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Predicting the effect of climate change on the geographic distribution of the endemic *Fritillaria aurea* in Türkiye

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İklim değişikliğinin Türkiye'deki endemik *Fritillaria aurea*'nın coğrafi dağılımına etkisinin tahmin edilmesi

Abstract: *Fritillaria aurea* is a rare, high altitude, endemic, and bulbous plant species in Türkiye. Although it is classified as least concern according to IUCN criteria, the species has a narrow distribution. This study utilized ensemble modeling to forecast potential future changes in suitable habitats for *F. aurea* by two Shared Socio-Economic Pathways (SSPs: SSP 1-2.6 and 5-8.5). These pathways were constructed using two General Circulation Models (GCMs) and covered the years 2035, 2055, and 2085. The results showed that the minimum temperature of the coldest month (bio6), mean temperature of the wettest quarter (bio8), and precipitation of the warmest quarter (bio18) have the largest influence on the potential species distribution. The ensemble model predicted that the highly suitable habitats of *F. aurea* would contract under all future SSP scenarios and it would lose almost all of its potential highly suitable distribution areas by the end of the century. The remained population of *F. aurea* could possibly harbour in only minor areas of the North Anatolian Mountains in the north and Taurus Mountains in the south. The results of the study could contribute to establishing conservation strategies and natural resource management policies for *F. aurea* against the potential impacts of climate change. The highly suitable habitats under pessimistic scenarios at the end of this century projected by the present study can be determined as protected areas for the species.

Key words: CMIP6, global warming, habitat prediction, ensemble model, plant species distribution

Özet: *Fritillaria aurea*, Türkiye'de nadir bulunan, yüksek rakımlı, endemik ve soğanlı bir bitki türüdür. IUCN kriterlerine göre az endişe kategorisinde sınıflandırılmasına rağmen, dar yayılışlı bir türdür. Bu çalışma, *F. aurea* için uygun habitatlarda gelecekteki potansiyel değişiklikleri iki Paylaşılan Sosyo-Ekonomik Yol (SSP'ler: SSP 1-2.6 ve 5-8.5) aracılığıyla tahmin etmek için topluluk modellemeyi kullanmıştır. Bu yollar 2035, 2055 ve 2085 yıllarını kapsayan iki Genel Dolaşım Modeli (GCM) kullanılarak oluşturulmuştur. Sonuçlar, en soğuk ayın minimum sıcaklığının (bio6), en yağışlı çeyreğin ortalama sıcaklığının (bio8) ve en sıcak çeyreğin yağışının (bio18) potansiyel tür dağılımı üzerinde en büyük etkiye sahip olduğunu gösterdi. Topluluk modeli, *F. aurea*'nın son derece uygun habitatlarının gelecekteki tüm SSP senaryoları altında daralacağını ve yüzyılın sonuna kadar potansiyel olarak son derece uygun dağıtım alanlarının neredeyse tamamını kaybedeceğini öngördü. *F. aurea'nın* geriye kalan popülasyonunun kuzeyde Kuzey Anadolu Dağları'nın ve güneyde Toros Dağları'nın yalnızca çok küçük bir kısmında barınması muhtemeldir. Çalışmanın sonuçları, *F. aurea*'nın iklim değişikliğinin olası etkilerine karşı koruma stratejileri ve doğal kaynak yönetimi politikalarının oluşturulmasına katkı sağlayabilir. Bu çalışmanın öngördüğü, bu yüzyılın sonundaki kötümser senaryolar altında son derece uygun habitatlar, tür için korunan alanlar olarak belirlenebilir.

Anahtar Kelimeler: CMIP6, küresel ısınma, habitat tahmini, topluluk modeli, bitki türlerinin dağılımı

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1. Introduction

Climatic drivers are the major determinants of plant species distribution along with geographical gradients (Woodward and Williams, 1987). Therefore, any alterations of climatic conditions highly overpressure plant species and diversity. According to the IPCC's 2021 report, it is projected that the average global temperature will rise by at least 1.5 °C by the end of 2100 (Allen et al., 2018). The human-induced warming triggers other impacts on plant species such as fragmentation, invasive species, overexploitation, and habitat loss (Mantyka-Pringle et al., 2012). Plant species are predicted to respond differently to climate change, and its effects are assumed to differ from region to region (Thuiller et al., 2005). Particularly, most studies reported that mountain regions will be most affected by climate change (Guisans and Theurillat, 2000; Liu and Chen, 2000; Diaz and Eischeid, 2007). The most serious and irreversible impact of climate change on species distributions will be loss of species. Due to both changes and vanish in the distribution limits of the species changes in their taxonomic and functional diversity are expected to be observed.

Fritillaria aurea Schott which is distributed in the Central Anatolian region in Türkiye is a rare, alpine, endemic, and bulbous plant species. According to IUCN (The International Union for Conservation of Nature 2024), it is assessed in the least concern threatened category. The species colonizes limestone substrates on north-facing rock outcrops and snow beds at an altitude of 1650-3000 m, particularly in Juniper openings (Rix, 1984; Tekşen, 2018). The current distribution is restricted to eastern and south-eastern Central Anatolia which includes middle and upper Kızılırmak (Halys) basin, the northern parts of the Euphrates, Konya and Adana provinces (Tekşen and Aytaç, 2011; Tekşen, 2018). *F. aurea* is a typical Irano-Turanian element, and it has campanulate-shaped and reddish-brown tessellated yellow flowers. The main threats to the populations of the species are overgrazing, habitat loss because of agricultural activities, and reduced water availability due to human activities. The ever-increasing anthropogenic disturbance and influence of climate change are likely to have disproportionately negative impacts on populations of the species more recently.

To acquire a deeper understanding of the potential effects of global climate change, various worldwide climate model simulations have been generated within the Coupled Model Intercomparison Project (CMIP) under the World Climate Research Program (WCRP). IPCC releases climatic conditions for the past, present, and future using different models under various emission scenarios based on greenhouse gases with the help of the Coupled Model Intercomparison Project (CMIP) as reports, and these are occasionally updated. The most recent publication of the Intergovernmental Panel on Climate Change sixth assessment report (IPCC, 2021) contains the findings of the Coupled Model Intercomparison Project Phase 6 (CMIP6). Species distribution models (SDMs) predict the potential impacts of climate change on the extent of a species' range and biodiversity in the past or the future with the help of these climatic conditions based on various emission scenarios of IPCC reports and using different algorithms (Pearson, 2007; Elith and Leathwick, 2009).

Endemic species have a high potential to disappear owing to narrow geographical range, small population size, low genetic variability, and the requirement for specialized ecological niches (Işık, 2011). These species are most sensitive to future climate changes (Da Silva et al., 2019). Accordingly, we deemed it necessary to investigate the potential spatial distribution of the species and the impact of climate changes in the future on *F. aurea* in Türkiye. We applied the ensemble technique to establish the potentially current suitable habitats for *F. aurea* under the current climate and understand the alteration of these potentially suitable habitats in the future due to climate change. Considering the survival of endemic species totally relies on national policies, the results of this study will supply useful information for academic research and aid to design effective sustainable ecological assessments for the conservation of the species.

2. Materials and Method

2.1. The study area and occurrence data

The region of Central Anatolia including the study area is located between latitude 39°N to 41°N and longitude 30°E to 38°E. Central Anatolia is a vast plateau that is limited between the North Anatolian Mountain ranges in the north and the Taurus Mountain ranges in the south. The topography is generally flat, with the elevation varying between 700 to 1100 m. There are a few volcanic mountains that can rise up to above 3000 m on this vast area. Regional precipitation varies between about 330 and 700 mm and average maximum temperatures are between 23°C and 29°C in this region, thus, the climate of the region is classified under an arid and semi-arid Mediterranean climate (Kenar and Kikvidze, 2019).

Species presence records were obtained from the field works by M. Tekşen and the verified occurrence points in different herbaria (AEF, AIBU, AKSU, ANK, E, EBKA, EGE, GAZI, HUB, ISTE, ISTF, ISTO, NGBB, and RSA [the acronyms follow Thiers, 2024]) listed in 33 locations in Türkiye (Tekşen, 2018) seen below.

***Fritillaria aurea*:** TÜRKİYE. Adana: Seyhan, Pozantı, Armutoluk, E of Hondu, 12 May 1952, *İ. Akkaş* 11873 (ISTF); Aksaray: Hasan Mt., 05 May 2021, *M. Tekşen* 5975 (AKSU); Kahramanmaraş: Göksun, between Püren pass and Değirmendere village, Kartallık, 1700-1800 m, 21 May 2000, *M. Tekşen* 1994 (fr.) (GAZI); ibid, 22 April 2001, *M. Tekşen* 2049 (fl.) (GAZI); ibid., 9 July 2001, *M. Tekşen* 2104 (fr.) (GAZI); ibidem, 24 May 1993, *Ekici* 1275 (GAZI); Göksun, Berit Mt., 19 June 1981, *B. Yıldız* 3005 (AIBU; HUB); Göksun, Binboğa Mt., above Karlı plateau, *P.H. Davis* 20024 (E); Kayseri: Sarız, Binboğa Mt., Yalak, 1700-1900 m, 7 May 1991, *Z. Aytaç* 3702 & *H. Duman* (AEF, HUB, GAZI); Pınarbaşı, Eğrisöğüt village, Şirvan Mt., 1900-2000 m, 25 July 2003, *M. Tekşen* 2204 (fr.) (GAZI); 24 km S. of Pınarbaşı, 1800-1900 m, 24 May 1965, *Coode & Jones* 1423 (ISTO, E, ISTF); Pınarbaşı, Eğrisöğüt-Beyçayır villages, around Kumuk Adil, c. 1700 m, 17 April 2001, *A. M. Özkan* s.n. (AEF); Pınarbaşı to Gürün, Ziyaret hill, 2000 m, 23 May 1965, *Coode & Jones* 19810 (ISTF); Pınarbaşı, Solaklar Köyü, Şirvan Mt., 4 June 2006, *A. Güner* 14239 et al. (NGBB); Yahyalı, Maden, Aladağlar, 25 May 2008, *A. Güner* 14857 et al. (NGBB); Malatya: Akçadağ, Bayramuşağı village, İskender Hayması, 26 April 1992, *B. Yıldız* 9087 (ISTE 94755); Darende, Ağılbaşı district, Ağılbaşı, Akbabaçalı Mt., 30 April 2008, *H. Yıldırım* 1372 (EGE); Doğanşehir, 29 April 2008, *M. Aslay* F44043 & *M. Tekşen* (EBKA); Doğanşehir, Eskiköy, Bey Mt., 3 May 1992, *B. Yıldız* 9102 (ISTE 94761); Doğanşehir, Eskiköy, Koçdere village road, 28 April 2008, *H. Yıldırım* 1294 (EGE); Doğanşehir, Söğüt, Kudılı village, Boğaboynu, 25 April 2009, *M. Aslay* F44063 & *M. Tekşen* (EBKA); Sürgü, Eski Kurucaova village, 24 May 1992, *B. Yıldız* 9308 (ISTE 94801); Mersin: Aslanköy, Ballık Mt., 11 May 1976, *T. Baytop* (ISTE 34852); Toros, Siehe 216 (ANK); Niğde: Aladağ, SW (south-west) Flank of Demir Kasık, 2400-2800 m, *Parry* 170 (E); Aladağ, 2700 m, 24 June 1964, *Wood & Gibson* 106 (E); Aladağ, Emli Valley, Parmaktaş, 2 May 2010, *M. Tekşen* 2359 (AKSU!); Aladağ, Tekneli plateau, 2700 m, 15 July 1979, *R. Carle & H. Kürschner* 79-433 (RSA); Sivas: Pınarbaşı to Gürün, 2000 m, 26 May 1960, *Stainton & Henderson* 5179 (E, RSA).

2.2. Current and future climatic data

We used the 19 bioclimatic layers of the CHELSA version 2.1 (Climatologies at High Resolution for the Earth's Land Surface Areas) dataset (Karger et al., 2021) as climatic environmental variables at a 30-arc sec spatial resolution (~1km) for four temporal ranges (1981-2010 "current times", 2011-2040 "2035s", 2041-2070 "2055s", and 2071-2100 "2085s"). We extracted the bioclimatic variable values of the grid cell using QGIS 3.18.2 (QGIS Development Team, 2021). We utilized Max Planck Institute Earth System Model (MPI-ESM1-2-HR; Gutjahr et al., 2019) and the Meteorological Research Institute Earth System Model Version 2.0 (MRI-ESM2.0; Yukimoto et al., 2019) data of the Global Circulation Model (GCM) produced by the Coupled Model Intercomparison Project Phase 6 database (CMIP6) (IPCC, 2021).

We used two Shared Socio-Economic Pathways (SSPs) having different scenarios based on the amount of greenhouse gas emissions and radiative forcing level considering the population and economic growth. The SSP 1-2.6 is a scenario that predicts a low level of greenhouse gas emissions, as indicated by its radiative forcing route. This scenario forecasts a global warming of less than 2°C by the year 2100, with a radiative forcing level of 2.6 W/m² by the same year. The SSP5-8.5 represents a scenario characterized by significant emissions, where radiative forcing is stabilized at 8.5 W/m^2 by the year 2100. This scenario is based on the assumption of unrestricted and rapid increases in both economic output and energy consumption resulting in the greatest levels of greenhouse gas emissions (Meinshausen et al., 2020).

2.3. Data analysis

We computed Variance Inflation Factors (VIF) for climatic variables using the "usdm" package in R to mitigate the issue of multi-collinearity. Environmental variables with a VIF exceeding 5 were subsequently eliminated (Naimi et al., 2014).

Species Distribution Models (SDMs) attempt to estimate the spatial patterns of species occurrences based on correlations between available presence records and the environmental conditions (Beery et al., 2021). We utilized the R package 'biomod2' version 3.5.1 which supports an ensemble model that combines different modeling techniques to generate potential distribution maps of *F. aurea* (Thuiller et al., 2009; R Core Team, 2013). We performed ten modeling algorithms: Multivariate Adaptive Regression Splines (MARS), Generalized Linear Model (GLM), Random Forest (RF), Generalized Boosted Model (GBM), Functional Data Analysis (FDA), Artificial Neural Network (ANN), Generalized Additive Model (GAM), Surface Range Envelope (SRE), Maximum Entropy (Maxent), and Classification Tree Analysis (CTA). We constructed 350 pseudo-absence records (PAs) using random generation. These records were then calibrated using an 80% occurrence dataset and assessed using a 30% occurrence dataset performing using 3-fold cross-validation. We chose to utilize the Receiver Operating Characteristic Curve (specifically the Area Under the Curve, AUC) and true skill statistics (TSS) to assess the correctness of the model. The AUC values range from 0 to 1. Models with AUC values closer to "1" exhibit greater accuracy. The formula for TSS is calculated by adding the sensitivity and specificity values and then subtracting 1. A higher number for TSS indicates a higher level of accuracy for the model (Allouche et al., 2006).

We generated the final potential species distribution map including habitat suitability levels ranging of values from 0 to 1 based on the ensemble model. The levels of suitability are categorized as follows: unsuitability (0-0.2), low suitability (0.2-.0.4), medium suitability (0.4-0.6), suitability (0.6-0.8), and high suitability (0.8-1).

3. Results

3.1. Model performance and the importance of environmental variables

We used only those bioclimatic variables (bio3, bio4, bio6, bio8, bio18, and bio19) after calculation of VIF values for the models (Table 1).

AUC value is an important metric used for evaluating the performance of the models. In our study, these values varied between 0.986 and 0.807, which shows that the models were highly accurate (Table 2). According to the results, the most accurate algorithm was MARS, whilst the least accurate was CTA. The performance of the ensemble model had an AUC value of 0.998 and a TSS value of 0.972, indicating that the ensemble model best performed in this study and could be used in the following analysis.

Table 1. The climatic variables utilized in constructing the models obtained from CHELSA Version 2.1 (Karger et al., 2021), along with their corresponding Variance Inflation Factor (VIF) values employed in model construction

Code	Bioclimatik variable	VIF value
BIO3	Isothermality (BIO2/BIO7) (* 100)	2.33
BIO4	Temperature Seasonality (standard deviation *100)	1.81
BIO6	Minimum Temperature of Coldest Month	1.14
BIO8	Mean Temperature of Wettest Quarter	4.47
BIO18	Precipitation of Warmest Quarter	3.39
BIO19	Precipitation of Coldest Quarter	2.14

Table 2. Receiver operating characteristics (ROC) and True Skill Statistics (TSS) values (± SD) of all the algorithms, ensemble model, multivariate adaptive regression splines (MARS), generalized linear model (GLM), random forest (RF), generalized boosted model (GBM), functional data analysis (FDA), artificial neural network (ANN), generalized additive model (GAM), surface range envelope (SRE), maximum entropy (MaxEnt), and classification tree analysis (CTA) performed with present climate conditions (1981–2010).

Algorithm	ROC ± SD	TSS ± SD
Ensemble model	0.998 ± 0.001	0.972 ± 0.002
MARS	0.986 ± 0.020	0.952 ± 0.050
GLM	0.979 ± 0.028	0.938 ± 0.073
RF	0.958 ± 0.050	0.862 ± 0.114
GBM	0.958 ± 0.045	0.847 ± 0.129
FDA	0.955 ± 0.046	0.828 ± 0.115
ANN	0.927 ± 0.008	0.804 ± 0.036
GAM	0.843 ± 0.089	0.690 ± 0.172
SRE	0.828 ± 0.050	0.657 ± 0.099
MAXENT	0.826 ± 0.036	0.652 ± 0.073
CTA	0.807 ± 0.068	0.614 ± 0.137
Algorithm	ROC ± SD	TSS ± SD

The environmental variables which were used in the model and the percent predictive contribution of each variable were calculated and converted to percentages (Fig. 2). Each environmental variable had different importance for the models in the study. The minimum temperature of the coldest month (bio6) had the maximum contribution to most algorithms such as MARS, GLM, and GBM, followed by precipitation of the warmest quarter (bio18; Fig. 1). The mean temperature of the wettest quarter (bio8) could be the third variable with an average contribution except for RF, FDA, and MaxEnt. Compared to precipitation variables, temperature variables (bio3, bio4, and bio6) contributed more to the GLM, which was among the first four algorithms with the highest AUC value.

3.2. Potential suitable habitat under current and future changes

The extent of potential distribution areas in the current and future climate conditions predicted by the ensemble model

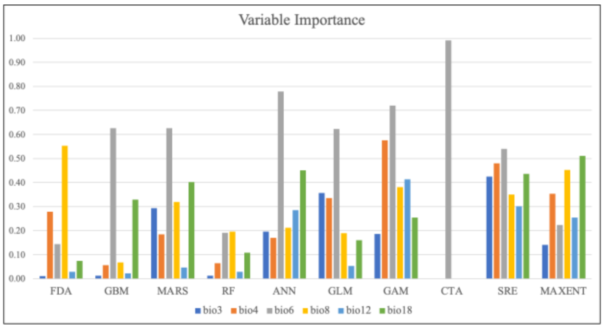

Figure 1. The importance of the selected environmental variables to FDA, GBM, MARS, RF, ANN, GLM, GAM, CTA, SRE (BIOCLIM), and MaxEnt models

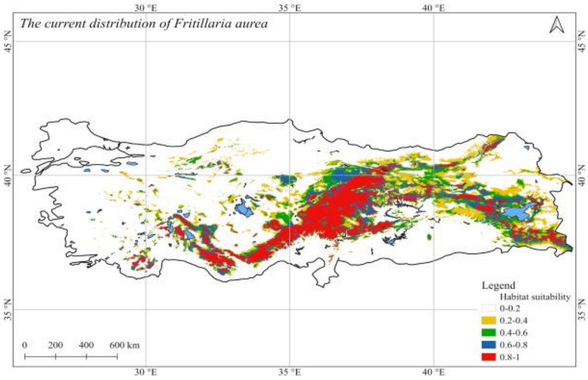

Figure 2. The ensemble model was used to forecast the suitable habitats for *Fritillaria aurea* from 1981 to 2010. The color white (0-0.2) indicates unsuitability, while yellow (0.2-0.4) indicates low suitability. Green (0.4-0.6) represents medium suitability, blue (0.6-0.8) signifies suitability and red (0.8-1) indicates high suitability.

are shown in Table 3. The current potential distribution area of *F. aurea* covers a large region at the intersection of eastern and south-eastern Central Anatolia, and further, the possible distribution of the species continues towards the south of Anatolia in the Mediterranean coastal region (Fig. 2). We established that 69.201 km^2 of these areas are highly suitable areas for *F. aurea.* Considering the projections for the current distribution of the species, both scenarios (SSP1-2.6 and SSP5-8.5) remarked that there would be a decline in the distribution of the species in both climate change scenarios and global climate models (Figs. 3-4).Although there were some small increases in the middle of the century, the MPI-ESM1-2-HR GCM model projected that the species' potential range would drop by 27% (equivalent to a loss of 18.776 km^2) under the SSP1-2.6. However, under the SSP5-8.5, the species' range would be reduced by 62% (equivalent to a loss of 42.821 km^2) by the end of the century. The MRI-ESM2.0 offers us more pessimistic scenarios. Accordingly, highly suitable habitats exhibit a strong downward trend; the possible habitat loss would be 42% (29.014 km^2) under SSP1-2.6, whilst the loss would be 92% (63.806 km^2) under SSP5-8.5 by the end of the century.

Furthermore, future models predicted that the species could have very narrow potential refuge areas in the transition zone between the Irano-Turanian and the Euxine region, in mountainous habitats in the west of the Black Sea region, and in the subalpine zone of central and western Taurus Mountains.

4. Discussions

Fritillaria aurea is one of the nearly 52 *Fritillaria* species recorded in Türkiye (Tekşen, 2018; Tekşen et al., 2024). The population size of *F. aurea* is progressively decreasing in its natural habitats and thus, the species may be at risk of extinction due to human disturbance and environmental change in the near future (Tekşen and Aytaç, 2011; Tekşen, 2018). The model under current climate conditions accurately predicted a large part of the suitable habitat of *F. aurea* in the southeast of Central Anatolia and central Taurus mountains which were consistent with our field

Table 3. Percentage and the predicted suitable area of the presence of *F. aurea* for the present day (1981-2010), 2035s (2011-2040), 2055s (2041-2070), 2085 (2071-2100) and under two different climate scenarios. Mean predicted results are from two global climate models [MPI-ESM1-2-HR and MRI-ESM2-0] which were modelled under 2035s-SSP126; 2035s-SSP585; 2055s-SSP126; 2055s-SSP585; 2085s-SSP126; and 2085s-SSP585. SSP5-8.5 refers to a Shared Socio-economic Pathway (SSP) scenario from the IPCC sixth assessment report (AR6) for a scenario with very high greenhouse gas emissions; SSP1-2.6 refers to a second SSP scenario with stringent mitigation of greenhouse gas emissions

Ensemble model			**MPI-ESM1-2-HR**		
Suitability Class Code	0	1	2	3	4
Unit of measure	km2	km2	km2	km2	km2
Current	541.931	75.980	51.823	40.995	69.201
2035/SSP126	519.006	95.720	59.747	53.830	51.628
2055/SSP126	528.669	91.864	59.959	50.407	49.030
2085/SSP126	529.417	88.102	56.803	55.183	50.425
2035/SSP585	530.440	89.367	51.339	47.647	61.137
2055/SSP585	528.669	91.864	59.959	50.407	49.030
2085/SSP585	570.710	90.028	53.238	39.575	26.380
Ensemble model			**MRI-ESM2-0**		
Suitability Class Code	0	1	2	3	4
2035/SSP126	541.931	75.980	51.823	42.198	37.893
2055/SSP126	566.086	83.490	43.055	41.170	46.115
2085/SSP126	580.578	77.902	44.607	36.656	40.187
2035/SSP585	552.292	91.606	54.877	42.460	38.692
2055/SSP585	595.871	76.174	40.994	40.029	26.863
2085/SSP585	662.493	56.426	36.934	18.684	5395

Total area: 779.932 km^2

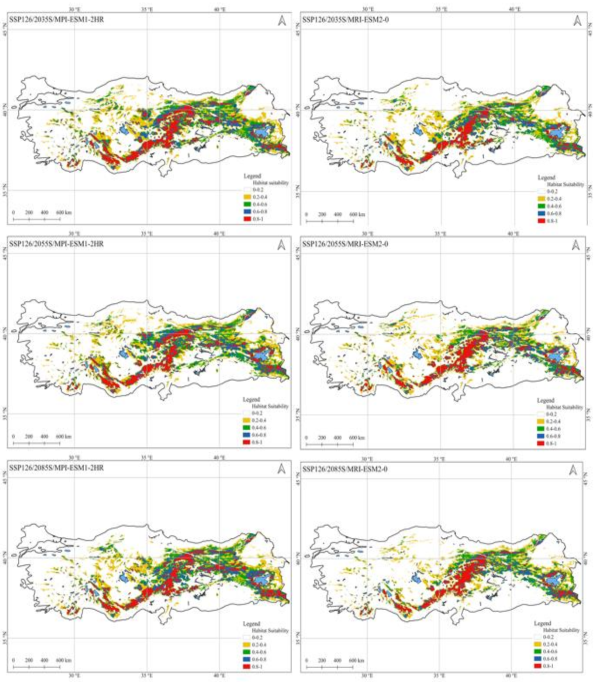

Figure 3. The predicted suitable habitats of *F. aurea* in 2035s, 2055s, and 2085s under the SSP5-8.5 scenario using the MPI-ESM1-2-HR and MRI-ESM2-0 GCMs derived from the ensemble model. White (0-0.2) represents unsuitability, yellow (0.2-.0.4) represents low suitability, green (0.4-0.6) represents medium suitability, blue (0.6-0.8) represents suitability, and red (0.8-1) represents high suitability.

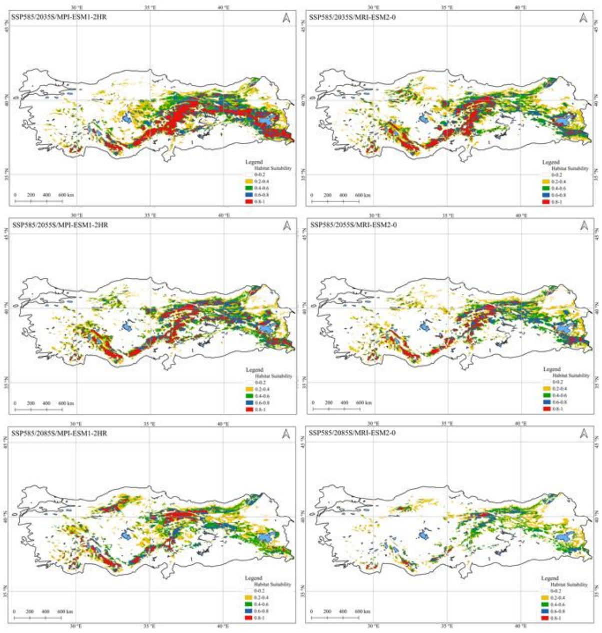

Figure 4. The predicted suitable habitats of *F. aurea* in 2035s, 2055s, and 2085s under the SSP5-8.5 scenario using the MPI-ESM1-2-HR and MRI-ESM2-0 GCMs derived from the ensemble model. White (0-0.2) represents unsuitability, yellow (0.2-.0.4) represents low suitability, green (0.4-0.6) represents medium suitability, blue (0.6-0.8) represents suitability, and red (0.8-1) represents high suitability.

studies. Besides this region, the ensemble model also predicted the south and east of Sivas province, the western Taurus Mountains, East of Van Lake, and high mountains in Hakkari province in southeasternmost of Anatolia as suitable habitats. Since the species grows at high altitudes (1000-3000 m a.s.l.), it is considered an alpine geophyte. The altitudes of the regions which are shown as potential distribution areas in the model are similar to the elevation of the current distribution areas. Therefore, we can state that similar climatic conditions and elevations prevail in these regions.

Seasonality and continentality are important factors in high altitude environments (Testolin et al., 2020). While seasonality comprises both temperature and precipitation (Lisovski et al., 2017), continentality is directly dependent upon annual monthly temperature-precipitation extremes (Deniz et al. 2011). The plants in alpine habitats adapted to extreme conditions such as cold temperatures and a short growing season. Therefore, the plants in these habitats are easily affected by seasonal changes in precipitation and temperature caused by global warming (Hamid et al., 2020). Low temperatures and precipitation are usual conditions during the whole year for the temperate high-altitude zone and the intensity of reduction in both these low temperatures and in precipitation tends to increase considerably with elevation (Billings and Mooney, 1968). The distribution range of our species is mostly determined by the lowest temperature during the coldest month (bio6), the amount of precipitation during the warmest quarter (bio18), and the average temperature during the wettest quarter (bio8).

Due to their adaptation to lower temperature regimes, the plants in alpine habitats are considered to be highly sensitive to global warming (Singh, 2008). In particular, it is estimated that endemic species of perennial plant, geophyte, and tree life forms will be adversely affected by climate change (Kobiv, 2017; Inouye, 2020). The plant species could respond to climate change usually contracting or shifting and expanding at best their distributions (Chen et al., 2011). Our study revealed the possible spatial changes in the suitable habitat of *F. aurea,* which is an alpine geophyte, under different future climate change scenarios. Accordingly, the potential highly suitable habitats of the species showed a downward tendency based on both two global climate model simulations, and further the potential distribution of the species were severe differences considering greenhouse gas emissions and radiative forcing level scenarios (SSPs). *Fritillaria aurea* would lose from one third to half of its potential distribution area under SSP1-2.6, whilst this ratio would be two out of three and even almost all under SSP5-8.5 until end of the century.

Narrow-ranging species usually grow in idiocratical habitats, and they are vulnerable to climate change (Da Silva et al., 2019). They will presumably encounter distribution shifts, and range restrictions or they will vanish due to limited ecological adaptability as a response to global warming (Dubos et al., 2022). Hereunder, *F. aurea* would contract a major part of its distribution to certain points that would mostly be mountainous habitats. These could be the transition zone between the Irano-Turanian and the Euxine regions and the subalpine zone of the central and western Taurus Mountains.

In conclusion, we predicted the potential distribution of *F. aurea* in the future by using various modeling algorithms and two global climate models under two different scenarios in our study. The minimum temperature of the coldest month (bio6), precipitation of the warmest quarter (bio18), and mean temperature of the wettest quarter (bio8) had the largest influence on *F. aurea* distribution. The large parts of the habitat of *F. aurea* were estimated to be lost by 2100 according to both climate scenarios. The distribution modeling of our species was created using only climatic parameters without including anthropogenic effects such as overgrazing, agriculture, and urbanization. It is a known fact that human activities have already generated negative effects on the distribution of species. When the negative impact of climate change joins with the pressure of human activities, the threat to the distribution of the species will increase further. Our results provide useful information to establish conservation strategies and determine the options for suitable areas in the future against the expected changes in the distribution of *F. aurea* which is an endemic species under changing climatic conditions.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors' Contributions

Nihal Kenar and Mehtap Tekşen conceived and designed research. The corresponding author analysed the data, wrote and edited the manuscript. Mehtap Tekşen provided data collection. Both authors read and approved the manuscript.

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