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New Findings on the Natural Vertical Distribution of Turkish Red Pine (Pinus brutia Ten.*)*

Kızılçamın (Pinus brutia Ten.*) Doğal Dikey Yayılışında Yeni Tespit*

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Abstract
Turkish red pine (*Pinus brutia* Ten.) is an important forest tree species found in many countries across the Eastern Mediterranean basin. In Türkiye, the red pine has its widest distribution in the Mediterranean Region, in areas under the influence of a maritime climate. This study aims to reveal and introduce the new vertical distribution elevation of the *P.brutia*, one of Türkiye's most important tree species. Thus, it aims to contribute to the knowledge regarding the natural distribution of the species. The newly identified vertical distribution of red pines was determined at an elevations of 1693 m and 1698 m on the southwest aspect of Dede Mountain in the village of Yukarıkükür, Anamur District, Mersin Province, at UTM 36S 473647 -4013298 and 473550-4013417. These findings are of considerable importance, as they represent a marginal population of Turkish red pine occurring at the highest altitudinal distribution known worldwide.

Öz
Kızılçam (*Pinus brutia* Ten.), Doğu Akdeniz havzasındaki birçok ülkeyi kapsayan önemli bir orman ağacıdır. Kızılçam Türkiye'de en geniş yayılışını Akdeniz Bölgesi'nde deniz iklimi etkisi altındaki sahalarda gerçekleştirmektedir. Bu çalışmada, Türkiye'nin en önemli ağaç türlerinden biri olan Kızılçam'ın yeni dikey yayılış yükseltisinin ortaya koyulması ve tanıtılması amaçlanmıştır. Böylece türün doğal yayılışına ilişkin bilgilere katkıda bulunulması amaçlanmıştır. Yeni tespit edilen kızılçamların dikey yayılışı Mersin ili, Anamur İlçesi Yukarıkükür köyü Dede Dağı mevkiinde, 1693 m ve 1698 m rakımlarda güneybatı bakıda UTM 36S 473647-4013298 ve 473550-4013417 koordinatlarında tespit edilmiştir. Bu bulgular, Kızılçamın dünyadaki en yüksek dikey yayılışını temsil eden bir marjinal popülasyon olması açısından büyük önem arz etmektedir.

INTRODUCTION

Turkish red pine *(Pinus brutia* Ten.*)* which is widely distributed in the Eastern Mediterranean Basin, is a forest tree species of ecological and economic importance (Boydak 2004). It is naturally found in regions between 15°-45° east longitude and 32- 45° north latitude in the Northern Hemisphere. *P.brutia* is distributed worldwide, primarily in Türkiye, but also in Italy, the South Aegean Islands, Cyprus, Lebanon, Jordan, Iraq, Syria, Crimea, and the Western Caucasus (Davis 1965-1985, Critchfield and Little 1966, Saatçioğlu 1976). The westernmost point of its distribution is the Calabria Peninsula in Italy, while the easternmost point is the "Zavita Atrush" region in northern Iraq (Asmaz 1993). *P. brutia* extends north to Crimea and south to Lebanon and Palestine.

With a distribution area of 5.2 million hectares within the forests of Türkiye, it is the pine species with the widest distribution (OGM 2025). *P. brutia* has its widest distribution in the Mediterranean Region, in areas under the influence of a maritime climate (Şefik 1964, Karatepe et al. 2014). The areas where *P.brutia* grows are mainly characterized by a Mediterranean climate with hot and dry summers and mild and rainy winters (Boydak 2004). The average annual rainfall in the regions where it is distributed ranges from 400 mm to 2000 mm, and the average annual temperatures vary

between 12 °C and 20 °C (Atalay et al. 1998). It has high temperature requirements and is rarely damaged by frost. Rainfall is generally irregular in the regions where the *P.brutia* species is distributed (Neyişçi 1987, Özkan and Kuzugüdenli 2010).

In the Mediterranean Region, which is under the influence of the Mediterranean climate, the distribution areas of forest formations are the Taurus Mountains and the Amanos Mountains. In the Mediterranean Region, due to the mountainous topographic structure, climatic characteristics and, consequently, the natural distribution areas of *P. brutia* are shaped. *P. brutia* can be found or have the potential to be found in the inland areas where the Mediterranean climate penetrates along the valleys, in addition to the coastal region where maritime influence can penetrate (Kantarcı 1991). Within the distribution area of the species, there is a dry period for almost half of the year, and dry forests constitute the dominant forest formation (Günal 2013). *P. brutia* naturally occurs in the lower and middle zones of dry forests in the Taurus Mountains. At higher elevations, this species gives way to species with lower temperature requirements *P. brutia* is generally found in pure stands up to 1000 m in the region, higher elevations it forms various stands with Black pine (*Pinus nigra* Arn.), Taurus cedar (*Cedrus libani* A. Rich.), Taurus fir (*Abies cilicia* Carr.), Stinking juniper (*Juniperus foetidissima* Willd.) and Prickly juniper (*Juniperus oxycedrus* L.) (Çatal and Carus 2005).

The Mediterranean Region, particularly due to the complex topography of the Taurus Mountains, encompasses different climate types, and this contributes to the region's rich plant diversity (Davis 1965–1985, Mayer and Aksoy 1986, Kürschner et al. 1997). Climate is one of the main physical geography elements determining the distribution of forests in the Taurus Mountains. Temperature, in particular, stands out as the key determinant in the vertical distribution of forests. Growing environment conditions, which vary depending on landforms and maritime influence, also significantly affect the physical and chemical properties of the bedrock and parent material. Altitude-related climate changes cause the formation of altitude and climate zones on mountain slopes, which in turn leads to differences in the species composition of forest communities across these zones. In the Taurus Mountains, slope aspect and southwest sea-influenced winds can lead to differences in climatic conditions at the same elevation, and consequently, changes in the species composition of forest communities (Kantarcı 1991).

Outside the Mediterranean Region, the *P.brutia* establishes pure or mixed forests in the Aegean and Southern Marmara Regions, while in the Black Sea Region, it naturally occurs in small stands in certain microclimate areas with Mediterranean climate characteristics (Sarıbaş and Ekici 2004).

P.brutia exhibits regional adaptations throughout its wide distribution area in Türkiye (Kurt et al. 2012). Natural stands are distributed across a wide variety of soil types and climatic conditions. Although it is a light-demanding species (Dafis 1986, Quézel 2000), it can form extensive forests during the "climax" stage (Boydak et al. 2006). Studies on the field index of *P.brutia* reveal that, despite its wide distribution in the Mediterranean basin, it does not show a significant distribution at high altitudes, except in some microclimate zones, when evaluated in terms of elevation. All these factors make it a relatively complex species.

It is known that conifers of the Eastern Mediterranean Basin possess higher levels of genetic diversity than other conifers. This is explained by the fact that their populations may have been preserved in favorable environments during the Last Glacial Maximum and were not affected by strong demographic and genetic bottlenecks (Fady-Welterlen 2005, Fady et al. 2008). These characteristics are important for the conservation of the forests formed by these conifers in Anatolia. *P. brutia* is a species with high genetic diversity and evolutionary history, and has formed highly resilient forest covers in the dry Mediterranean conditions. It is a drought-resistant species well adapted to the Mediterranean climate in terms of various physiological and morphological characteristics (Grunwald and Schiller 1988, Dirik 1994, Younis et al. 2024). Their ability to adapt to drought varies depending on the genetic or geographical origin of the species (Dirik 2000).

The ability of *P. brutia* to grow in a wide variety of soils and elevations, its high growth rate, and high productivity potential have made it one of the most promising pine species for plantations in the Mediterranean basin. *P. brutia* is the most widely used main forest tree species in Türkiye for meeting timber raw material needs. In addition, its resistance to drought, continental climate, and its capacity to regenerate after forest fires make it an exceptional forest species within the sensitive Mediterranean ecosystems. *P. brutia* has been identified as a target species for intensive forestry and tree improvement programs in Türkiye (Koski and Antola 1993). Furthermore, it plays a key role in the realization of ecosystem and environmental services such as biodiversity conservation, carbon sequestration, soil and water resource conservation, combating desertification, erosion prevention, recreation, and wildlife management (Keten and Gülsoy 2020). Therefore, *P. brutia* forests are an important species for multi-purpose forestry and have high economic and ecological value (Kurt et al. 2011). Due to the characteristics mentioned above, it is very important to maintain the presence of the *P. brutia* species in forests. The wide geographical distribution of the species in our country and the resulting diverse ecological conditions necessitate consideration in the development of strategies related to its management and planning, and a multifaceted investigation into potential threats is required. This is because, for thousands of years, the structure of almost the entire ecosystem in the Mediterranean Region has been disrupted due to excessive destruction. The potential natural vegetation has only been preserved in certain areas, in places inaccessible to humans (Cierjacks and Hensen 2004, Güneş 2020). The *P. brutia*, which is the subject of this study, is among the trees that have been most severely damaged in the Mediterranean Basin for centuries. The area of degraded *P.brutia* in our country is approximately 2.158.946 hectares.

The unique ecological conditions of the Mediterranean have made the region's forests a significant source of genetic material, and consequently, have also led to them facing numerous threats. At the same time, due to the long history of Mediterranean civilizations, the region has faced many threats over the years, influenced by both human and natural factors, and has taken its final form through the interplay of these factors. Land-use changes, climate change, grazing, forest fragmentation, forest fires, and the increasing frequency of diseases and pests, etc., are among the leading threats to Türkiye forests from the past to the present (Peñuelas and Sardans 2021, Fady et al. 2022, Koç et al. 2022). All these factors are major factors altering the distribution of many species in the Mediterranean ecosystem (Wahren et al. 1994, Ben-Said 2022). In recent years, climate change, in particular, has been increasing its impact in Türkiye, especially in the Mediterranean region, with rising temperatures and decreasing rainfall (Giorgi and Lionello 2008), causing numerous changes in forest ecosystems. One of the most significant effects of these changes is on species distribution. When climatic conditions change, plants either migrate, adapt to the changing conditions, or become extinct (Aitken et al. 2008, Ackerly et al. 2010, Arıcak et el. 2024).

The Mediterranean region, considered an arid and semi-arid area, is one of the at-risk regions in the temperate zone due to global warming. In the Eastern Mediterranean Basin, temperature increases that began in the 20th century have accelerated since the 21st century, and the most severe droughts in Türkiye have been observed in the last 30 years due to the sudden drop in winter rainfall (IPCC 2018, Koç et al. 2022). The main concern for the 21st century is the rate of climate change; this leads to an understanding that the current rate of climate change may exceed the rate of evolutionary changes, genetic adaptation, or migration in Mediterranean trees (Klein et al. 2012).

This study aims to reveal and introduce the new vertical distribution elevation of the *P. brutia*, one of Türkiye's most important tree species in economic and ecological terms. Thus, it is intended to contribute to the knowledge of the natural distribution of this species worldwide. Identifying and evaluating the new distribution elevation of the species will also be important in terms of effective conservation and management strategies.

MATERIALS AND METHODS

The material for this study consists of *Pinus brutia* identified during fieldwork in the Dede Dağı locality of Yukarıkükür Village, within the boundaries of Kükür Forest Sub-district Directorate, Anamur Directorate of Forestry (Figure 1). The species was selected as material because of the identified of a new individual distribution elevations in the Taurus Mountains at elevations of 1693 m and 1698 m, southwest aspect, at coordinates UTM 473647-4013298 and 473550-4013417 (Figure 2). It was determined that the species is found in pure stands up to an elevation of 1590 m in the forests of Anamur Directorate of Forestry, and then in mixed stands with black pine, cedar, and fir. The highest elevation reached by the species in stand form in the region was determined to be 1635 m. The *Pinus brutia* studied is located in the Mediterranean plant geography and has typical Mediterranean climate characteristics, with hot and dry summers and mild and rainy winters (Davis 1965-1985, 1988). The areas where the *Pinus brutia* are found are steep points on the southwest aspect where the slope changes very abruptly from 85-90% to 190-200%, the bedrock is mostly on the surface, and the soil depth is 5-8 cm. The *P. brutia* found at an elevation of 1693 m has a height of 14.7 m, a diameter of breast height (dbh) of 21.6 cm, and an age of 104 years. The other is located 152 m away in a straight line, at an elevation of 1698 m, with a height of 6.9 m, a diameter of breast height 12.2 cm, and an age of 53 years. Furthermore, in this study, literature reviews were conducted on the natural distribution areas of *P. brutia* in our country and the factors affecting its natural distribution areas.

Figure 1. Study area (Google Earth 2026)

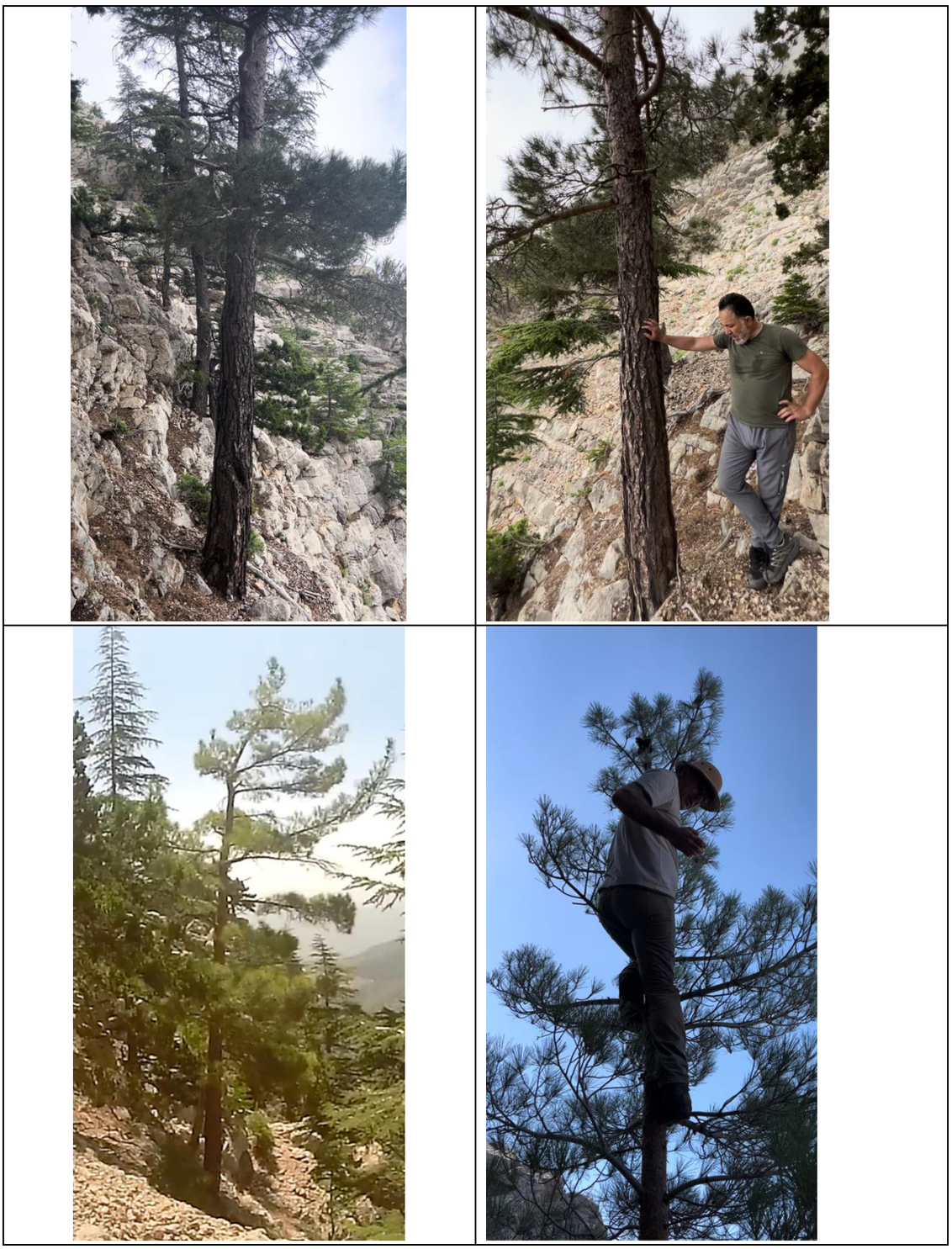

Figure 2. *P. brutia* detected at elevations of 1693 m and 1698 m, respectively

RESULTS AND DISCUSSION

The *P. brutia* is one of the coniferous tree species with the widest distribution area in our country. The species distribution, particularly within the Mediterranean region, is higher than in other regions. Within its wide distribution area, its distribution at very high elevations is limited, except for some microclimate zones (Özdemir and Çınar 2023). In this study,

new distribution elevations of 1693 m and 1698 m were identified in the Taurus Mountains in the Mediterranean region. Studies to date have determined its highest distribution at an elevation of 1650 m in the Ulucak Forest of the Sarıdana region in Anamur (Kayacık 1980, Atalay et al. 1998, Boydak et al. 2006, Chambel et al. 2013, Sarı 2016). Therefore, according to research conducted on its distribution in our country, there is an upward movement of approximately 48 m in its vertical distribution. In addition, it is known that *P.brutia* can reach extreme elevations of 1500 m in the Anamur Sarıdana region and 1595-1600 m in the Gölhisar forests (Karadağ 1999, Kılıç and Güner 2000).

Analysis of cross-sectional profiles taken from the sea towards the peaks of the Taurus Mountains in the Mediterranean region indicates that *P. brutia* can reach elevations of 1100-1300 m in stands on north- aspect and 1450-1500 m on south-aspect. However, it is emphasized that the distribution of *P. brutia* at 1500 m is individual in nature (Karatepe and Koyun 2017, Kuzugüdenli 2022). The maximum elevation of the species decreases as as its range extends north of the Mediterranean region (Kuzugüdenli 2022). For example, in the Aegean Region, *P.brutia* can reach 800-900 m; in the Marmara Region, 600-700 m. In general, the elevation ranges of *P.brutia* vary according to region. It is also distributed in Trakya, the northern Marmara coast, Keşan and Gelibolu, reaching elevation of 400 m. It is also found naturally on the Istanbul Islands (Saatçioğlu 1976, Atalay et al. 1998, Boydak et al. 2006). *P. brutia* is distributed in the Mediterranean region in areas where the influence of the maritime reaches the interior through valleys. The species reaches Mut along the Göksu River, north of Feke via the Seyhan valley, Gölbaşı along the Kahramanmaraş-Antakya trough, and further inland via the Eşen, Aksu, and Köprü rivers. It extends approximately 300 km inland along the Gediz Valley in Western Anatolia.

Apart from its main distribution in Türkiye, populations adapted to extreme conditions are also found in Pazarcık (Kahramanmaraş), Gölbaşı (Adıyaman), and Şırnak (Yılmaz et al. 2013). The population, which is distributed in the Afyonkarahisar region while maintaining its forest stand structure, is ecologically important as it is the most extreme population encroaching into the steppe (Turan 2018).

The distribution of plant species along the Mediterranean coast, depending on elevation, is closely related not only to general climatic conditions but also to local microclimatic differences created by topography. The Taurus Mountains, rising rapidly parallel to the coast and over short distances, create valleys closed to the north, limiting the access of cold air masses to the coast and creating a föhn effect; this effect is even greater in areas where the Taurus Mountains approach the coast and the altitude increases suddenly (Sarı 2010), and can alter the upper limits of species. In the areas north of Anamur, with steep, south-facing slopes exceeding 1500 m, these topographic features have raised the upper limit for maquis and *P.brutia* growth. The maquis formation, which is generally seen up to 800 m on the Mediterranean coasts, can reach 1300–1400 m here, while the red pine mostly reaches 1500 m, and in the sheltered area of the Sarıdana- Olucak (Ulucak) region it can reach up to 1650 m (Karatepe et al. 2014, Sarı 2016).

The study area, where *Pinus brutia* occurs, is situated within an ecosystem particularly vulnerable to climate change. Given its long history of human pressure, these factors are expected to affect its distribution and need to be evaluated. This is because one of the most significant impacts of climate is on the geographical distribution of the species. It has been stated that ongoing climate change and human impact will also affect the distribution of these coniferous trees in the Mediterranean Basin in the future (Yalçın 2012, Özdemir 2022).

Numerous datasets and models have examined the responses of various species to climate change. In plants, the most common responses to climate change are shifts in distribution range to higher latitudes or altitudes (Hughes 2000, McCarty 2001, Walther et al. 2002, Parmesan and Yohe 2003, Chen et al. 2011, Yalçın 2012, Rabasa et al. 2013, Thurm et al. 2018) and changes in their phenology (Cleland et al. 2007, Hu et al. 2015). In general, tree species worldwide respond to climate change through local adaptation or migration, especially in high-latitude and high-altitude forest ecosystems

where low temperature is generally considered the primary limiting factor determining tree distributions (Lenoir and Svenning 2015, Oldfather et al. 2020, Zhang et al. 2023). Most studies indicate that the main reason trees are shifting towards higher elevations is rising air temperatures due to climate change (Jump et al. 2009, Renwick and Rocca 2015). In Slovenia, an increase of 0.36 °C per decade has been reported in temperature for the last fifty years (Bertalanič et al. 2019). This temperature change is high enough to trigger movements in tree species populations. In addition, it has been shown that increasing temperature is not the only determinant of species upward migration along the elevation gradient, and that precipitation, species adaptation capacity, functional characteristics, anthropogenic land use and environmental constraints are also factors driving species upward (Peñuelas and Boada 2003, Ameztegui et al. 2010, Chen et al. 2011, Corlett and Westcott 2013, Grytnes et al. 2014, Maharjan et al 2022). For trees, the direction and magnitude of elevation changes may depend on the interactions between climate change and life history characteristic features (Renwick and Rocca 2015).

Yalçın (2012) stated that in the future, the distribution of *P. brutia* is expected to shift to higher elevations and towards the northern and northeastern regions of Türkiye due to the effects of climate change. He predicted that *P. brutia* could potentially gain extensive areas suitable for climate by 2080, and that a significant portion of its habitats could become unsuitable in the future.

Bussotti et al. (2014) state that tree species follow a natural migration pattern from south to north and from low to high altitudes. Lenoir et al. (2008), evaluating the altitude distribution of 171 forest plant species across France, including the Western Alps, reported that climate change has led to a significant upward shift of an average of 29 meters per decade in the optimum altitudinal of these species. Furthermore, the functional characteristics of species are important for understanding the potential responses of species to climate change. It has been reported that the elevations centers of herbaceous species in the French Alps shifted upward by an average of 85 m during certain periods, while woody species showed no significant change during the same time period.

Pressures resulting from anthropogenic impacts can affect changes in the elevations distribution of species (O'Sullivan et al. 2021). Globally, approximately 60% of mountainous areas worldwide, and predominantly lowland, are subject to intense human pressure (Elsen et al. 2020). In recent years, It has been suggested that anthropogenic disturbances, particularly those caused by tourism and recreation activities, may have contributed to the upward migration of lowland species (Zu et al. 2021). In the specific case of Türkiye, it is likely that similar effects have occurred in Mediterranean ecosystems that have been subjected to human intervention for many years.

Information on the effects of climate change and other environmental factors on the current distribution of forest trees, which are important for ecosystem services in our country, is limited. In this study, *P.brutia* individuals, which have been identified as having the highest vertical distribution in the world at 1693 m and 1698 m in Anamur and have seed retention capacity, will form the basis for future studies. This is because the identified Turkish red pines, especially by moving their distribution area to higher elevations depending on climate and other factors, may contribute to their survival while also exposing them to new biotic and abiotic pressures to which they are not adapted. This may lead to the disruption of species interactions and threaten the stability of existing communities. All of this will be important in terms of establishing the necessary conservation and management strategies in the ongoing process.

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