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Potential distribution mapping of *Orchis anatolica* (Boiss.) naturally distributed in Isparta province

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ABSTRACT **Research Article**

Background and aims This study focused on modeling the potential distribution of *Orchis anatolica*, a species belonging to the Orchidaceae family.
Methods As a result of field studies conducted between March and June from 2019 to 2022, presence data for this species were obtained from 30 sampling sites. Based on the collected data, the potential distribution of *Orchis anatolica*, which naturally occurs in the Isparta province, was modeled using the Maximum Entropy (MaxEnt) method. To determine the potential distribution, relationships between the presence data of the target species and 22 uncorrelated environmental variables including bioclimatic variables and base maps produced or digitized via geographic information systems were modeled and mapped using MaxEnt software.
Results According to the potential distribution model generated for *Orchis anatolica* (training dataset AUC: 0.974, test dataset AUC: 0.953), the environmental variables most influencing the species' distribution were identified as site index (bonitet), bio10, age class, bio12, and terrain ruggedness classes.
Conclusions This study investigated the relationships among the ecological characteristics, geographic distribution, and habitat features of *Orchis anatolica*, and produced a potential distribution map for the species in the Isparta region. It provides a valuable foundation for the conservation and sustainable use of *Orchis* diversity and genetic resources in Isparta province.

Key Words: Orchis, salep, MaxEnt, Isparta province

Isparta ili'nde doğal yayılış gösteren *Orchis anatolica* (Boiss.,)'nın potansiyel dağılım haritalaması

ÖZ

Giriş ve Hedefler Orchidaceae familyasına ait *Orchis anatolica*'nın orkide türünün potansiyel dağılım haritalaması incelenmiştir.
Yöntemler 2019-2022 yılları Mart-Haziran ayları arasında gerçekleştirilen arazi çalışması sonucunda sahada bu türe ait 30 örnek alanda var verisi elde edilmiştir. Elde edilen veriler doğrultusunda Isparta İli içinde doğal yayılış yapan *Orchis anatolica*'nın Maksimum Entropi Yöntemi ile potansiyel dağılım haritalamasını yapılmıştır. Potansiyel dağılım haritalaması belirlemek için ise Bio iklim değişkenleri, coğrafi bilgi sistemleri kullanılarak üretilen veya sayısallaştırılan altlık haritalar olmak üzere toplamda birbiriyle korelasyon göstermeyen 22 çevresel değişken ile hedef türe ait var verileri arasındaki ilişkiler MaxEnt yazılımı ile modellenmiş ve haritalanmıştır.
Bulgular Orchis anatolica için elde edilen potansiyel dağılım haritalamasına göre (eğitim veri seti AUC: 0,974, test veri seti AUC: 0,953) türünün dağılımını etkileyen çevresel değişkenlerin bonitet, bio10, yaş sınıf, bio12, engebelilik sınıfları olduğu belirlenmiştir.
Sonuçlar Orchis anatolica'nın ekolojik özellikleri, coğrafi dağılımları ve habitat özellikleri arasındaki ilişkileri araştırmış ve Isparta bölgesi için türlerin potansiyel dağılım haritasını oluşturmuştur. Isparta ilindeki Orchis çeşitliliğinin ve genetik kaynaklarının korunması ve sürdürülebilir kullanımı için değerli bir temel sağlamaktadır.

Anahtar Kelimeler: Orchis, salep, MaxEnt, Isparta ili

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1. Introduction

Approximately 12,000 plant taxa naturally grow in Turkey. The Orchidaceae family holds an important place within this diversity. This family comprises 26 genera and 234 taxa (Güner et al., 2022). Within the Orchidaceae family, the *Orchis* L. genus is a significant genus with its 49 taxa. Many orchid species growing in our country, especially those belonging to the genera *Orchis*, *Ophrys*, *Serapias*, *Platanthera*, *Anacamptis*, and *Dactylorhiza*, are collected from nature. Approximately 30 million individuals are uprooted from nature every year (Sezik, 2002). This orchid richness is at a considerable level, highlighting the need to value these resources and protect their sensitivity (Erdem, 2004).

O. anatolica L. is one of the terrestrial species of the *Orchis* genus within the Orchidaceae family. It naturally grows in pine and maquis forests, generally from the South Aegean Islands to Iran, particularly in some regions of Anatolia. Salep is obtained by drying the tubers of *O. anatolica*. It has been used as a powder or a traditional hot beverage with a pleasant taste since the Ottoman Empire period (Georgiadis et al., 2012; Hossain, 2011; Tamer et al., 2006).

Salep is obtained from 25 orchid species belonging to 9 genera found in Turkey (Kasparek et al., 1999; Sezik and Özer, 1983; Sezik and Baykal, 1991). The tubers of *Anacamptis pyramidalis*, *Dactylorhiza romana*, *Dactylorhiza osmanica* var. *osmanica*, *Himantoglossum affine*, *Ophrys fusca*, *Ophrys holosericea*, *Ophrys mammosa*, *Orchis anatolica*, *Orchis coriophora*, *Orchis italica*, *Orchis mascula* subsp. *pinetorum*, *Orchis morio*, *Orchis palustris*, *Orchis simia*, *Orchis spitzelii*, *Orchis tridentata*, and *Serapias vomeracea* subsp. *orientalis* are generally used in salep production (Sezik, 1967; Sezik and Özer, 1983; Tekinşen and Güner, 2010).

Today, salep has a significant economic value due to its widespread consumption as a hot beverage and in ice cream. Commercial salep available in the market contains glucomannans (11-44%, the active ingredient), starch (8-19%), reducing sugars (2-3%), and proteinaceous substances (Sezik, 1967). It has been shown that high-quality salep can be obtained from the tubers of *O. italica*, *O. morio*, *O. anatolica*, *O. tridentata*, and *S. vomeracea* ssp. (Tekinşen and Güner, 2010).

Potential distribution mapping created with Geographic Information Systems (GIS) is used to create maps with land characteristics by utilizing species presence data (Phillips et al., 2004). There are many methods used in species potential distribution mapping. One of these methods is MaxEnt. MaxEnt is a software that models species distributions based only on species presence records (Elith, 2011). MaxEnt is used to estimate the suitability level for the entire area by using the factors affecting the species' distribution based on its presence in the area and the values in this area (Baldwin, 2009). Since this method is based on presence data, it yields more accurate results with less data (Hernandez et al., 2006; Wisz et al., 2008).

The MaxEnt method is used in many areas such as species conservation and the protection of species' habitats, determining the future potential distribution areas of endemic and endangered species, and identifying their potential distributions (Pearson et al., 2007; DeMatteo and Loiselle, 2008; Suarez-Seoane et al., 2008; Yost et al., 2008; Boubli and Lima, 2009; Rödder and Weinsheimer, 2009; Thorn et al., 2009; Hoenes and Bendner, 2010).

Orchis anatolica is highly sensitive to habitat destruction, climate change, and anthropogenic pressures due to its limited geographical distribution (Kreutz, 1998; Delforge, 2006). This necessitates the conservation of the species and the sustainable management of its natural habitats. Collecting original data on its distribution, ecological requirements, and the threats it faces will provide a valuable resource for researchers working in the fields of botany and ecology (Pedersen and Faurholdt, 2007; Çolak et al., 2020).

In this study, the potential distribution mapping of *Orchis anatolica*, which naturally occurs in Isparta Province, is aimed. Although there are many studies conducted on *Orchis anatolica*, there are not enough studies on its potential distribution mapping. It is thought that this type of study will contribute to other studies to be carried out.

2. Materials and Methods

2.1. Field of study

The study area was defined as the boundaries of Isparta Province (Figure 1). The study site is located between 30º 47″ 49′- 31º 20″ 42′ east longitudes and 37º 18″ 10′- 37º 43″ 48′ north latitudes. Isparta is located on the Western Taurus Mountains and a large part of it lies on carbonate rocks (Dayan et al., 1999). Situated on a tectonic terrain, Isparta is associated with the Alpine orogenic movements and exhibits both closed and open basins. It is surrounded by basins where Lakes Eğirdir, Beyşehir, and Burdur are located. The city center of Isparta is established on a plain and is surrounded by hills. 70% of Isparta is mountainous, while 30% consists of plains and plateaus (Akten, 2008). Its highest mountain is Mount Davraz (Sargın, 2004). According to the statistics published by the General Directorate of Meteorology, covering data from 1929 to 2019, the annual average temperature is 12.2°C, the lowest temperature is -21°C in February, and the highest temperature is 41.2°C in August. The annual total precipitation is 570.2°C, the average number of rainy days is 99.3, the total sunshine duration is 85 hours, the average lowest temperature is-1.9°C in January, and the average highest temperature is 30.5°C in August (MGM, 2021).

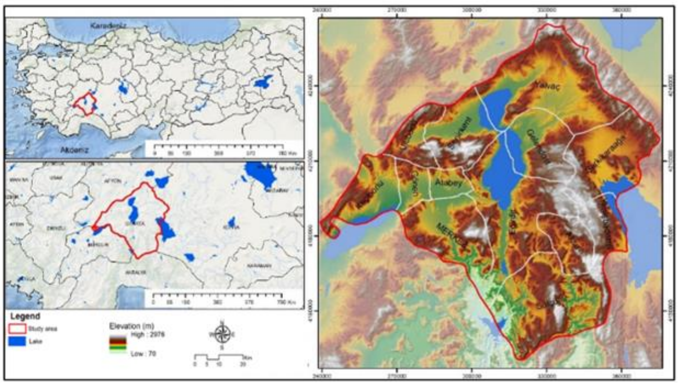

Figure 1. Location of the study area (Isparta Province)

2.2. Field studies

During field surveys conducted from 2019 to 2022, 132 representative 100×100 m plots were established across the study area. Presence/absence data of Orchid was recorded at 10 m intervals along a 100 m transect within each plot (10 subsamples). Species identifications, date, time, Global Position System (GPS) coordinates, and habitat characteristics were recorded on field inventory data.

2.3. Method

Field studies were completed, digital base maps of environmental variables were created to model O. anatolica and to determine potential distribution areas and maps. Elevation, aspect, slope, landform index, radiation index, topographic position index, heat index and directional suitability index maps of the region were created. Bioclimatic maps providing information about the climate of the study area were downloaded from the Chelsea Climate database (https://chelsa-climate.org/) (Riley et al., 1999; Gallant, 2000; Evans et al., 2014).

During the modeling process of the potential distribution areas of the species in the study area, abbreviation codes were assigned to 22 environmental variables and 19 climatic variables included in the study and recorded in digital format (Table 1).

In the statistical analysis phase, Pearson's distribution analysis can be taught among the aggressive variables and factor analysis among the climate variables to prevent multiple returns during the interval. As a result of Pearson's analysis analysis, variables with high distribution were removed and representative variables were selected for the removed variables.

In addition, through factor analysis of climate variables with high correlation, representative variables that could effectively represent all climate data were selected (Kano and Harada, 2000; Alin, 2010). In the modeling phase, the maximum entropy approach, also known as the Maxent method, was used.

During the modeling, the maximum entropy approach, also known as the Maxent method, was used. The working principle of this method, which uses var data, aims to determine the ecological demands of the species and determine the areas that are suitable and unsuitable for the species.

The MaxEnt method is a widely used method for species distribution modeling. It can provide better results with less variance data than other methods and gives high prediction accuracy (Obiakara et al., 2020; Özdemir et al., 2020; Hussein and Workeneh, 2021; Karakaya and Yücel, 2021).

3. Results

High correlation is observed between bioclimatic values and environmental variables, leading to multicollinearity (Şentürk, 2012; Süel, 2014). To eliminate this multicollinearity problem, Pearson Correlation Analysis (R^2 <0.85) and Factor Analysis were performed among 41 variables. As a result of the analysis, representative variables were selected, and the modeling stage was initiated.

Based on Pearson Correlation Analysis (R^2 <0.85) and Factor Analysis of environmental variables, a subset of 25 variables was chosen for subsequent modeling. These variables include bioclimatic variables Bio7, Bio12, and Bio10; solar variables 8am and noon; land surface form index; temperature index; slope (radians); slope (degrees); canopy cover; site index; bedrock; aspect; elevation; age class; aspect suitability index; solar radiation index; temperature; topographic position index (at scales of 3, 33, and 100); and terrain ruggedness index (at scales of 7, 31, and 21).

The resulting potential distribution model yielded an AUC of 0.974 for the training dataset and 0.953 for the test dataset (Figure 2). These AUC values suggest that the model demonstrates excellent predictive ability (Elith et al., 2006). Analysis of the ROC curves revealed no significant deviation in the average omission rate.

Table 1. Environmental variables and their codes included in the modeling

Environmental variables	Code	Environmental variables	Code
Solar Irradiance Index at, 8 pm	Sii	Altitude (m)	Altitude
Solar Irradiance Index at, noon	Noon		
Aspect suitability index	bui2	Age class	Age class
Ruggedness index	Rugged_7	Topographic position Index	Tpi3
	Rugged_31		Tpi33
	Rugged_21		Tpi100
Canopy Cover	Cc	Bedrock	Bedrock
Hillshade index	Hillshade	Aspect	Aspect
Heat (Bear)	Heat	Heat index	Si
Slope radian	slope_rdyn	Site index	Site index
Slope degree	Slope	Land position index	Lpi_5
Annual mean temperature	Bio1	Mean temperature of the coldest quarter	Bio11
Mean diurnal range	Bio2	Annual precipitation	Bio12
Isothermality	Bio3	Precipitation of the wettest month	Bio13
Temperature seasonality	Bio4	Precipitation of the driest month	Bio14
Max temperature of warmest month	Bio5	Precipitation seasonality	Bio15
Min temperature of coldest month	Bio6	Precipitation of the wettest quarter	Bio16
Temperature annual range	Bio7	Precipitation of the driest quarter	Bio17
Mean temperature of the wettest quarter	Bio8	Precipitation of the warmest quarter	Bio18
Mean temperature of the driest quarter	Bio9	Precipitation of the coldest quarter	Bio19
Mean temperature of the warmest quarter	Bio10		

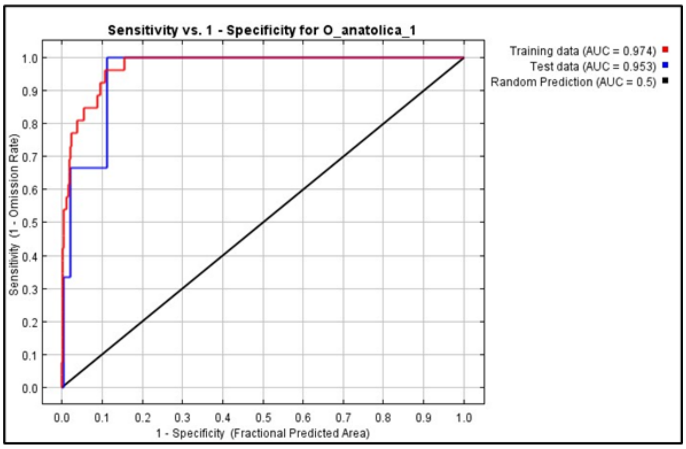

Figure 2. Evaluation of the *Orchis anatolica* potential distribution model's performance

O. anatolica, is influenced by the following contributing variables: site index, Bio10, age class, Bio12, and terrain ruggedness class (Figure 3).

Figure 3. Jackknife statistics plot for *O.anatolica*

Site index (forest stand productivity) had the greatest influence on the potential species distribution of *O. anatolica*. The species was found to have a higher probability of presence in areas with site indices ranging between I (highest productivity) and II (high productivity). Bio10 (Mean Temperature of Warmest Quarter) was the second most influential predictor variable for the potential distribution of *O. anatolica*. The species showed a higher probability of presence in areas with a mean temperature of the warmest quarter ranging from 20-22°C and 24-26°C. Age class as the third most influential predictor variable for the potential distribution of *O. anatolica*. The species' occurrence was associated with areas of period lengths 71-80 (age class 8), 11-20 (age class 2), and 41-50 (age class 5), in descending order of influence; no significant association was found for other period lengths. Bio12 (Annual Precipitation) was the fourth most influential predictor variable for the potential distribution of *O. anatolica*. The species showed a high probability of presence in areas with approximately 580 mm of annual precipitation. Slope was the fifth most influential predictor variable for the potential distribution of *O. anatolica*. The species showed a preference for very steep slopes exceeding 45% (Figure 4).

A potential habitat distribution map for *Orchis anatolica* was developed based on five environmental predictors. The map shows areas of high probability of *Orchis anatolica* occurrence in red, and areas of low or no probability in blue (Figure 5).

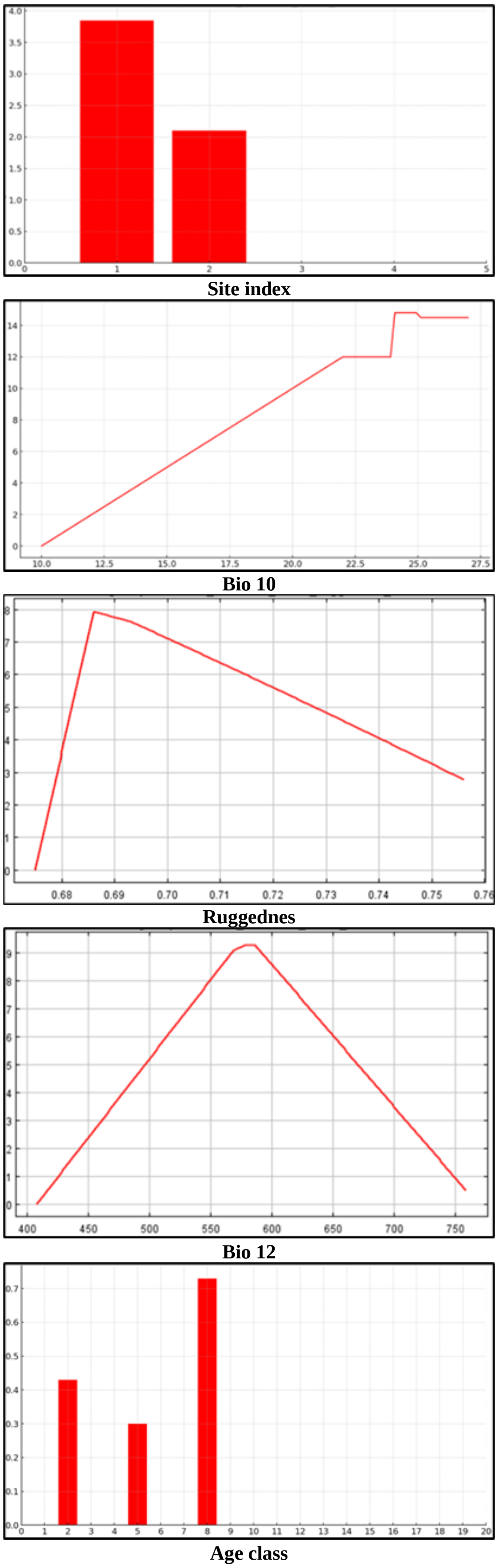

Figure 4. The marginal response curves of the variables that constitute the model for *O.anatolica*

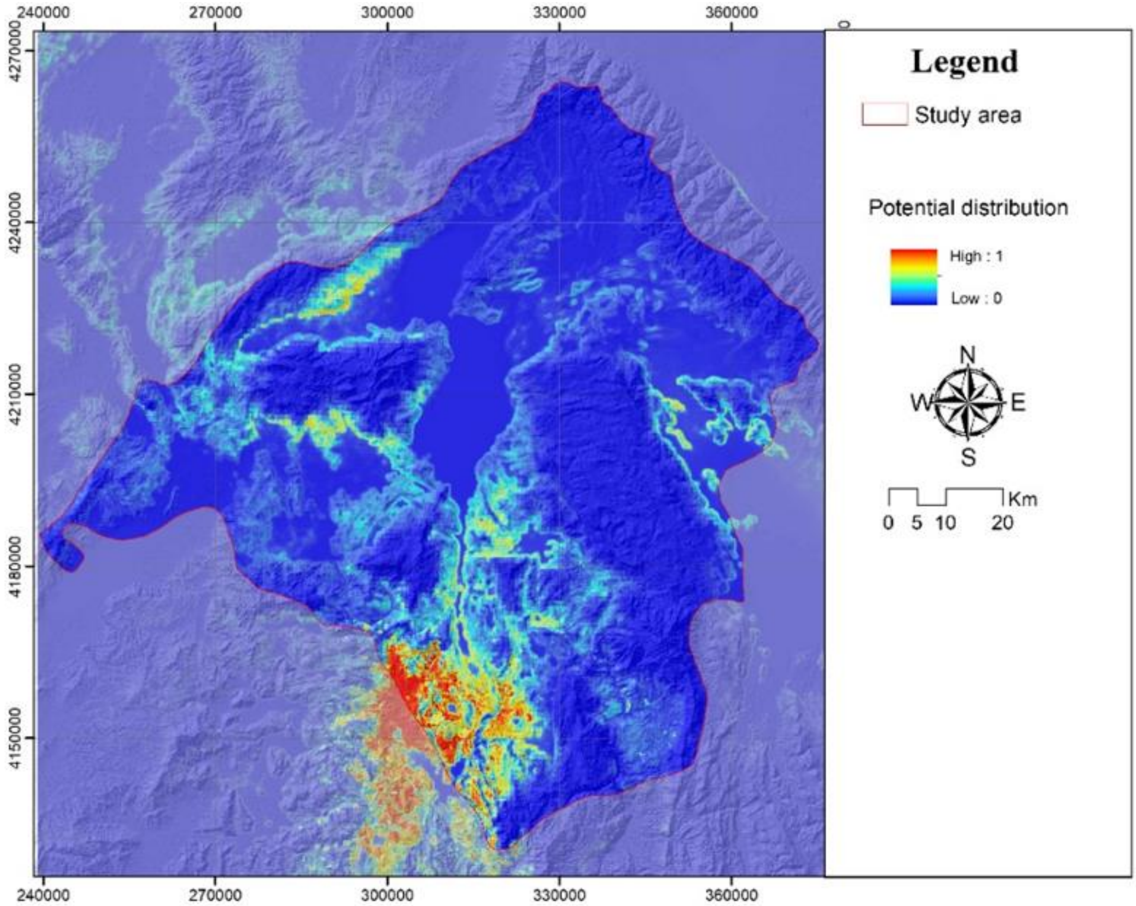

Figure 5. Species distribution model output for *O. anatolica*

4. Discussion and Conclusion

This study investigates the ecological characteristics (including soil properties, climatic factors, and vegetation composition), geographical distribution, and habitat features of *Orchis anatolica*, a species naturally distributed in the Isparta region. The primary objectives are to identify key ecological indicators influencing the species' potential distribution, develop a high-accuracy species distribution model, and generate a potential distribution map for *O. anatolica* in the study area. The Maximum Entropy (MaxEnt) algorithm was selected for species distribution modeling due to its well-documented performance with small sample sizes, its reliance on presence-only data, and its widespread use in biogeography and ecology.

Field surveys were conducted in the Isparta region, and data from 132 sampling locations were collected and formatted for statistical analysis. Digital layers representing ecological variables were generated using ArcGIS 10.2. Presence records of *Orchis anatolica*, the most widely distributed orchid species within the study area, were compiled and used for species distribution modeling and mapping. These field surveys revealed the presence of the Anatolian orchid (*O. anatolica*) at 30 of the 132 sampling locations.

The performance of the Maximum Entropy (MaxEnt) model, used to predict the distribution of the Anatolian orchid (*Orchis anatolica*) within the study area, was evaluated using Receiver Operating Characteristic (ROC) curves derived from training and testing datasets. Among three model iterations, the second sub-model (Training AUC: 0.974, Testing AUC: 0.953) exhibited the highest performance. The key environmental variables influencing the distribution of *O. anatolica* were identified as bonitation, Bio10 (Mean Temperature of Warmest Quarter), age class, Bio12 (Annual Precipitation), and ruggedness.

Site index emerged as the most influential variable in the potential species distribution model for Orchis anatolica. The model indicates a high probability of occurrence for this species in areas with stand yield capacities classified as first (highest yield capacity) and second (high yield capacity) bonitation classes. The second most influential variable was Bio10 (Mean Temperature of Warmest Quarter). The model suggests that *O. anatolica* is more likely to occur in areas where the mean temperature of the warmest quarter ranges between 20-22°C and 24-26°C. A study by Nigar (2021) also employed MaxEnt to model the potential distribution of another orchid species, *Ophrys apifera*, identifying correlations with the following bioclimatic variables: Bio2 (Mean Diurnal Range), Bio8 (Mean Temperature of Wettest Quarter), and Bio13 (Precipitation of Wettest Month). Their projections for 2030, under modelled climate change scenarios, suggest a decline in the distribution of *O. apifera.*

Age class was identified as the third most influential variable influencing the potential distribution of *Orchis anatolica*. The species' predicted occurrence was associated with areas corresponding to the 8th age class (71-80 year periods), the 2nd age class (11-20 year periods), and the 5th age class (41-50 year periods), respectively, with no significant association observed in areas belonging to other age classes. Bio12 (Annual

Precipitation) was the fourth most influential variable. The model suggests a higher probability of *O. anato*lica occurrence in areas with approximately 580 mm of annual precipitation. A review of the existing literature provided general information on the habitat requirements of *O. anatolica*; however, no previous studies were found that explicitly investigated the relationships between its distribution and bonitation, age class, mean temperature of the warmest quarter, or annual precipitation.

Ruggedness was identified as the fifth most influential variable affecting the potential distribution of *Orchis anatolica*. The model indicated a preference for very steep slopes exceeding 45%. These findings are consistent with previous studies reporting altitudinal limits for *O. anatolica* distribution: Altundağ et al. (2012) reported occurrences up to 1700 m, Tığlı and Fakir (2017) up to 1860 m, and Kayıkçı and Oğur (2012) up to 1600 m. Evans et al. (2020) also employed MaxEnt to model the potential distributions of *O. militaris*, *O. simia*, *O. purpurea*, and *O. thropphora*, finding that these species generally preferred areas with higher precipitation, with *O. militaris* showing a preference for cooler temperatures and *O. simia* for warmer temperatures and higher soil pH.

Çolak et al., (2020) examined the distribution of orchid species in Turkey and used MaxEnt software to model their potential habitats. Their research highlights the critical role of such models in identifying key areas for the conservation of geophyte plants. Similarly, Çolak and Yılmaz (2019) modelled the distribution of geophyte plants in Turkey using MaxEnt and assessed the impact of climate change on their potential future distributions. Their study emphasizes the importance of understanding climate change scenarios to inform future conservation strategies. Kreutz (1998) discussed the role of software like MaxEnt in modeling the habitats of orchid species in Turkey, contributing to a better understanding of the ecological requirements of geophytes. In conclusion, these studies underline the accuracy provided by MaxEnt in habitat modeling and its contribution to the development of effective conservation strategies for geophyte plants.

The environmental variables identified by the model are consistent with ecological data collected during field surveys, findings from previous scientific research, and information gathered through interviews with local villagers familiar with orchids in the Isparta region. This convergence of evidence underscores the significance of the predicted potential distribution of *Orchis anatolica*.

Studies on orchids clearly demonstrate their significant role in biodiversity. Orchids, constituting a vital part of Turkey's natural heritage, offer potential uses in various fields. However, ensuring their sustainability is challenging, and their distribution across the country is not yet fully documented. Unfortunately, the practice of harvesting orchids from the wild for commercial purposes remains a widespread issue in Turkey, and the consequent impacts on orchid populations are not fully understood.

The conservation of orchids is intrinsically linked to broader nature conservation efforts, and effective protection necessitates fundamental research. Biotope mapping, which identifies orchid distribution areas, habitat characteristics, and threats, is crucial for planning effective conservation measures. In Turkey, *Orchis* taxa are among the plant groups facing potential risks. These early-spring flowering species are particularly vulnerable to the intensifying effects of global climate change. A key step in *Orchis* conservation is the development of comprehensive inventories that document species distributions, population sizes, genetic diversity, and ecological requirements.

This study investigated the relationships between the ecological characteristics, geographic distribution, and habitat features of *Orchis* taxa, generating a potential distribution map for the species in the Isparta region. This work provides a valuable foundation for the conservation and sustainable utilization of *Orchis* diversity and genetic resources in Isparta province.

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