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Ferula Tadshikorum Pimenov Geographical Distribution Modeling and Climate Change Impact Assessment on the Distribution Area of the Species

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Abstract: Application of modern information technologies to botanical research, including models for predicting the potential distribution of species, is carried out through field studies and geographical points identified using collected herbarium specimens. [1].

1. Introduction

Although various ecological models have been developed to predict the distribution of species, among them MaxEnt (Maximum Entropy) has an advantage over other methods in terms of prediction accuracy [2].

Rare and endemic species with a limited distribution area are especially susceptible to the effects of climate change [3].

One such species, *Ferula tadshicorum*, has been studied to model its distribution and assess the impact of global climate change on its distribution. This species is distributed in Hisar (south-western part of Pamir Olay), Karategin ridges, Bobotog and low mountains in the south of Tajikistan [4; 19; 20]. Included in the Red Book of the Republic of Uzbekistan, it is considered one of the species whose range is decreasing due to the influence of anthropogenic factors [5; 21].

2. Research methods

In determining the coordinates of the areas where the species grows, the materials collected in the field research conducted during 2018-2023, samples stored in herbarium funds (TASH, MW, LE, AA, P, MO, BM, K, G), internet resources (plantarium.ru, GBIF) and it was carried out using the dissertation work conducted by Turginov O.T. [6], Achilova N.T. [22], Abduraimov A.S. [23], Khozhimatov O.K. [24], Ibragimov A.J. [25].

Coordinates were determined using Google Earth, SAS.Planet.Release.191221, Maps.me, ArcGis (10.5) and Tracklia programs. Modeling of species distribution areas MaxEnt version 3.4.1. (Maximum Entropy) program was used [7].

2.1. Data which was collected

A total of 914 specimens of the species were collected during the conducted research. Based on the collected samples, the distribution of the species was modeled and the impact of climate changes on the distribution area was evaluated. The place where these samples were collected, including the botanical geographical regions of Uzbekistan, the administrative region, and the number of collected samples are listed (Table 1).

Table 1. Areas where samples were collected and their number

Botanical-geographic regions	Маъмурий ҳудудлар	Number of coordinates, pcs
Bobotog	Surkhandarya	710
Boysun		168
Kohitang		2
Sangardak-Topalang		31
Torkopchigay	Kashkadarya	3

2.2. Bioclimatic variables and elevation data

Bioclimatic data WorldClim version 2.1, ENVIREM version 1.0 [8], elevation indicators DEM (Digital Elevation Model[1.1],[2.2]) topographic and soil data were downloaded from the online database (spatial resolution of 30 seconds) [9]. All these data were converted from GeoTIFF to ASCII format in QGIS version 3.22.9. The WGS 1984 (World Geodetic System 1984) projection was used to create the maps. Climatic indicators of herbarium samples were determined using Diva-GIS version 7.5 [10]. Environmental variables used in the study are presented in Tables 2, 3, 4.

Table 2. Trends in bioclimatic variability

Code	Trends in bioclimatic variability	Notes	Unit of measure
BIO1	Average annual temperature		°C
BIO2	Average range of the day		°C
BIO3	Isothermality	BIO1 / BIO7 * 100	%
BIO4	Seasonality of temperature	Coefficient of variation	
BIO5	Maximum temperature of the hottest month		°C
BIO6	The minimum temperature of the coldest month		°C
BIO7	Annual temperature range	BIO5 – BIO6	°C
BIO8	Average temperature of the warm quarter		°C
BIO9	Average temperature of the dry quarter		°C
BIO10	Average temperature of the warmest quarter		°C
BIO11	Average temperature of the cold quarter		°C
BIO12	Annual precipitation		mm
BIO13	Precipitation in the hottest month		mm
BIO14	Drought monthly rainfall		mm
BIO15	Seasonality of precipitation	Coefficient of variation	1
BIO16	Precipitation in the wet quarter		mm
BIO17	Precipitation in the dry quarter		mm
BIO18	Precipitation in the warmest quarter		mm
BIO19	Precipitation in the coldest quarter		mm
annualPET	Annual Potential Evapotranspiration		mm / year
aridityIndexThornthwaite	Drought index		
climaticMoistureIndex	Moisture index		
continentality	Index of continentality		°C

Table 3. Soil variables (physico-chemical properties)

Code	Soil variables	Notes	Unit of measure
ACDWRB_M	Soil acidity level		pH < 5 and low BS
CRFVOL_M_sl1	Coarse particle size	0.00 m deep	%
CRFVOL_M_sl2	Coarse particle size	0.05 m deep	%
CRFVOL_M_sl3	Coarse particle size	0.15 m deep	%
CRFVOL_M_sl4	Coarse particle size	0.30 m deep	%
CRFVOL_M_sl5	Coarse particle size	0.60 m deep	%
CRFVOL_M_sl6	Coarse particle size	1.00 m deep	%
CRFVOL_M_sl7	Coarse particle size	2.00 m deep	%
SLTPPT_M_sl1	Amount of clay (2-50 micrometer)	0.00 m deep	%
SLTPPT_M_sl2	Amount of clay (2-50 micrometer)	0.05 m deep	%
SLTPPT_M_sl3	Amount of clay (2-50 micrometer)	0.15 m deep	%
SLTPPT_M_sl4	Amount of clay (2-50 micrometer)	0.30 m deep	%
SLTPPT_M_sl5	Amount of clay (2-50 micrometer)	0.60 m deep	%
SLTPPT_M_sl6	Amount of clay (2-50 micrometer)	1.00 m deep	%
SLTPPT_M_sl7	Amount of clay (2-50 micrometer)	2.00 m deep	%
SNDPPT_M_sl1	Amount of sand (50-2000 micrometer)	0.00 m deep	%
SNDPPT_M_sl2	Amount of sand (50-2000 micrometer)	0.05 m deep	%
SNDPPT_M_sl3	Amount of sand (50-2000 micrometer)	0.15 m deep	%
SNDPPT_M_sl4	Amount of sand (50-2000 micrometer)	0.30 m deep	%
SNDPPT_M_sl5	Amount of sand (50-2000 micrometer)	0.60 m deep	%
SNDPPT_M_sl6	Amount of sand (50-2000 micrometer)	1.00 m deep	%
SNDPPT_M_sl7	Amount of sand (50-2000 micrometer)	2.00 m deep	%

Table 4. Topographic variables

Code	Soil variables	Notes	Unit of measure
DEM	Digital elevation model		M
GloSlopesCl1	Slopes	0 % ≤ slope ≤ 0,5 %	%
GloSlopesCl2	Slopes	0,5 % ≤ slope ≤ 2 %	%
GloSlopesCl3	Slopes	2 % ≤ slope ≤ 5 %	%
GloSlopesCl4	Slopes	% ≤ slope ≤ 10 %	%
GloSlopesCl5	Slopes	10 % ≤ slope ≤ 15 %	%
GloSlopesCl6	Slopes	15 % ≤ slope ≤ 30 %	%
GloSlopesCl7	Slopes	30 % ≤ slope ≤ 45 %	%
GloSlopesCl8	Slopes	slope > 45 %	%
GloAspectClN	Towards the slope	North: 0˚< aspekt ≤45˚ or 315˚<	˚

		aspekt ≤360˚	
GloAspectClE	Towards the slope	East: 45˚ < aspekt ≤ 135˚	˚
GloAspectClS	Towards the slope	South: 135˚ < aspekt ≤ 225˚	˚
GloAspectClW	Towards the slope	West: 225˚ < aspekt ≤ 315˚	˚
GloAspectClU	Towards the slope	Undefined: The slope gradient is not defined or the slope gradient is less than 2%	˚

2.3. Modeling the distribution of a species

MaxEnt estimated the possible distribution areas of a species from 0 (lowest probability distribution) to 1 (highest probability distribution) [11][12]. In the model, 75% of the species presence data were used as training data and 25% as test data [13]. For bioclimatic variables, correlation analysis was performed in SDMtoolbox panel of ArcGIS program [14] and variables with correlation coefficient higher than +0.8 were removed [15]. On the maps, the study area was divided into five categories according to the degree of suitability for the habitat of F. tadshikorum: unsuitable (0.00–0.20), low suitable (0.21–0.40), moderately suitable (0.41–0.60), highly suitable (0.61–0.80) and very highly suitable (0.81–0.1) consists of fields with validity [16].

2.4. Future climate scenarios

In its fifth report (AR5), the Intergovernmental Panel on Climate Change (IPCC, 2013) presented two Representative Concentration Pathway (RCP) climate scenarios (RCP 2.6, RCP 8.5) for 2050, downloaded from the WorldClim online database (www.worldclim.org). The projection of the mean annual air temperature increase in 2046-2100 used in the IPCC Fifth Report (AR5) is presented in Table 5 [17].

Table 5. Increase in global mean air temperature (°C) 2046–2100

	Scenarios	2046-2065 years		2081-2100 years	
		average	interval	average	interval
Average global temperature rise (°C)	RCP 2.6	1	0.4-1.6	1	0.3-1.7
	RCP 4.5	1.4	0.9-2.0	1.8	1.1-2.6
	RCP 6.0	1.3	0.8-1.8	2.2	1.4-3.1
	RCP 8.5	2.0	1.4-2.6	3.7	2.6-4.8

3. The results which was obtained

3.1. Altitude range and climatic parameters of the regions with F. tadshicorum populations

Based on the analysis of altitude indicators of existing herbarium specimens, the distribution range of F. tadshikorum is from 655 meters (Bobotog) to 2176 meters (Boysun), with an average altitude of 1180 meters (Fig. 1).

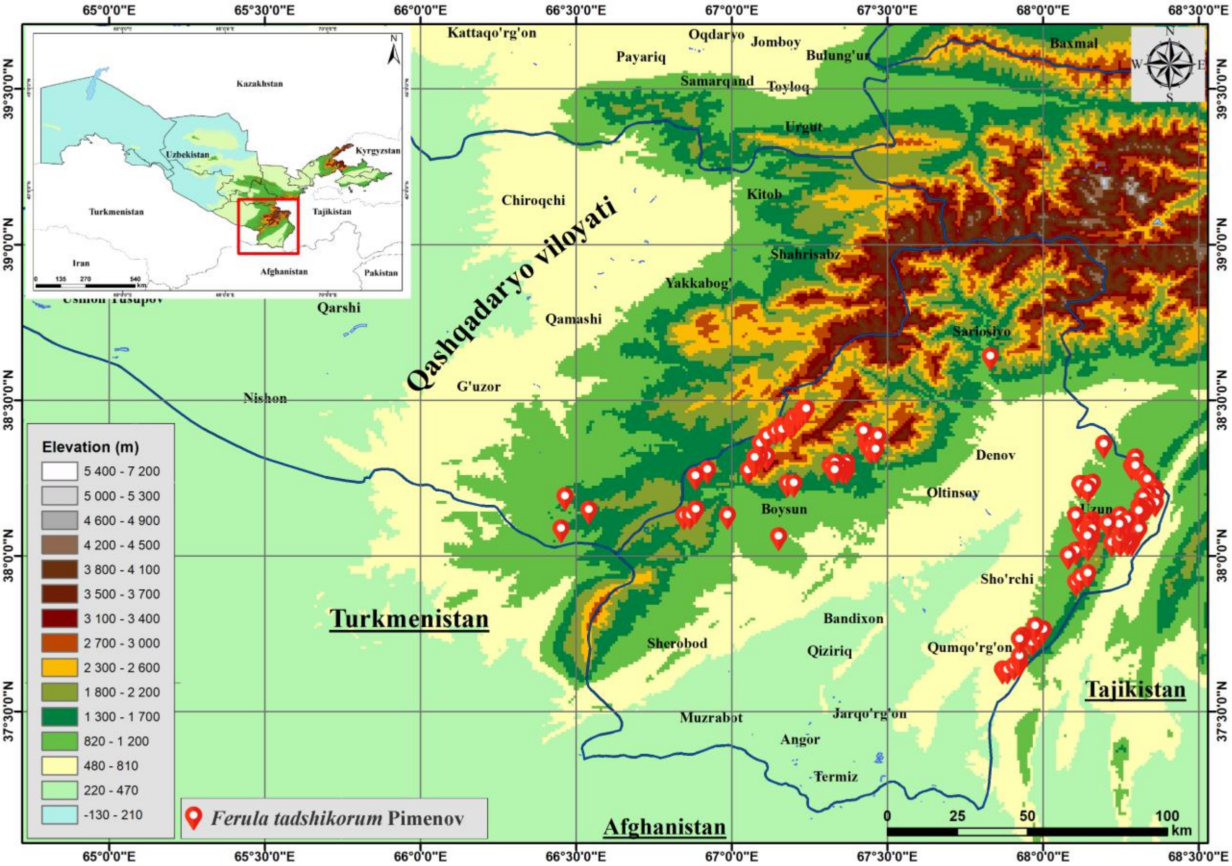

Figure 1. Altitude distribution map of F. Tadshicorum

The altitude range of the samples is 655-1529 m in Bobotog, 1083-2176 m in Boysun, 1206-1335 m in Kuhitang, 758-1124 m in Sangardak-Topalang, and 1117-1562 m in Torqopchigai (Fig. 2). It can be seen that the height gradient of the samples collected from Boysun Mountain is the highest.

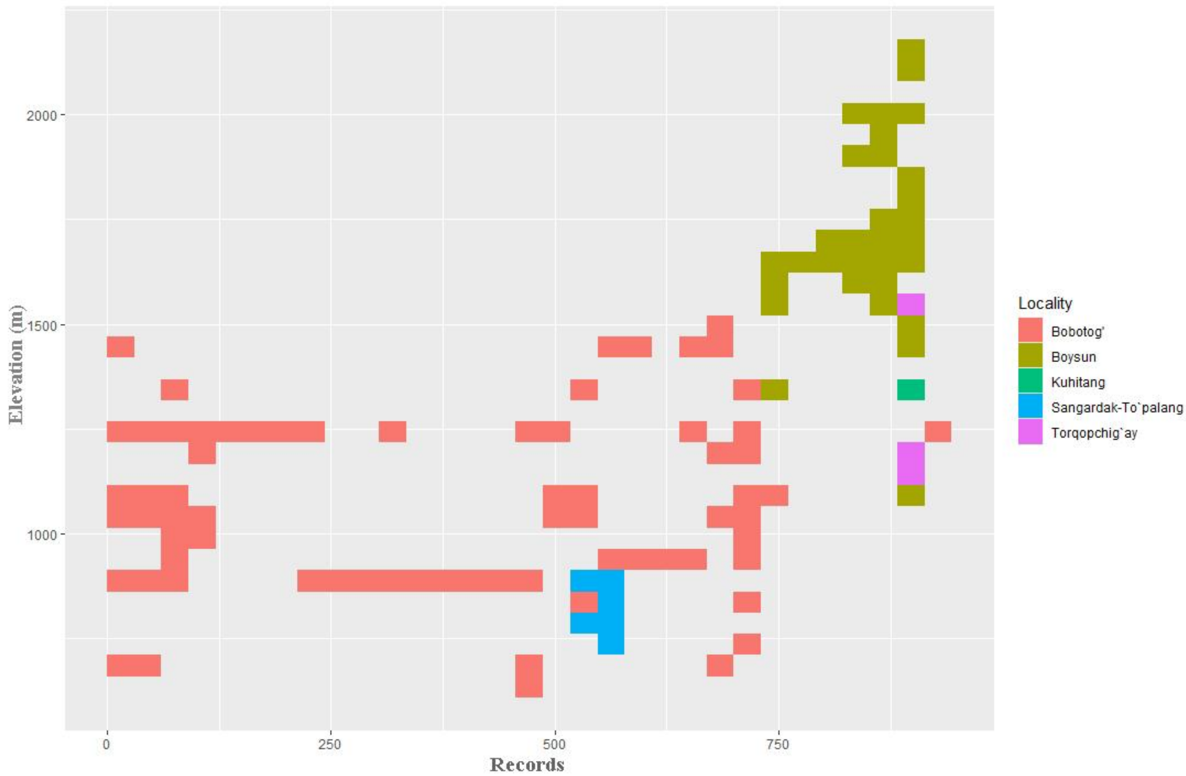

Figure 2. Altitude gradient of F. tadshicorum samples

Temperature and precipitation are the main factors determining the geographical distribution of species [18]. Therefore, the climatic parameters of the areas where herbarium specimens of the research object are available (annual average temperature, annual amount of atmospheric precipitation, the highest temperature of the warmest month and the lowest temperature of the coldest month) were analyzed. According to it, the average annual temperature of F. tadshikorum samples is 6.3–15.4°C (Fig. 3), the total amplitude of annual precipitation is 294–592 mm (Fig. 4), and the highest temperature of the hottest month is 25.7–35.9°C (Fig. 5). and the lowest temperature of the coldest month is -10.9– -1.8°C (Fig. 6).

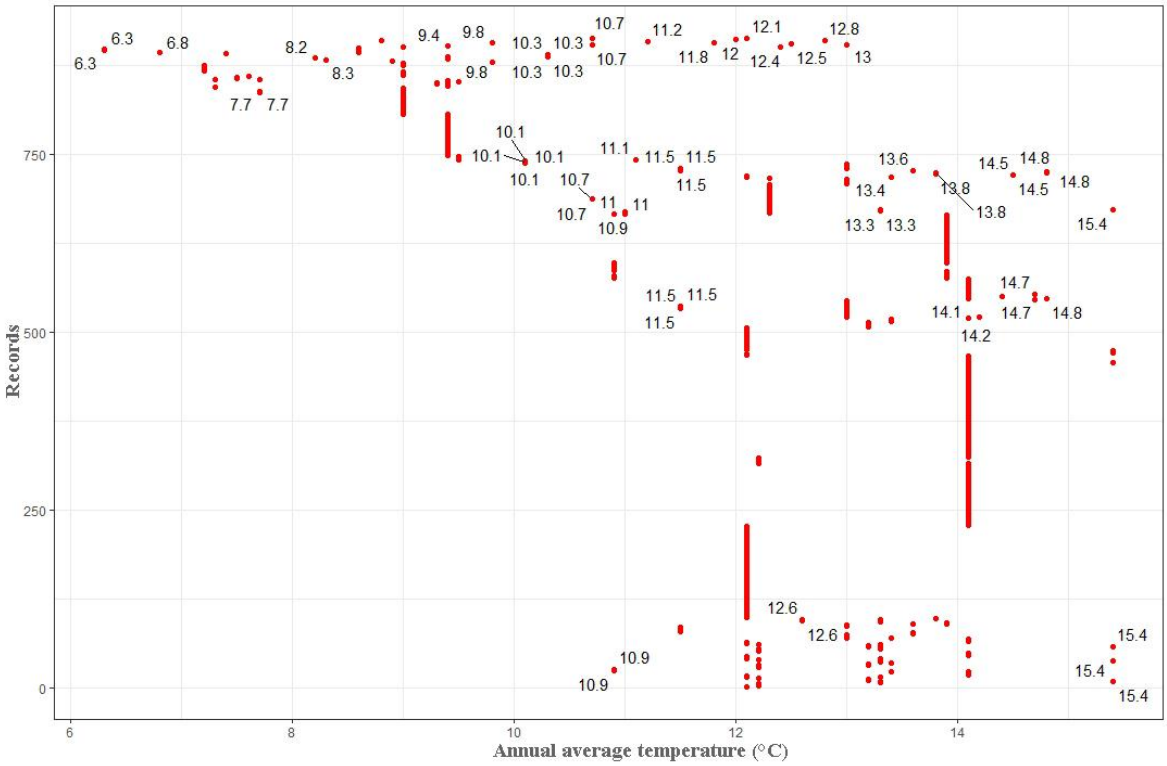

Figure 3. Average annual temperature of areas with F. tadshicorum specimens

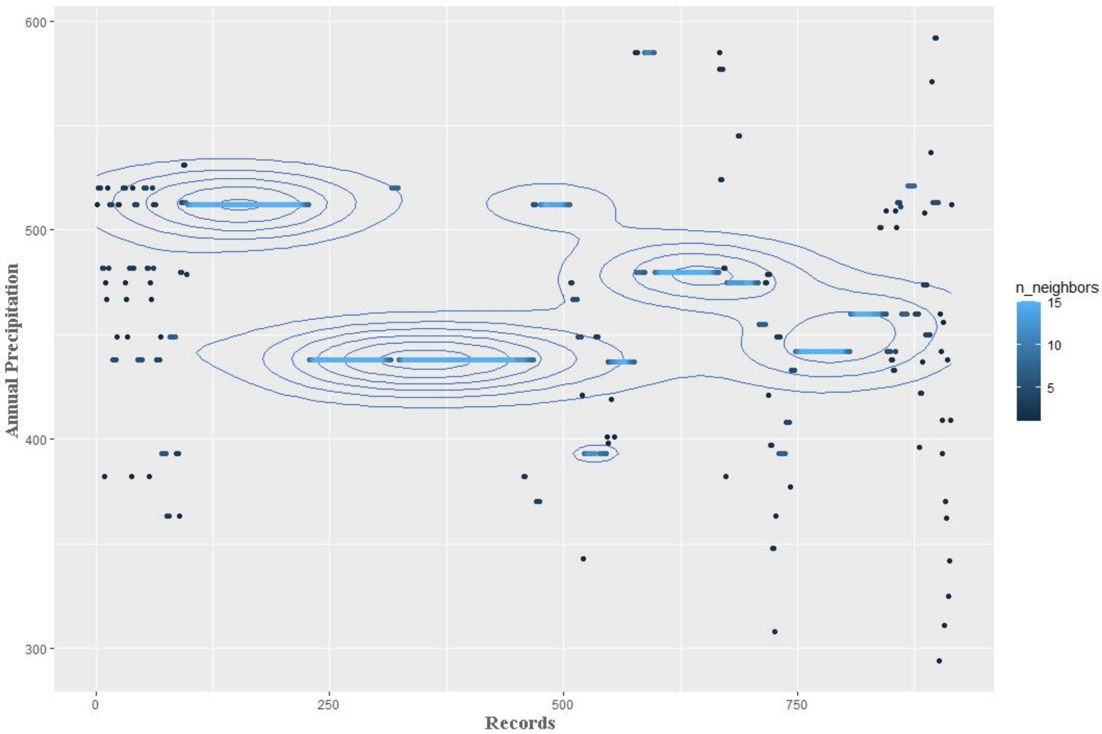

Figure 4. The annual amount of atmospheric precipitation of the areas where F. tadshikorum samples are available

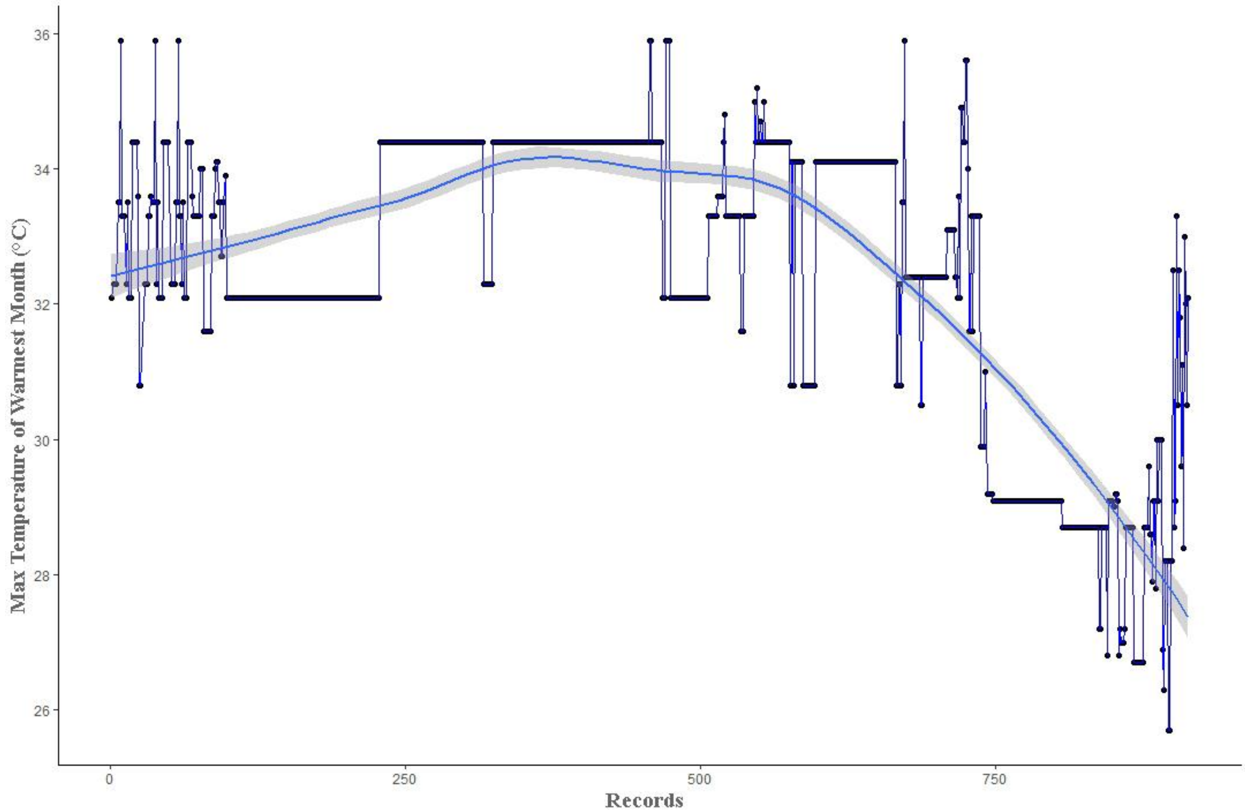

Figure 5. The highest temperature of the warmest month in the areas with F. tadshicorum samples

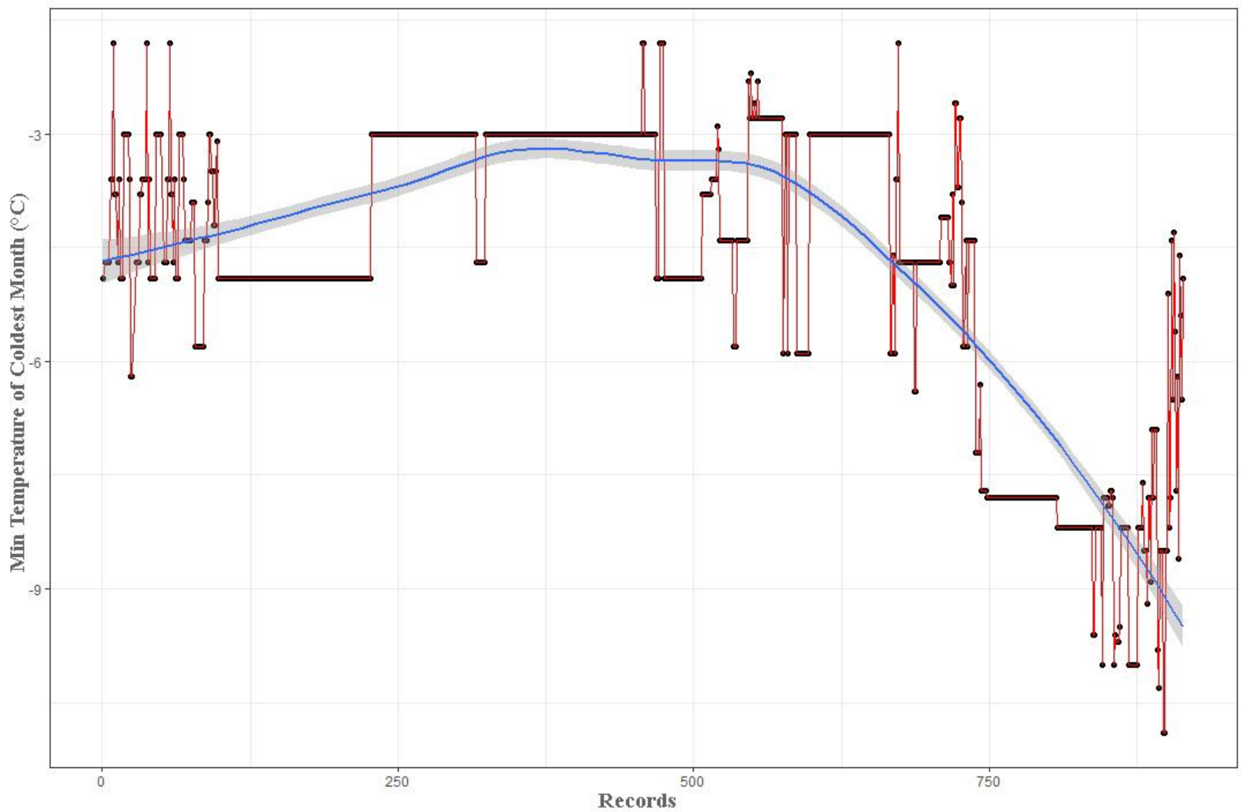

Figure 6. The lowest temperature of the coldest month at the sites with F. tadshicorum specimens

In order to determine the relationship between the height gradient of the areas where F. tadshicorum samples are available and the climatic factors, the height-average annual temperature (Fig. 7) and height-annual precipitation amount of the samples were determined (Fig. 8).

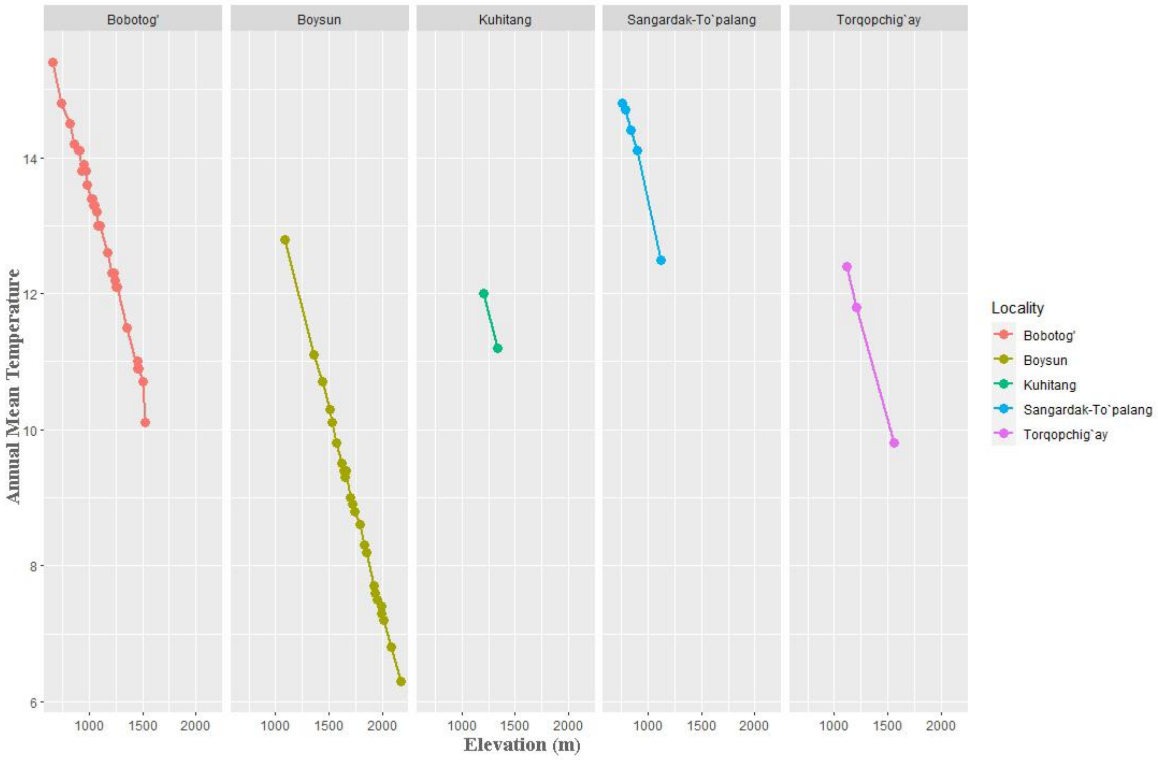

Figure 7. Altitude - average annual temperature indicators of the areas with F. tadshikorum samples.

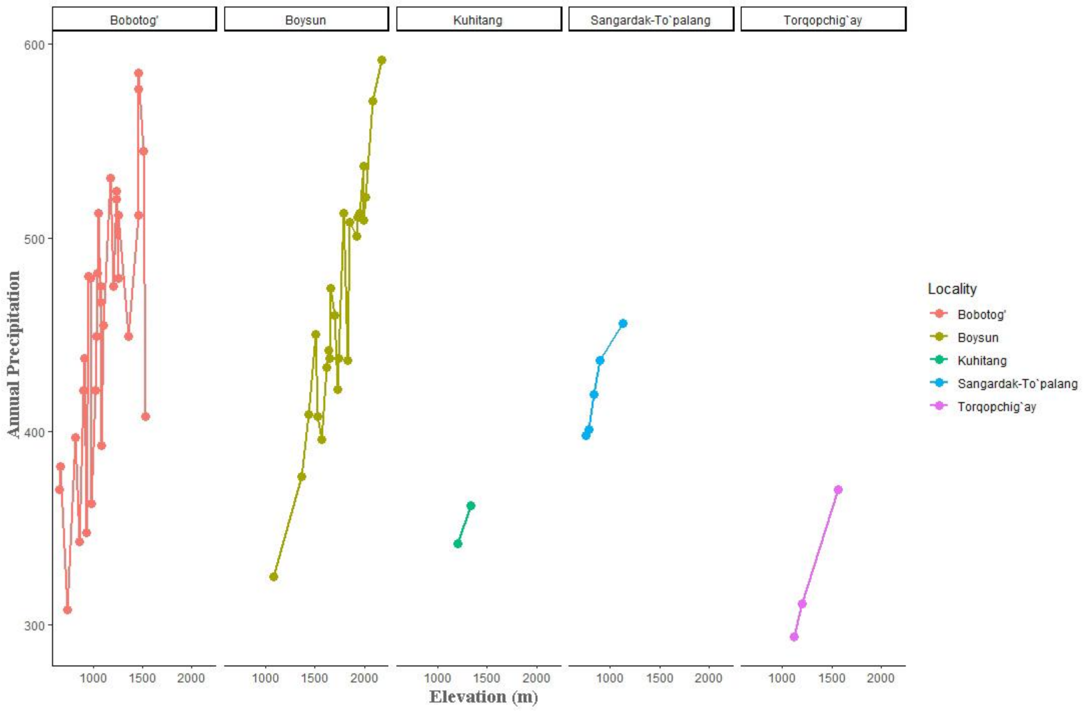

Figure 8. Altitude-annual precipitation of the areas with F. tadshicorum samples

Modeling the geographic distribution of F. Tadshicorum

3.2. Approximate accuracy of the model

The performance quality of the model was evaluated according to the AUC (area under the curve) value. The accuracy of the model's performance in predicting areas where F. tadshicorum can spread is very close to 1 in all cases with an average AUC=0.971 (Figure 9). This shows that the model worked with high accuracy.

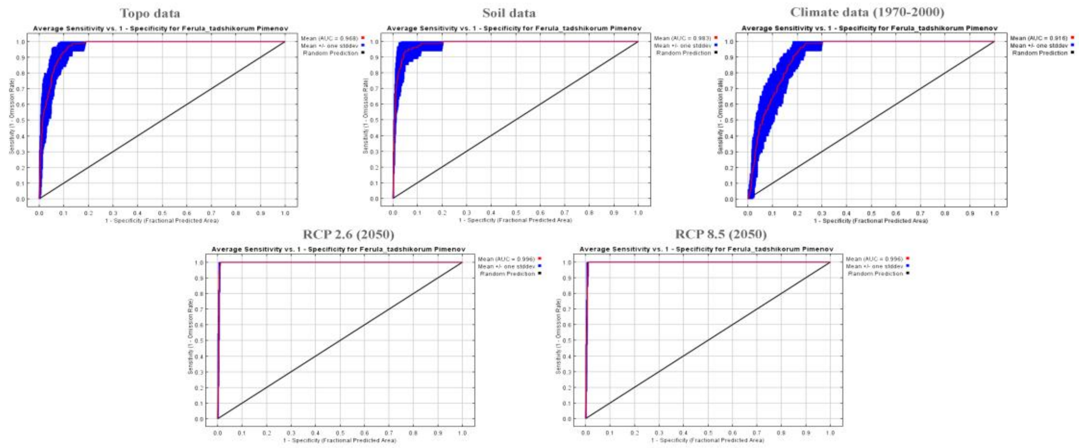

Figure 9. AUC value of the model for F. tadshicorum

3.3. Modeling the distribution of a species

Based on data collected from various sources, real and future potential distribution of F. tadshikorum was modeled based on topographical, soil and climatic variables (Figure 10). In Kashkadarya and Surkhandarya regions, the topographic model (5854 sq km) leads in terms of the size of the areas with the most favorable conditions for growth, while the lowest result belongs to the RCP 2.6 (2050) climate scenario (614 sq km) (Table 6). In both climate scenarios, the species' potential range is reduced. From this, it can be concluded that global climate changes have a negative effect on the spread of F. tadshicorum.

Table 6. Areas with the most favorable conditions for the growth of F. tadshicorum

Модел	Майдон (км кв)
Топографик	5854
Тупроқ	962
Иқлим (1970-2000)	2110
RCP 2.6 (2050)	614
RCP 8.5 (2050)	728

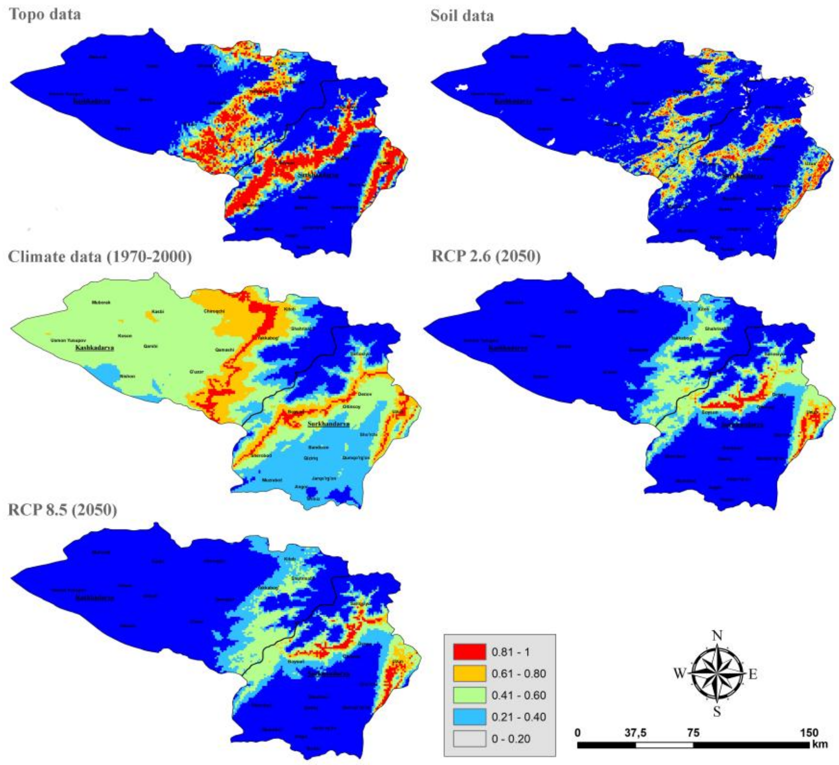

Figure 10. Areas of potential spread of F. Tadshicorum

Conclusion

Among the environmental variables, the best predictor for the growth of F. tadshicorum corresponds to the topographic model, which indicates that a large part of the study area has favorable topographic conditions for the growth of this species.

Due to global climate changes, i.e. increase in average annual temperature, the potential spread areas of F. tadshicorum will decrease.

According to all the modeling results, it was observed that the north-eastern part of Boysun and Bobotog botanical-geographic regions creates very favorable conditions for the growth of F. tadshikorum.

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