

SHORT COMMUNICATIONS

Potential Range of *Bulbocodium versicolor* (Ker-Gawl.) Spreng. (Colchicaceae, Liliopsida) in Russia

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The article presents a bioclimatic model of the potential range of *Bulbocodium versicolor* in European Russia. To build the model, we analyzed a matrix containing 166 *B. versicolor* localities in the studied region; the analysis was carried out in the SDMtoolbox program using the climatic parameters from the WorldClim open database. The model demonstrates that, given the available dataset on the modern climatic conditions, *B. versicolor* may occur in a wider geographical range comprising, at the very least, the Belgorod, Voronezh, Volgograd, Lipetsk, Penza, Rostov and Saratov provinces. Also, within European Russia, the most favorable conditions for *B. versicolor* are found in most of the Voronezh and Volgograd provinces as well as in some areas of the Right Bank and Left Bank of the Volga River adjacent to the Volga Upland (in the Saratov province). The maximum occurrence probability is 70–100% while the average occurrence probability is 40–60%. The maximum contribution to the model is made by the precipitation of the warmest and most humid quarter (June–August); a smaller contribution is made by the average temperature of the coldest (December–February) and warmest (June – August) quarters as well as by the average annual precipitation. The least contribution is made by the precipitation of the most humid month (July) and the driest quarter (March–May). Finally, we conclude that bioclimatic model facilitates a better understanding of the geographical distribution of the species in question.

Keywords: bioclimatic modelling, potential bioclimatic range, SDMtoolbox, *B. versicolor*.

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Precise information on a species' geographical distribution is fundamental for the monitoring and preservation of the species biodiversity as well as the testing of biogeographical hypotheses (Chiryulina, Bocharnikov, 2019). In general, the data concerning the distribution of the rare species are scarce (Ananyeva, Golynsky, 2013; Solodyankina et al., 2016), which complicates the performance of the above stated tasks.

Conventionally, the species' geographical ranges were depicted using the linear and grid methods. Today, those methods are being replaced by the innovative bioclimatic modelling methods based on the GIS-technology. As other researchers mention, the GIS-based modelling is a powerful tool for identifying the most climatically favorable sites for any taxon – species in particular (Ward, 2007; Olonova, Gudkova, 2017). Also, bioclimatic models may trigger the ground search for new species' localities in the territory enveloped by the obtained model. It is of particular importance for the definition of the rare species' ranges and the development of their preservation measures. Furthermore, a model of the species' potential range may be applied in the search for the natural sites suitable for the species reintroduction.

Currently, the maximum entropy mapping in the MaxEnt program is considered the most efficient approach to the species potential range modelling (Anderson et al., 2003; Phillips et al., 2006; Phillips, Dudík, 2008; Phillips, 2010). The MaxEnt program generates the maps showing the probability of the species' presence or absence in a particular locality. The probabilities are calculated based on the correlation of the various environmental factors and the species' known localities. Thus, using the data on the environmental values in the known localities, the program predicts the probability of the species occurrence in other localities.

The program also helps to evaluate the contribution of various climatic parameters to the potential range model. This information is fundamental for identifying the key limiting factors that hinder the species dispersal. In addition, based on the climatic values of the species' localities, one can define the species profile, namely the degree of its adaptability to the varied climatic conditions (Olonova, Gudkova, 2017; Ward, 2007).

In the present research, we attempt to build the bioclimatic model of the potential range of *Bulbocodium versicolor* (Ker-Gawl.) Spreng. in European Russia. *B. versicolor* is a relic of the postglacial period, belonging to the Melanthiaceae family and originated in the Mediterranean region (Mayevsky, 2014). The species is under protection throughout its whole range (Melnik et al., 2007; Tsvelyov, 2008). Its range is disjunctive; and it comprises primarily the forest-steppes and steppes of the East European Plain from the Podolsk Upland (Ukraine) to the Volga Upland (Russia). Individual small exclaves are found in Moldova, Romania, Hungary, Serbia and Italy (Csapody, 1982; Oltean et al., 1994; Conti et al., 1997; Conti, Bartolucci, 2012). In Russia, *B. versicolor* is confined to the Central Russian and Volga Uplands (Tsvelyov, 2008). The south-eastern and eastern borders of the species range pass in the Lower Volga region (Sagalayev, Shantser, 2006); its northern border also passes in the Saratov province (Petrova et al., 2015).

The research objective is to identify the most climatically favorable localities for *B. versicolor* in European Russia. Prior to the present research, we carried out the grid mapping of *B. versicolor* localities in the Lower Volga region based on the grid squares of the Atlas Florae Europaeae (Petrova et al., 2015). Upon the analysis of the available

herbarium specimens and wild specimens gathered in the known natural localities, we concluded that the data on the species distribution are highly fragmentary, and many of the species' descriptions are based on the same few localities. We noted that *B. versicolor* specimens grow in remote localities and flower for a very short period during the annual spring thaw. Considering the fact that *B. versicolor* natural populations are hard to reach, we proposed that new research methods are required to study the species' range and to define its preservation status.

Material and methods. In order to build the model, we compiled a matrix containing 166 natural species localities. For the matrix, we used the data obtained in the course of our own research and documented in other scientific literature as well as the material from the herbaria of Saratov State University (SARAT), Komarov Botanical Institute of the Russian Academy of Sciences (LE), Moscow State University (MW), Moscow Botanical Garden of Academy of Sciences (MHA) and Volgograd Regional Botanical Garden. For modelling, we selected the populations with two or more decimals in the coordinates. Such precise data were available only for the populations located in the East-European part of the species range in Russia – the Belgorod, Volgograd, Voronezh, Kursk, Lipetsk, Rostov, Saratov and Tambov provinces.

To reveal *B. versicolor* climatic profile and build the model of the species distribution, we used the SDMtoolbox v 2.4 program written in Python (v 2.7) (Brown et al., 2017). The data on the environmental parameters were extracted from the WorldClim Version 2 open database comprising 19 bioclimatic variables (Fick, Hijmans, 2017). The database contains the network at 30 second spatial resolution (~ 1 km) with the climatic parameters located in its nodes. Potential range modelling was performed using one of the tools of Run MaxEnt: Spakerally Jackknife (Brown et al., 2017). The contribution of

each variable was assessed in two independent ways: the direct assessment of the contribution in percentage terms and the permutation importance. The generated model was projected on the map built with the ArcGis 10.7 program.

Following the bioclimatic approach, we obtained a bioclimatic map of the species' potential distribution over European Russia. The map is shown in the Figure; the color gradient indicates the probability of the species occurrence (Figure).

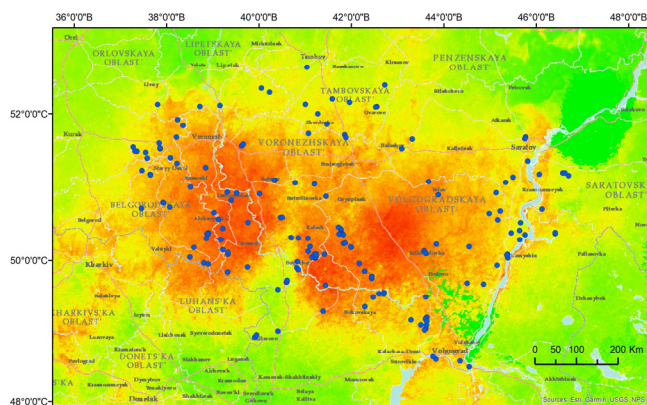


Figure. The model of *Bulbocodium versicolor* potential climatic range. The blue dots mark the known localities used to build the model. The gradient color marks the areas of the probable occurrence: the probability of occurrence 0–17.3% (green); 17.3–37.7% (light green); 37.7–58.4% (yellow); 58.4–79.6% (orange); 79.6–100% (red)

The accuracy of the obtained model is supported by the AUC value – a parameter which is used to assess the model fitness to predict the likelihood of the species occurrence in a site where it is known to be present. For our model, the training AUC is 0.992 and the test AUC is 0.991, which proves the high accuracy of the generated model (Araújo et al., 2005).

The obtained model shows that, given the available dataset on the climatic conditions, *B. versicolor* may occur in a wider range enveloping, at the very least, the Belgorod, Voronezh, Volgograd, Lipetsk, Penza, Rostov and Saratov provinces. In European Russia, the most favorable conditions for *B. versicolor* are found in most of the Voronezh and Volgograd provinces as well as in some areas of the Right Bank and Left Bank of the Volga River adjacent to the Volga Upland (in the Saratov province). The maximum occurrence probability accounts for 70–100% while the average occurrence probability amounts to 40–60%.

Also, the obtained potential range model allowed us to detect the contributions of various climatic variables into the species dispersal. As the Table shows, the model is impacted on by the following ecological factors: most significantly – by the precipitation of the warmest and most humid quarter (June–August), less significantly – by the average temperature of the coldest (December–February) and warmest quarters (June–August) and the average annual precipitation, and least of all – by the precipitation of the most humid month (July) and the driest quarter (March–May). Thus, the results indicate that the key factors affecting *B. versicolor* dispersal are the summer precipitation, the winter and summer temperatures, and the temperature seasonality. We attribute it to the fact that hot temperatures and moisture deficit result in drought that hinders the specimen's development, seed germination, shaping of new bulbotubers and the specimen's shift to dormancy.

Table. The WorldClim default bioclimatic parameters and their contribution to the obtained MaxEnt model, %

Parameter	Contribution	Permutation importance
The average temperature of the most humid quarter	22.2	1
Temperature seasonality (coefficient of variation)	11.8	0
Precipitation of the coldest quarter	10	4.6
Precipitation of the driest quarter	9.3	8.5
The average temperature of the warmest quarter	7.6	11.7
Precipitation of the warmest quarter	7.5	15.5
Average temperature of the driest quarter	7.3	0
Precipitation of the driest month	5.3	2.8
Precipitation of the most humid quarter	4.5	14.9
Average annual amplitude of temperature fluctuations	4.3	2.4
Average temperature of the coldest quarter	3.7	12.6
Precipitation of the most humid month	3.6	10.8
Isothermality	1.5	0.5
Average annual precipitation	0.8	11.2
Minimum temperature of the coldest month	0.4	3.5
Average annual temperature	0.2	0
Precipitation seasonality (coefficient of variation)	0	0.1
Maximum temperature of the warmest month	0	0
Monthly average daily amplitude of temperature	0	0

Thus, we draw a conclusion that the bioclimatic modelling of the species potential range is an efficient tool for studying the species distribution. We emphasize that limited literature data and scarce herbarium samples (Petrova et al., 2015) do not provide sufficient information on *B. versicolor* distribution. It is primarily due to the remoteness of the species' localities and the specimens' short flowering that coincides with the peak of the annual spring thaw. In this light, we suppose that the employed modelling method is crucial for investigating *B. versicolor* distribution, gaining a clearer idea of its range, monitoring the state of its populations and defining the species preservation status.

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**ПОТЕНЦИАЛЬНЫЙ АРЕАЛ
BULBOCODIUM VERSICOLOR (KER-GAWL.) SPRENG.
(COLCHICACEAE, LILIOPSIDA) НА ТЕРРИТОРИИ РОССИИ**

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При анализе матрицы, содержащей координаты 166 местонахождений *B. versicolor* в Европейской России, в программе SDMtoolbox с использованием информации о климатических параметрах среды из открытой базы данных WorldClim построена модель потенциального биоклиматического ареала этого вида. Модель демонстрирует, что в современных климатических условиях, исходя из имеющегося набора данных, *B. versicolor* может встречаться заметно шире, по крайней мере, на территории Белгородской, Воронежской, Волгоградской, Липецкой, Пензенской, Ростовской и Саратовской областей. Наиболее благоприятные условия по ареалу в пределах Европейской России для произрастания вида определены для всей большей части Воронежской и Волгоградской областей, а также по прилегающим к Приволжской возвышенности районам Правобережья и приволжским районам Левобережья Саратовской области. Максимальная прогнозируемая вероятность составляет 70 – 100%, но в среднем этот показатель находится на уровне 40 – 60%. Показано, что максимальный вклад в построение модели вносят осадки самого теплого и самого влажного (июнь – август) кварталов, в меньшей мере – средняя температура самого холодного (декабрь – февраль) и наиболее теплого (июнь – август) кварталов, а также среднегодовые осадки, и в ещё меньшей степени – осадки самого влажного месяца (июль) и самого сухого квартала (март – май). Биоклиматическая модель потенциального ареала позволяет более полно представить картину распространения вида.

Ключевые слова: моделирование, потенциальный биоклиматический ареал, SDMtoolbox, *B. versicolor*.

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