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Original article

The Relationship Between Certain Oak Species and Ecological Factors: An Analysis of Indicator Plant Species in Bozdağlar

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Abstract

This study aims to examine the relationships between Quercus cerris L. var. cerris, Quercus coccifera L., and Quercus infectoria Oliv. subsp. boissieri (Reut.) O.Schwarz and ecological variables using indicator species analysis and logistic regression methods. The modeling results demonstrated significant and high-accuracy performance for each species. For Q. cerris, the model yielded an AUC value of 0.774 for the training dataset and 0.761 for the test dataset, indicating "good" performance. The species' distribution was influenced by the variables BIO7, BIO3, BIO1, RUGI, and BIO12. For Q. coccifera, the model showed an AUC value of 0.892 for the training dataset and 0.887 for the test dataset, reflecting "very good" performance. The distribution of this species was primarily determined by BIO12 and BIO1. The model for Q. infectoria achieved an AUC value of 0.766 for the training dataset and 0.736 for the test dataset, indicating "good" performance, with BIO12 and BIO3 identified as the key variables affecting its distribution. Indicator species analysis was conducted using PC-ORD software to identify indicator species. The analysis revealed 11 positive and 31 negative indicator plant species for Q. cerris. For Q. coccifera, 8 positive and 1 negative indicator plant species were identified. Similarly, Q. infectoria was associated with 22 positive and 1 negative indicator plant species. This study provides a crucial foundation for understanding the distribution of oak species by integrating climate scenarios into modeling approaches, facilitating the prediction of climate change impacts and the development of strategies to mitigate these effects. The findings are expected to offer valuable insights into the ecological functionality and sensitivity of target species to environmental changes, serving as a reference for similar studies in various geographic regions. Additionally, this research establishes a significant scientific basis for sustainable forest management planning and biodiversity conservation, particularly within the Mediterranean Basin.

Keywords: Ecological Characteristics, Indicator Species, Indicator Species Analysis, Logistic Regression, Modeling, *Quercus* Spp.

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INTRODUCTION

Oak species (*Quercus* sp.), belonging to the family Fagaceae, are woody plants with broad ecological tolerance and extensive distribution (Tantray et al., 2017). Oaks, which are vital in forest ecosystems, provide critical ecosystem services, such as soil stabilization, regulation of the water cycle, and support for biodiversity. Additionally, they offer various economic benefits, including timber production, fuelwood supply, livestock grazing, and medicinal uses (Kremer et al., 2012; Tantray et al., 2017; Conrad et al., 2020). Despite their significant roles, oak species face severe threats due to human-induced impacts (Fei et al., 2011).

The genus *Quercus* is remarkable for its species richness, and is primarily distributed across the Northern Hemisphere. Globally, the genus encompasses approximately 435 species (Stump et al., 2024), whereas in Türkiye, it is represented by 17 species, along with their subspecies and varieties, comprising a total of 24 taxa (Yılmaz, 2018). This diversity places Türkiye in a significant position globally, in terms of the genetic and ecological wealth of oaks (Yaltırık, 1984; Tekpinar et al., 2021). Oak species account for approximately 29% of Türkiye's forests, covering an extensive area of 6.7 million hectares, making them one of the most widespread broad-leaved forest trees in the country (OGM, 2020).

The distribution of oak forests in Türkiye extends from the temperate rainforests of Northern Anatolia to the dry forests of the Central Anatolian steppes and Mediterranean maquis ecosystems (Tekpinar et al., 2021). However, a significant portion of oak forests in Türkiye are classified as degraded forests (OGM, 2020). This indicates severe degradation of the natural structure of oak forests caused by deforestation, overgrazing, climate change, and other anthropogenic effects (Plieninger et al., 2011; Stavi et al., 2022). These threats underscore the need to develop strategic approaches to the conservation of oak forests.

In this study, *Quercus cerris, Quercus coccifera*, and *Quercus infectoria* were examined as species with a significant distribution both in Türkiye and worldwide. *Q. cerris* is a deciduous tree species with a wide distribution in southern Europe and throughout Türkiye, except for the northeastern and eastern Anatolian regions. *Q. coccifera* is an evergreen, drought-tolerant shrub or small tree commonly found in the northwestern, western, and southern regions of Anatolia. *Q. infectoria*, a deciduous species typically found in low-altitude areas, is native to most parts of Türkiye and has a broader range, extending to Greece, the Caucasus, Iran, Iraq, Cyprus, Lebanon, Syria, and Israel (Yılmaz, 2018).

The study was conducted in the Bozdağlar region of Türkiye's Aegean region, which is located at the intersection of the Mediterranean and Aegean climatic zones. Bozdağlar, with its rich floristic diversity and varied habitat characteristics, serves as a natural laboratory for analyzing the distribution of oak species and their relationships with environmental variables. Additionally, the area's diverse elevation and habitat conditions allow for comparisons of the ecological tolerance of oak species (Koçman, 1984, 1985; Atalay et al., 2022; Tekeş, 2024). However, oak habitats are currently under intense anthropogenic pressures. Deforestation, agricultural expansion, overgrazing, wildfires, and urbanization adversely affect the population dynamics of oak species and threaten their natural regeneration. Particularly in the Mediterranean Basin, the increasing frequency of wildfires constrains the natural distribution of oak species and jeopardizes the functional services provided by these ecosystems (Plieninger et al., 2011; Habibi, 2016; Stavi et al., 2022). In this context, a detailed examination of the relationships between oak species and environmental variables, and the application of the resulting data to the development of conservation strategies, are essential for sustainable ecosystem management (Peñuelas and Sardans, 2021).

Indicator species analysis is a valuable tool for identifying species that serve as biological indicators of specific habitats or environmental conditions, thereby aiding the ecological understanding of these processes (Özdemir et al., 2017). This analysis plays a critical role in determining the effects of habitat requirements and environmental factors on ecological communities (Carignan and Villard, 2002; Siddig et al., 2016; Özdemir and Çınar, 2023). On the other hand, species distribution modeling approaches are widely employed to predict species' responses to environmental changes and to map their potential distributions (Gülsoy and Özkan, 2013; Şentürk et al., 2019; Acarer, 2024; Özdemir, 2024). In this study, indicator species analysis was conducted for *Q. cerris, Q. coccifera*, and *Q. infectoria*, which are distributed throughout the Bozdağlar region. Additionally, the relationships between these species and environmental variables were evaluated using a logistic regression analysis. This study aimed to improve our understanding of the habitat requirements of these oak species and, based on this knowledge, develop effective conservation strategies. These findings are expected to contribute to a deeper understanding of the impacts of climate change and anthropogenic habitat loss on oak ecosystems, and provide a scientific basis for sustainable natural resource management policies.

MATERIALS and METHODS

Study Area

The study area encompasses the Bozdağlar region, located within the provinces of Manisa and İzmir, and covers approximately 259,000 ha (Figure 1). The region experiences hot and dry summers with mild rainy winters. Phytogeographically, the site is situated within the Mediterranean Phytogeographical Region (Atalay and Efe, 2015). The dominant forest communities in the area include red pine (*Pinus brutia*), black pine (*Pinus nigra*), and chestnut (*Castanea sativa*) (Günal, 1987; Bekat and Oflas, 1990). Bozdağlar, as part of the Menderes Massif, consists of Paleozoic schists and Precambrian gneisses. The soil characteristics of the region are diverse, and include brown forest soils, red Mediterranean soils, rendzinas, alluvial, and colluvial soil types (Koçman, 1989; Atalay et al., 2022).

Data Collection and Preparation

The study was conducted across 170 sampling plots, each measuring 20 m × 20 m (400 m²). The geographic coordinates of the plots were recorded using GPS. During fieldwork, the plant species in each plot were documented in the presence/absence format. Following fieldwork, the recorded plant species were identified using the Flora of Turkey and the East Aegean Islands as references (Davis, 1965–1985; Davis et al., 1988; Güner et al., 2000). After the identification process was completed, a dataset consisting of inventoried plant species was created (Supplementary Table 1). To analyze the relationships between the target species and environmental variables, base maps of the climatic and topographic variables of the area were prepared using ArcGIS software (Table 1).

Table 1. Codes and descriptions of bioclimatic and topographic variables

Code	Explanation of Climate Variables	Code	Explanation of Topographic Variables
BIO1	Annual Mean Temperature	AFI	Aspect Favourability Index
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))	ASPE	Aspect
BIO3	Isothermality (BIO2/BIO7) (×100)	BED	Bedrock
BIO4	Temperature Seasonality (standard deviation ×100)	ELEV	Elevation
BIO5	Max Temperature of Warmest Month	HI	Heat Index
BIO6	Min Temperature of Coldest Month	HILL	Shading index
BIO7	Temperature Annual Range (BIO5-BIO6)	LAND	Land Surface Classification
BIO8	Mean Temperature of Wettest Quarter	REL8	Solar illumination index (08:00)
BIO9	Mean Temperature of Driest Quarter	RELN	Solar illumination index (12:00)
BIO10	Mean Temperature of Warmest Quarter	RI	Radiation index
BIO11	Mean Temperature of Coldest Quarter	ROUI	Roughness index
BIO12	Annual Precipitation	RUGI	Ruggedness index
BIO13	Precipitation of Wettest Month	SLOP	Slope
BIO14	Precipitation of Driest Month	SOLI	Solar illumination index
BIO15	Precipitation Seasonality (Coefficient of Variation)	SOLR	Solar radiation index
BIO16	Precipitation of Wettest Quarter	TPI	Topographic position index
BIO17	Precipitation of Driest Quarter		
BIO18	Precipitation of Warmest Quarter		
BIO19	Precipitation of Coldest Quarter		

After generating environmental base maps for the topographic and climatic variables, a gridded network with a cell size of 30 m × 30 m was created for the study area. All environmental variables were applied to this grid using the "Extract Multi-Values to Points" tool in ArcMap. Subsequently, all variables were saved in the ASCII format to ensure uniform cell sizes across the dataset.

Statistical Analyses and Modeling Process

Before initiating the modeling process, a Pearson Correlation Analysis was conducted in RStudio to prevent multicollinearity issues that could arise from high correlations among 16 topographic and 19 bioclimatic variables. The variables selected based on this analysis were included in the modeling process. Logistic regression analysis was performed on the dataset, which consisted of the selected environmental variables and presence/absence data for the target species. The analysis was conducted using R software with the pROC, ROCR, caret, funModeling, tidyverse, and ggplot2 packages. The accuracy of the resulting model was evaluated using the Area Under the Curve (AUC) value, a widely used metric that incorporates sensitivity and specificity indices. AUC values were classified according to Swets (1988) as: "Excellent" (AUC > 0.90), "Very good" (0.90 > AUC > 0.81), "Good" (0.80 > AUC > 0.71), "Low" (0.70 > AUC > 0.61), "Unsuccessful" (AUC < 0.60). Indicator Species Analysis was conducted using PC-ORD software to identify the indicator species within the study area (McCune and Mefford, 2011).

RESULTS

As a result of the research conducted in the study area, *Q. cerris* was recorded in 98 out of 170 sample plots, while *Q. coccifera* and *Q. infectoria* were identified in 22 plots. A total of 59 plant species were detected in the sample plots in which these three oak species were present. These species include both herbaceous and woody forms (Supplementary Table 1), reflecting the floristic diversity of the study area. Within the scope of this study, indicator species analysis was performed for the target species (*Q. cerris, Q. coccifera*, and *Q. infectoria*), and their relationships with environmental variables were examined in detail. The results revealed the environmental factors influencing the distribution of the target species. Findings related to the indicator species and modeling outcomes are presented below.

Variable Selection and Model Results

To prevent multicollinearity among the environmental variables used in this study, a Pearson correlation analysis was conducted. Variables with a correlation coefficient of p≥0.80 were excluded from the analysis (Gülsoy et al., 2016; Özdemir et al., 2020). As a result of this process, a total of 14 environmental variables were selected, including 4 bioclimatic and 10 topographic variables (Figure 2). These selected variables were employed in logistic regression analysis to explain the distribution and habitat preferences of oak species. The results of the analysis indicated that different environmental factors were the determinants for each species.

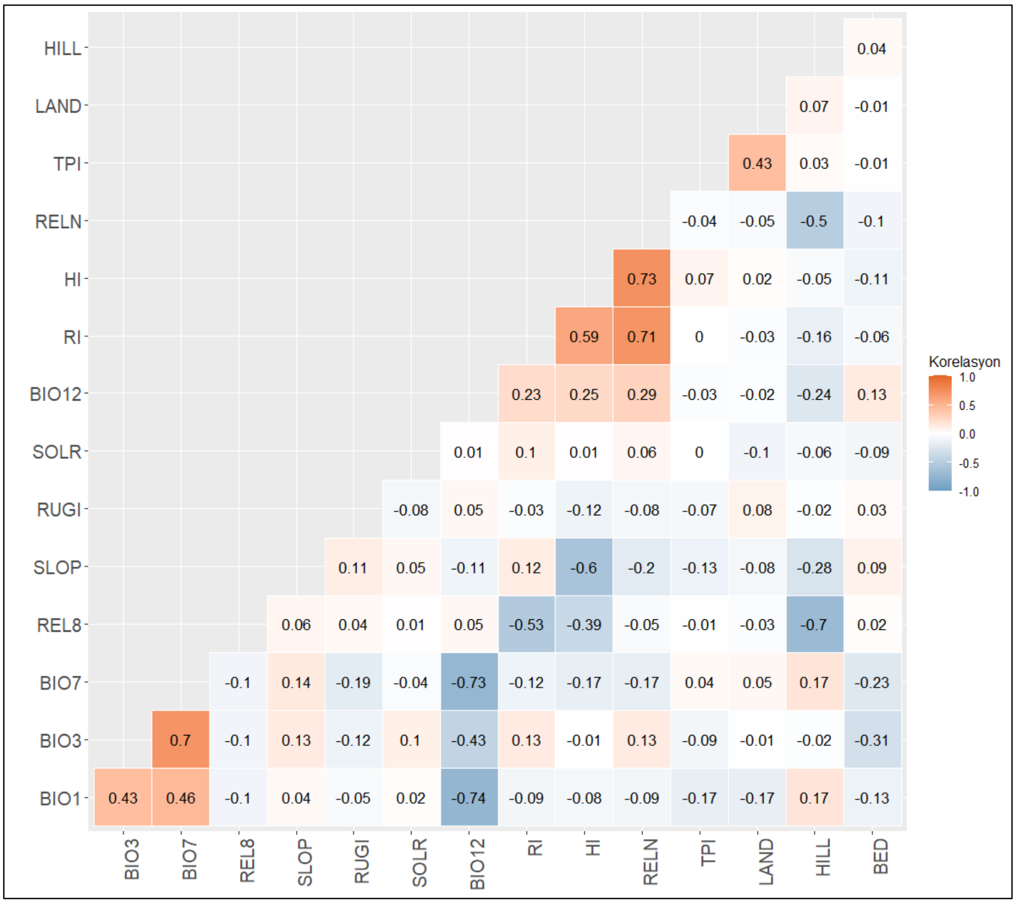
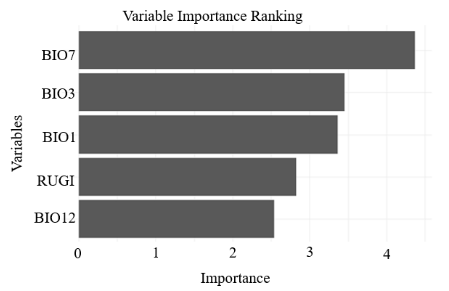


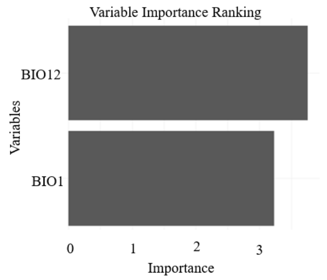
Figure 2. Correlation Analysis Results for Variables Selected for Inclusion in the Analysis

The analysis of *Q. cerris* revealed that the environmental variable that contributed most significantly to the species distribution was BIO7. This variable was followed by BIO3, BIO1, RUGI, and BIO12 in terms of importance (Table 2a). The model performance was evaluated using the Area Under the Curve (AUC) metric, with values of 0.774 for the training dataset and 0.761 for the test dataset (Table 3). These results indicate that the model performance was "good." For *Q. coccifera*, the analysis identified only two environmental variables influencing the distribution of species, BIO12 and BIO1, in order of importance (Table 2b). The AUC values of the model were calculated as 0.892 for the training dataset and 0.887 for the test dataset (Table 4), indicating a "very good" level of model performance. The analysis of *Q. infectoria* identified two variables influencing its distribution: BIO12 and BIO3, ranked by their contribution (Table 2c). The AUC values for this model were 0.766 for the training dataset and 0.736 for the test dataset (Table 5), indicating that the model performance was "good."

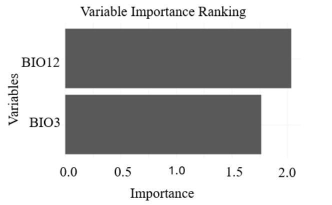
Table 2. Variables Contributing to the Models for the Three Oak Species



a. *Q. cerris*



b. *Q. coccifera*



c. *Q. infectoria*

Table 3. Logistic Regression Model Results for *Quercus cerris*

Variables	Estimate	Std. Error	Z value	Pr (>|z|)	Contributions of variables to the model	Nagelker R^2	Train AUC	Test AUC (ROC)
(Intercept)	222.100	67.780	3.277	0.001		0.305	0.774	0.761
BIO1	-0.707	0.210	-3.368	0.001	3.367724			
BIO3	1.156	0.335	3.452	0.001	3.45178			
BIO7	-2.269	0.519	-4.370	0.000	4.369913			
BIO12	-0.020	0.008	-2.539	0.011	2.538575			
RUGI	-251.200	88.870	-2.826	0.005	2.82643			

Table 4. Logistic Regression Model Results for *Quercus coccifera*

Variables	Estimate	Std. Error	Z value	Pr (>|z|)	Contributions of variables to the model	Nagelker R^2	Train AUC	Test AUC (ROC)
(Intercept)	9.235	7.009	1.318	0.188		0.559	0.892	0.887
BIO1	0.714	0.221	3.231	0.001	3.2311			
BIO12	-0.027	0.007	-3.757	0.000	3.756735			

Table 5. Logistic Regression Model Results for *Quercus infectoria*

Variables	Estimate	Std. Error	Z value	Pr (>|z|)	Contributions of variables to the model	Nagelker R^2	Train AUC	Test AUC (ROC)
(Intercept)	-13.157	12.247	-1.074	0.283		0.141	0.766	0.736
BIO3	0.488	0.277	1.764	0.078	1.763985			
BIO12	-0.010	0.005	-2.032	0.042	2.032486			

Indicator Species Analysis Results

The results of the indicator species analysis revealed that the three oak species developed associations with different plant species in environmental and ecological contexts. For *Q. cerris*, the analysis identified 11 species with positive associations and 31 with negative associations (Supplementary Table 2). The most significant positive indicator species for this oak were *Cynosurus echinatus and Crataegus monogyna* var. *monogyna*, *Pilosella piloselloides* subsp. *megalomastix*, *Pteridium aquilinum*, *Holosteum umbellatum* var. *tenerrimum*. The most significant negative indicator species included *Onobrychis crista-galli*, *Q. coccifera*, *Q. infectoria* subsp. *boissieri*, *Ranunculus paludosus*, and *Phillyrea latifolia* (Table 6). For *Q. coccifera*, the analysis identified 8 species with positive associations and 1 species with a negative association (Supplementary Table 3). The most significant positive indicator species were *Asparagus acutifolius*, *Alkanna tinctoria* subsp. *tinctoria*, *Anthemis pseudocotula*, *Arabis verna*, and *Anchusa undulata* subsp. *hybrida*. The only significantly negative indicator species was *Anthemis wiedemanniana* (Table 6). For *Q. infectoria*, the analysis identified 22 species with positive associations and one species with a negative association (Supplementary Table 4). The most significant positive indicator species were *Ranunculus paludosus*, *Colutea melanocalyx* subsp. *davisiana*, *Poa timoleontis*, *Rumex tuberosus* subsp. *tuberosus*, and *Asparagus acutifolius*. The only significant negative indicator species was *Q. cerris* var. *cerris* (Table 6).

Table 6. Most significant positive and negative indicator species for *Q. cerris, Q. coccifera,* and *Q. infectoria*

Target Species	Types of Positive Indicators	Types of Negative Indicators
Q. cerris	*Cynosurus echinatus*, *Crataegus monogyna* var. *monogyna, Pilosella piloselloides* subsp. *megalomastix, Pteridium aquilinum, Holosteum umbellatum* var. *tenerrimum*	*Onobrychis crista-galli*, *Q. coccifera* L., *Q. infectoria* subsp. *boissieri*, *Ranunculus paludosus, Phillyrea latifolia*
Q. coccifera	*Asparagus acutifolius*, *Alkanna tinctoria* subsp. *tinctoria, Anthemis pseudocotula*, *Arabis verna, Anchusa undulata* subsp. *hybrida*	*Anthemis wiedemanniana*
Q. infectoria	*Ranunculus paludosus*, *Colutea melanocalyx* subsp. *davisiana*, *Poa timoleontis*, *Rumex tuberosus* subsp. *tuberosus, Asparagus acutifolius*	*Q. cerris* var. *cerris*

DISCUSSION and CONCLUSION

This study aimed to investigate the relationships between *Q. cerris*, *Q. coccifera*, and *Q. infectoria* and environmental variables using indicator species analysis and logistic regression analysis. The results highlight the ecological characteristics of each species and their responses to environmental variables, demonstrating the reliability of the models. The modeling results for *Q. cerris* indicated that the variable contributing the most to its distribution was BIO7, followed by BIO3, BIO1, RUGI, and BIO12. The AUC values of 0.774 for the training dataset and 0.761 for the test dataset suggest that the model was performed at a "good" level. These findings reveal that *Q. cerris* is sensitive to temperature variations. Supporting this conclusion, Mezsaros et al. (2022) emphasized that this species is a xerophilous oak with a high drought tolerance. Furthermore, indicator species analysis identified 11 species that were positively associated and 31 species that were negatively associated with *Q. cerris*. These findings suggest that the habitats occupied by *Q. cerris* are floristically diverse, and that the species exhibits strong ecological interactions with various plant species.

The modeling results for *Q. coccifera* demonstrated that BIO12 and BIO1 variables significantly influenced its distribution. Notably, BIO12 contributed the most to the species' distribution, emerging as one of the key factors shaping its ecological tolerance. The AUC values of 0.892 for the training dataset and 0.887 for the test dataset indicated that the model was performed at an "excellent" level. Owing to its resilience to arid conditions, *Q. coccifera* gains a competitive advantage in low-precipitation areas and often becomes a dominant species in degraded habitats. These findings align with those of Al-Qaddi et al. (2017), who also highlighted the critical role of variables, such as BIO12, BIO7, and BIO5, in the distribution of this species. The indicator species analysis revealed a limited number of species positively associated with *Q. coccifera*, suggesting that it occupies a more restricted ecological niche. The dominance of *Q. coccifera* in Mediterranean ecosystems is attributed to its adaptability to environmental variables and competitive edge (Al-Qaddi et al., 2017; Öztürk and Altay, 2021).

The modeling results for *Q. infectoria* identified BIO12 and BIO3 as the primary environmental variables influencing its distribution. The AUC values, calculated as 0.766 for the training dataset and 0.736 for the test dataset, indicate that the model exhibited "good" performance. These findings suggest that *Q. infectoria* exhibits a distribution pattern that is sensitive to precipitation, emphasizing the significant role of climatic variables in shaping its ecological tolerance. Habibi (2016) highlighted the critical influence of climate on the distribution of this species. However, a study by Khanhasani et al. (2015) conducted in Iran revealed that *Q. infectoria* prefers alkaline soils and steep slopes, suggesting that geographical differences may alter the environmental factors that influence the distribution of species. The indicator species analysis revealed that the habitats occupied by *Q. infectoria* are rich in plant diversity, underlining their ecological significance. Positive associations with numerous plant species underscore the importance of these habitats. Furthermore, the sole negative relationship between *Q. infectoria* and *Q. cerris* indicated that their ecological niches largely did not overlap, suggesting distinct habitat preferences for the two oak species.

This study comprehensively examined the ecological requirements and the key environmental factors influencing the habitat preferences of *Q. cerris*, *Q. coccifera*, and *Q. infectoria*. These findings highlight the sensitivity of these species to environmental variables and their specific habitat needs, thereby providing critical scientific data for ecosystem management and conservation strategies. Increasing anthropogenic impacts and accelerating climate change pose significant threats to the population dynamics of these species (Plieninger et al., 2011; Stavi et al., 2022). Future research encompassing broader geographical areas and various climate scenarios will further enhance our understanding of the ecological processes and inform effective conservation strategies for these species. Modeling studies on oak species distribution are pivotal for predicting the potential impacts of climate change and formulating mitigation measures. The integration of advanced modeling techniques with long-term monitoring efforts can significantly improve the accuracy of predicting future potential distributions and contribute to shaping sustainable forest management policies (Al-Qaddi et al., 2017; Babalik et al., 2021). Additionally, the results of the indicator species analysis demonstrated that each oak species represents specific environmental conditions and serves as a key indicator for understanding ecosystem dynamics. In addition, grouping indicator species and identifying the environmental factors that influence these groupings offers practical applications to mitigate the impacts of climate change and increase the resilience of plant communities. The findings provide a critical foundation for predicting the potential distributions of these species in climate-sensitive regions like the Mediterranean Basin, serving as a guide for sustainable forest management and conservation planning (Özdemir, 2024).

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Conflicts of interest

There is no conflict of interest between the authors of the article.

REFERENCES

Acarer, A. (2024). Role of Climate Change on Oriental Spruce (*Picea orientalis* L.): Modeling and Mapping. *BioResources, 19*(2), 3845-3856. https://doi.org/10.15376/biores.19.2.3845-3856

Al-Qaddi, N., Vessella, F., Stephan, J., Al-Eisawi, D., & Schirone, B. (2017). Current and future suitability areas of kermes oak (*Quercus coccifera* L.) in the Levant under climate change. *Regional Environmental Change, 17,* 143-156. https://doi.org/10.1007/s10113-016-0987-2

Atalay, İ. & Efe, R. (2015). *Türkiye biyocoğrafyası*. Meta Basım Matbaacılık, İzmir.

Atalay, İ., Siler, M., & Altunbaş, S. (2022). Türkiye'de Oyuntu Erozyonu Oluşumu ile Ana Materyal Arasındaki İlişkiler. *Coğrafi Bilimler Dergisi*, *20*(1), 84-120. https://doi.org/10.33688/aucbd.982732

Babalik, A. A., Sarikaya, O., & Orucu, O. K. (2021). The Current and future compliance areas of Kermes Oak (*Quercus coccifera* L.) under climate change in Turkey. Fresenius Environmental Bulletin, 30(01), 406-413.

Bekat, L. & Oflas, S. (1990). Bozdağ (Ödemiş) Vejetasyonu. *X. Ulusal Biyoloji Kongresi*, 18-20 Temmuz 1990, Erzurum, Türkiye, 257-270.

Conrad, A. O., Crocker, E. V., Li, X., Thomas, W. R., Ochuodho, T. O., Holmes, T. P., & Nelson, C. D. (2020). Threats to oaks in the eastern United States: perceptions and expectations of experts. *Journal of Forestry*, *118*(1), 14-27. https://doi.org/10.1093/jofore/fvz056

Davis, P. H. (1965-1985). *Flora of Turkey and the East Aegean Island (Vols.1- 9).* Edinburgh, Edinburgh University Press.

Davis, P. H., Mill, R.R. & Tan, K. (1988). *Flora of Turkey and the East Aegean Islands (Vol. 10 (suppl.)).* Edinburgh, Edinburgh University Press.

Fei, S., Kong, N., Steiner, K. C., Moser, W. K., & Steiner, E. B. (2011). Change in oak abundance in the eastern United States from 1980 to 2008. *Forest Ecology and Management*, *262*(8), 1370-1377. https://doi.org/10.1016/j.foreco.2011.06.030

Gülsoy, S., & Özkan, K. (2013). Determination of environmental factors and indicator plant species for site suitability assessment of Crimean Juniper in the Acipayam District, Turkey. Sains Malaysiana, 42(10), 1439-1447.

Günal, N. (1987). Gediz ve Büyük Menderes arasındaki sahanın bitki örtüsü özellikleri. *İstanbul Üniversitesi Deniz Bilimleri ve Coğrafya Enstitüsü Dergisi*, *3*(4), 93-104.

Güner, A., Özhatay, N., Ekim, T. & Baser, K.H.C. (2000). *Flora of Turkey and the East Aegean Islands (Vol 11 (suppl.)).* Edinburgh, Edinburgh Univ Press.

Habibi, M. (2016). Investigating the impact of climate changes on qualitative and quantitative growth of oak trees (case study: central Zagros). *Open Journal of Ecology, 6*(6), 358-366. https://doi.org/10.4236/oje.2016.66034

Khanhasani, M., Sagheb-Talebi, K., Noori, F., & Khodakarami, Y. (2015). Effect of Soil and Physiographic Factors on Habitats Differentiation of Three Oak Species:(*Q. infectoria*, *Q. libani* and *Q. brantii*). *International Journal of Scientific Research in Environmental Sciences, 3*(2), 62. https://doi.org/10.12983/ijsres-2015-p0062-0070

Koçman, A. (1984). Bozdağlar ve çevresinin iklimi. *Ege Coğrafya Dergisi; 2*(1), 57-108.

Koçman, A. (1985). İzmir-Bozdağlar yöresinin yapısal jeomorfolojisi ve evrimi. *Ege Coğrafya Dergisi*, *3*(1), 63-86.

Koçman, A. (1989). *Uygulamalı fiziki coğrafya çalışmaları ve İzmir-Bozdağlar Yöresi üzerinde araştırmalar*. İzmir, Ege Üniversitesi.

Kremer, A., Abbott, A. G., Carlson, J. E., Manos, P. S., Plomion, C., Sisco, P., ... & Vendramin, G. G. (2012). Genomics of fagaceae. *Tree Genetics & Genomes*, *8*, 583-610. https://doi.org/10.1007/s11295-012-0498-3

McCune, B. & Mefford, M. J. (2011). PC-ORD. Multivariate Analysis of Ecological Data. Version 6.08, MjM Software, Gleneden Beach, Oregon, U.S.A.

Mészáros, I., Adorján, B., Nyitrai, B., Kanalas, P., Oláh, V., & Levanič, T. (2022). Long-term radial growth and climate-growth relationships of *Quercus petraea* (Matt.) Liebl. and *Quercus cerris* L. in a xeric low elevation site from Hungary. *Dendrochronologia*, *76*, 126014. ttps://doi.org/10.1016/j.dendro.2022.126014

OGM, (2020). Orman Genel Müdürlüğü Faaliyet Raporu. https://www.ogm.gov.tr/tr/ormanlarimiz/Turkiye-Orman-Varligi (Son Erişim Tarihi: 25.07.2024).

Özdemir, S. (2024). Effects of environmental variables on taxonomic diversity and grouping of plant communities in the Mediterranean region (Antalya). *European Journal of Forest Research,* 1-12. https://doi.org/10.1007/s10342-024-01736-3

Özdemir, S. (2024). Testing the Effect of Resolution on Species Distribution Models Using Two Invasive Species. *Polish Journal of Environmental Studies, 33*(2), 1325-1335. https://doi.org/10.15244/pjoes/166353

Özdemir, S., & Çınar, T. (2023). Determining indicator plant species of Pinus brutia Ten. Site index classes using interspecific correlation analysis in Antalya (Turkey). *Cerne, 29*, e-103188. https://doi.org/10.1590/01047760202329013188

Özdemir, S., Gülsoy, S., & Mert, A. (2020). Predicting the effect of climate change on the potential distribution of Crimean Juniper. *Kastamonu University Journal of Forestry Faculty, 20*(2), 133-142. https://doi.org/10.17475/kastorman.801847

Özdemir, S., Negiz, M. G., Turhan, U. U., Şenol, A., & Arslan, M. (2017). Indicator plant species of alpha diversity in Kuyucak Mountain district. *Turkish Journal of Forestry*, *18*(2), 102-109. https://doi.org/10.18182/tjf.289095

Özturk, M., & Altay, V. (2021). Role of *Quercus coccifera* (= *Q. calliprinos*) in the light of climate change scenarios in the Mediterranean Basin. *Plant & Fungal Research, 4*(2), 8-20. https://doi.org/10.30546/2664-5297.2021.4.2.2

Peñuelas, J., & Sardans, J. (2021). Global change and forest disturbances in the Mediterranean basin: Breakthroughs, knowledge gaps, and recommendations. *Forests*, *12*(5), 603. ttps://doi.org/10.3390/f12050603

Plieninger, T., Schaich, H., & Kizos, T. (2011). Land-use legacies in the forest structure of silvopastoral oak woodlands in the Eastern Mediterranean. *Regional Environmental Change*, *11*, 603-615. https://doi.org/10.1007/s10113-010-0192-7

Siddig, A. A., Ellison, A. M., Ochs, A., Villar-Leeman, C., & Lau, M. K. (2016). How do ecologists select and use indicator species to monitor ecological change? Insights from 14 years of publication in Ecological Indicators. *Ecological Indicators*, *60*, 223-230. https://doi.org/10.1016/j.ecolind.2015.06.036

Stavi, I., Thevs, N., Welp, M., & Zdruli, P. (2022). Provisioning ecosystem services related with oak (*Quercus*) systems: a review of challenges and opportunities. *Agroforestry Systems, 96*(2), 293-313. https://doi.org/10.1007/s10457-021-00718-3

Stump, A. J., Bershing, K., Bal, T. L., & Külheim, C. (2024). Current and Future Insect Threats to Oaks of the Midwest, Great Lakes, and Northeastern United States and Canada. *Forests*, *15*(8), 1361. https://doi.org/10.3390/f15081361

Swets, J. A. (1988). "Measuring the accuracy of diagnostic systems", *Science, 240*, 1285-1293. https://doi.org/10.1126/science.3287615

Şentürk, Ö., Gülsoy, S., & Tümer, İ. (2019). Potential Distribution Modeling and Mapping of Brutian Pine Stands in the Inner Parts of the Middle Black Sea Region in Turkey. *Polish Journal of Environmental Studies, 28*(1). https://doi.org/10.15244/pjoes/81682

Tantray, Y. R., Wani, M. S., & Hussain, A. (2017). Genus *Quercus:* an overview. *International Journal of Advance Research in Science and Engineering*, *6*(8), 1880-1886.

Tekeş, A. (2024). Ege Bölgesi-Bozdağlar Yöresi'nde bitki tür çeşitliliğinin günümüz ve iklim değişimi altında potansiyel dağılım modellemesi ve haritalaması. Isparta Uygulamalı Bilimler Üniversitesi, Lisansüstü Eğitim Enstitüsü, Doktora Tezi.

Tekpinar, A. D., Aktaş, C., Kansu, Ç., Duman, H., & Kaya, Z. (2021). Phylogeography and phylogeny of genus *Quercus* L.(Fagaceae) in Turkey implied by variations of trnT (UGU)-L (UAA)-F (GAA) chloroplast DNA region. *Tree Genetics & Genomes*, *17*, 1-18. https://doi.org/10.1007/s11295-021-01522-x

Yaltırık, F. (1984). *Türkiye meşeleri: teşhis kılavuzu*. Yenilik Basımevi. İstanbul.

Yılmaz, H. (2018). *Quercus* L. (Ed. Ü. Akkemik) Türkiye'nin Doğal-Egzotik Ağaç ve Çalıları. Orman Genel Müdürlüğü Yayınları, Ankara. s: 338-356.

APPENDIX

Supplementary Table 1. Plant species list detected in the sample areas

Plant Species Names	Plant Species Names
Alkanna tinctoria (L.) Tausch subsp. *tinctoria*	*Marrubium rotundifolium* Boiss.
Alyssum hirsutum M.Bieb.	*Myosotis arvensis* (L.) Hill subsp. *arvensis*
Anagallis arvensis var. *caerulea* (L.) Gouan	*Olea europaea* L.
Anchusa undulata L. subsp. *hybrida* (Ten.) Coutinho	*Onobrychis crista-galli* (L.) Lam.
Anthemis pseudocotula Boiss.	*Ornithogalum armeriacum* Baker
Anthyllis vulneraria L. subsp. *praepropera* (Kerner) Bornm.	*Osyris alba* L.
Anthemis wiedemanniana Fisch. & C.A.Mey.	*Paliurus spina-christi* P. Mill.
Arabis verna (L.) R.Br.	*Parentucellia latifolia* (L.) Caurel subsp. *latifolia*
Asparagus acutifolius L.	*Petrorhagia velutina* (Guss.) P.W.Ball & Heywood
Centaurea cyanus Hill.	*Phillyrea latifolia* L.
Cistus creticus L.	*Pilosella piloselloides* (Vill.) Sojak subsp. *megalomastix*
Colutea melanocalyx Boiss. & Heldr. subsp. *davisiana* (Browicz) D.F.Chamb.	*Pinus brutia* Ten.
Crataegus monogyna Jacq. var. *monogyna*	*Pistacia terebinthus* L.
Cynosurus echinatus L.	*Poa timoleontis* Heldr. ex Boiss.
Elaeoselinum asclepium (L.) Bertol.	*Potentilla reptans* L.
Erodium cicutarium subsp. *cicutarium* (L.) L Her.	*Pteridium aquilinum* (L.) Kuhn
Erica arborea L.	*Pyrus amygdaliformis* Vill. var. *amygdaliformis*
Euphorbia helioskopia L.	*Quercus cerris* L. var. *cerris*
Euphorbia rigida M.Bieb.	*Quercus coccifera* L.
Galium brevifolium subsp. *brevifolium* Sm.	*Quercus infectoria* Oliv. subsp. *boissieri* (Reut.) O.Schwarz
Galium lovcense Urum.	*Ranunculus ficaria* L. subsp. *ficariiformis* Rouy & Foucaud
Genista anatolica Boiss.	*Ranunculus paludosus* Poir.
Geranium purpureum Vill.	*Rumex tuberosus* L. subsp. *tuberosus*
Geranium rotundifolium L.	*Scaligeria napiformis* (Willd.) Grande
Gynandriris sisyrinchium (L.) Parl.	*Scorzonera sublanata* Lipsch.
Holosteum umbellatum var. *tenerrimum*	*Silene italica* (L.) Pers.
Lathyrus sativus L.	*Torilis leptophylla* (L.) Rchb.f.
Lavandula stoechas L. subsp. *cariensis*	*Trifolium stellatum* L. var. *stellatum*
Leontodon tuberosus L.	*Vincetoxicum tmoleum* Boiss.
Luzula forsteri (Sm.) DC.	

Supplementary Table 2. Positive and negative indicator plant species and their significance levels for the target species *Quercus cerris*

Target Species	Indicator Species	Indicator Group	Observed Indicator Value (IV)	Mean	Standard Deviation	p value	Indicator Direction
Q. cerris	*Cynosurus echinatus*	1	16.3	6.8	1.7	0.0004	+
	Crataegus monogyna var. *monogyna*	1	26.2	17.4	2.43	0.005	+
	Pilosella piloselloides subsp. *Megalomastix*	1	10.2	4.7	1.48	0.0052	+
	Pteridium aquilinum	1	19.4	12.4	2.25	0.0084	+
	Holosteum umbellatum var. *tenerrimum*	1	9.2	4.4	1.42	0.0088	+
	Genista anatolica	1	12	6.8	1.7	0.0136	+
	Centaurea cyanus	1	15.1	9.2	2.01	0.0142	+
	Ranunculus ficaria subsp. *ficariiformis*	1	8.2	4	1.36	0.0234	+
	Silene italica	1	10	5.4	1.58	0.029	+
	Torilis leptophylla	1	10	5.4	1.6	0.0298	+
	Luzula forsteri	1	6.1	3.3	1.18	0.0392	+
	Onobrychis crista-galli	0	16.7	5.4	1.65	0.0002	-
	Quercus coccifera	0	42.3	19.9	2.53	0.0002	-
	Quercus infectoria subsp. *boissieri*	0	30.6	8.8	1.87	0.0002	-
	Ranunculus paludosus	0	17.1	6.1	1.7	0.0002	-
	Phillyrea latifolia	0	24.8	11.1	2.1	0.0006	-
	Erodium cicutarium subsp. *cicutarium*	0	11.1	4	1.36	0.0016	-
	Pyrus amygdaliformis var. *amygdaliformis*	0	18.7	9.2	2	0.0018	-
	Erica arborea	0	9.7	3.5	1.32	0.0028	-
	Geranium purpureum	0	17.4	8.8	1.89	0.0034	-
	Marrubium rotundifolium	0	10.2	4.3	1.4	0.0042	-
	Anthemis pseudocotula	0	8.3	3.3	1.16	0.005	-
	Arabis verna	0	12.1	5.4	1.6	0.0054	-
	Olea europaea	0	8.3	3.2	1.17	0.006	-
	Parentucellia latifolia subsp. *latifolia*	0	12.1	5.4	1.63	0.0072	-
	Alkanna tinctoria subsp. *tinctoria*	0	10.7	5	1.51	0.0096	-
	Vincetoxicum tmoleum	0	8.8	4	1.33	0.01	-
	Asparagus acutifolius	0	18.5	11.5	2.13	0.0106	-
	Paliurus spina-christi	0	8.8	4	1.33	0.011	-
	Galium brevifolium subsp. *brevifolium*	0	6.9	2.8	1.17	0.0128	-
	Colutea melanocalyx subsp. *davisiana*	0	6.9	2.8	1.17	0.0132	-
	Geranium rotundifolium	0	10	5.4	1.62	0.0202	-
	Petrorhagia velutina	0	7.4	3.5	1.34	0.021	-

Supplementary Table 2. Positive and negative indicator plant species and their significance levels for the target species *Quercus cerris* (Continued)

Target Species	Indicator Species	Indicator Group	Observed Indicator Value (IV)	Mean	Standard Deviation	p value	Indicator Direction
Q. cerris	*Pistacia terebinthus*	0	14.2	8.5	1.96	0.0216	-
	Elaeoselinum asclepium	0	5.6	2.5	1.01	0.029	-
	Galium lovcense	0	5.6	2.4	1.00	0.03	-
	Scaligeria napiformis	0	5.6	2.5	1.02	0.0326	-
	Euphorbia helioskopia	0	5.6	2.5	1.02	0.0328	-
	Lathyrus sativus	0	5.6	2.5	1.02	0.0338	-
	Pinus brutia	0	31.1	25.1	2.62	0.0372	-
	Euphorbia rigida	0	9.4	5.8	1.58	0.0446	-
	Cistus creticus	0	36.2	30.8	2.51	0.0466	-

Supplementary Table 3. Positive and negative indicator plant species and their significance levels for the target species *Quercus coccifera*

Target Species	Indicator Species	Indicator Group	Observed Indicator Value (IV)	Mean	Standard Deviation	p value	Indicator Direction
Q. coccifera	*Asparagus acutifolius*	1	37.4	11.6	2.35	0.0002	+
	Alkanna tinctoria subsp. *tinctoria*	1	11.8	5.2	1.66	0.008	+
	Anthemis pseudocotula	1	8	3.2	1.39	0.018	+
	Arabis verna	1	11.2	5.4	1.76	0.018	+
	Anchusa undulata subsp. *hybrida*	1	13	7.3	1.88	0.0226	+
	Alyssum hirsutum	1	5.3	2	1.10	0.0366	+
	Anthyllis vulneraria subsp. *praepropera*	1	5.3	2	1.11	0.038	+
	Anagallis arvensis var. *caerulea*	1	7.3	3.7	1.40	0.045	+
	Anthemis wiedemanniana	0	14.3	8	2.01	0.011	-

Supplementary Table 4. Positive and negative indicator plant species and their significance levels for the target species *Quercus infectoria*

Target Species	Indicator Species	Indicator Group	Observed Indicator Value (IV)	Mean	Standard Deviation	p value	Indicator Direction
Q. infectoria	*Ranunculus paludosus*	1	32.7	7.3	3	0.0002	+
	Colutea melanocalyx subsp. *davisiana*	1	17.5	3.8	1.78	0.0012	+
	Poa timoleontis	1	33.9	13.9	3.87	0.0016	+
	Rumex tuberosus subsp. *tuberosus*	1	28	10.8	3.6	0.0042	+
	Asparagus acutifolius	1	30.4	12.8	3.83	0.0058	+
	Quercus coccifera	1	39.3	21.5	4.21	0.0064	+
	Elaeoselinum asclepium	1	13	3.3	1.54	0.0066	+
	Ornithogalum armeriacum	1	22.3	7.6	3.18	0.0066	+
	Erodium cicutarium subsp. *cicutarium*	1	15.8	4.8	2.54	0.012	+
	Onobrychis crista-galli	1	18.8	6.6	2.78	0.012	+
	Pyrus amygdaliformis var. *amygdaliformis*	1	23.7	10.4	3.67	0.0136	+
	Gynandriris sisyrinchium	1	9.1	2.1	1.39	0.0154	+
	Osyris alba	1	9.1	2.1	1.4	0.0156	+
	Myosotis arvensis subsp. *arvensis*	1	38.2	22.7	4.42	0.016	+
	Cistus creticus	1	46.2	32.5	4.35	0.0236	+
	Potentilla reptans	1	11.9	4.1	1.99	0.0274	+
	Leontodon tuberosus	1	17.5	7.6	3.17	0.0308	+
	Trifolium stellatum var. *stellatum*	1	29.9	17.7	4.14	0.031	+
	Pistacia terebinthus	1	19.9	9.9	3.46	0.0388	+
	Erica arborea	1	11.4	4.5	2.31	0.0402	+
	Scorzonera sublanata	1	8.5	2.8	1.48	0.045	+
	Lavandula stoechas subsp. *cariensis*	1	8.5	2.8	1.52	0.0488	+
	Quercus cerris var. *cerris*	0	66.2	33.6	4.2	0.0002	-