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Potential Distribution Modeling of Wild Olive (*Olea europaea* L. subsp. *europaea*) and Sage (*Salvia tomentosa* Mill.) in the Babadağ (Fethiye) Region

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Abstract: In today's world, non-timber forest products have gained increasing importance and are widely used in various fields such as medicine, pharmaceuticals, industry, food, cosmetics, and perfumery. Based on this, the aim of this study was to conduct species distribution modeling and produce potential distribution maps for two commercially important non-timber forest products in the Fethiye-Babadağ region. Firstly, field surveys were conducted to record presence data for the species. Digital maps for the environmental variables used in the modeling process were then generated. Climatic variables used in the modeling process were obtained from the CHELSA database. The MaxEnt method, which only utilizes presence data, was preferred for the modeling process. The models obtained for the wild olive (*Olea europaea* L. subsp. *europaea*) species and the sage (*Salvia tomentosa* Mill.) species had AUC values of 0.868 and 0.875, respectively. Based on the obtained AUC values, the models were found to be valid for both species. Potential distribution maps were obtained for each species based on these models. The maps revealed that the potential areas for the wild olive species are the eastern, western, and southern slopes of Babadağ, as well as the southeastern regions of Belencik and Ballıca within the study area. The potential areas for the sage species were identified in the high-altitude regions of Babadağ and the surrounding high-altitude hills. It is believed that these maps can play an effective and practical role in planning activities related to these species.

Keywords: MaxEnt, Non-wood forest product, *Olea europaea, Salvia tomentosa,* Species distribution modeling

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1. INTRODUCTION

Türkiye, due to its geographical and specific location characteristics, has led to the formation of various climate types, primarily the Mediterranean climate. Wild olive, as a member of the natural vegetation within the Mediterranean climate, is part of the maquis community. Olive (*Olea europaea* L.) is considered a bioindicator characterizing this zone, as it exhibits excellent adaptation to the Mediterranean climate zone (Sağlıker and Darıcı, 2005).

The olive tree is a valuable plant that holds historical and cultural significance, featuring prominently in many legends and myths from ancient times to the present day. Through findings from history as well as contemporary research, its ecological worth has been repeatedly demonstrated. According to archaeological studies conducted on the island of Santorini in the Aegean Sea, the journey of the olive tree on Earth dates back 39,000 years (Polat and Tunalıoğlu, 2012). This journey continued approximately 12,000 years ago in the Eastern Mediterranean basin, where it was part of the natural vegetation, and around 6,000 years ago, it was cultivated in Anatolia. The olive tree, being a plant that yields oil from its fruit, was initially valued by ancient societies and later by civilizations such as the Phoenicians, Minoans, Semites, Egyptians, Hittites, Greeks, Romans, and Arabs, who commercially exploited it (Rodriguez, 1997).

Research studies have revealed that the leaves and bark of *O. europaea*, which symbolize meanings such as friendship, brotherhood, strength, and peace, are used in folk medicine for the treatment of various ailments. Infusions prepared from these leaves and bark have been traditionally used for conditions such as diuretic, blood pressure-lowering, appetite-stimulating, blood sugar-reducing, constipation relief, fever reduction, as well as for cleaning and dressing inflammatory wounds. Pharmacological studies have provided evidence supporting these traditional uses (Kosak and Stern, 1959; Somova et al., 2004).

Another species addressed in the study is the Sage (*Salvia tomentosa*). *S. tomentosa* is one of the non-timber forest products that is heavily traded in our country. It is a member of the Lamiaceae family, which has 97 different taxa in Türkiye, including 51 endemic species (Davis, 1982; Başer, 2002; İpek and Gürbüz, 2010). This species is characterized by its 5-10 mm-sized, lavender-colored flowers and is a perennial plant. It is distributed in elevations ranging from 0 to 2000 m in our country (Özdemir and Özkan, 2016).

It is known by different names such as Sage, Şalba, and Kırçayı in different regions. In folk medicine, this species has been used since ancient times for conditions such as indigestion, pharyngitis, laryngitis, tongue inflammation, gum inflammation, oral mucosa inflammation, and to increase milk production in lactating women. Due to its known benefits, the name "Salvia" was given to the sage species, inspired by the Latin word "Salveo," meaning "to heal, to save." According to some sources, it is mentioned that Hippocrates (460-357 BC) also used this plant in some treatments due to its contents during ancient times. Another notable piece of information is that during the Ottoman period, *Salvia* L. species were recommended by physicians to enhance people's memories (Tepe et al., 2005; Tel et al., 2010).

Like in all medicinal and aromatic plants that form the basis of modern medicine, the range of applications for *S. tomentosa* species has increased from ancient times to the present. In recent years, *S. tomentosa* has been consumed as a tea, prepared by steeping it in hot water and consumed on an empty stomach. The plant solution is used for the treatment of rheumatic conditions. In different regions, the plant is recommended for various ailments such as relieving abdominal pain, healing inflammatory wounds, alleviating cold symptoms, asthma, cough, and respiratory diseases (Erol and Tuzlacı, 1996; Sezik and Yeşilada, 2002). The inclusion of *S. tomentosa* species in the category of medicinal and aromatic plants, as well as its use in the treatment of certain diseases, can be attributed to its phenolic compounds, minerals, and volatile oils. Therefore, numerous studies have been conducted on this species regarding these aspects (Ulukanlı et al., 2013; Dinçer et al., 2013; Özkan et al., 2018; Özcan et al., 2019; Koçer and İstifli, 2022).

As evident from the information provided above, both the wild olive and the sage species have significant economic value in terms of the country's economy and among the general public. The reason for conducting this study in the Babadağ region is the lack of previous research on the distribution models of non-timber forest products.

2. MATERIAL AND METHOD

The study was conducted in Babadağ and its surrounding areas, located within the boundaries of Fethiye district in Muğla province, Türkiye. The study area, which was selected as the research site, covers an approximate area of 44,000 hectares (Figure 1). The reason why this area was chosen as the study area is that Babadağ is one of the 9 hot spots in Türkiye. The area is in a very important position with this feature. The dominant climate in the study area is clearly Mediterranean. It is observed that the region has hot and dry summers, while winters are mild and rainy. The number of days with temperatures below freezing is quite low in the area.

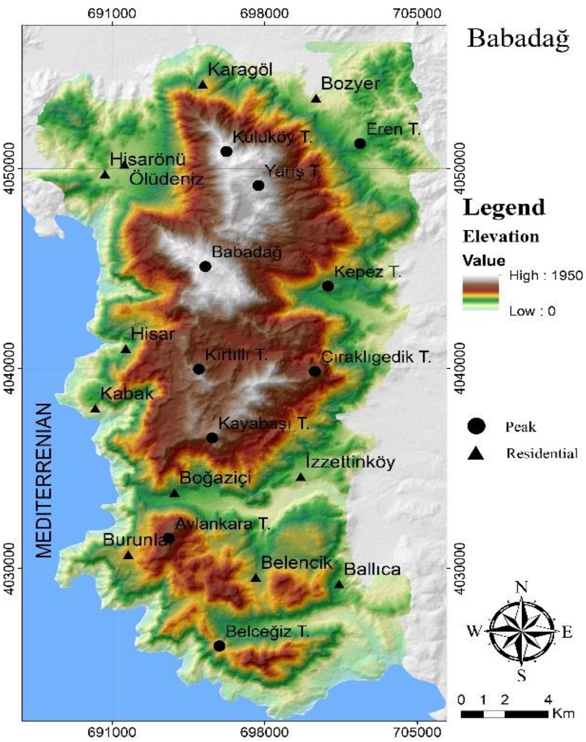

Figure 1. Location map of the study area.

During the field surveys, presence data of the two target species were recorded along with their coordinates. Following the completion of the fieldwork, digital layer of the environmental variables were generated for the species distribution modeling of the target species. Elevation, slope, heat index, radiation index, roughness index, ruggedness index, hillshade index, topographic position index, and canopy maps specific to the study area were obtained. In addition, climate variables for the research area were obtained from the Chelsa Climate database (Riley et al., 1999; Gallant, 2000; Evans et al., 2014). Finally, a bedrock map of the study area was obtained from the General Directorate of Mineral Research and Exploration (MTA), classified, and presented in Figure 2.

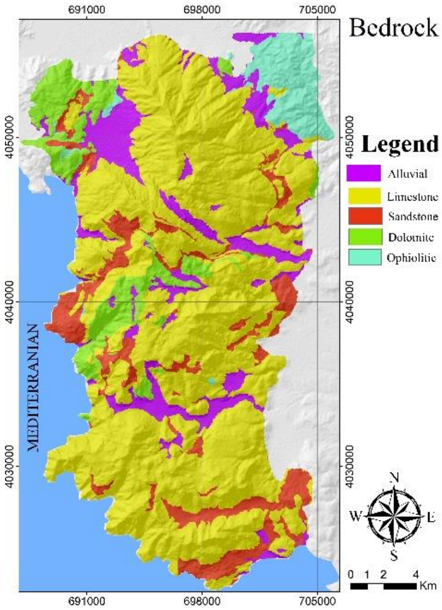

Figure 2. Bedrock map of the study area.

Therefore, following the completion of the fieldwork, digital thematic maps of the environmental variables were generated for the species distribution modeling of the target species, and they were transferred to digital format along with their abbreviation codes (Table 1).

Table 1. Abbreviations for environmental variables

Variable	Code	Variable	Code
Elevation	elvtn	Min temperature of coldest month	Bio6
Slope	slope	Temperature annual range	Bio7
Radiation index	radinx	Mean temperature of wettest quarter	Bio8
Bedrock	bdrck	Mean temperature of driest quarter	Bio9
Topographic position index	tpi	Mean temperature of warmest Quarter	Bio10
Heat index	heat	Mean temperature of coldest quarter	Bio11
Hillshade index	hillsh	Annual precipitation	Bio12
Roughness index	rough	Precipitation of wettest month	Bio13
Ruggedness index	rugged	Precipitation of driest month	Bio14
Stand canopy map	canop	Precipitation seasonality	Bio15
Annual mean temperature	Bio1	Precipitation of wettest quarter	Bio16
Mean diurnal range	Bio2	Precipitation of driest quarter	Bio17
Isothermality	Bio3	Precipitation of warmest quarter	Bio18
Temperature seasonality	Bio4	Precipitation of coldest quarter	Bio19
Max temperature of warmest month	Bio5		

During the statistical analysis stage, Pearson correlation analysis was initially applied among the environmental variables. This was done to address potential issues of multicollinearity that may arise during the modeling stage. Multicollinearity refers to the situation where independent variables exhibit high correlation among themselves, making it difficult to determine the true effects on the dependent variable (Alin, 2010). Based on the results of the Pearson correlation analysis, variables with high correlation were eliminated, and representative variables were identified for the eliminated ones. Similarly, through the factor analysis conducted among the climate variables, variables that could represent the entire set of climate data were chosen, considering their high correlation with each other.

In the modeling stage, the MaxEnt (Maximum Entropy) method, also known as the maximum entropy approach, was employed. This method operates solely based on presence data and aims to predict suitable and unsuitable areas for the target species by determining its ecological requirements. The MaxEnt method is widely preferred for species distribution modeling. The reasons for this preference include its ability to work with smaller sample sizes compared to other methods, its capability to produce better results with fewer presence data, and its high predictive accuracy (Obiakara et al., 2020; Özdemir et al., 2020; Hussein and Workeneh, 2021; Karakaya and Yücel, 2021).

3. RESULTS

As mentioned earlier in the study, a Pearson correlation analysis was conducted among the climate variables, and the results are presented in Figure 3.

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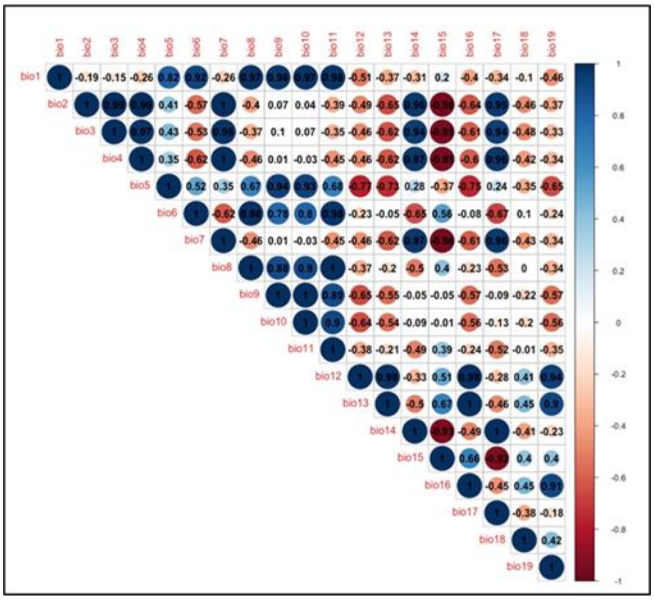

Figure 3. Correlation analysis results between climate variables

In the modeling stage, factor analysis was used to select representative variables among the bioclimatic variables in order to avoid multicollinearity issues affecting the models. Based on the results of the factor analysis, the variable bio1, which had the highest loading coefficient among the temperature variables, was selected as the representative variable. Similarly, the variable bio15, which had the highest loading coefficient among the precipitation variables, was chosen as the representative variable. After determining the representative climatic variables, separate correlation analyses were conducted for each species to select variables and proceed to species distribution modeling.

At this stage, Pearson correlation analysis was again applied to the environmental variables of the areas where wild olives were recorded. Variables with a correlation coefficient of p≥0.80 were eliminated. The Pearson correlation values among all variables are presented in Figure 4.

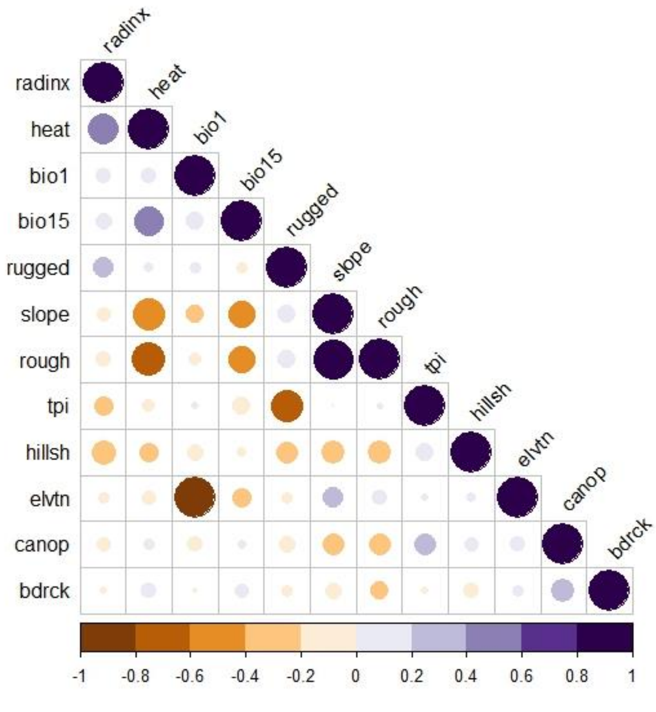

Figure 4. Pearson correlation analysis results of wild olives

Based on the analysis results, a correlation was found at the p≥0.80 level between bio1 and elevation, as well as between slope and roughness index. Therefore, the elevation and roughness index variables were not included in the model. Hence the comments that can be made with bio1 and slope variables will be more explainable (Tuğaç and Sefer, 2021; Tunalıoğlu and Gökçe, 2002). After conducting the modeling process with 10 independent variables, it was determined that 5 variables contributed to the model. When looking at the AUC (Area Under the Curve) values of the obtained model, the training AUC value was 0.868, and the test AUC value was 0.866. The Jackknife plot and marginal response curves of the variables that constitute this model are shown in Figure 5 and Figure 6, respectively.

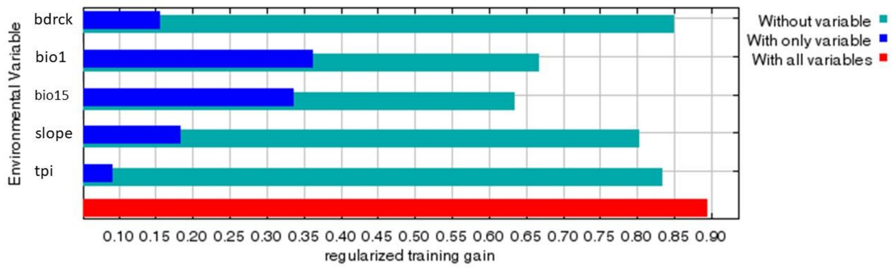

Figure 5. Jackknife test results for Variables of wild olive

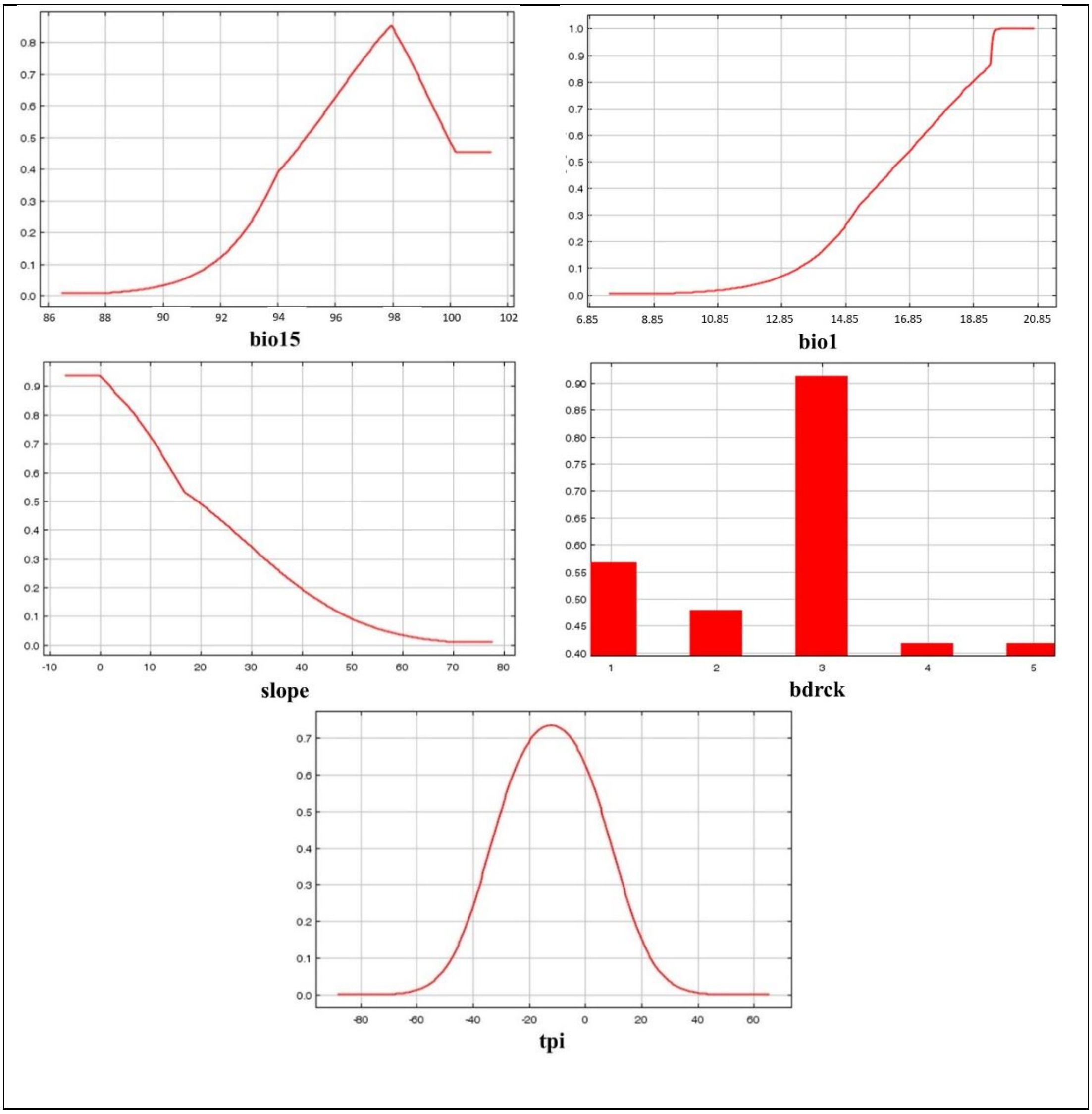

Figure 6. The marginal response curves of the variables that constitute the model for wild olive

According to the contribution ratios, the variables that shaped the model for the species were bio15, bio1, slope, parent material, and topographic position index, respectively. The potential distribution map of wild olive tree species in the study area was generated using the descriptive environmental variables obtained during the modeling process, and it is presented in Figure 7.

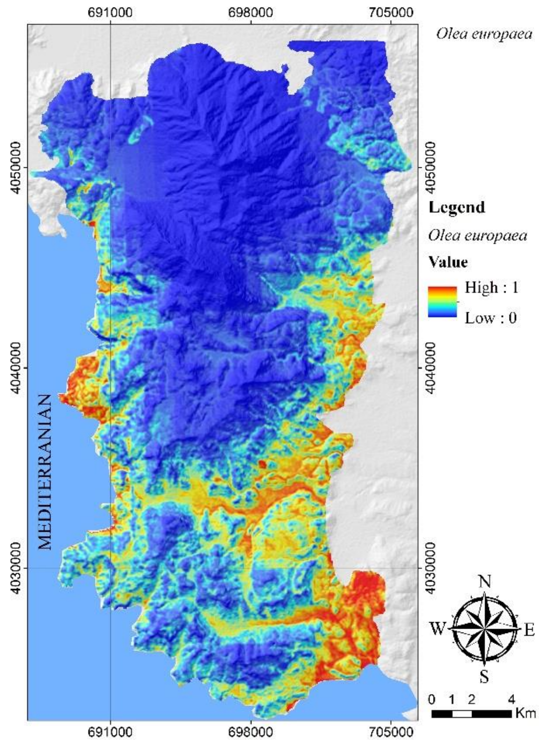

Figure 7. The potential distribution map for wild olive

When examining the potential distribution map of the species, it can be observed that the most suitable areas for the species are the eastern, western, and southern slopes of Babadağ, as well as the Belencik and Ballıca regions in the southeastern part of the study area.

Pearson correlation analysis was conducted among the environmental variables of the areas where S. tomentosa species was observed in the study area, and the results are presented in Figure 8.

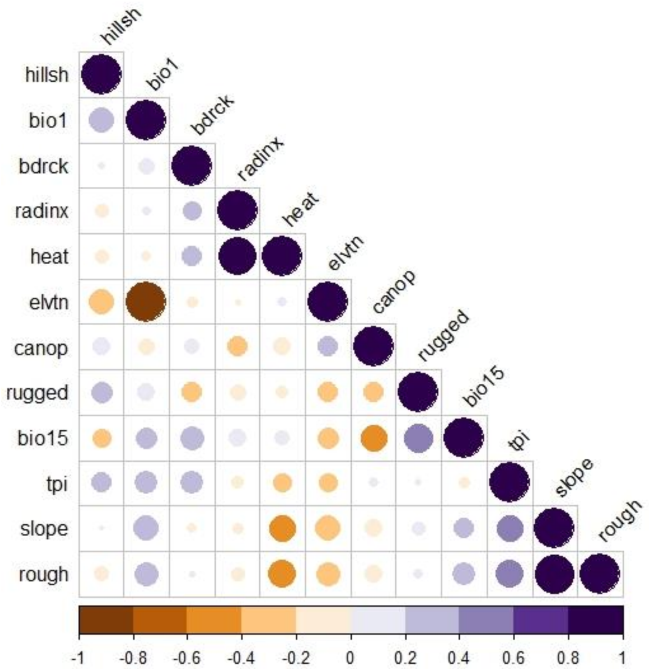

Figure 8. Pearson correlation analysis results of sage

When examining the results of the Pearson correlation analysis, a significant correlation ($p \geq 0.80$) was observed between bio1 and elevation, radiation index and heat index, as well as between slope and roughness index. Therefore, the variables bio1, heat index, and roughness index were not included in the modeling stage. Hence the comments that can be made with bio1 and slope variables will be more explainable (Özdemir and Özkan, 2016). The species distribution modeling was performed using 9 variables. After the modeling process, it was found that 5 variables contributed to the model. The training AUC value of the obtained model was 0.875, while the test AUC value was 0.812. The Jackknife plot and marginal response curves of the variables that constitute this model are shown in Figures 9 and 10, respectively.

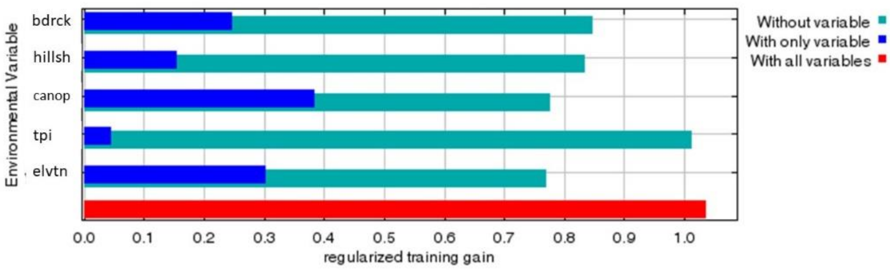

Figure 9. Jackknife test results for Variables of sage

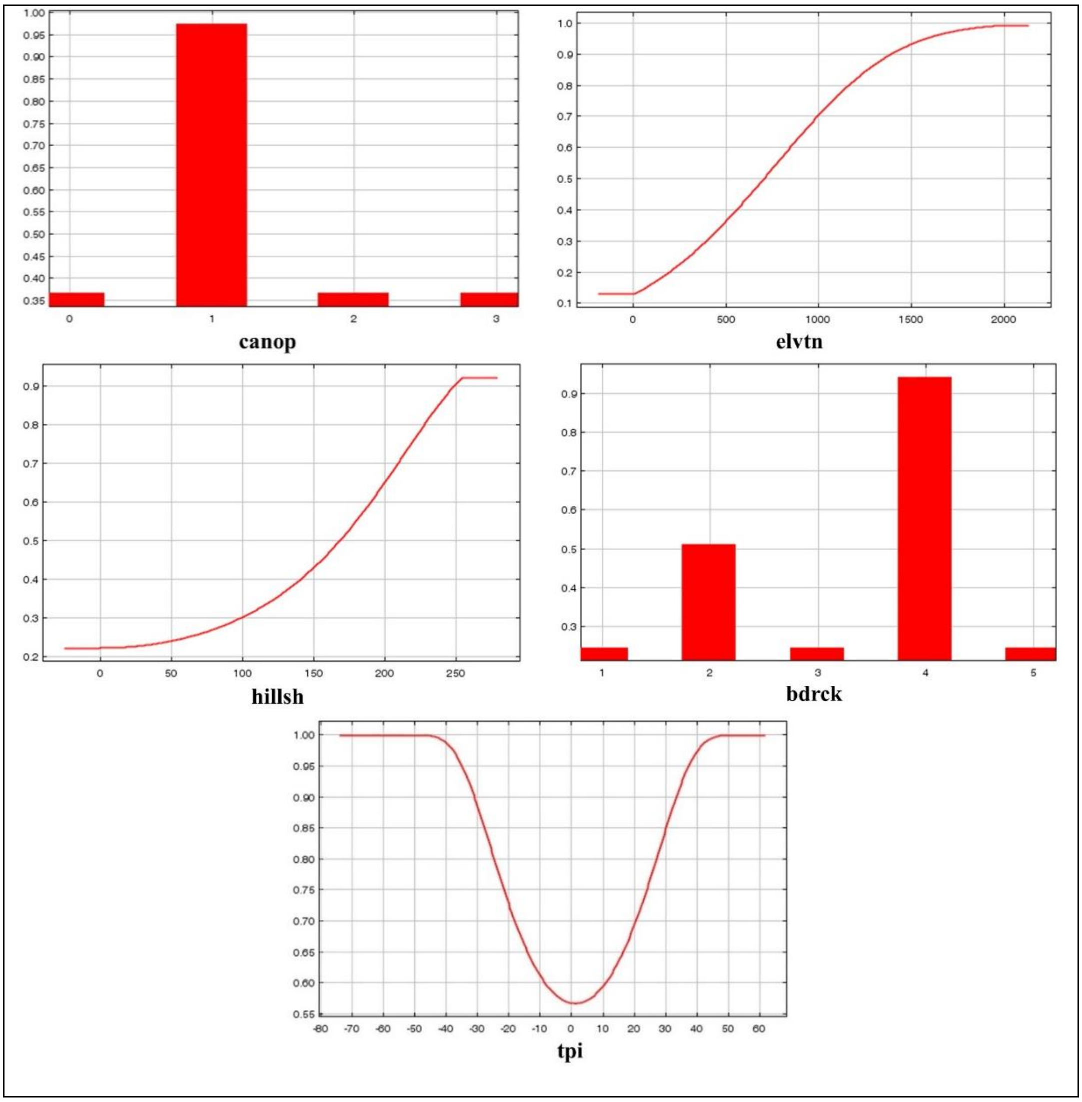

Figure 10. The marginal response curves of the variables that constitute the model for sage

According to the contribution rates, the variables that shaped the model for the species are ranked as follows: canopy, elevation, hillshade index, bedrock, and topographic position index. The potential distribution map for Sage was created using the descriptive environmental variables obtained during the modeling process and is presented in Figure 11.

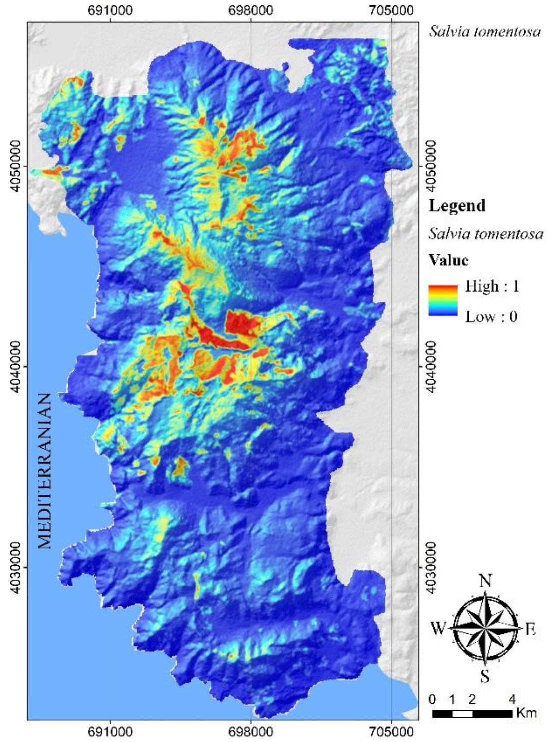

Figure 11. The potential distribution map for sage

Upon examining the potential distribution map of the species, it is determined that the potential areas for Sage within the study area are located in the high-altitude regions of Babadağ and the elevated hills in the surrounding area.

4. DISCUSSION AND CONCLUSIONS

There are numerous plant species that can be characterized as non-wood forest products and hold significant commercial importance in Türkiye. Wild olive and sage are among Türkiye's most commercially traded species, making them highly significant in trade. However, the intensive commercial pressure on these species has jeopardized their sustainable utilization and has led to an increased need for ecological studies. This situation highlights the importance of the obtained potential distribution models for wild olive and sage, particularly in the Babadağ region where they hold commercial significance. The models developed for these two species in this study were evaluated as "good" according to the performance classification proposed by Swets (1988).

The potential distribution modeling and map of the wild olive species were conducted as the first step in this study. The variable that contributed the most to the potential distribution of the species in the obtained model was bio15, which represents precipitation variability. It was observed that areas with seasonal precipitation variability exceeding 95% corresponded to the potential distribution of the species. Consequently, the potential distribution areas for the wild olive species were found to be located in the low-altitude regions which have low precipitation variability of the study area.

When examining the effect of the annual mean temperature variable (bio1) on the species, it was observed that the potential areas of the species were shaped within temperature values ranging from 15 to 20 °C. Similar studies representing almost the same growth environments have indicated that very low temperatures (below 0 °C) and extremely high temperatures (above 40 °C) have negative effects on olive plants (Efe et al., 2009). Another study determined that the optimal lower limit for the annual mean temperature for olive cultivation in Türkiye was 14.4 °C, while the upper limit was 19.2 °C (Tuğaç and Sefer, 2021).

The inclusion of the slope variable in the model indicates that the potential areas of the species consist of flat or slightly sloping areas in the study region. A study conducted by Tunalıoğlu and Gökçe (2002) stated that the distribution and yield of the species decrease in areas with higher slope degrees.

Regarding the effect of the bedrock variable, it was observed that areas with sandstone and alluvial deposits were suitable for the species. Some studies highlighting the species' soil requirements have emphasized the importance of soil pH, organic matter content, calcium content, and water holding capacity for olive trees (Galan et al., 2008; Aguilera and Ruíz-Valenzuela, 2009).

The last variable contributing to the model is the topographic position index. The topographic position index measures the difference in elevation between a specific point and the elevations of neighboring points (De Reu et al., 2013). A value close to 0 indicates a minimal elevation difference, implying a flat area in harmony with its surroundings. Negative values (-) indicate concave areas, while positive values (+) indicate convex areas that differ from the surrounding areas. In the model obtained for wild olive, it was observed that the suitable potential distribution areas for the species varied between -30 and +10. Hence, it can be inferred that the species prefers flat and slightly sloping areas with either concave or convex features as suitable growth habitats.

The findings obtained for wild olive in this study align with the results of the aforementioned literature studies, providing mutual support to each other.

The potential distribution modeling and map of the other species under investigation, the sage species, were conducted. The variable that contributed the most to the potential distribution of the species in the obtained model was canopy. Canopy refers to the extent to which the tree crowns provide shelter to the ground. When examining the effect of the canopy variable on the species, it is noteworthy that the potential areas of the species are concentrated in areas with a canopy closure degree of 1 (11-40%). Based on this, it can be concluded that while the species has a high light requirement, it also prefers a certain level of understory closure. A study by Tuna (2019) indicated that sage prefers forest clearings and disturbed forest areas in terms of its distribution, and it is found in the understory of low-closure Scots pine and black pine forests.

When examining the effect of the elevation variable on the potential distribution areas of sage, it is observed that the species increases its potential distribution from the lowest elevations in the region up to an elevation level of 2,000 m. In a relevant study, it was determined that the optimal elevation range for the species' distribution is between 150 m and 1,050 m (Özdemir and Özkan, 2016). Another study focusing on the habitat characteristics of sage in Kütahya-Türkmendağı indicated its distribution between 1,333 m and 1,677 m in terms of elevation (Tuna, 2019).
When considering the hillshade index, it is observed that potential areas of sage occur at levels between 170 and 250. Based on these values, it can be inferred that the species prefers shaded areas. In light of this information, it is possible to interpret that the species prefers relatively cool and shaded areas instead of excessively hot and sunny environments.

When examining the effect of the parent material variable, it is evident that the potential areas of the species predominantly consist of limestone and dolomite formations. A study by Eryiğit (2006) indicated that sage prefers soils formed on calcareous or volcanic rocks. Similarly, another study stated that sage grows efficiently in sandy soils rich in limestone content and is drought-resistant (Salem and İbrahim, 2010).

The last variable contributing to the model is the topographic position index. When examining its effect on the species, it is understood that sage is distributed in all types of landforms, including flat, concave, and convex surfaces, but it has a more suitable habitat in concave and convex terrains.

All this information demonstrates that the ecological characteristics of the regions constituting the potential distribution areas of sage in this study partially align with the findings of the literature. The observed differences can be attributed to the cosmopolitan and wide distribution of this species, its wide tolerance to various environmental factors, and variations in the type and number of variables used in the modeling process.

The fact that the people in the Fethiye region consume the species subject to the study in large quantities and unconsciously when appropriate, reveals the importance of creating a management plan for the forested areas in this region. Additionally, it is crucial to protect these species in their natural habitats along with their stand structure. It is a fact that the potential areas where these species are abundant or can be found need to be protected against roads, marble quarries, or other types of structures. Furthermore, when implementing silvicultural interventions in the forests where these species occur, their ecological requirements should be taken into consideration. For example, as mentioned in the study, the sage species shapes its potential areas in forests with low canopy closure. Therefore, in studies aimed at promoting the spread of this species, attention should be paid to the canopy closure of the upper layer of trees. On the other hand, similar considerations should be made for the target species within the scope, as variables such as radiation index and shading index shape the models. Hence, the sunlight or shade requirements of these species should be taken into account when intervening in the forests.

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Ethics Committee Approval
N/A

Peer-review
Externally peer-reviewed.

Conflict of Interest
The authors have no conflicts of interest to declare.

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