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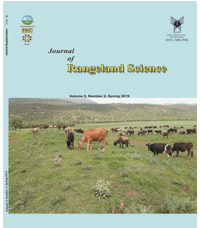

Research and Full Length Article:

Effect of Climate Change on Distribution of an Endangered Medicinal Plant (*Fritillaria Imperialis* L.) in Central Zagros, Iran

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Abstract. Climate change has a great impact on the species distribution range and many endangered plant species. *Fritillaria imperialis* as a species that is native to Central Zagros, Iran is a medicinal plant with great ecological and commercial profits. Its population has decreased considerably and the species would be endangered in later decades. Understanding the habitat needs of this species, evaluating habitat conditions, and forecasting its potential habitat are important for protecting *F. imperialis*. The presence of *F. imperialis* points recorded from our field surveys in Chaharmahal-va-Bakhtiari province as a part of Central Zagros, Iran in spring 2017. In order to model its distribution based on correlation analysis, two topographic variables and eight bioclimatic ones as the input of Maximum Entropy model (MaxEnt) were used. The results showed that temperature seasonality (55.1%) and precipitation of driest quarter (22.9%) were important factor drivers of *F. imperialis* suitable habitat. The accuracy of the maximum entropy model in predicting the distribution of the studied species was high (AUC=0.91) as 2.33% (37986 ha) in Chaharmahal-va-Bakhtiari Province for the *F. imperialis*, which has had suitability. About 18% and 16.5% of *F. imperialis* habitats in the area may be lost due to climate change by 2070 under two climate warming scenarios (RCP4.5 and RCP8.5, given by the IPCC). As shown by the model, under the current climatic conditions, the suitable habitat would be rendered to an unsuitable one in the future resulting in local extinction. The results of this study can be used to identify sites with high extinction probability of *F. imperialis* and protect susceptible habitats against the effects of climate change.

Key words: MaxEnt, Bioclimatic variables, Species distribution modeling, Suitable habitat, Chaharmahal-va-Bakhtiari province

Introduction

Climate change has a great impact on the species distribution range (Barrett *et al*., 2013), and endangeres many plant species (Yi *et al*., 2017). It results in species change, extinction, turnover and changes in the communities' structure and population (Yi *et al*., 2017). Many researchers used to simulate the change of vegetation habitat in order to study the requirements of species, design conservation reserves and recognize patterns of biodiversity (Pettorelli *et al*., 2012). Considering mid-range climate warming scenarios for 2050, Thomas *et al*. (2004) predicted that 15–37% of species in their sample of regions and taxa would be committed to extinction. Future distribution models under projected climate change scenarios predict significant changes for many plant species (e.g. Thomas *et al*., 2004; Khanum *et al*., 2013; Haidarian Aghakhani *et al*., 2017; Rana *et al*., 2017; Yi *et al*., 2017).

Fritillaria imperialis (Crown Imperial) is a member of the Lily family (Liliaceae) consisting of 99 species (Bonyadi *et al*., 2017). So far, 15 species have been identified in Iran. As one of the most attractive bulbs, *F. imperialis* is grown at high altitudes (>2000 m) in Zagros rangelands of Iran (Badfar-Chaleshtori *et al*., 2012; Mohammadi-Dehcheshmeh *et al*., 2008). It is a medicinal plant with great ecological and commercial profits. Due to its high ornamental and medicinal value and importance, this perennial plant attracts many tourists from all over the world to see the *F. imperialis* in nature. In Iran, wild populations of Crown Imperial are at risk of rapid destruction because of changing the rangeland to dry farmlands, inadequate protection, and pest overflow (Ebrahimie *et al*., 2006; Badfar-Chaleshtori *et al*., 2012). Therefore, it is highly necessary to assess the habitat of *F. imperialis* and do a swift action to conserve this species.

More recently, Species Distribution Modeling (SDM) tools are becoming more and more prevalent in ecology (Elith *et al*., 2006). The relationships between species occurrence and environmental and biophysical conditions in the subject area under the study are established in these models. Statistical models (such as Maxent) have been applied to investigate the effects of climate change on species distribution. These models use common empirical data to determine the relationships between current species distributions and environmental factors. Considering climate changes owing to a specific scenario, these statistical relationships are kept fixed as a pseudo-equilibrium assumption to obtain changes in species distributions. When integrated into a Geographic Information System (GIS), potential future distributions can be mapped in this procedure (Guisan *et al*., 1998). A variety of SDM methods are available to anticipate the potentially suitable habitat for a plant species (Kumar and Stohlgren, 2009; Tarkesh & Jetschke, 2016; Mazangi *et al*., 2016). Several models such as MaxEnt, GARP, DOMAIN, BIOCLIM, CART, GAM, and GLM are extensively used for prediction of species distribution. Among these models, Maximum Entropy method (MaxEnt) shows better results when there are inadequate data availability, and it has been successfully employed in previous research on predicting the distribution of species (Phillips *et al*., 2004; Estes *et al*., 2013; Elith *et al*., 2011). According to Wang *et al*. (2007), MaxEnt can be a more efficient tool for biodiversity conservation program, monitoring and management. The model is extensively used to predict the endangered species distribution (Kumar and Stohlgren, 2009) and the potential distribution of invasive species (Gama *et al*., 2016). In addition, it has been used to predict the distribution range of plant diseases and pests, to model the distribution of species, communities or ecosystems, to assess the impacts of climate, land use and other environmental changes on species distributions (Thomas *et al*., 2004), to lead to site choice of natural protection areas (Ferrier, 2002) and to identify areas for species reserves and reintroduction (Adhikari *et al*., 2012).

In this paper, the SDM model was applied to estimate geographical distribution of *Fritillaria Imperialis* in Chaharmahal-va-Bakhtiari Province. In addition, the model predicts possible distribution changes of the species under different future climate scenarios by 2070.

Materials and Methods

Study area

The studied region had a total area of 1.64 million ha in Chaharmahal-va-Bakhtiari Province located in Central Zagros Iran, which is very important in terms of biodiversity and ecological value (Hunnam, 2011; Fattahi *et al*., 2017; Mahmoudi *et al.*, 2018). This area has been destroyed extensively by livestock grazing and land use changes (e.g. modification of rangelands and forest into rain-fed agricultural fields). The presence of *F. imperialis* points recorded from our field surveys in Chaharmahal-va-Bakhtiari Province in spring 2017. In order to reduce spatial autocorrelation, we excluded records in points located closer than 1 km from each other.

Bioclimatic and Environmental Data

In this study, two periods including present and future (2070, an average of 2061-2080) were applied. Physiographic variables (elevation, aspect and slope) and bioclimatic variables (bio1–bio19) were used as the predictors of *F. imperialis* distribution. It should mentioned that physiographic variables were derived from the Digital Elevation Model (DEM). In the current study, 19 bioclimatic variables describing *F. imperialis* habitat, which have the basis for monitoring impact of climate change on organisms in many studies. These 19 bioclimatic layers should be obtained from three essential climatic variables (i.e. tmin, tmax, prec). WorldClim (http://www.worldclim.org) provides monthly maximum (tmax), minimum (tmin), and mean temperatures (tmean), and monthly precipitation (prec). Monthly precipitation was improved by average monthly precipitation obtained from weather stations across the province. Then, 19 bioclimatic variables were created in DIVA-GIS. Then, Pearson correlation test was carried out to check the correlation between the explanatory variables and remove highly correlated ones, with $r>0.8$ and $p<0.05$ (Table 1). Two topographic variables and eight bioclimatic ones were applied in order to model the distribution based on a correlation analysis (Table 2).

Future bioclimatic variables were derived from a global circulation model: HadGEM2-CC. Habitat suitability simulation was found on two climate-warming scenarios (RCP4.5 and RCP8.5) given by IPCC.

Table 1. Pearson correlation matrix for environmental variables

Var.	elevation	slope	aspect	bio1	bio2	bio3	bio4	bio5	bio6	bio7	bio8	bio9	bio10	bio11	bio12	bio13	bio14	bio15	bio16	bio17	bio18	bio19
elevation	1.00																					
slope	0.21	1.00																				
aspect	0.00	-0.02	1.00																			
bio1	-0.98*	-0.16	0.00	1.00																		
bio2	0.90*	0.11	0.03	0.90*	1.00																	
bio3	0.59	0.29	0.02	-0.60	0.52	1.00																
bio4	-0.03	-0.06	-0.01	0.14	-0.14	-0.40	1.00															
bio5	-0.98*	-0.16	0.00	0.99*	-0.88	-0.60	0.16	1.00														
bio6	-0.97*	-0.13	-0.00	0.99*	-0.94*	-0.53	0.7	0.97*	1.00													
bio7	0.76	0.00	0.02	-0.75	0.91*	0.18	0.26	-0.73	-0.83*	1.00												
Bio8	-0.96*	-0.17	-0.01	-0.97*	0.90*	-0.61	0.15	0.96*	0.96*	-0.74	1.00											
bio9	-0.98	-0.20	0.00	0.97*	-0.86*	-0.58	0.02	0.97*	-0.96*	0.72	0.95*	1.00										
bio10	-0.98*	0.16	0.00	0.99*	-0.89*	-0.61	0.17	0.99*	0.98*	-0.72	0.97*	0.97*	1.00									
bio11	0.97*	-0.15	-0.01	0.99*	0.90*	-0.57	0.11	0.99*	0.99*	-0.77	0.97*	0.97*	0.99*	1.00								
bio12	0.03	0.40	0.02	0.01	-0.15	0.36	-0.01	0.01	0.09	-0.35	-0.02	-0.08	-0.01	0.02	1.00							
bio13	-0.33	0.26	0.03	0.37	-0.48	0.11	-0.02	0.36	0.43	-0.57	0.33	0.29	0.35	0.38	0.90*	1.00						
bio14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00					
bio15	-0.86*	-0.13	0.01	0.89*	-0.78	-0.56	0.21	0.88*	0.86*	-0.61	0.85*	0.85*	0.88*	0.88*	0.11	0.46	0.00	1.00				
bio16	-0.28	0.33	0.02	-0.34	-0.44	0.12	0.10	0.34	0.41	-0.56	0.30	0.24	0.33	0.35	0.93*	0.95*	0.00	0.43	1.00			
bio17	0.83*	0.33	0.01	-0.79	0.71	0.62	0.05	-0.78	-0.76	-0.53	-0.78	-0.79	-0.78	-0.78	-0.24	-0.10	0.00	-0.71	-0.01	1.00		
bio18	0.86*	0.32	-0.02	-0.81*	0.68	0.56	0.18	-0.80*	-0.78	0.45	-0.78	-0.87*	-0.80*	-0.81*	0.28	-0.01	0.00	-0.71	0.02	0.93*	1.00	
bio19	-0.47	0.26	0.02	0.52	-0.57	0.01	0.05	0.52	0.58	-0.66	0.47	0.44	0.51	0.54	0.84*	0.95*	0.00	0.57	0.97*	-0.19	-0.19	1.00

Modeling

MaxEnt is a maximum entropy-based machine learning program that estimates the probability distribution for a species incidence on the basis of environmental constraints (Phillips *et al*., 2006). It requires only species presence data (not absence) and environmental variable (continuous or categorical) layers for the study area. An estimate of habitat suitability for the species is generated by MaxEnt, which ranges from 0 (the lowest suitability) to 1 (the highest suitability). Finally, response curves are generated by MaxEnt for each predictor variable, and the relative influence of individual predictors is estimated by its jackknife option. The locality of species was transformed into geographic coordinates (WGS84 datum) using ArcGIS 10.3. Model calibration was performed using the following parameter values in the MaxEnt model: random test percent=20% and training percent=80%, regularization multiplier=1, convergence threshold=0.00001, maximum iterations=5000, replication=15, maximum number of backgrounds points=10,000.

Table 2. The subset of least correlated explanatory variables used for calibration of focal species model

Number	Abbreviations	Variables	Source	Resolution
1	Slope	Slope	Worldclim	30 arc ~sec
2	Aspect	Aspect	Worldclim	30 arc ~sec
3	Bio3	Isothermality (BIO2/BIO7) (*100)	Worldclim	30 arc ~sec
4	Bio4	Temperature Seasonality (standard deviation *100)	Worldclim	30 arc ~sec
5	Bio7	Temperature Annual Range (BIO5-BIO6)	Worldclim	30 arc ~sec
6	Bio9	Mean Temperature of Driest Quarter	Worldclim	30 arc ~sec
7	Bio12	Annual Precipitation	Worldclim	30 arc ~sec
8	Bio17	Precipitation of Driest Quarter	Worldclim	30 arc ~sec

Model accuracy was determined using the area under the curve values (AUC) of receiver operating characteristic (ROC). AUC of the ROC function can be interpreted as a single measure of the overall accuracy that is both threshold- and prevalence-independent (Manel *et al*., 2001). The AUC varies from 0.5 to 1.0. In general, AUC values below 0.7 were considered poor, the values between 0.7 - 0.9 were regarded moderate and the ones above 0.9 were considered good (Hessl *et al*., 2007). To reclassify the outputs of MaxEnt for both current and future climatic conditions, ArcMap 10.3 (ESRI) and the extension Spatial Analysis were used. The presence grids in the projected raster layers were delineated using threshold value. The number of presence grids multiplied by the unit area (total area of Chaharmahal-va-Bakhtiari province (km^2)/total number of the grid within a zone) was regarded as the total suitability area. Suitability response curves indicate the quantitative relation between environmental variables and the logistic probability of presence (also identified as habitat suitability), and they deepen the understanding of the ecological niche of the species.

Results

Current Distribution Modeling

The MaxEnt modeling successfully delineated the potential distribution of *F. imperialis* in Chaharmahal-va-Bakhtiari province using eight variables. The relative contributions of four important variables entering the model to predict suitable regions for species presence were 55.1% (Bio4), 22.9% (Bio17), 7.6% (Bio7), and 6% (Bio3) (Fig. 1). The results of Jackknife test in the MaxEnt model showed that the Bio4 has the highest training gain when used in isolation for this species (Fig. 2). The area under ROC for training data indicates the validity and performance of the model with AUC value of 0.91, thereby indicating good performance of the model (Fig. 3).

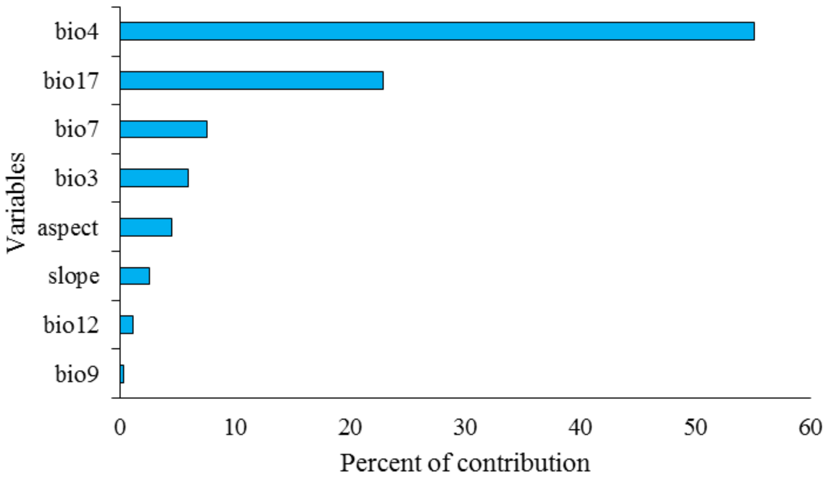

Fig. 1. Selected environmental variables and their contribution percent in Maxent model for *F. imperialis* in Chaharmahal-va-Bakhtiari Province

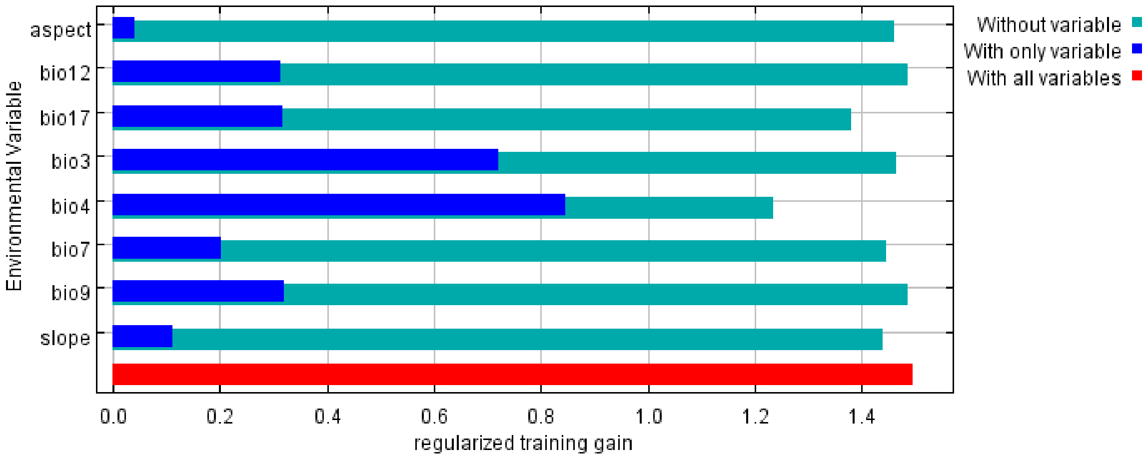

Fig. 2. The Jackknife test for evaluating the relative importance of environmental factors for *F. imperialis*

The MaxEnt model revealed that temperature is the primary factor affecting the distribution of *F. imperialis* (Fig. 2). The responses of four variables to *F. imperialis* suitability are illustrated in Fig. 4. The response curves showed that *F. imperialis* occurs in all types of habitats with temperature seasonality (bio4) of +8.6 to +8.72°C, temperature annual range (bio7) from +40.4 to +41.3°C, Isothermality (bio3) from 36.4 to 36.8°C, and precipitation of driest quarter (bio17) from 3 to 4.5 mm (Fig. 4). The average elevation of currently suitable areas was 2500 m. But based on the modeling results, this value will be 2700 m in 2070 (in the RCP4.5 scenario).

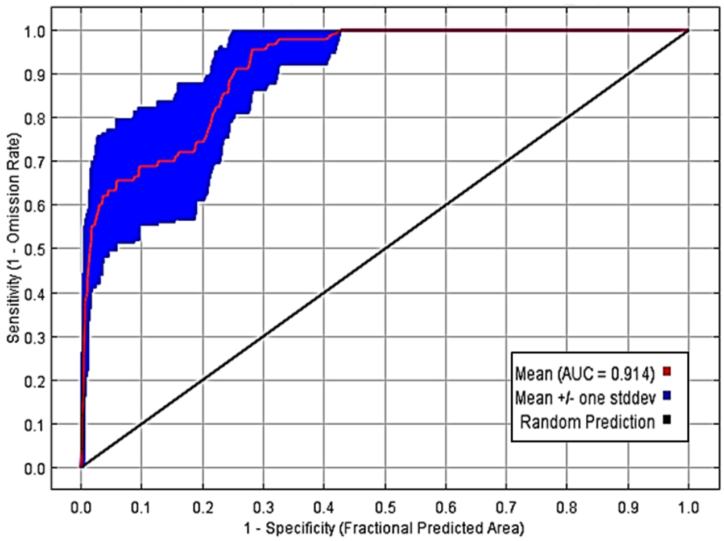

Fig. 3. ROC curve of the MaxEnt model

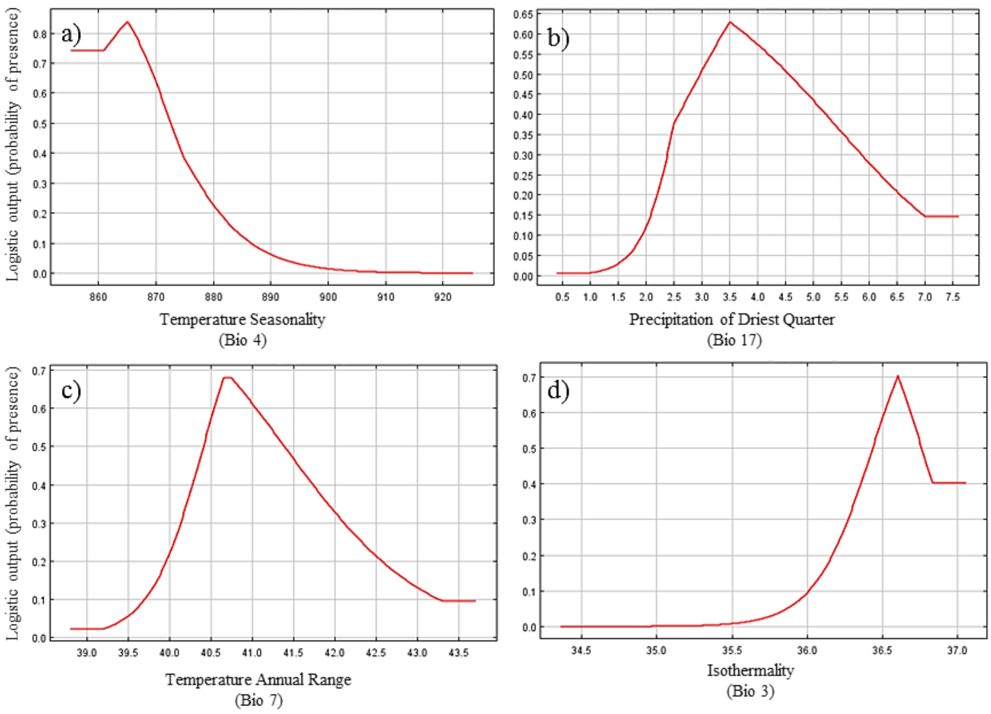

Fig. 4. Response curves of the selected important predictive variables showing logistic output (probability of presence) for *F. imperialis.* Temperatures are expressed in °C and precipitation in mm

The potential distributions of *F. imperialis* under the current environmental conditions are presented in Fig. 5 along with the occurrence locations. According to the model, the projected current suitable habitat for *F. imperialis* was about 37986 ha (2.33% of the total modeled area) (Table 3). They mostly occur in North of Chaharmahal-va-Bakhtiari province.

Table 3. The projected areas of *F. imperialis* under current and future 2070 climate change scenario (two trajectories) categorizing low, medium and high suitability value. (Note: area below 10th percentile training presences regarded as not suitable)

Suitability	**Low (0.1-0.4)**		**Medium (0.4-0.6)**		**High (>0.6)**	
	ha	**%**	**ha**	**%**	**ha**	**%**
Current	381329	23.35	72836	4.46	37986	2.33
RCP 4.5	379098	23.20	61127	3.74	31923	1.95
RCP 8.5	355122	23.20	57781	3.53	32689	2.00

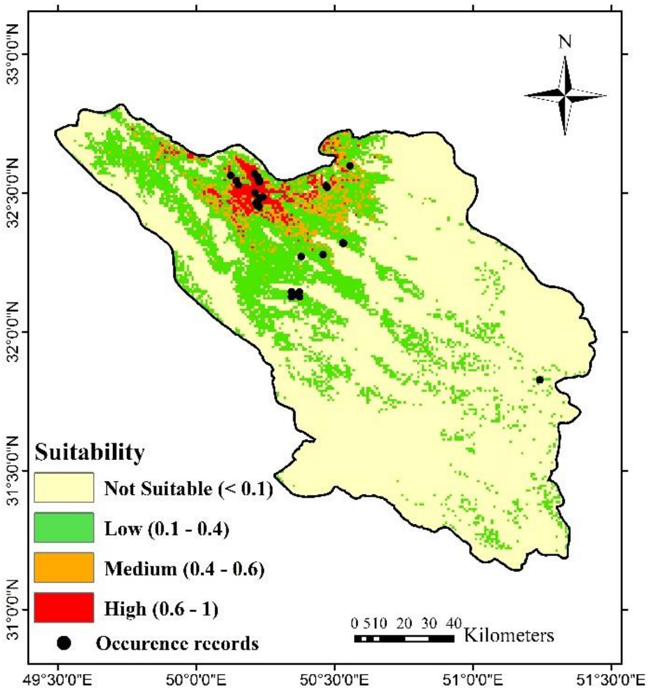

Fig. 5. Predicted potential distribution of *F. imperialis* under current bioclimatic conditions and location of occurrence used for modeling

Future Projection

By studying climate change in 2070, species distribution maps were developed based on the climatic requirements. These maps were prepared for the 2070 period based on RCP4.5 and RCP8.5 (Fig. 6). Species distribution maps showed that 2.33%, 1.95%, and 2% of the study area were recognized as highly potential habitats of *F. imperialis* in the current condition, RCP4.5 and RCP8.5 (2070) projections, respectively (Table 3). To investigate the impact of climate change on the geographic distribution of *F. imperialis*, habitat suitability maps were classified into two classes of appropriate and inappropriate and then, the difference between these two classes was calculated based on overlay operation (Table 4). Changes in geographic distribution of species in 2070 under scenario RCP4.5 as compared to current environmental conditions showed that *F. imperialis* might lose 18% of its climatically suitable habitats due to climate change factors by 2070 while in some areas (2%), the current unsuitable habitats may be converted into suitable (gain). Also, under RCP8.5 climate scenario, it might lose 16.5% of its climatically suitable habitats owing to climate change factors by 2070 while in some areas (2.56%), the current unsuitable habitats may be converted into suitable. Under RCP4.5 and RCP8.5 climate scenario, *F. imperialis* will shrink by 16% and 13.94%, respectively (Table 4).

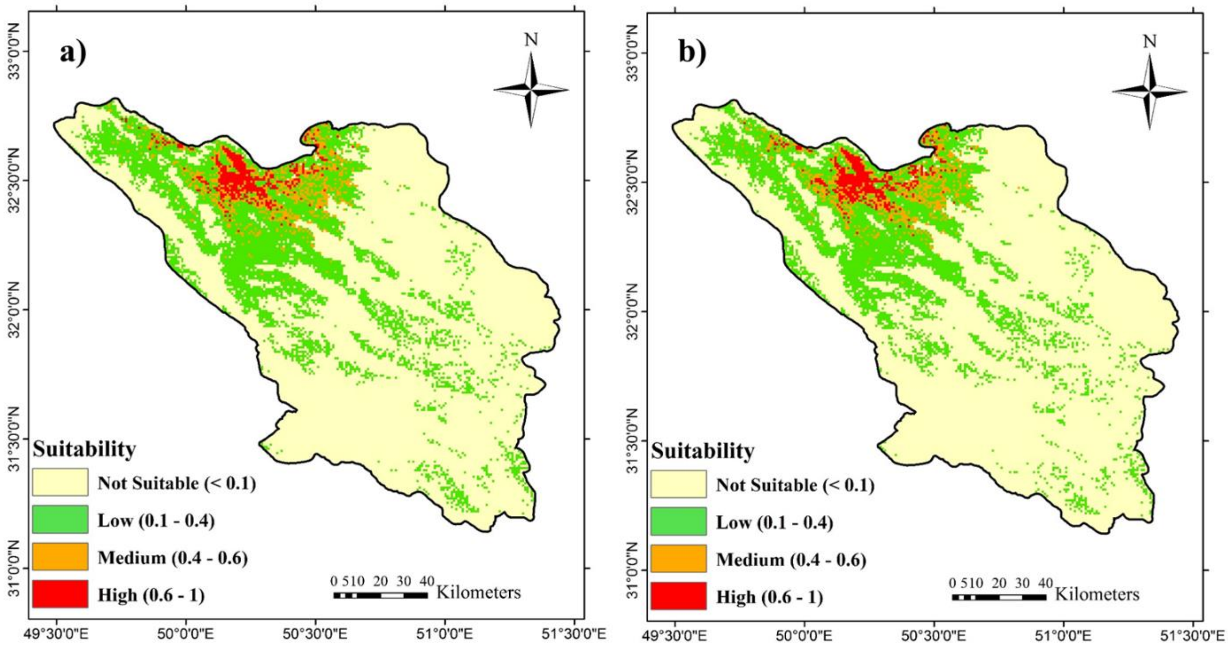

Fig. 6. Predicted future distribution of *F. imperialis* in future climate scenarios under 2 different RCP's (Representative Concentration Pathways) trajectories. (Figure (a) for RCP 4.5 and (b) for RCP 8.5)

Table 4. Changes in the geographic distribution of future (2070) under two trajectories with respect to the current distribution of *F. imperialis*

Scenario	Stable Presence (ha)	Stable Absence (ha)	Lost Habitat (ha)	Gained habitat (ha)	Habitat Loss (%)	Habitat Gain (%)	Habitat Change (%)
RCP 4.5	31156	1594945	6831	767	18	2	-16
RCP 8.5	31714	1594736	6273	976	16.5	2.56	-13.94

Discussion

Species distribution models assume that a certain equilibrium exists-that the species occurs in all environments where it is possible for it to survive, that it cannot survive outside this range, and that it is in equilibrium with climate. In fact, due to many reasons (time delay in response, limited dispersal, and anthropogenic influence), the situation is probably different for many species (Loehle and LeBlanc, 1996). Therefore, the potential changes in suitable habitat for *F. imperialis* reported here are not the real range of changes that will happen. Apart from climatic changes, other parameters such as soil or land transformations would be considered as contributing factors (Iverson & Prasad, 1998). This is impracticable and unnecessary to estimate all these processes when modeling the effects of climate change is performed on an extensive geographic scale (Pearson and Dawson, 2003). Moreover, despite the deficiencies of species distribution models, the overall patterns of predicted species range shift often match the observed biological tendencies (Parmesan *et al.*, 2005).

Monitoring by the use of species distribution modeling can help us distinguish the most important factors in determining species presence and designing conservation programs. According to the findings of this study, temperature seasonality, precipitation of driest quarter, temperature annual range and isothermality were identified as the most important variables for modeling the geographic distribution of *F. imperialis*. The mean annual temperature seasonality (Bio4) showed more effects on the distribution of *F. imperialis* relative to other variables. This was evident via the greater training gain and the top contribution. This could be due to the spatial variability of temperature regimes in Chaharmahal-va-Bakhtiari province caused by the complicated topography (Jaafari *et al.,* 2017).

To assess the accuracy of the maps produced by the model, AUC of ROC plot was used. Based on these results, the model is functioning well because whenever an implemented model has the AUC values of more than 0.9, it will be considered as an excellent model. Thus, in this research, Maxent was a robust technical modeling.

With regard to the future distribution of *F. imperialis* in this study, modeling suggests that their geographic distributions will shrink under predicted levels of climate warming. The study findings reveal that climate change could lead to some loss of current geographic range of the *F. imperialis* in the study area under RCP4.5 (18%) and RCP8.5 (16.5%) climate scenarios whereas the species is expected to gain some new suitable habitat under these scenarios. As shown by the model, in the future, the suitable habitat under the current climatic conditions would be rendered unsuitable, which ultimately leads to local extinction. Rana *et al*. (2017) studied the effect of climate change on *Fritillaria cirrhosa* and expressed that climate change could cause a loss in the parts of habitats.

Some species may be able to adapt to future climatic conditions due to phenological or physiological changes or as a result of adaptations to microclimate conditions responsible for population survival. In this study, *F. Imperials* showed range expansions towards higher peaks of the subject area under the study. Therefore, by increasing temperature due to climate changes, *F. imperialis* habitat's extent will decrease and this species will move toward high altitudes and thus regions with lower temperatures. Similar results have been obtained in many studies in which the movement of species affected by climate change has been studied (Thuiller, 2007; Walther *et al*., 2002).

The current study showed that *F. imperialis* is being threatened by climatic changes in Chaharmahal-va-Bakhtiari province. Model projections suggested that *F. imperialis* is vulnerable to climate warming. The results of this study can be used to identify sites with high extinction probability of *F. imperialis* and protect susceptible habitats from the effects of climate change. Hence, it requires an extra effort to protect such species as *F. imperialis* against climate change. Protected areas can be regarded as a good way for delimitation of areas with high conservation value regarding plant biodiversity including a greater number of such endangered plant species requiring specific protection. Moreover, they are also reasonable units to manage and provide other services to the public, e.g. ecotourism which is an important source of income for the economy of Chaharmahal-va-Bakhtiari province. Ongoing studies within this framework can guide future research toward conservation management goals and mitigate the threat of biodiversity. Moreover, the results of this study can help managers, experts, and relevant decision makers to apply appropriate protective measures and revival plans for this species.

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اثر تغییر اقلیم بر پراکنش گونه‌ی در معرض خطر انقراض و دارویی لاله واژگون در زاگرس مرکزی ایران

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چکیده. تغییرات اقلیمی اثر مهمی بر دامنه پراکنش گونه‌ها، به خصوص بسیاری از گونه‌های گیاهی در معرض خطر انقراض دارد. لاله واژگون یک گونه بومی منطقه زاگرس مرکزی ایران است که از نظر بوم‌شناسی و اقتصادی دارای اهمیت می‌باشد. به منظور حفاظت از گونه لاله واژگون، شناسایی نیازهای رویشگاهی، ارزیابی شرایط رویشگاه و پیش‌بینی رویشگاه بالقوه آن مهم است. در بهار ۱۳۹۶، بازدید از مناطق حضور گونه لاله واژگون در سطح استان چهارمحال و بختیاری به عنوان بخشی از زاگرس مرکزی انجام شده و نقاط حضور گونه مورد مطالعه ثبت گردید. بر اساس نتایج آنالیز همبستگی و به منظور مدل‌سازی پراکنش گونه‌ای، دو متغیر فیزیوگرافی و هشت متغیر زیست اقلیمی به عنوان متغیرهای ورودی مدل حداکثر آنتروپی مورد استفاده قرار گرفتند. نتایج نشان داد که دمای فصلی و بارندگی خشک‌ترین فصل سال به ترتیب با درصد اهمیت ۵۵/۱ و ۲۲/۹، مهمترین عوامل تعیین کننده تناسب رویشگاه گونه لاله واژگون بودند. مدل حداکثر آنتروپی در پیش‌بینی پراکنش گونه لاله واژگون دقت بالایی داشت(AUC=۰/۹۱) و سطح رویشگاه مناسب برای این گونه در سطح استان چهارمحال و بختیاری حدود ۲/۳۳ درصد(۳۷۹۸۶ هکتار) تعیین گردید. همچنین در سال ۲۰۷۰ تحت سناریوهای اقلیمی $RCP_{۴/۵}$، ۱۸ درصد و $RCP_{۸/۵}$، ۱۶/۵ درصد از وسعت رویشگاه گونه کاهش می‌یابد. بر اساس نتایج حاصل از مدل، تبدیل شرایط اقلیمی مناسب فعلی به نامناسب، منجر به کاهش رویشگاه گونه خواهد شد. نتایج حاصل از این مطالعه در شناسایی رویشگاه‌های با احتمال انقراض بالای لاله واژگون و حفاظت از رویشگاه‌های آسیب‌پذیر در برابر اثرات تغییرات اقلیمی موثر خواهد بود.

کلمات کلیدی: مدل حداکثر آنتروپی، متغیرهای زیست اقلیمی، مدل‌سازی پراکنش گونه‌ای، تناسب رویشگاه، استان چهارمحال و بختیاری