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Assessing the potential distribution of *Juniperus excelsa* M. Bieb. under current and future climate scenarios in the Chaharmahal va Bakhtiari province, Iran

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Abstract

Species distributions models (SDMs) are increasingly used to predict species' potential range shift or extinction risk in response to future climate change. Here, we used the ensemble predictions of the models in order to estimate the impact of climate change on the geographical distribution of *Juniperus excelsa* M. Bieb. in Chaharmahal va Bakhtiari province in the Central Zagros region, Iran. We projected climate change impacts for 2050 based on four scenarios of the increase in the greenhouse gases in the general circulation model MRI-CGCM3. We then used the bioclimatic and topographic variables to create a model ensemble from six different SDM algorithms including Generalized Linear Model (GLM), Flexible Discriminant Analysis (FDA), Artificial Neural Network (ANN), Generalized Boosting Method (GBM), Multivariate Adaptive Regression Splines (MARS), and Random Forest (RF). The findings indicated that 26.5% of the study area (4393.98 km^2) is suitable for the *J. excelsa*. Annual precipitation, slope and Isothermality had the highest overall contribution to model performance. Based on the different climate change scenarios, 36.63% to 77.63% of the species' suitable habitats will be loss by 2050. These results can provide reliable information on preparing adaptive responses for the sustainable management of the species.

Keywords: Climate change, Ensemble modeling, Random Forest, Species distribution modelling

Introduction

Climate plays a fundamental role in controlling the geographic distribution of plants (Box 1981). Hence, plant species may be expected to indicate marked redistributions in response to changing climate; this has been estimated at varying scales and in numerous places, typically by the utilization of species distribution models (Bakkenes *et al*. 2002; Lawler *et al*. 2006). Species distribution models (SDMs) can additionally be helpful, the most efficient methodology for ecosystem rehabilitation, plantation rangeland, conservation program, or genetic supply management. They use climate factors as independent predictors and biotic data as dependent predictors to supply a predictive model for species or ecosystem distributions (Hamann and Wang 2006).

Over the last decade, different SDM algorithms such as Classification and Regression Tree (CART, Breiman 1996), Generalized Linear Models (GLMs, McCullagh and Nelder 1989), Random Forest (RF, Breiman 2001), and Artificial Neural Networks (ANN, Ripley 1996) have been documented and applied. One of the most important challenges with the employment of SDMs is that the quantity of techniques accessible is massive and is increasing steadily, creating it difficult for users to select the foremost acceptable algorithm for their desires (Heikkinen *et al*. 2006). This can be significantly true once models are applied to estimate potential distributions of species into independent situations, which is that example of projections of species distributions under global climate change scenarios (Pearson *et al*. 2006). BIOMOD is a computer platform for building the ensemble model of species distributions that allows to combine a collection of different algorithms (Thuiller *et al*. 2009).

Junipers which are known for their medicinal, aromatic and wood values apply important ecological, economic and landscape roles (Özdemir *et al*. 2020; Fatemi *et al*. 2018). *Juniperus excelsa* is an evergreen tree up to 20 m tall belonging to the family Cupressaceae. The species grows in the eastern Mediterranean, Turkey, the Balkans, Iran, Pakistan, and Afghanistan (Ravanbakhsh *et al*. 2013). This plant, commonly known as Juniper, is one of the valuable species living in semi-arid mountains environments of the Irano-Turanian region (Sagheb-Talebi *et al*. 2014).

Previous studies showed that elevation, temperature, precipitation and soil play crucial roles in habitat selection of *J. excelsa* (For example, Fatemi *et al*. 2018; Özdemir *et al*. 2020; Fatemi *et al*. 2020; Arar *et al*. 2020; Naudiyal *et al*. 2021). *J. excelsa* is the most common juniper species in Iran and is sensitive to environmental changes, particularly climatic variations (Pourtahmasi *et al*. 2008). The species has been assigned to the Least Concern category (IUCN, 2016), whereas Iran's Department of Environment (DOE) suggests that the *J. excelsa* forests are endangered and rapidly shrinking (Fatemi *et al*. 2018).

Fatemi *et al*. (2018) investigated the effect of climate change on the geographic distribution of *J. excelsa* in the central and eastern Alborz Mountains, Iran. The study was done by the MaxEnt and two general circulation model, GFDL-CM3 and MRI-CGCM3. They resulted that Under RCP2.6, both models foretold that the species' presence area will gain, but under RCP4.5, models predicted that by 2070, some parts of its habitat in western and central heights will be lost because of climate change. Ozdemir *et al.* (2020) investigated the current and future potential distribution of Crimean juniper (*Juniperus excelsa* M. BIEB.) in the west of the Mediterranean region (Turkey). They foretold that the Crimean juniper would have effected by climate change, and its distribution will decrease dramatically. Arar *et al*. (2020) predicted an increase in the area of suitable habitats *J. phoenicea* under scenario RCP4.5 by 2050, whereas other scenarios revealed decreasing the distribution range of the species. Many studies have been predicted decreasing the geographical distribution of different tree species in Iran due to climate change (Haidarian *et al*. 2017a; Alavi *et al*. 2019; Naghipour *et al.* 2019a; Naghipour *et al.* 2021; Taleshi *et al.* 2019).

In this study, we applied species distribution modeling under predicted climate change scenarios in the Central Zagros region (Iran) to search for answers to the latter questions: 1) which areas are predicted in current as suitable habitats for *J. excelsa* in Central Zagros, Iran? 2) Will the distribution of the species likely expand or contract under various climate change scenarios by 2050?

Materials and Methods

Study Area

The study area is Chaharmahal va Bakhtiari province, a region of 1.6 million hectares in the Central Zagros Mountains in western Iran. In this mountainous area, elevations are between 783 and 4178 m above sea level. The annual precipitation ranges between 250 mm within the east and southeast and 1400 mm within the northwest of the province, with a provincial mean of 560 mm. The annual average temperature is 10 °C (Jaafari *et al*. 2017; Ashrafzadeh *et al*. 2019a, b).

Presence data

Sixty one presence records were collected across the study area. We removed duplicate points within a 1km buffer to exclude spatial autocorrelation. Finally, 50 presence points of *J. excelsa* were used for the distribution modeling (Figure 1).

Modeling

The chosen environmental predictors are classified in to two groups: 1) topographic variables (elevation, aspect and slope) and 2) bioclimatic variables (Bio1–Bio19). Environmental Data were obtained at a spatial resolution (30 arc-seconds ~1 km) from WorldClim the dataset (http://www.worldclim.org). We considered the bioclimatic variables belonging to current (1970-2000) and future (2041-2060, hereafter referred to as 2050) periods to project the impacts of climate change on *J. excelsa*. All 19 bioclimatic variables were used, that had been applied in many sorts of research because the base for monitoring impacts of climate change on the plant. The digital elevation model (DEM) was used to generate slope and aspect data layers. Before modeling, Pearson's correlation analysis ($R^2<0.8$) was used to examine the collinearity between different environmental variables (Naghipour *et al*. 2021). Finally, after removing the highly correlated layers, eight variables were employed in the distribution modeling. Uncorrelated predictors and mean of their contributions (%) in eight variables were employed in the distribution modeling in southwestern Iran (Table 1).

Table 1: Uncorrelated variables and mean of their relative importance in *J. excelsa* distribution models

Abbreviations	Variables	Relative importance
Bio12	Annual Precipitation	39.29
slope	Slope	29.3
Bio3	Isothermality (BIO2/BIO7) (* 100)	18.21
Bio4	Temperature Seasonality (standard deviation *100)	4.04
Bio15	Precipitation Seasonality (Coefficient of Variation)	3.74
Bio8	Mean Temperature of the Wettest Quarter	3.4
Bio17	Precipitation of the Driest Quarter	2.02
aspect	Aspect	0.17

We applied six modeling approaches including Generalized Linear Model (GLM), Generalized Boosting Method (GBM), Flexible Discriminant Analysis (FDA), Multivariate Adaptive Regression Splines (MARS), Artificial Neural Network (ANN) and Random Forest (RF) in an ensemble approach with the

Biomod2 package (Thuiller et al., 2016) in R v. 3.1.2 (R Development Core Team. 2014). Model performance was assessed using the area under the receiver operating the curve (AUC) and the true skill statistic (TSS). Both criteria are autonomous of prevalence within the species data (Allouche *et al*. 2006; Zipkin *et al*. 2012).

The entire area of suitable habitat was calculated using ArcGIS 10.3 software for all the models. For species, we built the six species distribution models employing a random subset of dataset containing 80% of the species presence data. We used the remaining 20% of the species presence data to evaluate the predictive performance of the models. We repeated this split-sample procedure ten times and have simulated the habitat suitability for 2050. A total of 240 probabilities in total (ten repetition- six modelling methods– Representative Concentration Pathways (RCPs)): RCP 2.6, RCP 4.5, RCP 6 and RCP 8.5 and one global circulation model MRI-CGCM3 (Meteorological Research Institute Coupled Global Climate Model version three) of habitat suitability for this species were generated.

Results

All models showed good-excellent prediction accuracy (AUC > 0.84 and TSS > 0.65) (Table 2). The Random Forest (RF) algorithm and Artificial Neural Network (ANN) provide the highest accuracy values (AUC = 0.99 and TSS = 0.99) (Table 2).

Table 2: Estimated values of the true skill statistic (TSS) and the area under the curve (AUC) implemented in different models

Model	MARS	FDA	GBM	ANN	GLM	RF	Average
AUC	0.98	097	0.98	0.99	0.84	0.99	0.96
TSS	0.94	0.91	0.96	0.99	0.65	0.99	0.90

Annual Precipitation (39.29%), slope (29.30%), and Isothermality (18.21%) had the highest contribution to the distribution models (Table 1).

According to the ensemble model, 26.5% (4393.98 km^2) of the study area is currently suitable habitat for the *J. excelsa* (Figure 1). The findings revealed that the central, southern and north-west parts of the province are the most suitable habitat for *J. excelsa*. Our results suggest that climate change can adversely affect the current distribution of *J. excelsa*. The results of all scenarios indicate a decrease of suitable habitats for *J. excelsa* by 2050 (Figure 2). The reduction of suitable habitats for *J. excelsa* will be 36.63% (RCP 2.6) to 77.63% (RCP 8.5) due to future climate change by 2050 (Table 3). While in the same period, about 9.15% to 48.96% will be added to the suitable habitats of this species (unsuitable habitats will become suitable.) (Figure 2 and Table 3).

Table 3 Changes in the area of suitable habitats (km^2) of *J. excelsa* by 2050 compared to the current distribution under different climatic scenarios and the MRI-CGCM3 model

Year/Scenario	Stable presence (km^2)	Stable absence (km^2)	Habitat loss (km^2)	Habitat loss (%)	Habitat gain (km^2)	Habitat gain (%)	Habitat change (%)
RCP2.6	2784.51	9986.45	1609.46	36.63	2151.57	48.96	12.33
RCP4.5	1317.17	11343.81	3076.81	70.02	794.84	18.09	-51.93
RCP6	1126.69	10924.88	3267.28	74.35	1213.14	27.61	-46.74
RCP8.5	980.18	11735.83	3413.79	77.63	402.18	9.15	-68.54

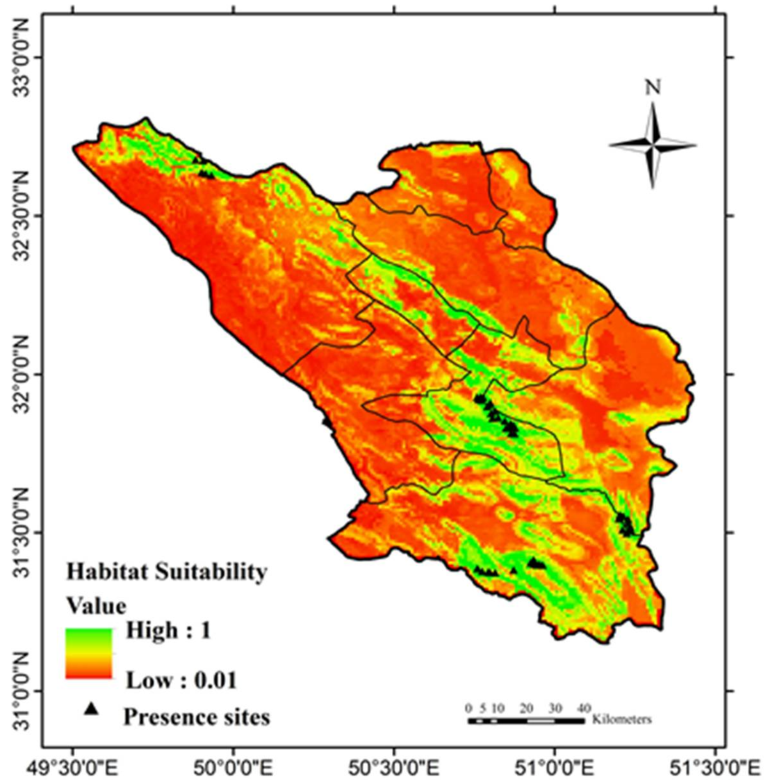

Figure 1: The ensemble map of current habitat suitability for *J. excelsa*

Discussion

The potential distribution of *J. excelsa* in Chaharmahal va Bakhtiari province have reached an alarming condition and are a significant worry for the natural resource departments and policymakers. In this study, we applied the ensemble approach to evaluate the impacts of climate change on the spatial distribution *J. excelsa* in Chaharmahal va Bakhtiari province (Iran) by the year 2050. The distribution modeling of *J. excelsa* helps to identify the suitable sites where the species can grow well. It's predicted that the *J. excelsa* will be affected by climate change and its distribution will decrease dramatically. Based on the findings, the currently suitable habitats in large parts of the study area would be changed to unsuitable habitat by 2050, which can result in local extinction. The findings indicated that decline of suitable habitats of the species will be 36.63% (RCP2.6) to 77.63% (RCP8.5) by 2050. However, the ensemble models indicated that by 2050 suitable habitats of the species will gain 48.96% (RCP2.6) to 9.15% (RCP8.5). Our findings are in accordance with the results of other studies (Fatemi *et al.* 2017: *J. excelsa*; Fatemi *et al.* 2018: *J. excelsa*; Arar *et al.* 2020: *J. phoenicea*; Dakhil *et al.* 2021: three endemic *Juniperus spp*.; Naudiyal *et al.* 2021: *Juniperus spp*; Ozdemir *et al*. (2020): *J. excelsa*; Fisher (1997): *J. procera*; MacLaren *et al*. 2016: *J. seravschanica*).

Monitoring using SDMs can help us to detect the foremost vital factors in determining species presence and in designing conservation programs. Based on the findings, annual precipitation, slope, and Isothermality are the most important variables affecting the distribution of *J. excelsa* in the study area. Water availability-related variables, particularly annual precipitation, contributed considerably as limiting determinants for the distribution of *J. excelsa*. Annual precipitation has a vital role in evaluating the presence of the studied central Zagros and central Iran species (Naghipour *et al*. 2019a; Haidarian *et al*. 2017a; Amiri *et al*. 2019; Sangoony *et al*. 2016). Annual precipitation has been reported as one of the most important variables in the habitat suitability of *J. excelsa*, (Fatemi *et al*. 2020; Dakhil *et al*. 2021).

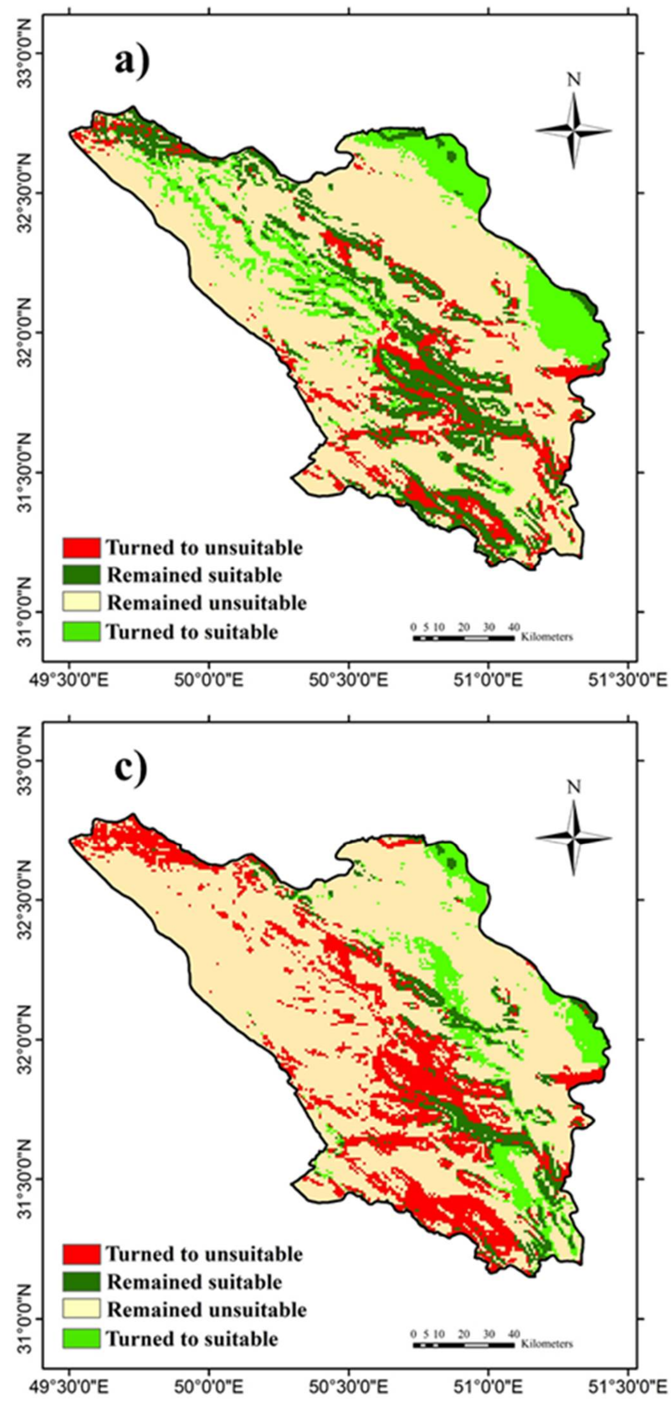

Figure 2: Changes in the suitable habitats of *J. excelsa* from current to future climatic conditions (2050) resulting from the ensemble model and based on the MRI-CGCM3 model with four RCP scenarios: (a) RCP2.6, (b) RCP4.5, (c) RCP6, and (d) RCP8.5

The spatial distribution of *J. excelsa* seems to be more influenced by the slope and it contributed to 29.3% in SDM of *J. excelsa*. In consistent with other studies (*J. phoenicea*; Arara *et al*. 2020; *J. excelsa*; Fatemi *et al*. 2018), our findings indicate that slope is one of the most important variables influencing habitat selection of *Juniperus* genus. Isothermality which indicates how the day-to-night temperatures fluctuate relative to the summer-to-winter fluctuations (Dakhil *et al*. 2021) contributed as an important predictor in the distribution modelling. Previous authors emphasized that different plant species living in Central Zagros have highly sensitive to the temperature variation (Naghipour *et al*. 2021; Haidarian, *et al*. 2021). Isothermality has been reported as one of the crucial predictors correlated with the distribution of other *Juniperus* species, e.g., *J. tibetica* and *J. komarovii*, in southwest China (Dakhil *et al*. 2021).

The elevation range of the presence points of *J. excelsa* was between 1837 to 3275 m, where the average elevation was 2552 m. The results of this study are consistent with the findings of a study by Fatemi *et al*. (2018) that revealed the presence of *J. excelsa* to be currently limited to the elevation range of 1800-3000 m. Also Ravanbakhsh & Moshki (2016) on forests of south central Alborz showed that *Juniperus* communities are present in the mountainous forests of the central Iranian plateau at the altitude of 1700 to 2800 (3400 in the southern regions) m A.S.L.

Based on the results, RF and ANN models had the highest accuracies (Both of them, AUC: 0.99, TSS: 0.99). These algorithms are efficient methods for the distribution modeling (Ardestani & Ghahfarrokhi 2021; Cheng *et al*. 2012; Haidarian *et al*. 2017b; Ashrafzadeh *et al*. 2019b; Naghipour *et al*. 2019b).

Conclusion

The importance of *J. excelsa* as one of the particular tree species of Irano-Turanian region and its relevant role in preventing erosion, desertification and soil conservation necessitate proper planning for species' preservation in Chaharmahal va Bakhtiari province. The current study showed that *J. excelsa* is being threatened by climatic changes. Hence, it needs an additional effort to protect species such as *J. excelsa* against climate change. This research showed annual precipitation, slope and Isothermality have played the most important roles in the habitat suitability of this species. According to the results, *J. excelsa* is expected to decrease the area of current distribution under 2050. Hence, the identification of suitable bioclimatic variables and the current and predicted map of habitat suitability could be a significant guide for the conservation and management of important plants. Continuous studies within this framework will guide future research toward mitigating the threat of biodiversity and conservation management goals. Moreover, the results of this study can help, managers, and relevant decision makers and experts, apply appropriate protective measures and revival plans for this species.

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