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An isolated population of relict *Pterocarya fraxinifolia* at the NW limit of its distribution range

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Abstract: Since the mid-Miocene, climatic cooling and Quaternary climatic oscillations have significantly reduced plant diversity. Consequently, Cenozoic plant communities across the Northern Hemisphere experienced range contractions, surviving as relict floras in southern refugia. Anatolia has served as a critical refugium during Pleistocene glaciations due to its geographic and paleoclimatic features, thus maintaining a rich relict flora. This study evaluates the overlooked population of the Cenozoic relict tree *Pterocarya fraxinifolia* along the Panayır River in Northwestern Thrace, Türkiye, addressing the anthropogenic and environmental threats impacting this disjunct population. Field surveys were conducted in 2024 to examine the population, outline its floristic composition, and assess associated threats. Furthermore, the climatic characteristics of the habitat were evaluated using high-resolution CHELSA climate data, which were validated against local meteorological station records through regression analyses and error metrics in R. This population is notable because it represents the westernmost known distribution of the species and is the closest population to Europe, where it formed part of mixed evergreen and deciduous forests during the Miocene and Pliocene periods. This small population is strictly restricted to the main course of the river and is established on the alluvial soils overlying the Quaternary alluvial deposits. This small area is surrounded with a plant community dominated by moisture-demanding species, highlighting the tree's strong reliance on humid riparian environments. The Panayır River dunes and their surrounding landscape has already been proposed for protection in the literature due to its habitat diversity, biodiversity, and the presence of threatened rare and endemic species. Additionally, it is home to one of the rare remaining populations of the important relict species *Pterocarya fraxinifolia* in Anatolia. Despite the threats posed by summer visitors, litter, overgrazing, logging, potential sea level rise, and the proposed nuclear power plant, the Panayır River lacks any formal protection status. Relict plant species offer valuable insights into both past and present evolutionary and biogeographical processes; therefore, the conservation of the Panayır River population is of vital importance due to these critical ecological and research aspects.

Keywords: Caucasian wingnut, riparian forest, conservation priority, Northwestern Thrace, Anatolia

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Introduction

The Earth's climate has undergone continuous fluctuations driven by internal and external forces, influencing the evolution and spatial distribution of plant species. Despite periods of climatic optimum during the Cenozoic, the era is largely defined by a progressive temperature decline (Mosbrugger et al., 2005; Tiffney & Manchester, 2001; Zachos et al., 2001). From around 15 million years ago, this trend contributed to a loss in temperate and subtropical plant diversity across the Northern Hemisphere, leading to a southward retreat into refugia that retained warm and humid conditions (Pound et al., 2012; Pound & Salzmann, 2017; Utescher et al., 2007). Furthermore, during the Pleistocene epoch, the climate oscillated between warm interglacial periods and cold glacial periods (Epica community members, 2004; Jouzel et al., 2007; Lisiecki & Raymo, 2007). As a result of these changes, some plants lost their distribution ranges, while others persisted in refugial areas with suitable climatic conditions (Hampe & Jump, 2011; Jackson & Weng, 1999; Ordonez & Svenning, 2016; Svenning et al., 2015). Consequently, plant communities that were once widely distributed across the Northern Hemisphere throughout the Cenozoic era became relict floras due to the contraction of their range. These relict plants have persisted in refugial areas located in southeastern and western North America, East Asia, and southwestern Eurasia (Milne & Abbott, 2002).

Anatolia is distinguished by its rich flora and high level of endemism. This remarkable biodiversity can be attributed to the region's geographical location, paleoclimatic history, and geomorphological complexity (Avcı, 2005; Davis, 1971; Noroozi et al., 2021; Zohary, 1973). These characteristics have made Anatolia an important refuge for plants over the years, including during the Pleistocene glacial periods (Médail & Diadema, 2009). Consequently, relict species such as *Pterocarya fraxinifolia* (Poir.) Spach, *Zelkova carpinifolia* (Pall) K. Koch (Bétrisey et al., 2018; Koç et al., 2024; Novák et al., 2024), *Quercus pontica* K. Koch (Menitsky, 2005; Strijk & Carrero, 2020), and *Liquidambar orientalis* Mill. (Günal, 1994; Koç et al., 2026; Ozdilek et al., 2012; Öztürk et al., 2008) contribute significantly to the diversity of Anatolia's flora.

Tertiary relicts are long-lived phylogenetic lineages that have endured changing environmental conditions, including long-term climatic fluctuations, over millions of years. As such, they are considered extant representatives of ancient floras. These relict taxa offer valuable insights into both historical and contemporary evolutionary and biogeographical processes (Kozlowski & Gratzfeld, 2013). In this context, Song et al. (2020) demonstrated that the disjunct distribution of *Pterocarya* between East Asia and southwestern Eurasia was shaped by the formation of the Gobi Desert and climatic cooling in northern Siberia during the Miocene, which fragmented the once continuous distribution of the genus. Thus, it is crucial to conduct comprehensive studies on relict species distributions and to ensure the conservation of known populations. Therefore, the aim of this study is to examine the distribution pattern of a previously known but unstudied population of the Tertiary relict tree *Pterocarya fraxinifolia* (Juglandaceae) in Northwestern Thrace, Türkiye, and to assess the threats facing this population. This population is notable for representing the westernmost known limit of its distribution, and is the closest population to Europe, where it formed a component of mixed evergreen and deciduous forests during the Miocene and Pliocene (Jiménez-Moreno & Suc, 2007; Magri et al., 2017; Popescu et al., 2010). Leroy et al. (2023) interpreted the absence of *Pterocarya* in modern and Holocene pollen records as evidence of its Pleistocene extinction in the Marmara Region and Europe. However, local sedimentary archives frequently fail to detect the species even when populations are present nearby (Bottema et al., 1993; Karlıoğlu Kılıç, 2019; Karlıoğlu Kılıç et al., 2020; Leroy et al., 2009; Yılmaz Dağdeviren & Karlıoğlu Kılıç, 2023; Yılmaz Dağdeviren et al., 2024). Conversely, Late Holocene *Pterocarya* pollen in Bulgarian marine sediments (Filipova-Marinova et al., 2024) might reflect the presence of Thracian populations such as the Panayır locality, or indicate transport from eastern populations, though counter-clockwise Black Sea currents (Oğuz et al., 1993) make the latter less probable. Therefore, asserting regional extinction based purely on local pollen absence is requires cautious interpretation. This absence in local archives is likely driven by geomorphological barriers, which may restrict wind-driven pollen dispersal (Maharramova et al., 2018). The North Anatolian Fault Zone's heterogeneous landscape (Okay et al., 2000; Şengör et al., 2005) and the deeply entrenched river valleys of Thrace (Turoğlu, 2014) act as physical barriers that may substantially constrain horizontal pollen flow. Situated inside such a deep valley, the Panayır population is topographically confined, which likely prevents its pollen from reaching regional archives. Furthermore, Çetin et al. (2025) observed that Düzce and Samsun populations diverge phylogenetically, suggesting that the western Black Sea region might harbor independent refugia. Given these complex dynamics, the origin of the Panayır population, which represents the absolute westernmost limit of the species, holds great biogeographical importance. However, this study does not involve genetic or molecular analyses. Instead, we investigate this isolated population independently to reveal its ecological characteristics, associated plant species, and conservation status, simply because its

severe isolation and potential historical value make it a critical priority for protection.

Riparian forests function as moisture-buffered ecological corridors that may serve as microrefugia under past and ongoing climatic fluctuations. Their stable hydrological conditions enable the persistence of relict and thermophilous species, contributing significantly to regional biogeographic continuity. Prior to this study, the distribution of *P. fraxinifolia* in Türkiye was considered to be restricted solely to the Anatolian side (Sabbagh et al., 2025), with its westernmost limit documented at Karadere, south of İzmit (Yaltırık, 1982). The Panayır River population is located approximately 205 km from this locality, indicating a geographically isolated western distribution. Such marked spatial discontinuity suggests that western populations persist as isolated remnants rather than forming a continuous range. Despite its biogeographical significance, this population has received little attention in the literature. The present study therefore provides a field-based assessment of this overlooked population, establishing baseline information on its ecological context and conservation needs.

Material and Methods

Pterocarya fraxinifolia and new location

Pterocarya is a Tertiary relict genus comprising six species of deciduous trees distributed in Southwestern Eurasia and Southeastern Asia. While five of the six are found in Southeastern Asia, *P. fraxinifolia* is the sole representative in Southwestern Eurasia (Kozlowski et al., 2018; Yaltırık, 1982). *P. fraxinifolia* is distributed along the eastern coast of the Black Sea in Georgia, on the southern slopes of the Greater Caucasus, in the Talysh Mountains of Azerbaijan, and along the southern coasts of the Caspian Sea, including the Elburz Mountains in Iran (Bétrisey et al., 2019; Browicz & Zieliński, 1982; Kozlowski et al., 2018). Additionally, there is an isolated population present in the Zagros Mountains (Akhani & Salimian, 2003) in Iran and in Türkiye, it is distributed in fragmented and restricted areas in both Northern and Southeastern Anatolia (Fig. 1; Avşar & Ok, 2004; Yaltırık, 1982).

In addition to its known distribution in Anatolia, there is a disjunct population in the Panayır River in Northwestern Thrace. Although this population has

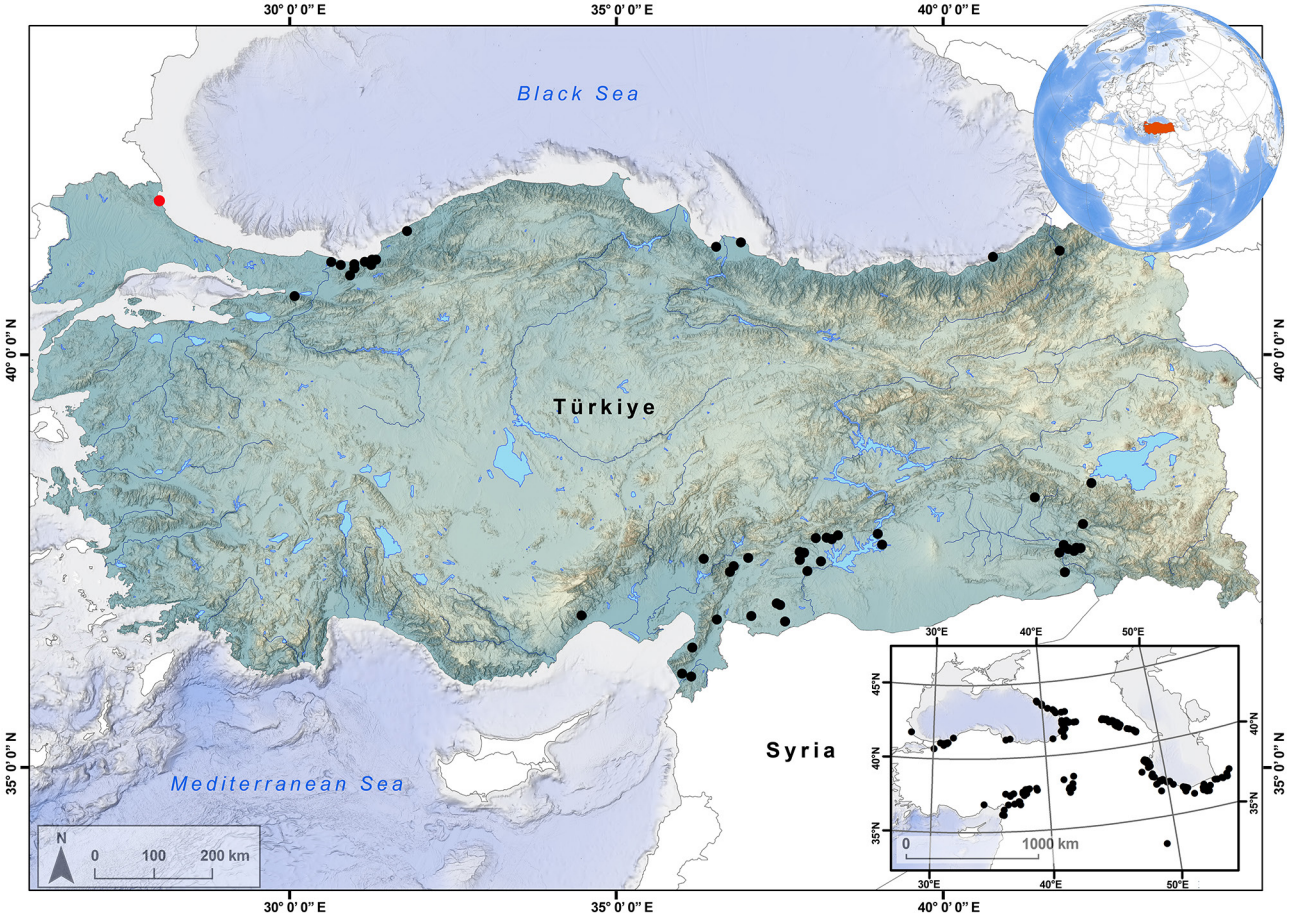


Fig. 1. Distribution map of *Pterocarya fraxinifolia* across Anatolia and its global range. The main map displays the regional distribution within Anatolia; red dot represents the disjunct Panayır River population. The inset map illustrates the global distribution records of the species

been known since a specimen (EDTU Herbarium no. 6623) was collected by Baki Kasaplıgil from the area in 1964, it has not been addressed in the literature. Field studies were conducted on 12 April, 30 June and 28 August 2024 to examine the population in question, outline its floristic composition, and assess the threats to the population. Initially, a field survey was carried out between the Kumlu River and Lake Saka (Fig. 2a). Sampling points were established at approximately 1 km intervals, and their geographic coordinates were recorded using GPS. At each sampling point, the surrounding area, including nearby stream corridors, was examined for woody and climbing plant species, while herbaceous taxa were excluded. Since no other *P. fraxinifolia* populations were found in this broader area, the detailed vegetation survey was specifically focused on the Panayır River valley. In this area, a cross-sectional topographic transect of approximately 1 km was established, descending from the upper slopes (~50 m a.s.l.) to the riverbed (~10 m a.s.l.). Along this transect, all woody and climbing plant species associated with *P. fraxinifolia* were identified and their spatial positions were recorded to construct a vegetation profile (Fig. 5). In this context, samples of trees, shrubs, and climbing plants surrounding *P. fraxinifolia* specimens were collected. A voucher specimen of *P. fraxinifolia* collected during these field studies was deposited at the ISTO herbarium (ISTO 39172). The identification of the collected plant specimens was based on Flora of Turkey and the East Aegean Islands (Davis, 1965–1985; Davis et al., 1988; Güner et al., 2000) and List of Turkey's Plants (Vascular Plants) (Güner et al., 2012). The taxonomic names of the species and their authorities were verified using the International Plant Names Index (IPNI, 2026) database. Furthermore, anthropogenic and environmental threats to the population were evaluated through direct qualitative field observations.

CHELSA is a climate dataset that contains high-resolution temperature and precipitation datasets for different time periods globally. To interpret the general climatic characteristics of the study area where the population is located, CHELSA Version 2.1 data for the period 1979–2021 were utilized (Karger et al., 2017). Although nearby meteorological stations exist, their data are incomplete and lack extended historical coverage, making CHELSA a more reliable source for this analysis. To evaluate the suitability of CHELSA data for the study area, observed temperature and precipitation records from the İğneada meteorological station (1979–1993; 41°52'59"N, 27°58'59"E), located 20 meters above sea level to the northwest of the population, were used. Ordinary Least Squares (OLS) linear regression analyses were conducted on a monthly basis to assess the agreement between station observations and CHELSA-derived values. Additionally, Root Mean Squared Error (RMSE) and Mean Bias Error (MBE) metrics were calculated to quantify prediction

Table 1. Woody and climbing plant species composition of the riparian forest associated with the *Pterocarya fraxinifolia* population along the Panayır River

Species	
Acer campestre L.	*Phillyrea latifolia* L.
Alnus glutinosa subsp. *glutinosa* (L.) Gaertn.	*Phytolacca americana* L.
Arbutus unedo L.	*Pistacia terebinthus* L. subsp. *terebinthus*
Asparagus acutifolius L.	*Prunus spinosa* L.
Calystegia silvatica (Kit.) Griseb.	*Pteridium aquilinum* (L.) Kuhn
Carpinus orientalis L.	*Pterocarya fraxinifolia* (Poir.) Spach
Cistus creticus L.	*Pyrus spinosa* Forssk.
Clematis vitalba L.	*Quercus cerris* L.
Cornus mas L.	*Quercus frainetto* Ten.
Corylus avellana L.	*Quercus petraea* (Matt.) Liebl.
Crataegus germanica (L.) Kuntze	*Robinia pseudoacacia* L.
Crataegus monogyna Jacq.	*Rosa canina* L.
Dioscorea communis (L.) Caddick & Wilkin	*Rubus* sp.
Erica arborea L.	*Ruscus aculeatus* L.
Erigeron sumatrensis Retz.	*Salix alba* L.
Ficus carica L. subsp. *carica*	*Sambucus ebulus* L.
Fraxinus ornus L.subsp. *ornus*	*Sambucus nigra* L.
Fagus orientalis Lipsky.	*Smilax excelsa* L.
Hedera helix L. subsp. *poetarum* (Nicotra) Nyman	*Sorbus aucuparia* L.
Humulus lupulus L.	*Tilia tomentosa* Moench
Juglans regia L.	*Torminalis glaberrima* (Gand.) Sennikov & Kurtto
Malus sylvestris (L.) Mill. *subsp. orientalis* (A. Uglitzkich) Browicz	*Viscum album* L.
Paliurus spina-christi Mill.	*Vitis vinifera* L.

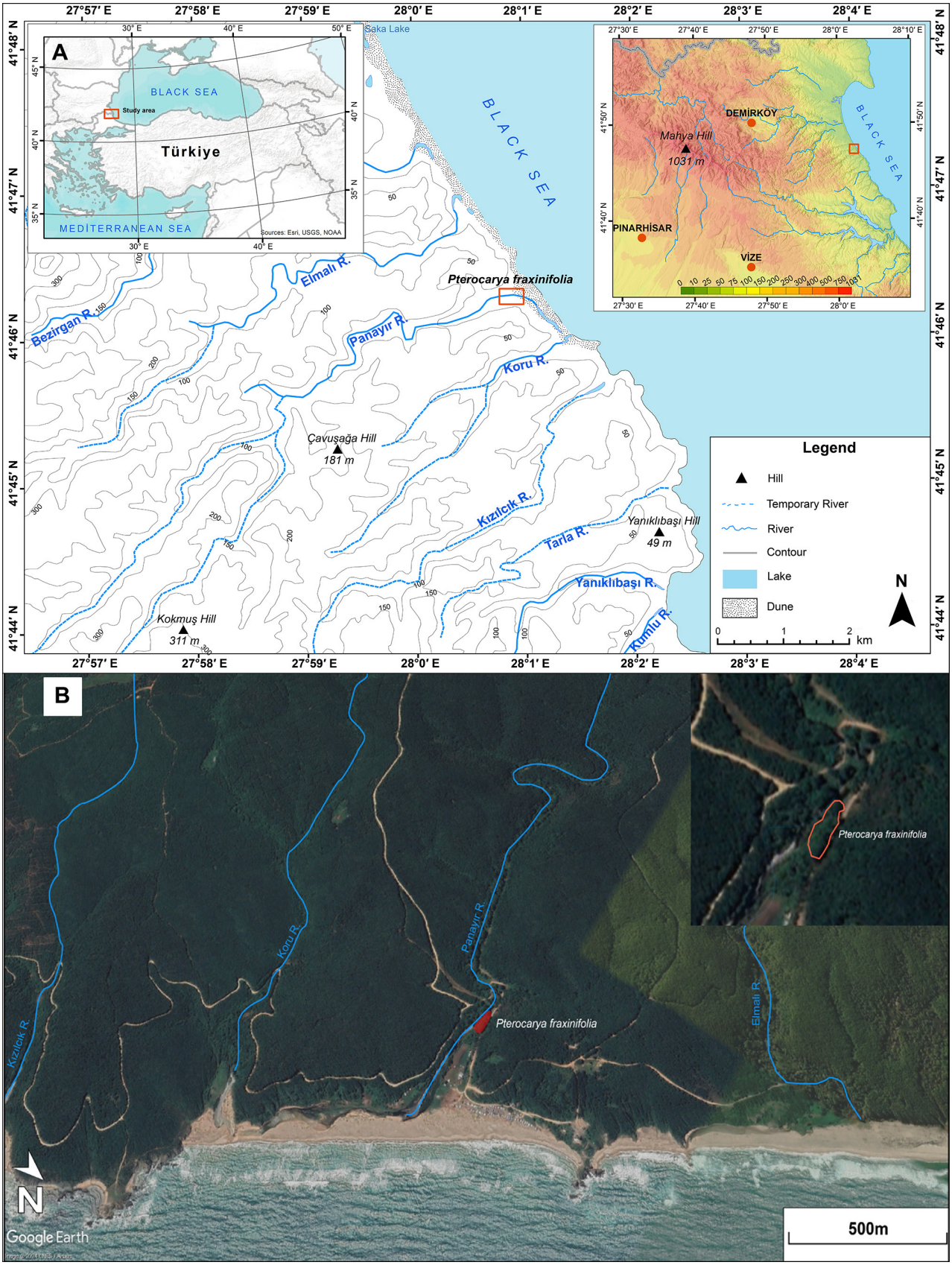


Fig. 2. (A) Topographic map of the surroundings of the Pterocarya fraxinifolia locality along the Panayır River. The population is indicated by a red rectangle. Inset maps show (left) the regional location of the study area and (right) the position of the Panayır River within Northern Thrace. (B) Satellite image of the Panayır River and its surroundings, viewed from the northeast (Google Earth)

accuracy and systematic bias, respectively. Based on the validated CHELSA dataset, annual mean temperature, total annual precipitation, and seasonal climate variables (Fig. 3, Fig. 6) were calculated and visualized for İğneada. These variables formed the basis of subsequent climate-related interpretations. All analyses were conducted in R (v 4.4.3; R Core Team, 2026) using the RStudio integrated development environment.

Results

The *P. fraxinifolia* population located along the Panayır River between 41°46'14.94"N, 28°00'48.53"E and 41°46'14.27"N, 28°00'51.60"E (Fig. 2), which has not been addressed in the literature, was evaluated, along with the surrounding trees, shrubs, and climbing plants (Table 1). This small population is strictly restricted to the main course of the river and occurs on alluvial soils overlying Quaternary alluvial deposits (Fig. 5), which aligns with the typical habitat described for the species (Davitashvili et al., 2024). The comparison between CHELSA data and observations from the İğneada meteorological station for the period 1979–1993 demonstrates a strong agreement, especially for temperature. The linear regression results (Fig. 3c) show a very high correlation (R^2 = 0.99, $p < 0.001$), a low mean bias (0.64 °C), and a root mean square error (RMSE) of 0.95 °C, confirming that CHELSA temperature estimates closely align with observed values. For precipitation, the relationship is moderately strong (R^2 = 0.76, $p < 0.001$), with CHELSA slightly underestimating observed values (mean bias = –11.45 mm; RMSE = 31.15 mm) (Fig. 3d). Although discrepancies are more noticeable during extreme precipitation events, these are not a concern for this study, which focuses on

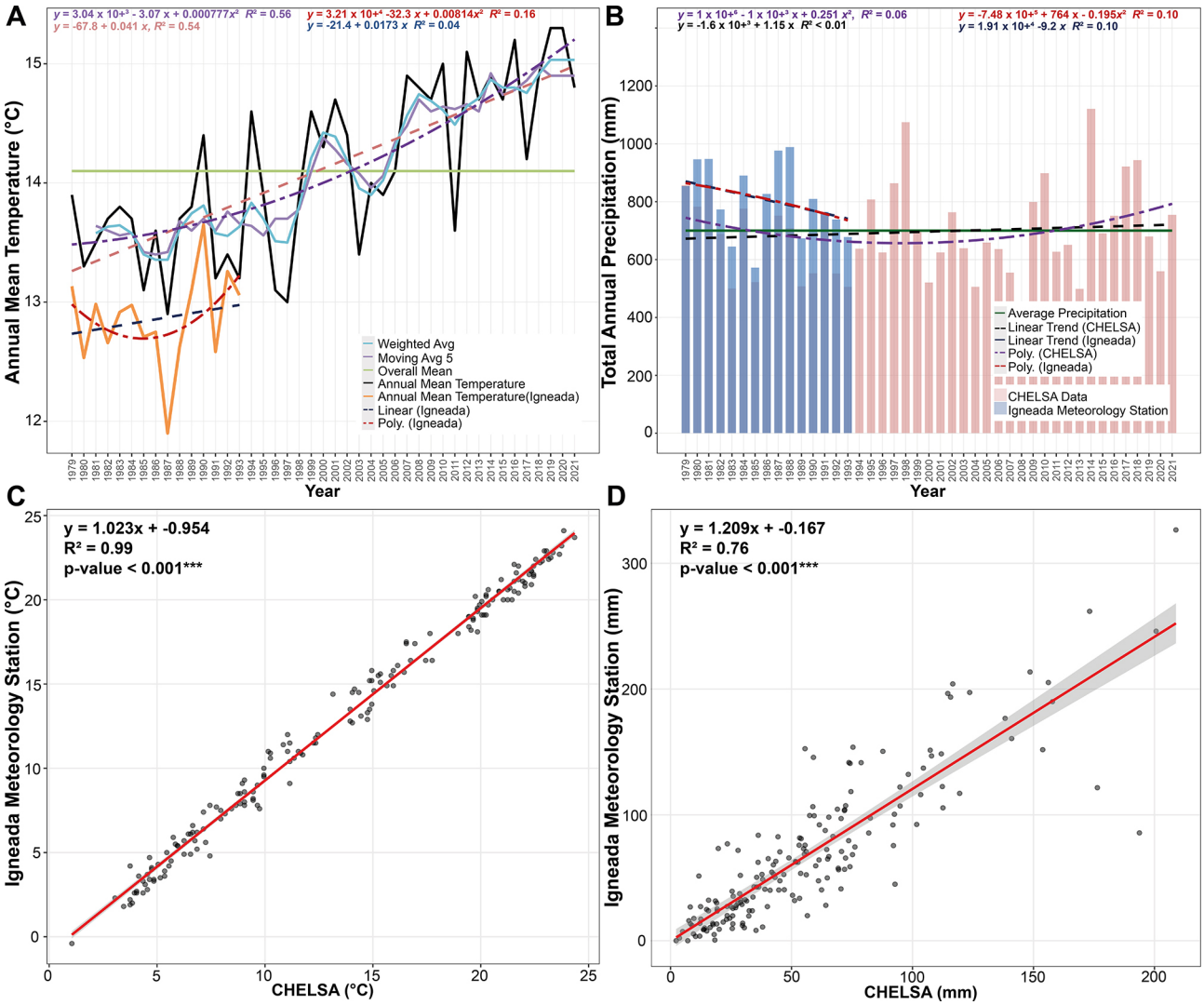


Fig. 3. Climatic trends and dataset comparison for the İğneada region (1979–2021). (A–B) illustrate annual mean temperature and total annual precipitation with fitted linear and polynomial trend lines. (C–D) present linear regression analyzes comparing CHELSA Version 2.1 data with station records for the overlapping period 1979–1993

general climatic patterns. The overall consistency between CHELSA and station data supports the use of CHELSA (1979–2021) as a reliable climatic source for the study area.

The long-term annual mean temperature in İğneada is 14.1 °C, ranging from a minimum of 12.9 °C in 1987 to a maximum of 15.3 °C, recorded in both 2019 and 2020. Linear, polynomial, weighted average, and 5-year moving average trends all indicate an overall increase in annual mean temperatures since 1987, with record-high values repeatedly observed since the early 2000s (Fig. 3a). The long-term average annual precipitation in İğneada is around 700 mm, with totals ranging from 423 mm in 2008 to over 1120 mm in 2014. Annual precipitation fluctuates noticeably, and many years since 2009 have seen above-average totals. While trend lines suggest a slight increase, low R^2 values indicate this is not statistically significant (Fig. 3). The population is situated on a north-facing aspect (Fig. 4b), which increases its exposure to humid air masses and influences local climatic conditions. Such humid microclimatic conditions align with the broader climatic regime of northwestern Türkiye. According to the Köppen–Geiger classification, the region is largely assigned to the Cfa climate type (Taşoğlu et al., 2024). Within this macroclimatic framework, CHELSA Version 2.1 data show that the Panayır River valley maintains a temperate and humid climate (Cfa), potentially contributing to the persistence of this relict population.

The Panayır River flows through a narrow valley of the same name before discharging into the Black Sea. At its mouth on the Black Sea coast, an extensive dune system (Panayır dunes) has developed, representing one of the least disturbed coastal



Fig. 4. Structural features of the Pterocarya fraxinifolia population in the Panayır River valley, northwestern Türkiye. (A) Tree-form individual bearing a fruiting spike. (B) Dense shrub layer beneath mature trees. (C) Regenerating shrub-form individuals within the understory. (D) Closed canopy formed by mature individuals

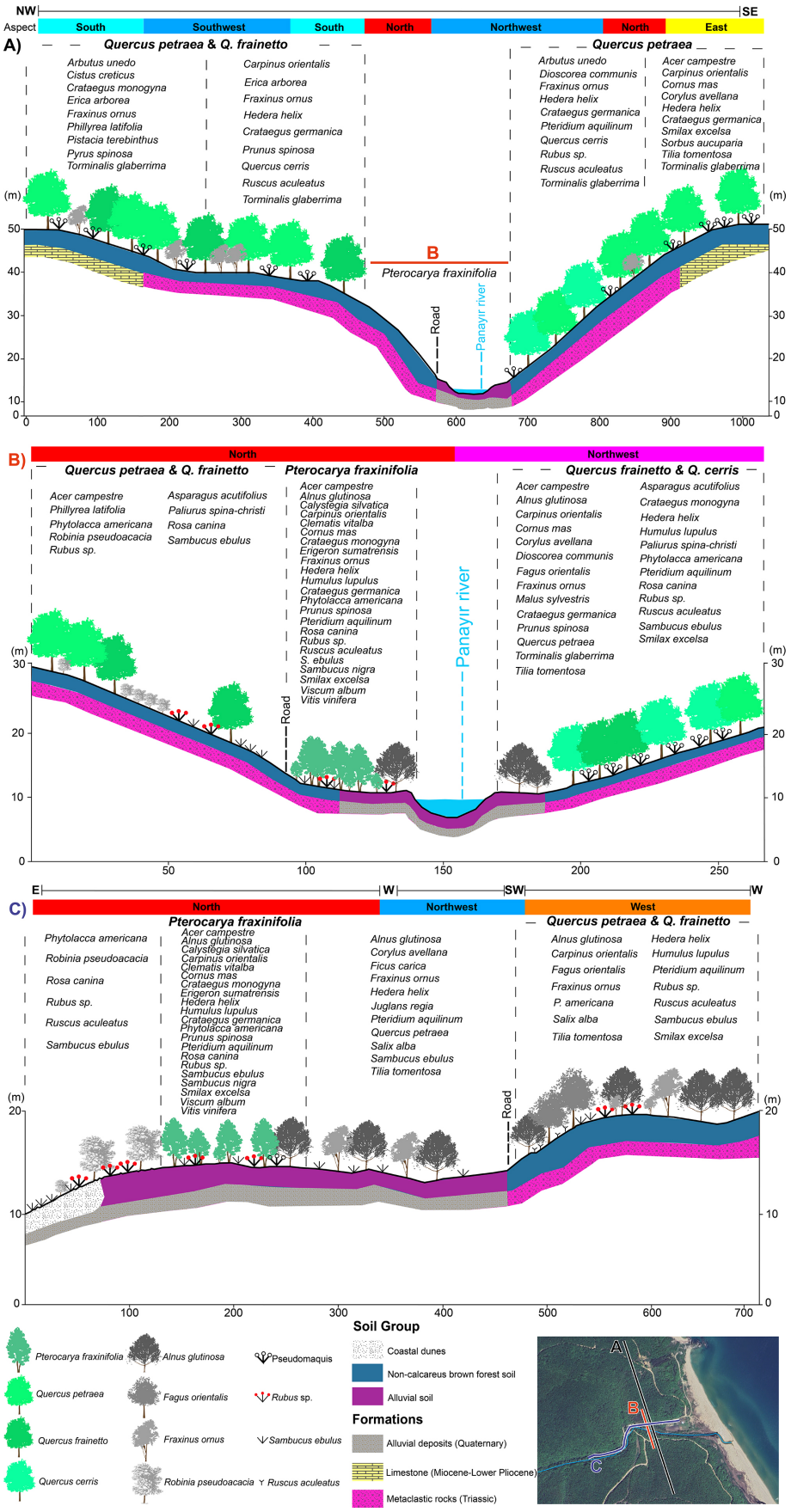


Fig. 5. Schematic transect illustrating the spatial distribution and vegetation structure of the Pterocarya fraxinifolia population along the Panayır River

dune areas in Thrace and extending approximately 20 km (Ozhatay et al., 2013). The population of *P. fraxinifolia* is located along the river at an elevation of 14 m a.s.l., approximately 330 m inland from the dune system, within the valley. To the north, it is bordered by an area disturbed by human activities, including logging. On its western side, the population is delimited by a road that also forms a clear boundary. Between the road and the riverbed, *P. fraxinifolia* constitutes the dominant woody element, exhibiting a continuous distribution composed of both mature trees and regenerating shrubs (Fig. 4). The population is confined within a restricted riparian polygon of approximately 4,658 m^2 (perimeter: 0.38 km). Active regeneration was observed in the form of both vegetative shoots and seed-origin seedlings. Furthermore, fruiting spikes were present on relatively young individuals, indicating that seed production is not restricted to old mature trees. Considering that the species has been known in this locality since a specimen (EDTU Herbarium no. 6623) was collected by Baki Kasaplıgil in 1964, the coexistence of mature trees, seed-producing younger individuals, and seed-origin seedlings provides field evidence consistent with continued recruitment and population persistence. At the northern boundary of the population, in the area impacted by human activity, *Robinia pseudoacacia* is present. Following this, *Pterocarya* is found densely along the roadside, extending to the riverbank. Within the core of the population, where *P. fraxinifolia* is most dominant, the vegetation is characterized by a dense layer of climbers such as *Smilax excelsa*, *Hedera helix*, and *Clematis vitalba*, alongside *Sambucus nigra* and *Rubus* sp. Towards the periphery of the riparian stand and the adjacent forest matrix, the vegetation transitions into a diverse arboreal assemblage comprising *Alnus glutinosa*, *Fraxinus ornus*, *Carpinus orientalis*, *Acer campestre*, *Quercus petraea*, *Tilia tomentosa*, *Ficus carica*, *Juglans regia*, and *Salix alba*. The shrub layer in these surrounding areas includes *Cornus mas*, *Corylus avellana*, *Prunus spinosa*, *Crataegus germanica, Crataegus monogyna*, *Rosa canina*, and *Ruscus aculeatus*. In addition, herbaceous taxa such as *Pteridium aquilinum* and *Phytolacca americana* occur in the area (Fig. 5b).

Discussion

The Panayır River is located in northern Thrace, in northwestern Türkiye, along the Black Sea coast. Thrace represents the southeastern extension of the Balkan Peninsula and is bordered by the Black Sea to the northeast and east, and by the Aegean Sea to the south. Despite its generally lower elevation compared to Anatolia, the region harbors a remarkable rich flora, comprising approximately 2,350 species, supported by diverse habitats such as coastal dunes, mountainous areas, plains, and floodplain forests (Uruşak et al., 2013). The Istranca Mountains, extending in a northwest–southeast direction across northern Thrace, exert a strong influence on the regional climate. Orographic uplift associated with these mountains enhances precipitation, making this the wettest part of Thrace, with annual totals reaching up to 1,400 mm. The interaction between humid air masses from the Black Sea and the complex topography creates locally mesic and stable climatic conditions, which may facilitate the persistence of relict and mesophilous woody species in sheltered valley systems such as the Panayır River corridor. South of the Istranca Mountains, precipitation decreases markedly, and this gradient is clearly reflected in the regional vegetation structure. Humid deciduous forests are primarily concentrated along the northern slopes of the Istranca range and extend northwards, in some locations reaching near sea level. These forests are heavily dominated by *Fagus orientalis*, while towards the coastal zone, the dominance gradually shifts to humid oak communities (Baytop, 1961; Dönmez, 1968; Yaltırık & Efe, 1988). In the area surrounding the Panayır River, *Quercus petraea* constitutes the main canopy species, locally accompanied by *Quercus frainetto*, *Fraxinus ornus*, and *Carpinus orientalis*. Along a northwest–southeast topographic gradient, at approximately 50 m a.s.l. in the western sector, mixed stands of *Q. petraea* and *Q. frainetto* are prominent. The shrub layer in these stands includes *Crataegus monogyna*, *Pyrus spinosa*, *Torminalis glaberrima*, *Phillyrea latifolia*, *Arbutus unedo*, *Pistacia terebinthus*, *Erica arborea*, and *Cistus creticus*. Descending into the Panayır valley (30–25 m a.s.l.), a noticeable compositional shift occurs in the shrub layer, characterized by the increased presence of *Fraxinus ornus*, *Carpinus orientalis*, *Rubus* spp., *Ruscus aculeatus*, *Crataegus germanica*, and *Quercus cerris*. With further decrease in elevation towards the road corridor, forest density gradually declines, transitioning into a more open vegetation structure. The clearing adjacent to the *Pterocarya* stand supports a mixed shrub–herbaceous assemblage beneath scattered *Quercus frainetto* and less frequent *Q. petraea*, reflecting increased light availability and disturbance influence. The road separating this area from the *Pterocarya* population represents a distinct anthropogenic boundary that likely contributes to edge effects and structural fragmentation. In contrast, the *Pterocarya* population at 14 m a.s.l. forms a relatively continuous corridor between the roadside and the Panayır riverbed. The presence of *Alnus glutinosa* and climbing species such as *Hedera helix* and *Smilax excelsa* indicates mesic and structurally complex conditions typical of riparian-influenced habitats. This contrasts with the more open and disturbance-associated vegetation observed outside the

stand. The dominance of *Robinia pseudoacacia* in the disturbed northern sector further highlights ongoing anthropogenic pressure. As a widely recognized invasive species in both Anatolia and Europe (Cierjacks et al., 2013; Kayacık, 1968; Pyšek et al., 2009), its presence highlights the ongoing anthropogenic disturbance affecting the surrounding habitat. Similarly, *Erigeron sumatrensis* represents another invasive element associated with disturbed habitats. It is documented as an alien species in the flora of Türkiye (Uludağ et al., 2017) and has significantly expanded its range across Southeastern Europe (Vladimirov et al., 2016). The occurrence of *Phytolacca americana* further reinforces the disturbance signal. This species, widely introduced in Central Europe, the Mediterranean Basin, and East Asia, is considered ecologically harmful due to its competitive impact on native plant communities (Balogh & Juhász, 2008). These alien species are currently confined to the disturbed margins and roadside edges, remaining absent from the core stand of *P. fraxinifolia*. In contrast, the southern sector of the population along the river corridor exhibits a more mesic and structurally developed vegetation. Species such as *Juglans regia*, *Ficus carica*, *Corylus avellana*, *Quercus petraea*, and *Salix alba* occur in proximity to the river, while *Alnus glutinosa* becomes locally dominant along the riparian stretch. The presence of *Fagus orientalis* in this sector is particularly noteworthy, as it reflects the influence of humid conditions associated with the river system. On the opposite slope of the Panayır River, extending southwest, mixed stands of *Quercus frainetto* and *Q. cerris* dominate the lower elevations. With increasing elevation, this association gradually transitions towards *Q. petraea* dominance, indicating a clear altitudinal and moisture-related vegetation gradient. This vegetation mosaic highlights the strong influence of topography and moisture gradients on species distribution, potentially creating localized refugial conditions within the river valley system (Fig. 5).

The surrounding area of the population contains numerous valleys and river systems. These areas were surveyed to assess the potential occurrence of additional *P. fraxinifolia* populations; However, no further populations were detected. During field observations conducted on 30 June 2024, all rivers in the vicinity -except the Panayır River- were found to have dried up. A subsequent survey on 28 August 2024 revealed that the Panayır River had also dried, with the exception of a small pond adjacent to the population (Fig. 6d–e). Given the projected increase in the frequency and duration of extreme climatic events under ongoing climate change, seasonal trend analyzes were performed using the Mann-Kendall test. The results indicate significant increasing trends in seasonal temperature for the period 1979–2021 based on CHELSA data (τ = 0.292–0.570, $p < 0.01$; Fig. 6a). In contrast, no statistically significant trends were detected for seasonal precipitation ($p > 0.05$; Fig. 6b). Although precipitation anomalies exhibit a slight upward trend (Fig. 6c), the low R^2 value indicates that the model explains only a small proportion of the interannual variability. Notably, most years between 2000 and 2012 experienced below-average precipitation. Climatic projections for northwestern Türkiye suggest a general warming trend accompanied by increased atmospheric moisture and greater climatic instability. Several studies indicate that the northward displacement of westerly storm tracks, particularly Atlantic cyclones, may increase precipitation along the southern Black Sea coast (Aykut & Turoğlu, 2023; Barcikowska et al., 2018; Giorgi & Lionello, 2008). However, rising temperatures are expected to enhance evapotranspiration rates, thereby intensifying seasonal water deficits especially during summer months when precipitation does not compensate for evaporative losses (Deveci & Konukcu, 2024). This pattern substantially increases the risk of seasonal drought. Field observations already reflect these emerging climatic pressures. Consequently, the isolated *P. fraxinifolia* population along the Panayır River appears increasingly vulnerable to prolonged drought stress. These findings highlight the urgent need for targeted conservation measures to ensure the persistence of this isolated population. On the other hand, while ecological niche modeling indicates that the SSP5-8.5 scenario projected for 2070 may lead to the emergence of climatically suitable habitats in Thrace and the Balkans, the historical failure of the species to naturally recolonize Europe during the Holocene demonstrates severe dispersal limitations that raise uncertainty about its ability to reach these new areas (Song et al., 2021).

P. fraxinifolia and riparian forests face significant threats from various anthropogenic activities, including logging, agricultural expansion, riverbed modifications, and hydroelectric power plant development (Kozlowski et al., 2018). In both Iran and Georgia, riparian forests have historically been severely impacted, often cleared or converted into pastures or plantations (Kozlowski & Gratzfeld, 2013). In Türkiye, the recent rapid increase in hydroelectric power plants poses a substantial risk to riparian forests and river ecosystems (Şekercioğlu et al., 2011). As a result, *P. fraxinifolia* has been classified as "vulnerable" according to IUCN criteria (Bétrisey et al., 2019). Although *P. fraxinifolia* is protected within various national parks and state reserves across Azerbaijan, Georgia, and Iran (Denk et al., 2001), current conservation frameworks do not always encompass the populations with the highest genetic diversity. Specifically, in the alluvial lowlands of Iran, core genetic groups remain underrepresented within the protected areas (Yousefzadeh et al., 2018). This gap is also

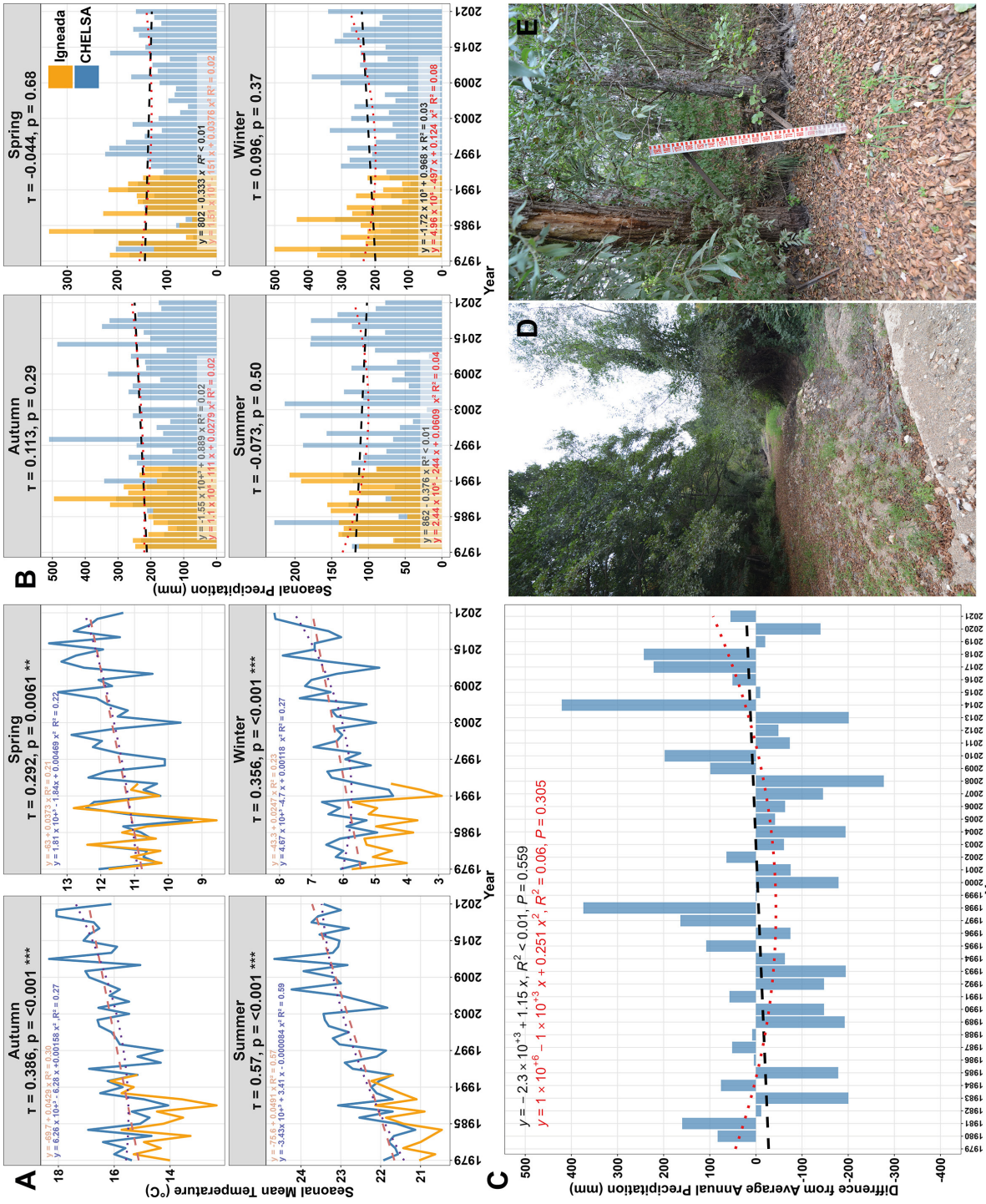


Fig. 6. Climatic trends and field observations for the İğneada region. (A–B) Seasonal mean temperature and total precipitation based on CHELSA (v2.1) data (1979–2021), including linear and polynomial trend lines. (C) Seasonal precipitation anomalies relative to the long-term annual mean (1979–2021). (D) The Panayır River on 28 August 2024, showing complete surface desiccation. (E) Evidence of historical water levels exceeding 50 cm within the riverbed

evident in Anatolia, where the species is distributed in highly fragmented populations across distinct northern and southern regions. In the south, specifically in Adıyaman, these populations are restricted to riverbanks in shrub like forms and face a severe risk of local extinction (Yılmaz, 2015). Consequently, the fact that most populations in Türkiye remain outside protected areas emphasizes the urgent need for targeted conservation measures.

The Panayır River is subject to multiple anthropogenic pressures, including intensive recreational use, litter accumulation, illegal construction, logging, and grazing (Ozhatay et al., 2013). These disturbances directly affect riparian habitat integrity and may exacerbate stress on the isolated *P. fraxinifolia* population. An additional potential threat arises from the proposed nuclear power plant in İğneada (World Nuclear Association, 2026), located in close proximity to the population. Although nuclear energy is promoted as a low-carbon strategy within Türkiye's long-term energy planning framework, large-scale infrastructure projects of this nature involve substantial land clearing, habitat degradation, and hydrological alteration during site preparation and construction phases. Evidence from other nuclear power plant projects in Türkiye demonstrates extensive forest loss and landscape transformation associated with such developments. For example, at the Sinop site, more than 650,000 trees were reportedly removed and approximately 268 ha of forest were cleared during initial site preparation (Çolak et al., 2019). Similarly, construction activities at the Akkuyu site resulted in significant forest cover reduction and expansion of artificial surfaces within the surrounding landscape (Iban & Sahin, 2022). Beyond direct habitat destruction, nuclear power plants may generate additional environmental pressures, including habitat fragmentation, road construction impacts, and thermal pollution associated with cooling water discharge. In coastal systems, elevated discharge temperatures can alter aquatic community composition and favor opportunistic species over sensitive taxa (Guimarães et al., 2023; Zhou et al., 2025). Furthermore, uncertainties regarding water supply sources raise concerns under projected drought scenarios. The potential reliance on regional reservoirs during consecutive dry years could intensify existing water stress in the broader region. Given the already increasing climatic vulnerability of the Panayır River system, the cumulative effects of recreational pressure, land-use change, and potential large-scale infrastructure development may substantially heighten extinction risk for this isolated *P. fraxinifolia* population.

The isolated *P. fraxinifolia* population along the Panayır River represents a relict stand with unique ecological and biogeographical significance. Its distribution and composition are strongly governed by topography and local moisture gradients, which facilitate microrefugial conditions that have allowed the species to persist despite regional climatic fluctuations. However, field surveys confirming the absence of additional populations in surrounding valleys underscore its extreme isolation. Seasonal analyses of CHELSA data reveal significant warming trends across all seasons, while stable precipitation patterns-combined with rising temperatures-point to an emerging water stress regime, as evidenced by the river desiccation events observed in 2024. This climatic vulnerability is exacerbated by multiple anthropogenic pressures, including intensive recreational use, habitat fragmentation, and the potential impacts of large-scale infrastructure projects, such as the proposed İğneada nuclear power plant. Furthermore, global mean sea level rise, projected to reach up to 1.01 meters under the SSP5-8.5 scenario by 2100 (IPCC, 2022), poses a critical threat to the Panayır coastal dunes and this vulnerable riparian corridor, which has already been identified as a 'high-risk' zone according to the Coastal Vulnerability Index (Ozsahin et al., 2023). Given that this population represents the westernmost limit of the species' global distribution and currently remains outside of any formal protected status, there is an urgent need for the legal designation of the Panayır River valley as a protected area to ensure the long-term persistence of this relict lineage.

The woody vegetation of the Panayır River valley shows notable similarities to that of the Strandzha Nature Park, located on the northern slopes of the Istranca (Strandzha) Mountains. Both localities share key taxa such as *Fagus orientalis*, *Quercus petraea*, *Q. cerris*, *Q. frainetto*, *Arbutus unedo*, and *Acer campestre* (Stoyanov et al., 2022). However, a distinction is the absence of *Pterocarya fraxinifolia* records in the Strandzha Nature Park. In this context, the Panayır River vegetation provides complementary information on the relict woody flora currently present in Thrace. Overall, the floristic similarities between these localities highlight the importance of the southeastern Balkan refugium in the broader context of southeastern European refugia. Nevertheless, whether this isolated population represents a direct relict of a historical European lineage or the result of a Holocene colonization from eastern populations remains an open question. In the absence of genetic data, future phylogeographic analyses would help clarify the evolutionary origin and colonization history of this marginal stand.

Although the İğneada Floodplain Forests National Park holds significant protection status, the Panayır River basin and its associated coastal dunes remain largely excluded from these effective conservation boundaries. This gap in protection is critical; Ozhatay et al. (2013) identified the Panayır River

region as a priority conservation area in Northwest Thrace, emphasizing its rich biodiversity and the presence of endemic and rare species, threatened habitats. Consequently, leaving this ecologically sensitive area without formal legal protection makes the *P. fraxinifolia* population particularly vulnerable to anthropogenic threats.

Conclusion

Relict plants, which have persisted through millions of years of environmental change, including past climate shifts, are increasingly threatened by anthropogenic pressures. Their limited natural habitats make them particularly vulnerable, potentially leading to local or complete extinction. These species provide valuable insights into evolutionary and biogeographic processes, highlighting the importance of studying their distribution and protecting known populations. This study focuses on the Panayır River population of *P. fraxinifolia*, the westernmost known population of the species, and assesses its climatic, geological, floristic, and environmental context. The Panayır valley has been identified in previous studies as a priority area due to its habitat diversity, rich biodiversity, and the presence of threatened and endemic species. It also harbors one of the few remaining populations of this important relict species in Anatolia. Based on our field observations, the absence of formal protection and limited local awareness of the ecological significance of the species are associated with human-induced clearings. These disturbances create structural gaps that may facilitate the establishment and spread of alien species such as *Robinia pseudoacacia*, which are currently confined to disturbed margins and roadside edges. Furthermore, our climatic trend analyses indicate significant seasonal temperature increases that coincide with the observed summer desiccation of the river. This pattern raises concerns regarding potential future water stress for this moisture-dependent species. Accordingly, management efforts should prioritize the protection of the riparian habitat, prevention of further habitat disturbance, and monitoring of alien species at the margins of the population. The expansion of the adjacent İğneada Floodplain Forests National Park boundaries to encompass the Panayır valley could provide an effective framework for long-term protection of the site. Local conservation actions should also include regulating recreational access where necessary, increasing public awareness, and monitoring and controlling alien species at the stand margins to prevent their spread toward the core area. Protecting this specific site is also important because, as the westernmost known stand, the isolated Panayır population may provide valuable material for future phylogeographic and biogeographic studies. While there is potential for other undiscovered populations, particularly in Thrace and northern Anatolia, the floristic, edaphic, and climatic baseline established in this study can serve as a practical guide for identifying such populations. The riparian forests preferred by *P. fraxinifolia* are highly valuable biological systems, and their protection is important not only for maintaining this isolated population but also for sustaining the broader ecological integrity of these sensitive environments.

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References

Akhani H & Salimian M (2003) An extant disjunct stand of *Pterocarya fraxinifolia* (Juglandaceae) in the central Zagros Mountains, W Iran. Willdenowia 33: 113–120. doi:10.3372/wi.33.33111.

Avcı M (2005) Çeşitlilik ve endemizm açısından Türkiye'nin bitki örtüsü. Journal of Geography 13: 27–55.

Avşar MD & Ok T (2004) A new distribution of Caucasian wingnut *Pterocarya fraxinifolia* (Poiret) Spach in the Kahramanmaraş region, Turkey. Journal of Environmental Biology 25: 45–50.

Aykut T & Turoğlu H (2023) Effects of climate change on streamflow in NE Edirne (NW Türkiye): implications for sustainable hydrological development. Sustainable Water Resources Management 10: 2. doi:10.1007/s40899-023-00985-1.

Balogh L & Juhász M (2008) American and Chinese pokeweed (*Phytolacca americana*, *Phytolacca esculenta*): The most important invasive plants in Hungary: Handbook of alien species in Europe (ed. by Z Botta-Dukát & L Balogh) Hungarian Academy of Sciences, Institute of Ecology and Botany, Vácrátót, pp. 35–46.

Barcikowska MJ, Kapnick SB & Feser F (2018) Impact of large-scale circulation changes in the North Atlantic sector on the current and future Mediterranean winter hydroclimate. Climate Dynamics 50: 2039–2059. doi:10.1007/s00382-017-3735-5.

Baytop A (1961) Trakya'da botanik gezilerimiz. Acta Biologica Turcica 11: 38–43.

Bétrisey S, Song Y, Yousefzadeh H & Kozlowski G (2019) *Pterocarya fraxinifolia*. The IUCN Red List of Threatened Species 2019: e. T66815986A66816002. doi:10.2305/IUCN.UK.2019-3.RLTS.T66815986A66816002.en.

Bétrisey S, Yousefzadeh H & Kozlowski G (2018) *Zelkova carpinifolia*. The IUCN Red List of Threatened Species 2018: e.T31303A131166773. doi:10.2305/IUCN.UK.2018-2.RLTS.T31303A131166773.en.

Bottema S, Woldring H & Aytuğ B (1993) Late Quaternary vegetation history of northern Turkey. Palaeohistoria 35/36: 13–72.

Browicz K & Zieliński J (1982) Chorology of trees and shrubs in south-west Asia and adjacent regions. Polish Scientific Publishers, Warsaw.

Cierjacks A, Kowarik I, Joshi J, Hempel S, Ristow M, von der Lippe M & Weber E (2013) Biological flora of the British Isles: *Robinia pseudoacacia*. Journal of Ecology 101: 1623–1640. doi:10.1111/1365-2745.12162.

Çetin B, Emre S, Zekiye Ö, Ertuğrul F & Eren B (2025) ISSR marker based genetic variation analysis in the riparian relict tree *Pterocarya fraxinifolia* (Juglandaceae) genotypes in Türkiye. Biology Bulletin 52: 66. doi:10.1134/S1062359024612916.

Çolak E, Chandra M & Sunar F (2019) The use of multi-temporal Sentinel satellites in the analysis of land cover/land use changes caused by the nuclear power plant construction. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLII-3/W8: 491–495. doi:10.5194/isprs-archives-XLII-3-W8-491-2019.

Davis PH (1965–1985) Flora of Turkey and the East Aegean Islands. Edinburgh University Press, Edinburgh.

Davis PH (1971) Distribution patterns in Anatolia with particular reference to endemism: Plant life of South-West Asia (ed. by PH Davis, PC Harper & IC Hedge) Botanical Society of Edinburgh, Edinburgh, pp. 15–27.

Davis PH, Mill RR & Tan K (1988) Flora of Turkey and the East Aegean Islands. Edinburgh University Press, Edinburgh.

Davitashvili N, Bétrisey S, Janiashvili Z, Matchutadze I & Kozlowski G (2024) First description and conservation implications of a unique stand of the Caucasian wingnut in Lapankuri (Georgia). Feddes Repertorium 135: 78–84. doi:10.1002/fedr.202300031.

Denk T, Frotzler N & Davitashvili N (2001) Vegetational patterns and distribution of relict taxa in humid temperate forests and wetlands of Georgia (Transcaucasia). Biological Journal of the Linnean Society 72: 287–332. doi:10.1006/bijl.2000.0502.

Deveci H & Konukcu F (2024) Modeling the effect of climate change on evapotranspiration in the Thrace Region. Atmosphere 15: 1188. doi:10.3390/atmos15101188.

Dönmez Y (1968) Trakya'nın bitki coğrafyası. İstanbul Üniversitesi Coğrafya Enstitüsü Yayınları, İstanbul.

EPICA community members (2004) Eight glacial cycles from an Antarctic ice core. Nature 429: 623–628. doi:10.1038/nature02599.

Filipova-Marinova M, Pavlov D & Slavova K (2024) Paleoclimate changes and ecosystem responses of the Bulgarian Black Sea zone during the last 26000 years. Nature Conservation 55: 201–248. doi:10.3897/natureconservation.55.121842.

Giorgi F & Lionello P (2008) Climate change projections for the Mediterranean region. Global and Planetary Change 63: 90–104. doi:10.1016/j.gloplacha.2007.09.005.

Guimarães LSF, de Carvalho-Junior L, Façanha GL, Resende NdS, Neves LM & Cardoso SJ (2023) Meta-analysis of the thermal pollution caused by coastal nuclear power plants and its effects on marine biodiversity. Marine Pollution Bulletin 195: 115452. doi:10.1016/j.marpolbul.2023.115452.

Günal N (1994) Relief, iklim ve *Liquidambar orientalis* (Anadolu sığla ağacı)'in güneybatı Anadolu'daki yayılışı arasındaki ilişkiler. Türk Coğrafya Dergisi 29: 175–190. doi:10.17211/tcd.18357.

Güner A, Aslan S, Ekim T, Vural M & Babaç MT (2012) Türkiye Bitkileri Listesi (Damarlı Bitkiler). Nezahat Gökyiğit Botanik Bahçesi ve Flora Araştırmaları Derneği Yayını, İstanbul.

Güner A, Özhatay N, Ekim T & Başer KHC (2000) Flora of Turkey and the East Aegean Islands. Edinburgh University Press, Edinburgh.

Hampe A & Jump AS (2011) Climate relicts: Past, present, future. Annual Review of Ecology, Evolution, and Systematics 42: 313–333. doi:10.1146/annurev-ecolsys-102710-145015.

Iban MC & Şahin E (2022) Monitoring land use and land cover change near a nuclear power plant construction site: Akkuyu case, Turkey. Environmental Monitoring and Assessment 194: 724. doi:10.1007/s10661-022-10437-6.

Intergovernmental Panel on Climate Change (IPCC) (2022) The ocean and cryosphere in a changing climate: Special report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge.

IPNI (2026) International plant names index. The Royal Botanic Gardens, Kew, Harvard University Herbaria & Libraries and Australian National Herbarium. https://www.ipni.org.

Jackson ST & Weng C (1999) Late Quaternary extinction of a tree species in eastern North America. Proceedings of the National Academy of Sciences 96: 13847–13852. doi:10.1073/pnas.96.24.13847.

Jiménez-Moreno G & Suc J-P (2007) Middle Miocene latitudinal climatic gradient in Western Europe: Evidence from pollen records. Palaeogeography, Palaeoclimatology, Palaeoecology 253: 208–225. doi:10.1016/j.palaeo.2007.03.040.

Jouzel J, Masson-Delmotte V, Cattani O, Dreyfus G, Falourd S, Hoffmann G, Minster B, Nouet J, Barnola JM, Chappellaz J, Fischer H, Gallet JC, Johnsen S, Leuenberger M, Loulergue L, Luethi D, Oerter H, Parrenin F, Raisbeck G, Raynaud D, Schilt A, Schwander J, Selmo E, Spahni L, Stauffer B, Steffensen JP, Stenni B, Stocker TF, Tison JL, Werner M & Wolff EW (2007) Orbital and millennial Antarctic climate variability over the past 800,000 years. Science 317: 793–796. doi:10.1126/science.1141038.

Karger DN, Conrad O, Böhner J, Kawohl T, Kreft H, Soria-Auza RW, Zimmermann NE, Linder HP & Kessler M (2017) Climatologies at high resolution for the earth's land surface areas. Scientific Data 4: 170122. doi:10.1038/sdata.2017.122.

Karlıoğlu Kılıç N (2019) Seven years of arboreal pollen monitoring in the İğneada waterlogged forests (NW Turkey). Eurasian Journal of Forest Science 7: 311–320. doi:10.31195/ejejfs.635736.

Karlıoğlu Kılıç N, Yılmaz Dağdeviren R, Acar D, Küçükdemirci M, Makaroğlu Ö, Karaöz MÖ, Şahin Altun D, Tutar A, Horuz A, Gürel A, Islam Z & Çağatay MN (2020) Akgöl'de (Sakarya) Fosil Polen Analizine Dayalı Paleovejetasyon Araştırmaları: İlk Bulgular. Journal of Geography 40: 219–230. doi:10.26650/JGEOG2019-0021.

Kayacık H (1968) Orman ve park ağaçlarının özel sistematiği. Cilt II: Angiospermae (Kapalı tohumlar). İstanbul Üniversitesi Orman Fakültesi Yayınları, İstanbul.

Koç DE, Ustaoğlu B & Biltekin D (2024) Effect of climate change on the habitat suitability of the relict species *Zelkova carpinifolia* Spach using ensembled species distribution modelling. Scientific Reports 14: 27967. doi:10.1038/s41598-024-78733-4.

Koç DE, Biltekin D & Ustaoğlu B (2026) Assessing climate-driven shifts in *Liquidambar orientalis* using ensemble species distribution models in the Eastern Mediterranean Region. BMC Plant Biology 26: 89. doi:10.1186/s12870-025-07872-1.

Kozlowski G & Gratzfeld J (2013) *Zelkova* – an ancient tree. Global status and conservation action. Natural History Museum Fribourg, Switzerland, 60 pp.

Kozlowski G, Bétrisey S & Song Y-G (2018) Wingnuts *(Pterocarya)* and walnut family. Relict trees: linking the past, present and future. Natural History Museum Fribourg, Switzerland.

Leroy SAG, Boyraz S & Gürbüz A (2009) High-resolution palynological analysis in Lake Sapanca as a tool to detect recent earthquakes on the North Anatolian Fault. Quaternary Science Reviews 28: 2616–2632. doi:10.1016/j.quascirev.2009.05.018.

Leroy SAG, Henry P, Peyron O, Rostek F, Kende J, Bard E & Tachikawa K (2023) Palynology, palaeoclimate and chronology from the Saalian Glacial to Saint-Germain II interstadial from two long cores at the limit between the Mediterranean and Euxinian regions. Quaternary Science Reviews 311: 108145. doi:10.1016/j.quascirev.2023.12.001.

Lisiecki LE & Raymo ME (2007) Plio–Pleistocene climate evolution: trends and transitions in glacial cycle dynamics. Quaternary Science Reviews 26: 56–69. doi:10.1016/j.quascirev.2006.09.005.

Magri D, Di Rita F, Aranbarri J, Fletcher W & González-Sampériz P (2017) Quaternary disappearance of tree taxa from Southern Europe: Timing and trends. Quaternary Science Reviews 163: 23–55. doi:10.1016/j.quascirev.2017.02.014.

Maharramova E, Huseynova I, Kolbaia S, Gruenstaeudl M, Borsch T & Muller LAH (2018) Phylogeography and population genetics of the riparian relict tree *Pterocarya fraxinifolia* (Juglandaceae) in the South Caucasus. Systematics and Biodiversity 16: 14–27. doi:10.1080/14772000.2017.1333540.

Médail F & Diadema K (2009) Glacial refugia influence plant diversity patterns in the Mediterranean Basin. Journal of Biogeography 36: 1333–1345. doi:10.1111/j.1365-2699.2008.02051.x.

Menitsky YL (2005) Oaks of Asia. Science Publishers, Enfield (NH), USA and Plymouth, UK.

Milne RI & Abbott RJ (2002) The origin and evolution of Tertiary relict floras. Advances in Botanical Research 38: 281–314. doi:10.1016/S0065-2296(02)38033-9.

Mosbrugger V, Utescher T & Dilcher DL (2005) Cenozoic continental climatic evolution of Central Europe. Proceedings of the National Academy of Sciences 102: 14964–14969. doi:10.1073/pnas.0505267102.

Novák P, Večeřa M, Gholizadeh H, Pustková Š, Szokala D, Kharazishvili D, Memiadze N, Sedláček V & Kalníková V (2024) Forests of the Tertiary relict tree *Zelkova carpinifolia* in Colchis (South Caucasus) and their regional vegetation context. Tuexenia 44: 9–32. doi:10.14471/2024.44.007.

Noroozi J, Khalvati S, Nafisi H, Kaveh A, Nazari B, Zare G, Minaei M, Vitek E & Schneeweiss GM (2021) Endemics determine bioregionalization in the alpine zone of the Irano-Anatolian biodiversity hotspot (South-West Asia). Alpine Botany 131: 177–186. doi:10.1007/s00035-021-00266-7.

Oğuz T, Latun VS, Latif MA, Vladimirov VV, Sur HI, Markov AA, Özsoy E, Kotovshchikov BB, Eremeev VV & Ünlüata Ü (1993) Circulation in the surface and intermediate layers of the Black Sea. Deep Sea Research Part I: Oceanographic Research Papers 40: 1597–1612. doi:10.1016/0967-0637(93)90018-X.

Ordonez A & Svenning J-C (2016) Strong paleoclimatic legacies in current plant functional diversity patterns across Europe. Ecology and Evolution 6: 3405–3416. doi:10.1002/ece3.2131.

Ozdilek A, Cengel B, Kandemir G, Tayanc Y, Velioglu E & Kaya Z (2012) Molecular phylogeny of relict-endemic *Liquidambar orientalis* Mill based on sequence diversity of the chloroplast-encoded matK gene. Plant Systematics and Evolution 298: 337–349. doi:10.1007/s00606-011-0548-6.

Ozhatay N, Akalin E, Güler N, Ersoy H, Yeşil Cantürk Y & Demirci Kayıran S (2013) Floristic richness and conservation priority sites in the northwest of European Turkey: Mt Yıldız-Kırklareli. Phytologia Balcanica 19: 77–88.

Ozsahin E, Ozdes M, Ozturk M & Yang D (2023) Coastal vulnerability assessment of Thrace Peninsula: Implications for climate change and sea level rise. Remote Sensing 15: 5592. doi:10.3390/rs15235592.

Öztürk M, Çelik A, Güvensen A & Hamzaoğlu E (2008) Ecology of tertiary relict endemic *Liquidambar orientalis* Mill. forests. Forest Ecology and Management 256: 510–518. doi:10.1016/j.foreco.2008.01.027.

Popescu S-M, Biltekin D, Winter H, Suc J-P, Melinte-Dobrinescu MC, Klotz S, Rabineau M, Combourieu-Nebout N, Clauzon G & Deaconu F (2010) Pliocene and Lower Pleistocene vegetation and climate changes at the European scale: Long pollen records and climatostratigraphy. Quaternary International 219: 152–167. doi:10.1016/j.quaint.2010.03.013.

Pound MJ, Haywood AM, Salzmann U & Riding JB (2012) Global vegetation dynamics and latitudinal temperature gradients during the Mid to Late Miocene (15.97–5.33 Ma). Earth-Science Reviews 112: 1–22. doi:10.1016/j.earscirev.2012.02.005.

Pound MJ & Salzmann U (2017) Heterogeneity in global vegetation and terrestrial climate change during the late Eocene to early Oligocene transition. Scientific Reports 7: 43386. doi:10.1038/srep43386.

Pyšek P, Lambdon PW, Arianoutsou M, Kühn I, Pino J & Winter M (2009) Alien vascular plants of Europe: Handbook of Alien Species in Europe (ed. by DA Planty-Tabacchi) Springer Netherlands, Dordrecht, pp. 43–61. doi:10.1007/978-1-4020-8280-1_4.

R Core Team (2026) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org/.

Sabbagh SA, Yousefzadeh H, Vatanparast M, Bakhtiarizadeh MR, Kozlowski G & Song Y-G (2025) Characterization of the chloroplast genome of a relict tree, *Pterocarya fraxinifolia* (Juglandaceae), and its comparative analysis. Scientific Reports 15: 44153. doi:10.1038/s41598-025-23028-5.

Song Y-G, Li Y, Meng H-H, Fragnière Y, Ge B-J, Sakio H, Yousefzadeh H, Bétrisey S & Kozlowski G (2020) Phylogeny, taxonomy, and biogeography of *Pterocarya* (Juglandaceae). Plants 9: 1524. doi:10.3390/plants9111524.

Song Y-G, Walas Ł, Pietras M, Sâm HV, Yousefzadeh H, Ok T, Farzaliyev V, Worobiec G, Worobiec E, Stachowicz-Rybka R, Boratyński A, Boratyńska K, Kozlowski G & Jasińska AK (2021) Past, present and future suitable areas for the relict tree *Pterocarya fraxinifolia* (Juglandaceae): Integrating fossil records, niche modeling, and phylogeography for conservation. European Journal of Forest Research 140: 1323–1339. doi:10.1007/s10342-021-01397-6.

Stoyanov PS, Mladenov RD, Mileva NS & Todorov KT (2022) Monitoring of vascular plant species from the southeastern part of Strandzha Nature Park, Bulgaria. Ecologia Balkanica Special Edition 5: 7–15.

Strijk JS & Carrero C (2020) *Quercus pontica*. The IUCN Red List of Threatened Species 2020: e.T194222A2304749. doi:10.2305/IUCN.UK.2020-3.RLTS.T194222A2304749.en.

Svenning J-C, Eiserhardt WL, Normand S, Ordonez A & Sandel B (2015) The influence of paleoclimate on present-day patterns in biodiversity and ecosystems. Annual Review of Ecology, Evolution, and Systematics 46: 551–572. doi:10.1146/annurev-ecolsys-112414-054314.

Şekercioğlu ÇH, Anderson S, Akçay E, Bilgin R, Can ÖE, Semiz G, Tavşanoğlu Ç, Yokeş MB, Soyumert A, İpekdal K, Sağlam İK, Yücel M & Nüzhet Dalfes H (2011) Turkey's globally important biodiversity in crisis. Biological Conservation 144: 2752–2769. doi:10.1016/j.biocon.2011.06.025.

Şengör AMC, Tüysüz O, İmren C, Sakınç M, Eyidoğan H, Görür N, Le Pichon X & Rangin C (2005) The North Anatolian fault: A new look. Annual Review of Earth and Planetary Sciences 33: 37–112. doi:10.1146/annurev.earth.32.101802.120415.

Taşoğlu E, Ozturk MZ & Yazıcı O (2024) High resolution Köppen–Geiger climate zones of Türkiye. International Journal of Climatology 44: 5248–5265. doi:10.1002/joc.8635.

Tiffney BH & Manchester SR (2001) The use of geological and paleontological evidence in evaluating

plant phylogeographic hypotheses in the Northern Hemisphere Tertiary. International Journal of Plant Sciences 162: S3–S17. doi:10.1086/323880.

Turoğlu H (2014) KB Trakya'nın Karadeniz kıyıları oluşum ve gelişimine morfolojik yaklaşım. Türk Coğrafya Dergisi 30: 345–356.

Uludağ A, Aksoy N, Yazlık A, Arslan ZF, Yazmış E, Üremiş İ, Cossu TA, Groom Q, Pergl J, Pyšek P & Brundu G (2017) Alien flora of Turkey: checklist, taxonomic composition and ecological attributes. NeoBiota 35: 61–85. doi:10.3897/neobiota.35.12460.

Uruşak EA, Özhatay FN, Güler N, Ersoy H, Başak N, Yeşil Y, Oral D & Demirci S (2013) The flora of Yıldız Mountains (Kırklareli) Biosphere Project area. Turkish Journal of Botany 37: 225–269. doi:10.3906/bot-1111-5.

Utescher T, Erdei B, François L & Mosbrugger V (2007) Tree diversity in the Miocene forests of Western Eurasia. Palaeogeography, Palaeoclimatology, Palaeoecology 253: 226–250. doi:10.1016/j.palaeo.2007.03.041.

Vladimirov V, Matevski V, Bancheva S, Delcheva M, Kostadinovski M & Ćušterevska R (2016) First report of *Erigeron sumatrensis* (Asteraceae) for the flora of the Republic of Macedonia. Flora Mediterranea 26: 203–207. doi:10.7320/FlMedit26.203.

World Nuclear Association (2026) Nuclear Power in Turkey. https://world-nuclear.org/information-library/country-profiles/countries-t-z/turkey.aspx.

Yaltırık F (1982) *Pterocarya* Kunth: Flora of Turkey and the East Aegean Islands (ed. by PH Davis) Edinburgh University Press, Edinburgh, vol. 7.

Yaltırık F & Efe A (1988) Trakya vejetasyonuna genel bakış ve İğneada subasar (Longos) ormanları. Journal of the Faculty of Forestry, Istanbul University, Series B 38: 69–75.

Yılmaz Dağdeviren R & Karlıoğlu Kılıç N (2023) Mert Gölü Longoz ormanlarının 2017–2022 yılları arasındaki güncel polen dağılımının belirlenmesi (İğneada, Kırklareli, Türkiye). Anatolian Journal of Forest Research 9: 21–27. doi:10.53516/ajfr.1220061.

Yılmaz Dağdeviren R, Karlıoğlu Kılıç N, Yakupoğlu C, Yakupoğlu N & Eriş KK (2024) The vegetation history of Lake Mert and its surroundings for the last 6600 years (Kırklareli, NW Türkiye). Quaternary International 679: 15–24. doi:10.1016/j.quaint.2023.12.001.

Yılmaz M (2015) New locality records and conservation of Caucasian wingnut (*Pterocarya pterocarpa* (Michx.) Kunth ex I.Iljinsk.) in southern Turkey. Anadolu University Journal of Science and Technology C – Life Sciences and Biotechnology 3: 39–44. doi:10.18036/btdc.75287.

Yousefzadeh H, Rajaei R, Jasińska A, Walas Ł, Fragnière Y & Kozlowski G (2018) Genetic diversity and differentiation of the riparian relict tree *Pterocarya fraxinifolia* (Juglandaceae) along altitudinal gradients in the Hyrcanian forest (Iran). Silva Fennica 52: 10000. doi:10.14214/sf.10000.

Zachos J, Pagani M, Sloan L, Thomas E & Billups K (2001) Trends, rhythms, and aberrations in global climate 65 Ma to present. Science 292: 686–693. doi:10.1126/science.1059412.

Zhou W, Yang Y, Han W, Song C, Meng Z, Zhang H & Han Q (2025) Effects of thermal discharge on the structuring of macrobenthic biological traits around the Sanmen nuclear power plant in the East China Sea. Marine Pollution Bulletin 213: 117705. doi:10.1016/j.marpolbul.2025.117705.

Zohary M (1973) Geobotanical foundations of the Middle East. Gustav Fischer Verlag, Stuttgart, Germany.