Predicting the potential distribution of an endemic steppe species *Artemisia salsoloides* Willd. under the climate change

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**Abstract.** Climate change poses a risk for rare plant species distribution in the future. The aim of this study was to predict the impact of moderate climate change on the growth and distribution of the rare endemic steppe species *Artemisia salsoloides* Willd. with the use of the maximum entropy method (MaxEnt). *A. salsoloides* distribution under moderate climate change (RCP 4.5 scenario) for 2040-2060 and 2061-2080 was modelled using a set of bioclimatic rasters (BIOCLIM) from the CHELSA database and topographic variables from GMTED2010. Model results showed an increase in the area of low and medium suitable habitats to the northeast of the current range, with no significant change in the area of highly suitable habitat predicted. The resulting models also showed no significant decline in habitat suitability in the current present sites in the future. Thus, moderate climate change will not have a significant negative impact on the distribution of the species, and no additional protection measures for the species in response to climate change are needed.

**1. Introduction**

Climate change is considered one of the main drivers of biodiversity change. Plant species confined to specific habitats with a narrow ecological amplitude are particularly vulnerable to the effects of the changes in the environment [1]. This includes the endemic species of the south-east of European Russia – *Artemisia salsoloides* Willd. – a perennial shrub 20–45 cm high with a ligneous tap-root [2]. The root system can extend below 1.5–2 m, which makes the plants well-adapted to the arid climate when growing on stony slopes. The modern range of the species includes the south of the European part of Russia, eastern part of Ukraine, Forecaucasia, southwest of Western Siberia and the north of Kazakhstan. The species is included in the Red Data Book of the Russian Federation [3], and in the Red Data Books of 15 regions of Russia [4]. *A. salsoloides* is a xerophytic species occurring in rocky calcareous habitats and it is usually found on slopes with outcrops of carbonate rocks (limestone, gypsum, etc.) [2, 5]. The main limiting factors for the species distribution are competition with sod-forming grasses, slope erosion processes, cattle grazing, and limestone and chalk mining [3, 5]. Due to the deep tap-root system the species is drought-resistant, although some authors note that droughts can have a negative effect on *A. salsoloides*, especially on seedlings and juvenile plants [6, 7].

The population size varies greatly depending on the area of suitable edaphic conditions. In the Republic of Bashkortostan (RB), a population may consist of less than a few dozens of individuals [5], while in southern parts of the range (Rostov Oblast) the number of individuals can reach 90 thousand with a population area can reach several hectares [8].
2. Problem Statement
Potential climatic changes can lead to an increase in suitable areas for the species, as well as to their decrease. In the latter case, it is necessary to assess the stability of known habitats in order to identify priority conservation sites and, in some cases, choose measures for its reintroduction from unstable habitats into more suitable ones [9]. The purpose of the study is to predict the effect of moderate climate change on the growth and distribution of the endemic species *A. salsoloides*.

3. Materials and Methods
To determine habitat suitability for the species, we used species distribution modeling approach in MaxEnt 3.4.1 [10]. Presence data consisted of 102 occurrence points of the species with the location accuracy up to 500 m. The data was provided by the UFA herbarium, and extracted from GBIF database [11] and scientific publications [12–21]. Because the RB had a greater number of points which was not representative of the actual species density, we randomly filtered presence points in RB that were less than 3 km apart to prevent model overfitting. Literature data on the species distribution, including regional Red Data Books containing occurrence points georeferenced with less accurate coordinates, were used for model validation. As environmental variables we used the set of bioclimatic variables (BIOCLIM) from the CHELSA database [22] and the topographic variables from GMTED2010 elevation data [23]. All variables had a spatial resolution of 30" in the WGS 84 coordinate system.

A moderate climate change scenario (RCP 4.5) was used for modeling climatic conditions in the future. The scenario represents a decrease in greenhouse gas emissions by the middle of the 21 century and stabilization of the radiative forcing by the beginning of the 22 century [24]. The RCP 4.5 scenario leads to an increase in average annual air temperature by 1.1–2.6°C by the end of the century [25]. Since the best modelling results are achieved with the use of model ensemble (i.e. by calculating the average of several climatic models) [26], we used the mean of CCSM4, NorESM1-M, MIROC-ESM, and INMCM4 [27-30] models based on recommendations for ensemble selection [26].

Modelling was performed for time periods of 2040–2060 and 2061–2080. Default model settings were chosen according to the recommendations [31]. Five-fold cross-validation was applied, where each of the five folds used 80% points as a training sample and 20% as a test sample. The final model was the average of the five folds. Species-specific variables were chosen from a CHELSA BIOCLIM set after a correlation analysis, where one of the variables with a correlation of 0.8 or more was excluded. When choosing the variables, more integrated predictors were preferred (quarterly rather than monthly). The AUC was used for statistical estimation of the model, and the jackknife test was used to assess the validity of the predictors' contribution to the models. We used Maximum test specificity minus sensitivity as the lowest threshold for habitat suitability [32]. To determine habitat suitability in each occurrence point, we created buffers with a radius of 50 m around the presence points, and the average value of suitability was calculated for each of the buffer polygons using the ‘Zonal statistics’ plugin in QGIS 3.16. Similarly, the average values of winter and summer precipitation were calculated for the polygons. The areas with different classes of habitat suitability were calculated using the ‘Raster Calculator’ for model reclassification, afterwards the rasters were digitized and the total area of polygons was calculated.

4. Results and Discussion
The AUC of the model of the modern potential range of *A. salsoloides* is 0.995, which corresponds to a high quality of the model [33]. Six environmental factors played the main role in modelling, with the precipitation in the driest quarter having the greatest percent contribution – 25.6% (BIO17, precipitation in the winter and early spring). The difference between the maximum and minimum elevation a.s.l. had a similar contribution percentage – 22.9%. Other climatic variables had a percent contribution of 10–15%, and they include the average temperature of the coldest (BIO11) and warmest quarter (BIO10), also the coefficient of variation of average monthly precipitation (BIO15) and the mean of the monthly temperature ranges (monthly maximum minus monthly minimum, BIO2).
In general, these factors describe the conditions of sharply continental climate. The significance of precipitation and temperature of the coldest quarter can be explained by the fact that the resting buds of the studied species are located above the soil surface.

The results of the modeling of the current potential range of the species are shown in figure 1. Habitat suitability values above the threshold (0.33) were divided into three groups. The values from 0.33 to 0.55 were classified as low suitable habitats, from 0.55 to 0.75 – as medium suitable, and 0.75 to 1.00 – as highly suitable. Within the medium- and high-suitability areas shown on the map the species grows only in suitable soil and edaphic conditions associated with the presence of outcrops of carbonate rocks.

![Figure 1. Current potential range of Artemisia salsoloides Willd.](image)

Highly suitable habitats are present to a greater or lesser extent in all parts of the potential range, with the exception of the southern fragments. Within the limits of the South Ural region and adjacent territories, highly suitable habitats are mostly confined to the xerophytic steppes of the south of the Bashkir Pre-Urals and Trans-Urals, as well as of the Orenburg Oblast. To the south, they are present but not widely distributed in Kazakhstan. The northern border of the potential range is strongly fragmented and appears in form of small areas in the Mesyagutovsky forest-steppe and in the northern regions of the Tatarstan Republic.

The analysis of habitat suitability values for 102 known localities of *A. salsoloides* has shown that 53 sites had high habitat suitability, 30 had medium suitability, and 16 had low suitability (figure 2). Highly suitable habitats are located in the south of the Central Russian Upland, on the Bugulminsko-Belebeyevskaya Upland, and in the Southern tip of the Urals. Three occurrence sites used in the modeling had the suitability values slightly below the threshold. All of them are confined to gentle and very gentle slopes, while highly suitable localities are confined to moderate slopes according to the slope classification by V. K. Zhuchkova and E. M. Rakovskaya [34].

Calculation of the most important climatic variables for steppe vegetation in the presence points using ensemble climatic data showed an increase in precipitation in the driest quarter (winter) by 13.2% (10.0 mm), and in the warmest quarter (summer) by 7.4% (12.5 mm) in case of climatic changes under the RCP 4.5 scenario compared to the current climate. At the same time, temperature in
the warmest quarter will increase by 2.2°C, which will largely offset the increase in precipitation in this period due to rapid evaporation.

![Map of Russia, Ukraine, and Kazakhstan with habitat suitability data](image)

**Figure 2.** Habitat suitability in the occurrence sites of *Artemisia salsoloides* Willd.

In some cases it will create the conditions leading to an increase in soil salinization, often observed in the Bashkir Trans-Urals and in the Orenburg Oblast.

The graph (figure 3) shows the results of modeling of the climate change impact on the areas with different habitat suitability of *A. salsoloides* in the Southern Urals and the European part of Russia.

![Bar chart showing changes in distribution areas](image)

**Figure 3.** Changes in distribution areas with different habitat suitability of *Artemisia salsoloides* Willd. in the 21st century under moderate climate change (RCP 4.5).

A significant increase in the areas with low habitat suitability and a slight increase in the areas with medium habitat suitability are expected under the predicted climatic changes in the 21st century. The increase in areas with low and medium habitat suitability is predicted mainly in the northeastern part of the range. These changes may be associated with a possible decrease in competition with less
drought-tolerant vegetation on stony soils. The influence of climatic changes on the areas of highly suitable habitats is insignificant, as they are confined to stony slopes, and the strong deep root system of *A. salsoloides* causes the species to have resistance to precipitation variability.

The trend of the change in areas with different habitat suitability was supported by the analysis of the climate change impact on the groups of localities divided by habitat suitability at present (figure 4). Although, the change in habitat suitability in the groups of localities was not statistically significant.

**Figure 4.** Effect of climate change on the habitat suitability of *Artemisia salsoloides* Willd. in the sites divided by habitat suitability at present. Letter (a) marks unsuitable sites, (b) – low, (c) – medium, and (d) – highly suitable sites.

The probability of an increase in the species distribution by settling in new habitats with low and medium suitability in the aftermath of climatic changes is low. The species reproduces by seeds [5], and, although in some cases the seed wind transfer into suitable habitats is possible, a complex of conditions is required for germination and plant establishment in new areas. These include sufficient humidity in the current year, as well as the absence of competition with other species. The spread of *A. salsoloides* may be facilitated by the exposure of bedrock during the extraction of construction materials (limestone, chalk), and by grazing intensification, which will increase if the productivity of steppe communities declines and if the forage base for ungulates reduces.

**5. Conclusion**

Resilience of endemic steppe species to climate change can potentially vary significantly depending on their drought tolerance. Modelling the impact of the likely climatic changes on the habitat suitability of *A. salsoloides* has shown that the environmental conditions in the known occurrence sites will not change significantly, and negative changes in the potential range of the species will not occur. Thus, in case of the moderate climate change, no additional protection measures for this rare species are needed.

The response of endemic species to climate change, to some extent, can be used to determine the climatic conditions favorable for the species formation. The high resistance of *A. salsoloides* to potential climatic changes may indicate the formation of this species in the very arid climate and in the predominance of shallow soils on carbonate bedrock. According to the literature data [35], such habitats were quite widespread in the late Pleistocene and early Holocene in the current range of the species.
Acknowledgments
This work was carried out as part of Government Contract of the Ministry of Education and Science of Russia №075-00326-19-00 on topic №AAAA-A18-118022190060-6 and with financial support from the Russian Foundation for Basic Research as part of scientific project №19-34-90028.

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