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Bioclimatic Modeling of *Phlomoides Kirghisorum* (Lamiaceae) Species Distributed in Fergana Valley

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ANNOTATION: The article analyzes the natural distribution area of the species *Phlomoides kirghisorum* Adylov, Kamelin & Makhmedov using the programs of type MaxEnt and ArcGis, the endemic of Central Asia (past, future). According to the results of the study, it is proved that the main distribution of the species coincides with the boundaries of the areali Tien–Shan mountain system (Uzbekistan, Kyrgyzstan, Kazakhstan). It is noted that the climatic factors that are optimal for the species are sufficient temperature and annual precipitation. According to both scenarios, it was found that the increase in temperature by 0.4–1.6 °C and 1.4–2.6 °C was directly influenced by the main bioclimatic factors such as Mean temperature of coldest quarter (Bio11), Precipitation seasonality (Bio15).

KEYWORDS: Bioclimatic modeling, Climate change, Fergana Valley, MaxEnt, Phlomoides kirghisorum, WorldClim.

INTRODUCTION

One of the most important problems facing humanity in the 21st century is the problem of modern climate change (Olonova et al., 2017). In the last century, the average temperature increased by 0.85 °C, and by the year 2100, the maximum temperature is predicted to increase to 8 °C (IPCC, 2019). According to the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC), by the end of the 21st century, the global average temperature will increase by 3.7 °C under the Representative Concentration Pathways (RCPs) scenario (Lee et al., 2020).

As one of the main environmental factors affecting species geography (Kreft et al., 2007), climate change is negatively affecting the regional distribution and phenology of plant hotspots. It is emphasized that the future disappearance of species sensitive to temperature and precipitation factors will be accelerated by the increase of global temperature and the influence of human activities, and the change of the potential distribution area (Yousefi et al., 2015).

Central Asia is one of the most vulnerable regions to climate change (Gulomov, 2022). Meteorological data have shown that air temperatures are increasing across Central Asia, and regional climate change scenarios show that temperatures will rise by 1°C–3°C in the next 20–40 years. If global greenhouse gas emissions are not reduced, temperatures are projected to rise by 3°C to 6°C above today's levels by the end of the century (Novikov et al., 2012).

For this reason, the development of strict measures to preserve endemic and rare plant species, sensitive to climate change, geographically isolated, is of urgent scientific and practical importance.

Bioclimatic modeling was carried out in order to estimate the future (2061–2080 years) potential distribution and growth habitat suitability of the species *Phlomoides kirghisorum* Adylov, Kamelin & Makhmedov as an endemic of the Fergana Valley.

The species is distributed in 14 habitat areas defined by 2 km^2 (IUCN; EOO= 2,605,687 km^2, AOO=40 km^2), and the distance between each area is 10–50 km. The species has been assessed as Endangered (EN) by the International Union for Conservation of Nature (IUCN) criteria B1ab (ii,iii)+2ab(ii,iii,iv) (Gulomov, 2022).

Important plant areas (IPAs) in the Fergana Valley (Central Asia) Category Aiii included (Komiljon Sh. Tojibaev et al., 2023).

During 2020–2023, as a result of targeted field research in the Ferghana Valley, new growth areas (41.317157°N, 71.660200°E; 41.140341°N, 71.773866°E; 41.2655 97°N, 71.888018°E) were identified and the composition of populations (about 500–600 individual) was studied. There are 200–250 individuals with reproductive potential in the identified areas.

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Phlomoides kirghisorum the chloroplast genome was studied in order to involve it in molecular studies (NCBI; https://www.ncbi.nlm.nih.gov/nuccore/ NC_067634.1? report=fasta).

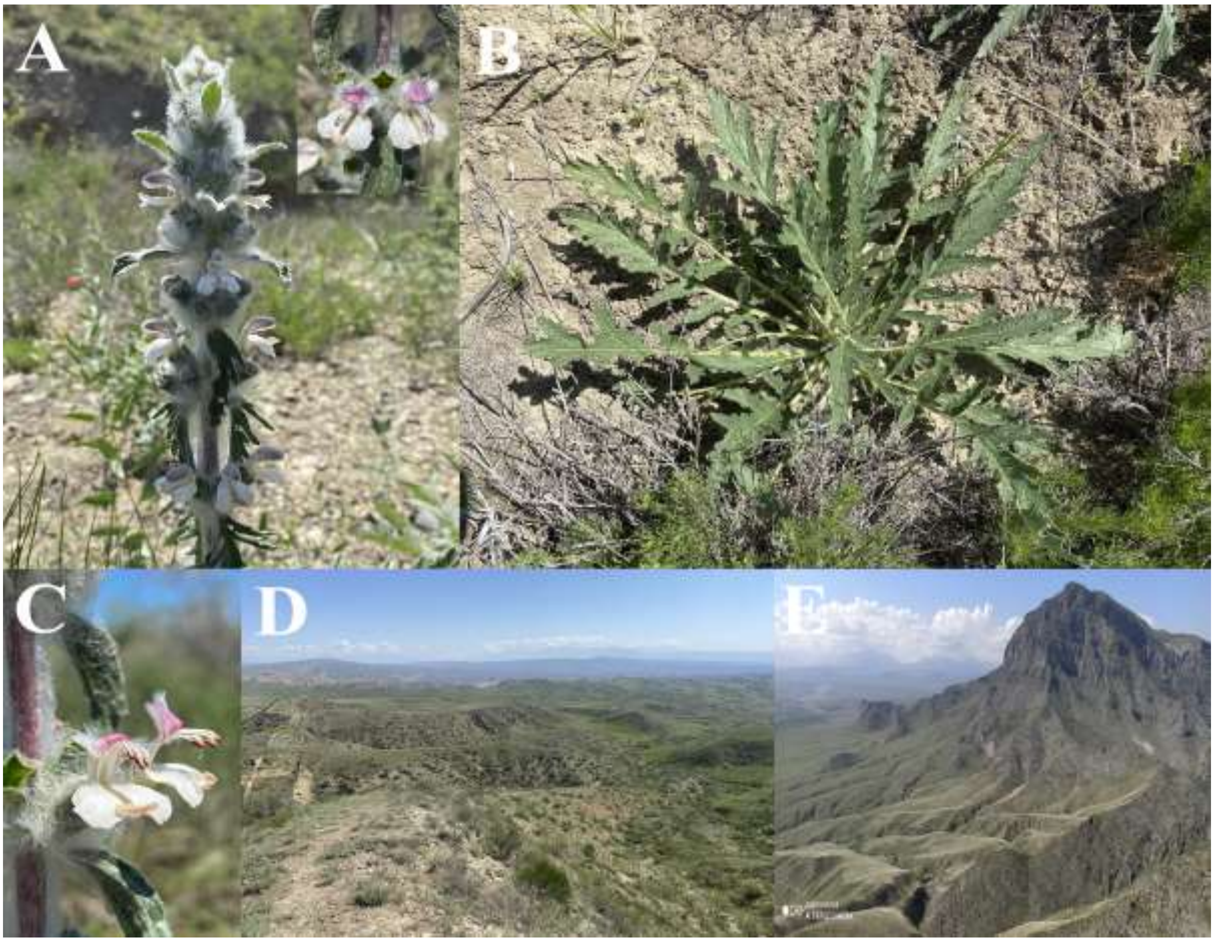

Figure 1. A–C) Picture of *Phlomoides kirghisorum* (by photo Gulomov, 2022). Species ecology. D–F; Arbaghish village, and Ungortepa massif, Namangan province, Uzbekistan.

There is no information on household or medical use. As a rare plant with a declining area, it is recommended for inclusion in the Red Books of Kyrgyzstan and Uzbekistan (Gulomov 2022). Existing Conservation Threats are habitat fragmentation, farmlands, and overgrazing.

MATERIAL AND METHODS

Species registration information. Location information of the species Global Biodiversity Information Facility (GBIF; http://www.gbif.org), was deposited at the Herbarium of the Kongju National University (KNH, collection number: 102, collected by Gulomov), Samples stored in the funds of the herbarium of the Institute of Biology (FRU) of the Kyrgyz Academy of Sciences (Lazkov, 2011) and the National Herbarium of Uzbekistan (TASH) were used. 20 GPS coordinates representing the areas indicated in the herbarium specimens were obtained using Google Earth Pro 7.1 software (www.Google.com/earth) and collected during targeted field research (Arbaghish village, Ungortepa massif, Namangan province, Uzbekistan) during 2020–2023 years enriched with information.

Environmental Variables and Processing. The climate variables were downloaded from the WorldClim v2.1 database (www.worldclim.org). Climate data includes 19 (Bio1–Bio19) bioclimatic variables (Tab.1) consisting of monthly temperature and precipitation. They represent annual trends, seasonality, extreme or limiting environmental factors. In addition to bioclimatic factors, edaphic factors were included.

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Table 1. Environmental variables

Variables	Description	Source	Unit
Bio 1	Annual mean temperature	WorldClim	°C
Bio 2	Mean diurnal range (mean of monthly (max temp –min temp))	WorldClim	°C
Bio 3	Isothermality (Bio2/Bio7) (*100) ºC	WorldClim	%
Bio 4	Temperature seasonality (standard deviation *100	WorldClim	–
Bio 5	Max temperature of warmest month	WorldClim	°C
Bio 6	Min temperature of coldest month	WorldClim	°C
Bio 7	Temperature annual range (Bio5–Bio6)	WorldClim	°C
Bio 8	Mean temperature of wettest quarter	WorldClim	°C
Bio 9	Mean temperature of driest quarter	WorldClim	°C
Bio 10	Mean temperature of warmest quarter	WorldClim	°C
Bio 11	Mean temperature of coldest quarter	WorldClim	°C
Bio 12	Annual precipitation	WorldClim	mm
Bio 13	Precipitation of wettest month	WorldClim	mm
Bio 14	Precipitation of driest month	WorldClim	mm
Bio 15	Precipitation seasonality (coefficient of variation)	WorldClim	1
Bio 16	Precipitation of wettest quarter	WorldClim	mm
Bio 17	Precipitation of driest quarter	WorldClim	mm
Bio 18	Precipitation of warmest quarter	WorldClim	mm
Bio 19	Precipitation of coldest quarter	WorldClim	mm
Altitude		WorldClim	m

Different climate scenarios were used to model species distribution using MaxEnt software (version 3.4.4). They were downloaded from 2.5 (~4.64 km^2 at the equator) minute common socio–economic pathways (SSPs) scenarios available from the Community Climate System Model (CCSM5) global climate for the future (www.worldclim.org).

The scenarios RCP2.6_2070s (SSP1–2.6 (ssp126) minimum greenhouse gases) and RCP8.5_2070s (SSP5–8.5 (ssp585) maximum greenhouse gases) based on IPCC proposed greenhouse gas concentrations (RCP) were used. According to the IPCC (2019) fifth report (AR5), the annual average temperature is 0.4–1.6 °C under the RCP 2.6 (2061–2080) scenario, and 1.4–2.6 °C under the RCP 8.5 (2061–2080) scenario. The RCP8.5 scenario envisages an increase of about 2.5 times the amount of carbon in the atmosphere at the end of the 21st century compared to today (Meinshausen et al., 2011).

Evaluation of MaxEnt model. Assessment of the future potential distribution of the species and the impact of bioclimatic factors was carried out based on the methodological recommendations of Phillips et al., (2006), Olonova et al., (2017). Initially, 20 coordinates in (Comma Separated Values) *CSV format were stored and 19 bioclimatic variables and altitude values obtained from the WorldClim database were imported into the MaxEnt model. To increase the accuracy of the simulation, the sample data were randomly used as test data (25%) and training data (75%). The algorithm was run using 500 iterations at 10,000 integrations with different randomizations (Bootstrap method). The resulting model was validated on the basis of the area under the curve (AUC) calculated from the receptor operating characteristic (ROC).

AUC (Area Under Receiver Operating Curve) is an effective autonomous threshold index capable of evaluating the model's ability (Deblauwe et al., 2011), whose growth factor is set from 0 (lowest probability distribution) to 1 (highest probability distribution). AUC values > 09 indicate high accuracy, values of 07–08 indicate good accuracy, < 07 indicate poor accuracy, and < 05 indicate poor accuracy (Pearson et al., 2007; Guo et al., 2017). Generally, the closer the value is to 1, the more likely the species is present (Xu et al., 2019).

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In the results of the conducted research, a logistic output format was used to create a continuous set of values in the interval from 0 to 1 and obtain a model of the evaluated species. The contribution of variable environmental factors is evaluated according to the results of the Jackknife test. The results obtained in MaxEnt were mapped using ArcGIS 10.6.1 software (WGS; World Geodetic System 1984). For bioclimatic variables, correlation analysis was performed in the SDMtoolbox panel of ArcGIS software.

RESULTS AND DISCUSSION

The approximate prediction accuracy (AUC – training data) of the MaxEnt model showed a high level of accuracy (0.986–0.999) overall. The significance of the distribution of environmental variables was analyzed using the Jacknife test, and the main environmental factors affecting the distribution of species were determined. The correlation coefficient is higher than + 0.8. On the map, high–level suitable areas for the distribution of the species are shown in red, moderately suitable areas in orange, and low and unsuitable areas in green and white colors.

In the period of industrial development (1970–2000), severe anthropogenic climate change has limited the range of the species, but the ecological niche of the species has shown that it can be spread in the Ketmen Mountains of Kazakhstan, Ardebil, Khorasan regions of Iran, and the West Alay, Kurama ridge of the Fergana Valley (Fig. 2).

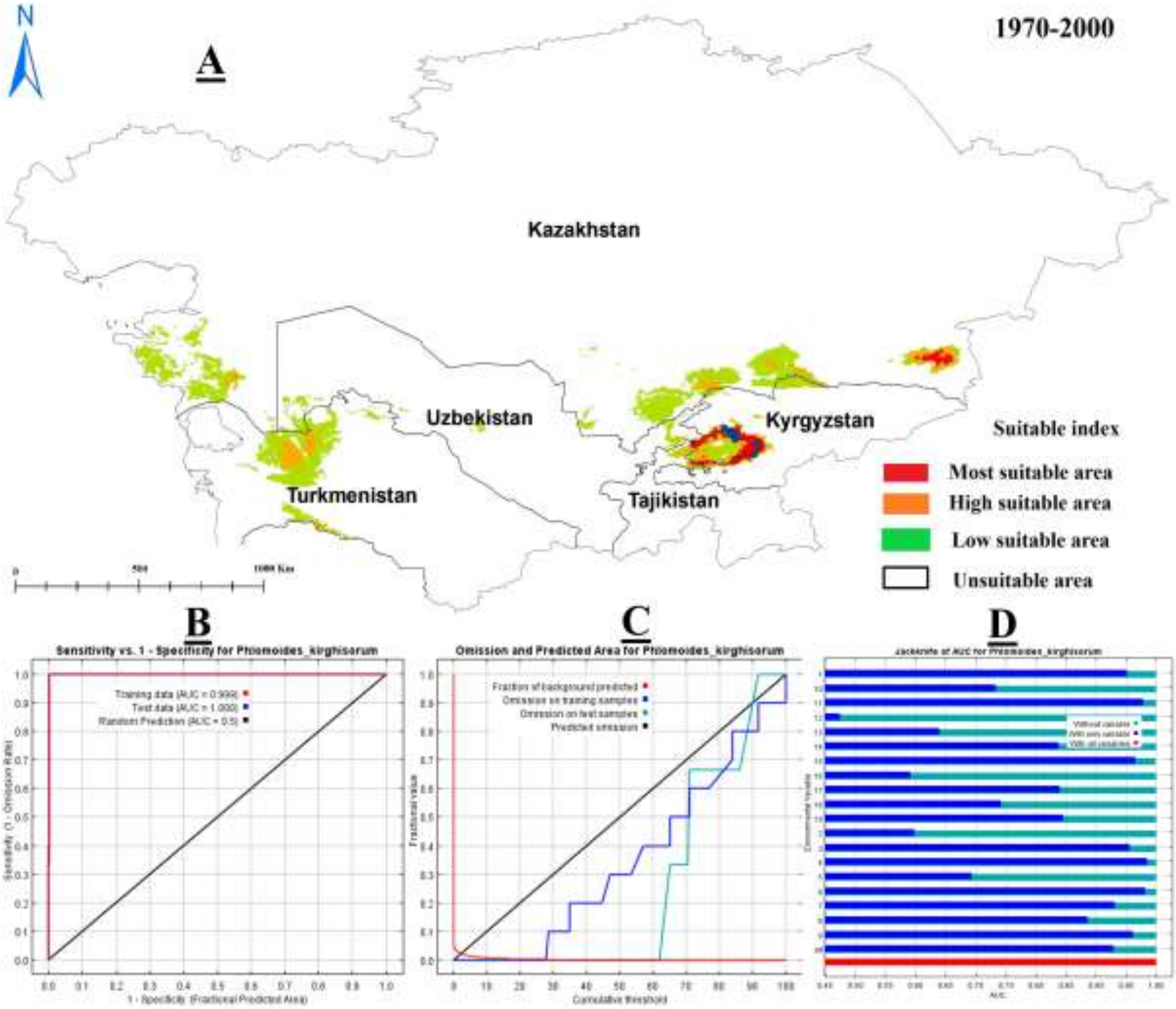

Figure 2. Results of bioclimatic modeling of distribution of *Phlomoides kirghisorum;* A) Results of modeling the period of industrial development (1970–2000); B) Receiver operating characteristic curve of species in MaxEnt model; C) Feasibility of a species prediction model; D) The Jackknife test result of environmental factor.

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The distribution of this species has not been recorded in the above–mentioned regions (Flora Kazakxtana, 1964; Flora Iranica, 1982). In general, the areas of high and medium suitability are 19<35 thousand km^2.

Under the climate scenario RCP2.6_2070 from the period of industrial development, the average temperature of the cold quarter (Bio11), the seasonality of precipitation (Bio15) showed that the high and medium suitable growth area (22<60 km^2) of the species expands with the increase of the minimum greenhouse gas concentration (Fig. 3).

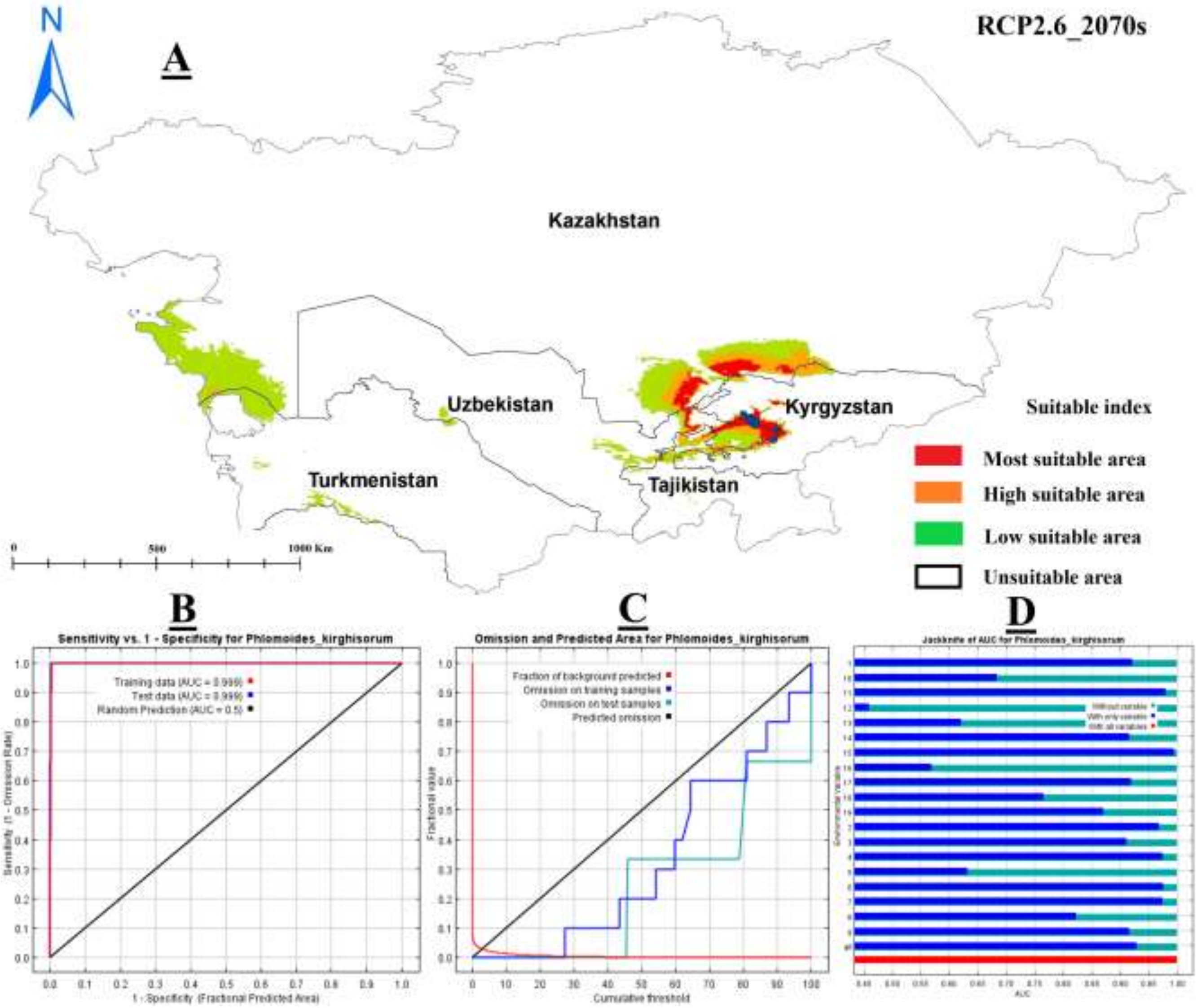

Figure 3. Results of bioclimatic modeling of distribution of *Phlomoides kirghisorum;* A) RCP2.6_2070s (2061–2080) modeling results; B) Receiver operating characteristic curve of species in MaxEnt model; C) Feasibility of a species prediction model; D) The Jackknife test result of environmental factor.

In particular, Iran's Khorasan region, Kazakhstan's Ketmen Mountains, and Western Aloy regions of the Fergana Valley will become unsuitable for the species, and the species habitat will expand toward Western Tiyanshan, Talas, and the Kyrgyz mountain range.

Under the influence of the same climate variables and under the RCP 8.5_ 2070 climate scenario, the area of high suitability areas (18<70 km2) continues to decrease, while the area of medium suitability areas continues to expand. In particular, it showed the direction of the Fergana Valley in Southern Chotkal, Fergana, Eastern Alay and Talas Alatau. (Fig. 4).

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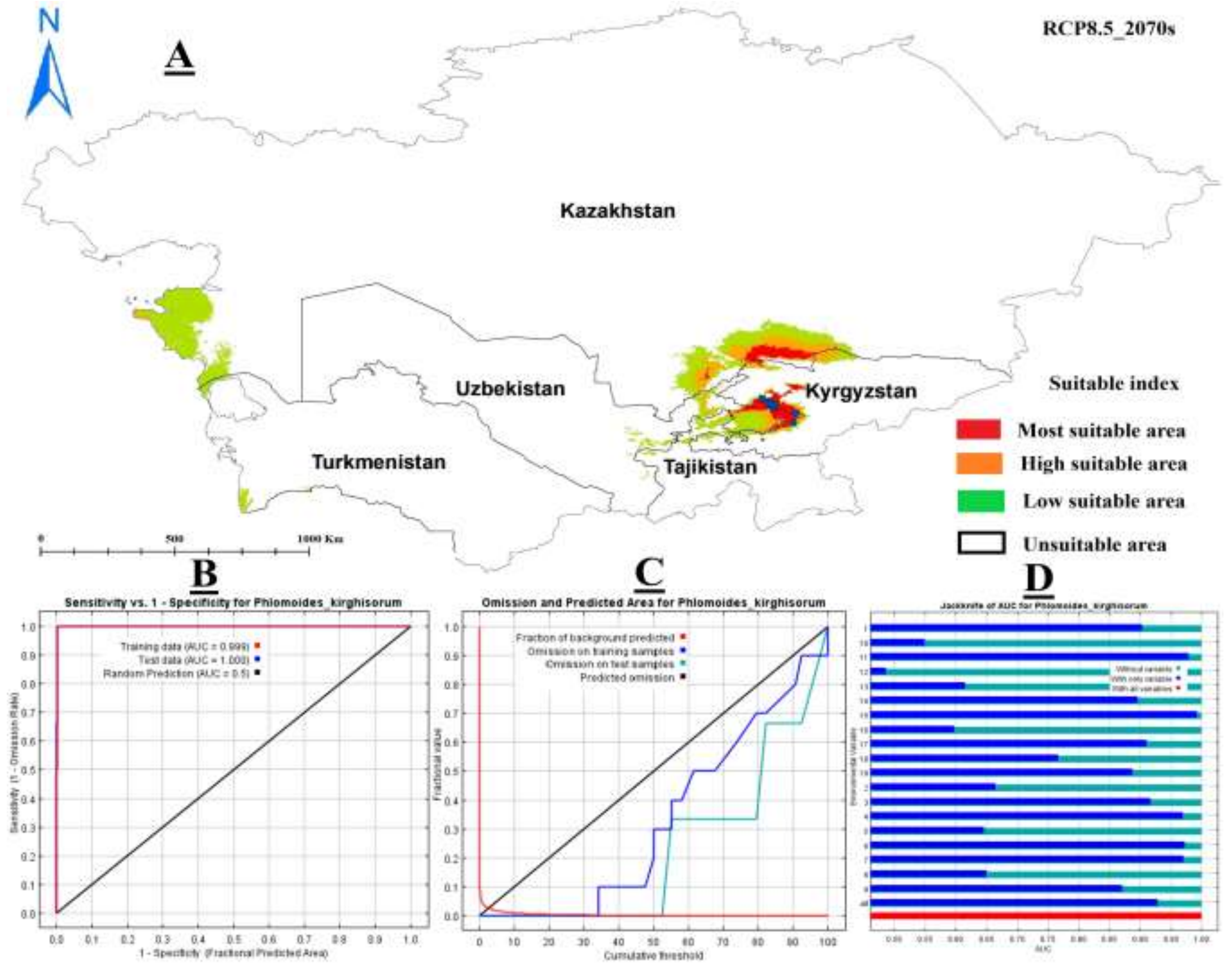

Figure 4. Results of bioclimatic modeling of distribution of *Phlomoides kirghisorum;* A) RCP8.5_2070s (2061–2080) modeling results; B) Receiver operating characteristic curve of species in MaxEnt model; C) Feasibility of a species prediction model; D) The Jackknife test result of environmental factor

The rest of the areas remain as areas of low suitability. The level of suitability corresponds to the average area in the area of residential areas. This indicates that the indicator of anthropogenic threat to the species is increasing. Climate change, pollution, habitat fragmentation, increase in the number of invasive species are considered one of the main problems of biodiversity in Fergana Valley region. These indicators indicate that the optimal and moderately suitable growth areas for the evaluated species are under strong anthropogenic threat (Fig. 5).

Temperature and precipitation factors were modeled separately under RCP2.6_2070, RCP8.5_2070 climate scenarios. The obtained results revealed that precipitation can have a positive effect on the species, and temperature is a relatively limiting climate factor that causes the species' optimal areas to expand (Gulomov, 2022).

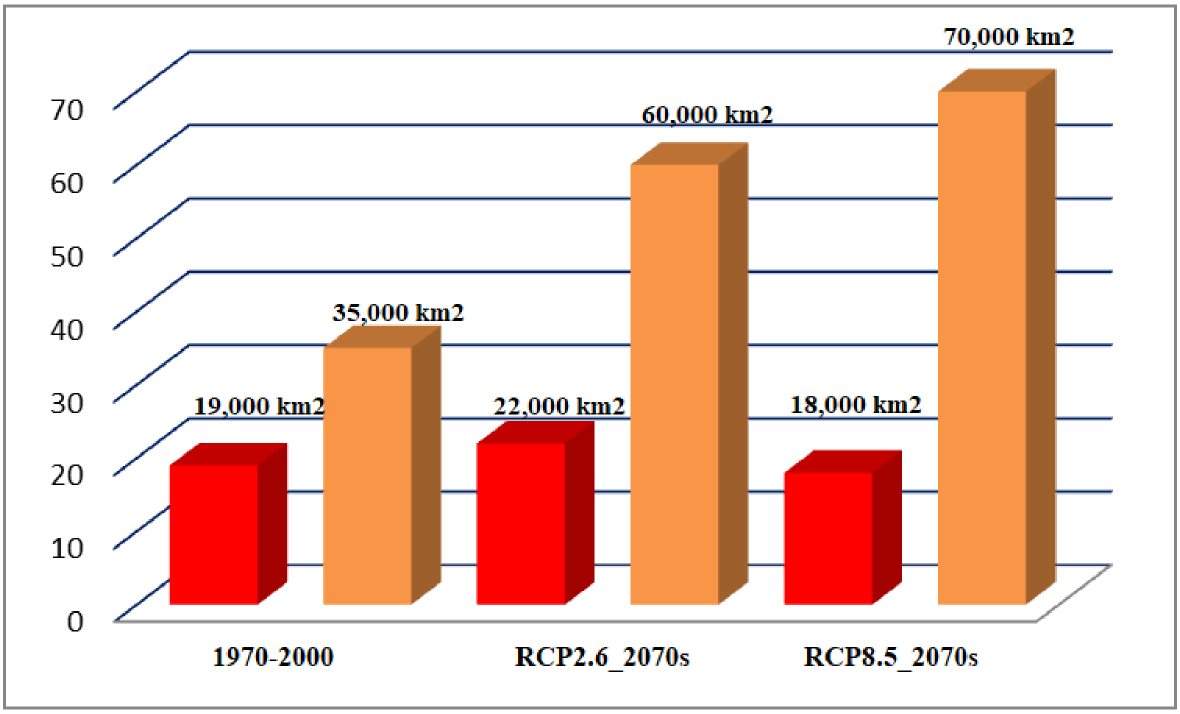

Figure 5. Area suitability (high and medium) index for different climate scenarios

The results of modeling are used to analyze rare and endangered species, to conduct long–term monitoring of them and to determine the ecological optimum of the species. Determining the ecological optimum of the species will allow for the successful introduction of these species in the future. In addition, data on rare and endangered species will be used in future editions of local Red Books (Uzbekistan, Kyrgyzstan).

CONCLUSION

Modeled species populations are located in areas under anthropogenic threat, with temperature increases under both climate RCP2.6_2070 (0.4–1.6 °C) and RCP8.5_2070 (1.4–2.6 °C) scenarios, showed that there is a direct relationship with the morphological characters of the species. The results of bioclimatic modeling allow to determine the most suitable potential growth areas for the restoration of the species population *in–situ* and *ex–situ* conditions and serve as a basis for planning strategies for sustainable use of resources.

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