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An approach to compare the environmental conditions of *Acer* in the Miocene and in the modern flora of Turkey, based on wood anatomy

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ABSTRACT. In this study, xeromorphy ratios were calculated for *Acer* L. (maple) fossil woods in order to infer the precipitation conditions in the Miocene at the sites of the fossils, based on a comparison with the xeromorphy ratios of selected extant *Acer* species. The four studied petrified wood samples came from three localities of the Galatean Volcanic Province in Turkey: Kozyaka village (Bolu Province, Seben District), İnözü Valley (Ankara Province, Beypazarı District), and Kıraluç precinct between Nuhhoca and Dağşeyhler villages (Ankara Province, Beypazarı District). The calculated xeromorphy ratios ranged from 3 to 18 for the present-day wood and from 13 to 19 for the early Miocene wood. Values over 10 (11–18) represent xeric conditions; the lower values (3–7) indicate mesic conditions in modern *Acer* woods. The xeromorphy ratios of the Miocene wood indicate xeric conditions; we conclude that the sites of the fossil *Acer* woods were xeric, very similar to the modern *Acer* woodlands of central and southern Anatolia.

KEYWORDS: *Acer*, palaeoecology, wood anatomy, Miocene, petrified wood, xeromorphy

INTRODUCTION

Wood identified from the geological record contributes to our knowledge of past vegetation structure and climate. In Turkey, petrified wood from the late Oligocene of Thrace and from the Miocene of Anatolia holds valuable information on forest and climate history. For example, the presence of taxodioid-type wood indicates riparian and swamp forest in Thrace (Özgüven-Ertan 1971, Kayacık et al. 1995, Akkemik et al. 2005, Akkemik & Sakınç 2013) and in Anatolia (Akkemik et al. 2009, Akkemik et al. 2017, Bayam et al. 2018). Based on the floristic composition of petrified wood, Akkemik et al. (2016) inferred the presence of riparian, mesic and mesic-xeric forest structures in north central Anatolia.

The vessel diameter and vessel density of angiosperm genera can give information on local environmental conditions. Vessel diameter can increase from xeric conditions to mesic conditions, and many studies have been done to understand the palaeoclimate and the evolutionary and ecological changes in wood anatomy (Wheeler & Baas 1991, 1993, Wiemann et al. 1998, 1999, Sakala 2007, Baas & Wheeler 2011). Today, calculation of mesomorphy is one the most useful approaches for understanding the effect of growth conditions on wood anatomy (e.g. Carlquist & Hoekman 1985, Carquist 1988, Lindorf 1994, Carlquist & Hoekman 1985, Barajas-Morales 1985, Perez 1989, Psaras & Sofroniou 1999, Alves & Alfonso 2002, Khalifah et al. 2006, Bosio et al. 2010, Noshiro et al. 2010, Pourtahmasi et al. 2011, Villiers et al. 2012, Izquierdo et al.

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2013, Mashari 2014, Ziaco et al. 2014, Olivar et al. 2015). In Turkey, many ecology-oriented studies of the wood anatomy of modern species have been performed as well (e.g. Şanlı 1977, Merev & Yavuz 2000, Akkemik 2003, Yaman & Sarıbaş 2004, Akkemik et al. 2007, Yaman 2007, Yaman 2008, Cihan & Akkemik 2013, Erşen Bak & Merev 2016). Another approach, calculation of xeromorphy ratios, was developed by Yaman (2008). Using the latter approach, Yaman (2008) and Cihan & Akkemik (2013) determined the site conditions of some modern woods in the Mediterranean region and Black Sea region.

Both approaches, mesomorphy and xeromorphy, use vessel features. The tangential diameter and length of vessel elements, and vessel density are used to calculate the mesomorphy ratio [(tangential diameter of vessel element/vessel density per square mm) × vessel element length] (Carlquist 1988). The xeromorphy ratio relies on radial and tangential diameter and vessel density. Petrified wood cannot be macerated, so it is almost impossible to measure vessel length in cases where the woods are not sufficiently well preserved to measure vessel member length in tangential and radial sections. Therefore, we prefer the xeromorphy formula presented by Yaman (2008) for determining the paleoclimatic conditions at the sites of petrified angiosperm wood.

In petrified wood from the early Miocene of Turkey (Akkemik et al. 2016, Bayam et al. 2018), one of the most common trees identified is *Acer*. The ecology of extant species of this genus has been studied in research examining their wood anatomy (Yaltırık 1971). Data from such studies enable us to compare the conditions at the sites of fossil *Acer* wood in the early Miocene with those of modern *Acer* species in Turkey, using vessel diameter and vessel density per square mm. The purpose of this study was to determine the precipitation conditions at the sites where *Acer* trees grew in the early Miocene of the Galatean Volcanic Province (GVP). We determined their xeromorphy ratios from the vessel element width and vessel density of fossil wood samples, and compared the ratios with those of extant species in order to infer the differences in precipitation conditions between the early Miocene and modern sites.

MATERIAL AND METHODS

Petrified wood of *Acer* from the early Miocene of Turkey was identified from sites in the western part of the Galatean Volcanic Province: Kozyaka village (Bolu Province, Seben District; coded as KOZ), İnözü Valley (Ankara Province, Beypazarı District; coded as INO), and Kıraluç precinct between Nuhhoca and Dağşeyhler villages (Ankara Province, Beypazarı District; coded as KIR) (Bayam et al. 2018) (Fig. 1; Tab. 1). These fossil wood samples were identified to generic level, and all came from the same geological unit, called the Hançili Formation of the early Miocene of the Galatean Volcanic Province. The anatomical characters of these four wood fossils, which are very similar, are described in detail in Akkemik et al. (2016) and Bayam et al. (2018). Because they show similar wood anatomy and are from the same time interval and geological formation and from nearby locations, they could be from the same fossil species of *Acer*.

The wood anatomy of modern species of *Acer* in Turkey (Tab. 1) was studied by Yaltırık (1968, 1971). Their vessel diameter and vessel density (Tab. 2) were given in detail in those two works.

We compared the wood anatomy of the early Miocene *Acer* trees with modern representatives of the genus in Turkey, using their xeromorphy ratios (Yaman 2008) to determine the precipitation conditions of the sites where the trees grew. This approach has yielded useful results in some studies of modern wood (Yaman 2008, Cihan & Akkemik 2013). This approach applies the following formula (Yaman 2008):

$$\frac{S}{V} = \frac{2\sqrt{(a^2 + b^2)/2}}{ab}$$

$$XERO = \frac{S}{V} \times f$$

where S is surface and V is volume, a = major radius of ellipse, b = minor radius of ellipse (a = half radial vessel diameter, µm; b = half tangential vessel diameter, µm), and f = vessel density per square mm. There is confusion in the literature about "pores per square mm"; some investigators count multiples and clusters of vessel elements as one, while others count individual vessel elements of each multiple or group separately, resulting in a higher number. We individually counted all vessels per square mm, including those in multiples and clusters. Yaltırık (1971) gave the number of all vessels per square mm, so we had to use this parameter for comparison. Wheeler (1986) also suggested counting all individual vessels for a better ecological interpretation.

In this method, vessel diameter and density, which can only be measured in transverse sections, are sufficient to calculate the xeromorphy ratio. Values near zero indicate mesic conditions, and high values represent xeric conditions. This criterion allowed us to compare the conditions of the Miocene sites of the *Acer* trees with those of the sites of their modern representatives. We used a threshold value of 10 to divide the wood into two groups; xeromorphy ratios higher than 10 indicate xeric conditions, and ratios lower than 10 indicate mesic conditions. Yaman (2008) did not propose any limit value for xeric/mesic conditions. The choice of any single number must be arbitrary to some extent. We chose the number 10 because this limit value is rather close to the average value of xeromorphy ratios determined for *Acer* in Turkey.

RESULTS

We determined the xeromorphy ratios from transverse sections of the four petrified *Acer* wood samples from the early Miocene of the GVP (Fig. 1) and from 14 modern species from different regions of Turkey (Tab. 2, Fig. 2), and grouped them from high to low, that is, from xeric to mesic conditions. The highest xeromorphy ratio was found for petrified wood from the Inözü valley (INL02), and the lowest one also for another petrified wood sample (KIR13). The higher xeromorphy ratios indicate xeric conditions, and those lower than 10 indicate mesic conditions.

The xeromorphy ratios range from 3 to 18 in the modern *Acer* taxa. The higher xeromorphy ratios of 11–18 for the species growing in south-western and central Anatolia [*A. monspessulanum* L. subsp. *monspessulanum*,

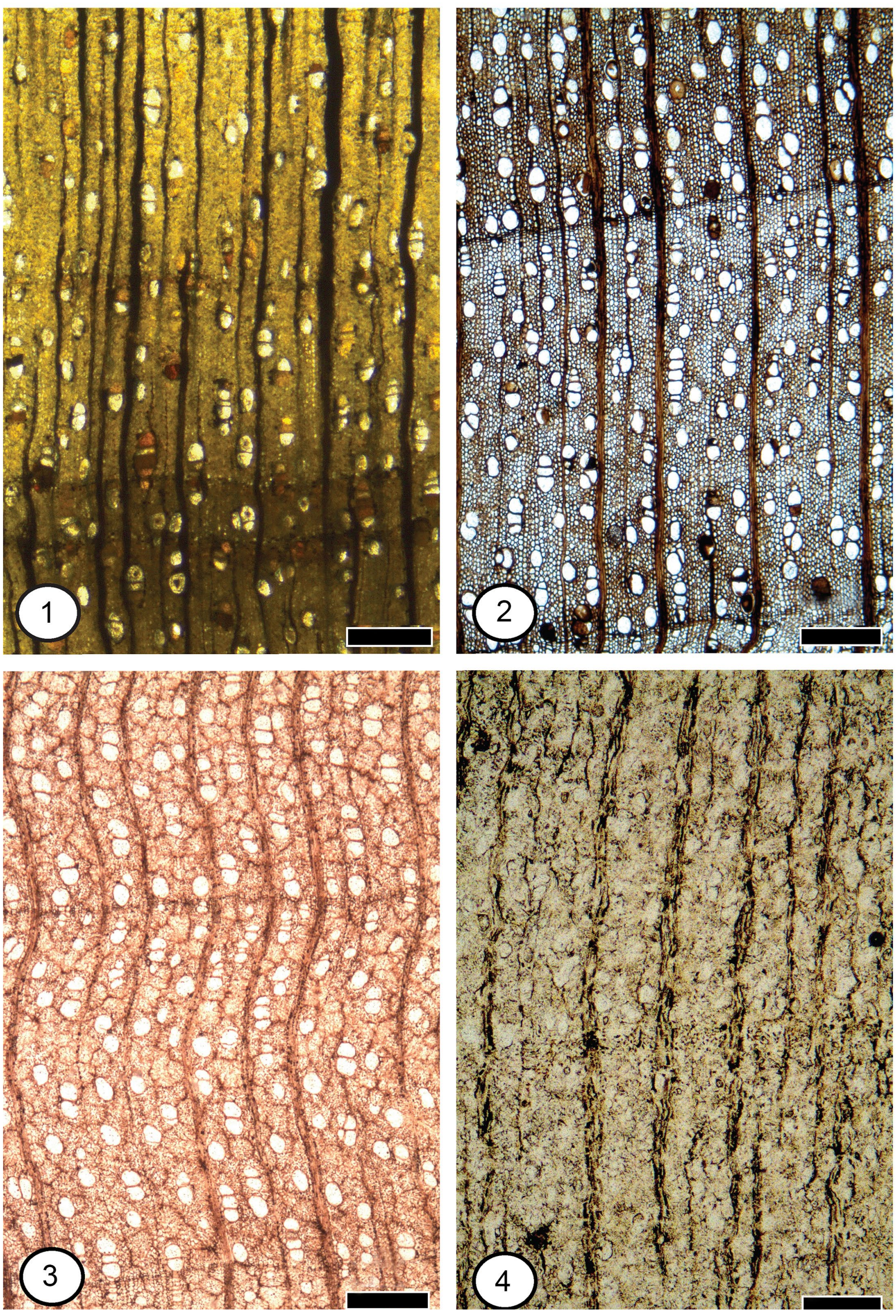

Fig. 1. Transverse sections of the identified petrified wood: (1) KOZ36 (Akkemik et al. 2016); (2) INL02; (3) INL06; (4) KIR13 (Bayam et al. 2018). Scale bar = 200 µm

A. monspessulanum L. subsp. *oxalianum* Yalt., *A. monspessulanum* L. subsp. *microphyllum* (Boiss.) Bornm., *A. sempervirens* L., *A. tataricum* L., *A. divergens* K. Koch ex Paxton and *A. hyrcanum* Fisch. & C.A. Mey. subsp. *tauricolum* (Boiss. & Balansa) Yalt.] reflect the effects of xeric conditions. These species grow in dry site conditions. In contrast, the species growing in northern Anatolia [*A. trautwetteri* Medw., *A. platanoides* L., *A. cappadocicum* Gled., *A. campestre* L., *A. hyrcanum* Fisch. & C.A. Mey. subsp. *hyrcanum*, *A. hyrcanum* Fisch. & C.A. Mey. subsp. *keckianum* (Asch. & Sint. ex Pax) Yalt. and *A. pseudoplatanus* L.] had lower xeromorphy ratios ranging from 3 to 7, reflecting the effects of mesic conditions. These species grow throughout the Black Sea region, which has a humid climate (Tab. 2; Figs 2, 3).

Very similar xeromorphy ratios were found for the modern and fossil wood (Tab. 2; Figs 2, 3). There is a very clear inverse relationship between xeromorphy ratio and precipitation in modern *Acer* species. In the modern maple species, xeromorphy increases with the decrease of precipitation (Fig. 4).

DISCUSSION AND CONCLUSION

The xeromorphy ratios of the samples of modern *Acer* wood showed a high negative correlation with precipitation. We infer that one of the main factors affecting the density and radial and tangential diameter of vessels is precipitation, and suggest that the findings for modern wood can be extrapolated to fossil *Acer* species.

The ecology of the wood anatomy of modern *Acer* taxa in Turkey was studied by Yaltırık (1968), who divided the wood into two groups based on its vessel density and the diameter of the vessels. In xeric conditions the average radial diameter is 31 µm, average tangential diameter is 31 µm, and average vessel density is 104 vessels per square mm. In mesic conditions the average values are 48 µm radial diameter, 53 µm tangential diameter, and 50 vessels per square mm. Xeric conditions (semi-dry and dry climate) are found in Kazdağları, the Taurus Mts and the Çoruh Valley. Mesic conditions are well represented in northern Turkey (Thrace, Marmara, Black Sea region) (Yaltırık 1968, 1971). The fossil *Acer* wood from the GVP

Table 1. Modern *Acer* taxa and their sites (Yaltırık 1971), and early Miocene petrified wood of the Galatean Volcanic Province (Akkemik et al. 2016, Bayam et al. 2018)

Taxa of *Acer* in Turkey*	Locality	Altitude (m)**	Annual precipitation (mm)***
Acer tataricum	Van: Çatak Crek, 15 km north of Çatak	1520	528
Acer divergens	Erzurum: Oltu-Bahçecik	1450	580
Acer sempervirens	İzmir: Kuşadası, Samsun Mountain, Sarıkayaderesi	250	612
Acer monspessulanum subsp. *monspessulanum*	Mersin: Mut-Adraz Mountain	1400	560
Acer hyrcanum subsp. *tauricolum*	K.Maraş: Between Andırın and Kuyucak	1200	574
Acer monspessulanum subsp. *oksalianum*	K. Maraş: Between K.Maraş-Andırın, Hartlap Region, Boğazgediği area	900	574
Acer monspessulanum subsp. *microphyllum*	K.Maraş: Süleymanlı (Zeytun) Kurudağ	1200	574
Acer hyrcanum subsp. *hyrcanum*	Artvin: Hatila Forest	1300	1008
Acer hyrcanum subsp. *keckianum*	Balıkesir: Kazdağ Karakoç Crek	950	814[1]
Acer campestre subsp. *campestre*	İstanbul: Belgrad Forest	100	1074[2]
Acer cappadocicum	Rize: Çamlıhemşin, Fırtına River, Oçhura Forest	450	1458
Acer pseudoplatanus	İstanbul: Bahceköy	100	1074[2]
Acer trautvetteri	Giresun: Bicik Forest	1460	1288
Acer platanoides	Artvin: Hatila Forest	1300	1008
Acer (INL02)	Ankara: Beypazarı-İnözü Valley	1117	
Acer (INL06)	Ankara: Beypazarı-İnözü Valley	1117	
Acer (KOZ36)	Bolu: Seben-Kozyaka Village	1245	
Acer (KIR13)	Ankara: Beypazarı-Nuhhoca-Kıraluç	1268	

* Shaded cells indicate the sites which have low precipitation.
** The altitudes for the fossil woods are their present altitudes, not their lifetime altitudes.
*** These precipitation data were taken from Turkish State Meteorology Service (www.mgm.gov.tr) unless otherwise indicated.
[1] Özel (1999).
[2] Cakir et al. (2010).

Table 2. Modern and early Miocene *Acer* taxa, their vessel diameter, vessel density and xeromorphy ratio

Taxa of *Acer* in Turkey	Province	Radial diameter (μm)	Tangential diameter (μm)	Vessel density per square mm	Xeromorphy ratio	Group
Modern taxa						
Acer tataricum	Van	28	32	134	18	Group 1
Acer divergens	Erzurum	30	32	130	17	
Acer sempervirnes	İzmir	28	26	103	15	
Acer monspessulanum subsp. *monspessulanum*	Mersin	28	30	86	12	
Acer hyrcanum subsp. *tauricolum*	K.Maraş	34	36	102	12	
Acer monspessulanum subsp. *oksalianum*	K.Maraş	34	32	91	11	
Acer monspessulanum subsp. *microphyllum*	K.Maraş	34	28	81	11	
Acer hyrcanum subsp. *hyrcanum*	Artvin	34	40	61	7	Group 2
Acer hyrcanum subsp. *keckianum*	Balıkesir	42	42	68	6	
Acer campestre subsp. *campestre*	İstanbul	48	52	55	4	
Acer cappadocicum	Rize	48	50	45	4	
Acer pseudoplatanus	İstanbul	58	62	50	3	
Acer trautvetteri	Giresun	48	60	35	3	
Acer platanoides	Artvin	56	62	37	3	
Early Miocene taxa						
Acer (INL02)	Ankara	30	32	146	19	Group 1
Acer (INL06)	Ankara	32	38	134	15	
Acer (KOZ36)	Bolu	34	36	123	14	
Acer (KIR13)	Ankara	34	42	125	13	

revealed very similar responses to site conditions. The average values for vessels of that wood are 33 μm radial diameter, 37 μm tangential diameter, and 132 vessels per square mm; these dimensions and the resulting xeromorphy ratios suggest that those fossil species grew in xeric conditions (Tab. 2).

The main problem with this approach is that the location of the samples of petrified wood inside the tree is unknown. The pieces collected from the area may be from the wood of a stem, branch or root. For *Acer rubrum* L., Zimmermann and Potter (1982) found that the vessel diameter was less in branch wood than in stem wood. Similar results were found for *Ficus carica* L. (Yaman 2014), *Terminalia superba* Engl. & Diels and *Pterygota macrocarpa* K. Schum. (Dadzie et al. 2016), some tropical trees (Fichtler & Worbes 2012) and Eocene wood (Wheeler & Landon 1992). Recently, Pulat & Yaman (2017) found very clear differences between stem and branch

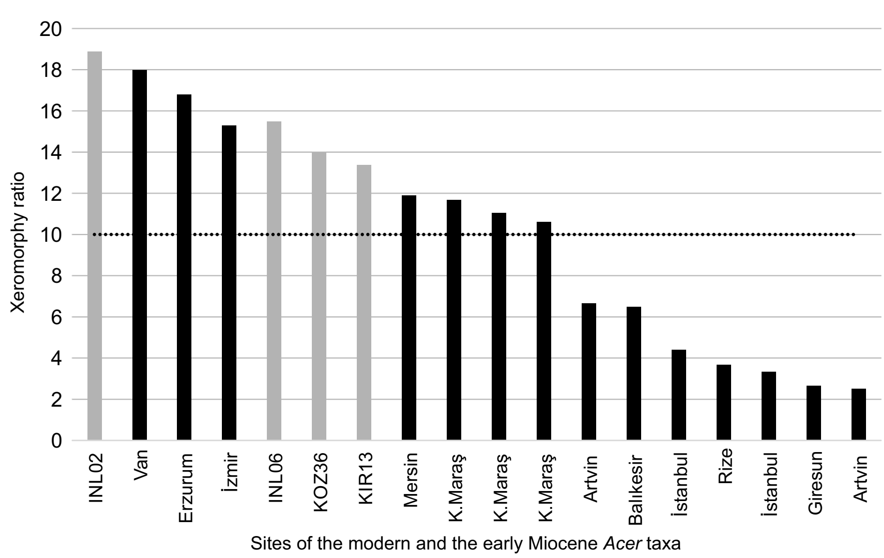

Fig. 2. Xeromorphy ratios of modern *Acer* taxa in Turkey and of fossil wood from three sites in the Galatean Volcanic Province. Dotted line is the arbitrary threshold for mesic and xeric conditions. Black columns represent modern wood; grey columns represent fossil wood

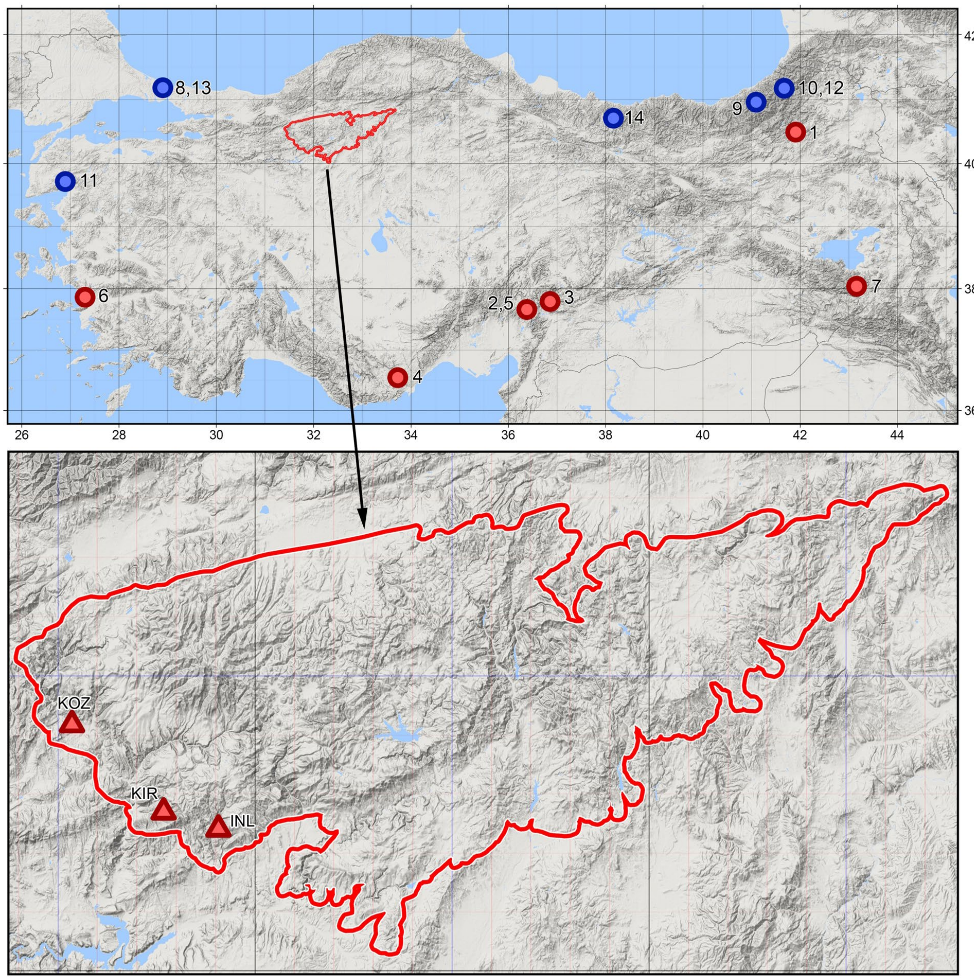

Fig. 3. Sites of modern *Acer* taxa (upper figure, with xeromorphy ratios) and sites of early Miocene wood samples (lower figure). Circles with numbers 1–7 denote xeric conditions, and those with numbers 8–14 denote mesic conditions. Triangles in lower figure denote xeric sites in the Galatean Volcanic Province

wood of *Alnus glutinosa* (L.) Gaertn., *Juglans regia* L. and *Robinia pseudoacacia* L. Generally, stem wood has vessels twice as wide as in branch wood, and vessel density is two to three times lower in stem wood than in branch wood.

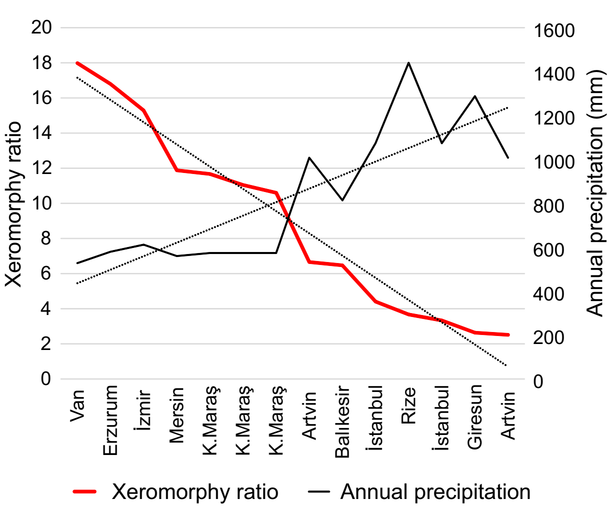

Fig. 4. Inverse relation between xeromorphy ratio and annual precipitation in modern *Acer* taxa

The vessel diameter of root wood is about 50% larger than in stem wood of the same tree (Yaman et al. 2013). For fossil taxodioid wood, Koutecký and Sakala (2015) found that the tangential diameter and length of tracheids in mature stem wood were higher than in branch wood and lower than in young stem wood. In another analysis of wood element diameter, Gryc et al. (2008) found that vessel diameter was lower in juvenile wood and higher in mature wood. Vessel number per square mm is higher in juvenile wood. These features could lead to a mistaken diagnosis of xeric conditions. In our Miocene *Acer* wood, however, the vessel diameters and xeromorphy ratios are very similar to those of the stem wood of one group of modern *Acer* species (Tab. 2). We conclude that most likely they are stem wood and that they may reasonably be used to infer the site conditions of those Miocene trees.

Both dry and humid conditions were present in the GVP. Findings by Akkemik et al.

(2016) and Bayam et al. (2018) showed that riparian vegetation was common in the western part of the GVP. Sclerophyllous oaks and junipers were also common in these areas, which had well-drained lowland forest areas and dryer conditions (Akkemik et al. 2016, Bayam et al. 2018). Denk et al. (2017a,b,c). The sites of *Acer* in the early Miocene varied from riparian forest to upland conifer forest. The presence of *Acer* may be evaluated based on the criteria of vegetation units VU0 and VU4–7 (Denk et al. 2017a,b,c, Güner et al. 2017). VU0 denotes subtropical, moist or dry light forest, VU4 denotes riparian forest, VU5 denotes well-drained lowland forest VU6 denotes well-drained upland forest, and VU7 denotes well-drained (lowland and) upland coniferous forest. Different *Acer* species are distributed within these vegetation units from the early Miocene Güvem fossil area in the GVP. Güner et al. (2017) described *Acer aegopodifolium* (H.R. Göppert) T.N. Baikovskaja, *A. dasycarpoides* Heer, *A. decipens* A. Braun, *A. ilnicense* Iljinskaja, *A. integrilobum* C.O.Weber, *A. pyrenaicum* Rerolle, *A. subcampestre* Göppert and *A. tricuspidatium* Bronn. from the early Miocene of Western Anatolia. Denk et al. (2017a) described A*cer angustilobum* Heer, *A. paleosaccharinum* Stur and *A. tricuspidatum* from the Güvem fossil area of early Miocene age in the GVP. So we see that *Acer* was represented by many species in the vegetation units (VU0, VU4–7) of the early Miocene. The petrified *Acer* wood we identified may belong to VU5–7, representing dry to semi-dry conditions.

The wood flora of the sites of *Acer* in the early Miocene of the GVP is composed of *Salix* L./*Populus* L., *Cedrus* Trew., *Pinus* L., *Ulmus* L. and *Quercus* L. Sect. *Ilex* in KOZ (Akkemik et al. 2016), *Cedrus* and *Quercus* sect. *Ilex* in INL, and *Salix*/*Populus*, *Picea* A. Dietr., *Quercus* sect. *Ilex*, *Ulmus* and *Zelkova* Spach in KIR (Bayam et al. 2018). The forest composition is roughly similar at the three fossil sites, and is composed of riparian and well-drained lowland forest trees and conifers.

This study demonstrated an approach to the use of fossil wood to assess the precipitation conditions of early Miocene sites of Turkey. We showed that xeromorphy ratios (Yaman 2008) can be used to assess some palaeoclimatic conditions at the sites of petrified wood.

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