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Tree rings of *Quercus ilex* L. and their relationships with some wood anatomical features and growing site conditions in Türkiye

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Abstract: *Quercus ilex* (Holm oak) presents itself as trees up to 14–15 m tall in suitable growing site conditions and as shrubs in unsuitable areas. The purpose of this study was to determine the relationships between tree-ring widths of *Q. ilex* and vessel features, tree diameters, climate, and site conditions throughout Türkiye. A total of 1020 cores from 510 trees were collected from 102 sampled sites throughout Türkiye. After using standard dendroclimatology methods, all tree-ring analyses were performed on these chronologies. As a result, tree-ring boundaries were found to be less visible in Türkiye, like in other Mediterranean areas. Mean sensitivity ranged from 0.32 to 0.48 in different regions. Temperature during spring and summer months in the Mediterranean region has a negative effect on tree-ring widths in general. Winter temperature generally has a positive effect on tree-ring growth, and an increase in winter temperature may promote tree-ring width. Monthly total precipitation from November to July has a significant positive effect on tree-ring width and it is higher in the Aegean Region. While tree rings are wide in the trees found in lowlands, they are narrow in shrubs and at high elevations. There are clear negative relationships between tree-ring width and elevation, the amount of leaves in the litter, total litter amount, organic carbon, and soil pH. Regarding tree height, tree diameter, and vessel features, they have positive and high correlations with tree-ring width, except vessel frequency, which has a significant negative correlation. As a result of grouping, while the ratio of sites belonging to the dry group is low in regions that have trees with wide tree rings, the ratio of sites of the dry group is very high in İzmir and Datça, which have trees with narrow tree rings. The region with the widest rings is the Marmara Region, followed by the western Black Sea and the northern and southern Aegean, respectively. In conclusion, *Q. ilex* is a species that survives in both xeric and humid sites. It has adapted to dry conditions by forming narrow tree rings in Datça and continues to be found in tall bush-shrub forms with individuals over 140 years old. Specimens of the same age are in the form of trees with diameters of 50–60 cm and heights of 10–15 m in Ereğli. For these reasons, this species should be taken into consideration in afforestation and given priority in protection in its natural habitats where soil conditions are favorable, at a maximum distance of 23 km from the sea and in near-coastal areas.

Key words: Holm oak, tree-ring growth, growing site, soil and tree rings, elevation effect, regional differences

1. Introduction

Quercus ilex, which spreads from the anti-Atlas Mountains to the Black Sea coast, has its main distribution area in the western Mediterranean Basin (Barbero et al., 1992; Akkemik et al., 2020; Günal, 2021). The distribution areas of this species in Türkiye are mainly coastal areas from sea level up to 300 m in the Black Sea Region to 400 m in Davutlar (mid-Aegean Region) and up to 1100 m in Datça (south-westernmost Anatolia). This species is found in tree forms in lower elevations and in shrub forms in growing sites of higher elevations (Akkemik et al., 2020).

In Türkiye, very limited research has been performed on *Q. ilex*. Akkemik et al. (2021) showed the ecological wood anatomical features of this species. They stated that the vessel frequency differed in different growing sites dramatically more than other wood features. According to the mesomorphy and xeromorphy ratios, the growing areas were classified into three different groups as humid, very humid, and dry. The highest ratio belonged to the dry group at 47%. The ratio of the humid group was 38% and

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the ratio of the very humid group was 15%. Almost half of the growing areas of *Q. ilex* are under dry conditions. According to the regional distribution of the dry groups, 60% are found in the Aegean Region, 46% in the Marmara Region, and 30% in the Black Sea Region. More than half of the growing sites in the southwest of Türkiye are drier for this species (Akkemik et al., 2021). Furthermore, there are high positive correlations between vessel frequency and tree cover, tree height, and stem diameter (Akkemik et al., 2021).

Contrary to the situation in Türkiye with regard to *Q. ilex*, many studies were performed in its distribution areas in the western Mediterranean Basin (e.g., Villar-Salvador et al., 1997; Garcia-González and Eckstein, 2003; Corcuera et al., 2004; Campelo et al., 2007, 2010; Gutiérrez et al., 2011; Abrantes et al., 2013; Balzano et al., 2020). Villar-Salvador et al. (1997) explained that in northeast Spain, mean maximum vessel diameter and total leaf area in *Q. ilex* increased with precipitation while vessel diameter and vessel element length showed no significant correlation. Similar results were found by Garcia-González and Eckstein (2003) and Campelo et al. (2010).

Tree-ring width is affected by many different conditions such as temperature, precipitation, elevation, soil, aspect, and the genetic structure of the tree species (Fritts, 1976; Schweingruber, 1988). The relationships between climate and tree-ring widths (Fritts, 1976; Pritzkow et al. 2014) and wood anatomy (e.g., Corcuera et al., 2004; Fonti et al., 2007; Liang et al., 2013; Pandey, 2021) have been studied for various tree species. Corcuera et al. (2004) found that *Quercus ilex* demonstrated greater drought resistance and showed the positive influence of January and June–August precipitation on internode length in 1994, which was a severely dry year. Nardini et al. (2000) explained that in northern Spain, *Q. ilex* xylem has higher vulnerability to frost than to drought in its northern limit of distribution.

The anatomical features of the wood elements that make up the tree ring provide important information about environmental factors and allow us to understand the climate adaptation process and response strategies of tree growth within changing environments (Wimmer, 2002). According to Allan et al. (2021), the climate is changing and tree growth and xylem anatomical traits of the tree species in the Mediterranean Basin are affected by these changes. For instance, increased drought causes narrower and shorter vessels and increasing frequency of vessels per square millimeter in *Q. ilex* (Akkemik et al., 2021). Together with climate, growing site conditions such as elevation, aspect, and soil affect tree-ring growth (Frits, 1976). In this context, the purpose of this study was to determine the relationships between tree-ring widths of *Q. ilex* and (1) temperature and precipitation; (2) some tree features such as tree height and diameter and some wood features such as vessel tangential diameter, vessel radial diameter, vessel length and vessel frequency, mesomorphy, and xeromorphy; and (3) some growing site conditions such as elevation, dry leaf amount (g/m^2) on the soil surface, pH at soil depths of 0–5 cm and 5–15 cm, total litter amount (g/m), and organic carbon at soil depths of 0–5 cm and 5–15 cm for all growing sites.

2. Materials and methods

Quercus ilex presents itself as trees up to 14–15 m tall in suitable growing site conditions and in shrub form in less favorable growth conditions and within sclerophyllous forests (Akkemik et al., 2020; Figure 1). We collected samples (predominantly increment cores and some stem discs) from all natural distribution areas of the species in Türkiye. A total of 1020 samples from 510 trees, two of each from breast height, were collected from 102 sampling sites (Figure 2), from five trees from each site.

2.1. Measurements of tree rings

Increment cores were mounted on wooden supports in the laboratory and sanded until the tree rings were clearly visible. They were then first divided into 10-year sections and tree-ring widths were measured using the LINTAB-TSAP measuring system. However, similar to some other species that grow in typical Mediterranean conditions, tree-ring boundaries were indistinct and tree-ring measurements were therefore rather difficult. As stated by Cherubini et al. (2003), the tree-ring boundary is generally indistinct in *Quercus ilex*. Cherubini et al. (2003) categorized trees that grow in Mediterranean climate conditions into four groups according to the formation of tree rings, and they placed *Q. ilex* into the group of "trees with continuous cambium activity." In many of the *Quercus ilex* increment cores measured in our study, the tree rings did not have distinct boundaries.

These tree-ring properties of *Q. ilex* affect tree-ring measurements. For example, Campelo et al. (2009) were only able to use 40 of 60 increment cores successfully in their study on *Quercus ilex* species in Portugal. Gea-Izquierdo et al. (2009) collected stem discs from 114 trees in their study conducted in Portugal and used only 25 of those discs to create a tree-ring chronology. A similar situation occurred in our study and only 647 cores from 364 trees (71% of trees, 63% of cores) were used. Quality control was performed on the measurements using COFECHA (Holmes, 1983) and errors stemming from these measurements were reduced as much as possible. Following this step, COFECHA controls were successfully carried out, except for the sites in Sinop. In Sinop there is a small distribution area of *Q. ilex*. About half of this area is around a dam built by the State Directorate of Water Affairs, while the other half is on a steeply sloping area open to northern Black Sea winds and on shallow



Figure 1. Tree (from İstanbul) and shrub (from Datça) forms of *Quercus ilex* in Türkiye.

soil. Both of these areas are under significant human impact. For that reason, we excluded the sites in Sinop from further analysis. After the COFECHA controls, the ARSTAN program (Cook, 1985) was used to build a mean chronology for each region to calculate correlation coefficients between tree-ring width and climate.

Mean sensitivity was calculated for the 93 sampled sites using the following formula (Fritts, 1976):

$$Ms = \frac{1}{n-1} \sum_{i=1}^{i=n-1} \left| \frac{2(x_i - x_{i-1})}{x_i + x_{i-1}} \right|$$

Ms = Mean sensitivity of annual rings
x_i = Annual ring width in the year of i
x_{i-1} = Annual ring width in the year of i – 1
n = Number of annual rings

2.2. Relationships between tree-ring widths and climate

Pearson correlation coefficients were calculated to find the effect of monthly mean, minimum, and maximum temperatures and monthly total precipitation on tree-ring width in seven different regions. These regions included Ereğli-Alaplı in the province of Zonguldak, Elmalı and Fenertepe in the province of İstanbul, Gökçeada in the province of Çanakkale, İzmir, the Davutlar district in the province of Aydın, and Datça in the province of Muğla. The R program[1] was used for analysis.

2.3. Relationships between tree-ring widths and tree diameters and vessel features

Relationships between average tree-ring widths and wood anatomical features were investigated for the total 93 sampled sites. Wood anatomical features obtained from the last 5 or 6 tree rings of each wood were previously determined by Akkemik et al. (2021) and were reused

1 R Core Team (2019). R: A Language and Environment for Statistical Computing [online]. Website https://www. R-project.org/ [accessed 1 November 2023].

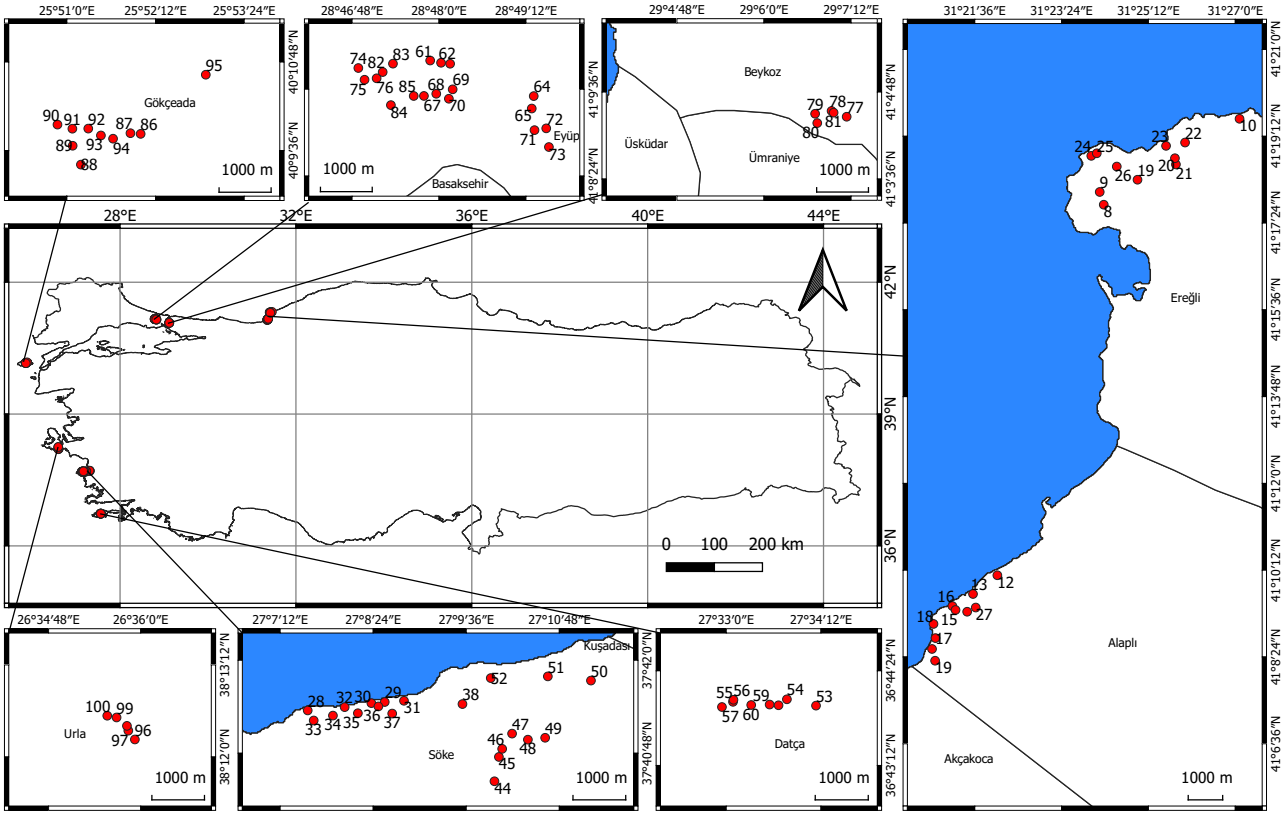


Figure 2. Sampling sites in the distribution areas of *Quercus ilex* in Türkiye.

here for comparison with tree-ring widths. In this context, radial and tangential diameters of vessels, vessel lengths, vessel frequency, and mesomorphy and xeromorphy values were used in correlation and regression analyses. In the regression model, the Akaike information criterion (AIC) was considered using jamovi software[2] and the R Program.

The significances of the correlation coefficients are indicated as * for 95%, ** for 99%, and *** for 99.9% confidence levels and NS for nonsignificant throughout the text.

Based on mesomorphy and xeromorphy ratios obtained from vessel features, the sampling sites within each of the eight regions were grouped as "very humid," "humid," and "dry" by Akkemik et al (2021) (Table 1). In this study, correlation coefficients between tree-ring widths and the ratios of these very humid, humid, and dry sites within the eight regions were calculated, and visual comparisons were made.

Finally, the method of canonical discriminant analysis was applied based on the average tree-ring widths of the eight regions and the anatomical features of their woods and the distances between the regions were determined.

2.4. Relationships between tree-ring widths and elevation

Elevation is one of the most significant factors affecting tree growth and wood formation in *Quercus ilex* (Akkemik et al., 2020, 2021). The average tree-ring widths of the species for each site showed a difference, and it is accepted that one of the reasons for this may be elevations ranging from sea level up to 1100 m. To determine the effect of elevation, correlation coefficients were calculated and regression and cluster analyses were performed to examine the relationship between elevation and tree-ring widths using the R program.

2.5. Relationships between tree-ring widths and some environmental conditions

Correlation coefficients were calculated between average tree-ring widths and environmental conditions such as slope, elevation, canopy cover, litter, pH, soil features at depths of 0–5 cm and 5–15 cm, and nitrogen and organic carbon in the soil. All of these data were produced for the 93 sites and all materials collected in the project.

Furthermore, we used a linear mixed model to investigate how environmental variables (topographic, soil, and stand variables) impacted mean tree-ring width

2 The jamovi Project (2023). jamovi (Version 2.3) [online]. Website https://www.jamovi.org [accessed 1 November 2023].

Table 1. Ratios of very humid, humid, and dry sites in the eight regions (Akkemik et al., 2021) and average tree-ring widths.

Regions	Ratio of very humid sites (%)*	Ratio of humid sites (%)*	Ratio of dry sites (%)*	Average tree-ring width for each region (mm)
Sinop	28.6	57.1	14.3	--**
Ereğli - Alaplı	30	35	35	1.50
Davutlar National Park	12	40	48	1.81
Datça	0	37.5	62.5	1.96
İstanbul-Fenertepe	5	45	50	1.46
İstanbul - Elmalı	40	40	2%	0.82
Gökçeada	10	40	50	1.39
İzmir - Çeşme	0	0	100	0.74

*: From Akkemik et al. (2021); **: not used in the analysis.

across our sampled sites. Candidate models differing in their random-effects structures were fitted by restricted maximum log-likelihood techniques (Zuur et al., 2009). The goodness-of-fit of the different models was compared using the AIC. The model with the lowest AICc and greatest w_i was considered the best and most parsimonious model. The model was applied using the GAMLj module (Galucci, 2019) for jamovi.

2.6. Similarities of mean tree-ring widths in eight regions

Canonical discriminant analysis was performed by treating average tree-ring widths, mesomorphy, xeromorphy, tangential and radial diameters of vessels, vessel cell length, and vessel frequency as a whole. Thus, the similarities of any regions to other regions were determined.

3. Results and discussion

3.1. Tree-ring features and sensitivity

Tree-ring boundaries of *Quercus ilex,* which is one of the sclerophyllous species in the Mediterranean region, are often indistinct or not very clear (Figures 3a–3f). Even specimens with clear tree-ring boundaries do not generally have sharp boundaries; the boundaries are usually present as a dark region (Figure 3) and are quite unclear for some trees (Figure 3a). In some specimens, tree-ring boundaries can be seen due to the pale brownish-pinkish parenchyma bands in series (Figure 3c). Even in the same core, some tree-ring boundaries are clearly visible, while others are unclear. As in the examples given in Figure 3, specimens whose tree-ring boundaries could be seen were selected and used in further analyses. In order to make the tree-ring analyses more accurate, it is necessary to take a high number of samples from Mediterranean sclerophyllous species.

While the tree-rings are narrow in samples from higher elevations (e.g., Datça, Figure 3f), they are wider in samples from lowlands (e.g., İstanbul, Figure 3e). Tree-ring boundaries are almost distinct in the distribution areas in the Aegean Region (Figure 3f), and they are also visible in the distribution areas in the Black Sea and Marmara Region (Figures 3b and 3e) or less visible (Figure 3b). Mostly between the latewood zone and the beginning of the earlywood, there are several dark zones containing fibers with thick walls. These zones may have fewer vessels or are regions without vessels. This is the portion most likely formed during the autumn or mild winter periods, obscuring the tree-ring boundary (Figure 3d).

Averages of mean tree-ring numbers (tree ages) of the sites are largely similar and range from 36.5 to 51.3, except Datça. These values are 51.3 in Ereğli-Alaplı, 42.4 in Elmalı, 36.5 in Fenertepe, 49.3 in Gökçeada, 39.5 in İzmir, and 43.6 in Davutlar. Due to having trees that have more than 140 tree rings, this value is higher in Datça at 79.3. However, in Datça, tree-ring widths are roughly similar from younger to older periods of the trees, being narrow through all age categories. For that reason, we evaluated all these sites as being within a similar age group and used them in comparisons of tree-ring widths from all sites.

Quercus ilex is a tree of the coastal areas of Türkiye, and its furthest distance from the sea is approximately 23 km. This figure was mistakenly stated as 3 km by Akkemik et al (2020). In actuality, the range of 3 km from the sea is the area where the species is most widespread. Due to growing in coastal areas, the tree-ring formation of this evergreen species, which grows in temperate-warm conditions at low elevations, continues almost throughout the whole year (Cherubini et al., 2003). The fact that the boundaries of the tree rings measured within the scope of this study are generally unclear is an indication of this formation in Türkiye.

Campelo et al. (2007) stated that the wood parenchyma bands are important in seeing the tree-ring boundaries. In oak woods, wood parenchyma cells form bands in the tangential direction. While these bands are widely spaced

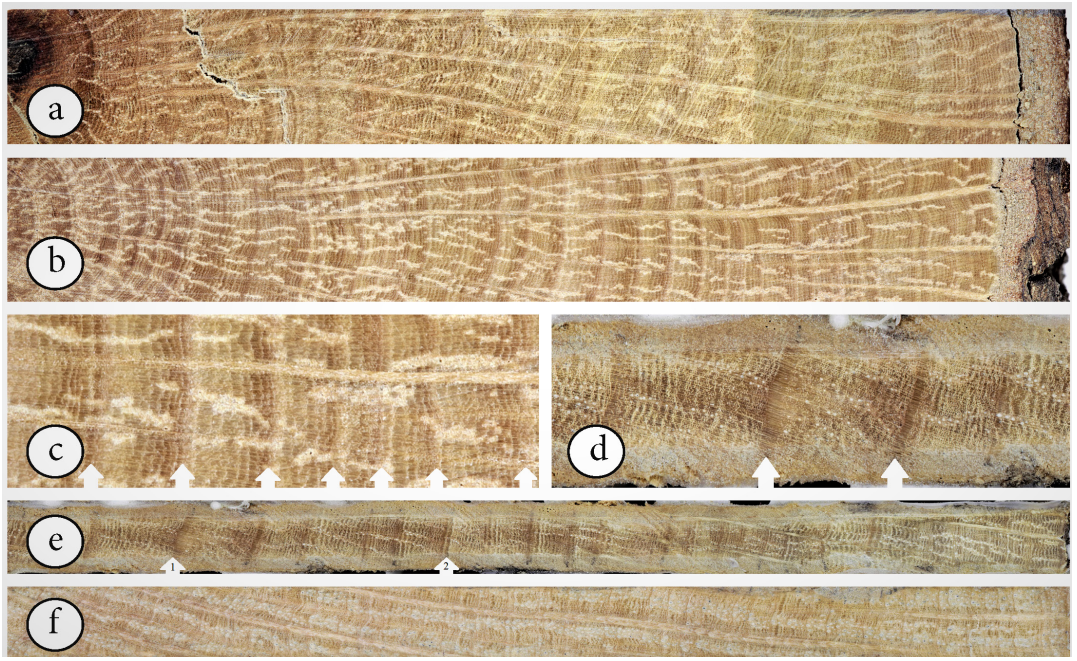


Figure 3. Several cores from samples: a) core from Ereğli-Alaplı (No. 20-5) having indistinct tree-ring boundary; b) core from Elmalı (No. 81-5) having tree-ring boundaries mostly visible, with tree-ring boundaries visible as dark regions; c) tree-ring boundaries can be seen due to the pale pinkish parenchyma bands and as dark regions (arrows); d) regions seen as dark bands without vessels between tree-ring boundaries (arrow); e) core with wide tree rings from Fenertepe (No. 68-4), with different types of dark boundaries, where arrow 1 shows a late dark region that looks as if it were formed after the finishing of the latewood and arrow 2 shows a dark region that looks as if it were formed as a last part of the latewood; f) core with narrow tree rings (more than 80 rings) from Datça (No. 56-3).

in the earlywood, they become more frequent towards the tree-ring border, and the parts where the bands become more frequent are indicated as the tree-ring boundaries. The uncertainty of the tree-ring boundaries make measurements difficult. In order to better understand the intraannual dynamics of *Q. ilex* wood formation in Türkiye, the cambium activity and xylem formation of *Q. ilex* in different distribution areas should be examined with a dendrometer. In the studies conducted by Cherubini et al. (2003) and Campelo et al. (2007), it was stated that tree-ring formations continue in winter.

The sensitivity coefficient, which expresses the magnitude of the changes in the width of the tree rings, is an important coefficient that shows the effect of habitat conditions on the tree-ring width (Fritts, 1976; Akkemik, 2004). The mean sensitivity coefficients were calculated as 0.32 for Davutlar, 0.34 for Gökçeada, 0.36 for İzmir, 0.37 for Fenertepe, 0.42 for Ereğli-Alaplı, 0.40 for Elmalı, and 0.41 for Datça. Campelo et al. (2009) found this value to be 0.50 in Portugal. The sensitivity coefficient of tree rings of the species is generally high, indicative of high variability in tree-ring width.

When the measured average, maximum, and minimum widths of the tree rings of *Q. ilex* in the distribution areas are compared on the basis of the sampled sites and regions (Figure 4), the tree-ring width is quite high in individuals that have reached tree form, exceeding 10 mm in some samples (Figure 4). The region where the widest ring was measured is İstanbul-Fenertepe, recorded as 14.10 mm. Although a small number of rings from early youth measured over 10 mm, the average ring width is 2.14 mm in Fenertepe, as the highest value in this region, and the lowest value (0.74 mm) was observed in Datça. The region with the highest variation in ring widths is Fenertepe and the region with the least is İzmir (Figure 4).

When the regional distribution of the average, maximum, and minimum widths of the tree rings is examined, the region in which the species forms the widest rings is the Marmara Region. Ring widths narrow in the western Black Sea Region and northern (Gökçeada) and southern (İzmir, Davutlar, and Datça) Aegean Region, respectively (Figure 4).

3.2. Relationships between tree-ring widths and climate

The tree-ring width of *Q. ilex* is affected by temperature and precipitation throughout its distribution areas in

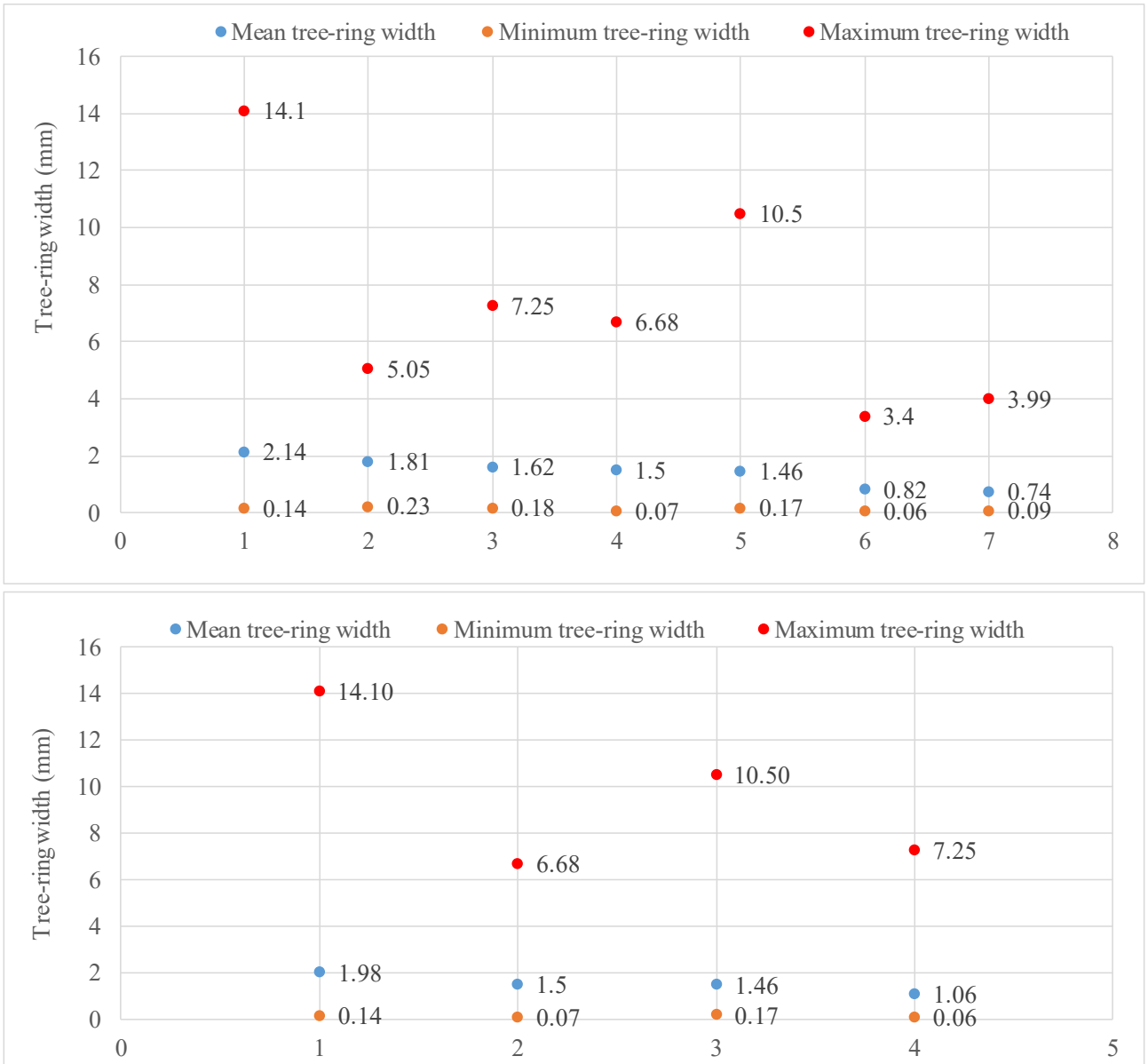


Figure 4. Average (blue point), maximum (red point), and minimum (orange point) tree-ring widths in sampling sites (top) and growing regions (bottom) in Türkiye. Site names are as follows (top): 1) Fenertepe, 2) Elmalı, 3) Davutlar, 4) Ereğli-Alaplı, 5) Gökçeada, 6) İzmir, 7) Datça. Region names are as follows (bottom): 1) Marmara Region, 2) Black Sea Region, 3) Northern Aegean Region, 4) Southern Aegean Region.

Türkiye. Temperature during spring and summer months has a negative effect on tree-ring widths in Türkiye (Figure 5). The negative effect of temperature on tree-ring width is not significant in Marmara Region, while it is significant in the other regions, particularly in July. The negative effect of maximum temperature is higher than that of minimum and mean temperatures. The results showed that an increase in spring and summer temperature may cause narrower ring formation, especially in areas where summer drought is intense and therefore there is not adequate water availability during this period. Winter temperature is an important limiting factor and has a generally positive effect on tree-ring growth. These positive effects are significant in some winter months of the Black Sea and Marmara Region and insignificant in the southern Aegean Region (Figure 5). Nijland et al. (2011) found that there was a positive correlation between ring width and temperature in January to April while a negative correlation was observed between ring width and summer (June–July) temperature. An increase in the minimum

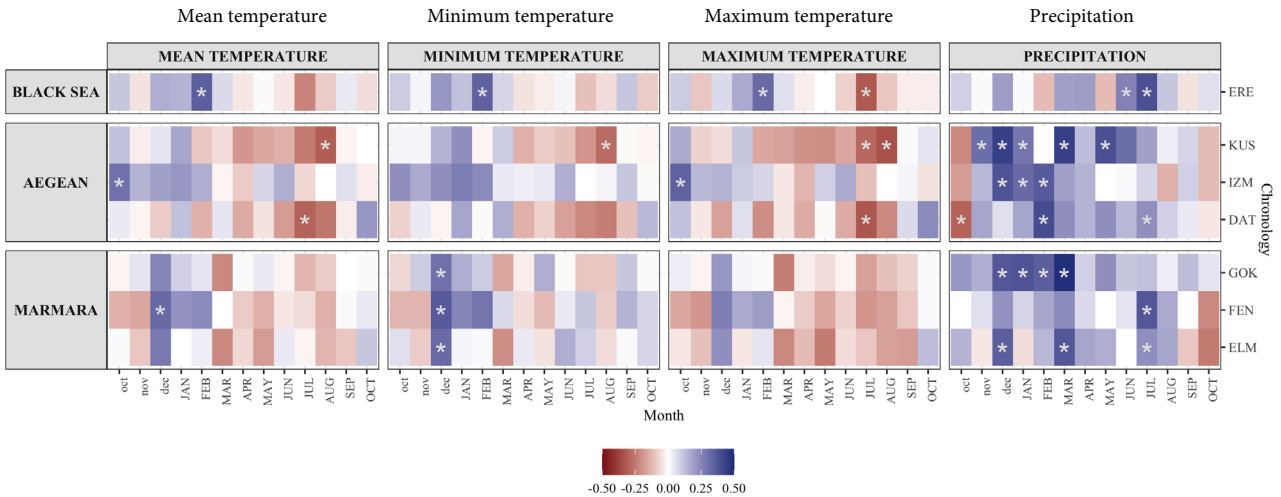


Figure 5. Relationships between tree-ring widths of *Quercus ilex* and monthly mean, minimum, and maximum temperatures and monthly total precipitation. Blue color represents positive correlation and brown represents negative correlation. Stars show 95% confidence levels of correlation coefficients.

temperature of winter months and absence of frosts would favor late autumn and winter photosynthesis and produce new wood cells (Miyazawa and Kikuzawa, 2005). Many previous studies have stated that the cambial activity of *Q. ilex* can continue all season under favorable conditions (Liphschitz and Lev-Yadun, 1986; Tretiach et al., 1997; Balzano et al., 2020).

For the relationship of tree-ring width with climate, monthly total precipitation is the most effective factor. Total precipitation from November to July has a significant positive effect on tree-ring width. This effect is higher in the Aegean Region than the Black Sea Region, which has less water-stressed conditions (Figure 5). Gea-Izquierdo et al. (2009) found that the tree-ring growth of *Q. ilex* is positively influenced by spring, summer, and the previous December's precipitation in Spain. Many previous studies on *Q. ilex* have also found that spring and summer precipitation is effective in radial growth (Campelo et al., 2009; Gea-Izquierdo et al., 2009, 2011; Nijland et al., 2011), similarly to other Mediterranean sclerophyllous species (Camarero and Rubio-Cuadrado, 2020). This result shows that trees of *Q. ilex* need water during the growing period, except summer, throughout its distribution area in Türkiye.

Water availability, i.e., precipitation, is the primary factor influencing tree-ring growth of *Q. ilex*, particularly in water-limited ecosystems in the Mediterranean Basin (e.g., Nabais et al., 1998–1999; Cherubini et al., 2003; Corcuera et al., 2004; Campelo et al., 2007; Zalloni et al., 2018a, 2018b). However, no relationship was found between summer precipitation and radial growth in areas where cambial activity stopped during the summer months (Cherubini et al., 2003; Campelo et al., 2009). Similar results were found in Türkiye and no significant relationships between late summer precipitation and tree-ring widths were observed.

3.3. Relationships between tree-ring widths and tree diameters and vessel features

Tree-ring width has a significant correlation with tree height at a value of 0.54***. Its correlation with tree diameter is positive and low at a value of 0.26*. The correlations of tree height and diameter with elevation are significantly negative at –0.39*** and –0.24*, respectively. While a linear relationship was determined between tree-ring width and tree diameter, a strong relationship between tree-ring width and tree height was obtained with a parabola (Figure 6). As tree diameters and heights increase, so do tree-ring widths.

The correlation coefficients of radial diameters of vessels, tangential diameters of vessels, vessel element lengths, and numbers of vessels per square millimeter with mean tree-ring width were calculated as 0.25*, 0.14 NS, 0.14 NS, and –0.40***, respectively (Figure 7). In general, low correlation coefficients were obtained as a result of the comparison of vessel features and tree-ring widths from a total of 93 different sampled sites. Akkemik et al. (2021) reported that the number of vessels per square millimeter showed the most variability, while the least variability was observed for vessel length (Figure 7). In this study, vessel frequency, which is among the vessel properties used to determine xeromorphy and mesomorphy rates, had the highest negative correlations with tree-ring width. In dry conditions, while tree-ring width decreases, vessel frequency increases. Because trees need narrower and higher numbers of vessels in dry conditions, this result

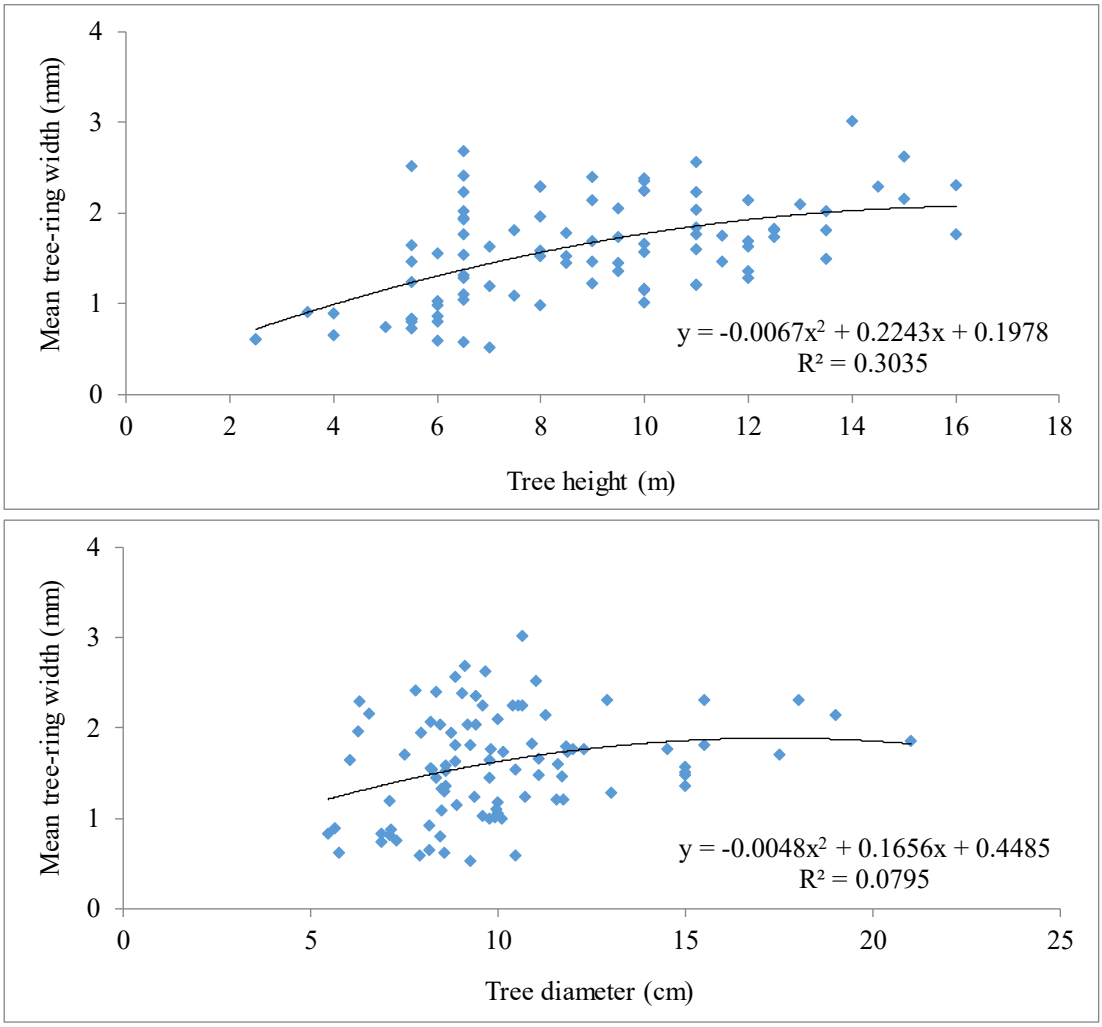


Figure 6. Regression analyses for estimation of mean tree-ring width based on tree height (top) and diameter (bottom).

can be evaluated as an indicator of the prominence of efficiency in water transport.

A graphical comparison showed negative relations between tree-ring widths and the ratio of dry sites (Figure 8) and positive relations between tree-ring width and the ratios of humid and very humid sites (Figure 8). These results reveal that the wood anatomy and dendrochronological data match. The correlation coefficients between tree-ring widths and the ratios of dry, humid, and very humid sites obtained from vessel features are –0.79***, 0.71***, and 0.63***, respectively.

While the results show a negative correlation between tree-ring width and the ratio of dry sites (Figure 8), the ratios of humid and very humid regions displayed clear positive correlations with tree-ring width (Figure 8). As expected, the relationship between tree-ring width and humidity is positive (Figure 8).

The correlation coefficients of the mesomorphy and xeromorphy ratios (Akkemik et al., 2021) calculated based on the vessel diameters and frequency with mean tree-ring width were 0.30** and –0.40***, respectively (Figure 9). While tree-ring width increases with humidity, it decreases with drought. As tree-ring width increases, the rate of xeromorphy decreases and the rate of mesomorphy increases.

3.4. Relationships between tree-ring widths and elevation

With elevation-based grouping, Datça clearly formed a separate group. Other groups were classified as 0–200 m and 200–500 m (Figure 10). Starting at 200 m above sea level, the ratio of plants turning to shrubs increases and individuals in stands mostly turn to tall shrubs or shrub form. Tree-ring width also becomes more narrow in these individuals. This case is most strikingly present in İzmir, Davutlar, and especially Datça. As a result, groups were established as described below (Figure 10):

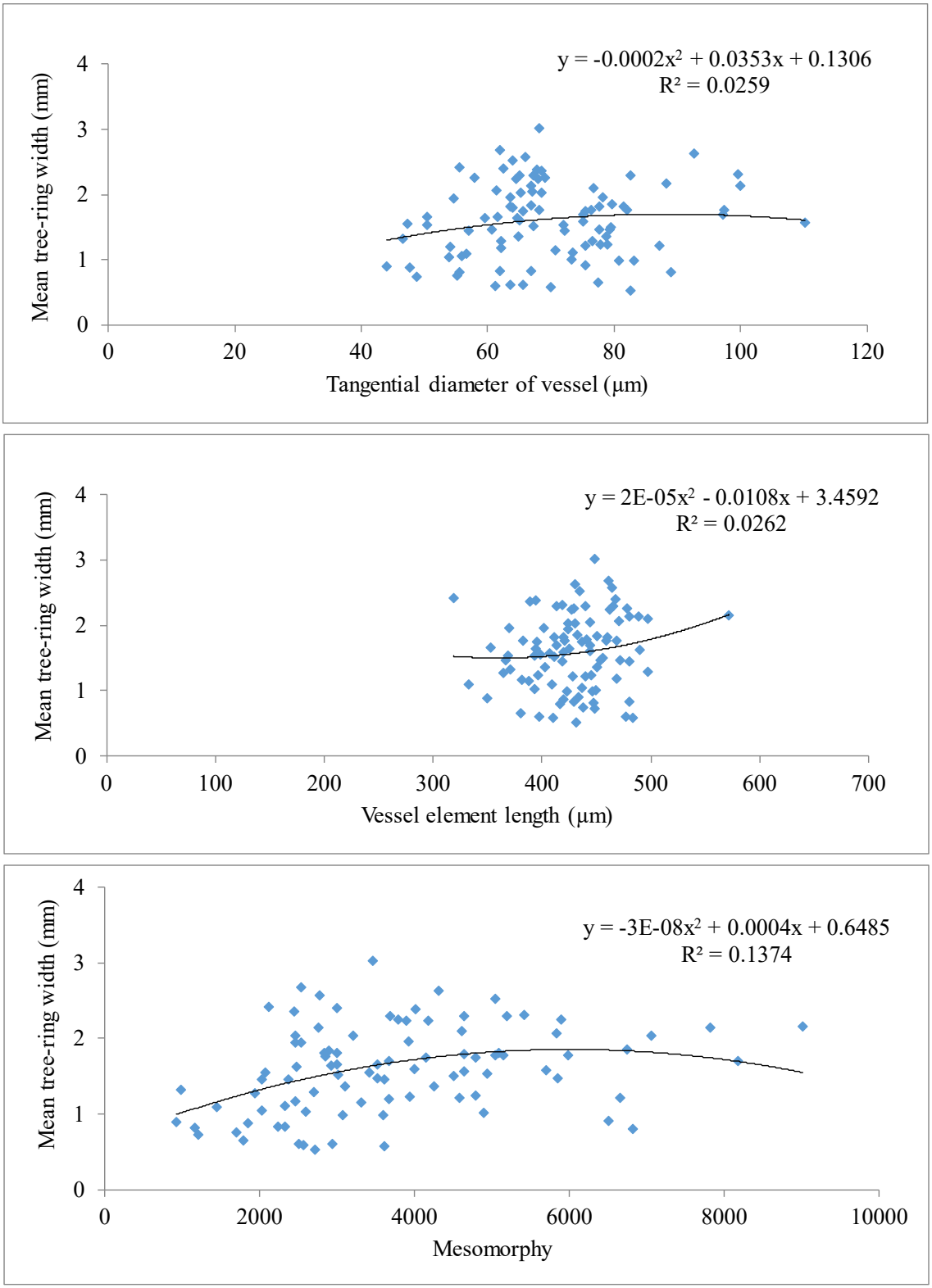


Figure 7. Relationships between mean tree-ring width and vessel tangential diameter (top), vessel element length (middle), and vessel frequency (bottom). The relationship is positive but low in the first two cases, while it is negative and higher for vessel frequency. This situation can be considered as a precaution taken to increase efficiency in water transport in dry sites.

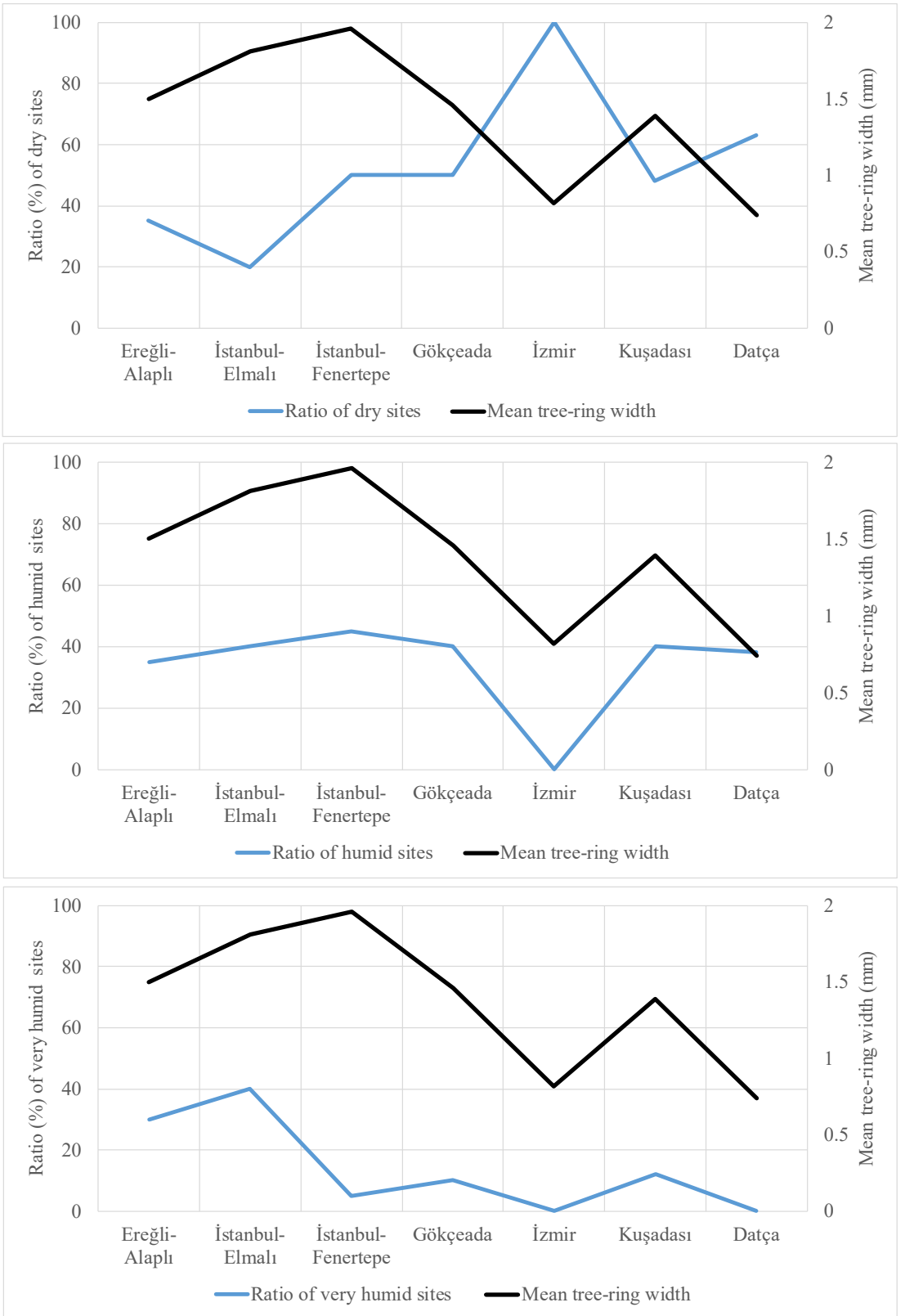


Figure 8. Comparison of tree-ring widths with the ratios of dry (top), humid (middle), and very humid (bottom) sites.

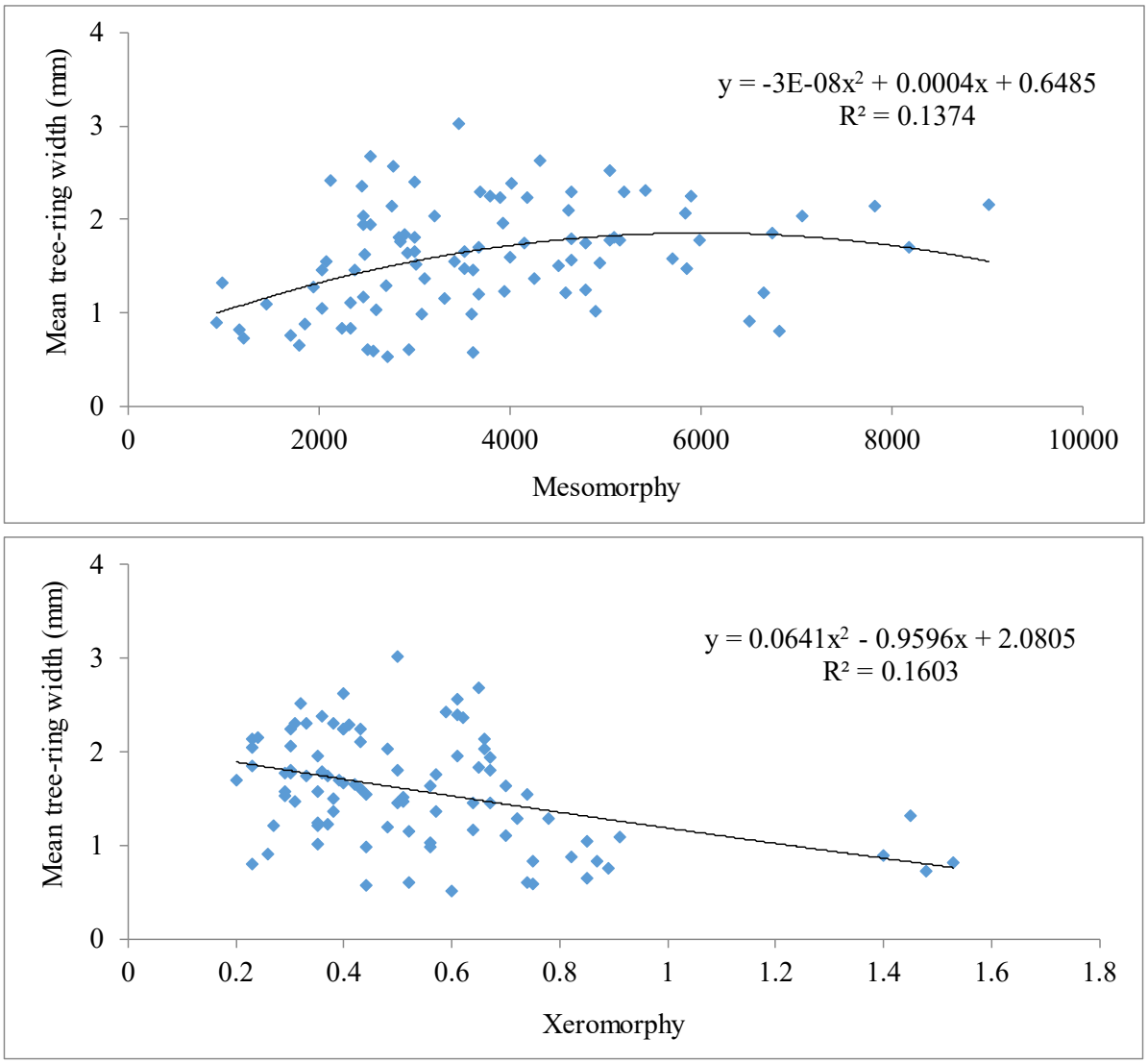


Figure 9. Relationships between tree-ring widths and mesomorphy (top) and xeromorphy (bottom) ratios.

- **Group 1:** The tree-ring widths of individuals in Datça, where the elevation is about 1000 m, were found to be narrower than in the other regions, and therefore they formed a completely separate group. The average tree-ring width of individuals in this group is below 0.8 mm.
- **Group 2:** According to the results of the cluster analysis, while one of the two main groups is Datça, the second group includes all other distribution areas. The second group is also divided into two large groups within itself.
- Group 2A. Sites with elevations of 200–500 m: Sampled sites 39, 44, and 47 in Davutlar National Park and site 69 from the upper part of Samson Mountain, as well as sites 97, 98, 99, and 100 in İzmir and 20 and 21 in Ereğli-Alaplı, are particularly included in this group. The average tree-ring width of the samples in this group is in the range of 0.8–1 mm.
- Group 2B. Sites with elevations of 0–200 m: This distribution area generally includes sampled sites located on bottom lands and partly on suitable sites around 200 m, with an average tree-ring width of over 1 mm. Sites with elevations of 200 m are included in this group, and partially sites 75, 84, and 85 in İstanbul; sites 40 and 43 in Davutlar National Park; and sites 95, 101, and 102 in İzmir. Since these sampled sites are generally represented by tall trees, they were included in the same group, which is near sea level.

As also indicated by this grouping, a clear decrease in tree-ring widths was obtained with elevation (Figure 11).

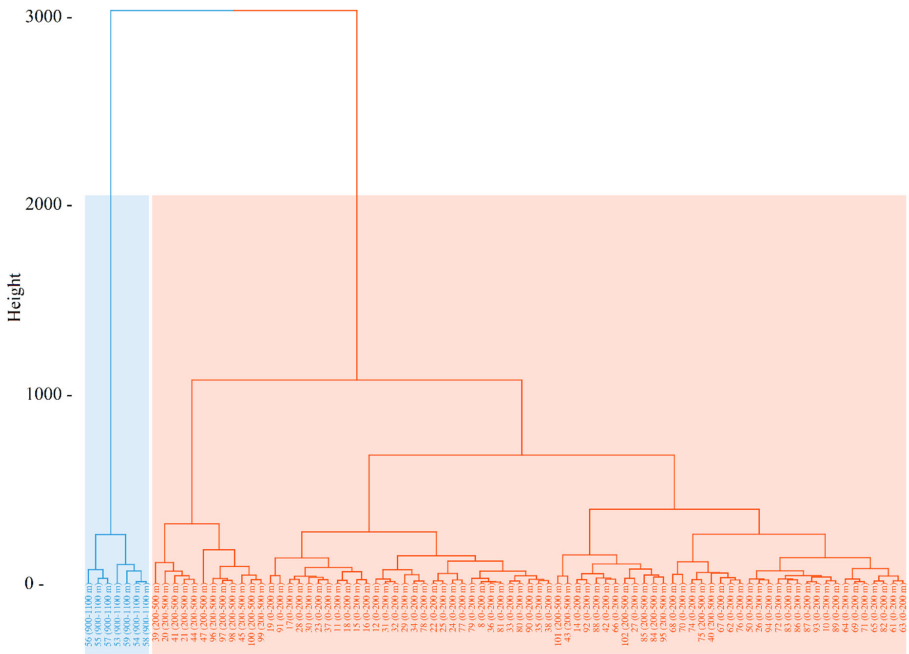


Figure 10. Grouping of tree-ring widths by elevation. The Datça region forms a distinctly separate group.

The correlation coefficient between mean tree-ring width and elevation is –0.50*** and statistically significant.

3.5. Relationships between tree-ring widths and some environmental conditions

Ring widths varied among the samples taken from this species in different regions. Trees in lowlands having deep soil conditions generally had wide tree rings; however, individuals on slopes, in sites far from the sea, and especially those in shrub form had narrow tree rings. The correlation coefficients between tree-ring widths and site conditions such as slope, elevation, canopy cover, soil, and litter are shown in Table 2. In particular, elevation, canopy cover, amount of leaves in the litter, pH values in the leaves and upper soil, and organic carbon values demonstrate moderate and statistically significant correlations with tree-ring width in general.

An evident negative relationship was identified between elevation and tree-ring width (Table 2). While individuals with wide tree rings in tree form are present in lowland areas, the highlands, and especially those in Davutlar, İzmir, and Datça, have individuals with narrow tree rings in shrub form. Thus, elevation is an important limiting factor for this species in Türkiye with a negative impact. A positive relationship exists between canopy cover and tree-ring width (Table 2). Since regions with high canopy cover generally have individuals in the tree form and these are usually present at lower elevations, the finding of a significantly positive relationship is to be expected. The correlation coefficient between canopy cover and elevation is also significant and negative with a value of –0.36**.

Among upper soil variables, the amount of leaves in the litter, amount of total litter, soil pH at depths of 0–5 cm and 5–15 cm, and amount of organic carbon have significant negative correlations with tree-ring width. The amount of litter being high can be explained by the lateness of the decay process. The correlation coefficients of the amount of leaves in the litter and total amount of litter with elevation are significantly positive with values of 0.22* and 0.48***, relatively. Because elevation causes an increase in the amount of litter and delays in the decomposition process, it is possible to talk about a negative relationship between tree-ring width and the amount of litter (Table 2).

Elevation has significant correlation coefficients with soil pH levels and organic carbon amounts ranging between 0.35*** and 0.46***. Since these values increase and tree-ring width decreases with elevation, they have negative correlations with tree-ring width.

According the results of the linear mixed model, we found that the variance explained by only fixed effects was rather small (R-squared marginal: 0.30), but the variance explained by both fixed and random effects was much higher than that considering fixed effects only (R-squared conditional: 0.75) (Table 3). Factors with positive

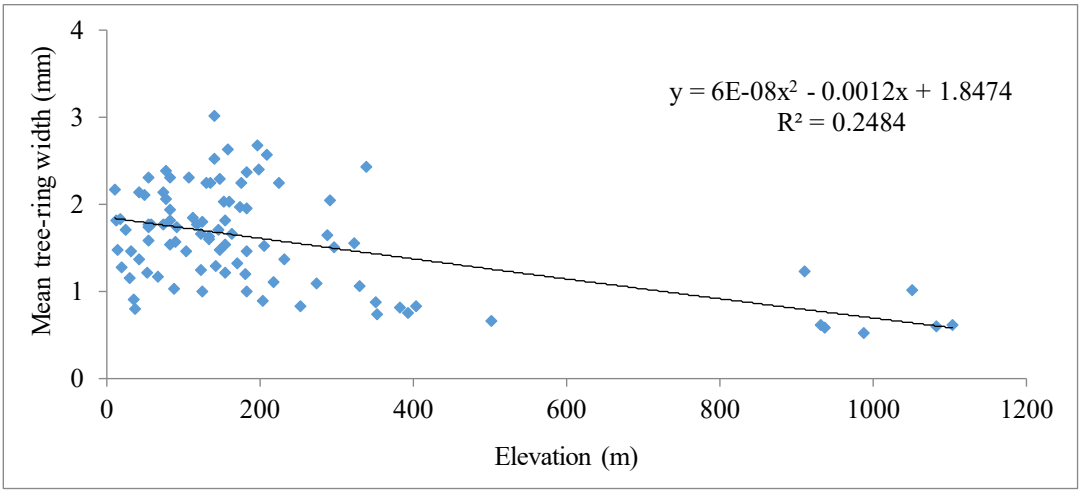


Figure 11. Relationships between mean tree-ring widths and elevation. There is a clear decrease in tree-ring widths from lower elevations to higher.

Table 2. Correlation coefficients between tree-ring width and some growing site conditions. Significant ones at 0.95 confidence level are indicated in bold.

Growing site feature	Correlation coefficient with mean tree-ring width	Growing site feature	Correlation coefficient with mean tre
Slope	0.08 NS	**Silt (%) at 0–5 cm depth**	**0.29****
Elevation (m)	**–0.50*****	Clay (%) in 0–5 cm depth	0.09 NS
Canopy cover (%)	**0.37*****	Volume weight (g L^{-1}) at 5–15 cm depth	–0.17 NS
Branch amount in litter (g m^{-2})	**–0.26***	Fine soil weight (g L^{-1}) at 5–15 cm depth	0.15 NS
Leaf amount in litter (g m^{-2})	**–0.51*****	**Stone weight (g L^{-1}) at 5–15 cm depth**	**–0.26***
Fermentation + humus layer weight (g m^{-2})	**–0.25***	Sand (%) at 5–15 cm depth	–0.09 NS
Total forest floor (g m^{-2})	**–0.30****	Silt (%) at 5–15 cm depth	0.17 NS
pH of branches in litter	–0.14 NS	Clay (%) at 5–15 cm depth	0.02 NS
pH of leaves in litter	**0.52*****	**pH of soil at 0–5 cm depth**	**–0.44*****
pH of fermentation + humus layer	–0.13 NS	**pH of soil at 5–15 cm depth**	**–0.42*****
Fine soil weight (g L^{-1}) at 0–5 cm depth	0.08 NS	**C org (%) at 0–5 cm depth**	**–0.36*****
Volume weight (g L^{-1}) at 0–5 cm depth	0.15 NS	**C org (%) at 5–15 cm depth**	**–0.40*****
Stone weight (g L^{-1}) at 0–5 cm depth	–0.08 NS	**N (%) at 0–5 cm depth**	**–0.24***
Sand (%) at 0–5 cm depth	**–0.21***	N (%) at 5–15 cm depth	–0.11 NS

coefficients have a positive effect on tree-ring width; on the other hand, variables with negative coefficients have the effect of reducing tree-ring width.

One of the most important factors is the canopy cover of trees, and a significantly positive correlation (0.37***) was obtained (Table 3). Increasing canopy cover may support the protection of water in the soil with higher humidity and lower temperature maintained under dense canopies. Furthermore, understory vegetation is sparse in dense stands of *Q. ilex*. For that reason, we obtained a positive and significant correlation between canopy cover and tree-ring width of *Q. ilex*. Tree-ring width is also high in stands with high canopy cover. On the other hand, the relationships between the amount of leaves in the litter on the soil surface and the elevation and tree-ring width are negative and significant. According to the linear mixed model, the relationship between tree age and tree-ring width is negative and significant. As in all trees, tree-ring

Table 3. Results of linear mixed model.

Fixed effects parameter estimates				95% Confidence interval				
Names	Effect	Estimate	SE	Lower	Upper	df	t	p
(Intercept)	(Intercept)	1.52	0.0614	1.396	1.63690	599.00	24.70	<0.001 ***
Canopy cover	Canopy cover	0.39	0.154	0.092	0.695	598.99	2.56	0.011 **
Litter leaf	Litter leaf	–0.002	0.000	–0.003	–0.000	564.31	–3.19	0.001 **
Elevation	Elevation	–0.002	0.001	–0.005	0.000	5.94	–1.71	0.138
Longitudinal curvature	Longitudinal curvature	–0.107*	0.027	–0.160	–0.0547	598.60	–3.96	<0.001 ***
Age of tree	Age of tree	–0.003	0.002	–0.010	–0.003	598.48	–3.63	<0.001 ***
Landform	Landform	0.004	0.001	0.000	0.006	595.31	2.68	0.008 **
Main mixed woody species	*Pinus nigra*-*Q. ilex*	0.21	0.115	–0.0193	0.431	598.84	1.79	0.074 NS
	Pinus brutia-Q. ilex	–0.23	0.076	–0.375	–0.077	590.95	–2.97	0.003 **
	Sclerophyllous species-*Q. ilex*	–0.32	0.224	–0.759	0.116	597.36	–1.44	0.151 NS

*: Normalized value of estimated longitudinal curvature.

widths of *Q. ilex* grow narrower according to tree age; therefore, there is a negative relationship between tree-ring width and tree age, as well.

Significant differences were also found in relationships with *Pinus nigra* Arnold, *Pinus brutia* Ten., and Mediterranean sclerophyllous species when they enter into the mix (Table 3). For example, ring width is greater in *Pinus nigra*-mixed areas, because *Q. ilex* becomes dominant in these areas. *Pinus nigra* was planted in the distribution area of *Q. ilex*, which does not form a mixture with *Pinus nigra* under normal conditions, and the latter species became dominant over time and showed better development compared to *Pinus nigra* trees. On the other hand, in areas with *Pinus brutia*, the ring width is narrow because *Pinus brutia* is dominant. Especially in areas with mixed *Pinus brutia* in İzmir and Datça, the species forms the lower layer of the tree layer in the stand. The fact that this species, which is a light tree, is under the shade of Turkish pine negatively affects its annual ring widths. For this reason, it may be recommended not to introduce *Pinus brutia* to areas where *Q. ilex* is pure and to apply forestry practices in favor of *Q. ilex* in *Pinus brutia*-mixed areas.

The tree rings are quite narrow in the mixed shrubs. As shrub density increases, the annual ring width narrows. This situation is also related to the elevation, and in higher areas, the canopy cover decreases, the diameter and height of the trees decrease, and the density of maquis species increases (Table 3). For this reason, tree rings are narrow in unfavorable areas where the cover of *Q. ilex* is low and other shrub species are dense.

As slope increases, tree-ring width narrows. This result shows that slope has a high negative effect on tree-ring width. The fact that the relationship between landform values and tree-ring width is also significant supports this result. Landform values are expressed with numbers between 1 and 16, and a value of 1 represents steeply sloped areas while a value of 16 represents lowland conditions. The tree-ring widths of *Q. ilex* are narrower in mountain sites on steep slopes and wider in lowland plains. Accordingly, the landform results also showed the existence of a linear relationship between elevation and tree-ring width (Table 3).

3.6. Similarities of mean tree-ring widths in eight regions

The results of canonical discriminant analysis showed that Datça, with its narrow tree rings, was separated from the others (Table 4; Figure 12). When analyzing the similarity of sampled sites based on regions, 86% of the samples in İzmir have the characteristics of İzmir, while the remaining 14% resemble those of the Gökçeada region more. On the other hand, 100% of the Datça samples reflect local features. The reason for this dissimilarity may be the fact that it is at the highest elevation. Elmalı, which has the widest tree rings, also showed 60% dissimilarity. The remaining 40% of samples are similar to those of the nearest region, Fenertepe. Regarding tree-ring widths, Ereğli and Alaplı show similar features (Table 4). These

Table 4. Percentages (%) of sampled sites showing regional characteristics according to discriminant analysis.

	Elmalı	Ereğli	Fenertepe	Alaplı	Davutlar	Datça	İzmir	Gökçeada	Total
Elmalı	60	0	40	0	0	0	0	0	100
Ereğli	0	89	0	11	0	0	0	0	100
Fenertepe	0	0	84	0	0	0	0	16	100
Alaplı	0	0	0	100	0	0	0	0	100
Davutlar	0	0	0	0	95	5	0	0	100
Datça	0	0	0	0	0	100	0	0	100
İzmir	0	0	0	0	0	0	86	14	100
Gökçeada	0	0	0	0	0	0	0	100	100

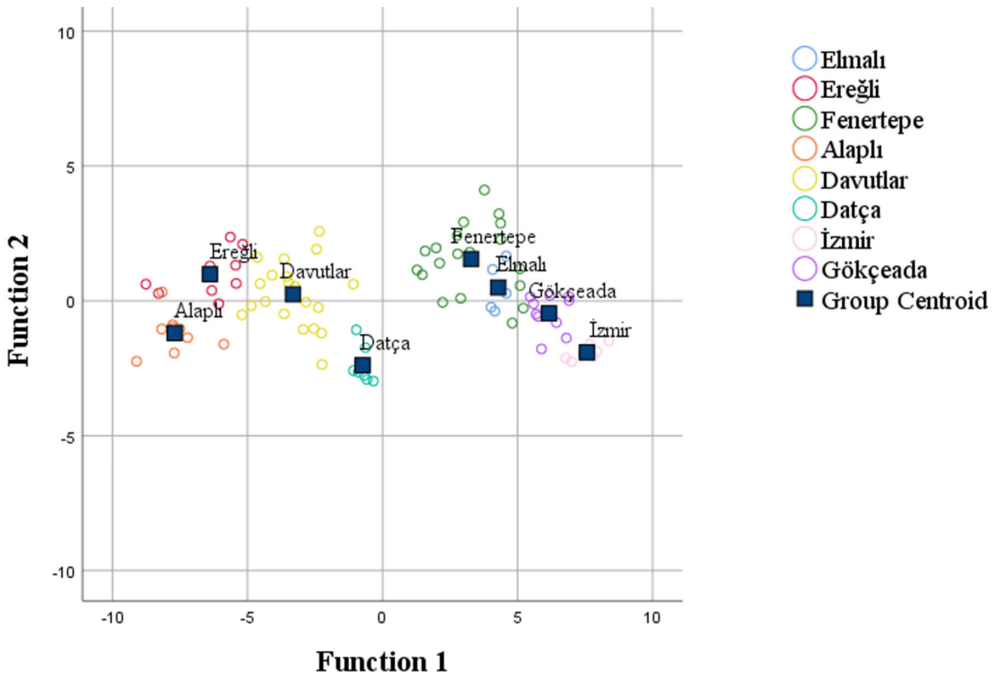


Figure 12. Based on canonical discriminant analysis, distribution of the regions and areas with respect to tree-ring widths and vessel characteristics.

results also demonstrate that there is distinction with respect to three regions: the Black Sea, Marmara, and northern (İzmir and Gökçeada) and southern (Davutlar and Datça) Aegean regions.

4. Conclusion

The region with the highest mean tree-ring growth is the Marmara Region. On both sides of İstanbul, the species shows rather good growth. According to canonical discriminant analysis, Elmalı and Fenertepe are similar.

Tree rings and climate relationships in Zonguldak demonstrated that reduction in rainfall negatively impacts tree-ring widths. The average values of the tree rings were lower than those of İstanbul. Average tree ring-width for the Black Sea Region was calculated as 1.50 mm and the annual growth was of excellent condition.

In the Aegean Region, the area with the highest tree-ring growth is Davutlar, which is also under protection as a national park. In this area, the average tree-ring width is 1.62 mm. In Gökçeada the tree-ring width is relatively lower, with an average of 1.46 mm. On the other hand, İzmir and Datça are the two distribution areas with the lowest tree-ring widths. Elevation is between 200 and 500 m in İzmir and 900 and 1100 m in Datça. As elevation

increases, there is an apparent decrease in tree-ring widths.

These tree-ring results showed that *Quercus ilex* grows well and forms wider rings in the Marmara and Black Sea regions. It was seen that the tree rings in these regions can be up to 14 mm wide, which is a very high value.

At present, this species continues its growth in the warm conditions of the Mediterranean Basin. Nevertheless, it is not a typical member of the maquis formation of its eastern boundary, Türkiye, because *Q. ilex* constitutes pure or mixed forests, particularly in the Black Sea Region and the Marmara Region, independently of the maquis. It is present as tall forest trees in Davutlar National Park, and with its competitive capacity and ability to form dense shadows it partially becomes the dominant species.

In the Mediterranean Region, it shows its best growth in Davutlar National Park and Samson Mountain, and it forms its widest annual rings in this region near the sea at elevations of 0–200 m. At higher elevations, the species takes shrub form. In İzmir and Datça it is generally present in shrub form or partially as individuals in arbuscule form. In lowland conditions with deep soil, it develops better than the maquis and achieves superiority.

In Datça, on the other hand, elevations between 900 and 1100 m are where the species finds sufficient humidity conditions. Also in Datça, in some stream valleys where moisture and soil conditions are good, individuals of this species descend to an elevation of 400 m. The species, which is seen as single individuals in lower parts of İzmir, gives the impression of being destroyed in these areas and makes its current distribution in the range of 200–400 m.

In suitable conditions, especially in the Black Sea Region, Marmara Region, and Davutlar National Park, its growth is generally in the form of trees, individuals growing from seeds show good development, and tree-ring widths reach high values.

In conclusion, *Q. ilex* grows in both xeric and humid areas. In Muğla-Datça, this species has adapted to dry conditions by forming narrow tree rings from the germination of the seed, with some over 140 years old; they are healthy and take tall bush-shrub forms. Trees of the same age have become trees with diameters of 50–60 cm and heights of 10–15 m in Ereğli. For these reasons, *Q. ilex* should be given priority as a species to be considered in forestry practices in Türkiye. It would be appropriate to cultivate this species in areas with low elevation close to the sea in habitats where soil conditions are suitable. In addition, its use in parks and gardens should be encouraged, especially in regions where the species grows naturally.

Acknowledgments

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