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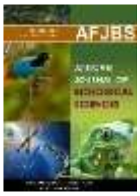

MaxEnt modelling for predicting the potential distribution of a food and medicinal species (*Elwendia persica* (Boiss.) Pimenov & Kljuykov)

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Abstract. In recent years, the demand for natural food and medicinal plants has increased. Climate change will affect ecological factors that influence species distribution patterns at different spatial and temporal scales. In the article the distribution of the *Elwendia persica* (Boiss.) Pimenov & Kljuykov species is modeled on the MaxEnt program. One of the important features of this type of modeling is the state of species populations in the future, as well as the analysis of their depletion. In the food industry, *Elwendia persica* (Boiss.) Pimenov & Kljuykov occupy a very important place. In the conditions of future climate change, climatic factors and topographic factors of two scenarios (SSP126 and SSP585) were adopted, and against the background of the MaxEnt model it has been used to simulate and predict the potential dispersal sites and dispersal ranges of *E. persica*. Future climate change results from 2080 to 2100 showed that under two emission scenarios, *E. persica* the range and distribution ranges of species habitats have been observed to initially increase and later decrease with future climate change. The response curves showed that this species prefers habitats with an annual temperature of 12.05–19.4 °C, annual precipitation of 170 to 420 mm and elevation range of 1245 to 2406 m a.s.l. Most of the potential current suitable conditions were located at the middle northern region of Turkestan and Zerafshan ridge (Uzbekistan, Tajikistan and others). Prediction models under two future climate change scenarios displayed habitat range shifts through the disappearance of *E. persica* in sites below 1200 m a.s.l., an altitudinal range contraction at 1200–1900 m and possible expansions towards higher elevation sites (2000–2400 m a.s.l.). Our findings can be used to define the high priority areas for reintroduction or for protection against the expected climate change impacts and future modifications.

Keywords *Elwendia persica*, MaxEnt, wild relative, food, medicinal, future, Uzbekistan

1. Introduction

Climate change poses negative impacts on plant species, particularly for those of restricted ecology and distribution range. Currently, the study of medicinal (Yang et al. 2022), agricultural and economic plant species on a global scale, as well as determining their place in the natural flora (Cao et al. 2023) is an important task (Abduraimov et al. 2023a). Due to the popularization of the use of medicinal products obtained from plants in recent years, an increase in demand for raw materials of wild, Medicinal, Food and some industrial plants collected from all regions of our country occurs (Saribayeva et al. 2022a; Xojimatov et al. 2021).

One of the most important peculiarities of high plants distributed naturally, resistance to external environmental factors (Shomurodov et al. 2021; Delgado et al. 2020; Kovalenko et al. 2022), while the raw materials extracted from them, while being very useful in human health, does not cause negative conditions in the human body (Mazidi et al. 2012; Kareshk et al. 2015; Hassanzadazar et al. 2018). In recent years, many studies have also been carried out in our republic on the cultivation and introduction of this type of plant (Mahmudov et al. 2022a; 2022b). Their populations of rare and endangered species are also being studied (Maxmudov et al. 2024; Khamraeva et al. 2023; Abduraimov et al. 2022). It is among such plants that *Elwendia* Boiss. we can also include representatives of the category (Boissier 1844). The order *Elwendia* is a genus in the family Apiaceae with 27 species distributed worldwide (https://powo.science.kew.org/). The distribution range of the range includes areas from eastern Turkey to Western China and the eastern parts of the Himalayas. Central Asia, the West Tion-shon and the Pamir-Alai regions are recognized as the main center of their origin (Abduraimov et al. 2023b; Kljuykov et al. 2018).

Since 1959, research began to be carried out on the critical revision (revision) of the representatives of the series (Degtjareva et al. 2009; 2013). Their analysis began to be carried out on the basis of samples stored in the herbariums of Tashkent (TASH), Bishkek (FRU), St. Petersburg (LE) and Dushanbe (TAD) (Kljuykov et al. 2018). The synopsis, compiled for representatives of the category, takes as a basis the names of the species, their synonyms, Botanical description, herbarium labels, collectors, references made to them, as well as general distribution areas (Kljuykov 1988).

Considered from regions with a high diversity of representatives of the Central Asian genus, 17 species of them are distributed in this particular region. The following 12 species of the order are distributed in the flora of Uzbekistan; *Elwendia angreni*, *E.capusii*, *E. kuhitangi*, *E. hissarica*, *E. chaerophylloides*, *E. intermedia*, *E. latiloba E. persica*, *E. salsa*, *E. seravschanica*, *E. setacea*, *E. vaginata*. According to Korovin (1959), 7 of these species are listed in the genus of *Bunium* (Kljuykov et al. 2018; Abduraimov et al. 2023c).

According to Kljuykov and others (Kljuykov et al. 2022), representatives of the category are considered to be one of the main components of the seasonal plant community in most regions. This is due to the fact that they end their vegetation relatively early. The main species of representatives of the genus are common in the Pamir-Alai Ridge. The inclusion of new species in science with the participation of the series in recent years requires regular research on the genus (Kljuykov et al. 2022).

Systematically, representatives of the genus are considered close to the *Bunium*. The order *Elwendia* through its anatomical-morphological structure, botanical-geographical distribution and cariology (Kljuykov 1988; Vasil'eva et al. 1985) and based on (Degtjareva et al. 2009; 2013) analysis of molecular results *Bunium* L. the category is separated from its composition as an independent genus. It differs from *Bunium* representatives in the large size of its fruit, the presence of double-bladed grass, geographical distribution and the number of chromosomes.

Representatives of *Elwendia*, like other species of the family Apiaceae, are widely used in certain areas of modern Pharma, as well as by local residents (Sofi et al. 2009; Kurbanov 2017). It is Elwendia persica (Boiss.) The Pimenov & Kljuykov variety is widely used in modern and traditional medicine, pharmaceutical, and as food.

1.1. Relevance and importance of modeling MaxEnt?

In addition to the current increase in population, demand for food and access to it have increased. This situation is observed to grow over the years. According to statistics, the world population is expected to increase by 3 times by 2050 (UN 2019). The increase in the world's population leads to habitat fragmentation and Extinction, an overexploited environment, and a decrease in the underlying resource that occurs continuously (UN 2015). Plays an important role in ensuring sustainable crop diversity, improving productivity, and meeting future food demand (UN 2019; FAO 2019). Therefore, solving existing problems and finding a solution to it is considered one of the important tasks of the present (Mavlanov et al. 2021; Ikeda et al. 2016; Scheffers et al. 2016). A slight change in temperature in the world's Mica greatly affects the structure and composition of the species in the ecosystem. This in turn leads to evolutionary adaptation of the species (Cornell et al. 1992).

Global climate change is largely a result of anthropogenic activity and has been confirmed as well (IPCC 2021). This would continue into the current century (Alimonti et al. 2022; Pielke et al. 2022) and became a major concern affecting many facets of human society and the components of global-scale biodiversity (Hughes et al. 2000; McCarty 2001). Such effects affect the physiology, phenology, and ecological structure of species. This has its effect on the natural populations of species (Di Nuzzo et al. 2021; Iler et al. 2019; Moukrim et al. 2020; Savage and Vellend 2015).

An increase in the total temperature on the planet Earth is one of the main indicators of damage to the environment, atmospheric air. An increase in the amount of a number of harmful substances in the composition of atmospheric air leads to climate change not only of temperature, but also of all regions of the planet (Secretariat…, 2020). Biodiversity conservation and modelling are considered important to mitigate the impact of climate change on ecosystems (Balmford 2005). Species dispersal models are commonly used to assess the availability of species based on geographic range, factors affecting their distribution, and environmental variables (Peterson et al. 2011; Qin et al. 2017). In this context, the MaxEnt (Maximum entropy) model has been shown to be the most reliable (Elith et al. 2006; 2010; Wis et al. 2008; Kumar and Stohlgren 2009) and high-performance than the genetic algorithm for data set production and a generalized additive model (Padalia et al. 2014; Panda et al. 2018; Feng et al. 2019). The climate modeling method is based on a combination of data of the geographic distribution of species (geographic coordinate) and the determination of the ecoclimatic niche of the species under study through climate descriptions of these points. Hence biodiversity is the basis of human life (Bhatii et al. 2021), a MaxEnt program is used to predict the geographical distribution of different plant species (Zagarjav et al. 2023). MaxEnt is a geographic-scale spatial model program of species based on the Java platform, which is primarily used to simulate and predict the potential distribution of species (Phillips et al. 2006). It is currently widely used in many fields, such as ecology, biochemistry, resource conservation, etc (Liu et al. 2021). Compared to other common models such as GARP (Genetic algorithm for rule set prediction), BIOclim (Biological prediction system), Domain (Domain model), and ENFA (Ecological niche factor analysis), MaxEnt provides high resolution pointers (Kogo et al. 2019). Species distribution modeling has a MaxEnt high position among algorithms in terms of advantages. The main reason for this lies in the fact that you are able to predict the spread of Threatened Species with great accuracy despite the lack of data, as well as the high possibility of determining the importance of environmental change using Jackknife_test.

Many studies have frequently used the MaxEnt model to predict current and future suitable habitats for various threatened and important medicinal plants (Kumar and Stohlgren 2009). Modeling the distribution of species in biogeographic and Ecological Research is a key tool in assessing the potential distribution of species (Liu et al. 2021)

It is estimated that Global climate change can negatively affect some species and even disappear. Forecasting using many global climate changes suggests that an increase in average surface temperatures from 0.3 to 4.8 °C at the end of this century, according to a special IPCC report, caused global greenhouse gas emissions to global warming of about 1 °C from pre-industrial temperatures. If this continues in the present photo warming between 2030 and 2052, it can reach 1.5 °C or 2 °C. In addition to determining the active points of biodiversity and the beneficial directions of their conservation in the current conditions, full attention should be paid to the fact that global climate change is a constant and large-scale problem of systematic conservation efforts.

To have a significant impact on species conservation, it is important to identify areas with high conservation value. Models of species distribution modeling and habitat compatibility have become an indispensable tool in Ecological Research and conservation (Villero et al. 2017). These models are capable of predicting the spread of invasive or endangered species under climate change scenarios and identifying areas of high importance to protect endangered species (Porfirio et al. 2014). In addition, public authorities are increasingly relying on these methods in making decisions on conservation (Sofaer et al. 2019). However, the distribution of species cannot be fully relied on modeling results because they often do not function adequately on spatially separated test data, especially if they are configured with spatially dependent data (Lee-Yaw 2022). In recent years, species dispersal models have become an important tool for studying future status. They combine known scattering points and related environmental variables to simulate the geographic distribution and reaction of species to climate change based on known algorithms (Sun et al. 2020). Climate change leads to changes in the corresponding ranges of species and accelerates the contraction of global biodiversity. Native and non-native species have the ability to alter the habitat and ecological processes, which not only pose a significant threat to biodiversity and ecological processes, but also affect the composition and structure of the plant community (Jamil et al. 2022).

Species dispersal models have become an effective tool for predicting potential dispersal and suitable habitat of target species. The resulting model is projected onto a digital map of the next studied area, which shows the potential distribution of the species, and the gradation color from dark to light determines where this species grows and where it can spread in the future. Based on the result developed by this method algorithm, relying on bio-climatic data, research will be carried out on regions favorable for the spread of plant species in the future. As well as a populational assessment of what condition the species is in and its range of distribution is studied based on the plant community composition. The information obtained on the basis of this method is also used in the use of rare, endangered, species of significant economic importance, as well as in monitoring them for many years.

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2. Materials and Methods

The study area

Environmental variables are important to explain the ecological distribution of habitats based on the ecological region of the species. The purpose of the study is E. since there is a prediction of the potential area of the persica species, we will consider the example of Uzbekistan, Tajikistan, Turkmenistan, Pakistan, Iran and Afghanistan, where the distribution area is most likely. The highest layer of these areas is located at 8253m above sea level, and the ecology also differs dramatically from one another, and the morphological diversity in the plant corresponds to geographical diversity.

Distribution point collection and processing

The distribution area of this species is distributed at an altitude of 1800-3500m above sea level, using mainly Field Research, Global Biodiversity Information Facility (https://www.gbif.org/ru/), National Herbarium of Uzbekistan (TASH) and available literature (Maryam et al. 2009; Remigius et al. 2014) sources from 2021 to 2024. Obtained artificially planted, repeated dispersal points were removed from data on the distribution of E. persica. At the same time modeling resulted in the separation of the intermediate distance of each scattering point at no less than 5km2 to minimize errors. A total of 113 coordinates were separated for modeling by changing and ordering geographic coordinates.

Climatic variable factor data acquisition and species distribution modeling

The worldclim 2.1 data Version, considered an open source of ecological data (https://worldclim.org/data/index.html), is used in data modeling involving several bioclimatic variables derived from monthly temperature and precipitation values. The MIROC6 (Model for Interdisciplinary Research on Climate) generation of the CMIP6 (Climate Model Intercomparison Project) model was developed in collaboration with the Atmosphere and Ocean Research Institute, University of Tokyo (Tatebe et al. 2019), with miroc6 generation representatives showing that overall reproducibility of moderate climate and internal climate variability is better and more optimal than that of MIROC5. MIROC6 da Shared was selected for three periods using climate forecasts within SSP1-2.6 and SSP5-8.5 from Socio-economic Pathways (SSP) scenarios, with 2.5-minute spatial resolution data of 19 bio-climate data for the current period 1970-2000, 2041-2060 and 2081-2100, and SRTM (Shuttle Topography Mission) 90m Digital Elevation Database v4.1 height data, ArcGIS 10.8.1. using Slope and Aspect data were released, and all GeoTIFF format data was converted to ASCII using the R-4.3.2 program.

The following parameters for simulation by the MaxEnt model are defined as "Create response curves", "Do jackknife to measure variable importance", "Random seed", "Write plot data", "Write background predictions", "Replicated run type cross validate", "Replicates 10", and "Output format logistic" (Phillips and Elith 2010).

The distribution of any species depends on variables with the climate, and this species can respond quickly to climate change. Many variables exhibit spatial collinearity, which can cause the model to be hato as a result, ultimately affecting the prediction results xam. Based on this, E. 19 climates as well as 3 topographic data related to the distribution of persica species have been isolated. To filter out indicators of environmental variables with high contribution to the distribution of the species, we applied Pearson correlation analysis to 22 environmental variables, using SDM Toolbox v2.6. (Fig. 1).

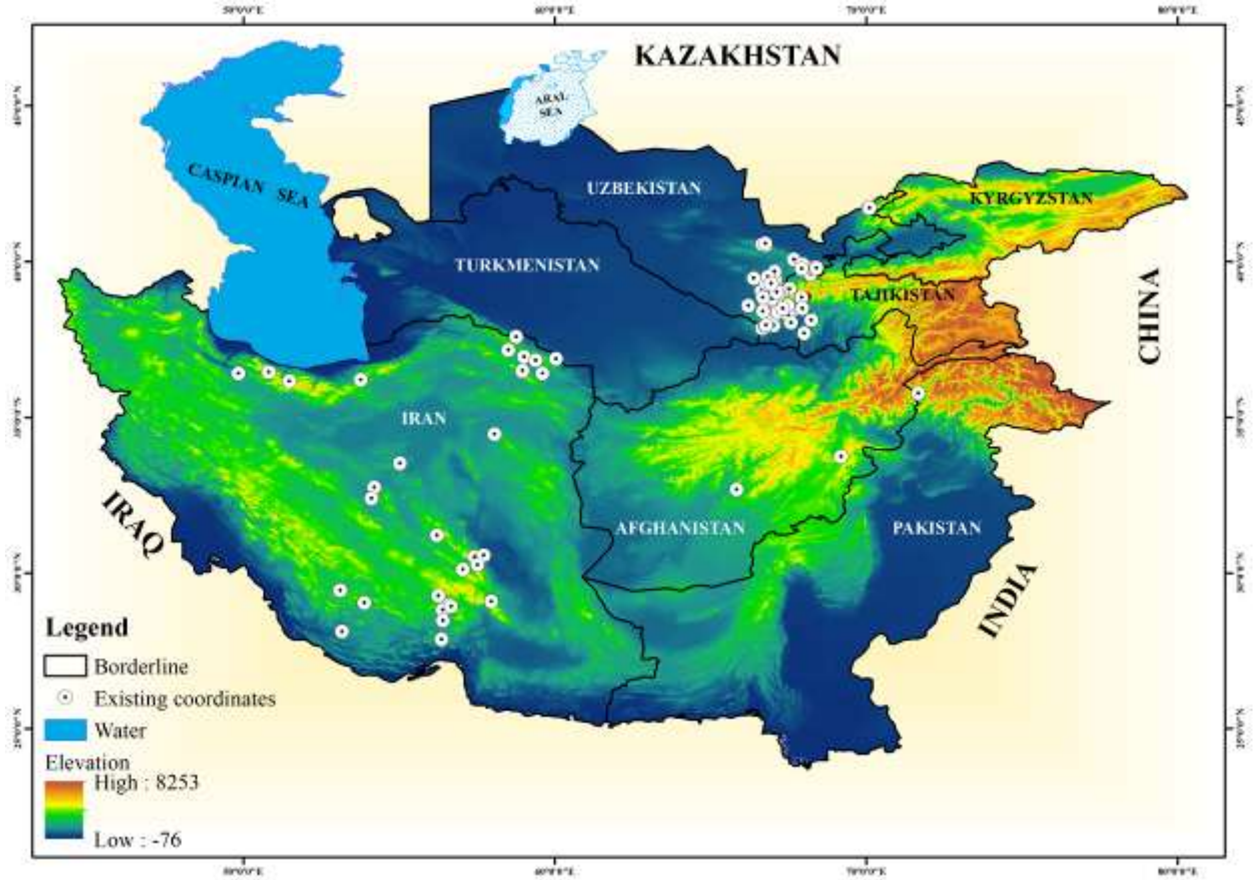


Figure -1. Elevation distribution of *E. persica*

Based on the result of the analysis, we separated the variables in the pointer |R|<0.7 according to the Pearson correlation principle. As a result of the analysis, E. factors positively affecting the likelihood of persica presence, BIO2 - Mean Diurnal Range, BIO3 - Isothermality (BIO2/BIO7) (×100), BIO7 - Temperature Annual Range (BIO5-BIO6), BIO8 - Mean Temperature of Wettest Quarter, BIO13 - Precipitation of Wettest Month, BIO17 - Precipitation of Driest Quarter, BIO18 - Precipitation of warmest quarter, bio19 - precipitation of coldest quarter and elevation, slope, and aspect topographic data have been revealed to be dominant environmental factors that control the potential geographic distribution of the species (Figure 2).

Figure.2. *Elwendia persica* (Boiss.) Pimenov & Kljuykov

Model parameter setting and accuracy evaluation

The results of this research are also currently used in environmental monitoring work (Saribaeva et al 2022b; Rakhimova et al. 2020; Rasool et al. 2024). The modern distribution of species, their maps and natural populations have been studied by a large number of scientists (Shomurodov et al. 2024; Behsko et al. 2023).

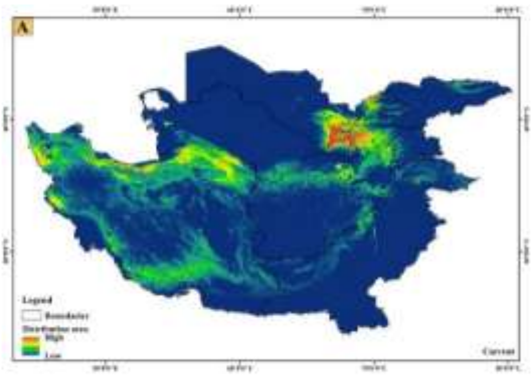
3. Results and discussion

Modeling the distribution of species has become increasingly important for the study of biodiversity, community ecology and conservation ecology in the last few decades. An important fact that can be known from the results of Model Transfer is the study of the importance and influence of different variables and the role of the species in influencing the habitat. Among all climate factors, BIO_19 and BIO_7 is the most important, *E. persica* growth and distribution expressed a strong association with precipitation and temperature (Tab. 1).

Table - 1: Various parameters of the main environmental variables of *E. persica*.

	Varible	**BIO2**	**BIO3**	**BIO7**	**BIO8**	**BIO13**	**BIO17**	**BIO18**	**BIO19**	**Elevation**	**Slope**	**Aspect**
Current	**Units**	^{0}C	^{0}C	^{0}C	^{0}C	mm	mm	mm	mm	Meters	Degree	Degree
	P/C	17.6	1	9.5	4.4	12.5	3.7	3.8	14	17.8	14.2	1.6
	P/I	0.9	9.4	30.2	13.9	9.7	4	3.7	1.2	17.8	7.2	2

In this study, climate factors and topographic factors of two emission scenarios (SSP126 and SSP585) were adopted in future climate change conditions, and the MaxEnt model was adopted in the background by E. persica it has been used to simulate and predict potential dispersal sites and dispersal ranges. Future climate change results from 2080 to 2100 showed that under two emission scenarios, E. the range and distribution ranges of persica species habitat have increased and decreased with future climate change (Fig. 2). This suggests that future climate change will have an important impact on the potential range of distribution and suitable habitat of this plant species.



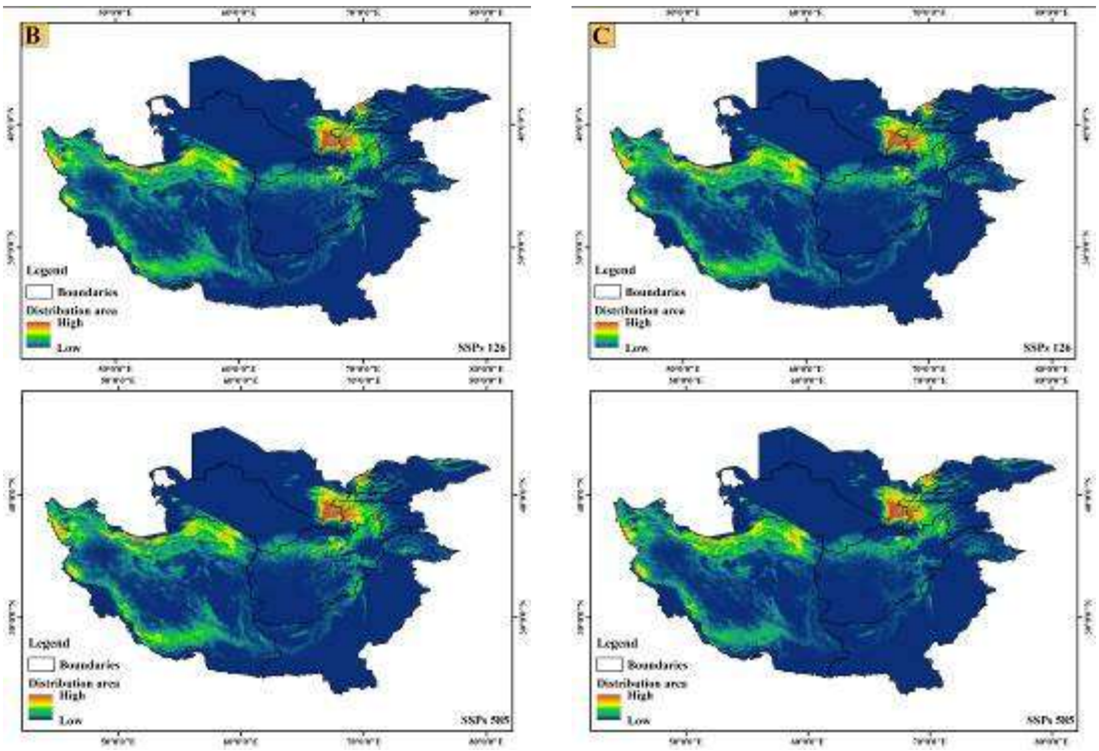


Figure - 2: Current and future spread of *Elwendia persica*:
A – current period, **B** - 2041-2060 and **C** - 2081-2100

The standard deviation of seasonal temperature variation is also controls the likelihood of *E. persica* presence, reducing the likelihood of species presence if temperature changes increase with increasing seasonal temperature in areas suitable for the species of natural distribution. Model results precipitation and temperature *E. persica* has shown to be dominant environmental factors that control distribution, and seasonal temperature changes are more pronounced in areas where the species is most likely to exist. However, a very drastic change can seriously affect the growth and distribution of the species. When the plant leaves the dispersal area, some ranges have disappeared again, indicating that temperature and precipitation have a more important impact on the species habitat. The results of the MaxEnt model show that the estimated 2 % (86-119. 50 km2) of the area studied by the current status of the species is E. the persica species is high for distribution, with an area average of about 9 % (393-470.03 km2), while an area of 89% (396-3502. 962 km2) is known to have an inappropriate minimum potential. These indicators are information based on the results of the analysis in the case of the natural distribution of the species (Tab. 2).

Table 2. Predicts species distribution using ssps126 and SSPs585 scenarios

Period (Climate scenarios)		**Habitat suitability**	**Area (km2)**	**Proportion (%)**
Current		High	86119,50	1.94
		Moderate	393470,03	8.85
		Low	3963502,962	89.2
2041-2060	**ssp126**	High	86242,21	1.94
		Moderate	418663,50	9.42
		Low	3935052,812	88.63
	ssp585	High	87120,58	1.96
		Moderate	414891,55	9.34
		Low	3937927,847	88.7
2081-2100	**ssp126**	High	86490,57	1.95
		Moderate	416959,97	9.39
		Low	3936380,705	88.66
	ssp585	High	77344,10	1.74
		Moderate	404895,42	9.12
		Low	3957607,783	89.14

In this study, while 25% of the distribution area was allocated as an experimental set, 75% was used as a training set for the MaxEnt model, and the Maximum iterations number was set at 1000. The accuracy of the simulation results was evaluated by the Receiver Operating Characteristic curve (ROC). The area surrounded by ROC and abcissa is the AUC (Area under Curve) value. The AUC value varies from 0 to 1, and the closer the AUC value is to 1, the better the predictive effect. In general, AUC less than 0.7 shows very poor predictive effects. AUC analysis shows the modeling efficiency for the selected species as follows: E. based on the geographical data of the persica species, the MaxEnt model generated AUC values of 0.950, 0.946, 0.948, 0.946 and 0.923, respectively (Fig. 3). In this case, above 0.5, model analysis shows better performance than prediction. The correlation between environmental variables and the scattering model is positively correlated, and when the AUC value is greater than 0.8, this suggests that the prediction results are very accurate. The evaluation of the AUC value of the model was evaluated according to the following criteria: 0.90-1.00 excellent; 0.80-0.90 good; 0.70-0.80 medium; 0.60-0.70, bad; 0.50-0.60 indicates a failed model.

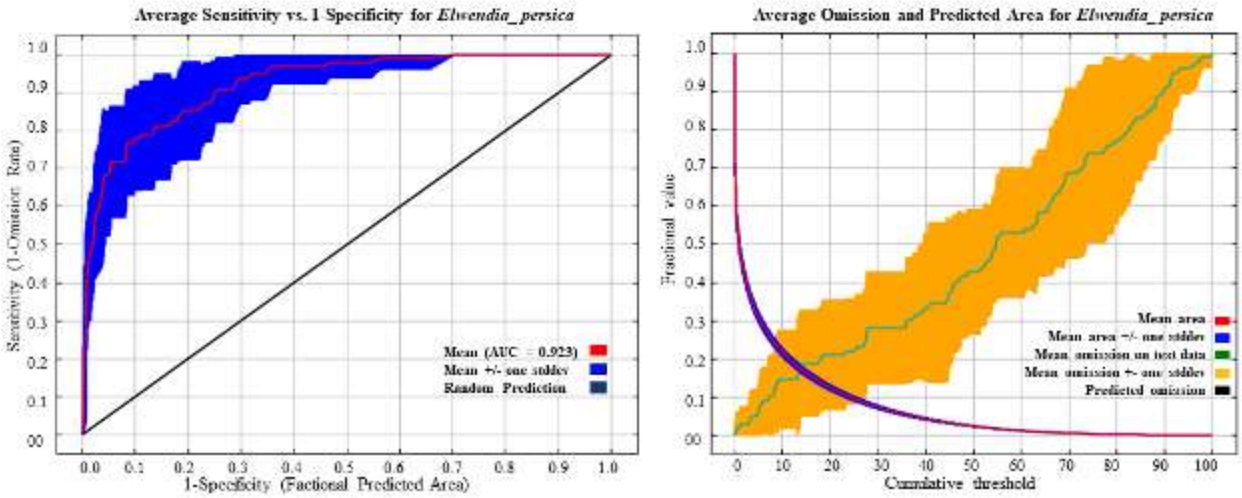


Figure - 3. ROC curve of MaxEnt results.

E. persica the average AUC and TSS values of the models for were evaluated in the MaxEnt model. The results show that the prediction of potential range areas for the species in current and future climates is very accurate and very well done. Under current environmental conditions, the average AUC and TSS values of the plant model were expressed as respectively (0.941, 0.889). In addition, AUC and TSS values greater than 0.88 indicate that they are more accurate and perform better (Fig. 4).

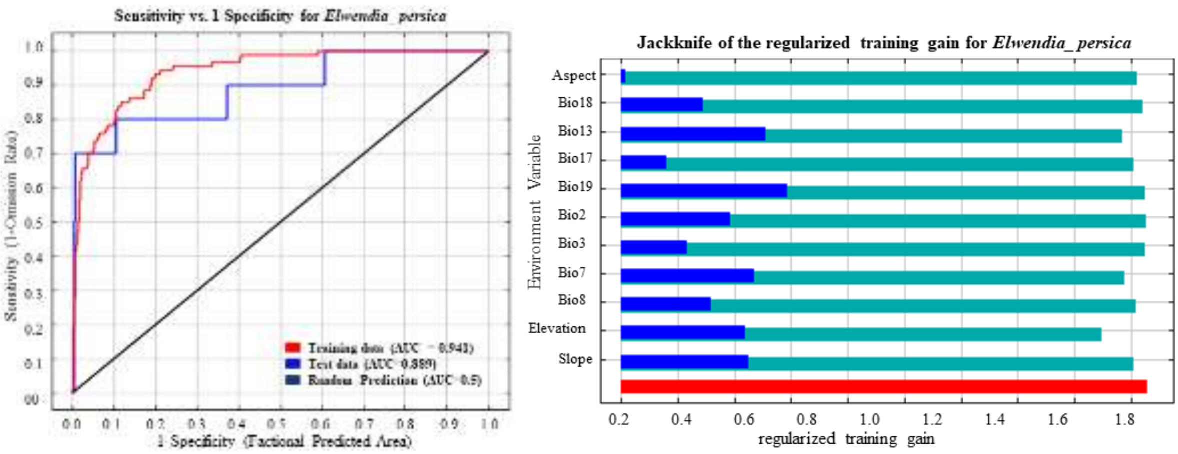


Figure - 4. Model performance and variables contribution. AUC which represents sensitivity versus 1 - specificity and results of the Jackknife test of variable importance: for each variable the turquoise bar shows how much the total gain is reduced if that specific variable is excluded from the analysis, the blue bar shows the gain obtained if this variable is used in isolation and the remaining variables are excluded from the analysis, and the red bar represents the gain obtained by introducing all the variables. AUC – area under the ROC, ROC – receiver-operating characteristic.

The percentage contribution of the Jackknife test has been used to assess the relative importance of each environmental variable affecting models of specific species in current climates. This method is recognized as the best index for small samples. This analysis helps to understand the relative importance of various environmental factors in the formation of species habitats. We have analyzed environmental variables that have a greater impact on the prediction outcome of each variable in the MaxEnt model. The total contribution rate of two types of variables is calculated. Climate variables for *E. persica*, the result was 66.5% and 73%, respectively. At the same time, topographic variables were 33.6% and 27% respectively. In conclusion, *E. persica* showed the potential distribution of that climate variables have a high impact and topographic variables have a relatively low contribution. The results obtained are related to the current state of the species and are similar.

4. Conclusion

Natural internal processes in the Global climate system may be associated with changes in natural or anthropogenic external influences. Global climate change indicates a change in the average state or variability of a climate that lasts for several decades or more. Another of the main reasons for the decline of the species is explained by the fact that they are picked by humans. The natural distribution area of the species is wide. Alternatively, it is also cultivated culturally in many countries around the world. Humans have been using the plant for several centuries. This study indicated that the geographic distribution of *E.persica* might undergo habitat range shifts through the disappearance of this species in sites below 1200 m a.s.l., range contraction between 1200-1900 m a.s.l. and range expansions towards optimum habitats at sites with higher elevation (2000–2400 m a.s.l.).

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