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The role of climate changes in the intensification of agricultural activities in Anatolia during the late Roman-early Byzantine period

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Abstract

The intensive agricultural period called the Beyşehir Occupation Phase (BOP) in Anatolia peaked during the Late Roman and Early Byzantine Periods. This study investigates whether climatic changes during this period influenced the intensification of agricultural activities. By evaluating pollen studies in Anatolia, the characteristics of agricultural activities were determined and compared with historical, archaeological, and palaeoclimatic data to explore the relationship between BOP, climatic changes, and their impact on agricultural activities and social structures. The findings suggest that favorable climatic conditions significantly contributed to the expansion of societies and the intensification of agricultural activities in general. However, cold and arid climatic conditions did not permanently and continuously affect agricultural activities and society, even though they may have caused temporary crises.

1. Introduction

Changes in land use due to climatic changes in the Quaternary period have become quite distinct due to the intensification of human influence, especially in the last 3000 years (Bell and Walker, 1992; Roberts, 2014). Although the Holocene is generally defined as a period of increased temperature and humidity, palaeoclimatic studies have determined it contains many climate change cycles (Love and Walker, 2015; Roberts, 2014; Roberts and Wright Jr, 1993).

To determine palaeoenvironmental changes, proxy environmental records such as pollen, algae, and diatom, which can be preserved especially in the swamp and lake sediments, are used (Gaillard et al., 1992). Among these, a field's palaeo land use and palaeo vegetation can be determined with fossil pollen data, widely used in environmental change studies (Bakker et al., 2013; Bottema and Woldring, 1984). These features are determined by the chronological interpretation of the proportional distribution of plant taxa in the pollen diagrams obtained from the pollen data (Birks, 1990; Iversen, 1941, 1949; Ören, 2022). Thus, agricultural periods can be determined according to the presence and rates of pollen showing agricultural activities.

The period between 250 BCE and 670 CE was the last stage of the intensive farming period of Antiquity, and this period is prominently reflected in the palaeoenvironmental record as well as in historical texts and archaeological materials (Behre, 1990; Roberts et al., 2016). Since the Late Bronze Age in Anatolia, the characteristic land use pattern has been the intensive agricultural period called the Beyşehir Occupation Phase (BOP) (Bottema et al., 1986; Eastwood et al., 1998). In this period, grain cultivation, fruit cultivation (olives, grapes, and walnuts), and substantial livestock farming activities were carried out. These agricultural practices have led to the development of an anthropogenic vegetation cover visible in the pollen data. This vegetation cover was first described in the pollen records of Lake Beyşehir in southwest Anatolia (Bottema and Woldring, 1984). The presence of similar pollen groups dating to the same period in other pollen fields in many parts of Anatolia (North Anatolia, Northwest

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Anatolia, Central Anatolia, Southwest Anatolia, Western Anatolia, and Eastern Anatolia) gave rise to the idea of a widespread land cover that represented the entire area throughout much of the Late Holocene (Bottema et al., 1993-1994; England et al., 2008; Miebach et al., 2016; Ören, 2018; Wick et al., 2003). The widespread occurrence of the BOP in the late stages of Antiquity shows that it became the standard form of agriculture for Roman and Byzantine societies.

The Byzantine Empire struggled with many difficulties in its Early Period (Treadgold, 2020). One of the most important was the unfavorable climate period that prevented the empire from reaching its previous economic and political power (Lambert, 2021). Changes in climate and human impact (e.g., socio-economic/political changes) are undoubtedly the most important triggering forces behind vegetation/land change (Bakker et al., 2013). Climate data not masked by the human impact is needed to determine climate changes during intensified human influence (Eastwood et al., 2007). Human activities can impact the land more than other factors, especially as deforestation and overgrazing lead to soil loss, erosion, and settlement abandonment. However, other factors have also affected the way humans use the land. Climate changes have caused significant changes in states' social, economic, and political structures (Haldon et al., 2014). For this reason, it is necessary to talk about the climate changes covering the study period.

Developing disciplines such as dendrochronology, palynology, sedimentology, and limnology has allowed scientists to identify several major climate fluctuations over the past 2000 years using proxy data analysis for the Eastern Mediterranean (Telelis, 2008). During the so-called Roman Climatic Optimum (RCO) or the Roman Warm Period (RWP/250 BCE-300 CE), the Dark Ages Cold Period (DACP), or the Late Antique Little Ice Age (LALIA/300-950 CE), the climate impact on the economy (on agricultural activities) and society of the Roman and Byzantine Empires have been a matter of curiosity (Büntgen et al., 2016). So far, studies examining the relationship between climate and the socioeconomic structure of societies have mostly investigated social structures (Knipping et al., 2008; Xoplaki et al., 2016). This study focuses on Anatolia and explains the relationship between agricultural activities obtained from pollen analysis data, the change periods of these activities, and climate changes.

The focus of this study is to discuss possible causal relationships between changes in climatic and agricultural activities that took place between 250 BCE and 670 CE. It should be noted that BOP depends on natural factors such as climate change as well as human factors. Therefore, one of the aims of this study is to distinguish between the human impact on vegetation and the role of climate change in the development of the BOP from 250 BCE to 670 CE. Therefore, this study aims to contribute to determining the relationship between climatic and socioeconomic (agricultural activities) changes. To achieve this aim, an interdisciplinary and comparative analysis was carried out using evidence on the climate and society of the Roman and Byzantine periods and climatological, environmental, archaeological, and textual evidence. The results obtained in this study will contribute to research on climate effects and social reactions in Anatolia during the Roman-Byzantine Period.

2. Material and methods

Ethics committee approval. All responsibility belongs to the researchers. All parties were involved in the research of their own free will. Ethics committee approval is not required as this study did not collect data on humans using experiments, methods, practices, etc.

Pollen records from different regions of Anatolia are the most important source of information about agricultural activities. Changes in pollen rates of anthropogenic plants such as grains, grapes, olives, and walnuts can indicate agricultural activities by providing information about the vegetation structure of a particular region in the past. Climate information can also be obtained from pollen data (Brewer et al., 2007; Eastwood, 2006; Kaniewski et al., 2013, 2014; Luterbacher et al., 2012). Thus, it becomes possible to compare with independent climate data and determine land use relationships.

The study focuses especially on the Late Roman-Early Byzantine Period, historically including the most intense period of the BOP and important periods such as droughts, famines, and decreased agricultural activities due to diseases. The agricultural activities and land use characteristics experienced during this period were obtained by evaluating the fossil pollen records. For this reason, within the scope of the study, pollen studies that have been conducted in different regions and represent BOP have been examined, and evaluations have been made in light of the results of these studies. For palaeoclimatic changes, palaeoclimatic data corresponding to this period as well

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as written sources containing information about palaeoclimates were used. In this context, the changes in agricultural activities that occurred during the Roman-Byzantine period were determined, and whether these changes were related to climatic changes was discussed.

3. Results and discussion

Anatolia is relatively rich in palaeoenvironmental data. In addition, data on vegetation and land use are available thanks to pollen analysis. A phenomenon that palynological data sheds light on throughout Anatolia and its surroundings is the Beyşehir Occupation Phase (BOP), a period of significant anthropogenic impact in which pollen taxa indicating fruit farming, grain farming, and animal husbandry activities increased (Bottema and Woldring, 1984). This period was the dominant agricultural period of the eastern Mediterranean from about 300 BCE to 700/800 CE (Bottema et al., 1986; Eastwood et al., 1998; England et al., 2008).

Intense agricultural activities during the period examined took place without megadrought, as in the Bronze Age. However, some dry periods were experienced during the BOP. Palaeoclimatic records show favorable and stable climatic conditions from 250 BCE to 300 CE, and this climate is relatively hot and humid (Büntgen et al., 2011; Ljungqvist, 2010). These hot and humid climatic conditions allowed the economic development of Anatolia and its surroundings during the Late Roman period (Table 1; Dean et al., 2015; Fleitmann et al., 2009; Izdebski, 2011; Izdebski et al., 2016; Ocakoğlu et al., 2016; Şimşek and Çağatay, 2018). Often referred to as the "Roman Warm Period" (RWP), this period coincided with the development, consolidation, and economic expansion of Roman political and military power (Haldon et al., 2014). This period was also called the "Roman Climatic Optimum" (RCO) because it was characterized by a generally warm climate, supporting the strong period of the Roman Empire (Telelis, 2008). From ~300 CE, a climatic shift occurred in Anatolia, in which the humidity decreased gradually. Although it changed more or less depending on local conditions, the amount of humidity reached its minimum levels between 350 and 470 CE (Göktürk et al., 2011; Jones et al., 2006; Kuzucuoğlu et al., 2011).

The occurrence of significant drought across the Eastern Mediterranean during this period is supported by evidence of low water levels in some lakes in the region, including Lake Marmara (Western Anatolia) (Besonen and Roosevelt, 2015). This dry period is characterized by increased positive isotope values in lake, cave, and marine sediments, aragonite precipitation in Lake Tecer in Central Anatolia (Kuzucuoğlu et al., 2011), and dominance of salt-tolerant diatoms in Lake Nar (Dean et al., 2013; Woodbridge and Roberts, 2011), XRF and positive carbon-oxygen isotope values in Lake Hazar in Eastern Anatolia (Ön et al., 2018) and multiple data including ostracodes, XRF, organic and inorganic carbon, $\delta^{18}O$ isotopes in Lake Van (Şimşek and Çağatay, 2018), positive isotope values in Sofular Cave in Northern Anatolia (Fleitmann et al., 2009; Göktürk et al., 2011) and pollen, diatom and positive isotope values in Lake Çubuk (Ocakoğlu et al., 2016). Most sediment core series shows that this arid and cold period lasted 150 years (Dean et al., 2013; Kuzucuoğlu et al., 2011). Sediment $\delta^{18}O$ data from Gölhisar Lake in Southwest Anatolia (Eastwood et al., 2007), data on speleothem $\delta^{18}O$ and Mg/Ca ratios from Kocain Cave (Jacobson et al., 2021), sediment and pollen data from Gravgaz Marsh and Bereket Basin (Bakker et al., 2013) emphasize the spatial heterogeneity of the climate in Anatolia. Records revealed that the Southwest Anatolia region shows more similarity with West Anatolia (Labuhn et al., 2018). These data showed that the climatic conditions were very high in precipitation and humidity between 330 CE and 400-460 CE; a rapid transition to drier conditions occurred from 460 CE, which continued until ~830 CE (Jacobson et al., 2022). Therefore, it seems likely that Southwest Anatolia had a slightly different climatic history. However, Central Anatolia, Eastern Anatolia, North Anatolia, and Northwest Anatolia shared a common hydroclimatic trajectory between 300 and 470 CE (Roberts et al., 2018).

Written climate records do not contain much information indicating arid conditions up to 470 CE. However, among the written sources, some records of churches talk about the dry conditions in Anatolia during the period of 350-400 CE. Between the sermons during the 4th and 5th centuries CE, those from 350-400 CE show increased poverty and crises (Kennedy, 2000; Stathakopoulos, 2017). For example, Basil the Great's sermon corresponding to this dry period describes an extremely cold and dry winter and a very dry and hot summer (Holman, 2001). It is possible to observe that in the Byzantine Empire, where there was very little war despite recurrent local livelihood crises in this period, many famines occurred during the period 350-470 CE, and there was a temporal relationship between drought and livelihood crises in Anatolia in the fifth century (Cameron, 1993; McCormick et al., 2012). Evidence suggests that these famines were caused by prolonged droughts (Eastwood et al., 2009; Haldon, 2007; Leng and Marshall, 2004). However, according to pollen data, the fact that agricultural activities continued in this period shows that the Empire took some precautions.

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Archaeological records indicate that large-scale water storage facilities and fountains were built during this period (Jacobs and Waelkens, 2013; Martens, 2006, 2008). These development activities carried out during the environmental pressure period slightly prevented the Empire from experiencing urban water shortages (Pickett, 2016). Thus, the period of dry conditions between ~350-470 CE did not cause a great social change, although it caused livelihood crises and socio-economic problems in Anatolia. For example, archaeological research in Sinop shows that the density of settlements along the coast has increased significantly since the 4th century (Doonan, 2003). This coast was known as the most suitable region for olive production along the Black Sea in the Antique Age. In the 1st century BCE, the famous geographer Strabo stated that this place was full of olive groves (Strabo, 2000). Strabo points out that these coasts of Sinop are an important center for olive production in the Black Sea due to their unique microclimate. In addition, olive pits were recovered from local amphorae from the late Roman period and excavated from the port area of Sinop (Doonan, 2004). According to the results of the archaeological research conducted around the ancient city of Balboura, located within the borders of Burdur province in south-western Anatolia, the settlement continued until the fifth century, as in the Sinop region (Coulton, 2012). Potsherds from this mountainous region increased in the fifth century (Izdebski, 2013). Therefore, the expansion trend peaked in almost every part of Anatolia in the 5th-6th centuries (Izdebski et al., 2016).

Table 1. The relationship between climate conditions, agricultural activities, and social changes between 250 BCE-670 CE

Date	Climate	Agricultural activities	Social changes
545-670 CE	Humid and hot climatic conditions	Increase in agricultural activities	Increase in welfare levels and in the number of settlements
536-545 CE	Cold climatic conditions	The Plague of Justinian and the cooling of the climate caused famine	Justinian Plague killed many people and caused a partial weakening of the Byzantine Empire
470-536 CE	Humid and hot climatic conditions	Intensification of agricultural activities	Increase in the number of settlements
300-470 CE	Humidity levels reached their lowest values	Continuation of agricultural production thanks to the reconstruction activities carried out by the empire	Increase in the frequency of livelihood crises and poverty
250 BCE-300 CE	Humid and hot climatic conditions	Intensification of agricultural activities	Increase in the number of settlements

This dry period ended abruptly, according to proxy climate records. For example, according to the Nar Lake isotope data, the transition from an arid climate to a humid climate occurred abruptly and rapidly between the years 470-536 CE (Izdebski et al., 2016). During this period, the $\delta^{18}O$ curve of Lake Van shows an increase in humidity (Issar, 1998) and indicates that the lake level is "abnormally" high (Brown, 1994). In addition, Lake Hazar XRF and carbon-oxygen isotope data (Ön et al., 2018), Sofular Cave isotope data (Göktürk et al., 2011), and Lake Çubuk isotope and planktonic diatom data (Ocakoğlu et al., 2016) show that warm and rainy climatic conditions prevailed during this period. Archaeological data show that the significant increase in precipitation after 470 CE allowed a significant increase in the number of settlements in Anatolia (Izdebski, 2013). Of course, there were other factors that mediated settlement and agricultural expansion in Anatolia. These include the development of Constantinople as a center of commerce (Mango et al., 1995), economic growth, and investments by aristocrats (Banaji, 2007). In addition, at this time, the annual precipitation had a regular regime, which increased the yield of rain-grown crops and increased agricultural stability (Rosen, 2007).

Until 900 CE, the climate had a variable characteristic during the so-called "Dark Ages Cold Period" (DACP) (Telelis, 2008). The coldest years during the study period were between 536-545 CE (Baillie, 1994). It has been suggested that the onset of this cold period was due to the Dust Veil Event, which occurred due to a volcanic eruption in 536 CE (Larsen et al., 2008). The high sulfate rates, which started in 536 CE and continued for 18 months, in the glacier samples obtained within the scope of the Greenland Ice Sheet Project 2 strengthen the possibility that severe volcanic activity had occurred (Larsen et al., 2008). David Keys (1999) has published a theory claiming that the 536 CE event was a large-scale natural disaster resulting from a volcanic eruption in the Equatorial region. The eruption, which Keys believes took place in Southeast Asia, created a layer of volcanic ash in the atmosphere. As a result of this layer formation, the influence of the solar rays was reduced by volcanic

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materials in the stratosphere, and this started a chain reaction of climatic chaos ranging from severe flooding to severe drought (Hirschfeld, 2006). As a result of this event, worldwide cooling occurred (Gunn, 2000). The summer cooling after this volcanic eruption was probably driven by positive feedback loops of ocean currents and sea ice (McGregor et al., 2015). In the tree ring samples taken from many regions worldwide, it is possible to find that the growth rings did not develop in the trees or that the damage was caused by frost events in 536 CE (Baillie, 1994). Unusual weather conditions have also been noted by historians such as Procopius and Cassiodorus, which caused crops to deteriorate and prevented fruit from ripening (Arjava, 2005). However, the bountiful harvest of the previous year prevented famine (Gunn, 2000; Stathakopoulos, 2017). This brief climatic cooling may have initiated the Plague of Justinian between 541-542 CE (Keys, 1999). The outbreak of the Justinian plague in the Byzantine Empire between 541 and 543 CE and its subsequent pandemic development followed widespread food shortages soon after the onset of the DACP (Hirschfeld, 2006; Larsen et al., 2008; Stathakopoulos, 2017). Spreading from Asia (Harbeck et al., 2013), this persistent disease killed millions and caused a partial weakening of the Byzantine Empire (Gunn, 2000; McCormick et al., 2012). Livelihood crises in the 6th century do not seem to be directly linked to climate change. Increasing famines in Anatolia around 500-550 CE are primarily related to the Justinian plague that emerged in 541 CE (Haldon et al., 2014).

A humid and warm period, interrupted by this short dry period, lasted about two centuries and peaked in the 6th and 7th centuries (Neumann et al., 2007; von Rad et al., 1999). According to the data of Nar Lake since 500 CE, the Ca/Sr ratios showed that the transition to much more humid conditions occurred, and these conditions led to an increase in welfare levels and an increase in agricultural activities (Jones et al., 2006). These agricultural activities continued until 670 CE (England et al., 2008). Humidity increased around Tecer Lake (Kuzucuoğlu et al., 2011). Winter precipitation increased while summer droughts continued around the lake from ~500 to 550 CE. As a result of the further increase in humidity from 550 to 650 CE, the lake level rose. These changes are consistent with the data from Nar Lake, which recorded a humid period from 545 CE to 750-800 CE (Kuzucuoğlu et al., 1998, 1999). As Tecer Lake data shows, this increase in humidity in Nar Lake is related to the increase in precipitation in the winter season and the decrease in evaporation rates in the summer (Kuzucuoğlu et al., 2011). Over time, a period of renewed agricultural prosperity coincided with the spread of rain-fed agriculture to arid areas, and this period formed one of the most suitable climatic periods for settlement and agriculture in some regions, such as Cappadocia, in the historical process (Izdebski et al., 2016). Low Ti and Ca values in Lake Van (Şimşek and Çağatay, 2018), low carbonate $\delta^{18}O$ values in Lake Nar (Dean et al., 2015), low speleothem $\delta^{13}C$ values in Sofular Cave (Fleitmann et al., 2009), and a negative shift in $\delta^{18}O$ in Lake Çubuk (Ocakoğlu et al., 2016) suggest that humid climatic conditions continued until at least 750 CE. The evidence of archaeological, historical, and environmental data regarding these climatic conditions and the strengthening of the Byzantine Empire clearly supports the intensification of economic activity in Anatolia during this period.

4. Conclusions

As a result of the evaluation of palaeoclimatic, palynological, archaeological, and historical data, it was determined that the high prosperity period of the Late Roman Empire and the Early Byzantine Empire and climate changes were largely compatible with the BOP, which was an intensive agricultural period. It was observed that the climate showed some fluctuations between 250 BCE and 670 CE, which was the period when the BOP was most intense and spread throughout Anatolia.

Between 250 BCE and 300 CE, the climatic conditions were hot and humid. These favorable and stable climatic conditions ensured the intensification of agricultural activities in Anatolia during the BOP compared to previous periods, and the number of settlements increased in this period. As a result, the Late Roman Empire was strengthened militarily, politically, and economically.

A gradual decrease in humidity occurred in most of Anatolia from ~300 CE, and humidity levels reached their lowest values between 350 and 470 CE. However, the data obtained from Southwest Anatolia showed that the climatic conditions had rainy and humid characteristics between 330 and 460 CE. Thus, although North Anatolia, Central Anatolia, and Northwest Anatolia experienced a similar hydroclimatic trajectory between 300 and 470 CE, Southwest Anatolia experienced slightly different conditions. Development activities were carried out for irrigation to reduce the effect of drought in regions where arid conditions prevail. Thus, although some crisis periods were experienced, they did not cause a great change in the lands of the Empire.

The dry period ended between 470-545 CE, intensifying agricultural activities and settlements. However, the Dust Veil Event in 536 CE and the Justinian Plague Epidemic interrupted this period of prosperity and caused the

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Byzantine Empire to weaken partially. From ~550 CE, the temperature and humidity increased even more and peaked in the sixth and seventh centuries. Thus, the period of agricultural prosperity in these favorable climatic conditions enabled agriculture to spread to arid areas.

Although the BOP has emerged largely due to anthropogenic factors, favorable climatic conditions appear to support this development significantly. Both the palynological record and archaeological and historical evidence reveal that much of the area was densely settled, and intensive agricultural activities were carried out. In light of all the results, it is understood that favorable climatic conditions were a reasonable contributing factor to the expansion of societies and the intensification of agricultural activities in general, but cold and arid climatic conditions did not have a permanent and continuous effect on agricultural activities and society, even if they caused some crises.

4.1. Theoretical implications

While the studies carried out to date, only include the dates between which the BOP occurred and the main characteristics of this period, this study has discussed the possible causal relationships between climatic and agricultural changes. Thus, the study has enabled the determination of the factors that played a role in the development of the BOP, which has a wide distribution in Anatolia, with multiple temporally and spatially data.

In particular, the study contributed to the determination of relationships between factors related to climatic and socioeconomic changes. The hypotheses developed in this study are expected to shed light on future research on climate effects and social reactions in Anatolia during the Roman-Byzantine Period. At the same time, it is thought to provide guidance for future research on determining the causes of other periods of prosperity and collapse in Anatolia in the historical process.

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Author contribution statements

The authors contributed equally to the research's design and implementation, analysis, and the manuscript's writing.

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Ethics committee approval

All responsibility belongs to the researchers. All parties were involved in the research of their own free will. Ethics committee approval is not required as this study did not collect data on humans using experiments, methods, practices, etc.

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