collections of Novosibirsk State University, the Institute of Systematics and Ecology of Animals (Novosibirsk), and the Federal Scientific Center of the East Asia Terrestrial Biodiversity (Vladivostok). The data from different publications [9-19] and from the collections of the Zoological Institute (Saint Petersburg, Russia) were also analyzed and used. As a result, our database contains the geographic coordinates of 73 points of the species occurrence.

2.3. Species Distribution Mapping and Modelling

Maps of species distribution were generated on the basis of geographic coordinates with QGIS 3.18.3. A Lambert conformal conic projection was selected as the basic map. Two distinctive packages to produce the species distribution models over its whole range were used. The first one (MaxEnt) is based on the machine learning [20-

22]. The second one (ellipsenm in the R environment) is based on producing a multidimensional ellipsoid envelope model of an ecological niche [23]. Both are limited by only presence data and depend on the number of localities, selected options of modelling and collection of variables used [20-23]. In the case of the MaxEnt models, the full sets of the so-called standard bioclimatic variables [24, 25] were used. Their accuracy was estimated by the area under the receiver operating characteristic curve values (AUC) for 25 replicates with cross-validation. The possible effects of the bioclimatic variables were estimated by their predictive contributions and the Jackknife tests. The following parameters were used for the MaxEnt models: features — auto, output format — cloglog, regularization multiplier = 1. In the case of the ellipsoid models, the several selected bioclimatic variables, namely the annual mean temperature, maximal temperature of the warmest month, minimal temperature of the coldest month, annual precipitation, precipitation of the warmest quarter, precipitation of the coldest quarter, were used, because this algorithm is very sensitive to correlation between variables. 25 replicates were counted as well, the method was covmat and the level used to produce the ellipsoids was 99%. In all cases, the 30 arcsecond spatial resolution was selected. Besides, the predicted averaged bioclimatic variables for 2021–2040 and 2041–2060 [24, 25] based on the global climate model CNRM-ESM2-1 [26] and the 3-7.0 Shared Socioeconomic Pathway (high greenhouse gas emissions [27]) were used to produce models for the future.

3. Results

3.1. The Actual Species Distribution

The taxon was described from the vicinities of Qiqihar (now in the Heilongjiang Province, North-East China) as *Arcyptera flavicosta meridionalis* [9]. Later Sir B. Uvarov [10] described another subspecies of *A. flavicosta*, namely *A. f. sibirica*, from the southern parts of Yakutia and the Baikal region, but, in almost all cases, without exact geographic localities. In the monograph of Bey-Bienko and Mistshenko [28], these subspecies were synonymized. Later Storozhenko and Paik [29] justified its status as the distinct species.

The northern boundary of the species range is approximately defined by the southern border of the taiga life zone (about 53°N), and the southern one — by the semi-deserts (about 44°N) in the inner parts of Eurasia and by the subtropics (about 39°N) near the Pacific coast of the continent (Figure 2). At least one insular population of the species was known from the southern parts of Republic of Sakha (Yakutia) [10]. The species range includes the southern parts of Central and East Siberia (however, in the Republic of Khakassia and the southern parts of Krasnoyarsk Krai, *A. microptera* (Fischer de Waldheim) occurs) [30] almost all Mongolia, except its southern arid parts [13, 15] the steppes and forest-steppes of North and North-East China [31, 32]. It is locally distributed in the southern parts of the Russian Far East [33, 34] in the northern parts of Korean Peninsula [14, 29, 35] and in the mountains of the north-eastern parts of the Tibetan Plateau [36]. Over all range, *A. meridionalis* occurs primarily in semi-arid grasslands, including the mountain ones, because its trophic preferences are commonly limited by grasses (Poaceae) [37].

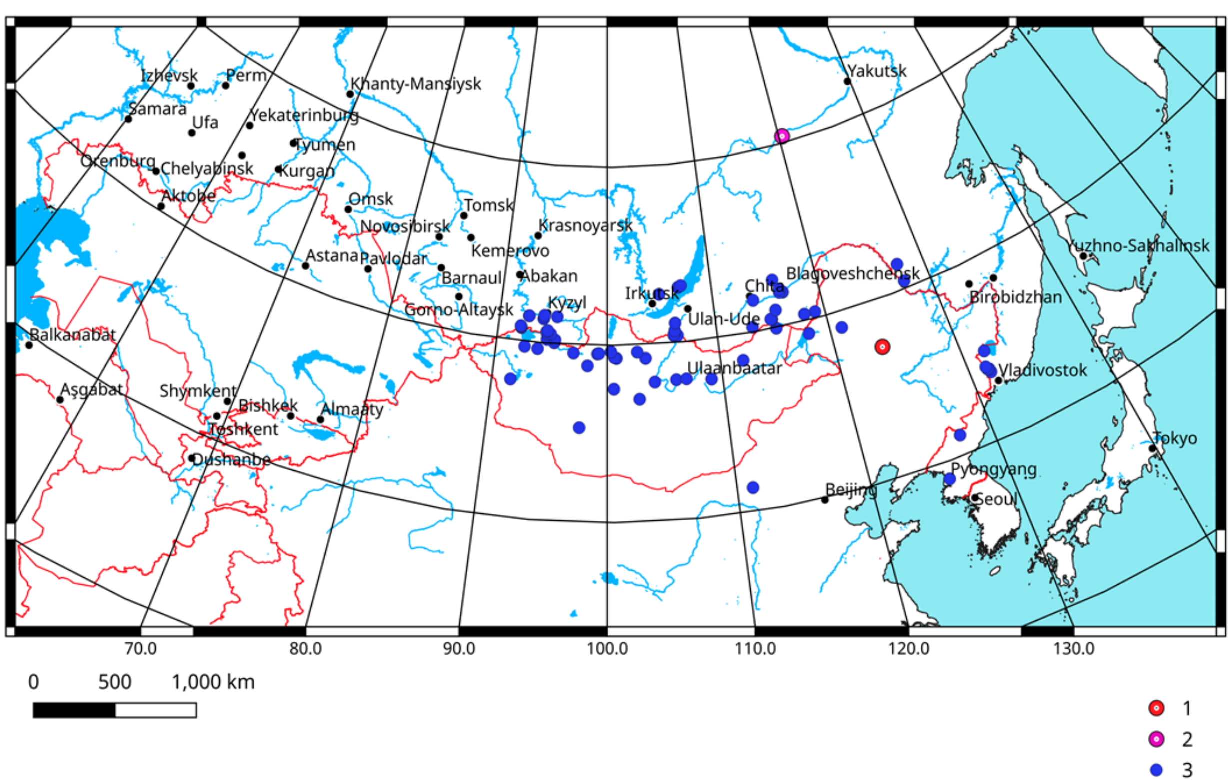


Figure 2. The general distribution of *Arcyptera meridionalis*.

Note: 1 — Type locality of *A. flavicosta meridionalis*; 2 — One of the type localities of *A. flavicosta sibirica* (With the geographic coordinates); 3 — All other localities.

3.2. The Species Distribution Models

The models of the *A. meridionalis* distribution for contemporary conditions show that the optimal areas for the species are in the steppes of the southern parts of Central and East Siberia, the northern parts of Mongolia and the northwestern parts of Inner Mongolia (Figure 3 and 4). Some isolated territories are also in the Angara River Basin (near Irkutsk), the southernmost regions of Yakutia, and several areas of the temperate Far East, where grasslands are relatively common. Besides, the maximum entropy model shows the regions with very suitable conditions for this species outside the actual species range, namely in the mountains of East Tien Shan, where actually another taxon from this group (*A. microptera turanica* Uv.) occurs. The maximum entropy model is well supported with AUC = 0.958 (Figure 5).

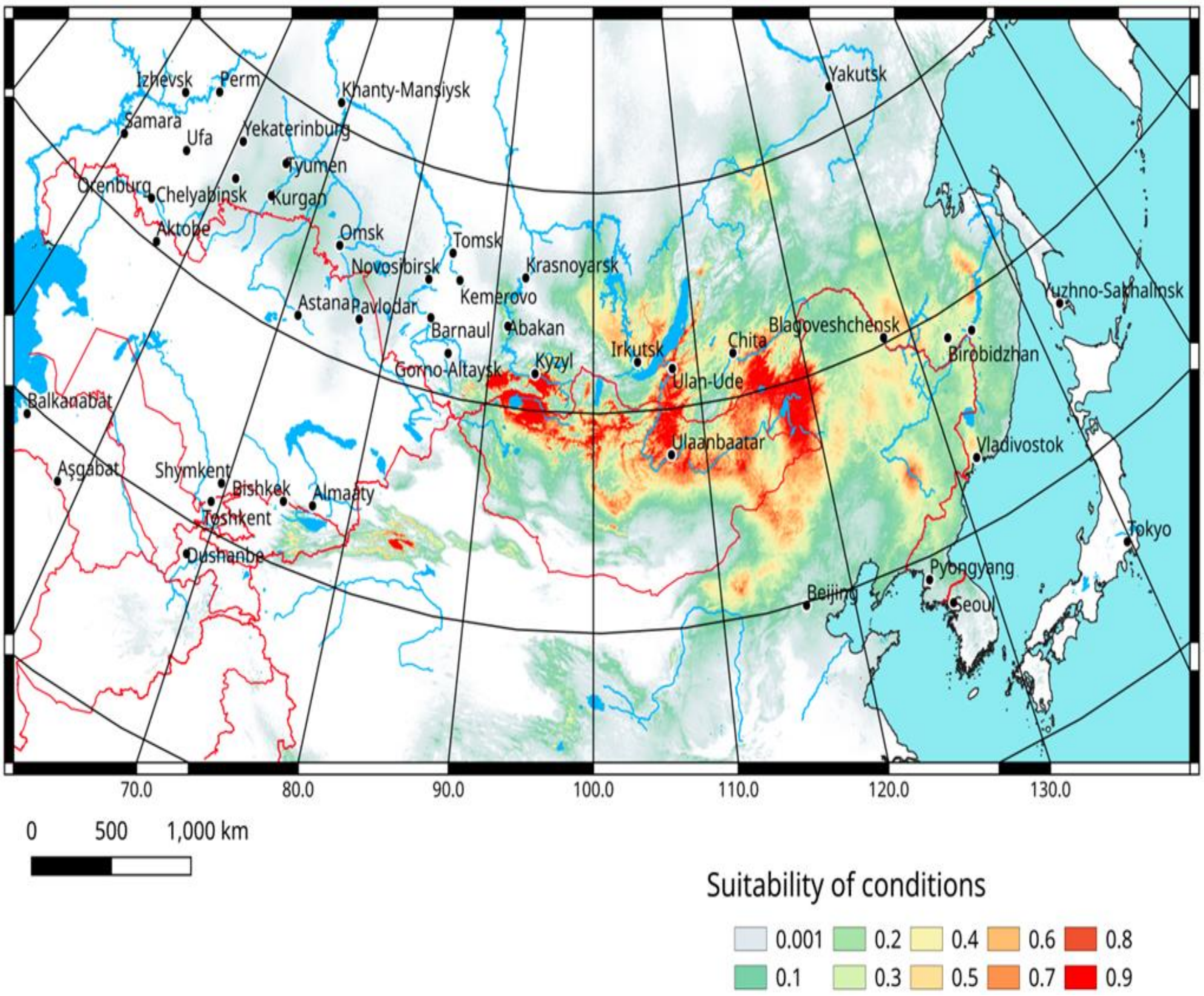


Figure 3. Predicted probabilities of suitable conditions for *Arcyptera meridionalis* (MaxEnt model, all bioclimatic variables for 1970–2000; point-wise means for 25 replicates with cross-validation).

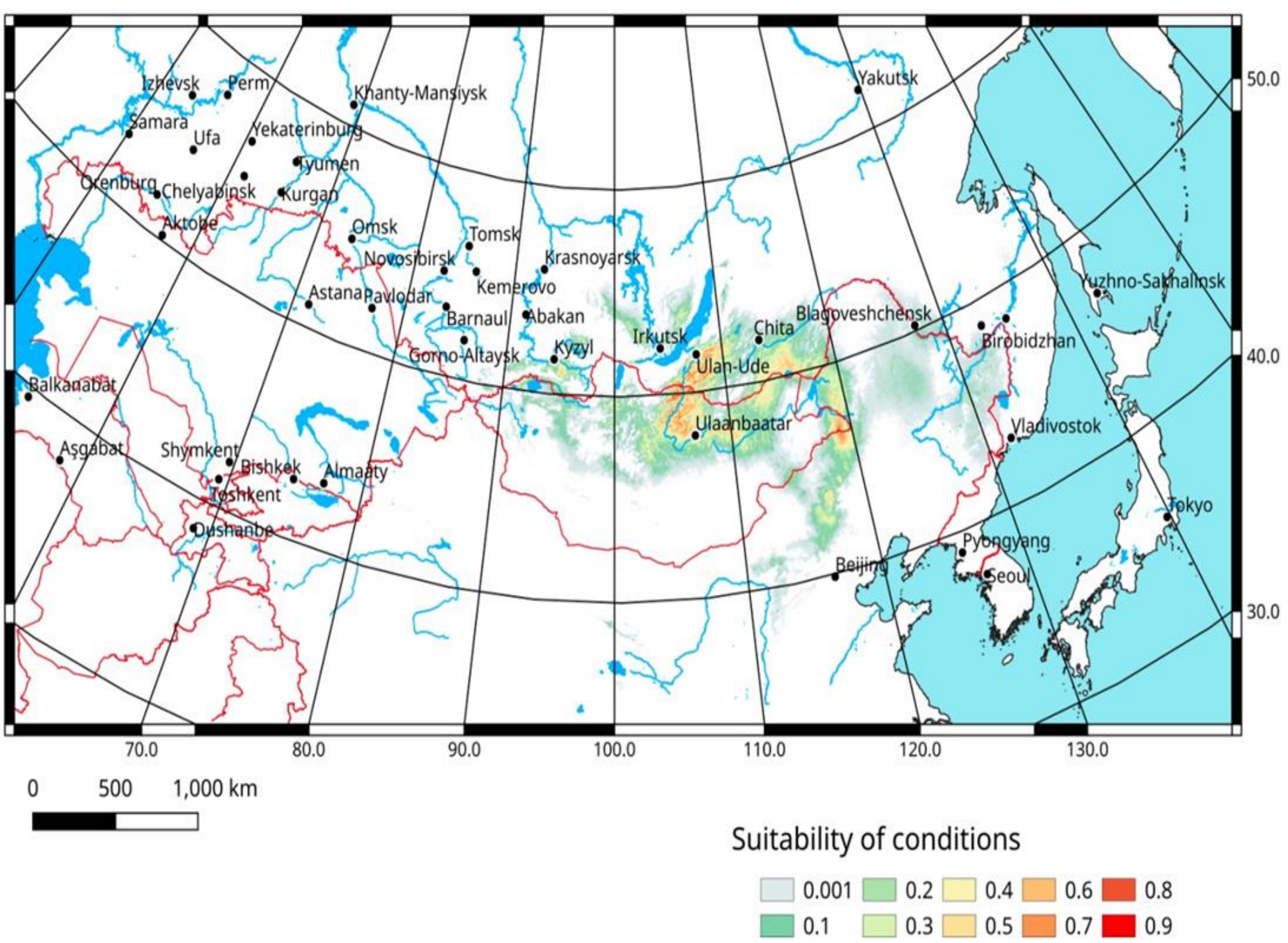


Figure 4. Predicted probabilities of suitable conditions for *Arcyptera meridionalis* (Multidimensional ellipsoid model, selected bioclimatic variables for 1970–2000; point-wise means for 25 replicates).

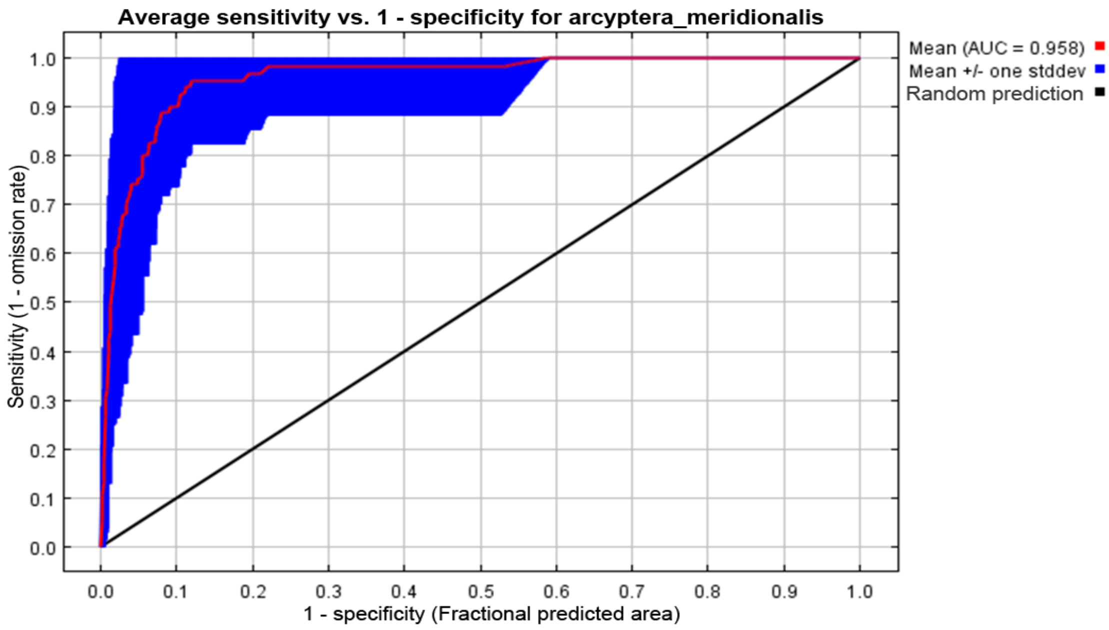
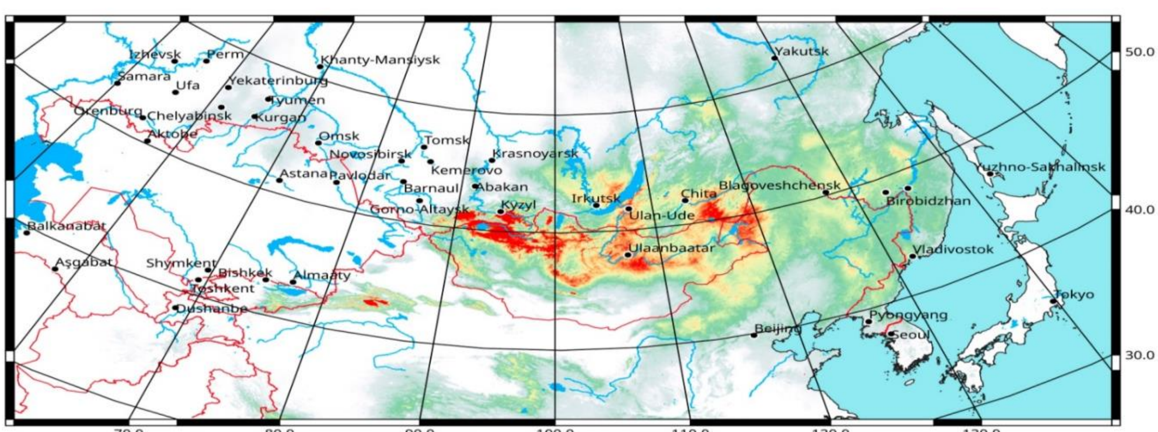


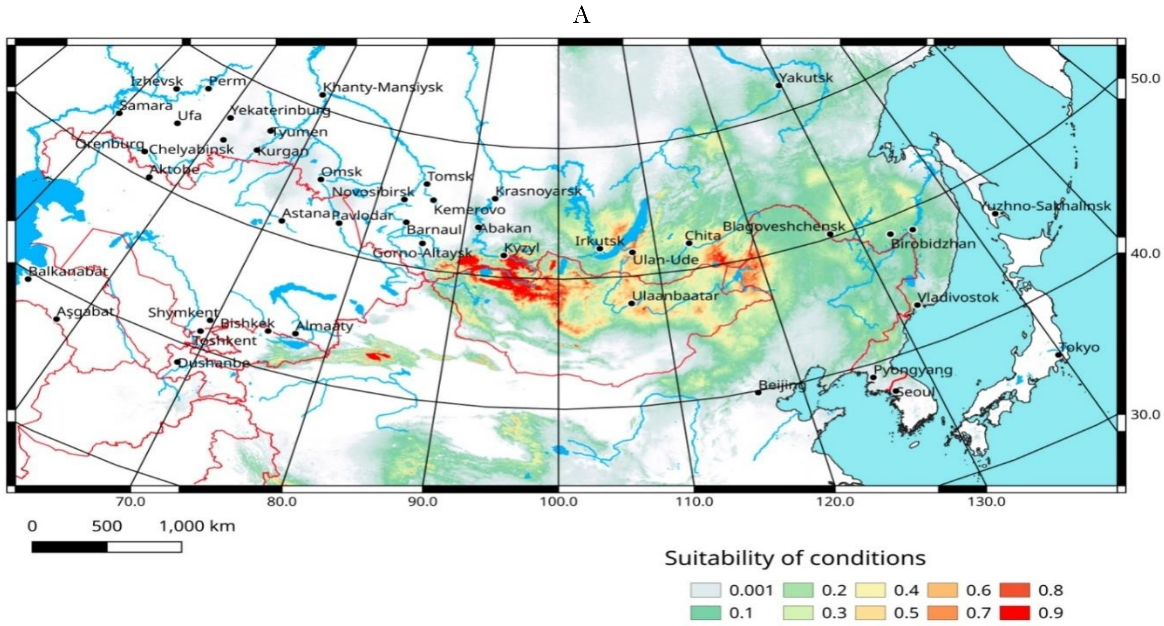
Figure 5. Reliability test for the *Arcyptera meridionalis* model (All bioclimatic variables for 1970–2000; 25 replicates with cross-validation).

Several bioclimatic variables significantly contribute to the model. Among them are precipitations seasonality (34.5%), annual mean temperatures (16.7), temperature seasonality (15), and annual precipitation (10.9%). The Jackknife test enables to add several other variables, such as precipitation of the coldest quarter and minimum temperatures of the coldest month. Hence, very low winter temperatures may be very important for the species, especially in South Siberia and Mongolia where they are often coupled with thin snow cover resulting in deep soil freezing and high levels of acridid egg mortality (cf. [19]).

The possible changes in the *A. meridionalis* distribution based on the actual data concerning its localities and the high greenhouse gas emissions look like relatively moderate (Figure 6). In the nearest two decades, the areas with very suitable conditions may remain almost the same. In 2041–2060, the optimal territory may significantly diminish, especially in the Angara and Selenga Rivers' Basins and in the Far East. The main region of the possible harmful activity will likely remain in Tuva in the central part of the Altai-Sayan Mts. and in the adjacent areas of West Mongolia. Besides, some problems with *A. meridionalis* will persist in the southeastern parts of Transbaikal Region (Dauria) in Russia and in the northwestern parts of Inner Mongolia in China (Figure 6, B).



A



B

Figure 6. Predicted probabilities of suitable conditions for *Arcyptera meridionalis* (forecasts of all bioclimatic variables for 2021–2040 (A) and 2041–2060 (B) according the global climate model CNRM-ESM2-1 and the 3–7.0 Shared Socioeconomic Pathway; point-wise mean for 25 replicates with cross-validation).

4. Discussion

Our models predict that the status of the grasshopper *A. meridionalis* as the important pest species will not change significantly in the nearest future, however, in the middle of this century, its distribution patterns will become more complicated. The areas those will be the most suitable for the species will remain mainly in the western (Tuva and North-West Mongolia) and central (the south-eastern parts of Transbaikal Region and the north-eastern parts of Inner Mongolia) parts of its range. Both territories are characterized by very high activity of herdsmen and density of grazing animals, especially sheep and goats. Besides, many plots are ploughed and used as agricultural fields for spring wheat, rye, and barley. In outbreak seasons, *A. meridionalis* may severely damage local grasslands and fields, particularly in the end of spring and the beginning of summer when young hoppers start to emerge and become active and when, in the region with an extreme continental climate and main precipitations in the second half of warm season, there are a few green plants in the grasslands. Such pattern is very typical for the Siberian-Mongolian steppes, where many grasshopper species are normally very abundant and the main period of their development is the middle and the end of summer [38]. Moreover, the possible harmful activity of *A. meridionalis* can be especially important due to its early hatching, particularly relative to fields of spring wheat and rye, because hoppers may damage and destroy shoots with first leaves and tillers.

The models generated for *A. meridionalis* look like quite different from the models for other steppe orthopteran species, both abundant (*Oedaleus decorus* (Germar) [39], *Bicolorana bicolor* (Philippi) [40]) and rare (*Miramiola pusilla* (Miram)) [41]. The models for these three species are similar, at least for the southern parts of West Siberia, and show evident trend: noticeable northward shifts of the areas with very suitable conditions. However, surprisingly, there are some resemblance between forecasts for two related, harmful, but quite different grasshopper species from the subgenus *Pararcyptera*, namely Siberian-Mongolian *A. meridionalis* and East-Mediterranean *A. labiata* [42]. The models for both species demonstrate some possible significant depletion of the territories with suitable conditions for each one in the second half of the 21st century.

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