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Prediction of the Potential Spatial Distribution of the *Vitis vinifera* (Narince cv) Species Under Current and Future Climate Change Scenarios Using the MaxENT Model

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Abstract: The negative impacts of climate change, such as increasing competition among species, habitat loss, and spatial shifts, have a strong influence on species distribution areas. Species distribution models are an important tool for protecting species from the adverse effects of climate change and for conserving biodiversity. In this study, the spatial impact of climate change on the distribution of the Narince (*Vitis vinifera)* cultivar, which has a natural distribution in Turkey, was predicted using the MaxEnt model. To determine how the species' distribution areas would be affected by climate change, the HadGEM3-GC31-LL climate model, developed based on the principles of the Coupled Model Intercomparison Project Phase 6 (CMIP6), was used. The potential distribution of the Narince cultivar for the periods 2041–2060 and 2081–2100 was modeled under SSP 2.45 and SSP 5.85 scenarios. The results of the study show that the predicted current distribution area of Narince (*Vitis vinifera)* cultivar corresponds to its present geographic distribution. Under current climate conditions, suitable areas for the Narince cultivar are calculated as 21.837 km², highly suitable areas as 5.169 km², and the total suitable area as 27.006 km². For the future climate change scenarios, under the SSP 2.45 scenario, the total suitable areas are predicted to be 22,877 km² for the 2041–2060 period and 24,225 km² for the 2081–2100 period. Under the SSP 5.85 scenario, the total suitable areas are estimated to be 23.908 km² for the 2041–2060 period and 22.781 km² for the 2081–2100 period. According to our findings, it has been determined that the spatial distribution of the species will change under future climate change scenarios, and its distribution in Turkey is expected to decrease.

Keywords: MaxEnt, Species Distribution Modeling, Climate Change Scenarios, GIS

Mevcut ve Gelecekteki İklim Değişikliği Senaryoları Altında *Vitis vinifera* (Narince cv) Türlerinin Potansiyel Mekansal Dağılımının MaxENT Modeli Kullanılarak Tahmini

Öz: İklim değişikliğinin türler üzerindeki rekabeti artırma, yaşam alanı kaybı ve mekânsal değişikliği gibi olumsuz etkileri, türlerin dağılım alanları üzerinde güçlü bir etkiye sahiptir. Türleri iklim değişikliğinin olumsuz etkilerinden korumada ve biyolojik çeşitliliğin korunmasında tür dağılım modelleri önemli bir araçtır. Çalışmada Türkiye'de doğal yayılış alanı gösteren Narince üzüm (*Vitis vinifera*) çeşidinin iklim değişikliğinden mekânsal olarak nasıl etkileneceği MaxEnt model ile tahmin edilmiştir. Türün yayılış alanlarının iklim değişiminden nasıl etkileneceğini belirlemek için Birleştirilmiş Model Karşılaştırma Projesi Aşama 6 (CMIP6) ilkelerine göre geliştirilen HadGEM3-GC31-LL iklim modelinin SSP 2.45 ve SSP 5.85 senaryolarına göre türün 2041-2060 ve 2081–2100 yıllarındaki potansiyel yayılış alanı modellenmiştir. Çalışma sonucunda Narince çeşidinin (*Vitis vinifera)* günümüz tahmini yayılış alanı mevcut coğrafi dağılımı ile uyuşmaktadır. Günümüz iklim koşullarında çeşide uygun alanlar 21.837km^2, çok uygun alanlar 5.169 km^2 ve toplam uygun alan 27.006 km^2 olarak hesaplanmıştır. Gelecek iklim değişikliği senaryolarından SSP2.45 senaryosunda 2041-2060 yılları arasında toplam uygun alanların 22.877km^2, 2081-2100 yılları arasında 24.225km^2 olacağı tahmin edilmektedir. SSP 5.85 senaryosunda 2041-2060 yılları arasında toplam uygun alanların 23.908km^2, 2081-2100 yılları arasında 22.781 km^2 olacağı tahmin edilmektedir. Bu sonuçlarımıza göre gelecek iklim değişikliği senaryoları altında çeşidin mekânsal dağılışının değişeceği ve türün dağılımının Türkiye'de azalacağı tespit edilmiştir.

Anahtar Kelimeler: CBS, İklim Değişikliği Senaryoları, MaxEnt, Tür Dağılım Modelleme

1.Introduction

Biodiversity forms the foundation of life-support systems necessary for the continuation of life on Earth and humanity. Natural balances, food resources, industry, and economy are directly related to biodiversity. From this perspective, biodiversity is an important source of wealth and power for every country (Uyanık et al., 2012). The *Vitis vinifera* species plays a significant role in the ecosystem by supporting biodiversity (Cangi & Yağcı, 2017). It prevents soil erosion, provides habitat for insect and bird species, and supports biodiversity. In addition to its support for biodiversity, this species holds great value in Turkey due to its economic significance, genetic diversity, and potential health benefits. It can be utilized in various forms such as table grapes, raisins, verjuice, molasses, fruit leather, and vine leaves (Soltekin et al., 2021). These alternative uses contribute to the economy by supporting rural development (Uysal et al., 2021).

Ecological factors such as climate and geographical location have a direct impact on grape cultivation. Among the climatic characteristics, temperature is a critical parameter that determines whether viticulture can be practiced in a particular region (Daler et al., 2024). In addition to temperature, annual rainfall and its seasonal distribution are of critical importance for vine growth. High soil moisture during bud break, shoot, and flowering development, followed by dry and stable atmospheric conditions from flowering to fruit ripening, are essential factors for vine cultivation. Excessive rainfall can cause waterlogging in the grapes, and excessive humidity can negatively affect the plant in terms of disease and pests (Doğan & Uyak, 2021). Another climatic factor affecting viticulture is wind, particularly its intensity and direction. The most detrimental winds for viticulture are the spring winds coming from the north, which lower temperatures and cause breakage in young shoots. Additionally, the moist southern winds in spring can promote diseases. Strong winds near harvest time can also cause damage to grape berries, especially in table grape-growing regions, leading to product and quality loss (Ataş et al., 2021).

Climate change significantly impacts biodiversity by reshaping global ecosystems and species distributions, leading to ecosystem degradation, a decline in biodiversity, and species extinction (Biju Kumar & Kekeç & Kadıoğlu, 2020). These effects pose a significant threat to biodiversity (Gür, 2023). Monitoring the spatial distribution of species is crucial in combating climate change and conserving biodiversity (Miller, 2010). In this context, spatial modeling of the Narince grape cultivar is necessary for its conservation and to ensure sustainable grape production in Turkey.

MaxEnt is used in various fields such as species distribution modeling, spatial ecology studies, decision-making, and quantum mechanics (Elith et al., 2011). In the field of species distribution modeling, MaxEnt helps to understand the impact of climate change on the spatial distributions of species by using global climate model outputs as environmental predictors. Studies have proven that MaxEnt performs well in predicting training data and classifying out-of-bag data, making it a practical tool for handling imbalanced and biased data in species distribution models (Elith et al., 2011; Merow et al., 2013).

This study aims to highlight the role of *Vitis vinifera* (Narince cv) species in supporting biodiversity within ecosystems and its economic importance, while evaluating the potential effects of climate change on this significant species. Accordingly, the study seeks to model the impacts of climate change on the population dynamics and habitat suitability of *Vitis vinifera* (Narince cv) species with the goal of informing sustainable conservation strategies for the species.

2. Materials and Methods

2.1. Study area

The study area is defined as the natural distribution range of *Vitis vinifera* (Narince cv) species within Turkey's borders. Turkey, located between 36° 35′ and 42° 02′ north latitudes and 26° 04′ and 44° 07′ east longitudes, has a total area of 783.562 km². The average elevation of the study area is 1132 meters, which is higher than the average elevation of 700 meters of the Earth's landmasses. Elevation, aspect, and mountain structures in Turkey affect the distribution of precipitation, temperature, and relative humidity, leading to regional climatic variations (Atalay, 2017).

2.2. Spatial modeling

The study employed the Maximum Entropy Algorithm. The reliability of the model outputs was assessed using the AUC (Area Under the ROC Curve) value derived from ROC (Receiver Operating Characteristic) analysis (Phillips et al., 2006). The closer the AUC test value is to 1, the more sensitive and descriptive the model is (Akyol & Örücü, 2019). To determine the impact level of environmental variables, the Jackknife test was used. This method allows for the determination of the importance levels of each independent variable in model construction (Phillips et al., 2006).

2.3. Environmental variables and species occurrence data

Sample points for the Narince grape (*Vitis vinifera)* cultivar included in the MaxEnt model were downloaded from the GBIF (Global Biodiversity Information Facility) website (Figure 2). 70% of the sample points were randomly selected as training data, while the remaining 30% were used as test data. The aspect parameter included in the model was derived from the 12.5-meter resolution DEM (Digital Elevation

Model) data provided by the ALOS-PALSAR satellite, which includes elevation data. Organic Carbon and Clay maps were produced using data downloaded from the SoilGrids site. To predict the current distribution of the species, bioclimatic variables with a spatial resolution of 30 arc-seconds (~1 km) were downloaded from the WorldClim site and maps (Table 1) were generated using ArcGIS 10.5 software.

2.4. Climate model

To determine how climate change will affect the species' distribution areas, the HadGEM3-GC31-LL climate model, developed according to the principles of the Coupled Model Intercomparison Project Phase 6 (CMIP6), was used. Both the intermediate mitigation

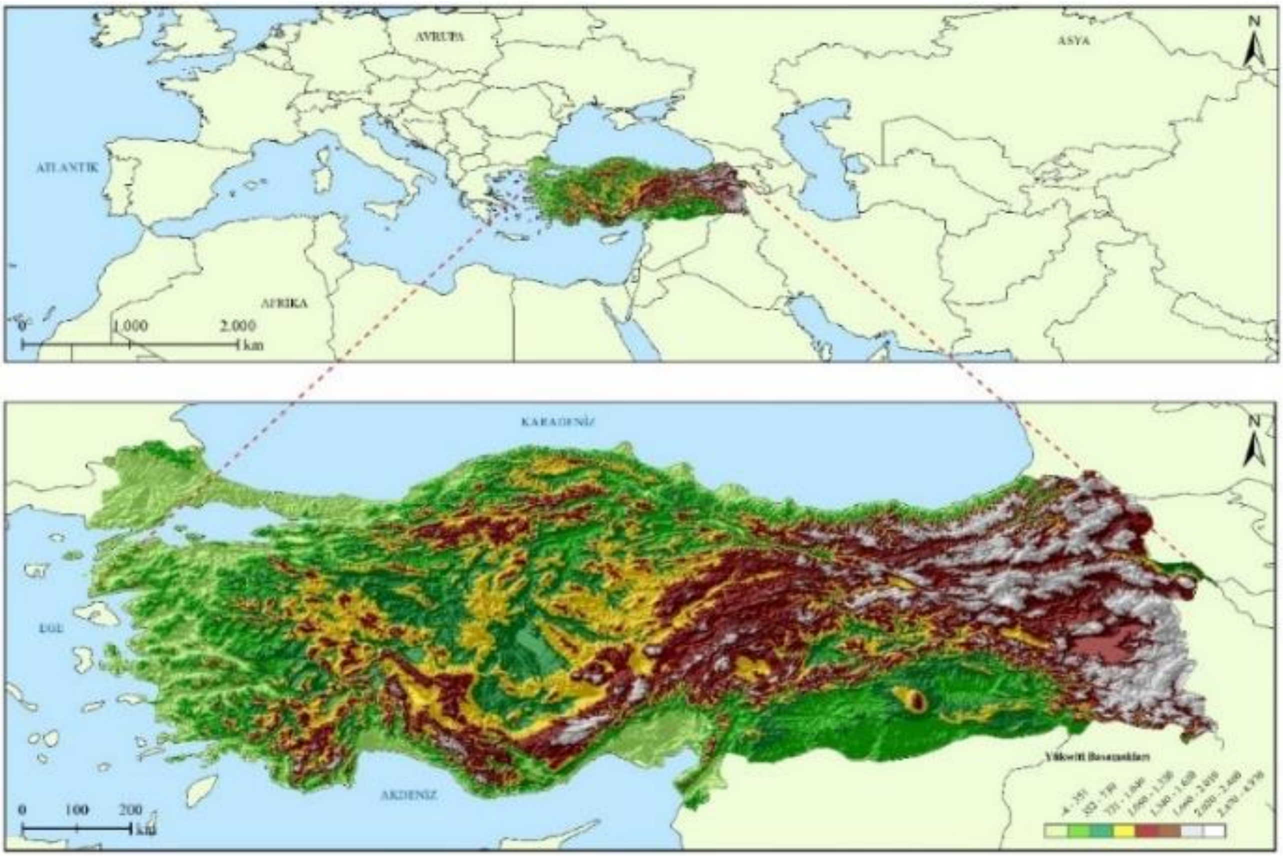

Figure 1. Location Map of the Study Area
Şekil 1. *Çalışma alanı haritası.*

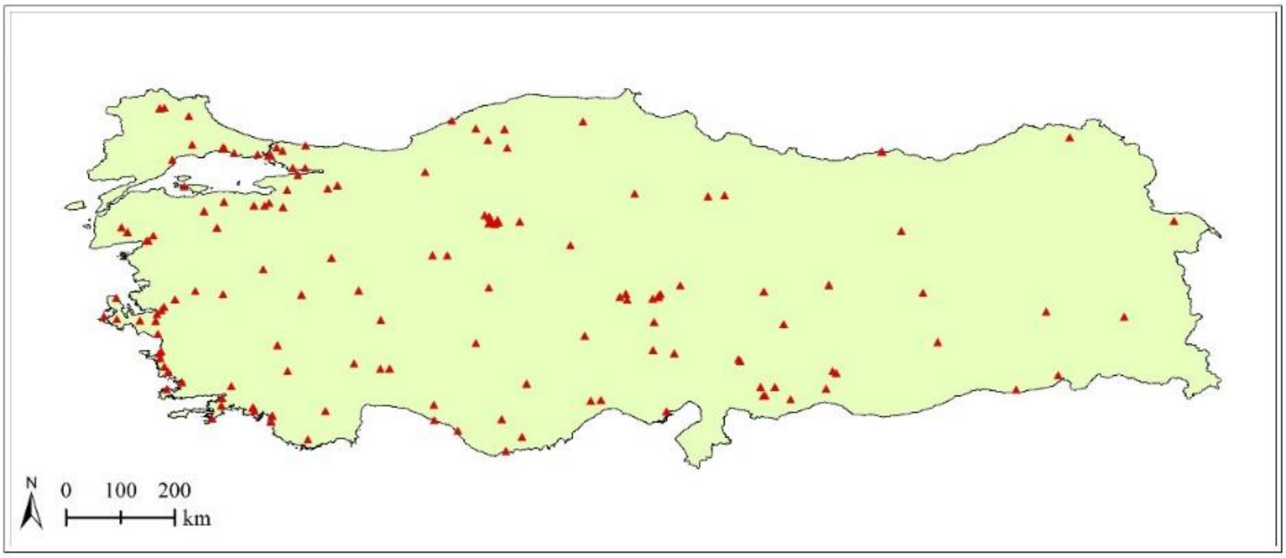

Figure 2. Species Distribution Points.
Şekil 2. *Türün noktasal dağılım haritası.*

Table 1: Environmental Variables Used in the Modeling.
Çizelge 1. *Modellemede kullanılan çevresel değişkenler.*

Code	Environmental Variable	Unit
Bio1	Annual mean temperature	°C
Bio2	Average of daily maximum and minimum temperatures	°C
Bio3	Isothermality (Equal temperature)	°C
Bio4	Seasonal temperature	°C
Bio5	Maximum temperature of the warmest month	°C
Bio6	Minimum temperature of the coldest month	°C
Bio7	Annual temperature range (Bio 5 – Bio 6)	°C
Bio8	Mean temperature of the wettest three months	°C
Bio9	Mean temperature of the driest three months	°C
Bio10	Mean temperature of the hottest three months	°C
Bio11	Mean temperature of the coldest three months	°C
Bio12	Annual precipitation	mm
Bio13	Precipitation of the wettest month	mm
Bio14	Precipitation of the driest month	mm
Bio15	Seasonal precipitation	mm
Bio16	Precipitation of the wettest three months	mm
Bio17	Precipitation of the driest three months	mm
Bio18	Precipitation of the hottest three months	mm
Bio19	Precipitation of the coldest three months	mm
Orgcar	Organic carbon	dg/kg
Clay	Clay content	percent
Aspect	Aspect	degree
cec	Cation exchange capacity	dg/kg
slope	Slope	degree
ph	pH watrer	pH*10
silt	Silt	degree

scenario (SSP 2-4.5) and the high mitigation scenario (SSP 5-8.5) were applied. Climate model data were downloaded from the WorldClim site in GeoTIFF format, processed using ArcGIS 10.5, and maps were generated.

3. Results and Discussion

3.1. Determination of the parameters to be used in the model

The presence of high multicollinearity among the parameters used in the MaxEnt model can lead to overfitting, thereby negatively affecting the accuracy of model predictions (Elith et al., 2011). To assess the multicollinearity between variables, Pearson correlation analysis was performed on the parameters listed in Table 1. According to Özcan (2024) and Esringü et al. (2021), parameters with a correlation value exceeding 0.70 contribute to multicollinearity. Consequently, variables such as bio 5, bio 6, bio 7, bio 13, bio 16, bio 17, bio 18, bio 19, cec, slope, pH, and silt were excluded from the model to prevent high variance inflation due to their significant multicollinearity.

The accuracy of the obtained model was evaluated using AUC assessment. According to this assessment, an AUC value of 0.50 indicates poor performance, an AUC value between 0.50 and 0.70 indicates average performance, and an AUC value above 0.70 indicates excellent performance (Li et al., 2024). In this context, the model's AUC value of 0.80 demonstrates good performance.

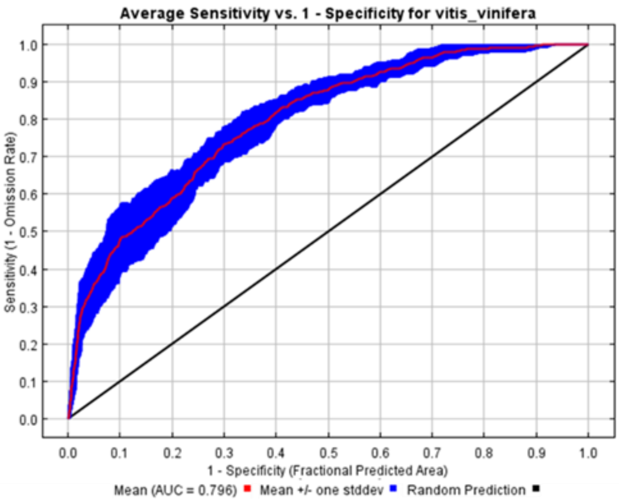

Figure 3. AUC Value Graph of the Model
Şekil 3. *Modelin AUC grafiği*

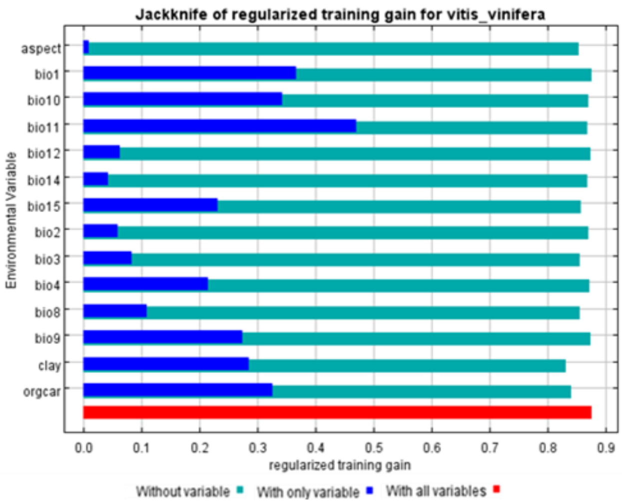

Figure 4. Jackknife Test Graph of the Model.
Şekil 4. *Modelin Jackknife Test Grafiği*

The Jackknife test is used to evaluate the effects of environmental variables on the model. It measures the contribution of each variable to the model (Li et al., 2024; Meena et al., 2024). The Jackknife test results for the Narince (*Vitis vinifera)* cultivar are presented in Figure 7. According to the graph, the parameter for the mean temperature of the coldest three months (bio11) is the environmental variable that provides the highest gain when used alone in the model. This is followed by Bio1, Bio10, and Organic Carbon. The environmental variable that most significantly reduces the gain when omitted is clay, suggesting it has the most unique information not provided by other variables. Zhang et al. (2021) used the MaxEnt model to analyze the distribution of grape species in Schuman by modeling their ranges between 1980 and 2019. According to the model results, the most suitable parameters for determining the potential distribution of grape species were, in order, accumulated active temperature, annual temperature, annual sunshine duration, and annual precipitation. These results align with our model outputs, where the annual precipitation parameter (bio1), which ranks second among the effective parameters in determining distribution, shows a notable similarity.

The response curves used to examine the importance of environmental variables are shown in Figure 5. Upon reviewing the response curves, it can be observed that parameters providing the most gain to the model include the Mean Temperature of the Coldest Three Months (bio11), the Mean Temperature of the Hottest Three Months (bio10), Seasonal Precipitation (bio15), Precipitation of the Driest Month (bio14), and the Mean Temperature of the Wettest Three Months (bio8). These parameters exhibit a positive relationship with the model. Conversely, Annual Mean Temperature (Bio1), Seasonal Temperature (bio4), Annual Precipitation (bio12), soil organic carbon, and clay parameters show a negative relationship with the model.

The MaxEnt model defines the probability of a species' presence within a given area using values ranging from 0 to 1 (Elith et al., 2011). In this study, threshold values for the spatial distribution of Narince (*Vitis vinifera)* cultivar were set as follows: 0-0.20 as unsuitable, 0.20-0.40 as not suitable, 0.40-0.60 as marginally suitable, 0.60-0.80 as suitable, and 0.80-1.0 as highly suitable. The map of the current potential spatial distribution areas of *Vitis vinifera* is shown in Figure 9.

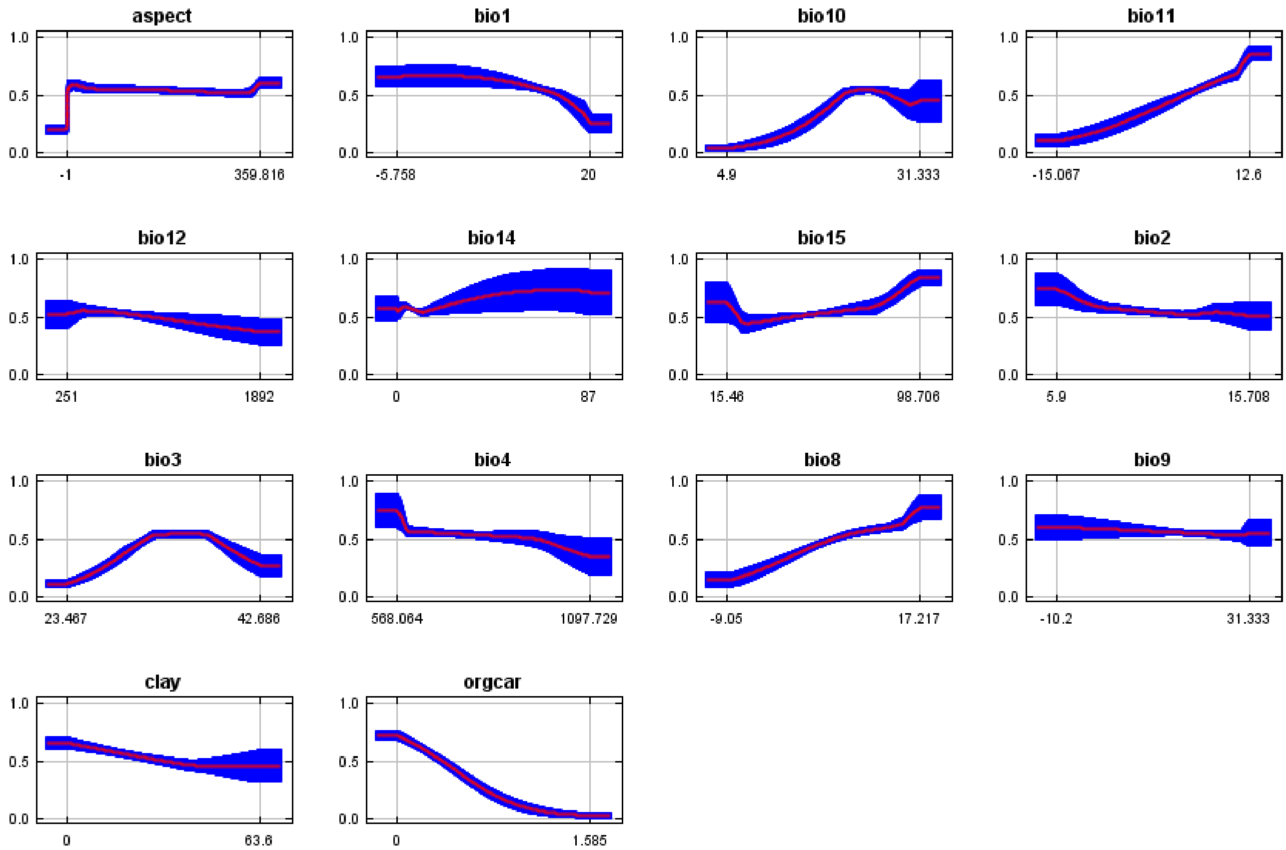

Figure 5. Response Curves of the Variables Included in the Model.
Şekil 5*. Modele Dahil Edilen Değişkenlerin Yanıt Eğrileri.*

The models created for Narince (*Vitis vinifera)* cultivar were converted to raster data in ArcGIS, threshold values were defined using the reclassify command, and area calculations were performed. The numerical data related to these calculated areas are provided in Table 2.

Table 2. Suitability levels of narince (*Vitis vinifera)* cultivar under different climate scenarios
Çizelge 2. *Narince (Vitis vinifera) çeşidinin farklı iklim senaryoları altında uygunluk düzeyleri*

Narince *(Vitis vinifera)* cultivar		SSP 2.45		SSP 5.85	
Suitability Level	**Current**	**2041- 2060**	**2081-2100**	**2041-2060**	**2081-2100**
Not Suitable	427.606	434.045	438.749	439.252	441.638
Unsuitable	246.424	248.154	243.092	234.367	231.110
Marginally Suitable	82.523	78.483	77.493	86.032	88.029
Suitable	21.837	16.735	17.406	18.687	17.203
Highly Suitable	5.169	6.142	6.819	5.221	5.578
Total (km^2)	783.562	783.562	783.562	783.562	783.562

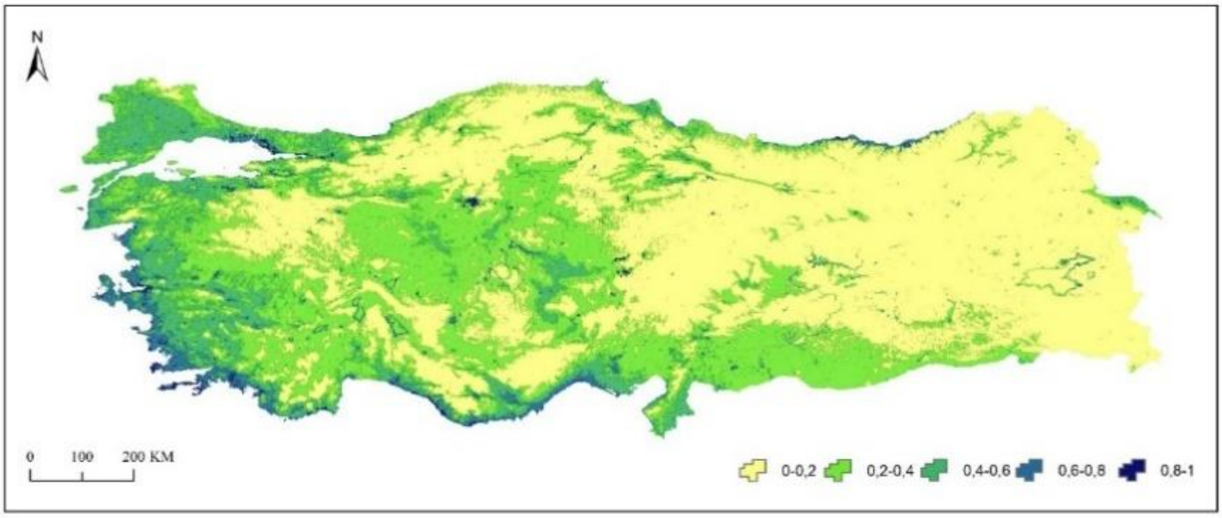

Figure 6. Predicted spatial distribution areas of *Vitis vinifera* (narince cv) species under current conditions.
Şekil 6. *Mevcut koşullar altında Vitis vinifera (narince çeşidi) türünün tahmin edilen mekansal dağılım alanları.*

Examining the map of the predicted spatial distribution areas under current conditions, it is observed that *Vitis vinifera* (Narince cv) species has very suitable growth conditions throughout the Aegean and Mediterranean coastal regions, the southern part of the Marmara Basin, the northern part of the Eastern Black Sea Basin, and the Tokat-Erbaa region. Suitable growing conditions are found in the Meriç, Susurluk, Gediz, and Büyük Menderes Basins. Conversely, the Aras, Çoruh, and Dicle Basins show conditions that are not suitable at all.

Climate change is having significant effects on ecosystems and biodiversity worldwide. In this context, understanding the future distribution and suitability changes for *Vitis Vinifera* (Narince cv) species is critical for assessing the impacts of climate change on agricultural production and biodiversity.

3.2. Potential spatial distribution under medium and high emission scenarios

Under the medium emission scenario, Narince (*Vitis vinifera)* cultivar maintains its density along the Mediterranean and Aegean coasts (Figure 7). These areas continue to provide suitable conditions for the species despite climate change. However, there are losses in marginally suitable areas in the Meriç, Marmara, Konya Closed, Sakarya, and Asi Basins. This can be attributed to microclimatic changes and reductions in water resources in these regions. In the southern part of the Dicle Basin, there is a shift from marginally suitable to suitable areas, indicating that the climate conditions in the region have become more favorable for the species. According to the numerical data in Table 2, the highly suitable areas increase from 5.169 km^2 to 6.142 km^2 between 2041-2060, while the suitable areas decrease from 21.837 km^2 to 16.735 km^2. This indicates an overall reduction in suitable areas despite an increase in highly suitable areas. In the period 2081-2100, highly suitable areas are projected to rise to 6.819 km^2, suitable areas to drop to 17.406 km^2, and unsuitable areas to increase to 438.749 km^2.

Under the high emission scenario, Narince (*Vitis vinifera)* cultivar continues to maintain its density along the Mediterranean and Aegean coasts. However, a transition from unsuitable to marginally suitable areas is observed in the Susurluk, Gediz, and Büyük Menderes Basins. This may indicate that the impacts of climate change are less severe in these regions, or that adaptation processes are occurring more rapidly. According to the numerical data in Table 2, highly suitable areas increase from 5,169 km² to 5.221 km² between 2041-2060, suitable areas decrease from 21.837 km² to 18.687 km², and unsuitable areas rise from 427.606 km² to 439.252 km². In the period 2081-2100, highly suitable areas are expected to increase to 5.578 km², suitable areas to decrease to 17.203 km², and unsuitable areas to rise to 441.638 km².

The results of this study highlight significant insights into how climate change may impact the spatial distribution of the Narince (*Vitis vinifera)* cultivar in Turkey. Using the MaxEnt model, we have projected potential changes in the habitat suitability of this key agricultural and biodiversity species under varying climate scenarios. The MaxEnt model demonstrated a reliable performance with an AUC value of 0.80, indicating that the model's predictions are robust and trustworthy. Jackknife analysis identified that the variable Average Temperature of the Coldest Three Months (Bio11) has the highest impact on the model, followed by Average Temperature of the Hottest Three Months (Bio10) and "Seasonal Precipitation (Bio15). These findings underscore the importance of temperature and precipitation variables in shaping the habitat suitability for Narince (*Vitis vinifera)* cultivar. Conversely, the "Clay" variable, when omitted, led to the most significant decrease in model performance, suggesting its critical role in the habitat modeling.

The current spatial distribution maps show that Narince cultivar thrives in the Aegean and Mediterranean coastal regions, southern Marmara Basin, northern Eastern Black Sea Basin, and Tokat-Erbaa region under present conditions. However, the impact of climate change scenarios (SSP 2.45 and SSP 5.85) reveals a troubling trend: potential suitable areas for Narince cultivar are expected to decline significantly in the future. Under the medium emission scenario (SSP 2.45), suitable areas are projected to decrease from 21.837 km² to 16,735 km² by 2041-2060, and further to 17.406 km² by 2081-2100 (Figure 7a, 7b). For the high emission scenario (SSP 5.85), suitable areas are expected to decrease from 21.837 km² to 18.687 km² by 2041-2060, and further to 17,203 km² by 2081-2100 (Figure 7c, 7d). These projections indicate a shift towards less suitable conditions for Narince cultivar in the future, with certain regions becoming less hospitable.

The decrease in suitable areas poses challenges for the sustainability of Narince (*Vitis vinifera)* cultivar cultivation and could affect the economic viability of grape production in Turkey. The results suggest that adapting agricultural practices and conservation strategies will be crucial to mitigate these impacts. Effective measures might include developing new cultivars resistant to climate stressors, optimizing water use, and enhancing soil management practices.

4. Conclusion

Species distribution modeling utilizes climatic and topographic factors to evaluate the impacts of climate change on species and potential spatial changes. It can also be employed to understand, interpret, and address the consequences of environmental changes on viticulture and biological diversity. Research indicates that climate change affects viticulture suitability and the distribution areas of the Narince cultivar by altering key determinants such as elevation, drought index, precipitation, and soil characteristics, potentially reducing the areas suitable for Narince cultivar cultivation.

In this study, the spatial impact of climate change on the Narince cultivar grapevine in Turkey was modeled using the MaxEnt algorithm. The results indicate that under the medium (SSP 2.45) and high (SSP 5.85) emissions scenarios of the Had-GEM climate model, the distribution areas of the Narince cultivar are projected to shrink between 2041-2060 and 2081-2100. This suggests a reduction in species diversity as one of the negative consequences of climate change.

When evaluating the ecological and economic aspects of the Narince cultivar, which is predicted to experience spatial loss under climate change scenarios, it is evident that negative impacts may arise in terms of biological diversity conservation, climate change mitigation, economic development, agricultural production, human health, and well-being. Currently, solutions to counteract these negative effects are insufficient. However, more research is needed to understand how we can mitigate the adverse effects of climate change on species spatial distributions. Therefore, more detailed studies on the interactions between climate change and species are necessary. Researchers and policymakers can use species distribution models to develop agricultural practices, conservation strategies, and land use plans that support the sustainability of grapevine cultivation. These efforts should address not only environmental impacts but also economic and social outcomes. Future research could facilitate spatial modeling efforts like this study and simplify the implementation of practices for conserving and sustaining biological diversity.

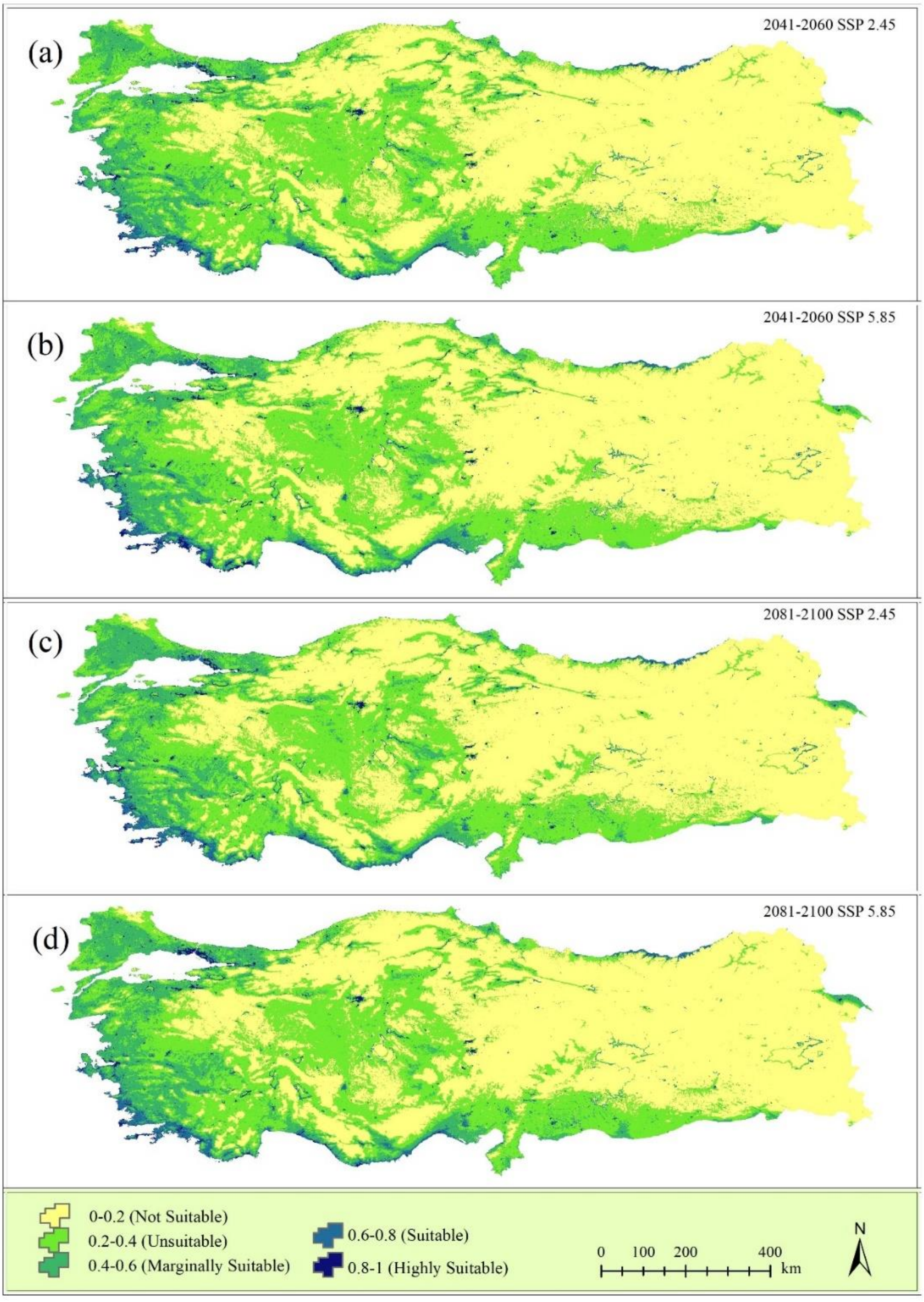

Figure 7: *Vitis vinifera* (Narince cv) Species Projected Spatial Distribution Under SSP 2.45 and SSP 5.85 Scenarios for the Years 2041-2060 and 2081-2100.

Şekil 7. *Vitis vinifera (Narince Çeşidi) türünün 2041-2060 ve 2081-2100 yılları için SSP 2.45 ve SSP 5.85 Senaryoları Altındaki Tahmin Edilen Mekansal Dağılımı.*

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