On the Edge of Survival: The Fragile Fate of Scots Pine (*Pinus sylvestris* L.) in Central Anatolia, Türkiye Under Climate Change

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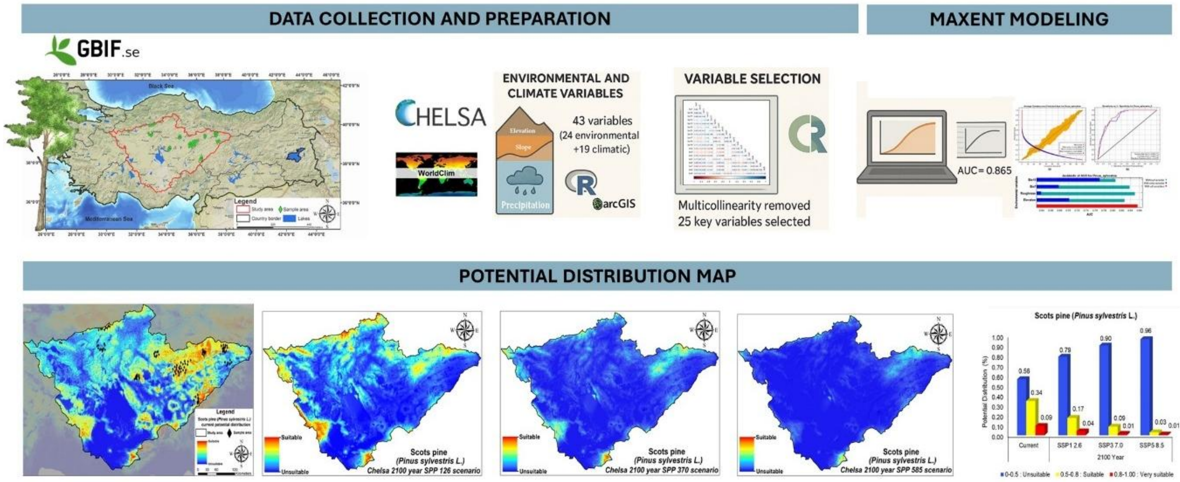
GRAPHICAL ABSTRACT



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Scots pine (*Pinus sylvestris* L.) is an essential species for biodiversity and ecosystem services in Türkiye, yet it is becoming increasingly vulnerable to climate change, especially in climatically marginal areas such as Central Anatolia. This study used MaxEnt modeling along with CHELSA V2.1 climate projections to evaluate the current and future distribution of Scots pine under three Shared Socioeconomic Pathways (SSP1 2.6, SSP3 7.0, SSP5 8.5) projected for the year 2100. The key climatic factors influencing habitat suitability include precipitation seasonality (Bio15) and temperature seasonality (Bio7). The results show that while 34% of Central Anatolia is currently suitable for Scots pine, habitat suitability could decline by 91% under SSP5 8.5, leaving only 4% of the region viable for the species by 2100. This significant reduction highlights the uncertain future of Scots pine populations in the area. Unlike previous research, this study provides a high-resolution analysis that incorporates fine-scale environmental and topographical variables, emphasizing the importance of mid-altitude refugia as potential climate shelters. Aligning with Sustainable Development Goal 15 (SDG15), this study underscores the need to incorporate climate projections into forest management practices. The findings contribute to a broader understanding of climate-induced range shifts and inform adaptive conservation strategies for other vulnerable tree species in semiarid regions.

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Keywords: Scots pine; Species distribution modeling; Climate adaptation; MaxEnt model; Forest resilience; Asia minor; Chelsa

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INTRODUCTION

Pinus sylvestris L., commonly known as Scots pine, is one of the most widely distributed pine species, ranking second among coniferous taxa within the Northern Hemisphere, with its geographical distribution extending from Western Europe to Central-Eastern Asia (Durrant *et al.* 2016; Tóth *et al.* 2017). The ecologically marginal populations of Scots pine in Türkiye are relics of the Tertiary period and have a patchy distribution, isolated by geographic barriers such as the Black Sea, the Anatolian Plateau, and the Caucasus Mountains from the main range in Europe, serving as remnants of glacial refugia (Naydenov *et al.* 2007; Dering *et al.* 2021). Dering *et al.* (2021) describes Scots pine populations in Türkiye and the South Caucasus as key components of biodiversity and evolutionary heritage and Naydenov *et al.* (2007) emphasizes the need to protect these relict populations by restricting seed transfers and prioritizing conservation efforts, as they represent a critical genetic reservoir and an essential component of the region's biodiversity. Nevertheless, these populations are threatened by climate change with projections indicating hotter and drier conditions, severe habitat contraction, upward and northward range shifts, and increased fragmentation (Takolander *et al.* 2019; Dering *et al.* 2021). In Central Anatolia, climate projections suggest a significant increase in temperature and a decrease in annual precipitation, exacerbating drought stress and limiting Scots pine regeneration (Altın *et al.* 2012; Ekberzade *et al.* 2024). Indeed Dering *et al.* (2021) predicts a loss of over 90% of the current distribution of Scots pine in southern Caucasus and Anatolia this century. By the end of 2080, approximately one-third of the current distribution of Scots pine in Europe might be lost, with southern stands being most affected (Dyderski *et al.* 2018; Takolander *et al.* 2019). While climate change is expected to significantly impact the distribution of Scots pine across its range, with variations in different climatic zones (Garzon *et al.* 2006; Hickler *et al.* 2012; López-Tirado and Hidalgo 2014; Dyderski *et al.* 2018; Fernández-Pérez *et al.* 2019; Takolander *et al.* 2019; Dering *et al.* 2021; Bulut and Aytaş 2023). Turkish populations face greater challenges due to their marginal habitats in Mediterranean and Anatolian climates, which are already geographically constrained, thus limiting migration options compared to other regions in Europe (Takolander *et al.* 2019).

The sustainability of Scots pine forests is essential because they offer valuable resources and play a significant role in conserving biodiversity and sequestering carbon. Although climate-adaptive forestry may need to incorporate drought-tolerant species in the future, Scots pine continues to be ecologically important for maintaining habitat stability and microclimatic conditions within its current range. Nevertheless, the persistent ramifications of climate change, characterized by rising temperatures and altered precipitation patterns, present substantial challenges to its prospective distribution. Indeed, recent projections regarding the future distribution of Scots pine in Türkiye have indicated considerable vulnerability in the context of climate change, with anticipated habitat contraction particularly in low-altitude and southern regions (Arslan and Örücü 2019; Bulut and Aytaş 2023; Ekberzade *et al.* 2024).

Species distribution models (SDMs) are critical tools for predicting these changes and guiding conservation strategies. These models combine environmental variables with species presence data to estimate potential distribution under current and future climate scenarios. Commonly used frameworks, such as the Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs), provide a range of future climate projections that enable researchers to explore potential outcomes for species distributions. Recent advancements in global climate datasets, such as CHELSA V2.1, further enhance the precision of SDMs by capturing fine-scale climatic variability (Karger *et al.* 2023). Maximum Entropy (MaxEnt) modeling predicts a species' potential distribution under changing climatic conditions. MaxEnt is particularly useful in ecological niche modeling, as it estimates a species' probability distribution based on various environmental factors (Warren and Seifert 2011; Merow *et al.* 2013; Cobos *et al.* 2019). Utilizing the MaxEnt modeling approach, researchers can predict how climate change will influence the potential distribution for this species across various regions. This modeling technique is particularly effective due to its ability to handle presence-only data and to incorporate a wide range of environmental variables, making it suitable for assessing potential distributions of species in response to climate change (Gritti *et al.* 2013). The MaxEnt model's reliance on presence-only data allows researchers to create robust models even with limited sampling, thereby enhancing the predictive power of ecological studies in the region (Suel 2019).

In Türkiye, the MaxEnt model has significantly contributed to assessing the potential distributions of various species, as well as biodiversity and conservation studies. This includes evaluating potential distribution for species such as the brown bear (Suel 2019; Acarer 2024a; Acarer and Mert 2024), roe deer (Tekin *et al.* 2018), Danford's lizard (Kıraç and Mert 2019), red deer (Oruç *et al.* 2017), and gray wolf (Suel *et al.* 2018). The model has also been used to predict land use and land cover changes under climate change scenarios (Kalayci Kadak *et al.* 2024). Furthermore, the MaxEnt modelling approach has been employed to predict the future potential distribution of various forest tree species, including Cremian juniper (Özdemir *et al.* 2020), Anatolian black pine (Arslan and Örücü 2019; Acarer 2024b; Cantürk *et al.* 2024), Oriental spruce (Acarer 2024c) and wild olive (Çıvğa 2025). Additionally, studies on Scots pine (Arslan and Örücü 2019; Bulut and Aytaş 2023) have also been conducted. Arslan and Örücü (2019) focused on the current and potential distributions of *Pinus nigra* Arnold and *Pinus sylvestris* L. using the MaxEnt model, analyzing changes projected under climate change scenarios specified in the fifth IPCC report, particularly RCP 4.5 and RCP 8.5 for the years 2050 and 2070. In a related study, Bulut and Aytaş (2023) examined the current and potential distribution of *Pinus sylvestris* L. in the Inner Anatolian Region of Türkiye, specifically investigating forest enterprises under the SSP2 4.5 and SSP5 8.5 climate change scenarios.

The wide distribution of Scots pine presents both opportunities and challenges for assessing its response to climate change. Marginal populations, such as those in Türkiye, are particularly important due to their unique genetic and ecological traits, shaped by extreme climatic and edaphic conditions (Dering *et al.* 2021). These populations exist at the southernmost and warmest edges of the species' range, where climatic stressors, including increasing temperatures and reduced precipitation, exert significant pressures. Understanding the vulnerability of these populations is critical, as they may serve as early indicators of broader shifts in the species' distribution. Assessing potential changes in potential distribution for Scots pine in this region is crucial for understanding the impacts of climate change on forest ecosystems in marginal habitats (Dering *et al.* 2021; Oskay *et al.* 2024).

Previous studies, such as those by Arslan and Örücü (2019) and Bulut and Aytaş (2023), have explored the potential distribution of Scots pine in Türkiye. However, these studies relied on lower-resolution climate datasets and a limited number of occurrence records, and their modelling approaches did not adequately consider fine-scale environmental and topographical variables. This study builds upon earlier research by utilizing a more comprehensive dataset that includes 158 presence records and high-resolution CHELSA V2.1 climate projections. Unlike previous studies that primarily focused on broad-scale climatic influences, this research integrates climate, topographic, and ecological factors to provide a more detailed and region-specific perspective on the future distribution of Scots pine in Central Anatolia.

This study investigated the marginal populations of Scots pine in Türkiye, aiming to enhance an understanding of how this species responds to climate change and to provide practical insights for conservation and adaptive forest management. By identifying potential climate refugia and areas at risk of habitat loss, the research informs strategies to mitigate the impacts of climate change on this important species. The investigation focuses on assessing the current and future distribution of Scots pine in Central Anatolia, using climate projections from the CHELSA V2.1 database for the year 2100 under various scenarios: SSP1 2.6, SSP3 7.0, and SSP5 8.5. This research aligns with Sustainable Development Goal 15: Life on Land, which aims to support the sustainable management of ecosystems. It highlights the importance of Scots pine forests in maintaining biodiversity and ecological balance. The findings will aid in developing adaptive forest management strategies, ensuring the long-term health of these vital landscapes. Additionally, it addresses gaps in the existing literature concerning the impacts of climate change on forest ecosystems.

EXPERIMENTAL

Scots Pine Habitat Characteristics in Central Anatolia

The Scots pine longitudinal distribution encompasses over 14,000 kilometers, stretching from 8°W in Spain to 141°E in Siberia, while its latitudinal distribution covers more than 3,700 kilometers, ranging from 37°N in Spain and Türkiye to 70°N in Norway, Sweden, and Finland (Durrant *et al.* 2016; Tóth *et al.* 2017; Dering *et al.* 2021). Throughout its northern range within the subarctic region, Scots pine exhibits continuous growth from Scandinavia to Siberia. Conversely, within its southern range, shaped by the effects of postglacial warming during the Holocene, it demonstrates a discontinuous distribution characterized by island-like and fragmented populations, including those in the arid mountainous regions of southern Spain, Türkiye, Georgia, and Crimea (Tóth *et al.* 2017; Dering *et al.* 2021). The altitudinal distribution of Scots pine demonstrates considerable variability, extending from sea level to elevations reaching 2,700 meters, dependent upon the climatic conditions encountered across its geographical distribution. In the northernmost regions of its range, populations of Scots pine are located at sea level, whereas in the southern areas, it may occupy altitudinal zones from sea level to elevations exceeding 2,600 meters in the Caucasus and Northeast Anatolia, Türkiye (Tóth *et al.* 2017; Dering *et al.* 2021; Atalay 2023).

In Türkiye, Scots pine is one of the most important native pine species, both ecologically and economically (Topaçoğlu and Genç 2019; Sağlam and Sakici 2024). As the pine species with the widest global distribution, Scots pine occupies a significant area in Türkiye, covering approximately 1.41 million hectares, which constitutes approximately 6% of the total forested area of the nation (Durkaya *et al.* 2016; Sağlam and Sakici 2024). Scots pine populations in the Asian part of Türkiye in Anatolia, also known as Asia Minor, represent the most arid and warmest place within the Scots pine niche (Dering *et al.* 2021), and the southernmost extent of the species' distribution are of profound ecological and genetic importance (Naydenov *et al.* 2007; Dering *et al.* 2021). These populations are primarily distributed across three major regions: the Black Sea region, Central Anatolia, and Northeastern Anatolia, where they inhabit diverse ecological zones with varying climatic, altitudinal, and soil conditions (Atalay 2023). In the Black Sea region, Scots pine thrives in humid environments with high precipitation and fertile soil, often forming mixed forests with *Fagus orientalis* Lipsky. (oriental beech) and *Abies nordmanniana* (Steven) Spach (Nordmann fir). The altitudinal range here extends from sea level to approximately 1,800 meters. This region supports dense and genetically diverse populations due to the favourable environmental conditions and ecological interactions. Northeastern Anatolia, with its mountainous terrain and colder climates, provides a unique habitat for Scots pine. These populations are found at altitudes from approximately 1,200 meters to 2,700 meters, with adaptations for cold hardiness and significant snowfall (Atalay 2023).

Populations in Central Anatolia are adapted to a semi-arid climate characterized by cold winters, hot, dry summers, and limited precipitation. Found at altitudes ranging between 1,000 and 1,600 meters, these populations often coexist with drought-tolerant species such as *Quercus* and *Juniperus*. Their growth patterns reflect adaptations to water scarcity, making them genetically distinct and resilient to harsh conditions (Gücel *et al.* 2008). Central Anatolia, the study area, has a semi-arid climate characterized by low annual precipitation, typically ranging from 300 to 600 mm. The region experiences considerable temperature variations across the seasons, with hot, dry summers and cold winters, during which temperatures often drop below freezing (Altın *et al.* 2012; Tuğaç *et al.* 2022). These climatic conditions pose significant challenges for tree species, including Scots pine, which is particularly sensitive to drought and requires specific moisture levels for optimal growth (Bueis *et al.* 2016). The species is integral to forest ecosystems, offering habitat for numerous wildlife species and contributing to local economies through timber production. Economically, Scots pine is indispensable to Türkiye's timber sector, underpinning industries such as construction, furniture manufacturing, and paper production, thus serving as a foundational element of regional economies (Topaçoğlu and Genç 2019). Due to human activities, significant portions of the Scots pine forests in Türkiye have been gradually transformed into unproductive areas. Currently, rapid rehabilitation efforts are underway in these regions (Durkaya *et al.* 2016).

Data Collection and Preparation

This study aimed to determine the current and future (2100 year) distribution of Scots pine in the Central Anatolian region of Türkiye. Presence data for Scots pine in Central Anatolia were first obtained from the Global Biodiversity Information Facility (GBIF) website, an open-access database (GBIF 2024). In addition to the presence data obtained from GBIF, to obtain accurate and reliable results of species distribution modeling, presence data of the target species were obtained from various articles, master's and doctoral theses conducted in the Central Anatolia region (Tunç 2019; Orhan 2021; Oskay *et al.* 2024; Ursavaş and Edis 2024). Careful measures were implemented to ensure that the presence data collected originated from natural habitats. Özcan *et al.* (2024) noted that presence data derived from planted locations do not accurately represent the ecological and natural characteristics of the species in question. Consequently, to delineate the current and potential distribution of Scots pine, 158 presence data points from the species' natural habitats were gathered, as illustrated in green on the map (Fig. 1).

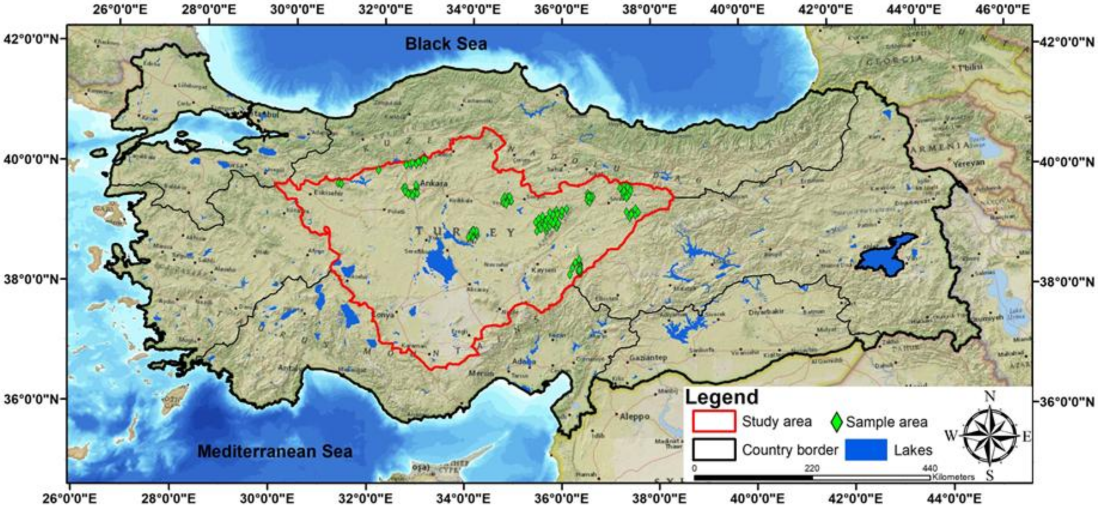

Fig. 1. Location of the study area and georeferenced presence data of Scots pine

Numerical-Based Environmental and Climate Variables Map Production Process

After collecting data on Scots pine from its natural habitat, base maps of numerical environmental and climatic variables were generated to model its potential distribution. To create these digital base maps, first the digital elevation model covering the study area was downloaded from the website https://www.usgs.gov/. Then, the resulting digital elevation model with a pixel size of approximately ~1x1 km (30 arc seconds) was resized according to the study area, and the appropriate coordinate system (*Lambert Conformal Conic ED50*) was introduced. Finally, environmental variables of the area were produced using the ArcGIS Pro software, based on the digital elevation model in which the appropriate coordinate system was introduced according to the study area boundary. These variables, which are produced by different formulas, indexes or arctoolbox, are: elevation, elevation class, slope, slope class, aspect, aspect class, aspect suitability index, solar illumination index (8pm, 6pm, 4pm, 2pm, noon, 10am, 08am, 06am, solar illumination), solar radiation index, hill shade index, ruggedness index, roughness index, topographic position index, compound topographic index, heat load index, temperature index (mc_cune) and landform surface shape index (Acarer 2024a, b, c). Thus, a total of 24 environmental variables that could be effective in Scots pine distribution were produced.

Once the environmental variables for the study area were established, the next step was to produce climate variables to understand their effects on species distribution. Currently, the WorldClim and Chelsa climate scenarios are the most preferred options. The Chelsa climate scenarios, which provide high-resolution climate data for the Earth’s land surface areas, are hosted by the Swiss Federal Institute for Forest, Snow, and Landscape Research (WSL). This dataset is globally scaled, has a very high resolution of 30 arc seconds (approximately 1 km), and is openly accessible (CHELSA 2024). Given that the study area covers 161738 km², the Chelsea climate scenarios were selected for this study as they offer a broader range of results for larger geographical areas compared to the WorldClim dataset. Chelsa climate scenarios are widely used to determine the effects of climate variables on Scots pine distribution (Dering *et al.* 2021; Vospernik *et al.* 2024). These climate data include five climate envelope models: GFDL-ESM4, IPSL-CM6ALR, MPI-ESM1-2-HR, MRI-ESM2-0 and UKESM1-0-LL. Although there are different climate envelope models, they are all based on temperature and precipitation values derived from climate variables. In this context, Chelsa climate variables derived from temperature and precipitation variables were obtained from the https://chelsa-climate.org/ internet address (Karger *et al.* 2023). The obtained 30 arc seconds (~1x1 km) pixel size Chelsa climate envelope models include 19 different climate variables from bio1 to bio19. In addition to the variables obtained for the current potential distribution of Scots pine, climate variables belonging to the UKESM1-0-LL climate envelope model’s 2100-year SSP1 2.6, SSP3 7.0, and SSP5 8.5 climate scenarios were also obtained. The climate variables obtained were resized based on the study area. As a result, a total of 43 digital and model-based base map production processes were completed, including 24 environmental and 19 climate variables.

Environmental Variable Selection and Pre-Modeling Analysis

Before proceeding with the modelling and mapping of Scots pine, a comprehensive statistical analysis was conducted on the base maps created within the designated study area. This included Pearson correlation analysis to identify and exclude variables with an absolute value greater than 0.80, ensuring minimal multicollinearity. Additionally, factor analysis was employed to pinpoint the most representative variables, emphasizing temperature and precipitation seasonality, significantly influencing Scots pine distribution. These statistical methods were conducted using R software and ArcMap 10.8 for spatial data preprocessing. Since closely related values in species distribution models can lead to multicollinearity issues during the modelling phase, careful variable selection is essential (Suel 2019). To address this, Pearson correlation analysis was performed using the R software. Variables exhibiting an absolute value greater than 0.80, were excluded to minimize multicollinearity issues (Fig. A1). This approach aligns with findings in the literature, where similar thresholds have been recommended for species distribution modelling (Özdemir *et al.* 2020; Acarer 2024b). These variables were initially created in raster format and then converted to ASCII format to facilitate the modeling phase of the maxent method. To provide reliable potential distribution projections for Scots pine, only the most representative and independent variables were converted to ASCII format and the modeling phase was started.

Maximum Entropy (MaxEnt) Modeling and Mapping Approach

The Maximum Entropy (MaxEnt) method is an important tool in ecological niche modelling (ENM) and species distribution modelling (SDM). These techniques help researchers understand the habitat preferences and distributions of different species based on the principle of maximum entropy (Özdemir *et al.* 2020). Its primary aim is to predict the potential distribution of species utilizing presence-only data, a feature that is particularly advantageous when absence data is scarce or nonexistent. This model operates by maximizing entropy, thereby yielding a probability distribution that accurately represents the environmental conditions linked to the known presences of a species (Khattak *et al.* 2022). One of the key advantages of the MaxEnt model is its strong predictive capability, which often outperforms other modelling techniques in various scenarios. Research shows that MaxEnt consistently achieves better results in predicting species distributions compared to alternative models like GARP, mainly when the input data is biased or limited (Townsend Peterson *et al.* 2007; Wang *et al.* 2018). This is especially important in ecological studies, as accurate predictions are essential for informing conservation strategies and habitat management. Additionally, the model’s ability to manage complex interactions between species and their environments provides deeper insights into ecological dynamics, particularly in changing climate conditions (Kearney *et al.* 2010).

Although it has many advantages, the accuracy of the model obtained with the MaxEnt method needs to be checked. In this audit, care must be taken to ensure that there are no significant deviations or swellings in the omission chart first presented. In other words, care must be taken to ensure that the predicted omission line is not completely visible and that the average omission follows the predicted omission line. Another important issue in evaluating model accuracy is generally checking Area Under the Curve (AUC) values. The AUC value ranges from 0 to 1 and indicates how confident the model is. AUC values are categorized to indicate the model’s predictive power: values between 0.9 and 1 are considered excellent, 0.8 to 0.9 are good, 0.7 to 0.8 are fair, 0.6 to 0.7 are poor, and values below 0.5 indicate a failed model (Astuti *et al.* 2021). However, for these values, it is necessary to ensure that the AUC value of the training and test data set is the highest. At the same time, care should be taken to ensure that the difference between the AUC values of the training and test data sets is the lowest. Finally, if the AUC value of the test data set exceeds the AUC value of the training data set, the model is considered invalid (Fielding and Bell 1997; Merow *et al.* 2013).

RESULTS AND DISCUSSION

Key Variables Influencing Scots Pine Distribution

According to the results of the statistical analysis (r>0.80) applied to the 43 environmental and climate variable base maps produced at the beginning of the study, it was concluded that 25 digital base maps (21 environmental and 4 climate variable) would represent the distribution of Scots pine in Central Anatolia. In other words, it has been revealed that climatic and topographic factors have a critical effect in shaping the potential distribution of Scots pine. Factor analysis was conducted to identify the most representative variables influencing the distribution of Scots pine in Central Anatolia. The results of the factor analysis indicated that the model comprised four climate variables that best represented the distribution of Scots pine, accounting for a cumulative value of 96.2% and a variance of 5.51% (Table A1). These variables were identified as follows: mean diurnal air temperature range (bio2: 0.873), annual range of air temperature (bio7: 0.794), and precipitation amount of the driest month (bio14: 0.724) and precipitation seasonality (bio15: 0.895) (Table A2). Among these, temperature seasonality (Bio7) and precipitation seasonality (Bio15) were the strongest predictors in Central Anatolia, highlighting the species' sensitivity to climate change. Bio7 illustrates the impact of extreme temperature fluctuations on physiological stress, growth, and seedling establishment. Increased temperature seasonality can lead to higher evapotranspiration rates and reduced soil moisture, particularly during dry summer months. This situation poses challenges for Scots pine, which needs sufficient moisture during its growing season. Studies indicate that prolonged soil moisture deficits reduce tree vigour and increase susceptibility to pests (Dyderski *et al*. 2018; Jaime *et al*. 2019). Temperature seasonality may worsen water stress in lowland and south-facing slopes, where shallow, rocky substrates limit water retention. Similarly, Bio15 indicates that Scots pine thrives in environments with stable moisture availability. High precipitation variability, characterized by intense droughts followed by heavy rainfall, can disrupt nutrient uptake and increase soil erosion risk, limiting suitable habitats. In Central Anatolia, this variability may lead to more surface runoff and less soil moisture during dry periods. Moreover, high precipitation seasonality raises the likelihood of wildfires, as dry forest fuels become more susceptible to ignition during storms (Sánchez-Salguero *et al.* 2017). Scots pine's low post-fire regeneration capacity compared to other Mediterranean pines such as *Pinus brutia* and *Pinus halepensis* (Fernández-Pérez et al., 2019) poses additional threats to its habitat.

These results confirm the critical role of temperature and precipitation in determining potential distribution for Scots pine, as previously reported in studies such as Bueis *et al.* (2016). After determining the four most effective climate variables (Bio 2, Bio 7, Bio 14 and Bio 15) on the potential distribution of Scots pine, their correlation with other 24 environmental variables were examined. According to the correlation analysis results, it was determined that three environmental variables showed a high correlation. The elimination method among the environmental variables showing high correlation was based on the surface shape of the study area and three environmental variables were not included in the modeling stage.

Modelling Performance of MaxEnt Approach

This study examined the current and future potential distribution of Scots pine under existing climatic conditions and projected climate scenarios (SSP1 2.6, SSP3 7.0, SSP5 8.5) for 2100, employing the MaxEnt modelling approach. The standard deviation of the average omission rate for the current potential distribution model of Scots Pine, considered to be good, was 0.021 (Fig. 2a), indicating that the model minimized false negatives, effectively capturing the areas suitable for Scots pine growth. Additionally, the model exhibited strong predictive performance, attaining AUC values of 0.865 for the training dataset and 0.864 for the test dataset (Fig. 2b), indicating a high level of accuracy and confirm the model's ability to discriminate between suitable and unsuitable habitats accurately (Swets 1988). These results are consistent with similar studies employing MaxEnt for species distribution modeling, where AUC values above 0.85 are considered indicative of high predictive accuracy (Özdemir *et al.* 2020; Acarer 2024b,c). This high predictive accuracy ensures the model can reliably project potential distribution for Scots pine under various future climate scenarios (*e.g.*, SSP1 2.6, SSP3 7.0, SSP5 8.5). Consequently, it provides a solid foundation for identifying potential climate refugia and regions at risk of habitat loss, which is critical for conservation planning and adaptive forest management in the face of climate change.

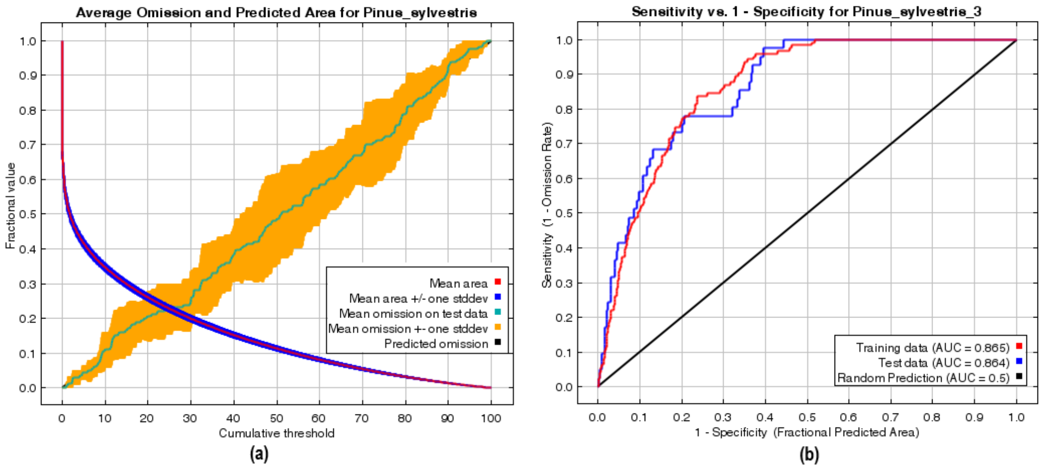

Fig. 2. Model performance of MaxEnt for Scots pine: (a) Average omission and predicted area plot, showing model consistency with a low standard deviation (0.021); (b) Sensitivity vs. 1-specificity (ROC curve) for training and test datasets, highlighting strong predictive accuracy with AUC values of 0.865 and 0.864, respectively

Previous studies on the distribution of Scots pine provide valuable context. For example, Arslan and Örücü (2019) modeled the potential distribution of Scots pine using only 34 occurrence records, a sample size that is considered insufficient for making reliable predictions. The Area Under the Curve (AUC) values of the Receiver Operating Characteristic (ROC) curve for *Pinus sylvestris* were calculated as 0.964 for the training dataset and 0.968 for the test dataset. While these values indicate "excellent" model performance, the higher AUC value for the test dataset compared to the training dataset raises concerns about the reliability of the model. In ecological niche modeling, the AUC of the training dataset is typically expected to be equal to or slightly higher than that of the test dataset, as the model is optimized for the training data while the test data represents unseen, independent observations (Fielding and Bell 1997; Merow *et al.* 2013).

In contrast, a more recent study by Bulut and Aytaş (2023) addressed these limitations by incorporating higher-resolution climate data and using SSP scenarios from the latest CMIP6 projections. This study utilized a larger dataset and more rigorous validation metrics, such as the True Skill Statistic (TSS), which enhanced the reliability of its findings. However, it also had limitations, including insufficient spatial coverage of occurrence data and a limited exploration of extreme climate indices that could impact Scots pine distribution in Türkiye's marginal environments.

Climatic and Ecological Drivers of Potential distribution

The jackknife analysis identified several key environmental variables that significantly influence the current distribution of Scots pine. These variables include precipitation seasonality (Bio15), mean temperature range (Bio7), elevation, and surface roughness, as illustrated in Fig. 3. Among these, precipitation seasonality (Bio15) had the most significant impact on the model, highlighting the importance of stable and reliable moisture availability for the survival and regeneration of Scots pine. The considerable role of the mean temperature range (Bio7) also indicates the species' sensitivity to temperature fluctuations. Elevation reflects the tree's adaptation to specific altitudinal zones, while surface roughness emphasizes the importance of topography in creating suitable habitats for Scots pine.

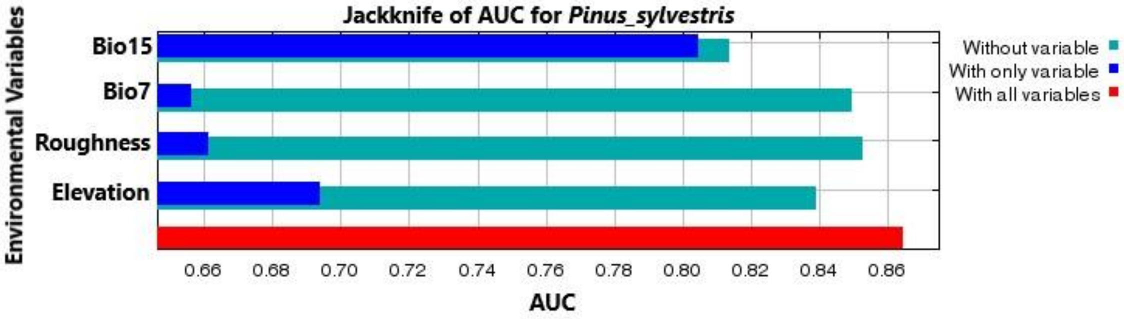

Fig. 3. Jackknife plot of variables contributing to the current distribution model of Scots pine

The potential distribution of Scots pine in Central Anatolia is significantly influenced by climatic and ecological factors, as illustrated in Fig. 4. Bioclimatic variables, particularly Bio7 (temperature seasonality) and Bio15 (precipitation seasonality), provide valuable insights into the ecological tolerances and limitations of Scots pine in the Central Anatolia region (see Fig. 4A and 4B). These findings are consistent with studies by Bueis *et al.* (2016) and Merow *et al.* (2013), which highlight that temperature and precipitation variability are critical determinants of Scots pine distribution, especially in semi-arid regions.

Scots pine displays remarkable adaptability to various climatic conditions, flourishing in areas where the mean annual temperature ranges from -2°C to 14°C, with optimal growth typically occurring between 2°C and 6°C. The species can endure extreme minimum temperatures below -35°C and prefers summer temperatures that do not exceed 30 °C (Atalay 2023). However, Fig. 4a shows that Scots pine thrives best in regions where temperature seasonality (Bio7) ranges from 25 to 35 °C. Beyond this range, potential distribution declines sharply, indicating the species' reduced capacity to cope with extreme seasonal temperature fluctuations with harsher climatic conditions. Figure 4b illustrates the response of Scots pine to precipitation seasonality (Bio15). Potential distribution peaked when Bio15 was within the range from 100 to 460 mm, suggesting that Scots pine thrives in areas with relatively stable rainfall patterns. However, suitability declines when Bio15 exceeds 460 mm, indicating that the species struggles to adapt to highly variable precipitation patterns. Areas with extreme variability in temperature or precipitation impose significant ecological constraints on the species. This dual sensitivity highlights that Scots pine occupies a narrow ecological niche in the region and depends on specific climatic conditions that are increasingly threatened by climate change.

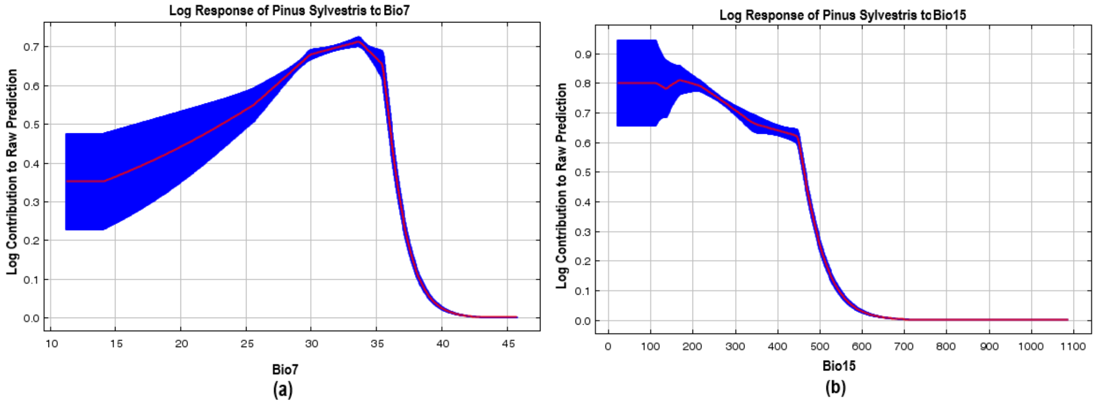

Fig. 4. Response graph of Scots pine potential Distribution to Climatic (Bio7 (a), Bio15 (b)) variables

The ecological variables of surface roughness and elevation were found to significantly impact Scots pine distribution in Central Anatolia (Fig. 5). Elevation is particularly crucial in determining potential distribution for this species. Optimal conditions for Scots pine occur between 1.500 and 2.500 meters, with peak suitability around 2000 meters (Fig. 5a). This elevation range reflects the species' adaptation to mesic and cooler mid-altitude environments, where temperature and precipitation are well-balanced (Atalay *et al.* 2014). At elevations below 1.000 meters, suitability decreases, which is likely due to competition with steppe vegetation. Additionally, conditions above 3000 meters make the habitat less suitable, as more extreme climatic factors, such as lower temperatures and increased UV radiation, impose significant abiotic stress on the species (Körner 2007).

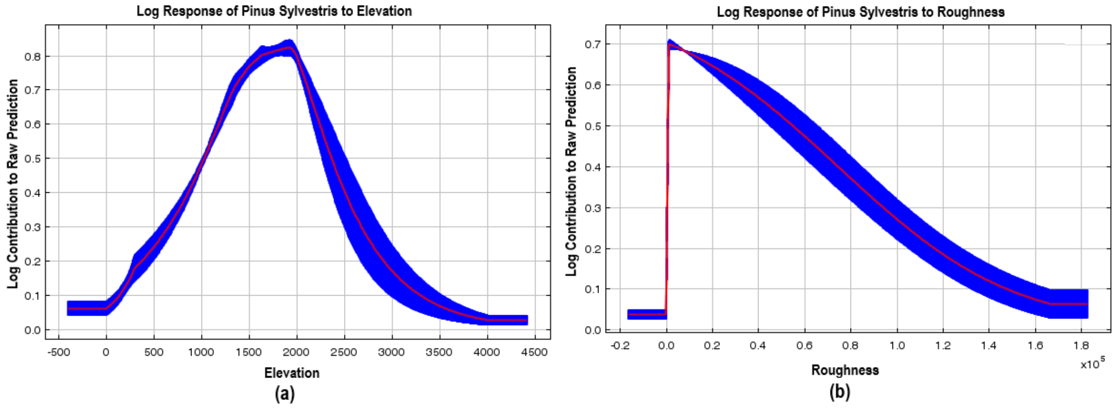

Fig. 5. Response graph of Scots pine potential distribution to Ecological (elevation (a) and roughness (b)) variables

Terrain roughness shows a unimodal relationship with the distribution probability of Scots pine. Suitability probabilities are lowest in areas with extremely flat or low terrain. Conversely, the suitability for Scots pine growth declines significantly in excessively rugged terrains. This suggests that Scots pine thrives better in moderately rugged areas, which is likely due to improved water drainage and greater microhabitat diversity. In contrast, extremely flat or highly rugged terrains may hinder seedling establishment and growth. Dufour *et al.* (2006) noted that increasing terrain roughness decreases the area of individual habitats, reduces connectivity between similar habitats, and therefore increases habitat isolation.

Projected Distribution Under Current and Future Climate Scenarios

The current distribution map (Fig. 6) reveals that Scots pine is primarily found in high-altitude regions (1200 to 2000 m), where moderate temperature variability and consistent precipitation create optimal growth conditions. Additionally, surface roughness in these areas plays a crucial role in providing localized microclimatic stability, buffering against extreme weather conditions. These results are consistent with previous studies, which emphasize the ecological preferences of Scots pine and the significance of topography in maintaining suitable habitats under changing climatic conditions (Karger *et al.* 2023).

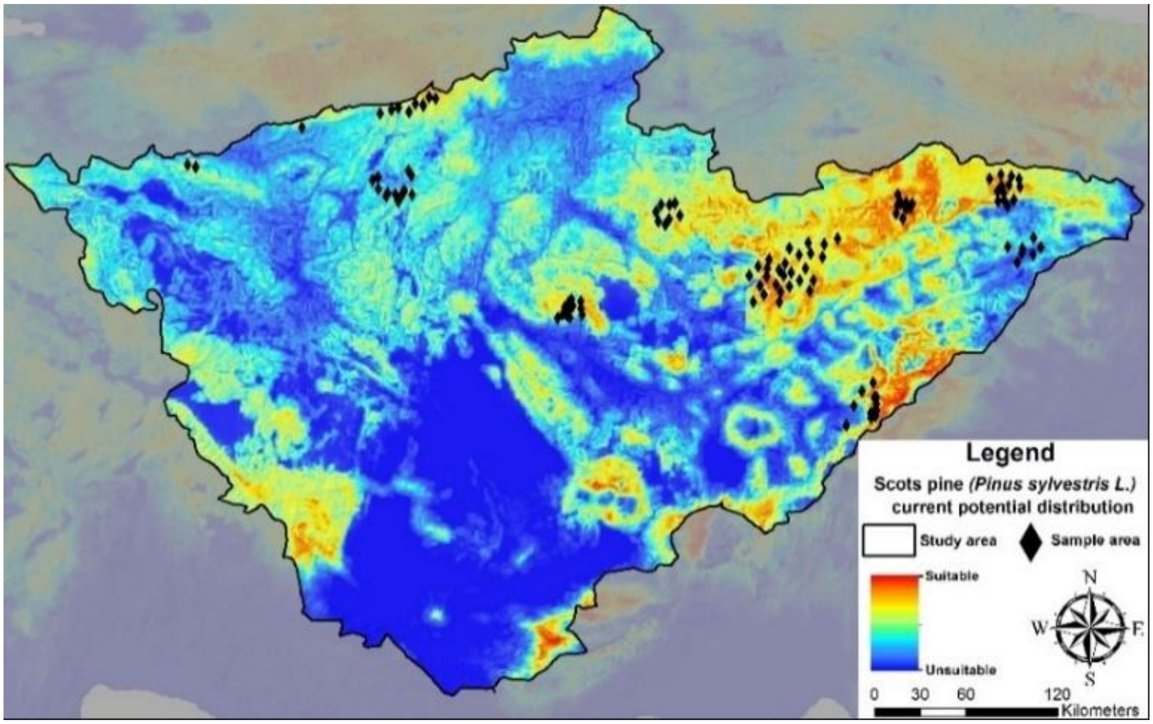

Fig. 6. Current potential distribution map of Scots pine in Central Anatolia

The distribution maps (Fig. 7a,b,c) illustrate the projected distribution of Scots pine in Central Anatolia under different climate scenarios for the year 2100 (SSP1 2.6, SSP3 7.0, and SSP5 8.5). Figures 7 (a), (b), and (c) display suitability maps, while Fig. 7 (d) quantifies the distribution rates for each suitability class. Under the SSP1 2.6 scenario, suitable habitats are more widespread, albeit fragmented, concentrated in mid-altitude and mesic areas and the model predicts relatively stable habitat conditions, with suitable areas for Scots pine found in high-altitude and climatically favorable regions (Fig 7a). The concentration of suitable habitats in mid-altitude and mesic areas suggests that Scots pine may benefit from favorable climatic conditions, such as increased moisture availability during critical growth periods. Research indicates that winter-spring temperatures and moisture availability play a significant role in promoting the growth of Scots pine, particularly in coastal and mesic environments (Janecka *et al.* 2020). However, under the SSP3 7.0 (Fig 7b) and SSP5 8.5 (c) scenarios, suitable habitats become increasingly sparse, with severe fragmentation and near-total loss of highly suitable areas. The stability of habitat conditions under the SSP1 2.6 scenario also raises questions about the long-term viability of Scots pine populations. While the model predicts relatively stable conditions, it is essential to consider the potential for extreme weather events and climatic anomalies that could disrupt these habitats. For instance, drought conditions, which have been shown to negatively impact the growth and survival of Scots pine, may become more frequent even in otherwise favorable climates (Sakici *et al.* 2023). The interaction between drought stress and habitat fragmentation can exacerbate the challenges faced by Scots pine, leading to increased mortality rates and reduced regeneration success (Hereş *et al.* 2012). However, in SSP3 7.0 (Fig 7b), potential distribution decreases markedly, leaving only fragmented and isolated areas suitable for Scots pine. This reduction reflects a loss of habitat connectivity, which is crucial for maintaining genetic flow and population resilience. By SSP5 8.5, the landscape is dominated by unsuitable habitats, and highly suitable areas are almost entirely absent. SSP5 8.5 exhibits a dramatic loss of suitable habitats, with only a negligible portion of the region remaining favorable for Scots pine. These findings suggest that Scots pine populations in Central Anatolia are at significant risk of local extinction under high-emission scenarios.

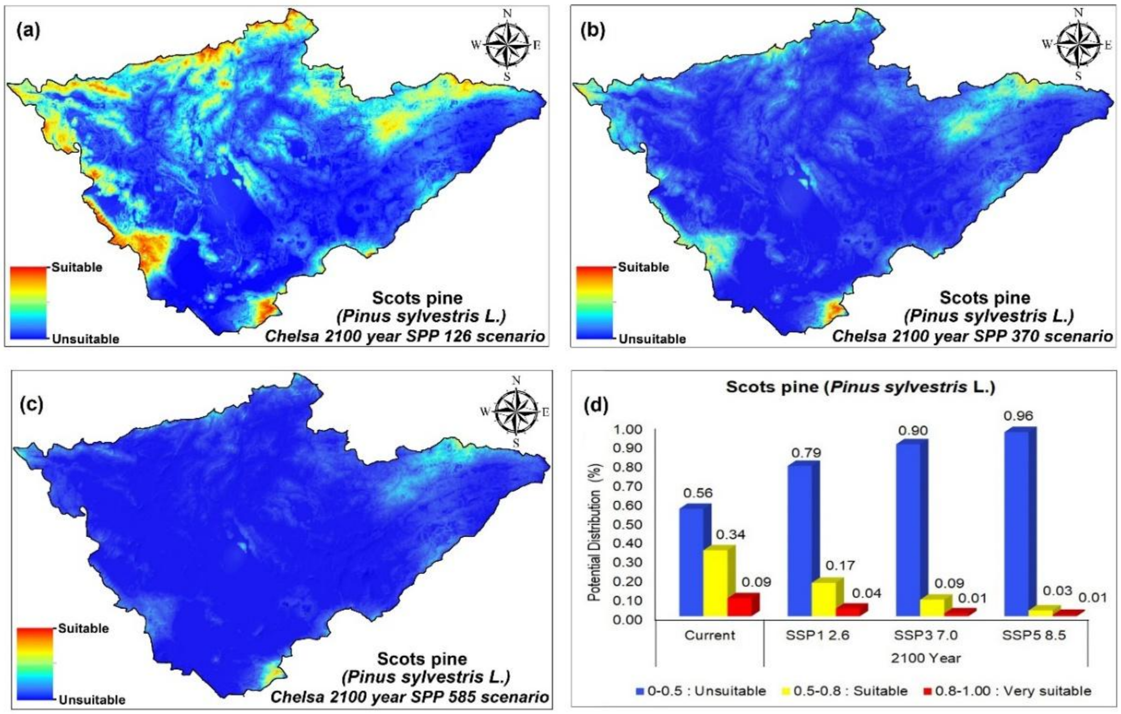

Fig. 7. Potential distribution maps for Scots pine in Central Anatolia, under current and future climate scenarios SSP1 2.6 (a), SSP3 7.0 (b), SSP5 8.5 (c) and Estimated potential distribution proportions for 2100 (d)

This study indicates remarkable habitat fragmentation in Scots pine population in Central Anatolia, particularly under SSP3 7.0 and SSP5 8.5, which further compounds the challenges for Scots pine by disrupting genetic flow and increasing the risk of inbreeding, thereby threatening populations resilience. Fragmented populations often exhibit reduced genetic diversity, leading to lower adaptive capacity and increased vulnerability to climate extremes and pests (Sánchez-Salguero *et al.* 2017; Dorado-Liñán *et al.* 2019). Dering *et al.* (2021) highlights the high genetic variability of Scots pine populations in the Caucasus, mirrored by their ecological uniqueness. Fragmentation reduces connectivity between habitat patches, hindering seed dispersal and ecological resilience. Naydenov *et al.* (2007) emphasizes the need to protect these relict populations by restricting seed transfers and prioritizing conservation efforts, as they represent a critical genetic reservoir and an essential component of the region's biodiversity. Fragmented populations often exhibit reduced genetic diversity, leading to inbreeding and decreased adaptive potential (Sánchez-Salguero *et al.* 2017; Dorado-Liñán *et al.* 2019). Additionally, fragmentation disrupts ecological interactions, such as ectomycorrhizal associations vital for nutrient uptake and tree health (Aleksandrowicz-Trzcinska *et al.* 2018). Edge effects in fragmented habitats further exacerbate vulnerabilities to pests, diseases, and climatic stressors (Jaime *et al.* 2019).

The distribution proportions shown in the bar graph (Fig. 7d) summarizing the potential distribution percentages and corroborate these patterns, highlights the quantitative impact of climate change on Scots pine distribution. Under current conditions, 34% of the area is classified as moderately suitable, while 9% is highly suitable. However, unsuitable areas already dominate, accounting for 56% of the landscape.

In the SSP1 2.6 scenario, moderately suitable areas decrease to 17%, while highly suitable areas drop to 4%. Unsuitable areas expand to 79%, indicating a substantial reduction in habitat quality despite optimistic emission reductions. In the SSP3 7.0 scenario, moderately suitable areas further decline to 9%, with highly suitable areas shrinking to 1%. Unsuitable areas dominate 90% of the region, reflecting the intensifying impact of climate change. The SSP5 8.5 scenario shows unsuitable areas accounting for 96% of the region. Moderate and highly suitable areas shrink to only 3% and 1%, respectively, emphasizing the unsustainable future for Scots pine under this scenario. Dering *et al.* (2021) also indicate a dramatic reduction in Scots pine habitats in Anatolia and Caucasus, with over 90% of the current distribution potentially lost under future climate scenarios. The present projections indicate an even more significant reduction in suitable habitats for Scots pine, particularly under SSP5 8.5 scenarios, with unsuitable habitats expanding to 96%, outpacing the reductions reported by both Dering *et al.* (2021) and Bulut and Aytaş (2023).

The findings of this study on Scots pine in Central Anatolia reveal a more severe reduction in future potential distribution compared to projections by Bulut and Aytaş (2023), despite overlapping geographic coverage. Both studies (Dering *et al.* 2021; Bulut and Aytaş 2023) indicate an expansion of unsuitable habitats and a decline in suitable areas under future climate scenarios, but the reductions projected in this study are significantly more pronounced. This study predicts a more significant reduction in suitable habitats for Scots pine compared to the findings of Bulut and Aytaş (2023), especially under the SSP5 8.5 scenario, with 96% of the area projected to become unsuitable by 2100. This difference may be due to the use in the present analysis of a more comprehensive dataset, higher-resolution climate projections, and the inclusion of additional topographical and ecological factors, such as elevation and roughness, which were not fully considered in previous studies. Furthermore, while Dering *et al.* (2021) emphasized the genetic uniqueness of Scots pine populations in the region, this study focuses on their ecological vulnerability and identifies specific mid-altitude refugia that could act as climate shelters. This refined analysis provides valuable insights for conservation planning, underscoring the need for targeted interventions in areas most likely to support Scots pine populations.

Comparisons with Arslan and Örücü (2019), Bulut and Aytaş (2023), and this study collectively offer valuable insights into the current and future distribution of Scots pine in Türkiye, albeit with differing methodologies and geographic focuses. Arslan and Örücü (2019) conducted a national-scale assessment using 34 presence data points, finding 87.1% of Türkiye unsuitable for Scots pine under current conditions, rising to 93.5% by 2070 under RCP 8.5. In contrast, Bulut and Aytaş (2023) focused on Inner Anatolia, with partial overlap in Central Anatolia. This study improves upon these efforts by using 158 presence data points to deliver a more detailed and robust analysis of Central Anatolia, a climatically marginal and ecologically critical region for Scots pine conservation. While Arslan and Örücü (2019) reported broad trends, their limited dataset may have underestimated regional variations, particularly in Central Anatolia, where this study reveals significantly higher current suitability (56% unsuitable) but a steeper decline under future scenarios (96% unsuitable by 2100 under SSP5 8.5).

The implications of habitat changes extend beyond distribution patterns, affecting Scots pine growth dynamics and ecological interactions. Projections align with previous studies (Bulut and Aytaş 2023; Ekberzade *et al.* 2024) that reported habitat contraction in low-altitude and southern regions, with high-altitude areas serving as potential refugia. Ekberzade *et al.* (2024) emphasize altitudinal shifts, identifying regions such as the Hakkari and Munzur Mountains (exceeding 3,000 meters) as potential refugia. However, these extreme elevations pose physiological challenges for Scots pine, which thrives in mesic, mid-altitude environments (1,500 to 2,500 meters). These regions may be less affected by extreme heat and aridity, providing a critical buffer for Scots pine populations. The findings of this study, supported by Dering *et al.* (2021), highlight the critical role of mid-altitude regions as primary refugia. Thus, high-altitude regions are unlikely to provide long-term refuge for Scots pine. Nevertheless, region-specific analysis and microclimatic considerations are essential to validate the potential of high-altitude areas for Scots pine conservation.

Beyond their ecological importance, Scots pine forests play a vital role in carbon sequestration and provide essential ecosystem services, especially in semi-arid and montane regions such as Central Anatolia. As a dominant coniferous species, Scots pine significantly contributes to carbon storage in both biomass and soil, aiding in mitigating climate change by absorbing atmospheric CO_2. However, the projected reduction in suitable habitats for Scots pine under the SSP3 7.0 and SSP5 8.5 scenarios poses a threat to this crucial function, potentially diminishing regional carbon sinks and worsening the impacts of climate change (Dyderski *et al.* 2018). Similar trends have been observed in boreal forests, where warming-induced changes in tree composition affect carbon dynamics, resulting in increased carbon release from soil respiration and disturbances such as wildfires and pest outbreaks (Hickler *et al.* 2012; Sánchez-Salguero *et al.* 2017). In addition to carbon sequestration, Scots pine forests offer critical ecosystem services, including soil stabilization, water regulation, and support for biodiversity. The loss of Scots pine habitats could lead to increased soil erosion and a decline in water retention capacity, further affecting regional hydrology and agricultural productivity. The socio-economic consequences of these ecosystem changes are particularly concerning for communities that depend on forest resources for timber production, non-timber forest products, and tourism-related activities. These findings highlight the urgent need to integrate climate-adaptive forest management strategies into broader environmental and economic policies to ensure long-term sustainability.

The findings of this study align with broader trends observed in marginal populations of Scots pine across Europe and Asia, where habitat loss due to climate change is altering species distributions. For instance, in the Iberian Peninsula, Scots pine populations in Mediterranean climatic zones are experiencing significant range contractions. This decline is primarily attributed to rising temperatures, prolonged droughts, and increased fire frequency (Sánchez-Salguero *et al*. 2017). Similar to the present work's projections for Central Anatolia, the research in Spain indicates that lowland and dry-edge populations of Scots pine are particularly vulnerable, with habitat suitability decreasing significantly under high-emission scenarios (López-Tirado and Hidalgo 2014). In contrast, some mid- and high-altitude populations in the Pyrenees and northern Spain have been identified as potential climate refugia, reflecting the present findings on the importance of mid-altitude refugia in Central Anatolia.

In the Caucasus region, Scots pine populations share similarities with those in Türkiye, as they are geographically isolated and genetically distinct. Research by Dering *et al.* (2021) suggests that over 90% of Scots pine habitats in the Caucasus could be lost by the end of the 21st century under high-emission scenarios, closely aligning with the present projections for Türkiye under SSP5 8.5. However, unlike Central Anatolia, where habitat fragmentation poses a significant challenge, the Caucasus benefits from larger forested refugia at higher elevations, which may enhance resilience against climate change. This indicates that while the vulnerability of Scots pine is consistent across different marginal populations, the extent of habitat loss and potential for survival varies based on regional topography and connectivity.

Additionally, Scots pine populations in semi-arid regions of Central Asia, such as Mongolia and the Altai Mountains, face similar challenges driven by drought. Wang *et al.* (2018) found that increased temperatures and seasonal variability in precipitation are key limiting factors for Scots pine persistence in these areas, highlighting the significance of Bio7 and Bio15, which emerged as the strongest climatic drivers in our study. These comparisons emphasize that while Scots pine has a broad ecological range, its survival in marginal environments highly depends on localized climatic and topographical conditions.

By integrating these broader findings, the present study provides valuable insights into the commonalities and regional differences affecting the future distribution of Scots pine. Understanding how marginal populations respond to climate change at various latitudes and elevations is crucial for developing targeted conservation strategies adaptable across different bioclimatic zones. Also, this study emphasizes the urgent need to integrate species distribution modeling into biodiversity policies and climate resilience frameworks. Given the projected habitat loss of up to 96% for Scots pine in Central Anatolia under high-emission scenarios, conservation strategies should focus on protecting mid-altitude refugia, establishing ecological corridors, and implementing adaptive afforestation programs. These measures align with Sustainable Development Goal 15 (SDG15), particularly in safeguarding forest genetic resources and promoting ecosystem resilience. Furthermore, the results contribute to ecosystem-based adaptation (EbA) efforts by identifying priority areas for climate-resilient forest management. Protecting Scots pine habitats not only mitigates biodiversity loss but also supports carbon sequestration, reinforcing the role of nature-based solutions (NbS) in climate adaptation strategies. These insights are critical for informing Türkiye’s National Biodiversity Strategy and Action Plan (NBSAP) and aligning regional forestry policies with global sustainability goals.

To mitigate the projected decline of Scots pine in Central Anatolia under climate change, conservation efforts should focus on protecting mid-altitude refugia (1.500 to 2.500 m) through legal safeguards and land-use restrictions, while establishing ecological corridors to enhance genetic connectivity *via* afforestation and landscape planning. Establishing ecological corridors is vital for maintaining connectivity between fragmented habitats, facilitating the movement of Scots pine and other tree species, including *Quercus* spp. These corridors facilitate gene flow, enhance biodiversity, and provide pathways for species migration in response to climate change (Hu *et al.* 2021). For Scots pine, which may face habitat fragmentation due to climate-induced shifts, these corridors can serve as essential lifelines, enabling populations to adapt to new environmental conditions and maintain genetic diversity. Selecting drought-tolerant genotypes for reforestation can improve resilience against increasing temperature variability and declining moisture availability. Fire risk mitigation strategies, including controlled burns, fuel load reduction, and firebreak creation, are essential to reduce wildfire susceptibility. Continuous monitoring using remote sensing, field surveys, and ecological modeling will enable adaptive management. Lastly, integrating these conservation strategies into national policies, such as Türkiye’s NBSAP and SDG15, will ensure long-term sustainability and alignment with global biodiversity commitments. For a detailed framework on conservation strategies derived from these model predictions, refer to the Appendix, Table A3.

While silvicultural treatments such as thinning and selective harvesting can enhance the resilience of Scots pine to climate change, their long-term effects remain uncertain, especially in the complex and variable environments of Central Anatolia. This study primarily has focused on the natural climatic and topographical factors that affect the distribution of Scots pine without explicitly addressing the impacts of forest harvesting or management practices. Removing competing tree species near Scots pine stands may create opportunities for local expansion. However, large-scale logging or unsustainable harvesting practices could worsen habitat fragmentation and heighten vulnerability to climate-related stressors (del Río *et al.* 2017). Given the unpredictability of these effects under changing climate conditions, forest management interventions have not been included in the conservation strategy. However, incorporating forest management scenarios into future modelling efforts would offer a more comprehensive understanding of how tree harvesting interacts with climate change and influences the distribution dynamics of Scots pine.

Future research should focus on testing adaptation strategies through field trials, including assisted migration experiments, drought-tolerant genotype selection, and mixed-species plantation trials in climate-vulnerable regions. Incorporating long-term monitoring of Scots pine populations across different elevations and microclimates will be essential to refine conservation priorities and improve resilience-based forest management strategies.

CONCLUSIONS

1. Scots pine in Central Anatolia faces significant challenges under future climate scenarios, as much of its current habitat is projected to become unsuitable. The region’s semi-arid conditions and limited availability of mesic habitats make it particularly

vulnerable, with up to 96% of its range predicted to be unsuitable by 2100 under SSP5 8.5. The steep reduction in potential distribution, coupled with increased fragmentation, poses significant challenges for the conservation and management of Scots pine populations in this region.

2. While extinction in lowland and semi-arid areas is highly probable, small populations may persist in isolated mid-altitude refugia (1.500 to 2.500 meters), such as the Ilgaz and Bolkar Mountains. However, these fragmented refugia are unlikely to sustain large or genetically diverse populations, increasing the risk of local extinction.
3. A natural northward shift toward cooler, wetter regions, such as the Black Sea Mountains, is theoretically possible but limited by habitat fragmentation, dispersal constraints, and competition from other species. Assisted migration to northern Türkiye, particularly to higher altitudes in the North Anatolian Mountains, could enhance the species' survival prospects.
4. These findings highlight the urgent need for adaptive conservation and sustainable forestry strategies to protect Scots pine in Türkiye. Key measures include habitat restoration, the establishment of ecological corridors, and the promotion of drought-tolerant genotypes to address the impacts of climate change. Conservation efforts should prioritize protecting and restoring mid-altitude and mesic areas, which have been identified as critical refuges for Scots pine. In forest management, incorporating mixed-species plantations that include drought-resistant hardwoods, such as *Quercus* spp. species, can enhance forest stability. Additionally, assisted migration of Scots pine to higher elevations may help ensure its persistence in a warming climate. Using species distribution modelling in forestry planning can optimize reforestation efforts, ensuring that forest adaptation measures align with long-term sustainability goals. Furthermore, it is essential to implement strategies that mitigate habitat fragmentation and maintain genetic diversity to safeguard the long-term viability of this species.
5. This research has emphasized the need for region-specific conservation planning that integrates local climatic and ecological factors, contributing to the broader discourse on forest adaptation and resilience in the face of global climate change.
6. Future research should incorporate additional variables, such as soil characteristics and biotic interactions, to refine species distribution models. Long-term monitoring of Scots pine populations and habitat dynamics is crucial to validate the projections and guide evidence-based interventions. This approach will not only enhance the understanding of Scots pine's ecological requirements but also inform global efforts to conserve forest biodiversity in the Anthropocene.

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REFERENCES CITED

Acarer, A. (2024a). "Brown bear (*Ursus arctos* L.) distribution model in Europe," *Šumarski list* 148(5-6), 1-12. DOI: 10.31298/sl.148.5-6.4

Acarer, A. (2024b). "Response of black pine (*Pinus nigra*) in Southwestern Anatolia to climate change," *BioResources* 19(4), 8594-8607. DOI: 10.15376/biores.19.4.8594-8607

Acarer, A. (2024c). "Role of climate change on Oriental spruce (*Picea orientalis* L.): Modeling and mapping," *BioResources* 19(2), 3845-3856. DOI: 10.15376/biores.19.2.3845-3856

Acarer, A., and Mert, A. (2024). "21st century climate change threatens on the brown bear," *Cerne* 30, e-103305. DOI: 10.1590/01047760202430013305

Aleksandrowicz-Trzcinska, M., Szaniawski, A., Studnicki, M., Bederska-Blaszczyk, M., Olchowik, J., Urban, A., *et al.* (2018). "The effect of silver and copper nanoparticles on the growth and mycorrhizal colonisation of Scots pine (*Pinus sylvestris* L.) in a container nursery experiment," *iForest-Biogeosciences* 11(5), 690. DOI: 10.3832/ifor2855-011.

Altın, T. B., Barak, B., and Altın, B. N. (2012). "Change in precipitation and temperature amounts over three decades in central Anatolia, Turkey," *Atmospheric Climate Sciences* 2(1), 107-125. DOI: 10.4236/acs.2012.21013

Arslan, S. E., and Örücü, Ö. (2019). "Present and future potential distribution of the *Pinus nigra* Arnold and *Pinus sylvestris* L. using maxent model," *International Journal of Ecosystems Ecology Sciences* 9(4), 787-798. DOI: 10.31407/ijees9425

Astuti, I., Yudaputra, A., Rinandio, D. S., and Yuswandi, A. (2021). "Biogeographical distribution model of flowering plant *Capparis micracantha* using support vector machine (SVM) and generalized linear model (GLM) and its *ex-situ* conservation efforts," *International Journal on Advanced Science Engineering Information Technology*, 11(6), 2328. DOI: 10.18517/ijaseit.11.6.14582

Atalay, İ. (2023). "Native occurrence areas of Anatolian Scots pine (*Pinus sylvestris* L. var. sylvestris) forests and their vegetation composition in Anatolia, Türkiye," *Turkish Journal of Forestry Research* 10(2), 182-196. DOI: 10.17568/ogmoad.1313237.

Atalay, I., Efe, R., and Öztürk, M. (2014). "Ecology and classification of forests in Turkey," *Procedia-Social Behavioral Sciences* 120, 788-805. DOI: 10.1016/j.sbspro.2014.02.163

Bueis, T., Bravo, F., Pando, V., Turrión, M.-B., and Forestry (2016). "Relationship between environmental parameters and *Pinus sylvestris* L. site index in forest plantations in northern Spain acidic plateau," *iForest-Biogeosciences* 9(3), 394. DOI: 10.3832/ifor1600-008.

Bulut, S., and Aytaş, İ. (2023). "Modeling potential distribution and above-ground biomass of Scots pine (*Pinus sylvestris* L.) forests in the Inner Anatolian Region, Türkiye," *Environmental Monitoring Assessment* 195(12), 1471. DOI: 10.1007/s10661-023-12101-z.

Cantürk, U., Koç, İ., Özel, H. B., and Şevik, H. (2024). "Possible changes of *Pinus nigra* distribution regions in Türkiye with the impacts of global climate change," *BioResources* 19(3), 6190-6214. DOI: 10.15376/biores.19.3.6190-6214

CHELSA (2024). "Climatologies at high resolution for the earth's land surface areas," (https://chelsa-climate.org/), accessed on November 24, 2024.

Cobos, M. E., Peterson, A. T., Barve, N., and Osorio-Olvera, L. (2019). "kuenm: An R package for detailed development of ecological niche models using Maxent," *PeerJ* 7, e6281.

Çıvğa, A. (2025). "Unlocking the habitat suitability of wild olive to improve its industrial potential: A comprehensive distribution modeling study," *BioResources* 20(1), 1214-1229. DOI: 10.1536/biores.20.1.1214-1229

del Río, M., Bravo-Oviedo, A., Pretzsch, H., Löf, M., and Ruiz-Peinado, R. (2017). "A review of thinning effects on Scots pine stands: From growth and yield to new challenges under global change," *Forest Systems* 26(2), eR03S. DOI:10.5424/fs/2017262-11325

Dering, M., Baranowska, M., Beridze, B., Chybicki, I., Danelia, I., Iszkuło, G., *et al.* (2021). "The evolutionary heritage and ecological uniqueness of Scots pine in the Caucasus ecoregion is at risk of climate changes," *Scientific Reports* 11(1), 22845. DOI: 10.1038/s41598-021-02098-1

Dorado-Liñán, I., Piovesan, G., Martínez-Sancho, E., Gea-Izquierdo, G., Zang, C., Cañellas, I., Castagneri, D., Di Filippo, A., Gutierrez, E., Ewald, J., *et al.* (2019). "Geographical adaptation prevails over species-specific determinism in trees' vulnerability to climate change at Mediterranean rear-edge forests," *Global Change Biology* 25(4), 1296-1314. DOI: 10.1111/gcb.14544

Dufour, A., Gadallah, F., Wagner, H. H., Guisan, A., and Buttler, A. (2006). "Plant species richness and environmental heterogeneity in a mountain landscape: effects of variability and spatial configuration," *Ecography* 29(4), 573-584. DOI: 10.1111/j.0906-7590.2006.04605.x

Durkaya, A., Durkaya, B., and Ulu Say, Ş. (2016). "Below-and above ground biomass distribution of young Scots pines from plantations and natural stands," *Bosque* 37(3), 509-518. DOI: 10.4067/S0717-92002016000300008

Durrant, T. H., De Rigo, D., and Caudullo, G. (2016). "*Pinus sylvestris* in Europe: distribution, habitat, usage and threats," *J European Atlas of Forest Tree Species* 14, 845-846.

Dyderski, M. K., Paź, S., Frelich, L. E., and Jagodziński, A. M. (2018). "How much does climate change threaten European forest tree species distributions?," *Global Change Biology* 24(3), 1150-1163. DOI: 10.1111/gcb.13925

Ekberzade, B., Yetemen, O., Ezber, Y., Sen, O. L., and Dalfes, H. N. (2024). "Latitude or altitude as the future refugium? A case for the future of forests in Asia Minor and its surroundings," *Ecology Evolution* 14(4), e11131. DOI: 10.1002/ece3.11131.

Fernández-Pérez, L., Zavala, M. A., Villar-Salvador, P., and Madrigal-González, J. (2019). "Divergent last century tree growth along an altitudinal gradient in a *Pinus sylvestris* L. dry-edge population," *Forests* 10(7), 532. DOI: 10.3390/f10070532

Fielding, A. H., and Bell, J. F. (1997). "A review of methods for the assessment of prediction errors in conservation presence/absence models," *Environmental Conservation* 24(1), 38-49. DOI: 10.1017/S0376892997000088

Garzon, M. B., Blazek, R., Neteler, M., De Dios, R. S., Ollero, H. S., and Furlanello, C. (2006). "Predicting habitat suitability with machine learning models: the potential area of *Pinus sylvestris* L. in the Iberian Peninsula," *Ecological Modelling* 197(3-4), 383-393. DOI: 10.1016/j.ecolmodel.2006.03.015

GBIF (2024). (https://www.gbif.org/2024), Accessed on November 24, 2024.

Gritti, E. S., Gaucherel, C., Crespo-Perez, M.-V., and Chuine, I. (2013). "How can model comparison help improving species distribution models?," *PLOS One* 8(7), e68823.

DOI: 10.1371/journal.pone.0068823

Gücel, S., Özkan, K., Celik, S., Yuecel, E., and Oeztuerk, M. (2008). "An overview of the geobotanical structure of Turkish *Pinus sylvestris* and *Carpinus betulus* forests," *Pakistan Journal of Botany* 40(4), 1497-1520.

Hereş, A.-M., Martínez-Vilalta, J., and Claramunt López, B. (2012). "Growth patterns in relation to drought-induced mortality at two Scots pine (Pinus sylvestris L.) sites in NE Iberian Peninsula," *Trees* 26, 621-630. DOI: 10.1007/s00468-011-0628-9

Hickler, T., Vohland, K., Feehan, J., Miller, P. A., Smith, B., Costa, L., Giesecke, T., Fronzek, S., Carter, T. M., Cramer, W., *et al.* (2012). "Projecting the future distribution of European potential natural vegetation zones with a generalized, tree species-based dynamic vegetation model," *Global Ecology Biogeography* 21(1), 50-63. DOI: 10.1111/j.1466-8238.2010.00613.x

Hu, J., Liu, Y., and Fang, J. (2021). "Ecological Corridor construction based on least-cost modeling using visible Infrared imaging radiometer suite (VIIRS) nighttime light data and normalized difference vegetation index," *Land* 10(8), 782. DOI: 10.3390/land10080782

Jaime, L., Batllori, E., Margalef-Marrase, J., Navarro, M. Á. P., Lloret, F., and Management (2019). "Scots pine (*Pinus sylvestris* L.) mortality is explained by the climatic suitability of both host tree and bark beetle populations," *Forest Ecology Management* 448, 119-129. DOI: 10.1016/j.foreco.2019.05.070

Janecka, K., Harvey, J. E., Trouillier, M., Kaczka, R. J., Metslaid, S., Metslaid, M., *et al.* (2020). "Higher winter-spring temperature and winter-spring/summer moisture availability increase Scots pine growth on coastal dune microsites around the South Baltic Sea," *Frontiers in Forests Global Change Biology* 3, 578912. DOI: 10.3389/ffgc.2020.578912

Kalayci Kadak, M., Ozturk, S., and Mert, A. (2024). "Predicting climate-based changes of landscape structure for Turkiye *via* global climate change scenarios: A case study in Bartin river basin with time series analysis for 2050," *Natural Hazards* 1-19. DOI: 10.1007/s11069-024-06706-x

Karger, D., Nobis, M. P., Normand, S., Graham, C. H., and Zimmermann, N. E. (2023). "CHELSA-TraCE21k-high-resolution (1 km) downscaled transient temperature and precipitation data since the Last Glacial Maximum," *Climate of the Past* 19(2), 439-456. DOI: 10.5194/cp-19-439-2023.

Kearney, M. R., Wintle, B. A., and Porter, W. P. (2010). "Correlative and mechanistic models of species distribution provide congruent forecasts under climate change," *Conservation Letters* 3(3), 203-213. DOI: 10.1111/j.1755-263X.2010.00097.x

Khattak, R. H., Teng, L., Ahmad, S., Bari, F., Rehman, E. U., Shah, A. A., and Liu, Z. (2022). "In pursuit of new spaces for threatened mammals: Assessing habitat suitability for Kashmir Markhor (*Capra falconeri cashmeriensis*) in the Hindukush Range," *Sustainability* 14(3), 1544. DOI: 10.3390/su14031544

Kıraç, A., and Mert, A. (2019). "Will Danford's lizard become extinct in the future," *Polish Journal of Environmental Studies* 28(3), 1741-1748. DOI: 10.15244/pjoes/89894

Körner, C., (2007). "The use of 'altitude'in ecological research," *Trends in Ecology and Evolution* 22(11), 569-574. DOI: 10.1016/j.tree.2007.09.006

López-Tirado, J., and Hidalgo, P. J. (2014). "A high resolution predictive model for relict trees in the Mediterranean-mountain forests (*Pinus sylvestris* L., *P. nigra* Arnold and *Abies pinsapo* Boiss.) from the south of Spain: A reliable management tool for reforestation,” *Forest Ecology Management* 330, 105-114. DOI: 10.1016/j.foreco.2014.07.009

Merow, C., Smith, M. J., and Silander Jr, J. A. (2013). "A practical guide to MaxEnt for modeling species' distributions: what it does, and why inputs and settings matter,” *Ecography* 36(10), 1058-1069. DOI: 10.1111/j.1600-0587.2013.07872.x

Naydenov, K., Senneville, S., Beaulieu, J., Tremblay, F., and Bousquet, J. (2007). "Glacial vicariance in Eurasia: Mitochondrial DNA evidence from Scots pine for a complex heritage involving genetically distinct refugia at mid-northern latitudes and in Asia Minor,” *J BMC Evolutionary Biology* 7, 1-12. DOI: 10.1186/1471-2148-7-233

Orhan, F. (2021). *Determination of Decomposer Fungal Communities in Early Stages of Scots Pine (Pinus sylvestris L.) Needle- Litter Decomposition,* Master’s Thesis, Çankırı Karatekin University, Çankırı, Türkiye.

Oruç, M. S., Mert, A., and Özdemir, İ. (2017). "Modelling habitat suitability for red deer (*Cervus elaphus* L.) using environmental variables in Çatacık region,” *Bilge International Journal of Science Technology Research* 1(2), 135-142.

Oskay, F., Çakır, F., and Çakır, M. (2024). "Fungal Communities of Scots Pine Needles from a Marginal, Understudied Population in Türkiye,” *BioResources* 19(4). DOI: 10.15376/biores.19.4.9560-9581

Özcan, A. U., Gülçin, D., Tuttu, G., Velázquez, J., Ayan, S., Stephan, J., *et al.* (2024). "The future possible distribution of Kasnak Oak (*Quercus vulcanica* Boiss. and Heldr. ex Kotschy) in Anatolia under climate change scenarios,” *Forests* 15(9), 1551. DOI: 10.3390/f15091551

Özdemir, S., Gülsoy, S., and 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. DOI: 10.17475/kastorman.801847

Sağlam, F., and Sakici, O. E. (2024). "Dynamic site index models sensitive to ecoregional variability for Scots pine stands in Western Black Sea Region of Türkiye,” *Environmental Monitoring Assessment* 196(11), 1034. DOI: 10.1007/s10661-024-13189-7

Sakici, O. E., Özcan, G. E., Seki, M., and Sağlam, F. (2023). "The effects of pine mistletoe (*Viscum album* subsp. austriacum) on the growth of Scots pine and Crimean pine in Turkey,” *Forest Pathology* 53(2), e12802. DOI: 10.1111/efp.12802

Sánchez-Salguero, R., Camarero, J. J., Gutiérrez, E., Gonzalez Rouco, F., Gazol, A., Sangüesa-Barreda, G., *et al.* (2017). "Assessing forest vulnerability to climate warming using a process-based model of tree growth: Bad prospects for rear-edges,” *Global Change Biology* 23(7), 2705-2719. DOI: 10.1111/gcb.13541

Suel, H. (2019). "Brown bear (*Ursus arctos*) habitat suitability modelling and mapping,” *Applied Ecology Environmental Research* 17(2). DOI: 10.15666/aeer/1702_42454255

Suel, H., Mert, A., and Yalcinkaya, B. (2018). "Changing potential distribution of Gray wolf under climate change in Lake District, Turkey,” *Applied Ecology Environmental Research* 16(5). DOI: 10.15666/aeer/1605_71297137

Swets, J. A. (1988). "Measuring the accuracy of diagnostic systems,” *Science* 240(4857), 1285-1293. DOI: 10.1126/science.3287615

Takolander, A., Hickler, T., Meller, L., and Cabeza, M. (2019). "Comparing future shifts in tree species distributions across Europe projected by statistical and dynamic process-based models,” *Regional Environmental Change* 19, 251-266. DOI: 10.1007/s10113-018-1403-x

Tekin, S., Yalçınkaya, B., Acarer, A., and Mert, A. (2018). "A research on usage possibilities of satellite data in wildlife: Modeling habitat suitability of Roe deer (*Capreolus capreolus* L.) with MaxEnt," *Bilge International Journal of Science Technology Research* 2(2), 147-156. DOI: 10.30516/bilgesci.399017

Topaçoğlu, O., and Genç, E. (2019). "Forest edge effects on seedlings in mixed Oriental beech (*Fagus orientalis* Lipsky)-Scots pine (*Pinus sylvestris* L.) stands," *Applied Ecology Environmental Research* 17(2). DOI: 10.15666/aeer/1702_22192231

Tóth, E. G., Köbölkuti, Z. A., Pedryc, A., and Höhn, M. (2017). "Evolutionary history and phylogeography of Scots pine (*Pinus sylvestris* L.) in Europe based on molecular markers," *Journal of Forestry Research* 28(4), 637-651. DOI: 10.1007/s11676-017-0393-8

Townsend Peterson, A., Papeş, M., and Eaton, M. (2007). "Transferability and model evaluation in ecological niche modeling: A comparison of GARP and Maxent," *Ecography* 30(4), 550-560. DOI: 10.1111/j.0906-7590.2007.05102.x

Tuğaç, M. G., Özbayoğlu, A. M., Torunlar, H., and Karakurt, E. (2022). "Wheat yield prediction with machine learning based on MODIS and landsat NDVI data at field scale," *International Journal of Environment Geoinformatics* 9(4), 172-184. DOI: 10.30897/ijegeo.1128985

Tunç, T. (2019). *Litter Decomposition in Different Development Stage of Anatolian Black Pine Stands in Çankiri-Eldivan Region*, Master's Thesis, Çankırı Karatekin University, Çankırı, Türkiye.

Ursavaş, S., and Edis, S. (2024). "Environmental and topographical factors influencing moss distribution in semi-arid regions: A study of Çankırı-Eldivan Mountain," *Anatolian Bryology* 10(2), 179-190. DOI: 10.26672/anatolianbryology.1594697

Vospernik, S., Vigren, C., Morin, X., Toigo, M., Bielak, K., Brazaitis, G., Bravo, F., Heym, M., del Rio, M., Jansons, A., *et al.* (2024). "Can mixing *Quercus robur* and *Quercus petraea* with *Pinus sylvestris* compensate for productivity losses due to climate change?," *Science of the Total Environment* 942, 173342. DOI: 10.1016/j.scitotenv.2024.173342

Wang, R., Li, Q., He, S., Liu, Y., Wang, M., and Jiang, G. (2018). "Modeling and mapping the current and future distribution of *Pseudomonas syringae* pv. actinidiae under climate change in China," *PLOS One* 13(2), e0192153. DOI: 10.1371/journal.pone.0192153

Warren, D. L., and Seifert, S. N. (2011). "Ecological niche modeling in Maxent: the importance of model complexity and the performance of model selection criteria," *Ecological Applications* 21(2), 335-342. DOI: 10.1890/10-1171.1

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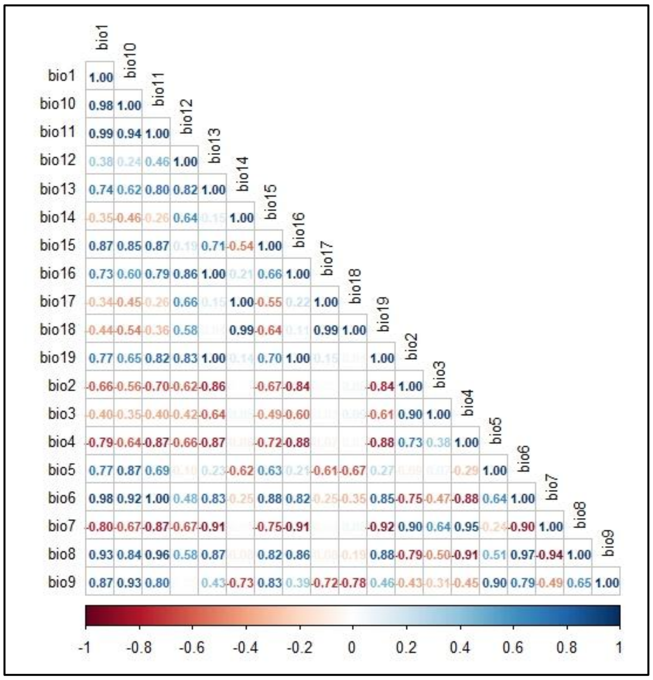
APPENDIX



	bio1	bio10	bio11	bio12	bio13	bio14	bio15	bio16	bio17	bio18	bio19	bio2	bio3	bio4	bio5	bio6	bio7	bio8	bio9
bio1	1.00																		
bio10	0.98	1.00																	
bio11	0.99	0.94	1.00																
bio12	0.38	0.24	0.46	1.00															
bio13	0.74	0.62	0.80	0.82	1.00														
bio14	-0.35	-0.46	-0.26	0.64	0.15	1.00													
bio15	0.87	0.85	0.87	0.19	0.71	-0.54	1.00												
bio16	0.73	0.60	0.79	0.86	1.00	0.21	0.66	1.00											
bio17	-0.34	-0.45	-0.26	0.66	0.15	1.00	-0.55	0.22	1.00										
bio18	-0.44	-0.54	-0.36	0.58	[illegible]	0.99	-0.64	0.11	0.99	1.00									
bio19	0.77	0.65	0.82	0.83	1.00	0.14	0.70	1.00	0.15	[illegible]	1.00								
bio2	-0.66	-0.56	-0.70	-0.62	-0.86		-0.67	-0.84	[illegible]	[illegible]	-0.84	1.00							
bio3	-0.40	-0.35	-0.40	-0.42	-0.64	[illegible]	-0.49	-0.60	[illegible]	[illegible]	-0.61	0.90	1.00						
bio4	-0.79	-0.64	-0.87	-0.66	-0.87	[illegible]	-0.72	-0.88	[illegible]	[illegible]	-0.88	0.73	0.38	1.00					
bio5	0.77	0.87	0.69	[illegible]	0.23	-0.62	0.63	0.21	-0.61	-0.67	0.27	[illegible]	[illegible]	-0.29	1.00				
bio6	0.98	0.92	1.00	0.48	0.83	-0.25	0.88	0.82	-0.25	-0.35	0.85	-0.75	-0.47	-0.88	0.64	1.00			
bio7	-0.80	-0.67	-0.87	-0.67	-0.91		-0.75	-0.91	[illegible]	[illegible]	-0.92	0.90	0.64	0.95	-0.24	-0.90	1.00		
bio8	0.93	0.84	0.96	0.58	0.87	[illegible]	0.82	0.86	[illegible]	-0.19	0.88	-0.79	-0.50	-0.91	0.51	0.97	-0.94	1.00	
bio9	0.87	0.93	0.80		0.43	-0.73	0.83	0.39	-0.72	-0.78	0.46	-0.43	-0.31	-0.45	0.90	0.79	-0.49	0.65	1.00

Fig. A1. Pearson correlation analysis results for climate variables

Table A1. Cumulative Variance Explained by Principal Component Analysis

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	Variance%	Cumulative %	Total	Variance %	Cumulative %
1	9.273	53.435	53.435	9.273	53.435	53.435
2	5.093	26.860	73.295	5.093	26.860	73.295
3	2.551	12.372	82.667	2.551	12.372	82.667
4	1.327	5.509	96.177	1.327	5.509	96.177
5	0.221	1.165	99.142			
6	0.096	0.348	99.390			
7	0.021	0.108	99.698			
8	0.012	0.062	99.860			
9	0.008	0.044	99.904			
10	0.007	0.039	99.943			
11	0.005	0.025	99.968			
12	0.002	0.013	99.981			
13	0.001	0.007	99.988			
14	0.001	0.005	99.993			
15	0.001	0.003	99.997			
16	0.000	0.003	99.999			
17	0.000	0.001	100.000			
18	4.134E-16	2.176E-15	100.000			
19	-9.124E-16	-4.802E-15	100.000			

Table A2. Representative Component Table for Chelsa Climate Variables

Parameters	Component			
	1	2	3	4
bio1	0.764	0.610	0.106	0.172
bio2	-0.734	0.289	**0.573**	-0.189
bio3	-0.669	0.287	0.566	-0.215
bio4	-0.804	0.231	0.471	-0.046
bio5	0.326	0.246	0.497	0.087
bio6	0.795	0.392	-0.105	0.174
bio7	-0.767	**0.794**	0.568	-0.128
bio8	0.835	0.304	0.048	0.112
bio9	0.653	0.697	0.238	0.165
bio10	0.636	0.713	0.242	0.157
bio11	0.866	0.473	-0.014	0.145
bio12	0.532	-0.708	0.429	0.145
bio13	0.694	-0.639	0.324	-0.025
bio14	-0.597	-0.289	0.128	**0.724**
bio15	**0.895**	-0.209	0.100	-0.382
bio16	0.681	-0.630	0.370	-0.026
bio17	-0.596	-0.355	0.175	0.692
bio18	0.681	-0.630	0.370	-.026
bio19	0.668	-0.632	0.386	-.026

Table A3. Practical Conservation Actions for Scots Pine Under Climate Change*

Conservation Action	**Objective**	**Implementation Considerations**
Protecting Mid-Altitude Refugia	Preserve Scots pine populations in climatically stable mid-altitude regions (1,500–2,500 m).	Identify priority conservation zones, enforce legal protections, and restrict land-use changes in these areas.
Establishing Ecological Corridors	Enhance genetic connectivity between fragmented populations.	Develop afforestation projects linking isolated stands, ensure habitat continuity in landscape planning.
Drought-Tolerant Genotype Selection	Improve Scots pine resilience to increasing temperature seasonality and declining moisture availability.	Conduct genetic studies, select drought-resistant variants for reforestation and afforestation programs.
Fire Risk Mitigation Strategies	Reduce wildfire susceptibility in Scots pine habitats under climate change.	Implement controlled burns, reduce fuel loads, create firebreaks, and establish early warning systems.
Monitoring and Adaptive Management	Track habitat shifts and adjust conservation strategies based on real-time environmental data.	Use remote sensing, field surveys, and ecological modeling to inform adaptive forest management.
Policy Integration and Land Use Planning	Align conservation strategies with national and international biodiversity policies.	Incorporate Scots pine conservation into Türkiye’s National Biodiversity Strategy and Action Plan (NBSAP) and Sustainable Development Goal 15 (SDG15).

*Note: This supplementary material outlines key conservation strategies to mitigate the projected decline of Scots pine in Central Anatolia under climate change scenarios. This table presents these conservation actions along with their objectives and implementation considerations.