A pedoanthracological and palynological approach to study man-climate-ecosystem interactions during the Holocene in Persepolis basin (SW-Iran)

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To my reasons to live:

Mina & Saeed

And

To my wings to fly:

Niloufar & Behzad

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1. Summary

It is generally discussed and accepted that the climate, human, and the vegetation are in a close interaction in southwest Asia since the presence of the human beings in the area. In this regard, Iran and specifically the Zagros Mountains were an important part of the Fertile Crescent. This area playes a critical role as the progenitor sanctuary for early civilizations and is a key region to understand the Holocene hydroclimatic evolution in SW Asia because of its proximity with the Indian Ocean monsoon system. For this strategic geographical position and considering a near-continuous history of human occupation (since Neolithic times 7000 BC), the Persepolis basin has been selected for a multidisciplinary palaeoenvironmental study in the frame of Paleo-Persepolis project conducted by a French-German instutional consortium and financed by the ANR and DFG. This basin has witnessed the presence and emergence of several great civilizations (Elamite, Achaemenid–Persian, and Sasanian). In addition to climatic changes, such civilizations left substantial impacts on the environment by their social structures as well as different strategies in exploiting the resources. The present study contributes to the Paleo-Persepolis project and focuses on studying the vegetation dynamics and fire history of the Persepolis and surrounding areas. This thesis aims to investigate the past vegetation changes of the basin during the Holocene epoch within the human-climate-ecosystem nexus of Southwestern Zagros.

Chapter 2 summarized the present state of the art on climate, vegetation, archaeology and palaeoecology of the Persepolis basin. It provides an overview of the Paleo-Persepolis project and the main aims. Moreover, it explains the objectives and goals of the present thesis as well as important notes on methodological approaches.

The study presented in **Chapter 3** introduces the modern floristic list of woody species and the first wood anatomy and charcoal identification keys besides the reference collections for the major arboreal taxa of the Persepolis basin. This study was crucial to build a background for reconstructing the historical woody vegetation applying a (pedo-)anthracalogical approach. It represents an anatomical multi-entry identification key using the diagnostic microscopic features of 41 taxa according to IAWA code.

In **Chapter 4** the results of a high-resolution palynological investigation on a Holocene sediment core from seasonal saline Lake Maharlou is presented. In this chapter, the emphasis was put on studying the role of man in modifying the natural vegetation and landscapes of the area as well as the dominant agricultural practices during Imperial Persia (550 BC-651 AD; 1299-2500 cal BP) and notably the Achaemenid Empire (2500-2280 cal BP; 550-330 BC). Lake Maharlou is the closest waterbody to the Persepolis basin (~ 60 Km to Marvdasht plain) and provides excellent conditions for preserving pollen archives. Palynological survey on this lake provided the first pollen evidence of *Punica granatum* suggesting the large-scale pomegranate plantations, a fact that is supported by the historical documents

(PFa33). The pollen record depicts a significant increase in agriculture and suggest urban development during Persian empires and Early Islamic dynasties. These results, supports the presence of the so-called 'Persian gardens' by demonstrating the growth in cultivating the symbolic and shadow providing trees. Altogether, with the significant presence of agro-pastoral indicators, the extensive human activities and development of urban areas has been suggested.

Chapter 5 addressed the history of arboriculture in ancient Iran using palynological evidence. This chapter represents a review of pollen diagrams published from different regions of Iran. Moreover, the chapter represents a summary of historical and archaeological evidence to support the presence of the identified tree taxa. This chapter implies that the history of tree cultivation inferred from pollen analysis, besides other anthropogenic activities (cereal cultivation and sylvo-pastoral practices), provides a direct and very important piece of information about the definitive adoption of sedentary lifestyle. Large-scale arboriculture revealed in pollen diagrams is thus robust evidence for sedentism and even the formation of urban centers.

Chapter 6 presents the results of the first fire history reconstruction in the in the interior parts of the Iranian Plateau and the Zagros Mountains during the last ~ 4000 years. This chapter reconstructs the fire history and addresses the drivers of the significant fire episodes, using macroscopic charcoal records from the Lake Maharlou. The results illustrate the similar patterns for fire incidence and frequency inferred from charcoal counts and area data without reducing the influence of small fragments. The screened charcoal peaks showed high compatibility with the reconstructed palaeohydrology and pollen-inferred vegetation dynamics of the basin as well as the historical evidence. The history of biomass burning comprises two regional and a local fire episodes of which, the youngest macro charcoal peak is likely related to the dry climate, while the inferred fire episodes during 2200-2000 cal yr BP demonstrate local biomass burning events correlated with dominant pastoral nomadism and lifestyle change of inhabitant.

Chapter 7 illustrates the results of an anthracological survey on archaeobotanical wood charcoal remains from a prehistoric site of Tepe Rahmatabad in Persepolis basin. The species composition of the studied charcoal assemblage suggests that the site was located in Zagros steppe-forest vegetation type. In addition to the reconstructed overview of the surrounding landscape, this chapter describes the correlations between the charcoal frequencies of some taxa such as pistachio and almond, with the firewood and fruit gathering strategies of Rahmatabad site inhabitants during the Neolithic period. It shows that despite the common presence of oak in southern Zagros woodland and finding a fragment of oak cotyledon, the oak charcoal was not identified in the assemblage. It may point to the availability of diverse sources for obtaining firewood with less effort and different applications of natural tree species.

2. Introduction

2.1. The Paleo-Persepolis project: investigating Human-Climate-Ecosystem interactions during the Holocene in Persepolis Basin as a 'System Model' in south western Iran.

As an important part of the Fertile Crescent, Iran and specifically the Zagros Mountains were among the progenitor sanctuaries for early civilizations. The long history of complex interactions between societies, climate and environmental landscape has placed this region at the center of attention for many palaeoenvironmental studies (e.g. Sumner 1972, 1988; Kimiaei et al, 2006; Djamali et. al, 2009, Jones et al, 2015, Miller 1985, 2003; Riehl et al 2015; Shumilovskikh et al. 2017; van Zeist & Wright 1963; van Zeist & Bottema 1977). Such investigations are beneficial in assessing the recent social and environmental situations in interaction with climatic change by revealing the human-environment interactions in the past (Jones et al. 2018).

In this regards and considering a near-continuous history of human occupation (since Neolithic times 7000 BC), the Persepolis basin has been selected for a multidisciplinary palaeoenvironment study in the frame of Paleo-Persepolis project conducted by a French-German instutional consortium and financed by the ANR and DFG. This basin has witnessed the presence and emergence of several civilizations (Elamite, Achaemenid, and Sasanian). In addition to climatic changes, such civilizations left substantial impacts on the environment by their socio-economic organization as well as different strategies in exploiting the natural resources. Focusing on the critical role of water resources in the human-environment interactions and sensitive hydrological setting of the basin to climatic variations, the Paleo-Persepolis project aims at combining palaeoecology, history and archaeology by evaluating the availability of water resources to past human societies, as well as to evaluate human impact on ecosystems by analysing several proxies (including pollen, charcoal, fossil insects) from different archives (lakes, mires, soils and sediments). Epigraphic and historical documents, as well as bio-archaeological remains from plants and animals, are also studied. Moreover, human-independent high-resolution hydroclimatic records is established using biological proxies (chironomids, cladocera) in correlation with available geochemical records.

The present study contributes to the Paleo-Persepolis project and focuses on investigating the vegetation dynamics and fire history of the Persepolis basin. This thesis aims to investigate the past vegetation changes of the basin during the Holocene epoch within the human-climate-ecosystem nexus of Southwestern Zagros.

2.2. The present thesis: An anthracological and palynological approach to study man-climate- ecosystem interactions during the Holocene in Persepolis basin (SW-Iran)

2.2.1. Objectives

In spite of well-studied archaeology and history of the Persepolis Basin and in addition to several archaeobotanical (plant macro-remains) investigations (e.g. Miller, 1985, 2003, 2011; Miller and Kimiaie, 2006), palaeoecological studies and past vegetation reconstructions are very infrequent in this basin. Other palaeoecological surveys in Iran are conducted mainly in the north and northwestern parts of the country (e.g. Zeribar, Mirabad (van Zeist and Bottema, 1977), Urmia (Bottema, 1986; Djamali et al., 2008b) and Almalou (Djamali et al., 2009b)). The nearest past vegetation reconstructions in southern Zagros were carried out at Lake Parishan in Helle River system (Jones et al. 2015) and Lake Maharlou (Djamali et al., 2009a) in the south of the Persepolis basin. However, the chronology of the events and reconstructed changes in the vegetation are questionable in the study about Maharlou Lake, because of uncertainty in calculated ages (Djamali et al. 2011b).

On the other hand, although palaeoecological studies have revealed the impacts of societal changes on SW Zagros ecosystems during different historical periods, the detailed reconstruction of vegetation history during Imperial Persia (550 BCE to 651 CE), remains obscure. Moreover, the fire history of the region is largely unknown, and was mainly described in few palynological studies through the presence and concentration of microscopic charcoal particles in records, counted and quantified in conjunction with palynology on pollen slides. For instance, Djamali et al. (2009b) briefly addressed the importance of fires in Lake Maharlou region by illustrating several considerable peaks of micro-charcoal concentration. Fire has a complicated connection with the anthropogenic activities and climatic changes (Finsinger et al. 2014; Mooney and Tinner 2011). These are the primary determinants for extent, severity, and frequency of fire events in the ecosystem. Therefore, it is necessary to use proxies that provide more reliable information about local fire episodes and reconstruct robust fire history scenarios. Consequently, the main aim of the present study is to present an explicit scheme of the vegetation and ecosystem changes in interaction with climate and human activities, during the Holocene in Persepolis basin. In this regards, the palynological and anthracological approaches and methods were applied: 1) to reveal the regional vegetation changes during the Classical and Late Antiquity with particular focus on the Achaemenid Empire (550-330 BC), 2) to reconstruct a robust fire history and postulate the extent and frequency of fire occurrence, 3) to complement the knowledge about the vegetation changes at a local scale, in interaction with the prehistoric human community during the Neolithic period and 4) to develop an optimized anatomical identification key and provide the first wood and charcoal reference collections for the study area, in order to enhance the accuracy of anthracological surveys.

2.2.2. Note on the methodological approaches

Pollen analysis is a common approach used in palaeoecological investigations to study palaeo-vegetation dynamics. Based on the habitat and preferred ecological condition of taxa, several indicator palynomorphic types (pollen and Non- pollen) are defined to demonstrate the impact of different factors on the ecosystem (Moore et al. 1991). On the other hand, some other reconstructions employ wood charcoal analysis (in different size classes and contexts) to reveal the biomass burning history, inferring the forest species diversity and its changes during the time as well as the application of wood in human life history. Wood charcoal particles can be studied in three different size categories: micro-charcoals (10-150 µm), macro-charcoal (>150 µm – 1 mm) fragments and mega-charcoals (> 1 mm) which are taxonomically identifiable (Robin et al. 2013a; Whitlock & Larsen, 2001). Mega-charcoal identification provides information about fire history on a very local scale. Soil charcoal particle (mega charcoal) analysis (pedoanthracology) is also useful for dating fire history by taking advantage of AMS-C14-dated charcoal pieces. Moreover, this proxy helps in taxonomically identifying the burnt species and therefore in reconstructing the past vegetation composition (Robin et al., 2013a), while macro and micro charcoal particles are been used to reveal fire signals within an extra-local to regional scale.

Palynology and anthracology are often used independently, however the number of studies that employed these analyses as complementary approaches is increasing (e.g., Carter et al. 2018; Fyfe et al. 2018; Nelle et al. 2010; Poschlod & Baumann, 2010). It is worth to mention that both methods have advantages and disadvantages in demonstrating vegetation changes (Nelle et al. 2010, Robin et. al. 2013a & b).

Palynology provides data with high taxonomic resolution about woody and herbaceous species, higher plants and cryptogams, and NPPs (Non-Pollen Palynomorphs). Furthermore, pollen data from peat or lake sediment cores usually are chronostratified, which is useful for following the paleo-vegetation changes through time. Nevertheless, site-related interpretation is not feasible by pollen data while it reflects the species variation on a regional scale. In addition, suitable sites with appropriate conditions to accumulate and preserve pollen grains – lakes or mires - are not common, especially in semi-arid or arid regions.

Anthracology appears as a helpful method in the absence of pollen records and in the regions with poor pollen conservation condition but also to validate potential palynological data. While micro and macro charcoal analyses show the chronology of biomass burning episodes, the taxonomic data from mega charcoal usually provides non-continuous data about the fire events. Also, reconstructing the vegetation changes based on archaeological charcoal data is usually biased due to the influence of human selection.

Consequently, palynology and anthracology were applied as complementary methods in the present study to investigate the linkage among climate, vegetation, fire as well as anthropogenic activities in the past 4000 years in Persepolis basin.

2.2.3. The study area: Persepolis Basin

Persepolis Basin is located in the interior part of Kur River system. This basin encompasses the most important historical and archaeological sites in Fars province and South west of Iran. In the present study, we defined the Persepolis basin as the elevated intermountain plain (>1600 m) of Marvdasht. Djamali et al (2018) added the two adjacent sub basins in the north and the northwest. The main drainage for the water system of Pesepolis basin are the large playa lake systems of the Neyriz (Lakes Bakhtegan and Tashk).

Worth to mention that the present study targeted the Persepolis basin; however, depending on the different nature and need of the performed investigations as well as the availability of study materials; the study area has been slightly modified. In this regards, the palynology and fire history reconstruction surveys have been carried out on a sediment record from Maharlou Lake. Maharlou Lake is the closest waterbody to the Persepolis basin (~ 60 Km to Marvdasht plain), which provides excellent conditions for preserving pollen archives. Considering this fact combined with its large basin provides a great opportunity to study the impact of natural phenomena and anthropogenic activities on the regional vegetation.

The anthracological study of archaeological material was carried out on the prehistoric site of Tepe Rahmatabad that is located near Kamin (Saadatshahr) plain, northeast of Persepolis historical monuments and along the royal road towards Pasargadae. Tepe Rahmatabad hosted different groups of ancient communities for millennia. Based on the archaeological records, Rahmatabad site represents a precious piece of information to fill the cultural gap of the Early Holocene. This site represents the first evidence for the pre-Neolithic culture and the oldest pottery evidence (~ 8^{th} millennia BC) in the Fars province (Azizi et al, 2014).

To take the first step for an anthracological survey, developing wood and charcoal reference collections and an optimized anatomical identification key appeared to be fundamental in SW Zagros and study area. Among all forest vegetation classes in Iran, Parsa Pajouh & Schweingruber (1985) made the only comprehensive anatomical atlas for Hyrcanian forest at the southern shore of the Caspian Sea. In order to cover the most diversity of woody species, the samples were also taken from other parts of Kur River basin, in case of finding new woody taxa.

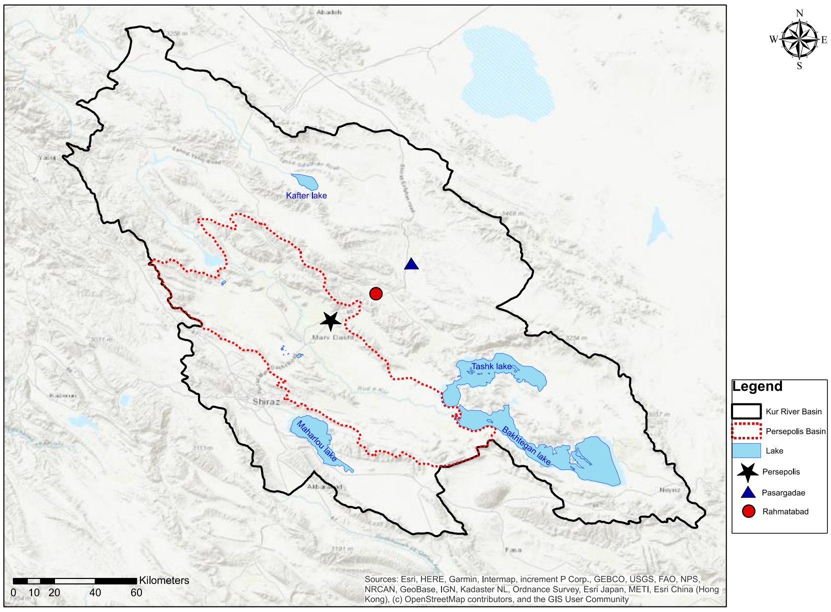
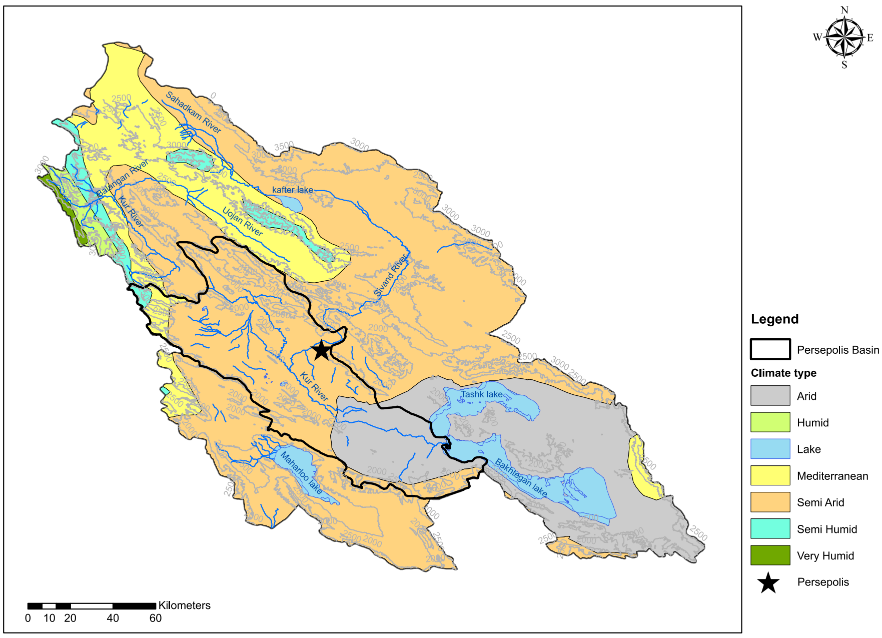


Figure 2-1: Kur River Basin (black line) and location of the defined basin of Persepolis (dotted red line); Persepolis (black star) and Pasargadae (Blue triangle) historical monuments; Rahmatabad Neolithic site (red circle). Main waterbodies showed by blue polygons.

Climate

Persepolis basin has very particular bioclimatic and biogeographical settings. It is located between Mediterranean bioclimates (Mediterranean pluviseasonal/xeric) in the west and Tropical (tropical desertic) bioclimate in the east (Djamali et al., 2011a). It has Mediterranean continental climate with the main climatic types of arid and semi-arid (Djamali et al., 2011a; available data from IRIMO[1] and FRW[2]). According to recorded meteorological data, a decreasing moisture gradient is observed from west to east with an average annual precipitation of around 300 mm/year and the mean annual temperature is 17.6 ^{o}C based on Shiraz synoptic station. The maximum of precipitation fall in January (79.8 mm) and dry season lasting about 6 months from May to October.

Figure 2-2: Climate types in Kur River Basin (according to Iran Meteorological Organization - IRIMO) and defined basin of Persepolis (black line); Persepolis monuments (black star)



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[1] Iran Meteorological Organization

[2] Forest, Range and watershed Management Organization of Iran

Vegetation

Biogeographically, Persepolis basin is located in the boundaries of the Irano-Turanian (north) and Saharo-Sindian (south) biogeographical regions. According to Zohary (1973), the Iran-Turanian steppic vegetation comprises of pistachio and almond (*Pistacia- Prunus* (syn: *Amygdalus*) xeromorphic-forest and corresponds to the Irano–Anatolian region (IT2) in Léonard's concept (Djamali et al 2012b; Doostmohammadi et al 2018).

In the Kur river Basin as well as the study area, the main forest vegetation communities consist of scattered high-grown wild pistachio (*Pistacia khinjuk* , *P.atlantica*) and almond trees and shrubs (mainly *Amygdalus scoparia*) associated with shrubs such as *Cerasus microcarpa*, *Rhamnus persica*, and *Ficus carica*. They associate gradually with Brant's oak (*Quercus brantii*) at higher altitudes (ca. 1000-2000 m) (Frey & Probst 1974; Frey 1982; Carle & Frey 1977; Zohary 1973; Djamali et al. 2009). However, due to long-term history of anthropogenic impacts, *Pistacia*-*Amygdalus* vegetation has been delimited and substituted with cushion shaped montane tragacanthic species in higher altitudes and *Artemisia* steppes in lowlands (Djamali et al 2011). Therefore, today the potential vegetation of pistachio-almond scrub mostly observed in less disturbed areas. The main forest vegetation communities in the study area based on the final report and land cover map of Iran (FRW, 2005) are shown in Figure 2-3. It is necessary to mention that the composition of main arboreal taxa has altered from the present vegetation map; *Ziziphus* sp. and *Juniperus* sp. have not been recorded and identified in the most recent field investigations (2016-2017).

According to Akhani (2004) succulent chenopods such as *Salicornia* spp. and *Halopeplis pygmaea* dominated the saline flat plains around the lake Maharlou as well as halophytic grass and sedge species suchlike *Aeluropus littoralis*, and *Juncus rigidus*. Moreover, the marshland around Lake Tashk and Bakhtegan support the fringing vegetation mostly consisting of *Tamarix* spp. (e.g. *T. arceuthoides*), *Suaeda* spp., *Cressa* spp. and *Salicornia* spp. The elevated mountain ranges between these lakes include scattered *Pistacia* spp. stands with *Artemisia* sp. vegetation in plains (Scott, 1995). In addition, reed vegetation of *Phragmites australis*, *Typha* spp. dominated the wet mudflats around the study area and the karstic springs. Figure 2-3 demonstrate the Main plant communities of forest vegetation in the Kur River Basin and the study area of Persepolis basin based on the vegetation map from Forest, Range and watershed Management Organization of Iran (FRW, 2005).

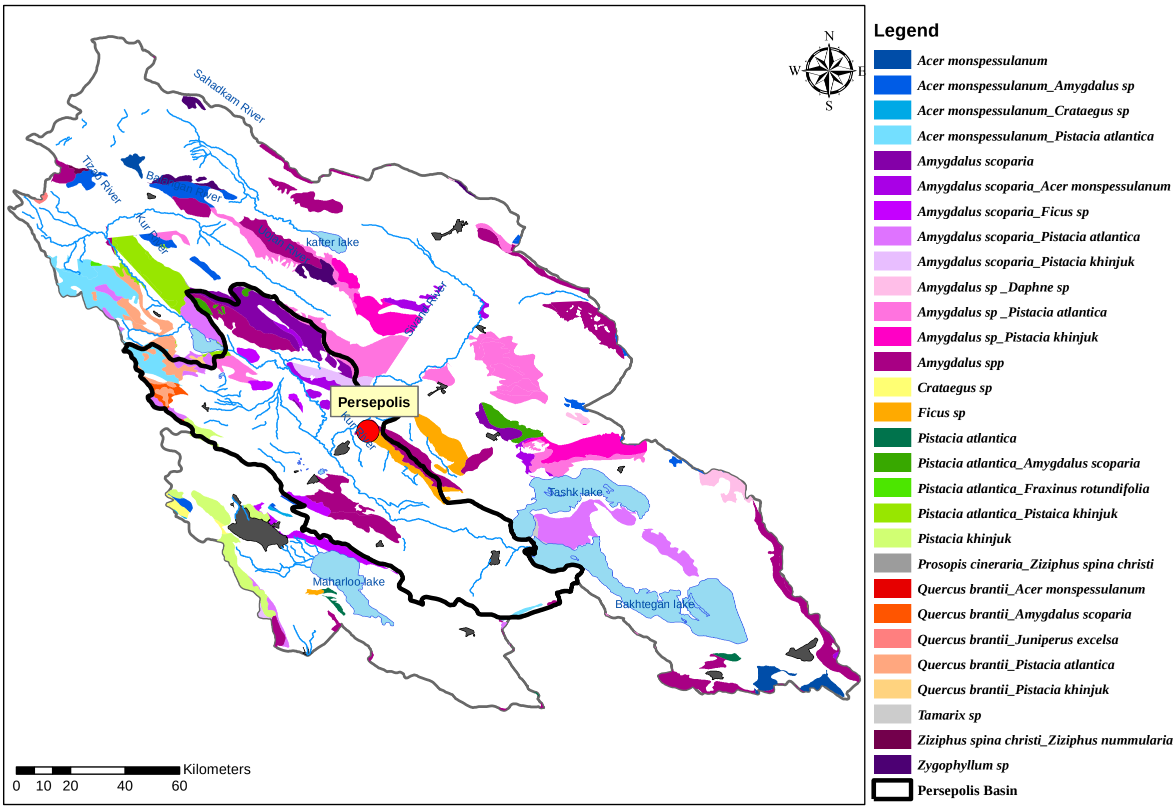

Figure 2-3: Main plant communities of forest vegetation in the Kur River basin and Persepolis basin showed with thick black line.

Archaeology and Palaeoecology:

Through the particular geological and geographical features, foothills and valleys of the Zagros Mountains have provided appropriate resources of water and arable lands for human settlement in the past (Petrie et al, 2018).

Abundance of karstic springs support human settlements with numerous freshwater resources, while the variety of microclimates with different precipitation and altitudinal ranges provide them with diversified raw materials and natural supplies (flora and fauna). The central and southern Zagros are considered among the very first centres for plant and animal domestication events and therefore the best setting for studying the man-environment interactions (Riehl et al., 2013; Miller, 2014, 2013, 2011; Kimiaei et al. 2006; Zeder and Hesse, 2000; Sumner et al 1972). For instance, the rich archaeobotanical remains from aceramic Neolithic site of Chogha Golan in west of Zagros Mountain, have recently extended back the starting point of agricultural practices into the Epipaleolithic period (Riehl et al. 2013). Livestock management history in the highlands of western Zagros date back to 10000 years ago (Verdugo et al 2019, Zeder and Hesse 2000).

Beside the Khuzestan plains, the more extensive basin of Kur River at the eastern ends of Zagros (Fars province) has experienced the presence of human settlements for millennia (Sumner, 1972). Kur River Basin (KRB) has witnessed deep changes of human lifestyle from local and scattered populations with a nomadic way of living to sedentary farmers and to the developed urban societies started by Elamite dynasties (2700-540 BC). Elamites were amongst the civilizations that increased the social complexity in SW Asia by dominating different landscapes and centralizing the populations in the plains during the fourth millennium BC. The city of Anshan, the eastern capital of Elam, was constructed at highlands of Kur River Basin (Tal-e Malyan) and had several phases of occupations and abandonment from Forth to late Second millennia BCE (Miller, 2014). The Kur River Basin (*Pārsa*) roughly covers the area where Persians started their domination during the Achaemenid governance (550-330 BC) to establish their "universal empire" (Wiesehofer, 1996). They chose this area to found their new capitals of Pasargadae and Persepolis. After the Arab invasion (651 A.D), the development processes in the area stopped for a while but restarted under the first post-Sasanian Iranian dynasties such as the Buyids (935-1062 A.D.) who expanded irrigation works and agriculture in the lower Kur River Basin (Sumner & Withcomb, 1999).

Although anthropogenic impacts on the landscape and even permanent changes in plant species composition and distribution pattern in Kur River Basin existed since the Elamite period (Miller, 2014), the Persepolis Basin and surrounding areas witnessed unprecedented urbanism and human influences since the Achaemenid period. The changes in livelihood, demographic increase as well as the development of urban centers and innovation of associated infrastructures such as hydraulic works resulted in agricultural development (Gondet 2011; Wiesehöfer 1996). This prosperity combined with the appreciation for gardens in Persian culture has led to the expansion of agriculture and extensive tree cultivation during the Achaemenid and Sasanian (224 - 651 AD) periods (Djamali et al. 2011; 2015; Shumilovskikh et al., 2017). According to available pollen data from Lake Maharlou and Lake Parishan in the adjacent basin, the main cultivated trees in southern Zagros were walnut (*Juglans*), plane tree (*Platanus*), and grapevine (*Vitis*). They have a long history of domestication and cultivation in the area dating back to the 1st to 2nd Millennia BC, but their continuous presence as cultivated trees began since Late Elamite period (~1200 BC) (Djamali et al 2011; Miller, 1985; Potts 2018; Shumilovskikh et al. 2017). Olive (*Olea*) appeared as an important arboricultural element during Achaemenids and Seleucid periods (320-247 BC) around the Lake Parishan (Djamali et al 2015;   et al 2015). In addition, pollen and archaeological wood fragments of cypress tree family (Cupressaceae) reveal different purposes for arboricultural practices (providing timber and shade) from Achaemenid to post-Sasanian periods (Djamali et al, 2017).

3. Modern flora and local wood identification key for Persepolis basin, Fars province (SW-Iran) – an overview

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3.1. Abstract

This study presents the results of a floristic and anatomical survey of woody species in the Persepolis basin, Fars province (SW-Iran). The background is the reconstruction of the historical woody vegetation applying a (pedo-)anthracalogical approach. Due to the novelty of anthracological research in SW of Iran and lack of supporting information, wood and charcoal reference collections are required. The southwestern part of Iran and particularly Persepolis basin is located at the border of the Irano-Turanian and Saharo-Sindian floristic region. Being an ecotone, the Persepolis basin has a high species diversity, particularly what concerns woody plants. The scattered pistachio- almond (*Pistacia spp.-Amygdalus spp.*) scrub combined with Brant's oak (*Quercus brantii*) at higher altitudes have been considered as the general vegetation type of the basin. In addition, the study area has a long history of human occupation and arboriculture practices, with many species introduced to the basin by historical civilizations suchlike the Achaemenid (2280-2500 BP; 550-330 BC) and Sassanian (1299-1726 BP; 651-224 AD) Empires. During two sampling seasons (2015 & 2016), we collected wood material from 41 taxa in the study area to build the wood anatomy and charcoal collection. An anatomical multi-entry identification key was developed using the diagnostic microscopic features of samples according to IAWA. In *Prunus* (syn: *Amygdalus*) genera, woody perennial *Astragalus spp*., *Alhagi spp*., *Ficus spp.* and *Salix spp*. the wood anatomy features are not sufficient to identify the taxa up to species level. The present study is a scratch on the surface to identify woody species or charcoal by their anatomy in the SW of Iran. Therefore, complementary surveys with more samples are necessary to cover a wider range of anatomical modifications of the species under different ecological conditions.

3.2. Introduction

Iran has a vast area of 164.8 million hectares. The country is a meeting point for different types of climate as well as floristic regions. According to FAO (Jafari, 2012), about 52.4% of this area is covered by rangelands; 8.6% are forests and 19.5% of the area is classified as deserts, including bare salty lands. Based on the floristic composition also climatic and ecologic features, the forest vegetation of Iran can be classified into different regions as: Hyrcanian humid and broadleaves forests which are located along the Caspian coast; Arasbaran semi humid forests in eastern Azerbaijan province (NW Iran) (designated as UNESCO biosphere reserve); semi dry forest steppe of Zagros mountains ranging northwest to southeast; Irano-Turanian central vegetation, which includes dry mountainous and desert forests; finally tropical arid forest vegetation along the Persian Gulf and Oman Sea (FAO, 2012-2015 report). Worth to mention that among all forest vegetation classes in Iran, the only comprehensive wood anatomy atlas is about Hyrcanian forest (Parsa pajouh & Schweingruber 1985). Information about other forest types is represented in nonspecific publications, which mostly have done in limited spots.

The present study has been done in Persepolis Basin located in the southern part of the Zagros Mountains (Fars - SW Iran); in the area of pistachio and almond (*Pistacia- Prunus* (syn: *Amygdalus*) xeromorphic-forest steppe. According to Djamali et al. (2009), pistachio and almond vegetation type has existed in the SW of the Zagros Mountains since the mid-Holocene with its maximum extent during the fourth millennium BC. based on the information provided in floristic references of the country (e.g. Asadi et al 1989-2019; Mozzafarian 2005; Rechinger 1966), Persepolis basin contains around 10% of the woody species diversity of the country (Supplement S3.1).

Palaeoenvironmental studies in Zagros Mountains showed the presence of human and anthropogenic activities since the Epipaleolithic period (Riehl et al. 2013). Foothills of southern Zagros in Kur River basin (KRB) have been considered among the very first locations for plant and animal domestication attempts (Kimiaei et al. 2006; Miller 2014, 2013, 2011; Sumner et al 1972). These studies show dramatic changes in regional vegetation history and significant phases of deforestation due to anthropogenic and climatic factors. Such activities have left irreversible impacts on woody vegetation composition and woodland expansion in the area. In this regard, Miller (1985, 2014) suggested a phase of ancient woodland clearance in the vicinity of the archaeological site of Tepe Malyan (Fars province-Persepolis basin) in the mid-third- millennium BC, which led to a decline in *Juniperus* vegetation from the *Pistacia-Amygdalus-Acer-Juniperus* community around this site. This composition never recovered afterwards possibly due to a slow climatic aridification in late Holocene and intensified human pressure on the natural vegetation.

Such archaeo-anthracological surveys generally dealt with wood and charcoal materials from archaeological excavations. Therefore, human lifestyle and their approaches in collecting wood and woodland management have been the most effective factor which influenced the species compositions in thearchaeological remains. Based on the “Principle of Least Effort” (Théry-Parisot et al. 2010), prehistoric communities tended to collect the firewood from the nearest woody vegetation, which needs the least labor. Consequently, the archaeological remains (wood/charcoal) demonstrate the overall vegetation of the study area to a limited extent and depends on the inhabitants strategy in dealing with woodland . For instance, the anthracology study of the prehistoric site of Tepe Rahmatabad in the Persepolis Basin (Chapter 7) shows the compatibility of the wood charcoal assemblage with the modern vegetation type of the Zagros woodlands and demonstrates that the study site was located near the *Pistacia- Prunus* (*Amygdalus*) formation. However, despite the presence of oak as a common genus today in the southern Zagros woodland, due to selection by humans, no *Quercus* sp. charcoal has been identified in this assemblage. Therefore, to reconstruct a more detailed scheme of the local vegetation composition, using other sources of wood and charcoal (e.g., soil charcoal) has complementary value.

For this purpose, wood anatomy keys based on the modern woody flora are the most appropriate tools. In addition, compare to the general identification keys from other geographical regions and countries (e.g. Crivellaro & Schweingruber 2013; Neumann et al 2001; Schweingruber et al 1990), regional keys can cover the most site-specific variations in the anatomy of local woody species, for example in response to the local microclimate. The aim of this study, therefore, was to a first step for performing an anthracological survey, to develop a wood and charcoal reference collections and an optimized anatomical identification key for the study area.

3.3. Study site

Physical setting and Vegetation

Persepolis Basin is located in the interior part of Kur River system. This basin encompasses the most important historical and archaeological sites in Fars province and South west of Iran. In the present study, we defined the Persepolis basin as the elevated intermountain plain (>1600 m) of Marvdasht. Djamali et al (2018) added the two adjacent sub basins in the north and the northwest. The main drainage for the water system of Pesepolis basin are the large playa lake systems of the Neyriz (Lakes Bakhtegan and Tashk). In order to cover the most diversity of woody species, the samples were also taken from other parts of Kur River basin, in case of finding new woody taxa. Persepolis basin has very particular bioclimatic and biogeographical settings. It is located between Mediterranean bioclimates (Mediterranean pluviseasonal/xeric) in the west and Tropical (tropical desertic) bio climate in the east (Djamali et al., 2011a). The main climatic types of the basin are semi arid and aris climate type based on available data from the Iran Meteorological Organization (IRIMO) and Forest, Range and watershed Management Organization of Iran (FRW). According to recorded meteorological data a decreasing moisture gradient is observed from west to east with annual precipitation ranging from 449 mm at Doroudzan to 205 mm at Neyriz. Biogeographically, Persepolis basin located in the boundaries of the Irano-Turanian (north) and Saharo-Sindian (south) biogeographical regions. According to Zohary (1973), Iran-Turanian steppic vegetation comprises of pistachio and almond (*Pistacia- Prunus* (syn: *Amygdalus*) xeromorphic-forest and corresponds to Irano–Anatolian region (IT2) in Léonard’s concept

(Djamali et al 2012b; Doostmohammadi et al 2018). According to the land-use map of forests, range and watershed management organization of Iran (FRW, 2002) actual forest vegetation covers about 24 percent of the basin total area. The main forest vegetation communities consists of wild pistachio (*Pistacia khinjuk*, *P.atlantica*) and almond trees and shrubs (mainly *Amygdalus scoparia*) associated by maple (*Acer monspessulanum*) and shrubs as *Cerasus microcarpa*, *Rhamnus persica* and *Ficus carica*. They are gradually combined with Brant's oak (*Quercus brantii*) at higher altitudes (ca. 1000-2000 m). However, due to long-term history of anthropogenic impacts, *Pistacia*-*Amygdalus* vegetation has been delimited and substituted with cushion shaped mountainous tragacanthic species at higher altitudes and *Artemisia* spp. in lower lands (Djamali et al 2011b). Therefore, the potential vegetation of pistachio-almond scrub mostly observed in less disturbed areas by human activities. According to the final report and land cover map of Iran (FRW, 2005) the main plant communities of forest vegetation in the study area are shown in Figure 1. It is necessary to mention that the composition of main arboreal taxa has altered from the present vegetation map; *Ziziphus* sp. and *Juniperus* sp. have not been recorded and identified in the most recent field investigation (2016-2017).

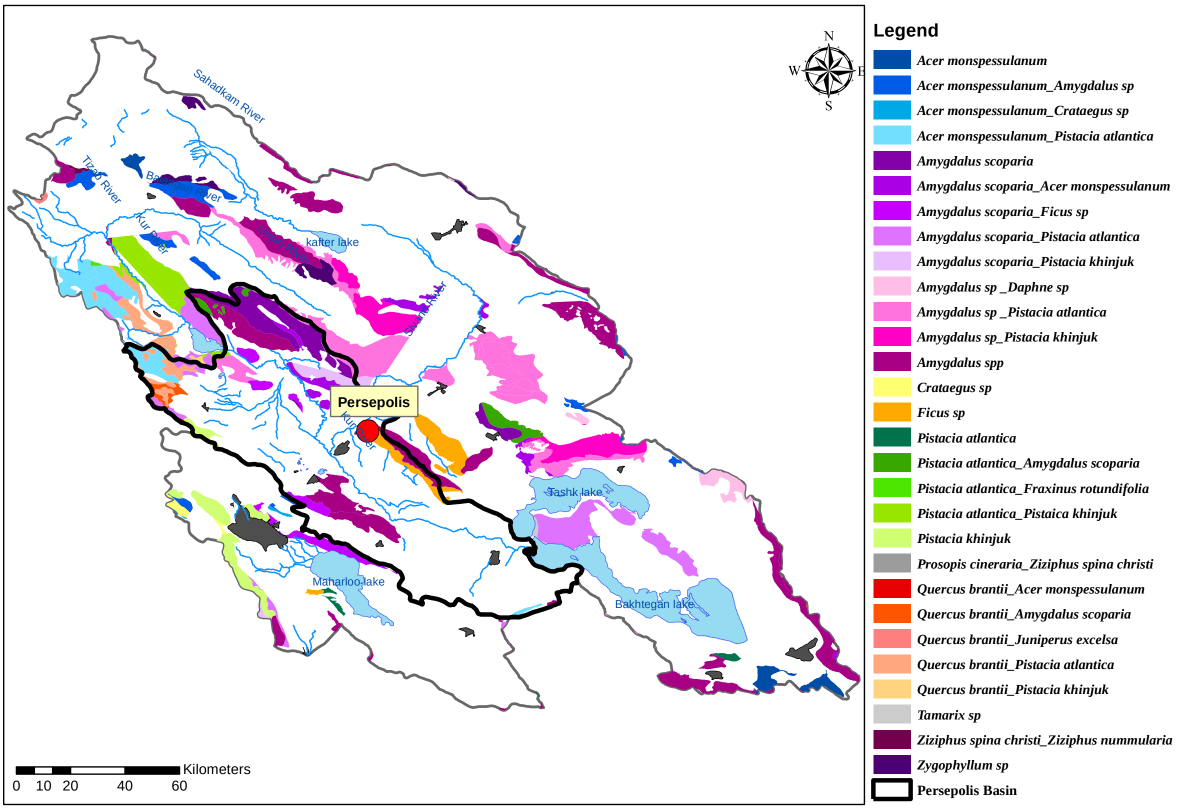

Figure 3-1: Main plant communities of forest vegetation in the Persepolis basin (from FRW, 2005)

3.4. Materials and Methods

In order to prepare the wood and charcoal reference collection, woody plant material (trees and shrub) was sampled from different sites in the study area (2015 & 2016) also around the archaeological sites.

First, a floristic list of the woody species was prepared based on the literature review (Appendix A). This list was updated during the field visits. In this regards, 41 samples from the most common taxa of modern vegetation have been collected (Table 3.1). In the laboratory, samples were cut in 1-2 cm length pieces, using the coping saw for soft woods and the band saw for hard ones. In order to prepare the wood anatomy collection, different softening and embedding techniques were applied based on the hardness of woods. Hard woods were immersed in boiling water for 2-5 minutes then stored in a mixture of 96% alcohol, water, and glycerin (1:1:3) for 2-3 weeks prior to cutting. In the case of softwoods, the boiling phase was skipped (techniques derived from www.woodanatomy.ch , Crivellaro & Schweingruber 2013). The samples were either hand cut or by using a fixed object-moving knife sledge microtome (Reichert, Nr. 328663). The sections were stained with Astra blue (0.5%) and safranin (0.1%) then mounted in glycerin, observed, and imaged by light transmission microscope equipped with a digital camera.

Table 3-1: Studied species from modern vegetation of Persepolis Basin

No.	Species	Family
1	*Acantholimon sp.*	Plumbaginaceae
2	*Acer monspessulanum*	Aceraceae
3	*Alhagi comelorum*	Fabaceae
4	*Alhagi maurorum*	Fabaceae
5	*Prunus* (syn:*Amygdalus*) *erioclada*	Rosaceae
6	*Prunus* (syn:*Amygdalus*) *eburnea*	Rosaceae
7	*Prunus* (syn:*Amygdalus*) *scoparia*	Rosaceae
8	*Astragalus fasciculifolius*	Fabaceae
9	*Astragalus glaucacanthus*	Fabaceae
10	*Capparis spinosa*	Capparidaceae
11	*Salsola vermiculata*	Amaranthaceae
12	*Celtis caucasica*	Ulmaceae
13	*Prunus microcarpa*	Rosaceae
14	*Citrus sp.*	Rutaceae
15	*Cupressus sp.*	Cupressaceae
16	*Daphne mucronata*	Thymelaeaceae
17	*Ebenus stellata*	Fabaceae
18	*Ephedra foliata*	Ephedraceae
19	*Ficus carica*	Moraceae
20	*Ficus johanis*	Moraceae

No.	Species	Family
21	*Fraxinus rotundifolia*	Oleaceae
22	*Halocnemum strobilaceum*	Amaranthaceae
23	*Juglans regia*	juglandaceae
24	*Morus alba*	Moraceae
25	*Myrtus communis*	Myrtaceae
26	*Nerium indicum*	Apocynaceae
27	*Noaea mucronata*	Chenopodiaceae
28	*Pistacia atlantica*	Anacardiaceae
29	*Pistacia khinjuk*	Anacardiaceae
30	*Platanus orientalis*	Platanaceae
31	*Populus euphratica*	Salicaceae
32	*Prunus persica*	Rosaceae
33	*Prosopis farcta*	Fabaceae
34	*Pteropyrum aucheri*	Polygonaceae
35	*Punica granatum*	Punicaceae
36	*Ricinus communis*	Euphorbiaceae
37	*Salix acmophylla*	Salicaceae
38	*Suaeda chlearifolia*	Amaranthaceae
39	*Vitex agnus-castus*	Lamiaceae
40	*Vitis vinifera*	Vitaceae
41	*Tamarix arceuthoides*	Tamaricaceae

In order to prepare the charcoal collection, dry wood fragments were covered with sand in porcelain crucibles and burned in a furnace (Nabertherm, B180) for 5-8 minutes in 400℃. Anatomical features of charcoal samples were studied and imaged by reflected light microscope equipped with digital camera. The images of the selected species are presented in supplementary material S.2.3 (Fig. 2.2- 2.21). The diagnostic microscopic features of each sample were recorded according to IAWA (1989) (Supplement S.2.2) and applied to develop the anatomical identification key.

3.5. Results

In the case of most taxa, the identification key can separate perfectly the different taxonomical groups based on the microscopic features. However, in some Rosaceae and more specifically Amygdaloideae subfamily members (*Prunus*; syn *Amygdalus*) the wood anatomy features are not sufficient to identify the taxa up to species level. Similarly about woody perennial *Astragalus spp*. (A.fasciculifolius, A. glaucacanthus), *Alhagi spp*. (*A.maurorum, A.commelorum*), *Ficus spp.*, (*F.carica*, *F.johanis*) and *Salix spp*. (*S.acmophylla*, *Salix cf purpurea*) the wood anatomy features are not sufficiently different to identify the taxa up to species level. It is noteworthy that complementary studies with more samples are necessary to cover all the possible modifications in the anatomy of species under different ecological condition. Based on the anatomical study of wood and charcoal of 41 woody species in Persepolis basin, the following multi-entry identification key has been generated as below:

1a	Vessels absent (Coniferous type with tracheids)	*Cupressus* sp.
1b	Vessels present	2
2a	Vessels in discrete vascular bundles accompanied by fiber caps.	Monocotyledonae
2b	Vessels not in discrete vascular bundles	3
3a	Included phloem present	4
3b	Included phloem absent	7
4a	Growth ring distinct	5
4b	Growth ring indistinct	*Salsola vermiculata (syn: Caroxylon vermiculatum)*
5a	Spiral thickening in vessel elements present	*Halocnemum strobilaceum*
5b	Spiral thickening in vessel elements absent	6
6a	Vascular/ vasicentric tracheids present, storied structure present (axial parenchyma , vessel, fiber elements)	*Noaea mucronata*
6b	Vascular/ vasicentric tracheids absent, storied structure absent	*Suaeda chlearifolia*
7a	Ring-porous wood	8
7b	Diffuse and semi ring-porous wood	13
8a	Spiral thickening in vessel elements present	9
8b	Spiral thickening vessel elements absent	12
9a	Radial Intercellular canals present	10
9b	Radial Intercellular canals absent	11
10a	Ground tissue fibers with distinct bordered pit	*Pistacia khinjuk*

10b	Ground tissue fibers with simple to minutely bordered pit (libriform fibers)	*Pistacia atlantica*
11a	Vessels arranged in Radial files mostly in late wood, Tylosis present, rays 3-7 seriate	*Morus alba*
11b	Late wood vessels arranged in tangential bands sometimes festoon-like, Tylosis absence, rays uniseriate and multiseriate	*Celtis caucasica*
11c	Ring porous to semi-ring porous, with radial or cluster arrangement in late wood vessels, small vessels (>100 um), apotracheal parenchyma, rays uniseriate and 3-5 seriate, mostly heterogeneous, widely spaced spiral thickening	*Prunus (Amygdalus, Cerasus)* spp.
12a	Early wood vessels normally in groups of 2-3 radial files, latewood vessels mostly solitary, parateracheal parenchyma present in tangential band or rarely vasicentric, rays uni-biseriate short , not longer than 20-25 cells, mostly homogenous	*Fraxinus rotundifolia*
12b	Early wood vessels large (100-200 um), Scalariform perforation plate, scalariform ray-vessel pits, large rays, 5 to more than 15 seriate, homogenous and heterogonous rays	*Vitis vinifera*
12c	Early vessels solitary but in compact few rows or in tangential short groups, rays 4-10 seriate, heterogeneous, storied parenchyma present	*Tamarix arceuthoides*
12d	Ring-porous to semi-ring-porous, early vessels often in short (2 cells) radial files also solitary, Paratreacheal parenchyma, long rays with 2-3 seriate, heterogeneous with procumbent and square cells	*Vitex agnus-castus*
12e	Growth ring distinct, ring porous to semi-ring porous, early vessels not bigger than 50 um, often in clusters or tangential bands, simple perforation plate, vessel pits with distinct borders, alternate to scalariform, Apotracheal parenchyma presents in tangential bands with more than 3 cells in width that define the growth ring borders, rays more than 10 seriate, heterogeneous, sometimes very long (~800um)	woody *Astragalus* spp. (*A.fasciculifolius, A. glaucacanthus, …*)
13a	Diffuse and semi ring-porous wood	14
13b	Clearly diffuse porous	16
14a	Rays exclusively uniseriate	15
14b	Rays 4-10 seriate	*Platanus orientalis*
15a	Rays homogenous	*Populus euphratica*
15b	Rays heterogeneous	*Salix acmophyla*
15c	Semi ring-porous to ring porous, early wood vessels in one or two tangential bands, late wood vessels in dendric, radial, flame-like groups, rays homogenous, simple perforation plate, thick-walled ground tissue mostly comprise of fibers and libriform tracheids, mostly storied.	*Daphne mucronata*
16a	Reticulate or other types of perforation plate	17
16b	Simple perforation plate	18
17a	Foraminate perforation plate	*Ephedra foliata*
17b	Simple and scalariform perforation plate together	*Platanus orientalis*
18a	Spiral thickening present	19
18b	Spiral thickening absent	20
19a	Vessels in short radial files 2-4(5), vessel pits alternate and vessel diameter is about 5 µm. Rays 1-3 seriate, heterogeneous	*Acer monspessulanum*

19b	Growth rings distinct by bands of thick walled fibers, vessels small <50um solitary, apotracheal parenchyma present, rays 1-3 seriate heterogeneous with square and upright marginal cells.	*Myrtus communis*
20a	Rays homogenous	21
20b	Rays heterogeneous	22
21a	Growth ring boundaries indistinct, Vessels small (40-50 um) arranged solitary and short radial files (2-3), libriform fibers present, Rays (1)-2-(3) seriate, homogenous with long procumbent cells.	*Citrus sp.*
21b	Growth ring boundaries distinct, Vessels 50-100 um in diameter, arranged short radial files (2-4), Tylosis frequently present, rays 1-3 seriate, homogenous with procumbent cells, sometimes one marginal row of square cells	*Juglans regia*
21c	Growth ring boundaries rather indistinct, Vessels small (50-100 um) arranged solitary and short radial files 2-(3), Paratracheal parenchyma present, rays 1-2 seriate, homogenous with procumbent cells, long up to 50 cells, intervessel pits distinctly bordered	*Prosopis farcta*
22a	Rays in two types uniseriate and 2-3 seriate, large early wood vessels (50-100 µm) solitary with tangential arrangement	*Alhagi* spp.
22b	Rays exclusively uniseriate	23
22c	Rays mainly more than 10 cells in width	*Ebenus stellata*
22d	Rays cells 1-3 seriate	24
23a	Solitary vessels arranged in short radial files (2-3), ground tissue fibers apotracheal, ray-vessel pits large, rays heterogeneous with upright and square cells.	*Salix* spp.
23b	Growth rings often indistinct, 4 or more vessels arranged in radial files, vessel pits alternate very small >> 5 µm , rays uni- and sometimes biseriate, heterogeneous with square and upright cells, fibers septate	*Punica granatum*
24a	Growth ring indistict, vessels solitary sometimes arranged tangentially, vessel pits very small, Vessel diameter 50-100 µm, simple perforation, libriform fibers present, rays heterogeneous with square and procumbent cells	*Pteropyrum aucheri*
24b	Vessels solitary in radial files of 2-4, simple perforation, vessel diameter 50-<D≤100 µm, vessel pits very small >5µm, ray-vessel pits distinctly bordered, rays heterogeneous mixed of square, procumbent and upright cells	*Nerium indicum*
24c	Growth ring indistinct, vessels arrange in radial files of 4 or more, Vessel diameter 100-200 µm, vessel pits alternate bordered, vascular tracheids present, libriform fiber present, rays heterogeneous with square and upright cells	*Ricinus communis*
24d	occasionally with tylosis, axial parenchyma in tangential bands with more than 3 cells in width, libriform fibers present, ray-vessel pits horizontally enlarged to scalariform, rays heterogeneous with square and upright marginal cells,	*Ficus spp.*
24e	Vessels small >50 um in diameter, arranged in long radial files of 2-5-(7) cells, vessel pits small >>5 um, clearly bordered, vascular tracheids present, rays 1-3 seriate heterogeneous with mixed square, upright and procumbent cells,	*Capparis spinosa*

4. Vegetation history of Maharlou Lake basin (SW Iran) with special reference to Achaemenid period (550-330 BC)

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4.1. Abstract

This study presents the results of a high-resolution palynological investigation on a Holocene sediment core from seasonal saline Lake Maharlou in Zagros Mountains, SW Iran. We place the emphasis on studying the role of man in modifying the natural vegetation and landscapes of the area as well as the dominant agricultural practices during Imperial Persia (550 BC-651 AD; 1299-2500 cal BP) and particularly the Achaemenid Empire (2500-2280 cal BP; 550-330 BC). The scattered pistachio- almond (*Pistacia spp.-Amygdalus (syn: Prunus) spp.*) scrub combined with Brant's oak (*Quercus brantii*) at higher altitudes have been considered as the general vegetation type of the Lake basin. The presented pollen data provide the first pollen evidence of *Punica granatum*, an under-represented species implying the large-scale pomegranate plantations, a fact that is supported by the historical documents of Persepolis Fortification Archive (PFa33) about intensive arboricultural activities in the Achaemenid heartland. The pollen record depicts a significant increase in agriculture and suggest urban development during Persian empires and Early Islamic dynasties. The present diagram shows that arboricultural activities which had already started during Elamites, intensified under Achaemenids and reached its highest level during Sasanian to Early Islamic period. This finding is compatible with historical records showing that Fars province and Shiraz, in particular, witnessed economic and agriculture flourishing during the late Antiquity and early Islamic Iranian dynasties. The presence of the so-called 'Persian gardens' is possibly supported by the continuous curve of Cypress tree (Cupressaceae) that increases simultaneously with other cultivated trees especially plane tree (*Platanus*), both trees being cultivated for their symbolic values and shadow. Furthermore, a general contemporaneous increase in pollen values of semi-cultivated native trees such as *Salix*, *Fraxinus*, and *Ulmus*, in addition to significant presence of

agro-pastoral related pollen types suggests the extensive human activities and development of urban areas. The variations in Poaceae/*Artemisia* ratio (P/A) and *Artemisia* + Chenopodiaceae (syn. Amaranthaceae) /Poaceae ratio (A + C)/P pollen ratios seem compatible with the hydrological scheme of the basin and shows periods of aridity followed by higher moisture availability with presence of mesic grasslands. We suggest that anthropogenic activities played the leading role in vegetation change in Maharlou Lake basin enhanced by climatic changes during the last ~3700 years.

4.2. Introduction

As the progenitor sanctuary for early civilizations, Iran and specifically the Zagros Mountains, have been at the center of attention for many palaeoenvironmental studies to investigate human-environment interactions in the past (e.g. Djamali et al. 2008, 2009a; Jones et al. 2015; Kimiaei et al. 2006 ; Miller 1985, 2003; Rieh et al. 2015; Shumilovskikh et al. 2017; Sumner 1972, 1988).

Through the particular geological and geographical features, the foothills and valleys of the Zagros Mountains have provided appropriate resources of water and arable lands for human settlement in the past (Petrie et al, 2018). Abundance of karstic springs support human settlements with numerous freshwater resources, while the variety of microclimates with different precipitation and altitudal ranges, provide them with diversified raw materials and natural supplies (flora and fauna). The central and southern Zagros are considered among the very first locations for plant and animal domestication attempts and therefore the best setting for studying the man and environment interactions (Kimiaei et al. 2006; Miller 2014, 2013, 2011; Riehl et al. 2013; Sumner et al. 1972; Zeder and Hesse, 2000). For instance, the rich archaeobotanical remains from aceramic Neolithic site of Chogha Golan in west of Zagros Mountain, extended back the starting point of agriculture practices into the Epipaleolithic period (Riehl et al. 2013) and livestock management history in the highlands of western Zagros date back to 10000 years ago (Verdugo et al 2019, Zeder and Hesse 2000).

Beside the Khuzestan plains (Khuzestan province - SW Iran), the more extensive basin of Kur River at the eastern ends of Zagros (Fars province), has experienced the presence of human settlements for millennia (Sumner, 1972). Kur River basin (KRB) has witnessed deep changes of human lifestyle from local and scattered populations with a nomadic way of living to settled farmers and the developed urban communities started by Elamite dynasties. Elamites were amongst the civilizations that increased the social complexity in the Near East by dominating different landscapes and centralizing the populations in the plains during the fourth millennium BC. The city of Anshan, the eastern capital of Elam, constructed at highlands of Kur River Basin (Tal-e Malyan) and has several phases of occupations and abandonment from forth to late second millennia (Miller, 2014). The Kur River Basin (*Pārsa*) roughly covers the area where Persians started their domination during the Achaemenid kings (550-330 BC) to establish their “universal empire” (Wiesehofer, 1996). They choose this area to found their new capitals of Pasargadae and Persepolis. After the conquest of Muslims (651 A.D), the development processes in the area have continued by the governors of the Early and Middle Islamic periods, suchlike Buyids (935-1062 A.D.) who expanded irrigation works and agriculture in the lower Kur River Basin (Sumner & Withcomb, 1999).

Although anthropogenic impacts on the landscape and even permanent changes in plant species composition and distribution pattern in KRB existed since the Elamites period (Miller, 2014), the Persepolis Basin and surrounding basins witnessed unprecedented urbanism and human influences since the Achaemenid period. The changes in livelihood, demographic increase as well as development of urban centers and innovation of associated infrastructures such as hydraulic works, resulted in agricultural development (Gondet 2011; Wiesehöfer 1996). This prosperity combined with the appreciation for gardens in Persian culture has led to the expansion of agriculture and extensive tree cultivation during Achaemenid and SasanianSasanianSasanian periods (Djamali et al. 2011, 2015; Shumilovskikh et al., 2017). According to available pollen data from Lake Maharlou and Lake Parishan, the main cultivated trees in southern Zagros, were walnut (*Juglans*), plane tree (*Platanus*), and grapevine (*Vitis*). They have a long history of domestication and cultivation in the area dating back to the 1st to 2nd Millennia BC, but their continuous presence as cultivated woody species began since Late Elamite period (~1200 BC) (Djamali et al. 2011; Miller, 1985; Potts 2018; Shumilovskikh et al. 2017). Olive (*Olea*) appeared as an important arboricultural element during Achaemenids and Seleucid periods around the Lake Parishan (Djamali et al. 2015; Jones et al. 2015). In addition, pollen and archaeological wood fragments of cypress tree family (Cupressaceae) reveal different purposes for arboricultural practices (providing timber and shade) from Achaemenid to post-Sasanian periods (Djamali et al. 2017). Maharlou Lake has excellent pollen preservation conditions which combined with its large basin, provides a great opportunity to study agro-pastoral and arboriculture activities in the regional-scale through a palynological investigation. However, in spite of several palynology surveys (Djamali et al. 2009a, 2011a; Jones et al. 2015), detailed data about the vegetation history in southern Zagros Mountains during Imperial Persia, remains obscure. Therefore, by using a sediment core from Maharlou lake with an accurate chronology (Brisset et al., 2018) we aim to reveal: 1) the changes in the vegetation of Maharlou Lake basin in antiquity and during the succession of Persian Empires, with particular focus on Achaemenids. 2) Whether the lake Maharlou basin was a center for arboriculture in Fars and how was its chronology? 3) The diversity of cultivated tree species in the basin evident in indicator pollen types.

4.2.1.Study site

Physical setting

Lake Maharlou (1,455 masl) is a large shallow hypersaline playa lake with the depth of 1.5 m, located in Fars Province, 20 Km to Shiraz and about 60 Km southeast of Persepolis at the southeastern tail of Zagros Mountains. This lake (Figure 4-1), which assumed to exist since early Pleistocene, has the area of 24910 Km^2 and is fed by precipitation, surface runoff and karstic springs around the lakeshore. From geological point of view, Maharlou catchment is dominated by sedimentary rocks mainly composed of limestone, sandstone, shale and dolomite (Djamali et al. 2009a; Safe et al. 2016).

According to Koppen climatic classification system (Critchfield 1974; Rahimzadeh et al. 2009), the study area has mid latitude steppe: semiarid; cool or cold climate type and in Worldwide Bioclimatic classification by Rivas-Martinez (et al., 2008) it has a Mediterranean xeric-continental type bioclimate (Djamali et al., 2011). Based on recorded meteorological data from world meteorological organization (WMO) in Shiraz synoptic station (the nearest station in 20 Km east of the lake), mean annual precipitation and temperature are recorded of 384.3 mm and 17.2 ^{oC} respectively. The maximum of precipitation falling in January (79.8 mm) and dry season lasting about 6 months from May to Octoberin this site. .

Vegetation

According to Zohary (1973), Maharlou Lake situated in Iran-Turanian phytogeographical region with the steppic vegetation of pistachio and almond (*Pistacia-Amygdalus (syn: Prunus)*) xeromorphic-forest. Itcorresponds to Irano–Anatolian region (IT2) in Léonard's concept (Djamali et al. 2012; Doostmohammadi et al. 2018). Today, in the Lake Maharlou basin, this vegetation type consists of scattered high-grown wild pistachio (*Pistacia Khinjuk* , *P.atlantica*) and almond trees and shrubs (mainly *Amygdalus (syn: Prunus) scoparia*) associated with shrubs such as *Cerasus microcarpa*, *Rhamnus persica*, and *Ficus carica*. They associate gradually with Brant's oak (*Quercus brantii*) at higher altitudes (ca. 1000-2000 m) (Carle & Frey 1977; Djamali et al. 2009a; Frey 1982; Frey & Probst 1974; Zohary 1973). However, due to long-term history of anthropogenic impacts, *Pistacia-Amygdalus (syn: Prunus)* vegetation has been delimited and substituted with cushion shaped mountainous tragacanthic species in higher altitudes and *Artemisia* steppes in lowlands (Djamali et al 2011). In addition, saline flat plains of lake surrounding are mostly dominated by succulent chenopods such as *Salicornia* spp. and *Halopeplis pygmaea* also halophytic grass and sedge species as *Aeluropus littoralis*, and *Juncus rigidus* (Akhani 2004). Moreover, small and large wetland systems with a dense aquatic vegetations dominated by reed community (*Phragmites australis*, *Typha* spp.) cover the north and northwestern parts and also at the emergence of karstic springs.

4.3. Materials and Methods

After the first palynology study on a 150 cm core of the Lake Maharlou at 2009 (Djamali et al. 2009a), in autumn 2012, 4 short continuous drives, each 1 meter in length, were sampled with a Russian Corer in the north-western part of the Lake Maharlou (29°27'40,5"N; 52°43'45,6"E). After excluding disturbed overlapped parts between each drives in the Institut Méditerranéen de Biodiversité et d'Ecologie (IMBE-Marseille); the resulted master core (MAH-B) with 355 cm length was studied for pollen analysis. To avoid contamination by fossil organic carbon and the 'hard water effect', seven samples of botanical macro remains were radiocarbon dated at Poznan Radiocarbon Laboratory (Brisset et. al. 2018). The age-depth model was developed by Brisset et al (2018) using a smooth spline (type 4 argument) in the Clam R package (Blaauw 2010), based on probability distributions of the ^{14}C ages, and the IntCal13 calibration curve (Reimer et al. 2013). The age-depth model (Figure 4-2) indicates that MAH-B spans the last 3800 ± 370 years, with an average 2σ uncertainty of 250 years.

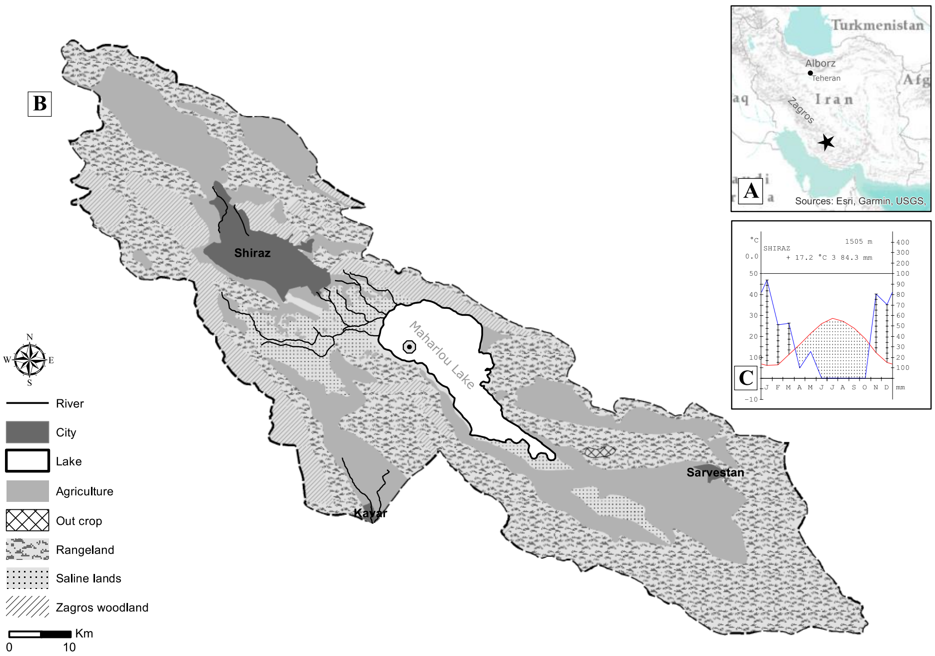
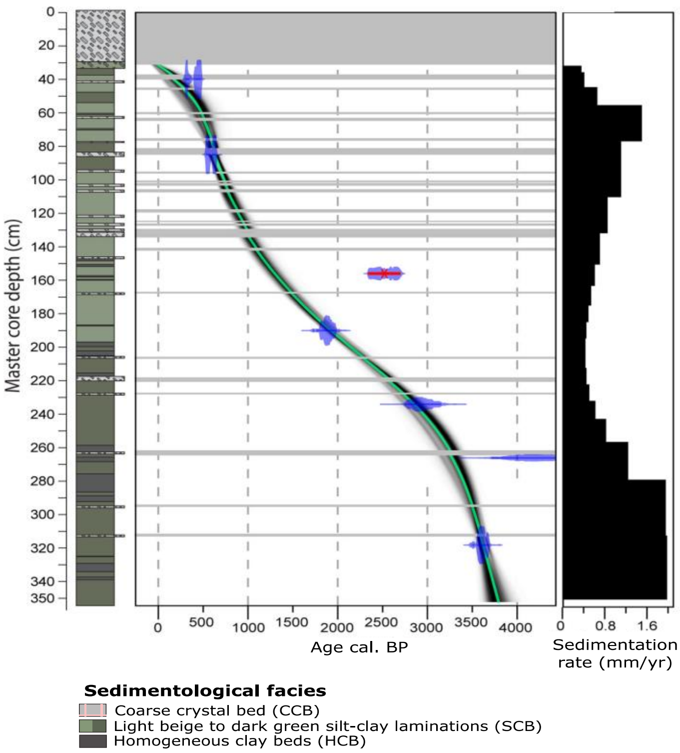


Figure 4-1: A: Location of the study site in southwest of Iran (black star). B: Map of the lake Maharlou watershed including the general land use including the Zagros woodland vegetation type area. The location of MAH-B core showed with black and white circle. C: Bioclimatic diagram of Shiraz (from Worldwide Bioclimatic Classification System, 1996-2019: http://www.globalbioclimatics.org)

The total length of the core was subsampled in 10cm intervals. In addition, for the higher resolution palynological analysis on Achaemenid period, subsamples were taken every 2cm from the corresponding section and adjacent parts which covers 300 years before and more than 500 years (185–230 cm, correspond to1700-2800 cal BP) after the Achaemenids period. Samples were treated according

Moore et al. (1991) and Lycopodium markers (Batch no. 1031, 3862) used to assess the pollen concentrations (Stockmarr 1971). The general palynological process of Moore et al. (1991) has modified by multiple warm HCl treatment to eliminate the residual fluorosilicate complexes of HF reaction until no or very few crystals remain. Pollen samples were studied by ZEISS phase contrast light microscopes at IMBE and the Institute of Ecology and Conservation Biology, University of Regensburg. Pollen identification carried out using the reference collections of IMBE and pollen atlases of Europe and Northern Africa (Beug 2004; Moore & Webb 1978; Reille 1992, 1995, 1998). The minimum number of 300 pollen grains were counted per slide as well as the informative NPPs. Micro charcoal concentrations were determined according to Wang et al. (1999) as an indicator for regional fire events. TILIA (ver. 2.0.41) and C2 (ver. 1.7.7) software were used to calculate the pollen percentage and to create the pollen diagram.

Figure 4-2 : Age-depth model for core MAH-B and lithostratigraphy and sedimentation rate. The AMS 14C ages are represented by their probability density functions. The age rejected before modeling is crossed in red. The calculated model is given in the grey scale (higher probability is darker), and the best model is shown as a green line. Grey horizontal band illustrates a layer interpreted as non-continuous sedimentation (coarse crystal beds), which were ‘‘removed’’ before age modelling (Adapted from Brisset et. al. 2018). Details of the model discussed in Brisset et al 2018.



4.4. Results and interpretation:

The total number of identified pollen taxa in the 57 spectra were 121 pollen types comprising 41 arboreal and 80 non-arboreal taxa besides many other informative NPPs (Non-Pollen Palynomorphs). A list of identified pollen types is available in supplementary material (S4.1). Figure 4-3 depicts the pollen percentages and zonation based on variation of the relative frequencies of different pollen types. The result of the high-resolution palynological analysis corresponds to 300 years before and more than 500 years after Achaemenid period is presented in figure 4.3b. Referred to the age-depth model (Figure 4-2), the best-calculated ages of the top and the base of the diagram are around 13 and 3739 cal. BP, respectively, which correspond to the modern time and the Middle Elamites period. Based on variations in pollen spectra and cluster analysis (CONISS, included in Tilia, Grimm, 1987), the diagram was divided into three zones (A, B and C) and four subzones (B1, B2, C1 and C2) (Table 4-1).

Table 4-1: Summarized description and interpretation in local pollen assemblage zones

LPAZ			**Historical period**	**Zone description**	**Interpretation**
A	Depth limits (cm) Age limits (cal yr BP) Duration (yr) Pollen Sample no. subzone	352-264 3731-3348 383 12 -	Early to Middle-Elamites	40% decrease in *Artemisia*, high values of Ephedraceae (up to 5%), generally high value of P/A ratio and very low values of C+A/P ratios, 20% decrease in *Quercus* at the end of the zone- grow in agriculture indicator types and coprophilous fungi spores- Presence of *Rumex* and *Plantago lanceolata*	Dominance of open vegetation (*Pistacia-Amygdalus (syn: Prunus)* scrubs); steady status of natural forest vegetation, Cereal cultivation and pastoral activities , higher moisture availability
B	Depth limits (cm) Age limits (cal yr BP) Duration (yr) Pollen Sample no. subzone	264- 177 3348-1612 1736 26 B1, B2	Late Elamites to early Sasanian	Increase in *Artemisia* (>50%) concurrent with grassland and arboreal pollen decline (< 20%), high diversity of cultivated trees, First record of Pomegranate cultivation- appearance of *Riella* spores, Constant presence of *Tribulus* and *Prosopis farcta*	arboriculture development and higher diversity of cultivated species , water management practices and expansion of water-logged area around the lake, decline in grassland and intensive pastoral activities
C	Depth limits (cm) Age limits (cal yr BP) Duration (yr) Pollen Sample no. subzone	177-30 1612-13 1599 19 C1, C2	early Sasanian to present time	Unique increase in arboreal pollen, striking high values of *Platanus* with highest values of other cultivated trees. Lowest values of *Pistacia* (< 5%) and *Acer* (<1%) , Grow in desert shrubs values	Intense arboriculture, urbanization and evolution of new urban centers, destruction in pistachio-almond vegetation in lower altitudes in the lake basin, possible increase in aridity or water exploitation.

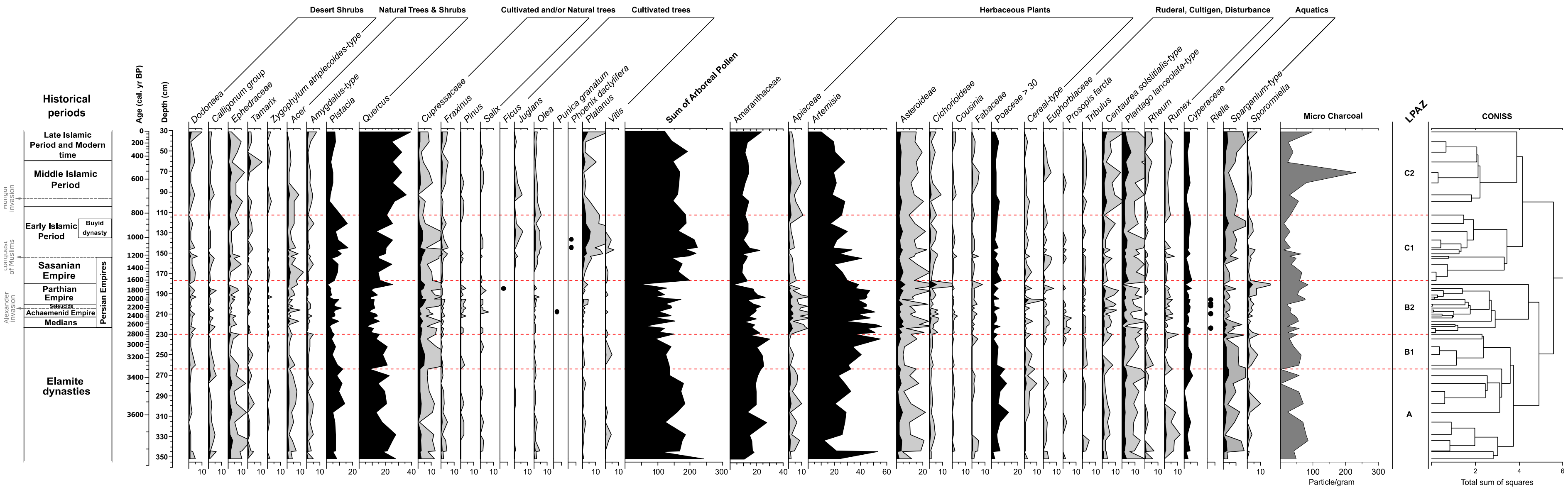


Figure 4-3a: Pollen percentage diagram for Lake Maharlou for a selection of taxa; exaggeration curves (×5) are coloured in light grey; rare species with percentages < 0.5% are marked with ●. Dash-lines separeate the LPAZs (Local Pollen Assemblage Zones).

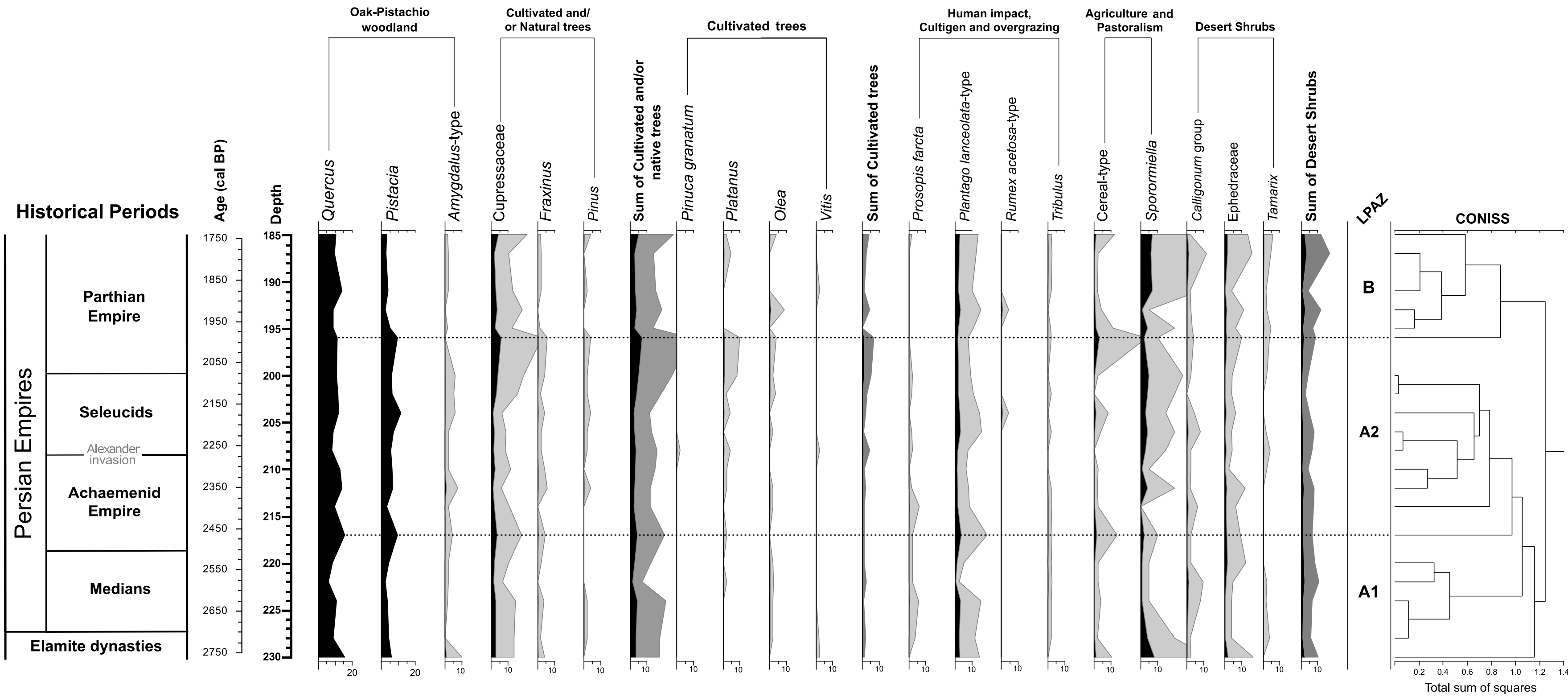


Figure 4-3b: Pollen percentage diagram of a selection of taxa, obtained from the high resolution palynological analysis corresponds to 300 years before and more than 500 years after Achaemenid period.; exaggeration value (light grey) × 5; Dash-lines show the LPAZ (local pollen assemblage zones).

LPAZ A dated between 3348 and 3731 cal. BP and includes the correspondence time of mid to late Elamite period dynasties. A glance at the pollen percentages shows apart from the sharp decrease in Artemisia pollen percentages (from around 55% to 15%) at the beginning of the zone, there are no significant changes in many pollen types.

In addition, Poaceae/*Artemisia* (P/A) (Figure 4-4) index shows the highest values in this zone that indicates moisture availability and presence of mesic steppes in high elevations (Dehghani et al, 2017). In contrary, the aridity index of (*Artemisia* + Chenopodiaceae)/Poaceae (A + C)/P) shows the lowest values in LPAZ A. During the LPAZ A, the natural forest vegetation indicators depict a steady status with some changes in *Quercus* and *Pistacia* percentages. *Quercus* values slightly varies between 30-10% and shows general decrease towards the end of zone A, while *Pistacia* pollen increases up to 15% in the same zone. The decline of *Quercus* pollen percentage associates with remarkable growth in the value of agriculture and "cereal cultivation" indicator (Cereal-type). This indicators show higher frequencies at the end of the zone A as well as presence of domesticated animals and pastoral activities, inferred from the relatively high value of *Sporormiella* spores (coprophilous fungi). Moreover, presence of mesic grasslands (high P/A ratio) can indicate the availability of fodder for grazing animals. These changes are compatible with the phases of population increase and developing the first urban centres (late Kaftari phase: ca. 2200-1600 BC; 4150-3550 BP) in Kur River Basin (Miller, 2014). In the same period, *Rumex* and *Plantago lanceolata* pollen-types demonstrate a continuous presence with relatively high values. These pollen types indicate the presence of cultigen and ruderal plant communities (Behre 1981; Djamali et al. 2009b; Jones et al. 2015; Li et al. 2010; Stevenson, 1981).

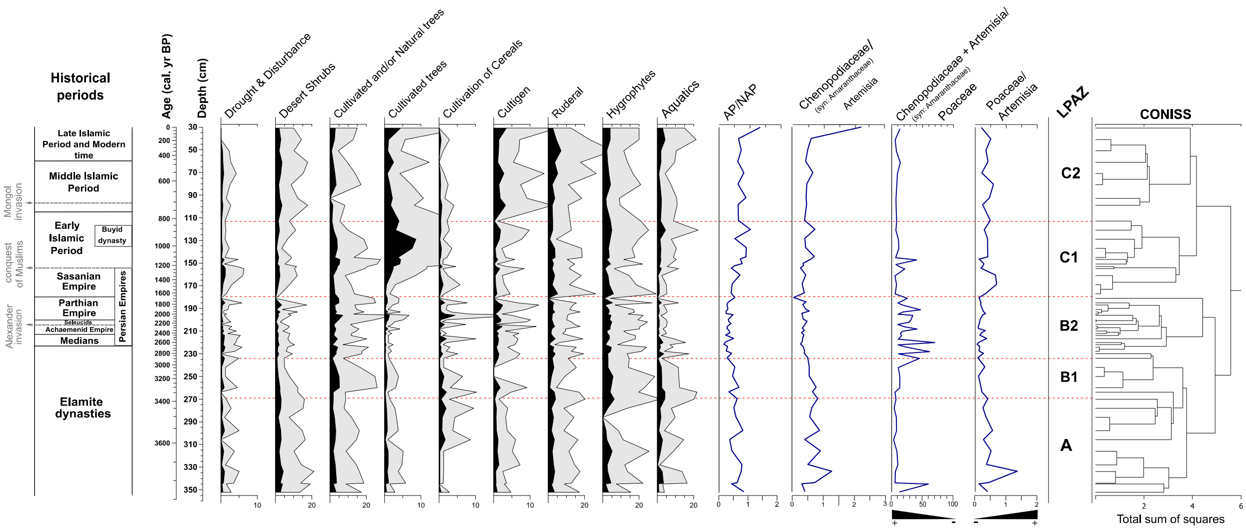


Figure 4-4: Pollen percentage diagram for ecological groups and main pollen ratios; exaggeration curves (×5) are coloured in light grey; Underlined arrows indicate moisture correlation with respective index.

LPAZ B (ca. 3348-1612 cal. BP) divided to two subzones of B1 (ca. 3348-2812 cal. BP) and B2 (ca. 2812-1612 cal. BP). Historically, this LPAZ coincides with the late Elamite period in subzone B1 and covers the most time of Imperial Persia (include Medians, Achaemenids, Seleucids and the early Sasanid period) in B2. Zone B is characterized by a significant rise in the *Artemisia* (up to 55%), and simultaneously decline of arboreal pollen the lowermost value (< 20%) at the end of subzone B2. This general reduction in arboreal pollen is clearly due to remarkable decline in natural trees and shrubs pollen including *Quercus*, *Pistacia* and *Amygdalus (syn: Prunus)* (drop to 10, 0.8, and 0 percentages respectively). Among cultivated and/or natural trees, *Fraxinus* decreases in the same fashion with natural trees, while *Pinus* and *Salix* show slight increase during the Imperial Persia period. In zone B, cultivated trees show higher diversity than zone A, very under represented pollen types of pomegranate and fig appear in this zone while *Platanus* and *Olea* show relatively higher values than former period. Besides, the desert shrubs value particularly Ephedraceae declines during this period. This pattern continues over the Sasanids and even until the Buyid dynasties periods. Presence of under-represented pollen types of *Vitis*, *Punica granatum* and *Ficus* (Djamali et al. 2009a, Turner and Brown, 2002) in this zone supports the idea of arboriculture development mostly as orchards and vineyards near to the lake. Agriculture development under the semi-arid climate of southern Iran relies on the water resources availability. Geoarchaeological studies show water control practices during Achaemenid period in Kur river basin (Schacht et al, 2012). In this regards, spontaneous presence of *Riella* spores (liverwort) in subzone B2 reflects the presence and expansion of waterlogged area around Maharlou Lake. Moreover, according to the recent hydrological scheme (Brisset et. al. 2018), the lake had a period of wet condition with increase in surface runoff during ca. 3800-2000 cal. BP which can explain the high values of *Artemisia* pollen represented in this zone as well as the macro-charcoal accumulation peak (Saeidi Ghavi Andam et al, unpublished data). They can be associated with transportation by the fluvial material from distant areas with dominant *Artemisia* vegetation and macro-charcoal supply. Stevenson (1981) has described similar phenomenon about fossil pollen record of Turan biosphere reserve in Iran.

Grass pollen-type (Poaceae>30µm) shows a gradual decrease during the zone B, concurred with lower available moisture in grasslands, inferred from P/A and (A + C)/P) indices. The decline of grasslands, coincides with the constant presence of *Tribulus*, *Prosopis farcta*, Euphorbiaceae and *Cousinia*. These taxa have poor representation in modern and fossil pollen records and represent the disturbed and overgrazed landscape in semi-arid areas (Dehghani et al, 2017; Djamali et al, 2012a; Stevenson, 1981). These spiny species are unpalatable for livestock and demonstrate the low quality and least favoured fodder for grazing. Altogether, with the highest percentages of *Sporormiella* spores (up to 4%) in zone B, suggest the intensified pastoral activities and overgrazing. Presence of disturbed areas and ruderal species also reflected in Amaranthaceae values. Amaranthaceae pollen demonstrates relatively high values (30%) in this zone, while other potential halophytic plants like *Tamarix*, does not represent a comparable growth. According to floristic studies and vegetation maps of Maharlou Lake (Carle & Frey 1977; Frey & Probst 1974), Amaranthaceae species dominate the xerophytic-halophytic habitats around the lake. Considering relatively low values of Amaranthaceae (Chenopodiaceae)/*Artemisia* (C/A) ratio (Fig. 4-4), this variation in Amaranthaceae percentages is most probably due to increase in ruderal taxa of this group rather than expanding the halophytic formation. Similarly, Stevenson (1981) described about the modern and fossil pollen records of Turan Biosphere (NE Iran).

LPAZ C (ca. 1612 cal BP to present) comprises of subzone C1 (ca. 1612-815 cal BP) and C2 (ca. 815 cal BP to present). Historically, the subzone C1 coincides with the early period of Sasanian Empire to almost the end of Early Islamic period (ca. 1150-800 BP) according to Sumner and Whitcomb (1999). Subzone C2 covers the Middle Islamic period (ca. 800- 450 BP) and the Late Islamic period (Safavid to modern time).

The most characteristic feature in the lower part of LPAZ C (subzone C1) is the remarkable increase in arboreal pollen. This growth is mainly due to striking high values of *Platanus* pollen (more than 5%) that is unique throughout the record. It shows nearly the same values towards the end of the diagram. In addition to *Platanus*, other cultivated trees like *Juglans*, *Olea*, and *Vitis* demonstrate their highest values that concluded as intensified arboriculture. Cereal cultivation were also present in the area, evident from continuous curve of Cereal-type pollen along with cultigen and ruderal taxa like *Centaurea solstitialis*, *plantago lanceolata*, Euphorbiaceae and *Rumex*. However, increase in arboriculture coincides with slight decrease in cereal cultivation and pastoralism indicators in zone C. These changes are compatible with archaeological and historical evidence (Sumner & Withcomb, 1999) and may indicate urbanization and evolution of new urban centres. Regional forest vegetation does not change significantly during subzone C1, while in C2 *Pistacia* and *Acer* pollen drop to their lowermost values (less than 5% and 1% respectively). Although *Quercus* curve grows slightly. Similarly explained by Miller (2014) during Kaftari phase (ca. 2200-1600 BCE), such difference between *Quercus* and *Pistacia* values in Kur River basin, would represent more destruction in pistachio-almond vegetation in lower altitudes due to increasing number and area of settlements.

Growing values of desert shrubs (e.g., Ephedraceae and Tamarix) in LPAZ C with a slight increase in Amaranthaceae and C/A values at the end of the zone are evidence for possibly extending the halophytic vegetation belt around the lake due to suggests drier climate with enhanced evaporation by Brisset et al (2018).

4.5. Discussion

- *Changes in the vegetation of Maharlou Lake basin during Classical and Late Antiquity*

Paleoenvironmental studies in southeastern Zagros Mountains mostly have provided vegetation data about long periods (e.g., Holocene epoch); while a special focus on details of events during Imperial Persia (550 BC-651 AD), and particularly Achaemenid period have scarcely been discussed. Achaemenids have started to build the first superpower of the antiquity with a comprehensive and well-organized management system centred in Persepolis region (50 km north of Maharlou Lake). The rise of such a geopolitical power needs the intensive exploitation of natural resources and has potentially left intensive impacts on the ecosystems. Despite the historical importance of Achaemenid Empire, their specific influence on the environment, has been addressed often together with other dominating empires (e.g., Median and Sasanian) and has not been revealed in detail, due to relatively low chronological resolution of palaeoenvironmental records. Therefore, a part of the recent survey refers to the vegetation changes in Maharlou Lake basin by applying the high-resolution palynology exclusively to Achaemenid period. This period has a relatively short time compared to the whole MAH-B record. Nevertheless, the amplitude of variations in pollen percentages is significant and provide the possibility to detail the vegetation change (Fig. 4.3b).

In Figure 3b, sum of cultivated trees demonstrate increasing values; as an evidence for the beginning of orchards and gardens development (e.g. “Persian garden”). Obviously, it has started with *Olea*, *Punica* and *Platanus* cultivation by Achaemenids, and *Juglans* by Sasanids then continued to the summit of arboriculture with *Phoenix dactylifera* and *Platanus* during Buyid dynasty (Figure 4-3a).

In post-Achaemenid period, the detailed pollen graph represent signs of a local aridification phase corresponding to lower lake levels (after 2000 cal BP; Brisset et al, 2018). This evidence combined with variation in desert shrubs (*Zygophyllum*, *Ephedra*, and *Tamarix*) values and other anthropogenic pollen indicators like ruderals; draw a sketch of an overexploited vegetation also, suffering from drying climate. Furthermore, the shrinkage of the water-logged areas around Lake Maharlou is revealed by absence of *Riella* spores during the late Imperial Persia. In saline lake systems with vast flat littoral zones, *Riella* is suggested to be the indicator of higher lake levels (Djamali et al. 2008a,b) and its disappearance, demonstrates the decrease in inflow or precipitation caused by climatic changes or human activities in Lake Maharlou.

Concurrently, the summary curve of natural trees (Fig 4.3b) represent the lowermost values, during Imperial Persia and in particular the Achaemenid period. It might reflects the deforestation to provide timber and/or as a consequence of intensified grazing pressure, on the vegetation combined with the undesirable local climatic condition.

In more detail, *Pistacia* and *Amygdalus (syn: Prunus)*, the natural vegetation type around the lake, show significant reduction, while *Quercus* increases (Fig 4.3b). Compare to oak, pistachio grows in lower altitudes with warmer climate (Taheri Abkenar et al. 2016) and is more accessible to people for obtaining firewood or fodder. Pourreza et al (2008) showed that overgrazing, absence of desirable seedbed and lack of seeds (due to low seed production rate or collecting seeds and young shoots for human and animal consumption) have the main impacts on *Pistacia* vegetation in Zagros Mountain. Moreover, El-Moslemany (1986) noted the sensitivity of pistachio seedlings to high temperatures and the negative impact on regeneration potential. In conclusion, the drier climate after 2000 cal BP, combined with anthropogenic pressure during the Imperial Persia, and later in the middle Islamic period presumably affected the natural pistachio vegetation in the basin. The time period afrer 2000 cal yr BP corresponds to Roman Warm Period in Europe and the North Atlantic with higher than normal temperatures (Wang et al. 2013). Worth to mention that such negative impacts seem to have been mitigated in several distinctive phases (Fig. 4.3a). Presumably, by conserving the *Pistacia* trees (Shumilovskikh et al. 2017) started by Medians and Achaemenids then followed by Sasanids (Fig. 4.3b).

- *On the cultivated trees in Maharlou lake basin; new arboricultural elements*

In contrast to the history of cereal and earliest crops domestication (10000-12000 BP; Allard, 1999), humans started to bring trees, fruit trees in particular, under control and domestication during the last 5000 years (Chandra et al 2010).

The long history of tree cultivation and introducing new arboreal elements to the south west of Iran is documented in a few publications (Djamali et al. 2009a, 2011a, 2015, 2017; Jones et al. 2015; Miller 1985; Shumilovskikh et al. 2017). The present study is an update to the last studies focused on Maharlou Lake basin and presents new arboriculture elements. In this study, pollen types of *Platanus*, *Punica granatum*, *Vitis*, *Ficus*, *Olea*, *Juglans* and *Phoenix dactylifera* are used to define arboriculture activities. In addition, a particular attention is paid to the pollen curves of *Fraxinus*, *Salix*, *Pinus*, Cupressusaceae and *Ulmus*, which show interesting changes when compared to the above trees (Figure 4-3a). Considering the fact that these species have naturally grown stands in the basin, Dehghani et al. (2017) suggested that human beside their natural growths might have cultivated them.

Among cultivated trees, *Platanus* shows the most significant changes throughout the present record and is present in almost all periods (Fig. 4.3a). Based on charcoal records (2200 -1800 BCE) Miller (1985) suggested the early cultivation of *Platanus* by Elamites. Constant presence of plane tree pollen in south west of Iran is also well described in previous investigations (Djamali et al. 2009a, 2011, 2016; Shumilovskikh et al. 2017). The present diagram shows the *Platanus* pollen values started to increase during the Achaemenids and reached to the highest percentages during Sasanian Empire to the Early Islamic period and Buyids dynasty in particular. The early Muslim governors suchlike Adud al-Dawla (Ajod al-Dawla, of the Buyid dynasty) invested much effort to develop the irrigation systems for an intensive agriculture in the lower Kur River Basin and constructing the Band-e Amir dam (Sumner & Withcomb, 1999). The productive agriculture moderation has ended by the Mongol invasion of SW Asia (1220 AD; 730 BP). During the Ilkhan period (677-700 BP), the province of Fars suffered from severe destructions and abandoned irrigation channels, which destroyed arable fields and orchards. Cultivated trees like *Olea*, *Juglans* and especially *Platanus* represent similar trends of depletion in this period (Fig. 4.3a). This pattern has also been shown in NE Iran and Gorgan plain in Kongor pollen record (Shumilovskikh et al. 2017) and by archaeological charcoal remains (Qal'eh Kharabeh; Poole & Gale 2013).

Similar to *Platanus*, *Juglans* represents increasing trend from Sasanian period. According to Potts (2018) and following the Radde's dictum, both *Platanus* and *Juglans* trees are introduced to Iranian flora; with very few exceptions of native trees in Hyrcanian region. Based on available palynological and archaeological data and written sources, plane trees were cultivated in Iran since early second millennium while walnut plantation has begun in the middle of the third millennium. Previous pollen records from Fars province (Maharlou and Parishan) had also showed very old records for plane tree and walnut cultivation. Parishan Lake (in ~ 100 km West of Maharlou Lake) is a large and shallow freshwater to brackish wetland, located in a narrow intermountain basin, surrounded by agricultural lands. Jones et al. (2015) showed the peak of tree cultivation in Parishan Lake basin, concurrently with rising of Achaemenids. The peak is primarily due to *Olea*, *Platanus* increase, and subsequently, *Juglans* pollen started to appear by the end of Seleucids and the beginning of the Parthians Empire.

According to the present study and contrary with Djamali et al. (2009a, 2011, 2016), the prominent peak of cultivated trees in Lake Maharlou coincides with the late Sasanians and the Early Islamic period. These two closely located lakes of Maharlou and Parishan share similar geology while they have relatively different elevation ranges and bioclimatic conditions. Prosperous arboriculture in the Maharlou Lake basin would had been promoted by advanced water management that largely developed during Achaemenids and Sasanians.

In Figure 4-3a, Cupressaceae represents a continuous curve with the distinct phases of increase in pollen percentages from late Elamite period to Achaemenids, up to the early Islamic period. Regarding the almost absence of juniper trees from the region today, we hypothesized that the pollen of this family is mostly produced by cypress tree. Finding of cypress pollen may confirm the hypothesis that this was an important constituent of ancient 'Persian gardens' which were favoured by Achaemenids and Sasanians (Djamali et al.2017). Cypress wood has also been used as timber in the construction of monuments by Sasanians and early Muslim dynasties. However, the starting date for planting cypress tree may go back to the late Elamite period.

In the same period, the very under-represented pollen type of *Vitis* (Turner & Brown, 2004) presents and shows its relatively high percentages. It can support the idea of different crop type cultivation in Maharlou Lake basin compared to the adjacent basin of Lake Parishan. Based on the natural habitat condition and ecological preferences of Cupressaceae and *Vitis*, the open valleys in Maharlou Lake basin could have provided more suitable areas for grapevine and cypress tree cultivation. Besides, the hydrological condition of the basin during 3800–2000 cal year BP, provided more water in slopes and higher river flow (Brisset et al., 2018), could have supported tree cultivation without advanced irrigation requirement. Therefore, the frequent appearance of *Vitis* from Elamite to mid-Parthian period would be due to fluvial input of pollen from vineyards in river valleys (Turner and Brown; 2004). Then, during the Sasanian period, tree cultivation would have been extended to other basins by the help of the advanced irrigation techniques. Fig 3a shows the last peak of *Vitis* concurrent with the climax of other cultivated trees (*Platanus*, *Olea*, *Juglans*) in the Early Islamic period. Nevertheless, this hypothesis needs to be also verified by historical and archaeological evidence.

In accordance with other cultivated trees, *Olea* pollen depicts a constant presence throughout the MAH-B record in present study. It has relatively low values during the Elamites and Median periods and starts to increase after Achaemenids.

The frequent changes in *Olea* pollen values and peak percentages during the Persian Empires, specifically late SasanianSasanian period, have been interpreted as olive cultivation in many pollen records of Iran (Djamali et al 2009a b, 2011, 2015; Jones et al 2015). The historical evidence of seedling inventories obtained from Persepolis Fortification Archive (PFa 33) also supports olive cultivation in southern Iran and Achaemenid heartland (Henkelman, 2013).

Contrary to Shumilovskikh et al (2017) who concluded that, *Olea* reached to the maximum presence in Maharlou basin during the Achaemenid period, our data (Fig.3a) depicts the most distinctive values of *Olea* occurring after Sasanian and declining clearly by Mongol invasion. This observation is contemporary of evidence for olive cultivation in northern Zagros (Djamali et al. 2009a; van Zeist 1967; van Zeist & Bottema 1977) and in contrary with evidence from Lake Parishan (Djamali et al. 2011, 2015). In this context, we suggest that the olive cultivation was first practiced by Achaemenids in the lower plains around Lake Parishan and later extended to Maharlou basin during Sasanians and Buyids.

- *The diversity of cultivated tree species in Maharlou Lake basin. New arboricultural element for Southern Zagros mountains*

Pomgranate (*Punica granatum*) has a vast natural distribution from Balkans to Northwestern India but is mostly restricted to the Iran-Turanian and Mediterranean floristic regions (Levin, 2006, Zohry, 1973). Despite of the difficulties in detecting the indigenous species, Reschinger (1966) reported pomegranate natural populations from northern Iran (Gorgan, Mazandaran & Gilan provinces) as well as northern part of Azerbaijan, Kurdestan, Qazvin and Baluchestan.

The discovery of the pollen of pomegranate in Maharlou record is the first report for southern Iran, which seems too far from the proposed natural stands of the tree in Iran. Pomegranate is extremely under-represented in modern pollen rain due to insect- and self-pollination suggesting that few counted pollen grains may indicate large-scale plantations (Morton 1987). The documented pomegranate pollen grains were extracted from sediments dating back to the Achaemenid period (subzone B2).Outside our study area, Bottema (1986) identified rare pomegranate pollen in the Urmia Lake (NW Iran). However, due to age uncertainty of that record and the location of the lake in NW Iran, no solid conclusion can be made about the exact age and possible cultivation of the tree.

The domestication practices of pomegranate supposed to have started in Transcaucasia-Caspian area and Northern Turkey around the late Neolithic period (Chandra et al. 2010; Levin 2006a). Pomegranate use can be traced back to the fourth millennium BCE in the ancient Near East and Mediterranean region. Besides having dietary and medicinal properties, the pomegranate fruits have been widely used as a symbol of fertility to decorate clothes and jewelleries of the royal Assyrian women (SAAo: letters SAA 7, 72 and 81). It also appears in several Assyrian rituals and royal gardens as shown by their rock relief representations (SAA 20) (Figure 4-5). In addition, pomegranate name appears in PFa 33 from Persepolis Fortification Archive (PFA). The Elamite administrative texts that recorded tree seedling inventories produced to be planted in five “paradises” in Achaemenids heartland (Henkelman, 2013). In this tablet, that is mostly written in Aramaic or Elamite languages, the name pomegranate (ka-ru-kur) appears with the name of other fruit trees like pear, quince, mulberry, olive, date and apple. In conclusion, the special pollen dispersal of this species along with the historical records, strongly support the hypothesis of fruit trees and particularly pomegranate cultivation in the Maharlou Lake basin. These facts also, strengthen the hypothesis according to which the flowers offered by Achaemenid kings in Persepolis reliefs are more probably representing pomegranate rather than lotus flowers (Keshavarzi 2014; Tilia 1972; Ward 2003).

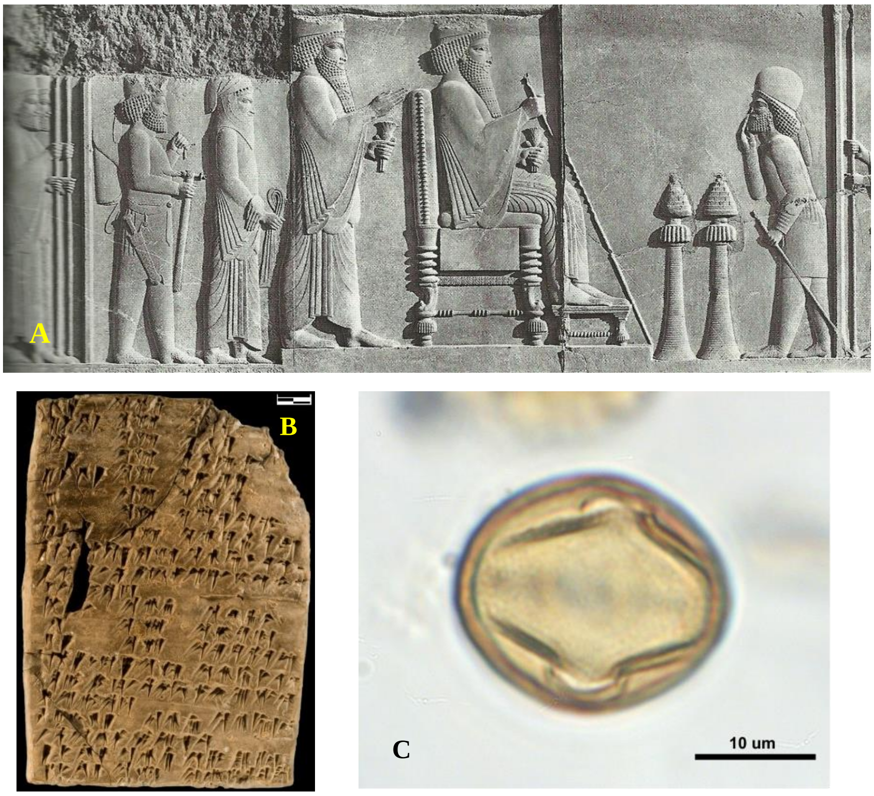


Figure 4-5: A: Central rock relief of the northern stairs of the Apadana shows Darius and Xerxes I (in the middle) holding a flower in the left hand (© www.livius.org). B. PFa 33 from Persepolis Fortification Archive (Henkelman, forthcoming). C. *Punica granatum* pollen grain

4.6. Conclusion

The present palynology survey of MAH-B core provided an updated reconstruction for the vegetation in the Lake Maharlou basin. The obtained results demonstrated the role of anthropogenic activities in modifying the landscape of the basin during the last ~ 4000 years, which enhanced by climatic changes.

The pollen record showed that the plane tree, grapevine, fig tree, walnut, and date palm were the main cultivated trees in the basin. Moreover, by the present study, *Punica granatum* was introduced as a new arboricultural element in ancient Persia, which its cultivation dating back at least to Achaemenid period. This newly documented tree is the first report for southern Iran. The distance between Maharlou Lake and the proposed natural stands of the tree in Iran, as well as its special pollen dispersal, along with the historical records, strongly support the hypothesis of fruit trees and particularly pomegranate cultivation in the Maharlou Lake basin. In the present study, we attempted to demonstrate the specific influence of Achaemenids on the environment. They intensified the arboricultural practices in the Maharlou basin by developing orchards and gardens (e.g. "Persian garden") of fruit trees (e.g. olive and pomegranate) and non-fruit bearing trees (plane tree). In this regard, we support the hypothesis about the important role of cypress in ancient 'Persian gardens' as well as the cultivation of other natural but non-fruit bearing trees in these gardens. Our results demonstrated that in contrast to the near basin of the Lake Parishan, arboriculture in Lake Maharlou basin reached to its prominent level during the late Sasanians and the Early Islamic period. The flourishment in agriculture would had been promoted by advanced water management practices and irrigation systems that largely developed during Achaemenids and Sasanians. Subsequently, the early Muslim governors invested much effort to develop these systems and intensifying agriculture in the lower part of the Kur River Basin. Finally, by the Mongol invasion and During the Ilkhan period, the agricultural prosperity of Fars province collapsed. The present study demonstrates that in spite of the similarity in some ecological features (e.g., geology) between adjacent basins of Maharlou and Parishan Lakes and most likely because of their relatively different elevation ranges and bioclimatic conditions, the period of arboriculture flourishing was not comparable in these basins. In this regard, we suggested that the tree cultivation in Lake Maharlou basin had been promoted during Achaemenids and Sasanians with the help of the advanced irrigation techniques although this hypothesis needs to be also verified by historical and archaeological evidence.

5. An update on the history of arboriculture in Ancient Iran

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5.1. Palynological evidence of tree cultivation in Iran: strengths and pitfalls

Palynology has greatly contributed to our understanding of the history of arboriculture in Ancient Iran and in this regard, is a complement to archaeological, epigraphic and literary sources (Potts, 2018). It is based on extraction, identification, and quantification of pollen grains deposited in wetlands (lakes, ponds, and peat bogs), guano deposits, coprolites, archaeological layers and any other material able to capture and preserve the pollen grains. The technique is one of the strongest tools in Quaternary palaeoenvironmental studies to reconstruct the terrestrial ecosystem changes, climatic changes and anthropogenic activities (Behr 1981; Moore et al. 1991). Late Holocene natural sediments mostly contain pollen of cultivated plants including the cultivated tree species. The Holocene pollen records are thus a source of information to understand the history of arboriculture (Bottema and Woldring, 1990). However, trees, and plants in general have different capacities of pollen production and dispersal and their pollen grains do not show the same resistance to destructive processes such as oxidation and bacterial activities leading to biased representation of plants.

Table 5-1: A list of the tree species for which the cultivation history can be reconstructed by pollen analysis.

			Pollen representation outside the local plantations		
Scientific name	**Common name**	**Familly**	**Under-representated**	**Over-represented**	**N/A**
Cupressus sempervirens L.	Mediterranean cypress	Cupressaceae		●	
Elaeagnus angustifolia L.	Persian olive	Elaeagnaceae			●
Fraxinus spp. L.	Ash	Oleaceae	●		
Hippophae rhamnoides L.	Sea buckthorn	Elaeagnaceae	●		
Juglans regia L.	Persian walnut	Juglandaceae	●		
Morus alba L.	While mulberry	Moraceae			●
Olea europaea L.	Olive	Oleaceae	●		
Phoenix dactylifera L.	Date palm	Arecaceae	●		
Pinus spp. L.	Pine	Pinaceae		●	
Platanus orientalis L.	Oriental plane	Platanaceae	●		
Populus spp. L.	Poplar	Salicaceae	●		
Punica granatum L.	Pomegranate	Lythraceae	●		
Ricinus communis L.	Castor oil plant	Euphorbiaceae		●	
Salix spp. L.	Willow	Salicaceae		●	
Vitis vinifera L.	Grape vine	Vitaceae	●		

Table 5-1summarizes the state of pollen representation of common cultivated trees reported from Iran (Bottema, 1986; Djamali et al., 2009a-b, 2011, 2015; Naqinezhad et al., 2017; Ramezani et al., 2008; Talebi et al., 2016) but also the first author's unpublished data (see below).

As seen in Table 1, among the 15 cultivated trees recorded in the pollen diagrams of Iran, 9 species are under-represented and only 4 species are over-represented and no information is available for 2 species. This fact indicates that fossil pollen spectra provide a biased image of tree cultivation in the past. While species like pine and cypress produce and disperse huge amounts of pollen, some other species like poplar, olive and grapevine whether produce low amount of pollen or their pollen are weakly dispersed. To this should be added the taphonomic history of sediments which causes the differential corrosion and preservation of pollen leading to relative increase of some resistant taxa in expense of more fragile taxa (Havinga, 1967).

A contribution by W. Henkelman to the present chapter (Henkelman, forthcoming) lists the name of several cultivated trees found in the Persepolis Fortification archive of which at least three species i.e. quince (*Cydonia oblonga* Mill.), apple (*Malus domestica* Borkh.), and pear (*Pyrus communis* L.). These trees along with several others belong to the family of Rosaceae, which is famous for its very low pollen representation in modern and fossil pollen assemblages (Djamali et al., 2009c). In the Irano-Turanian scrub communities, the wild Rosaceae trees are also abundant and produce very similar pollen types to the cultivated trees. A remarkable example is the wild dominant almond species of Zagros *Prunus scoparia* (Spach) C.K.Schneid. (syn. *Amygdalus scoparia*) which has the same pollen morphological type as the domesticated almond *Prunus dulcis* (Mill.) D.A.Webb (syn. *Amygdalus sativa* Mill.). Although the latter could have been domesticated and cultivated in most of the Iranian plateau in the past, its pollen cannot be distinguished from the wild almond showing that palynology is an inappropriate tool to trace the history of almond cultivation in the past. The same fact also applies to other cultivated Rosaceae trees which have their wild relatives with similar pollen morphologies. *Pistacia* species are also very difficult to distinguish based on their pollen morphology and it is very difficult to distinguish the cultivated pistachio (*Pistacia vera* L.) from the wild species (*P. atlantica* Desf. and *P. khinjuk* Stocks) using the palynologist' light microscope. The insect-pollinated fig trees (*Ficus carica*) constitute another example of commonly cultivated fruit trees in SW Asia and Mediterranean region, which can only exceptionally be found in fossil pollen records. Indeed, there is more probability that tiny seeds of fig tree are found in the sediments than their pollen (Shumilovskikh et al., 2017; Tinner et al., 2009).

Lots of information on the past arboricultural elements are thus lost due to phenological characteristics and taphonomic histories of different cultivated plant species. This fact highlights the need to use multidisciplinary approaches by comparing palynological, archaeobotanical, historical, and epigraphic sources together to achieve an unbiased image of arboricultural practices in the past.

5.2. Special note on diversity and chronology of cultivated trees in the pollen records of Iran

Here, we base our presentation of cultivated trees on the available pollen diagrams studied with high resolution. A review of pollen diagrams published from different regions of Iran reveals 15 cultivated trees (Table 5-1) of which the cultivated nature of some of them is only inferred by their frequency covariations with definitely cultivated trees. This group includes pine (*Pinus* spp.), cypress (*Cupressus sempervirens*), willow (*Salix* sp.), and ash (*Fraxinus* sp.) (Djamali et al., 2015).

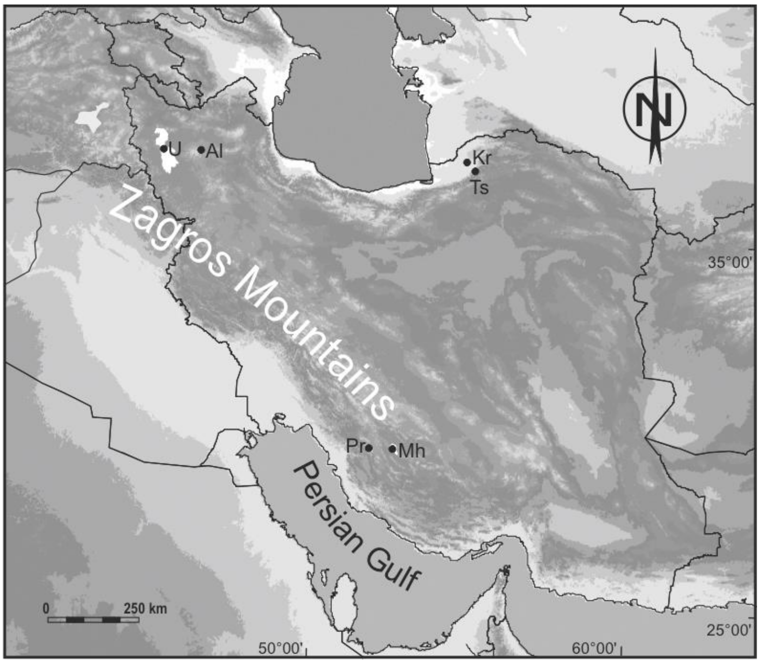

Figure 5-1: Wetlands for which high resolution pollen records are available and treated in the text. Pr: Parishan, Mh: Maharlou, U: Urmia, Al: Almalou, Kr: Kongor, Ts: Tuskachal.

Cupressus sempervirens. Mediterranean cypress has the same pollen type as juniper (*Juniperus* spp.). Its cultivated origin can be inferred when its increase correlates with other cultivated trees. In the Fars region where the presence of natural stands of cypress is very uncertain, any increase of Cupressaceae pollen may be a good indication for its cultivation. Cypress woods have recently been documented from the Sasanian and early post-Sasanian monuments (Djamali et al., 2017).

Eleagnus angustifolia. Persian olive (also Russian olive) has a very characteristic pollen that can be identified even when it is damaged. Individual pollen grains of Persian olive are found in different periods in the Lake Urmia sediments with more occurrences during the Penultimate Glacial and the Last Interglacial (Djamali et al., 2008a; see European Pollen Database to visualize data). The pollen of the tree has been found in the Sasanian age sediments of Pasargadae (unpublished data). Today this tree is found in most of the Iranian plateau and has a sacred status with common occurrences in cemeteries. Its occurrences in very old sediments in NW Iran attest that it is native to Iran and could have been replanted in Iran and adjacent regions.

***Fraxinus* spp.** Ash tree is a riparian tree needing a relatively continuous supply of water. Its frequencies covary with some cultivated trees in Lake Maharlou (SW Iran) suggesting that the development of irrigation systems for cities and gardens have also favoured its plantation by man. Two species of ash are native to Iran including *Fraxinus excelsior* and *F. rotundifolia*, the latter being common in Zagros (Murray, 1968).

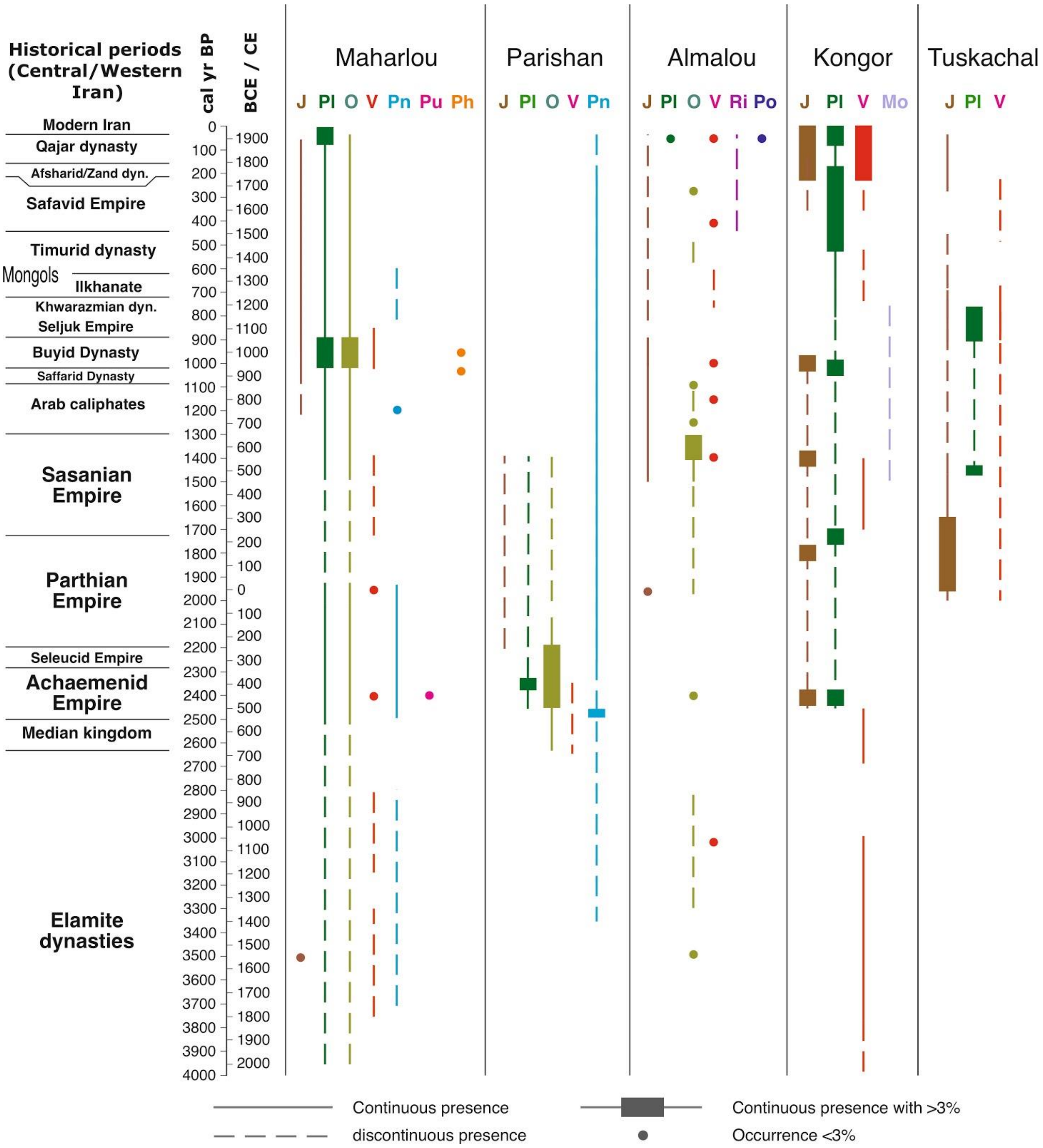

Figure 5-2: Pollen curves of dominant cultivated trees in a selection of pollen diagrams from Iran. See Fig. 1 to see the location of the pollen sites. The abbreviations represent the tree taxa: J: *Juglans*, Mo: *Morus*, O: *Olea*, Pl: *Platanus*, Pn:*Pinus*, Po: *Populus*, Pu: *Punica*, Ph: *Phoenix*, Ri: *Ricinus*, V: *Vitis*.

Hippophaë rhamnoides. Sea buckthorn has today a limited distribution in northwestern Iran from the high elevation valleys in Azerbaijan highlands to Alborz Mountains (Murray, 1968 ; Sabeti, 1976) but has been a widespread tree in the Irano-Anatolian plateau during the last glacial period (Djamali et al., 2008b). The pollen of sea buckthorn are found in the Partho-Sasanian sediments of Lake Ovan, a small landslide lake in the Alborz Mountain near the archaeological site of Alamut Castle (Djamali, unpublished data). Nowadays, buckthorn is cultivated as hedge to delimit the gardens in the vicinity of the lake and the same usage can be envisaged in the past.

Juglans regia. Walnut is one of the most widespread cultivated trees in Iran besides the oriental plane (Djamali et al., 2011; Potts, 2018). Its cultivation dates back to the second Millennium BCE during the Elamite kingdom in Fars region. The apogee of walnut cultivation dates to the Partho-Sasanian and early post-Sasanian periods in NW, SW and NE Iran (Djamali et al., 2011; Shumilovskikh et al., 2017). Although the mention of the name of walnut in very old Mesopotamian sources remains uncertain, the archaeobotanical evidence show the use of walnut wood in writing boards by Assyrians in Nimrud (Potts, 2018).

Morus alba. Pollen of White mulberry have recently been found in the sediments of Lake Kongor in NE Iran from 450 to 750 CE (Figure 5-2) (Shumilovskikh et al., 2017). The mulberry cultivation around this lake located in the SE Caspian plain is also confirmed by the finding of the seeds in the sediment. The possible introduction of the tree from China for silk production during Sasanian Empire is suggested by Shumilovskikh et al. (2017). However, the mulberry has also been listed in Persepolis Fortification archive (Henkelman, forthcoming) but with no precision of the species of Mulberry (*M. alba* or *M. nigra*). Another record of white mulberry comes from the modern sediments of Lake Urmia.

Olea europaea. Olive pollen is found in almost every pollen record from SW, NW and NE Iran (Shumilovskikh et al., 2017). Although its climax occurs during the Sasanian Empire in the pollen sites located in northern Persia, the evidence of its massive cultivation has been reported from the Fars region under the Achaemenid Empire (Djamali et al., 2015). Olive pollen can travel very long distances and forms a background pollen in many pollen diagrams of the Middle East. The pollen may also come from the natural wild olive trees growing in southern Iran (Djamali et al., 2009a) and its cultivation origin is ascertained only when its percentages exceed the background values (>1%). The olive pollen percentages in Lake Parishan pollen record exceed by far the background values and attest to its cultivated origin (Djamali et al., 2015). The olive is mentioned several times in Persepolis Fortification archive (Henkelman, forthcoming).

Phoenix dactylifera. Date palm is native to North Africa and SW Asia (Moore, 1980) and seems to have been domesticated in several different locations (Gros-Baltazard et al., 2018) of which the Persian Gulf is the most important domestication centre (Gros-Baltazard et al., 2018; Tengberg, 2012). In Iran, the northern limit of the zone of date palm cultivation which also marks the biogeographical boundary between Saharo-Sindian and Irano-Turanian regions (Djamali et al., 2011b), passes by southern Fars (Moore, 1980). Pollen of date palm has recently been found in sediments of Lake Maharlou to the west of Shiraz dating to the Buyid dynasty from 10^{th} to 11^{th} century CE. Although the pollen values are very low and less than 1%, they indicate the date palm cultivation not too far from the lake. Date palm seems to be underrepresented in pollen rain. For example in the Lake Yoa oasis in northern Tchad, the percentages of *Phoenix dactylifera*-type pollen mostly vary between 3 to 5 percents even if the tree has been very locally present around the site since 850 years ago (Lézine et al., 2011).

***Pinus* spp**. No species of pine is native to the modern Iran and the nearest relict population of the genus is found in Iraqi Kurdistan (Browicz, 1994). *Pinus* pollen is thus whether a background pollen coming by long-distance wind transport or indicates plantation by man. In Lake Parishan pollen record the frequency changes of pine pollen shows co-variations with other cultivated trees strongly suggesting its cultivated origin (Djamali et al., 2015).

Platanus orientalis. Oriental plane is one of the mostly present arboricultural elements in almost all available pollen diagrams of Iran (Shumilovskikh et al., 2017). It can be tracked back at least to the early 2nd Millennium BCE in SW Iran. The maximum plantation of the tree is observed in different periods. While in the NE Iran it occurs during Partho-Sasanian era, in the SW Iran this is correlated to the Buyid dynasty (10th-11th century CE) but appears much earlier during the Elamite kingdom (Figure 5-2). The plantation and wood use of plane tree is mentioned in several Mesopotamian sources from the Late 3rd and early 2nd Millennium BCE (Potts, 2018). Further, the ubiquitous plantation of the tree in the Persepolis Basin during the Achaemenid era is also mentioned in a text dating to the 3rd century BCE (Potts, 2018; Henkelman, forthcoming). The almost continuous curve of plane pollen in the Maharlou basin suggest that the tree has been extensively planted in the highlands of Elam and its timber or objects made of its wood would have then been imported to Mesopotamia since the Elamite kingdom.

***Populus* spp**. In the Old World, only the lucky palynologists may find fossil pollen of poplar in the sediments. Poplar pollen has a very low sporopollenin content and degrades very fast in sediment/soil profiles making it an extremely under-represented and almost absent pollen in the fossil records (Li et al., 2005). Poplar pollen has been found in very recent sediments of Lake Urmia dating to the middle of the last Millennium (Unpublished data from core U6, Lake Urmia). The poplar wood is nowadays frequently used for construction purposes and multiple other uses. We have recently identified poplar woods used in construction in an archaeological site dating to the time of Mannaean kingdom in Kurdistan Province of Iran (unpublished data) indicating the significant plantation of the tree in NW Iran during the last millennia. As cited by Potts (2018) and Henkelman (forthcoming), the poplar has also been cultivated in large scale besides plane tree in the Persepolis Basin in the 3rd century BCE and if its pollen have not been evidenced in the pollen diagram of Fars, it is most probably due to the extremely low pollen representation of poplar species.

Punica granatum. Pomegranate is the most newly documented tree in southern Iran from the pollen record of Lake Maharlou and is dated back to the Achaemenid period. The tree is extremely under-represented in modern pollen rain due to insect- and self-pollination (Morton 1987). Pomegranate has a vast natural distribution from Balkans to Northwestern India but mostly restricted to the Irano-Turanian and Mediterranean floristic regions (Zohry, 1973; Levin, 2006). Despite difficulties in detecting the indigenous species, the natural pomegranate populations in Iran have been reported mainly from the North, Northwest, and Baluchestan (Reschinger, 1966). However, the first report of *Punica granatum* pollen in southern Iran seems too far from the supposedly natural stands of the tree in N and NW Iran. It is worth mentioning that Bottema (1986) identified rare pomegranate pollen in the Urmia Lake.

However, due to the age uncertainty of that record and the location of the lake in NW Iran, no solid conclusion can be made about the exact age and possible cultivation of the tree in the Urmia Lake basin. Historically, the use of pomegranate can be traced back to the fourth millennium BCE in the SW Asia and Mediterranean region. Pomgranete is mentioned in the Persepolis Fortification archive (Henkelman, forthcoming). Considering the particular pollen dispersal and the natural distribution of the species along with the historical records, we suggest that pomegranate was cultivated in the Maharlou Lake basin. The discovery may strengthen the hypothesis according to which the flowers offered by Achaemenid kings in Persepolis reliefs are pomegranate rather than lotus flowers. (Tilia and Tilia, 1972-78; Keshavarzi 2014; Ward, 2003).

Ricinus communis. Pollen of Castor oil plant are reported in the pollen diagrams of NW Iran particularly Lake Urmia and Lake Almalou since 16th century (Djamali et al., 2009b). The authors explain this as a late introduction of the species under the Safavid Empire. The introduction of *Ricinus communis*, a species endemic to tropical Africa, seems however, an older event in the Indian sub-continent dating to the second Millennium BCE (Blench, 2003). Ricinus-like pollen have been found in some layers of the first Millennium BCE in Lake Maharlou possibly indicating an earlier introduction of the species from Mesopotamia. Indeed, castor oil may have first been planted by Ancient Egyptians (see Djamali et al., 2011a and references therein).

***Salix* spp**. Willow species are riparian trees naturally growing along streams and rivers worldwide. However, the increase in pollen of willow may not only be related to increase in water discharge in natural fluvial systems. It may also indicate the increase of surface water streams related to extended irrigation systems. Willow along with poplar form the most widespread riparian elements growing and planted in the rural areas. A concurrent increase of willow with other arboricultural elements may thus indicate the development of permanent settlements and presence of villages and urban areas.

Vitis vinifera* subsp. *vinifera. Grapevine is an entomophilous tree with extremely low pollen production and dispersal which presence can be attested with even <2% pollen percentages (Turner and Brown, 2004). *Vitis* pollen are found in many pollen diagrams from different regions of Iran including the Caspian region where the wild grapevine is considered as one of the possible ancestors of the domesticated grapevine (Naqinezhad et al., 2017). Cultivated grapevine (*Vitis vinifera* subsp. *vinifera*) is the cultivar of the wild grapevine (*Vitis vinifera* subsp. *sylvestris*) (This et al., 2006). The latter species has a very wide distribution area in Eurasia ranging from western Europe to eastern Asia with the SW Asia being considered as the centre of diversity of the its subspecies (Naqinezhad et al., 2017). Although the oldest evidence of the edible use and wine production from wild grapevine dates back to 8th to 6th Millennium BCE from Caucasus and Anatolia (Terral et al., 2010), the true domestication and cultivation of grapevine seems to date to the Early Bronze Age (Miller et al., 2008). In the Iranian plateau the grapevine cultivation has been attested in Malyan in the Persepolis Basin during the 4th Millennium BCE (seeds) and 3rd Millennium BCE (seeds and wood) (Miller, 2008). Grapevine cultivation during the Achaemenid territory may be deduced from the mention of “grapes” in Persepolis Fortification archive

(Henkelman, forthcoming). Grapevine pollen is found a discontinuous curves since the Elamite dynasties in the Maharlou pollen record and as two occurrences during the Achaemenid period in Parishan record (Figure 5-2).

5.3. Concluding remarks

Although palynology has much contributed to our knowledge on the history of arboriculture in Iran (Potts, 2018), it cannot provide a complete image of tree cultivation because of the biases related to the differential pollen representation of taxa and taphonomic degradation of many pollen grains. These facts cause the over-representation of some cultivated taxa in expense of the under-representation of others. The common fruit trees of Rosaceae family (almond, apple, pear, peach, cherry, quince) form the major absents in the pollen-evidenced arboricultural elements. A comparison to epigraphic and historical sources as well as the archaeobotanical evidence is necessary to obtain a more exhaustive image of tree cultivation history in Iran and other regions of the world. The other discrepancy of palynology in revealing the arboricultural history in Iran is the scarcity of pollen diagrams from Iran and especially the lack of pollen diagrams from many historically important parts of Iran such as the southeastern, eastern, and central Iran. The different bioclimatic and phytogeographical contexts of these areas may reveal a different picture of arboricultural practices when compared with the highlands of Zagros, Alborz and Kopeh Dagh presented in this article.

Understanding the history of tree cultivation is only a fraction of the information provided by pollen analysis besides other anthropogenic activities (cereal cultivation and sylvo-pastoral practices). However, it is a very important piece of information directly informing of the definitive adoption of sedentary lifestyle. Large-scale arboriculture revealed in pollen diagrams is thus a robust evidence for sedentism and even the formation of urban centres. A particular attention should thus be paid to the arboricultural information included in the pollen diagrams by Quaternary palynologists. This attention concerns, among others, a careful checking of pollen slides for rare pollen grains of under-represented species such as pomegranate and more taxonomically precise identification of some pollen taxa belonging to important groups such as the Rosaceae.

6. A study of fire history in southern Zagros Mountains based on macro-charcoal analysis of Lake Maharlou sediments (Fars Province, SW Iran)

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6.1. Abstract

The present study is the first attempt to investigate the history and drivers of fire during the last ~ 4000 years in the interior parts of the Iranian Plateau and the Zagros Mountains. Macro charcoal records from the seasonal saline Lake Maharlou were used to reconstruct fire episodes. Maharlou Lake is one of the major waterbodies in the Persepolis region with a long history of significant changes in ecosystem and vegetation due to human impacts and climatic factors. The results illustrate the similar patterns for fire incidence and frequency, which inferred from charcoal counts and area data without reducing the influence of small fragments. The screened charcoal peaks showed high compatibility with the reconstructed palaeohydrology and pollen-inferred vegetation dynamics of the basin as well as the historical evidence. The history of biomass burning comprises two regional and one local fire episodes. The most recent (~ 700 cal yr BP) and the oldest (~3600 cal yr BP) episodes were associated with secondary charcoal deposition from regional fires. The youngest macro charcoal peak was likely related to the re-deposition of charcoal particles due to dry climate and lake desiccation, while the increased runoff at ~3600 cal yr BP resulted in further charcoal accumulation. By contrast, the inferred fire episodes during 2200-2000 cal yr BP demonstrate local biomass burning events with low magnitude and high frequency. Historical and palynological evidence suggest that pastoral nomadism and changes in lifestyle of the inhabitants were the main driving force for this peak. Unscreened charcoal count-based peaks with statistically insignificant areas between ~3200-1200 cal yr BP illustrate the complex relationship between charcoal area and counts in Maharlou Lake basin. Notably, the concurrent low values of background charcoals have made the identification of robust fire episodes with consensus

significant peaks relatively complicated. We suggest that the influence of extreme hydrological changes on macro charcoal deposition must be considered in seasonal ecosystems such as Maharlou Lake. Frequent desiccation events can result in several charcoal reworking and re-deposition and could increase the rate of breakage during taphonomy.

6.2. Introduction

Southwestern Iran and specifically the Zagros Mountains range, are known as the progenitor sanctuary for early civilizations. Through particular geological and geographical features, the foothills and valleys of the Zagros Mountains have provided appropriate resources of water and arable land for human settlement in the past (Petrie et al, 2018). Abundance of karstic springs support human settlements with numerous freshwater resources, while the variety of microclimates with topographic and geological heterogeneities, provide them with diversified raw materials and natural supplies (flora and fauna).

The central and southern Zagros is considered among the very first locations for plant and animal domestication attempts (Miller 2014, 2013, 2011; Riehl et al., 2013; Sumner et al 1972). For instance, the rich archaeobotanical remains from aceramic Neolithic site of Chogha Golan west of the Zagros Mountains, extend back to the starting point of agricultural practices into the Epipaleolithic period (Riehl et al. 2015) and livestock management history in the highlands of western Zagros date back at least to 10000 years ago (Verdugo et al 2019, Zeder and Hesse 2000).

At the southeastern section of Zagros (Fars province), the Persepolis region has experienced the presence of human settlements for millennia (Sumner, 1972). The related hydrological basins to this regions, like Kur River basin (KRB) and Maharlou basin, have witnessed deep changes of human lifestyle from local and scattered populations with a nomadic life to settled farmers. The social complexity of the region increased by Elamite dynasties (4^{th} millennium BC), who dominated different landscapes to centralize the populations and developing urban communities. Such extensive anthropogenic activities in the area undoubtedly affected the ecosystem dynamics and the landscape. Many palaeoenvironmental studies have been performed on different archives and proxies to investigate human-environment interactions in the past (e.g. Djamali et. al, 2008b, 2009; Jones et al, 2015; Kimiaei et al, 2006; Miller 1996, 1985, 2003; Shumilovskikh et al. 2017; Sumner 1972, 1988).

Generally, several parameters are involved in changing a landscape and the dynamics of an ecosystem, of which some are employed or enhanced by humans to manage the vegetation. Fire is among such factors that can happen naturally besides being used by human communities. It has a complicated connection with the historical anthropogenic activities and climatic changes (Finsinger et al. 2014; Mooney and Tinner 2010). Power et al. (2018) assumed two different contexts when people benefit from burning practices: either low production ecosystems with natural scarcity in resources or highly productive ecosystems that are severely exploited by an increasing population. Additionally, burning was used to open the landscape for agriculture and to build the new settlement areas (Behre, 1981; Mooney & Tinner 2011; Robin et al. 2013). Moreover, Power et al (2018) argued that fire application has a substantial impact on ecosystem structure and biodiversity; also, it can increase the agricultural yields in the over-exploited ecosystems.

Broadleaf forests are considered as less sensitive woodlands to natural ignition compared to conifer-dominated forests (Robin et al. 2013). Therefore, taking into account the general vegetation type of the south western Zagros and KRB, which mostly comprises the scattered pistachio-almond (*Pistacia spp.-Amygdalus spp.*) scrub combined with Brant's oak (*Quercus brantii*) at higher altitudes, natural fires are expected to happen with very low frequencies. Although, considering the history of human presence and activities in this part of Zagros and Maharlou Basin ecosystems, burning practices were very likely employed by the inhabitants for different purposes; to provide new arable fields or to prepare agriculture lands for the next season of cultivation, as practiced today. In recent decades, the number of human-induced wildfires in Iran grows significantly (Jafari et al 2018; Jamshidi Bakhtar et al. 2019; Pourreza et al 2008) and were intensified by global climate change and increase in dry biomass of grasses in the understory (FAO, 2000; Mirzaei, 2016).

In this regards, studying the history of fire events (natural or human-induced) can provide new insight into the history of vegetation in the Maharlou Basin. Among appropriate proxies, the abundance of stratified charcoal fragments in peat and sediments (microscopic and macroscopic charcoals) are the most informative and useful tools to reconstruct fire history in regional and local scale in a watershed (Finsinger et al. 2014; Higuera et al. 2007; Mooney & Tinner 2011; Remy et al. 2018; Robin et al. 2013). According to the deposition distances (Mooney & Tinner 2011; Whitlock & Larsen 2001), macro charcoal particles provide information about local and extra-local or regional fire events. Depending on the available laboratory materials and the charcoal concentration in the sediment records, macro charcoal particles are mostly considered as 125-250 µm and >100 µm fractions (Conedera et al. 2009; Mooney & Tinner 2011; Remy et al. 2018; Whitlock & Larsen 2001). Obtained information from macro charcoal surveys can be completed and combined with the site-specific data from other proxies such as microscopic charcoal particles and pollen data from palynological records.

In spite of several studies that dealt with different aspects of palaeoecological changes in the KRB basin, no investigation about the history of fire events had so far been undertaken in the interior part of the Iranian plateau including the Maharlou Basin. Among appropriate sites in Persepolis region Maharlou Lake has a relatively large basin, which combined with its well-documented palynology, geochemistry, and hydrology during the Late Holocene (Brisset et al. 2018; Djamali et al 2009 a; 2011a), provides an excellent opportunity to study past fire signals. Therefore, by using a sediment core from Maharlou Lake with an accurate chronology (Brisset et al., 2018), we aim to reconstruct the history of fire events of the basin through a macro charcoal investigation.

6.3. Study site

Physical setting

Lake Maharlou (1,455 m asl) is a large shallow hypersaline playa lake with a mean depth of 1.5 m during the wet season, located in Fars Province, 20 Km to Shiraz and about 60 Km southeast of Persepolis at the southeastern tail of Zagros Mountains. This lake (Figure 6-1), which is assumed to exist since early Pleistocene (Djamali et al. 2009a), has an area of 24910 Km^2 and is fed by precipitation, surface runoff and karstic springs around the lakeshore. From a geological point of view, sedimentary rocks dominate the Maharlou catchment. They are mainly composed of limestone, sandstone, shale and dolomite (Djamali et al., 2009a; Safe et al. 2016). According to Koppen climatic classification system (Critchfield, 1974; Rahimzadeh et al. 2009), the study area is a mid latitude steppe with semiarid, cool or cold climate type. In Worldwide Bioclimatic classification by Rivas-Martinez et al. (2008) it has a Mediterranean xeric-continental bioclimate type (Djamali et al. 2011). Based on recorded meteorological data of Shiraz synoptic station (the nearest station in 20 Km east of the lake), mean annual precipitation and temperature are recorded as 305.6 mm and 17.6 °C, respectively during the last 30 years. The maximum of precipitation falls in January (79.8 mm) and dry season lasts about 6 months from May to October.

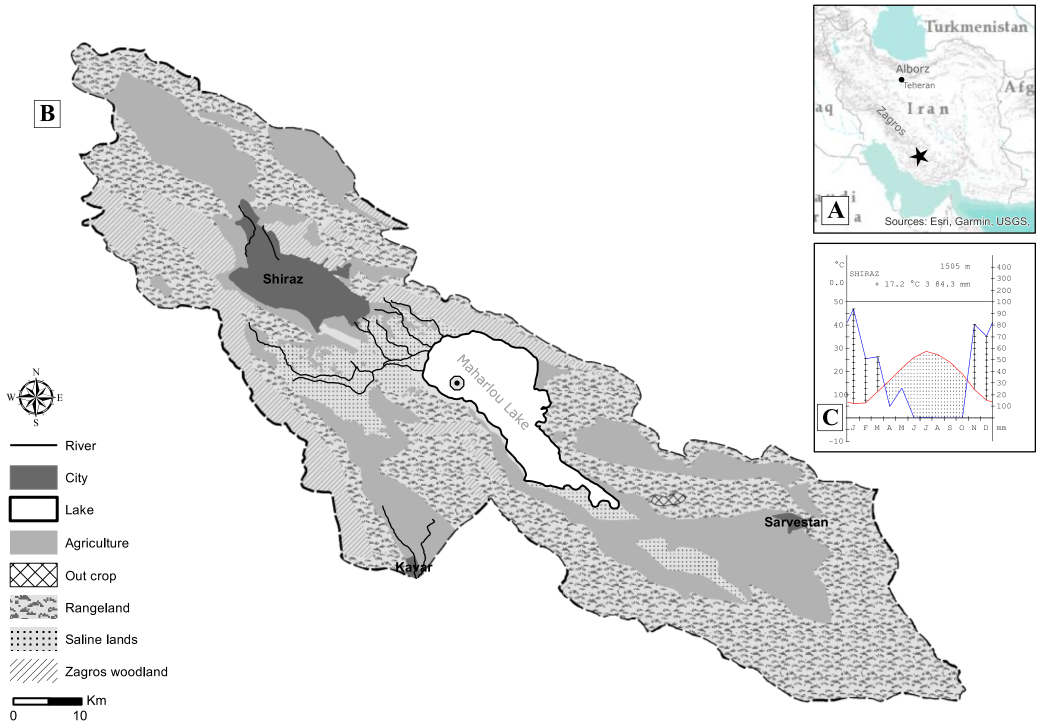

Figure 6-1: A: Location of the study site in southwest of Iran (black star). B: Map of the lake Maharlou watershed including the actual general land use including the Zagros woodland vegetation type area. The location of MAH-B core shown with black and white circle. C: Bioclimate diagram of Shiraz (from Worldwide Bioclimatic Classification System, 1996-2019: http://www.globalbioclimatics.org)

Vegetation

According to Zohary (1973), Maharlou Lake is situated in the Irano-Turanian phytogeographical region with open vegetation of pistachio and almond (*Pistacia-Amygdalus*) xeromorphic-steppe forest, which corresponds to the Irano–Anatolian region (IT2) in Léonard's concept (Djamali et al 2012b; Doostmohammadi et al 2018;). Today, in the Lake Maharlou basin, this vegetation type consists of scattered high-grown wild pistachio (*Pistacia khinjuk, P.atlantica*), almond trees and shrubs (mainly *Prunus scoparia* syn: *Amygdalus scoparia*) associated with shrubs such as *Cerasus microcarpa*, *Rhamnus persica*, and *Ficus carica*. They associate gradually with Brant's oak (*Quercus brantii*) at higher altitudes (ca. 1000-2000 m) (Djamali et al. 2009a; Carle & Frey 1977; Frey & Probst 1974; Frey 1982; Zohary 1973). However, due to a long-term history of anthropogenic impacts, *Pistacia-Amygdalus*/*Prunus* vegetation has been delimited and substituted with cushion shaped mountain tragacanthic species in higher altitudes and *Artemisia* steppes in lowlands (Djamali et al. 2011). In addition, saline flat plains in the lake surroundings are mostly dominated by succulent chenopods such as *Salicornia* spp. and *Halopeplis pygmaea*, as well as halophytic grass and sedge species such as *Aeluropus littoralis* and *Juncus rigidus* (Akhani 2004). Moreover, small and large wetland systems with a dense aquatic vegetation are dominated by a reed community (*Phragmites australis, Typha* spp.) that covers the northern and northwestern parts; also around the emergence of karstic springs.

6.4. Materials and Methods

In autumn 2012, four short continuous drives, each 1 meter in length, were sampled with a Russian Corer in the north-western part of Lake Maharlou (29°27'40,5''N; 52°43'45,6''E). After excluding disturbed overlapped parts between each drive, the resulted master core (MAH-B) with 355 cm length was studied for macro charcoal analysis. To avoid contamination by fossil organic carbon and the hard water effect, seven samples of botanical macro remains were radiocarbon dated at Poznan Radiocarbon Laboratory (Brisset et. al. 2018). The age-depth model (Fig. 2) was developed by Brisset et al. (2018) using a smooth spline method in the Clam R package (Blaauw 2010). The age-depth model indicates that MAH-B spans the last 3800 ± 370 years, with an average 2σ uncertainty of 250 years (Figure 6-2).

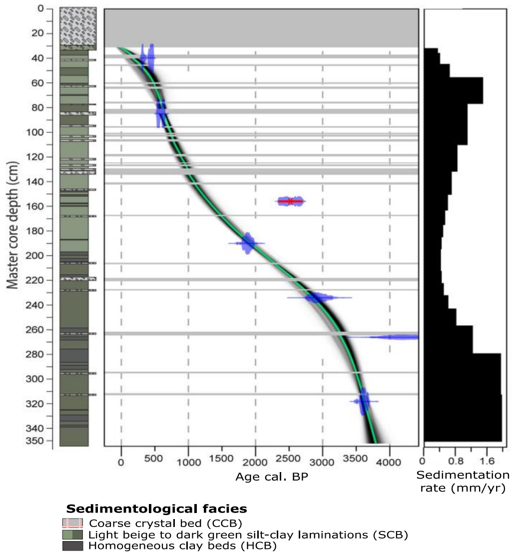

Figure 6-2: Age-depth model for core MAH-B and lithostratigraphy and sedimentation rate. The AMS 14C ages are represented by their probability density functions. The age rejected before modelling is crossed in red. The calculated model is given in the grey scale (higher probability is darker), and the best model is shown as a green line. Grey horizontal band illustrates a layer interpreted as non-continuous sedimentation (coarse crystal beds), which were ''removed'' before age modelling (Adapted from Brisset et. al. 2018). Details of the model discussed in Brisset et al 2018.

According to the average sedimentation rate, the sequence was continuously subsampled for two cm^3 of material (Conedera et al. 2013). The macro charcoal particles (> 200 µm) obtained by the sieving method (Millspaugh & Whitlock, 1995; Mooney & Tinner, 2011; Stevenson & Haberle 2005; Whitlock & Larsen 2001). In order to preserve only the fragments of charcoals, the sieved material was sorted manually. Charcoal count and area measurements were made using a digital camera (Zeiss. Axio cam 305 colours) and the digital greyscale images were processed in ImageJ software (ver.1.51 K). For fire episode reconstructions, macro charcoal counts and area measurements were transformed to charcoal concentrations (particles cm^{-3}). Subsequently, charcoal number and charcoal-area accumulation rates (respectively denoted as $CHAR_{\#}$: number cm^{-2} yr^{-1} and $CHAR_{A}$: μm^2 cm^{-2} yr^{-1}) (Carter et al. 2018; Finsinger et al. 2016; Higuera et al. 2009, 2010). To infer local fire episodes and peak detection, the CharAnalysis tool 0.9 (Higuera, 2009 - Matlab platform ver.R2017b), was utilized in two different runs for $CHAR_{\#}$ and $CHAR_{A}$ following Finsinger et al. (2014). The original code of CharAnalysis requires as input equidistant evaluations (every cm) of the sediment probe. Since the evaluation scheme of our probe was irregularly spaced, the code had to be adjusted to that situation. According to Whitlock and Larsen (2001) and considering the different sedimentation rates along the MAH-B core (Brisset et al. 2018), the records were first interpolated to a constant temporal resolution of 17 years. Then low frequency charcoal variations in a charcoal record ($CHAR_{Back}$) and high frequency variations or charcoal peak component ($CHAR_{Peak}$) were obtained from breaking down the $CHAR_{\#}$ and $CHAR_{A}$ using a robust locally weighted polynomial regression (LOWESS) with a moving-window width of 700 years. This resulted in a robust signal-to-noise index (SNI) (Kelly et al. 2011) and goodness-of-fit between the empirical data and the $CHAR_{Back}$ data for both the count- and area-based records. The SNI > 3 considered as the cutoff value for appropriate records for peak detection (Kelly et al. 2011). The Gaussian mixture model with the thresholds of 99.9th percentiles, used to identify the C_{noise} distribution and to separate peak samples representing actual fire events from surrounding noise in the $CHAR_{peak}$ series (Higuera et al., 2009). Following Gavin et al. (2006) and Higuera et al. (2010) and to omit the sampling effects on charcoal number, fire peaks inferred from charcoal count ($CHAR_{\#}$), were screened with the minimum count peak-screening test by using the method proposed by Finsinger et al. (2014) and the ARCO (v1.0) package in R. In comparison to macro charcoal particles to study local fire events, the micro charcoal influx was also used to evaluate the regional fire activities (Conedera et al. 2009; Finsinger et al. 2016; Whitlock and Larsen, 2001). Micro charcoal particles (>10 µm in diameter) were counted on pollen slides and the counts were transformed to influx rate (particles cm $^{-3}$ yr^{-1}).

6.5. Results

The charcoal number and charcoal-area accumulation rates ($CHAR_{\#}$ and $CHAR_A$) showed strong correlation (Pearson's r coefficient = 0.75, p- value= < 2.2e-16). The $CHAR_A$ and $CHAR_{\#}$ show relatively similar variation through the record; however, the charcoal count is more variable at the end of the record (Figure 6-3). Charcoal counts were mostly below 100 particles per sample, which had the smallest areas (Figure 6-3). $CHAR_A$ record principally comprised of very minute charcoal particles (area by µm^2). Generally, samples with the smallest charcoal counts possessed the highest $C_{\#}/C_A$ ratio, suggesting that the taphonomic process because of breakage produced an insignificant bias (Finsinger et al., 2014).

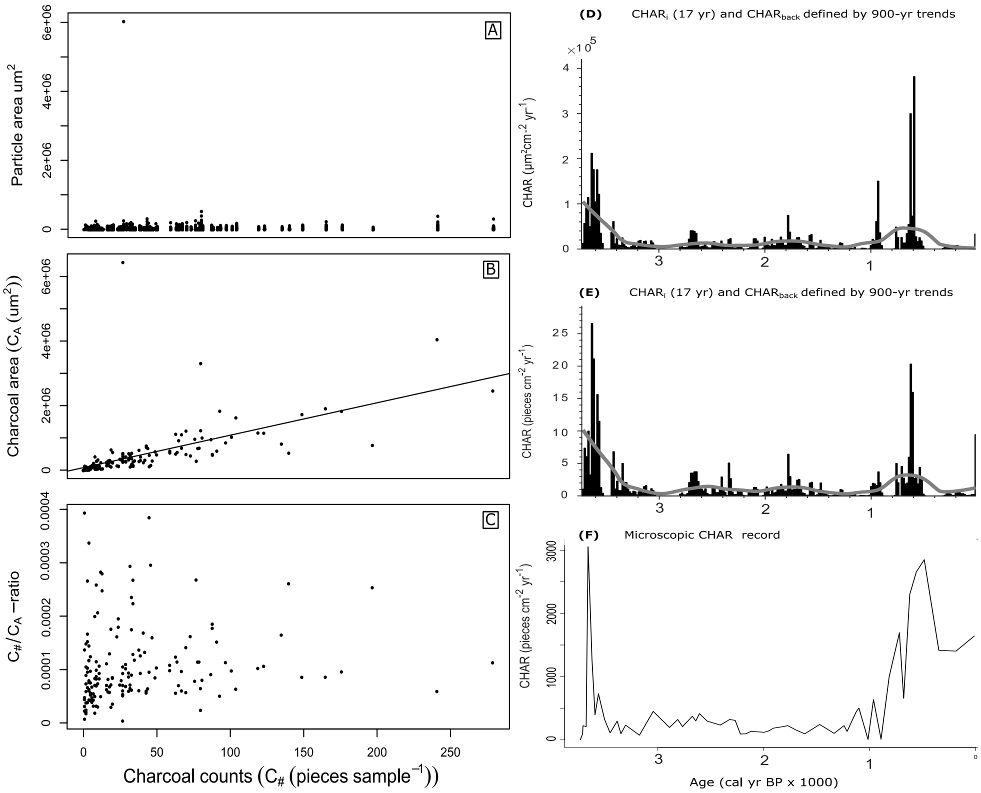

Figure 6-3: Left column: Scatter plots demonstrating the relationships between charcoal counts ($C_{\#}$) and charcoal-particle area (A), sum of the charcoal-particle areas (C_A) in samples (B), and the $C_{\#}/C_A$ ratio (C). Right column: Interpolated macroscopic charcoal-accumulation rates ($CHAR_i$, black bars) and low frequency charcoal, background charcoal ($CHAR_{back}$, grey line) based on (D) charcoal area and (E) charcoal number measurements. (F) Microscopic charcoal accumulation rate (CHAR record) from MAH-B core high-resolution palynology (Chapter 4).

CHAR$_{back}$ in charcoal count and charcoal area (CHAR$_{\#}$ and CHAR$_A$) show the highest values from the end of the record to ~3600-3200 cal yr BP, again increase for over 500 years between ~1000-400 cal yr BP. Microscopic CHAR follows the similar trend with CHAR$_{back}$ and increased values at the beginning and the end of the record (Figure 6-3), reflecting the biomass burning on a regional scale.

Several unscreened peaks were detected from CHAR$_{\#}$ and CHAR$_A$ (12 and 15 peaks, respectively) (Figure 6-4). Generally, the SNI (signal-to-noise index) values exceeded the threshold value of 3.0 (Kelly et al. 2011) for both records (5.59 and 5.46 for CHAR$_{\#}$ and CHAR$_A$ respectively). SNI values suggesting the records are both suitable to detect charcoal peaks during the studied time period in Maharlou Lake.

According to Carter et al. (2018), CHAR$_A$ record with particles smaller than 150µm result in unclear determination of fire frequencies and fire return interval. Both CHAR$_{\#}$ and CHAR$_A$ records showed similar pattern of increasing fire frequency in zone C; also the highest frequencies at the end of this zone and zone B (2800-1000 cal yr BP). However, reconstructed fire frequencies inferred from CHAR$_A$ had the highest values around 2000 yr cal BP with an average of about 7 fire episodes in 1000 years (mFRI = ~114 years). CHAR$_{\#}$- inferred fire frequencies are generally lower between 2800-1000 cal yr BP (c. four fires/1000 years (FRI = ~ 250 years)). The records demonstrate similar trends in peak magnitude with high values and significant peaks in zones A and C. While both records show relatively low to moderate peak magnitudes during zone B (Figure 6-4).

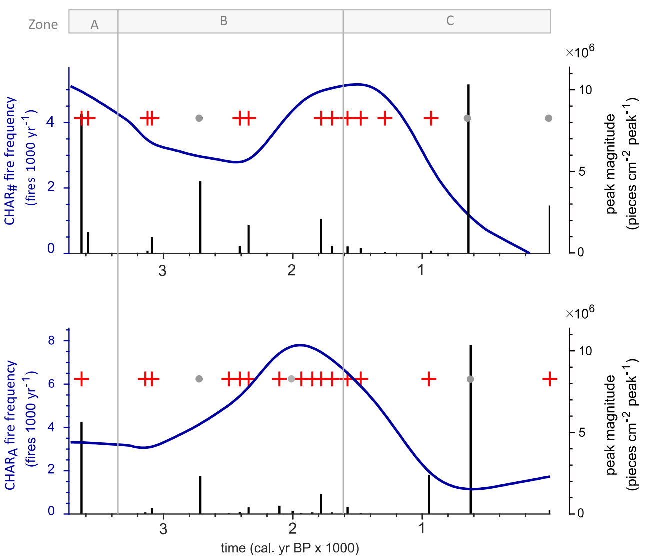

Figure 6-4 : Reconstructed fire history for the Lake Maharlou inferred from macroscopic charcoal count (CHAR$_{\#}$: bottom) and macroscopic charcoal area (CHAR$_A$: top). Smoothed fire-frequency records (Blue lines), peak magnitude (black bars), significant fire episodes (red crosses), and non-significant fire episodes (grey dots). Grey vertical lines are associated with the pollen assemblage zones (LPAZ) detected from cluster analysis (CONISS). Zones labelled as A-C (from: Chapter 4)

The peak screening analysis resulted in the detection of different number of fire episodes inferred from macroscopic charcoal count and charcoal area records (Figure 6-5). CHAR$_{\#}$ peaks mostly passed the screening test (12 peaks), whereas few CHAR$_A$ peaks remained significant after the screening (five peaks). Figure 5 depicts that all the screened CHAR$_A$ peaks had significant charcoal counts (pieces samples $^{-1}$) which meets the suggested rule of thumb that peak samples should have at least 20 charcoal particles while non-peak samples have less than 10 pieces of charcoals (Higuera et al. 2010). Most of the failed CHAR$_A$–inferred fire episodes occurred during the periods represented low charcoal count;

for instance, the insignificant peaks younger than 2000 yr cal BP. In contrary, some of $CHAR_{\#}$- inferred peaks (e.g. younger than 1000 cal yr BP) failed the screening test due to very small charcoal areas, coincides with high values of $CHAR_{back}$; suggesting the biomass burning in regional scale.

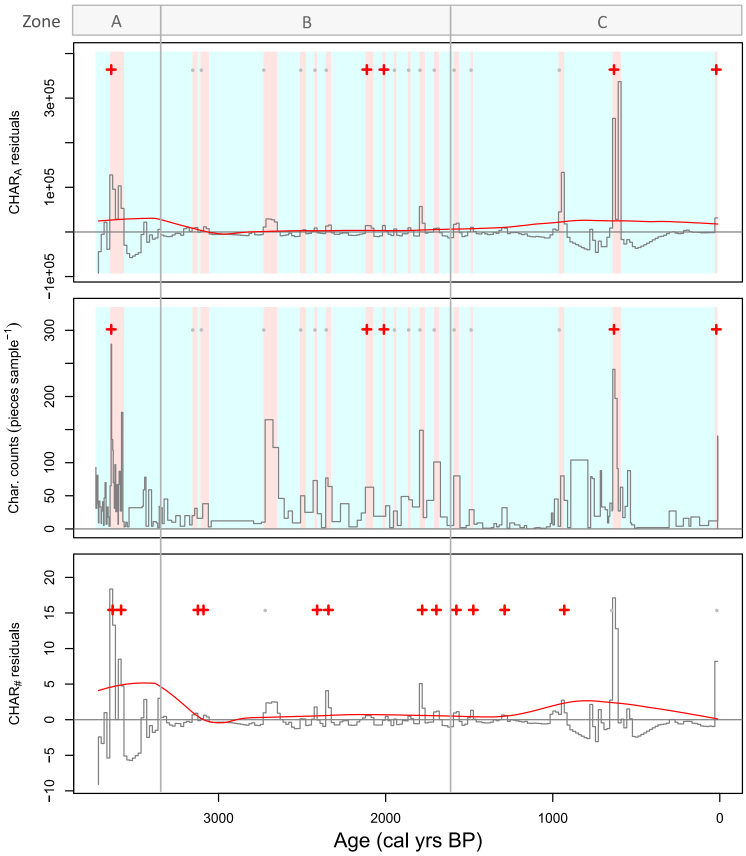

Figure 6-5 : Comparison of reconstructed fire histories based on $CHAR_A$ (top) and charcoal count per sample (middle) and $CHAR_{\#}$ (bottom). Grey lines (CHAR residuals = $CHAR_i$ – $CHAR_{back}$), Threshold (red lines), significant charcoal peaks that passed the screening tests (red crosses), insignificant charcoal peaks that failed the screening test (grey dots)

6.6. Discussion

Generally, due to the depth (3.6 m) and the age covered by MAH-B core (~ last 3800 cal yr BP), the detected charcoal peaks could not correlate with the major climatic events of the late Holocene (4.2 ka event). Therefore, the variation in local hydrology and the climate beside the historical land-use changes of the basin must be used to discuss the possible reason for macro charcoal- inferred fire episodes. Reconstructed fire episodes in Lake Maharlou, based on charcoal area and counts show relatively different patterns without and with peak-screening test (Finsinger et al. 2014). Before the test, both records demonstrate similar trends of biomass burning in the last ~ 3800 cal yr BP. High frequency of fire episodes during 2800-1000 cal yr BP (zones B and C), in addition to the biomass burning around 3600 cal yr BP (zone A) as well as fire episodes in zone C around ~1000 and ~1500-1600 cal yr BP are evident (Figure 6-4).

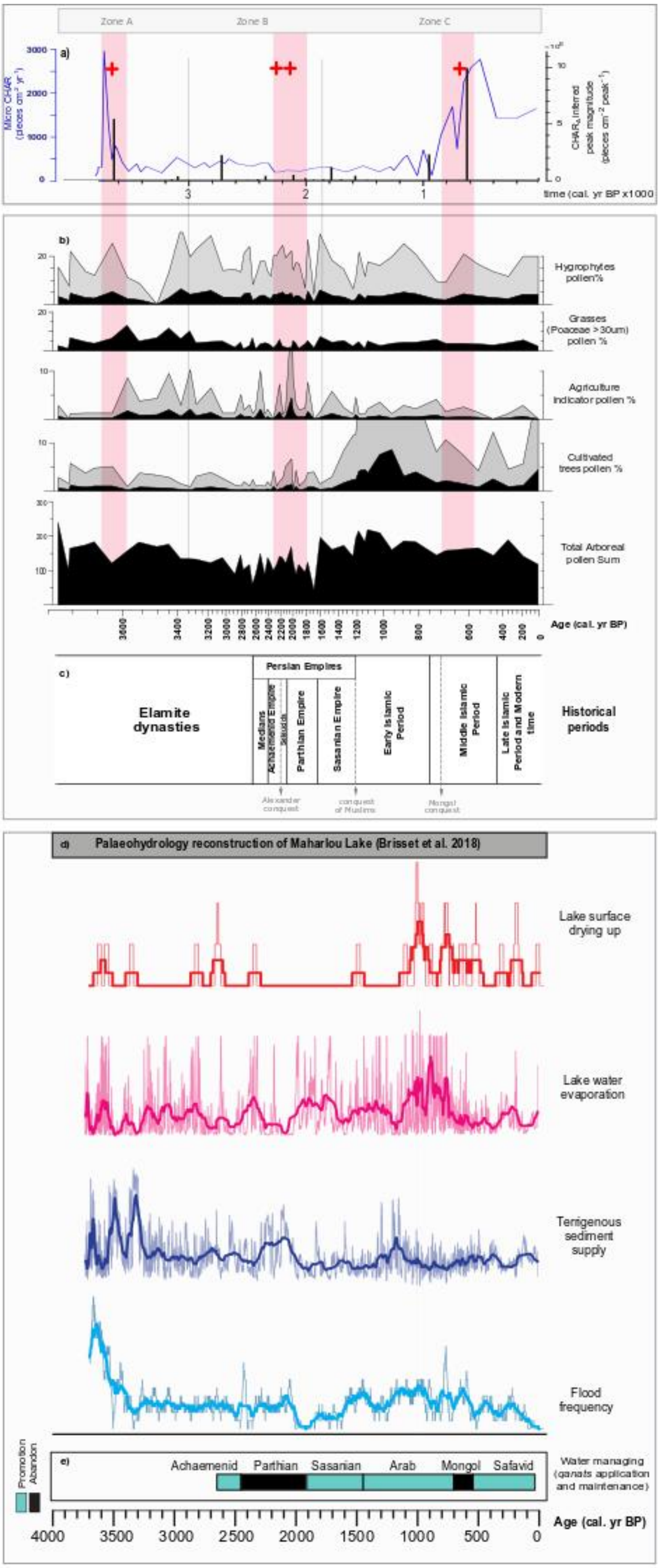

Figure 6-6 : Comparison of reconstructed screened fire episodes with main vegetation changes based on palynology (Saeedi et al, unpublished data) and reconstructed palaeohydrology of Maharlou Lake (adapted from Brisset et al. 2018). a) Screened charcoal area based peaks (red crosses), peak magnitude (black bars), Micro CHAR record (blue line), charcoal accumulation peaks correspondent time (pink bars). b) Selected groups of explanatory pollen types, exaggeration curves marked with filled grey polygons. c) Historical periods. Major events showed in dotted grey lines. d) Reconstructed hydrology of the lake during last ~ 4000 yr cal BP. e) Main changes in water managing in Fars region (Iran) and attention paid to repair and construction of new *qanats*. (d and e adopted from Brisset et al. 2018).

Zone A, represents the oldest screened peak inferred from both charcoal area and counts, occurred around 3600 cal yr BP (3630-3640 cal yr BP) (Figure 6-3Figure 6-6). The background charcoal and Micro CHAR records represented their highest value during this time suggesting regional fire events with the relatively high magnitudes (Fig.4). Historically this peak of biomass burning corresponds to the mid-Elamite period. According to palynological results, this episode occurred just before starting the growing trend of cereal cultivation, also a slight increase in some hygrophilous and aquatic pollen types like Cyperaceae (Figure 6-6). The palaeohydrology study of the lake (Brisset et al. 2018) identified wet conditions and a distinct increase in flood frequency for this period, as well as peaks of terrigenous sediment supply at 3700-3650 and 3500-3450 cal yr BP. As suggested in many studies (e.g. Conedra et al 2009; Whitlock and Anderson, 2003), the deposition time of macro charcoal particles strongly depends on the environmental conditions such as weather conditions, geomorphology and the drainage patterns of the watershed, season, etc. In some cases, charcoal particles are transported over many years after the fire incidence as well as they are re-suspended and redeposited inside the lake. Considering the high fluvial activity during 3800-2000 cal yr BP (Brisset et al. 2018) and the absence of major historical events, the charcoal peak corresponding to ~3600 cal yr BP could have secondary sources. Therefore, such charcoal particles were likely transported to the lake through the increased run-off of the watershed. Consequently, due to the absence of strong evidence for vegetation reversal as a consequence of a fire event, the associated peak of charcoal with enhanced fluvial detrital supply, is likely a result of catchment redistribution due to erosion rather than related to fire dynamics.

In zone B, peak detection and screening analysis indicated two close fire episodes between correspondent ages of ~ 2200-2000 cal yr BP. The local SNI values of these peaks exceeded the threshold of 3.0 suggested by Kelly et al. (2011). The background charcoal and Micro CHAR represented their lowest value during this time, supporting a non-regional (local) scale for these episodes. According to historical and archaeological records of Fars province and Maharlou Lake basin, the identified peaks correspond to the beginning of the Seleucids period, and few decades after the end of the Achaemenid Empire and Alexanders's invasion (330 BC / 2280 BP), until the mid-Parthian period. The abandon of permanent settlements (cities, villages) and changing to nomado-pastoralism might have started by Greek invasion. Consequently, the economy of Persia collapsed and urbanism ended in the capital region of the Empire (Persepolis region). All such consequences of Greek invasion, followed by the indifference of Parthians to Fars region. In this regard, Manuel (2018) described the Parthians and Seleucid's minor attention to using and maintaining the subterranean water transfer tunnels (*qanat* or *kariz* system) which resulted in the abandonment of these hydraulic structures, and a decrease in irrigated agriculture. Moreover, because of the dominance of nomad-o pastoral activities and woodcutting, the scrub communities were more affected.

Considering the response time needed for macro charcoal transfer and deposition in the Lake, the peaks are likely correlated with the vast destructions by Alexander. Moreover, they might have correlated to the destruction of *Pistacia-Amygdalus*/*Prunus* woodlands in Maharlou Lake basin during the Parthians period. As suggested by Djamali, et al. (2010a) in this time, nomadic lifestyle and pastoral production increased in the Zagros Mountains compared to previously organized settlements and agricultural activities. Despite the very short time correspondent to macro charcoal peaks, the palynological survey on MAH-B core indicates a slight increase in total arboreal pollen types that is mainly correlated to cultivated trees like *Platanus*, while the main natural trees of Zagros vegetation show no changes (e.g., *Quercus*) or even a slight decrease (*Pistacia*). The semi-natural tree pollen types (e.g., *Fraxinus*, *Salix*, Cupressaceae) represent similar trends of growth with arboreal pollen types. In addition to tree species, the main herbaceous groups varied significantly. The indicator types for agriculture showed the highest values while grass pollen (Poaceae 30-45 µm) represented the lowest percentages throughout the record. The combination of different CHAR records ($CHAR_{back}$, $CHAR_{\#}$, $CHAR_{A}$, Micro CHAR) as well as the ecological conditions besides the dominant lifestyle of the inhabitants, suggest a local scale for the macro charcoal peaks at ~ 2200-2000 cal yr BP. Most likely, numerous low magnitude fires occurred scattered across the lake watershed.

According to archeological and anthropological documents, the pastoral nomadism existed in the mountain belt of Iran and Zagros Mountains since prehistoric times (Encyclopedia Iranica). This lifestyle is a form of subsistence farming and has been described as “specialized offshoot” for agriculture (Encyclopedia Iranica). Pastoral nomadism is mainly based on herding of domesticated animals, while crop production and farming is only for survival.

After peak-screening test, $CHAR_{A}$-inferred fire history shows a peak (SNI= 12.4) in biomass burning around ~700-600 cal yr BP in zone C. This peak is concurrent with the high values of Micro-CHAR and $CHAR_{back}$ that suggest a regional scale for possible fire episodes rather than a local event (Figs. 5 & 6). Brisset et al. (2018) reconstructed the paleohydrology of the Maharlou Lake (Figure 6-6). They indicated many desiccation events under the influence of an arid climate during 1100-700 cal yr BP. These desiccation phases led to the maximum decrease in the lake water body in this period. Therefore, the charcoal particles accumulation in the corresponding layers to this peak (~700-600 cal yr BP) might be due to increase in sedimentation rate. Charcoal particles can be transferred to the waterbody by wind and water inflow and need to be transferred through the water column to settle on the lake bottom and incorporated to the lake sediments. In this regards, we suppose that decreasing water depth in the lake could have accelerated the deposition of the floating light charcoal particles from water column to the substrate. As Brisset et al.(2018) demonstrate , the second highest sedimentation rate in MAH-B core occurred in the period of 2000-400 cal yr BP (1.1 mm/yr) which comparable to the macrocharcoal peak at ~700-600 cal yr BP (Figure 6-5).

In addition and according to charcoal morphological classification by Enache and Cumming (2006), the reconstructed charcoal peaks before 1000 cal yr BP were mostly comprised of the type S and F classes. These classed can originate from different tissues of wood (type S) and fibrous fragments or grass cuticles (type F). Both types are very fragile; therefore, the significant charcoal count and insignificant charcoal area in this reconstructed episode could be due to breakage associated with lab treatment or taphonomy (Figure 6-7).

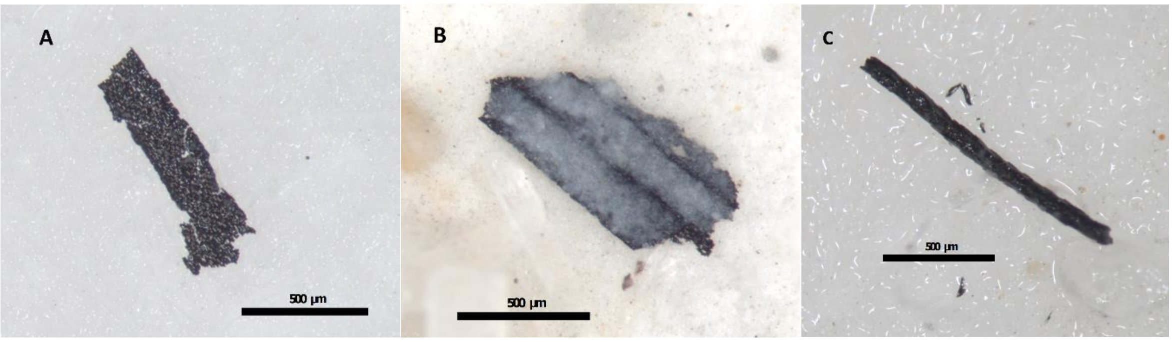

Figure 6-7 : Macro charcoal morphological classes according to Enache and Cumming (2006): S-type (A), F-type (B: grass leaf & C).

Additionally, few $CHAR_{\#}$-inferred fire episodes have been detected in zone C that shows insignificant charcoal area. For instance the screened fire episode at ~ 800-900 cal yr BP, which in spite of the insignificant charcoal area, is concurrent with high values of background charcoal. This peak is likely correlated to a regional scale biomass burning and one of the major historical events in the basin. Following the Mongols invasion (~1220 AD) and during the Ilkhanate period (1256-1335 AD), Fars province was ravaged and suffered from severe destructions in arable fields, orchards and irrigation channels.

Pollen evidence about variations in vegetation composition plays an important role in fire reconstructions based on lake-sediment records (Conedra et al 2009; Mooney and Tinner 2011; Whitlock and Larsen 2001). In this regards, palynological survey on MAH-B record illustrate the decay of arboriculture and significant decline in agriculture after the Mongols invasion, while the sum of ruderal vegetation expanded (Chapter 3). Figure 6 illustrates the main pollen groups and macro charcoal variations as well as the major historical periods and events. As described in historical references (Encyclopedia Iranica) Mongols descendants dominated and ruled the Fars province (Ilkhanate; 1256-1335 AD). Their massive destruction in natural and man-made landscape combined with the local instability in environmental and political circumstances in the area, forced people to change their lifestyle and adopted pastoral nomadic mode of life to guarantee their survival. The increased pressure on forest/shrub ecosystem by nomad communities caused more wood collection and burning. Therefore, it suggests a general increase in charcoal deposition and charcoal influx to the lake through many large and small regional fires. Furthermore, the arid climate of 1100-700 cal yr BP (Brisset et al.2018), the low area of charcoal particles ($CHAR_A$ screened record) as well as high values of Micro-CHAR and background charcoal support the regional and large scale biomass burning for the

The correspondent time of MAH-B core has no interference with the significant climatic events in the basin. Moreover, the palaeohydrology of the basin showed that other factors like erosion and of catchment redistribution had played the main role in the deposition of macro charcoals in Maharlou

Lake. In this regards and based on the reconstructed history, the fire didn't have a critical role in changing the vegetation of the basin during the last ~4000 years, and it was principally under the control of anthropogenic factors.

6.7. Conclusion

The fire history of a region and the role of fire as a disturbance factor have been investigated in many studies around the world. However, no similar investigations had so far been undertaken in the interior parts of the Iranian Plateau. Moreover, some studies, especially in Europe, used macro charcoal records as a complementary proxy with soil charcoals (mega charcoals > 1mm) (e.g. Robin et al. 2013) or plant macro remains to reconstruct local fire episodes or to study the woody vegetation dynamics. Intensive modern land use as well as soil erosion in the past makes it difficult to perform pedoanthracological studies in arid and semi-arid areas, like the southern Zagros. To find suitable soil charcoal records in such landscapes, a thorough field survey has to be conducted and test samplings taken, and soil samples sieved locally. As this frequently is not feasible with satisfying results due to organisational or political reasons, the present study examined the potential of using the macroscopic charcoal count and area of an already available sediment core to study fire history in South-western part of Iran.

The fire history of Maharlou Lake basin during the last ~ 4000 yr cal BP was reconstructed here by three major episodes. The recent and the oldest reconstructed episodes (~ 700-600 and ~3600 cal yr BP, respectively) are related to secondary charcoals with regional sources. The youngest macro charcoal peak is likely associated with the re-deposition of charcoal particles due to dry climate, while the increased runoff at ~3600 cal yr BP resulted in charcoal accumulation. By contrast, the inferred fire episodes during 2200-2000 cal yr BP demonstrate local biomass burning events with low magnitude and high frequency. Therefore, a long-lasting nomado-pastoral lifestyle dominating the area during post-Achaemenid to Sasanian epoch. Historical and palynological evidence suggest that pastoral nomadism and changes in inhabitant lifestyle were the main driving force for the occurrance of this peak. The results of the present study illustrated the similar patterns for fire incidence and frequency inferred from charcoal counts and area data without reducing the influence of small fragments. However, by reducing the influence of small fragments, the screened peaks were highly compatible with the reconstructed palaeohydrology and pollen-inferred vegetation dynamics of the basin as well as the historical evidence. Nevertheless, the identification of robust fire episodes with consequent significant peaks appeared relatively complicated in Maharlou Lake basin. For instance, several unscreened $CHAR_{\#}$ peaks were identified between ~3200-1200 cal yr BP, while they were not significant based on the charcoal area record. Thus, in the case of a large lake basin in a semi-arid region, the advantage of the charcoal area in studying fire history can be demonstrated, most notably when the background charcoal record has low values.

In a seasonal lake system such as the Maharlou Lake, the influence of extreme hydrological changes must always be considered. Frequent desiccation events result in several charcoal re-depositions and could increase the rate of breakage during taphonomy. Besides, the impact of varying sedimentation rates on the charcoal accumulation rates should be taken into account.

7. Anthracological analysis of Tepe Rahmatabad, a Neolithic site in Persepolis basin, Fars province (SW-Iran)

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7.1. Abstract

This study presents the results of an anthracological survey on archaeobotanical wood charcoal remains from a prehistoric site of Tepe Rahmatabad in Persepolis basin, SW Iran. The site is situated in Kamin Plain and has been excavated in 2005, 2009 and 2010. The charcoal assemblage contains in total nine taxa (*Pistacia*, *Prunus/Amygdalus*, *Tamarix*, *Myrtus*, *Fraxinus*, Salicaceae, Chenopodiaceae, Lamiaceae and Fabaceae) suggesting that the site was located in Zagros steppe-forest vegetation type. *Pistacia* and *Prunus/Amygdalus* charcoal have relatively high frequencies in all periods. This high proportion depicted the presence of a reliable and renewable source of firewood in the site vicinity. The socio-economic changes in the site during the Chalcolithic period led to increase in wood exploitation, mainly from pistachio almond vegetation. In addition to the presence of fruit stone fragments of these taxa supports the idea of prehistoric collection of firewood in addition to fruits. The relatively high values of pistachio charcoal is consistent with the period of expansion in pistachio-dominated vegetation in the southwest Asia. The absence of *Quercus* charcoal along with the presence of its acorn fragment in the assemblage suggested infrequent oak stands in the site surrounding, which was controlled by climatic factors rather than woodland management practices. Comparing the present results with the major climatic events and archaeological data, suggested that in the Pulvar River basin had not been influenced by the 8.2 cooling events and had provided a suitable microclimate for cold-sensitive relict taxa. The present study also supports the importance of oak acorns as a nourishing source for prehistoric

communities and their livestock. Moreover, the significant high proportions of *Tamarix* sp. charcoal in some Neolithic periods is compatible with presence of the remains of Cyperaceae and suggested the presence of the peat bogs and the moist ecosystems in the vicinity of the sites. Additionally the mono-specific horizon of *Tamarix*, demonstrated the early stages of Tahmatabad settlement formation during the Pottery Neolithic. The results of the present study implies that the anthropogenical changes in regional vegetation of the SW Zagros have not begun by the early Holocene and during the Neolithic time.

7.2. Introduction

Being a part of the cultural sphere of 'East Wing of the Fertile Crescent' (Nishiaki et al. 2013), Fars was the homeland for several prehistoric societies during Neolithic and Chalcolithic, to the period of Persian Empires and long after the Muslim conquest (Potts et al., 2005). In Fars, most of the famous excavated and documented archaeological sites such as Tal-e Mushki, Tal-e Jarri, Tal-e Bakun, and Tal-e Malyan are located in Persepolis and Kur River Basin (Fig. 1). These sites correspond to different phases of cultural development from the first agricultural settlement at Tal-e Mushki (late 7th millennium BC) to the first walled settlement and urban center in Tal-e Malyan (city of Anshan, ~ mid 3rd millennium BC).

Tepe Rahmatabad is among the significant prehistoric sites in the Persepolis basin. It is situated in Kamin plain and at the vicinity of Pulvar River, northeast of Persepolis and along the royal road towards Pasargadae. Rahmatabad site hosted different groups of ancient communities for millennia. Based on the archaeological records from a series of excavations in Rahmatabad, this site represents the oldest aceramic Neolithic evidence in the Fars province (7450-7000 BC). This piece of information about pre-Neolithic culture is precious to fill the gap in cultural differentiation in the Early Holocene also to complete the chronology of the regional history socio-cultural changes during 10000-6000 BC. (Rahmatabad Phase; Azizi et al, 2014)

According to the archaeological evidence and ^{14}C dating, Rahmatabad site was occupied since the early 7th millennia BC and abandoned later for a period of ~ 1400 years (6300-4900 BC). The next occupation phase started in Chalcolithic period (in Fars province 5th millennim BC) which is known as Bakun phase in Fars. Bakun culture demonstrates the uniform socio-economic differentiations (e.g. craft specialization and administrative development) in the early settlements of relatively entire Fars (Alizadeh et al 2004, 2006, Azizi et al, 2014; Hejebri et al 2013, Nishiaki et al 2013). Rahmatabad site was unoccupied after the Bakun phase; until the Achaemenid period (for ~ 4000 years) when it was considered as a monitoring point along the way between Pasargadae and Persepolis (Azizi et al, 2014).

The archaeobotanical study of the Rahmatabad site resulted in the identification of 32 taxa of cultivated (wheat, barley) and wild plants with some cultigen taxa. In spite of the diversity in cultivated plant remains, Rahmatabad assemblage does not show signs of local domestication practices. Wild plant remains comprises of *Pistacia* and wild almond (*Prunus/Amygdalus*) nutshells and the inner part of an oak acorn (cotyledone) (Tengberg & Azizi, 2016).

This study represents the results of an archaeo-anthracological survey of charcoal remains from Rahmatabad site. We aim to complement the knowledge about Rahmatabad surrounding landscape and about the vegetation changes in the Persepolis basin during the Neolithic period in interaction with a prehistoric human community.

7.3. Study site

Prehistoric site of Tepe Rahmatabad is located in Persepolis basin, SW Iran. The site is situated at the southern part of Tang-e Bolaghi and close to Kamin (Saadatshahr) plain (N30° 0.6′ 42.41″ E53° 0.3′ 26.94″) (Figure 7-1). It is a small rounded hill (5 m above the surrounding plains) close to Pulvar (Sivand) River, covering the area about half a hectare at the elevation of 1774 masl. Rahmatabad site was investigated during a series of excavations in 2005, 2009 and 2010 and in 7 different trenches (A-H). In the first season, A-E trenches was excavated (Bernbeck et al. 2005; Fazeli Nashli & Azizi Kharanaghi 2008; Fazeli Nashli et al. 2009). The trenches G and H were studied at the second season of excavation in order to improve the chronology of the site (Azizi Kharanaghi et al. 2014).

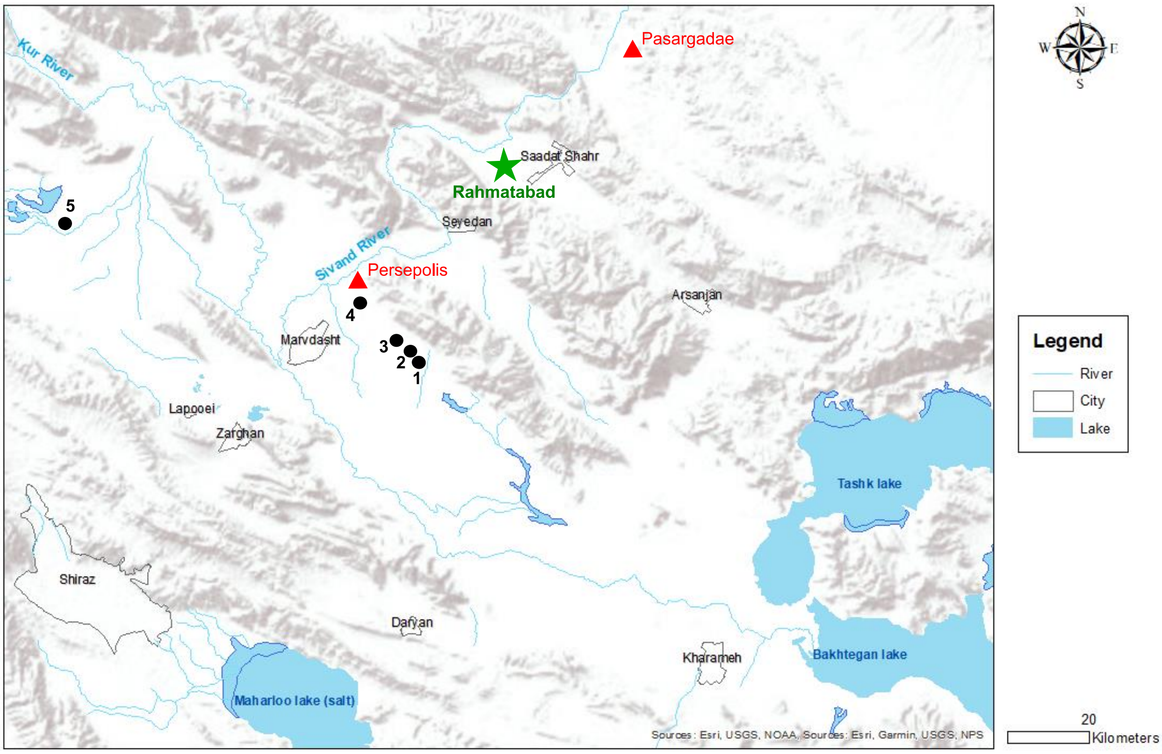
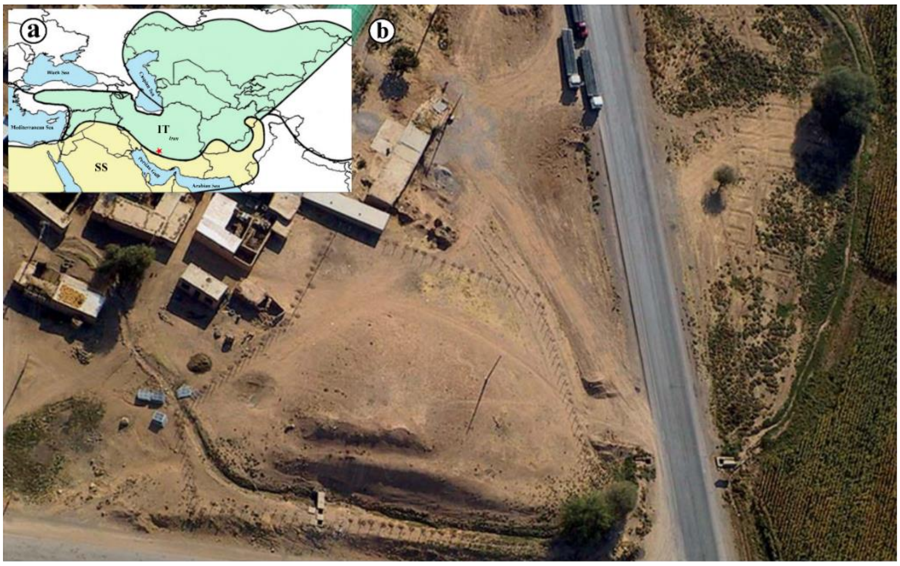


Figure 7-1: Black circles show important prehistoric sites in Persepolis basin 1: Tal-e Jarri A, 2: Tal-e Jarri B, 3: Tal-e Mushki, 4: Tal-e Bakun A & B, Tal-e Malyan. Triangles: Persepolis and Pasargadae sites. Star: Rhamatabad site location (adapted from Alizadeh et al 2004).

Being located in Saadash Shahr basin and near the Persepolis basin, Rahmatabad site also has a very particular bioclimatic and biogeographical setting. According to the map of main climatic types of Iran (by Meteorological Organization of Iran -IRIMO), it has semi-arid climate type with the main precipitation during autumn and winter. Biogeographically, Rahmatabad site is located in the Irano-Turanian region (Figure 7-2). Therefore, the potential vegetation of the study area is the typical Zagros vegetation of wild pistachio (*Pistacia khinjuk*, *P. atlantica*) and almond (*Prunus/Amygdalus* spp.), where Brant's oak (*Quercus brantii*) is gradually gaining importance as an adjoined component at higher altitudes (ca. 1000-2000 m). The Pulvar River provided the permanent water source for arable fields to cover the lowlands of Tang-e Bolaghi and developing the riparian vegetation (Azizi et al 2014). According to Mozzafarian (2009), nine species of genus *Amygdalus* have been reported from Fars Province, which *A.scoparia* is the dominant species in Fars as well as the entire country. Following Potter et al. (2007a) and Wen et al. (2008), the genus *Prunus* is broadly described and contained the *Amygdalus spp*. Therefore, in the present study, *Prunus* were used as the accepted taxonomical name for almond species.



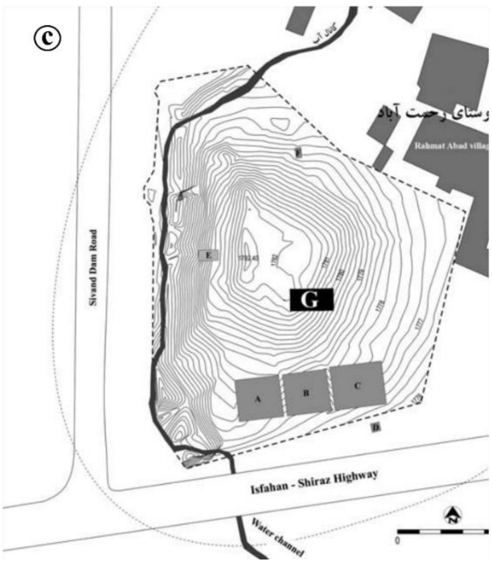


Figure 7-2: a) The location of Rahmatabad site (red star) in the country and the phytogeographic regions according to White and Léonard (1991), IT: Irano-Turanian, SS: Saharo-Sindian b) Aerial photo of Tepe Rahmatabad. c): topographical map of Tepe Rahmatabad, showing the location of trenches. (Adapted from Azizi Kharanaghi et al. 2014)

7.4. Materials and Methods

The archaeological charcoal remains were obtained by flotation and sieving during the site excavations (Table 7-1). Then they were sorted and stored at the Archaeobotany laboratory of the "National Museum of Natural History" of Paris (MNHN). The remains were obtained from four different trenches in 27 stratigraphic units (SU). Considering the preservation situation of charcoal fragments and the floristic diversity of Irano-Turanian region, in every trench about 100-300 charcoal fragments (20-60 fragments per SU) were anatomically studied. Because of inappropriate preservation, fragments with the size bigger than 4mm were not abundant. Therefore, following Zalucha (1989), charcoal remains were passed through different mesh-sized sieves (1 and 2 mm) and then were "grab-sampled" with different size and shapes (Miller, 1985). A dark/bright field light microscope (Olympus BX51) was used at the Archaeobotany laboratory of MNHN to study the specimens. The remains were identified based on available anatomical atlases and identification keys (Crivellaro et al, 2013; Fahn et al, 1986; IAWA, 1989; Jagiella and Kürschner, 1987; Neumann et al, 2001; Parsa & Schweingruber, 1995; Schweingruber, 1990) and the reference collection of the institute. All identified taxa and anatomical types were photographed with a Nikon eclipse (LV150L) microscope equipped with Nikon digital camera (DS-Fi1), also by electron microscope imagery by NeoScope (JCM-5000) SEM.

7.5. Results and Discussion

Anthracology study of Rahmatabad site resulted in the identification of 671 charcoal fragments from 27 stratigraphic units, dating back to pre-Pottery Neolithic (7467-7171 cal BC) up to Chalcolithic (4778-4548 cal BC). Table 7-1 shows the list of obtained (by flotation) and studied samples during the excavations (2005-2011). In total, the Rahmatabad charcoal assemblage contains nine identified taxa (*Pistacia*, *Prunus/Amygdalus*, *Tamarix*, *Myrtus*, *Fraxinus*, Salicaceae, Chenopodiaceae, Lamiaceae, and Fabaceae) and four unknown types of wood. Table 7-2 demonstrates the identified taxa organized by chronological order within trenches.

Table 7-1: List of obtained and studied samples during the excavations (2005-2011) organized by trench and Stratigraphic unit numbers. (Adapted from Tengberg & Azizi, 2016). TR: Trench, SU: Stratigraphic unit.

TR	SU	Period	Local phase	Approx. date (BC)	Cal BC (2 sigma)	Archaeological context
C	3001	Chalcolithic	Middle Bakun	4500		Compact surface layer with some ash and burnt soil
C	3002	Chalcolithic	Middle Bakun	4500		Thick (70cm) ashy layer near pottery kilns
C	3007	Chalcolithic	Middle Bakun	4500	4778-4548	Ashy deposits inside kiln 1
C	3010	Chalcolithic	Middle Bakun	4500		light ashy layer
C	3023	Chalcolithic	Middle Bakun	4500		Hard layer with pottery and small stones
C	3024	Chalcolithic	Middle Bakun	4500		Ashy layer probably associated with kiln 2 (refuse from burning)
C	3025	Chalcolithic	Middle Bakun	4500		Hard soil
C	3033	Pottery Neolithic	Mushki	6000		Ashy layer , 20 cm thick
C	3035	Pottery Neolithic	Mushki	6000	7038-6698	Ashy layer, 34 cm thick
G	7020	Chalcolithic	Middle Bakun	4500	4945-4763	Soft sediment layer with ash lenses
G	*7021**	*Chalcolithic*	*Middle Bakun*	*4501*		*Ashy layer, 20 cm thick*
G	7029	Pottery Neolithic	Mushki	6000	6217-6028	Ashy layer 65 cm thick
G	7030	Pottery Neolithic	Mushki	6000		Clay/ash layer, 50 cm thick
G	7033	Pre-pottery Neolithic	Rahmad Abad Phase	8000	7047-6743	Thick (55cm) ashy layer
G	7038	Pre-pottery Neolithic	Rahmad Abad Phase	8000		Ashy layer, 8 cm thick
G	7039	Pre-pottery Neolithic	Rahmad Abad Phase	8000		Ashy layer, 7 cm thick
H	8007	Chalcolithic	Middle Bakun	4500		Hard layer, 48 cm thick
H	8015	Chalcolithic	Middle Bakun	4500		Hard soil with charcoal, 24 cm thick
H	8018	Chalcolithic	Middle Bakun	4500		Ashy layer, 24 cm thick
H	8028	Chalcolithic/Neolithic	Middle Bakun/Mushki	5000		Compact ashy layer, 26 cm thick
H	8032	Chalcolithic/Neolithic	Middle Bakun/Mushki	5000	4797-4584	Hard soil with charcoal, 60 cm thick
H	8038	Pottery Neolithic	Mushki	6000		Fill of soft ash in circular pit (8041)
H	8040	Early Pottery Neolithic	Formative Mushki	6000		Mix of sediment and ash with charcoal, 10 cm thick
H	8048	Pre-pottery Neolithic	Rahmad Abad Phase	8000	7321-7075	Soft burnt layer with ash, 40 cm thick
H	*8050**	*Pre-pottery Neolithic*	*Rahmad Abad Phase*	*8001*		*Burnt soil layer, 15 cm thick*
H	8051	Pre-pottery Neolithic	Rahmad Abad Phase	8000		Burnt soil layer, 26 cm thick
H	8053	Pre-pottery Neolithic	Rahmad Abad Phase	8000	7467-7171	Hard sediment and ash layer, 25 cm thick
I	9004	Early Pottery Neolithic	Rahmad Abad Phase	6000		Thin (6cm) ashy layer
I	9006	Early Pottery Neolithic	Rahmad Abad Phase	6000	6699-6471	Burnt soil, 28 cm thick

* Grey color shows the samples with no charcoal fragments or unidentifiable fragments less than 1mm in size.

The identified charcoals of *Prunus/Amygdalus* and *Tamarix* showed two types of porosity: diffuse-porous and semi-ring-porous in *Prunus/Amygdalus* specimens, ring-porous and semi- to diffuse-porous in *Tamarix* specimens implying the existence of at least two different species of these genera in the studied charcoal assemblage. However, this result may have been obtained due to the bad preservation conditions and small sized fragments. Figure 7-3Figure 7-9 show the SEM images of the diagnostic anatomical features in identified taxa.

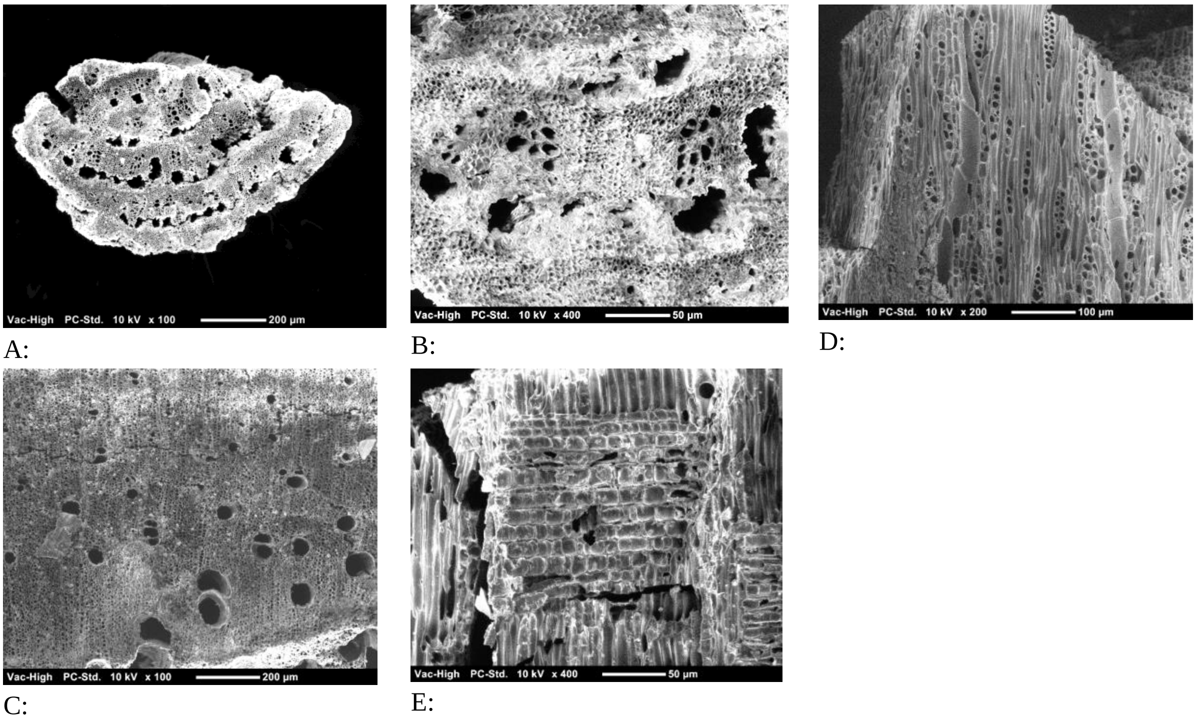
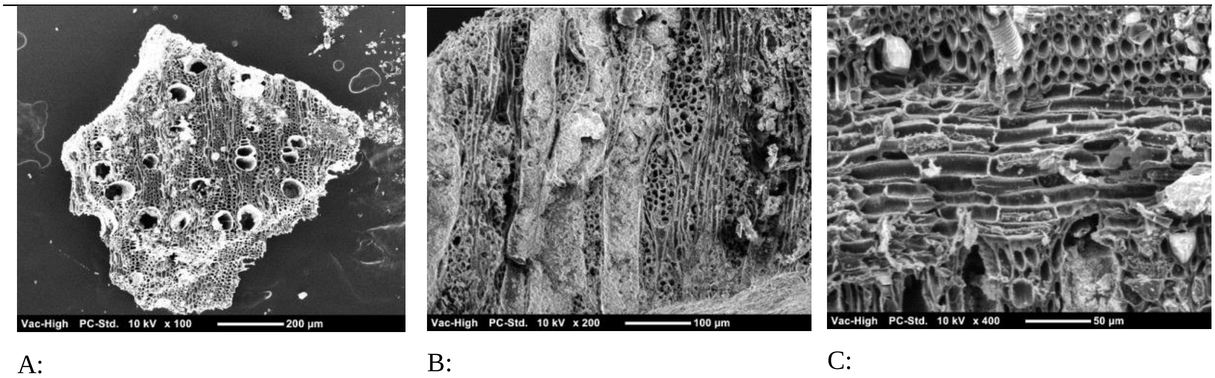


Figure 7-3: SEM microphotographs of wood charcoal specimens from Tepe Rahmatabad. TS: Transversal section, TLS: Tangential section, RS: Radial section. Chenopodiaceae, (A&B: TS), *Fraxinus* (C: TS, D: TLS, E: RS).



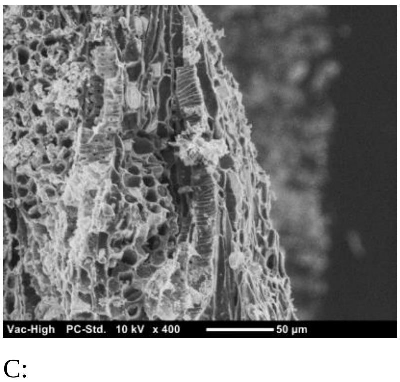


Figure 7-4: SEM microphotographs of wood charcoal specimens from Tepe Rahmatabad. TS: Transversal section, TLS: Tangential section, RS: Radial section. Lamiaceae (A: TS, B: TLS, C: RS, D: Spiral thickening).

Table 7-2 : Proportion of identified taxa organized by chronological order within trenches and Stratigraphic units**.**

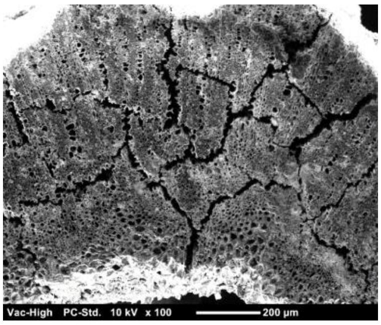
	Trench	**C**									**G**						
	Period	**Pottery Neol.**		**Chalcolithic**							**Pre-Pottery Neol.**			**Pottery Neol.**		**Chalcolithic**	
	Local phase	**Mushki**		**Bakun**							**Rahmatabad**			**Mushki**		**Bakun**	
	Stratigraphic unit	**3035**	**3033**	**3025**	**3024**	**3023**	**3010**	**3007**	**3002**	**3001**	**7039**	**7038**	**7033**	**7030**	**7029**	***7021***	**7020**
Identified Taxa	***Pistacia***	0.02	0.35	0.587	0.357	0.158	0.15	0.75	0.35	0.55	0.5	0.2	0.286	0.8	0.6		0.364
	Prunus/Amygdalus	0.02	0.45	0.196	0.214	0.526	0.55	0.05	0.4	0.2	0.143	0.05	0.381	0.05	0.25		0.045
	Tamarix	0.96	-	0.087	0.048	0.211	0.05	-	-	0.1	0.357	0.7	0.333	0.1	-		0.136
	Myrtus	-	-	0.043	-	0.053	0.05	-	-	-	-	-	-	-	0.05		0.091
	Fraxinus	-	0.05	-	0.143	-	-	-	0.25	0.05	-	-	-	-	-		0.045
	Salicaceae	-	0.1	0.022	0.214	-	-	0.2	-	0.05	-	-	-	-	0.05		0.045
	Chenopodiaceae	-	-	0.043	-	-	-	-	-	-	-	-	-	-	-		0.045
	Lamiaceae	-	-	0.022	0.024	-	0.05	-	-	-	-	-	-	-	-		-
	Leguminoseae	-	-	-	-	0.053	-	-	-	-	-	-	-	-	0.05		0.136
	indeterminate	-	0.05	-	-	-	0.15	-	-	0.05	-	0.05	-	0.05	-		0.091

* Grey color shows the samples with no charcoal fragments or unidentifiable fragments less than 1mm in size.

Table 7-3 continue: Proportion of identified taxa organized by chronological order within trenches and Stratigraphic units.

Trench		H											I	
Period		**Pre-Pottery Neol.**				**Early Pottery Neol.**	**Pottery Neol.**	**Transition Neol./Chalco.**		**Chalcolithic**			**Early Pottery Neol.**	
Local phase		**Rahmatabad**				**Formative Mushki**	**Mushki**	**Mushki/Bakun**		**Bakun**			**Formative Mushki**	
Stratigraphic unit		**8053**	**8051**	***8050***	**8048**	**8040**	**8038**	**8032**	**8028**	**8018**	**8015**	**8007**	**9006**	**9004**
Identified Taxa	***Pistacia***	0.16	0.85		0.053	0.05	0.1	0.5	0.35	0.1	0.7	0.5	0.21	0.45
	Prunus/Amygdalus	0.02	0.15		0.316	0.21	0.9	0.05	0.5	0.9	0.3	0.4	0.10	-
	Tamarix	0.68	-		0.421	0.42	-	0.45	0.1	-	-	-	0.46	0.25
	Myrtus	-	-		0.053	-	-	-	0.05	-	-	0.05	-	-
	Fraxinus	-	-		-	-	-	-	-	-	-	-	-	-
	Salicaceae	-	-		-	-	-	-	-	-	-	-	-	-
	Chenopodiaceae	0.02	-		-	0.05	-	-	-	-	-	0.05	0.04	-
	Lamiaceae	-	-		0.053	0.21	-	-	-	-	-	-	-	-
	Leguminoseae	-	-		-	-	-	-	-	-	-	-	-	-
	indeterminate	0.12	-		0.105	0.05	-	-	-	-	-	-	0.19	0.3

* Grey color shows the samples with no charcoal fragments or unidentifiable fragments less than 1mm in size.



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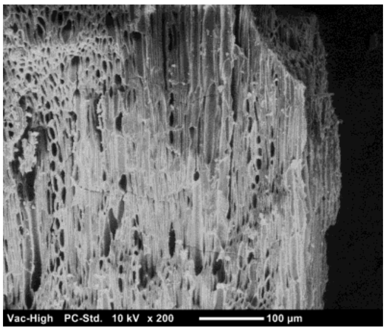

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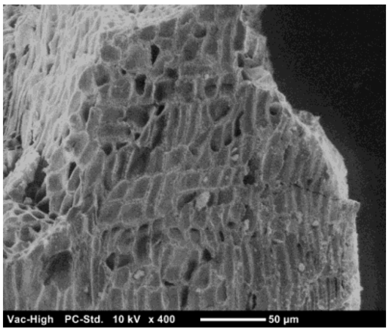

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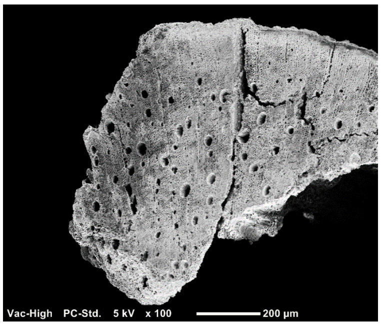

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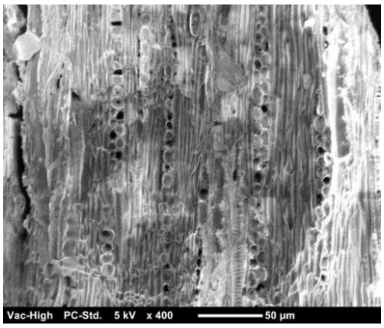

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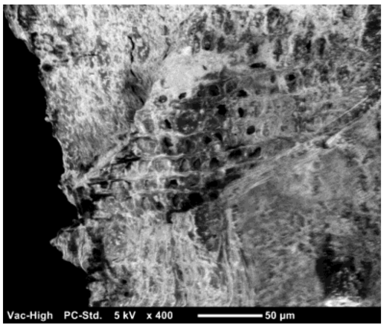

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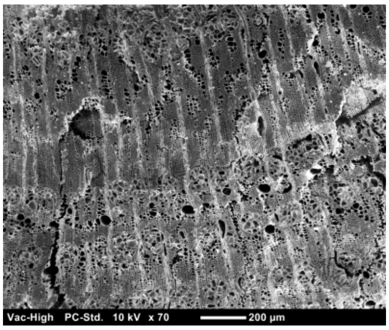
Figure 7-5: SEM microphotographs of wood charcoal specimens from Tepe Rahmatabad. TS: Transversal section, TLS: Tangential section, RS: Radial section. Chenopodiaceae, Leguminoseae (A: TS, B: TLS, C: RS). *Myrtus* (D: TS, E: TLS and spiral thickenings, E: RS)



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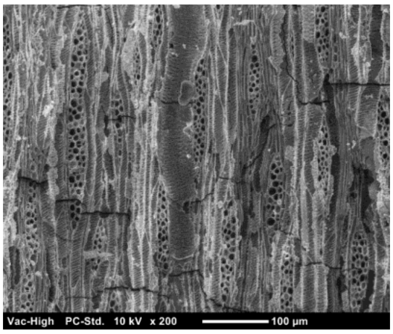

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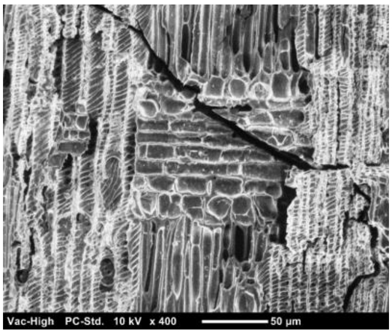

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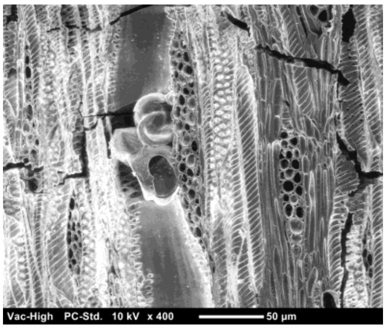
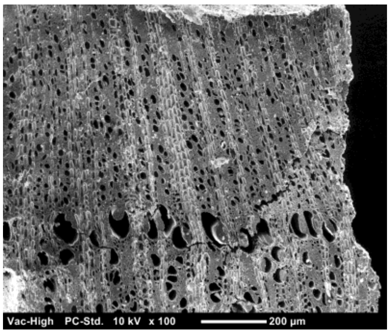
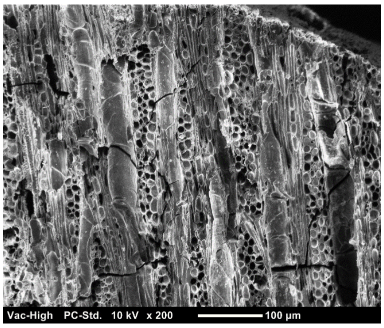


D:

Figure 7-6 : SEM microphotographs of wood charcoal specimens from Tepe Rahmatabad. TS: Transversal section, TLS: Tangential section, RS: Radial section.*Pistacia* (A: TS, B: TLS, C: RS, D: Spiral thickening, tylosis and bordered vessel pits).



A:



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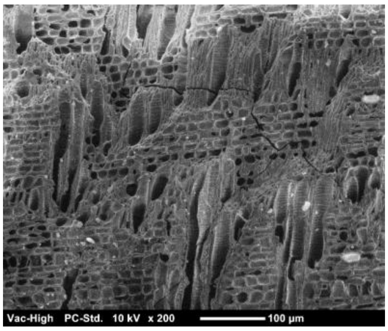
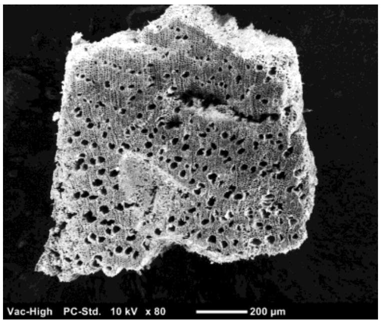
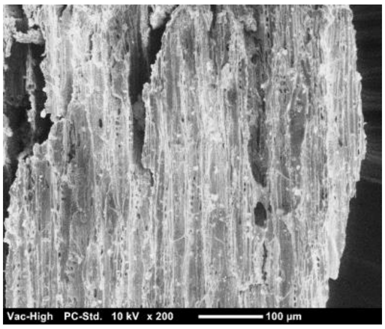


C:

Figure 7-7 : SEM microphotographs of wood charcoal specimens from Tepe Rahmatabad. TS: Transversal section, TLS: Tangential section, RS: Radial section.*Prunus/Amygdalus* (A: TS, B: TLS, C: RS and Spiral thickening).



A:



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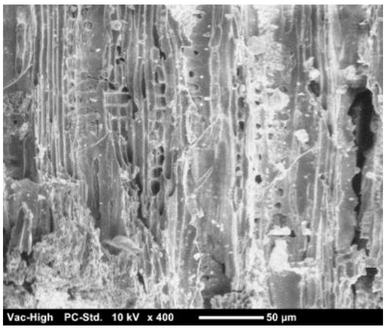

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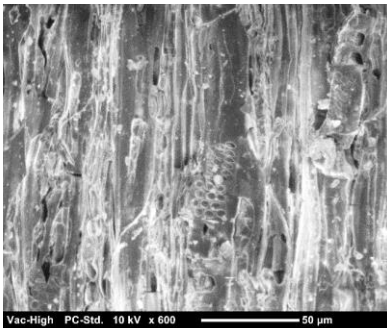
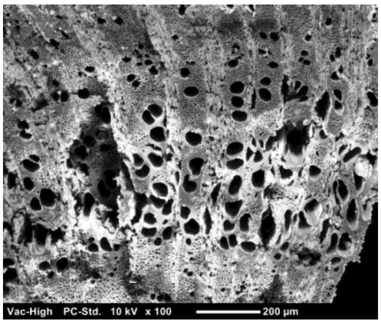
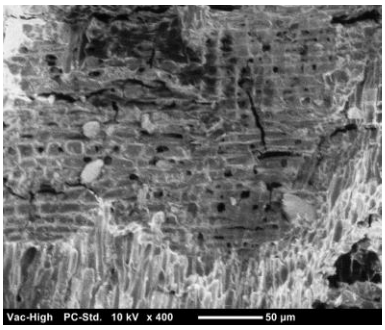


D:

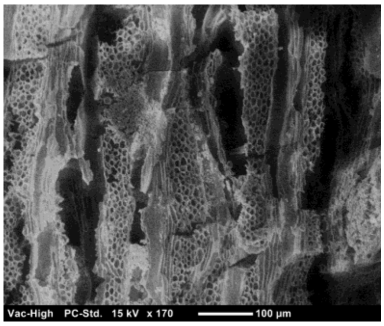
Figure 7-8: SEM microphotographs of wood charcoal specimens from Tepe Rahmatabad. TS: Transversal section, TLS: Tangential section, RS: Radial section. Salicaceae (A: TS, B: TLS, C: RS, D: Ray-Vessel pits).



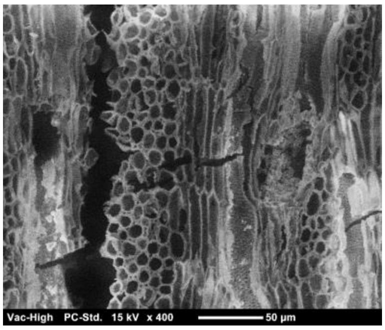
A:



B:



C:



D:

Figure 7-9: SEM microphotographs of wood charcoal specimens from Tepe Rahmatabad. TS: Transversal section, TLS: Tangential section, RS: Radial section.*Tamarix* (A: TS, B: TLS, C: RS, D: Storied structures - vessels and fibers).

Figure 7-10 shows the composition of Rahmatabad charcoal assemblage in chronological order and percentages of identified taxa.

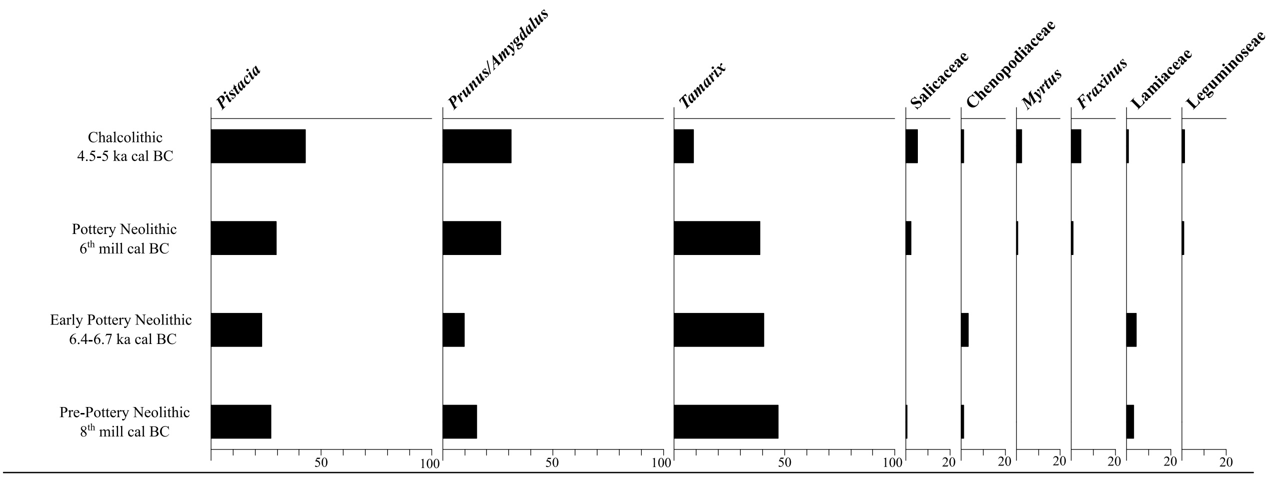


Figure 7-10: Percentage fragment count from all examined charcoal samples from Rahmatabad site.

According to Matthews (2016), fuel source selection by prehistoric communities depends on the availability of resources, which is determined mostly by precipitation gradients and microclimate. Compare to other fuel sources, like dung and grasses, wood is considered as the main fuel in highland and elevated archaeological sites, where the precipitation was enough to maintain the woody vegetation. Moreover, the availability and abundance of collectable dry-wood, structure and seasonality of the stand are other effective factors to choose the firewood (Matthews, 2016)

In this regard, Théry-Parisot et al. (2010) believe that prehistoric communities collected the firewood from the nearest woody vegetation with the least labor ("Principle of Least Effort"). Therefore, the species composition of a charcoal assemblage can reflect the historical vegetation of the site surroundings. Figure 9 depicts the structure of the studied charcoal assemblage, which is highly compatible with the modern vegetation composition of the Zagros woodlands. Therefore, Rahmatabad site was most likely located close to the pistachio-almond vegetation stands. This vegetation type existed in the SW of Zagros Mountains at least since the mid-Holocene with its maximum extent during the fourth millennium BC (Djamali, et al 2010b; Robert et al.2018). Moreover, the Rahmatabad charcoal assemblage is highly compatible with the developed summary of archaeological charcoal composition by Roberts et al. (2018) for the west of Iran during early Holocene (Pre-Pottery Neolithic period). It shows high proportion of riparian taxa as well as *Pistacia* and *Prunus/Amygdalus* combined with the relatively low values of oak and very small proportions of other species.

Pistacia and *Prunus/Amygdalus* charcoal types are relatively abundant in the assemblage (Figure 7-10) and covers more than 50% of the charcoal remains in all periods. The archaeobotanical study of the site (Tengberg & Azizi 2016) showed the remains of fruit stone and fragments of wild pistachio and almond dated to the Chalcolithic and transitional Neolithic-Chalcolithic period. The low frequency of these remains together with the abundance of their charcoal might have been due to carbonization of fruits attached to the collected firewood. Consequently, it supports the idea of collecting firewood rather than exclusively collecting *Pistacia* and *Prunus/Amygdalus* fruits for human consumption. Moreover, Pistachio charcoal showed relatively significant values throughout the Neolithic period, which is consistent with the period of expansion in pistachio-dominated vegetation in the southwest Asia (Asouti, 2017; Asouti & Kabukcu, 2014; Robert et al. 2018).

During the series of excavations, larger quantities of sediment were collected from correspond layers to the Chalcolithic period. This may be a reason for the higher plant diversity in this context. In spite of that, the increase in *Pistacia* and especially *Prunus/Amygdalus* charcoal during the Chalcolithic period (4500 -5000 cal BC) can be correlated with the socio-economic changes at the site. During the excavations, many pottery workshops have been found in the southern part of the site. According to Azizi et al. (2014) and based on the archaeological remains, Rahmatabad site changed to an industrial point for pottery production during the Bakun phase (5200-4100 BC). Thus, the demand for fuel and firewood increased during this period. High wood density and lignin content of broad-leaved species are critical factors in selecting wood for making fire and charcoal production (Taghi Mollaei, 2019). Both wild pistachio and almond wood are shown to be used as an excellent source of fuel for heating and charring (Encyclopedia Iranica; Monjauze, 1980; Rosengarten 2004). In this regard, Horne (1982) discussed the role and importance of wild almond and pistachio and some other hardwood taxa in charcoal production and ancient metallurgy in Iran. According to her, these taxa burn with an especial hot flame. Depends on the size, different parts of the plant were been used, either the pollarded branches or the shoots and roots of the uprooted plant. The efficiency of using charcoal compare to wood for smelting also mentioned by Miller (1985) at Malyan during the fourth to second millennia.

Moreover, the presence of pistachio and almond fruit remains may provide a piece of evidence for the way in which wood was collected, by using the young branches, which carry fruits. In addition, it might show a possible selection strategy in firewood gathering also managing the woodlands. Asouti & Kabukcu (2014) discussed the role of human and anthropogenic factors in the expansion of *Quercus* woodlands during early-mid Holocene in the Irano-Anatolian region (which includes the Zagros mountain range as well). They argued that by the increase in population and establishment of large settlements, prehistoric landscape management practices (like deliberate conservation or selective exploitation of taxa, etc.) restricted the grasses and woody species of Rosaceae and Maloideae as natural competitors for *Quercus*. In this regard, they concluded that, *Quercus* gradually overtook the managed areas and the oak-dominated woodland substituted the post-Pleistocene semi-arid grasslands. People were supported this expansion, by controlling the oak competitors with livestock grazing and firewood collecting, as well as enhancing the vegetative expansion of oak stands by coppicing, pollarding and shredding.

Nevertheless, the application of this idea to explain the presence and expansion of oak-dominated woodlands in the Zagros Mountain, particularly the southwestern part, should be made with careful consideration. The climatic and geographic conditions in southwest Zagros Mountain are different from Anatolia and played a significant role in the species expansion during the early- Holocene. In this regards, Djamali et al (2010b) studied the role of early Holocene climatic and hydrological changes of the Near East in the expansion of oak woodlands in the Zagros-Anti-Taurus- Mountains ranges. They have concluded that the atmospheric circulations controlled the precipitation pattern and seasonality during the early Holocene. Such atmospheric setting created a Mediterranean continental climate type with the winter-dominated precipitation over these mountain ranges, which is incompatible with the ecological demands of Zagros oak woodland species. Similarly, Robert et al. (2018) emphasized on the critical role of climatic shifts in vegetation change of southwest Asia during the last glacial-interglacial transition. They reconstructed the climate based on the stable isotope data and compared it with the demographic information as well as periods of vegetation changes, inferred from pollen and charcoal records.

The Zagros woodlands oak taxa (in particular *Q.brantii*), depend on spring precipitation for regeneration, and they are not tolerant to long dry seasons. Phytogeographical distribution of species implies that *Quercus brantii* reaches to its distribution limits in the southwestern Zagros and south of Shiraz (El-Moslimany 1986, Zohary 1973). In contrary to Asouti and Kabu Kabukcu (2014) which described the oak expansion with the aid of anthropogenic factor, Sagheb talebi (2014) described the unique capacity of Oak species, especially Brant's oak, to outcompete other taxa and form pure oak stands with low density (the number of species per ha) and species diversity. As he described based on the modern condition of Zagros oak woodland, the low canopy coverage of such vegetation led to an increase in the thickness of dry upper layer in the soil and consequently, regeneration of the trees from seedlings or saplings appeared very difficult in most oak forest stands.

Considering the presented evidence, we concluded that pistachio and almond abundance in Rahmatabad charcoal assemblage was most likely due to infrequent oak stands in the site surrounding, which was controlled by climatic factors, rather than the application of particular management practices by the inhabitants.

In addition, the botanical macro remains assemblage of the site contains a fragment of an oak acorn correspond to Chalcolithic period, while no *Quercus* has been identified in the Rahmatabad charcoal assemblage. This finding can be interpreted in different way and oak might have been used for other purposes than fuel. For instance, Grasso et al (2019) studied the different application of the deciduous oak wood in Salento Peninsula (Italy) during the Bronze to the Middle Ages. They showed the deciduous oak stands were reserved and used for constructing the buildings due to their mechanical properties. Alternatively, the oak acorns might have been collected separately for human consumption as described by Tengberg and Azizi (2016). Before starting with crop cultivation, acorns were among the important nourishing sources food for prehistoric communities when they depended on wild and edible plants (Rosenberg, 1984). The high nutritional value of oak acorns provided also a reliable fodder for the livestock (Beinlich et al. 2005; Sagheb talebi 2014; Taghi Mollaei, 2019). From ethnobotanical point of view, it has been shown that using the oak fruits, roasted or baked into bread, has a very old history in Iran and it is still in use by some local communities and nomads in the Zagros mountains (Encyclopedia Iranica; Sagheb talebi 2014; Zohary 1973). Besides all of the oak species with edible acorns, the Zagros oak (*Quercus brantii*) is the only species in Asia and more specifically in the Middle East which the acorns are used for making bread (FAO, 1995)

The absence of *Quercus* charcoal were reported similarly from other Neolithic sites during the early Holocene. For instance, in Pınarbaşı site in Konya basin (Anatolia) and in Tepe Abdul Hossein in western Zagros. Such results were linked to climatic variations as well as the anthropogenic impacts (Asouti & Kabukcu 2014; Roberts et al. 2018). Moreover, similar to Rahmatabad, Pınarbaşı charcoal assemblage showed a high frequency of *Prunus/Amygdalus* charcoal. It might be explained by the "Principle of Least Effort" in collecting the wood and other resources, which suggested by Théry-Parisot et al. (2010). Accordingly, this charcoal assemblage shows that other firewood sources like *Pistacia*, *Prunus/Amygdalus*, or *Tamarix* were available near to the sites while collecting oak wood from distant locations was difficult. Therefore, we proposed that prehistoric people tended to use the oak fruits rather than carrying its wood for fire over long distances, while, the higher growth rates in some taxa like *Tamarix* provided them with a renewable source of firewood in their vicinity.

As illustrated in figure 9, the genus *Tamarix* presents in all studied historical periods the highest proportions in Pre-Pottery Neolithic horizon (up to 50%) compared to the Chalcolithic period (~ 10%).

Tamarix is among the main associated taxa with riparian and moist habitat of the study area and the presence of such indicators is correlated to the location of Rahmatabad site close to Pulvar (Sivand) River (500 m distance). Therefore, the accumulated driftwood of fast growing riparian species could provide an easy source of firewood fuel at the riverbanks. Moreover, the charcoal assemblage of SU 3035 from Pottery Neolithic horizon (7038-6698 BC) comprises mainly *Tamarix* charcoal. Henry & Théry-Parisot (2009) argued that a mono-specific assemblage in an ethno-anthracological approach could reflect the wood management practices and the duration of the site occupation, which led to the development of different management strategies in exploiting the resources. The dominance of riparian taxa were also observed in other Neolithic sites in Konya (Boncuklu and Çatalhöyük) (Roberts et al. 2018), suggesting that the riparian species were important taxa in the initial occupation levels. In this regard and considering the correspondent age of this mono-specific subunit, appears more likely related to the early stages of settlement in Rahmatabad, which were continued for a long period (ca. 4000 years according to archaeological evidence).

Moreover, high values of tamarisk charcoal are congruent with the presence and fluctuations in the values of Cyperaceae family macro remains (Tengberg & Azizi 2016). Most likely because of the expansion in the peat bogs and the moist ecosystems in the vicinity of the sites. Worth to mention that such bogs and wetlands are still present near to the Rahmatabad site and Pulvar River (personal observation by Djamali).

Among the identified taxa in Rahmatabad charcoal assemblage, the presence of *Myrtus* in the Pottery Neolithic and Chalcolithic horizons (6-4.5 ka Cal BC) is interesting. *Myrtus communis* is one of the typical thermophilous species in the Mediterranean maquis. The phylogeographical survey on *Myrtus communis* has been used to study the floristic linkage between Mediterranean and Irano-Turanian floristic regions (Migliore et al, 2012). This species is known to exist as a natural Mediterranean relict element in the southern part of the Zagros Mountains, which forms small populations close to water bodies (Djamali et al, 2015; 2017). Myrtle charcoal in Rahmarabad assemblage thus shows the presence of relict populations in the Pulvar River basin at least since the sixth millennium BC, and shows that a suitable microclimate for cold-sensitive taxa like *Myrtus* did exist. Moreover, presence of myrtle pollen grains were reported from the sediment archives in the lower latitudes in Parishan Lake (Fars province) and Konar Sandal peat land (Kerman province) during the last 4000 years (Jones et al. 2015; Gurjazkaite et al 2018). In this regard, myrtle charcoal record of Rahmatabad might be the oldest evidence for the cultivation or natural occurrence of *Myrtus communis* near to human settlement, as hypothesized by Gurjazkaite et al. (2018).

7.6. Conclusion:

The anthracological study of archaeological wood charcoal remains of the Rahmatabad site provides data on the woody vegetation composition of the study area during the Pre-Pottery Neolithic to Chalcolithic period. The results are compatible with the historical evidence about the socio-economic changes at the site. The species composition of the charcoal assemblages shows that Rahmatabad was located within the Zagros woodland vegetation type and is in accordance with the archaeological charcoal composition for the Southeastern Anatolia, North Iraq and west of Iran during early Holocene and Pre-Pottery Neolithic period (Roberts et al. 2018). Therefore, it suggests a relatively similar vegetation composition around the prehistoric settlements in the eastern part of the Fertile Crescent and along the Zagros-Anti Taurus Mountain ranges.

In this regards, the present study showed that the oak stands were located in far distances of Rahmatabad site and its distribution mainly defined by the climatic changes. Moreover, beside the data from archaeobotanical macro remains, the present study the possible consumption of oak acorns by Rahmatabad inhabitants.

Pistacia and *Prunus*/*Amygdalus* trees were likely more abundant in the Early Holocene compare to vegetation reconstructions based on palynological data (Matthews 2013). These taxa generally present in low concentrations in the pollen records because of the pollen dispersal (pistachio) and the pollination strategy (almond) (Asouti 2005, Asouti and Austin 2005). The present study showed the existence and application of *Prunus*/*Amygdalus* vegetation in the last 8000 years. The fact demonstrates the value of anthracology in revealing the dynamics of under-represented taxa, like Rosaceae, in pollen records.

The variation of the taxa frequency is in accordance with the possible woodland management and different exploitation practices by Neolithic people. The present study suggests that Rahmatabad inhabitants employed pistachio, and almond stands mainly as a source of wood. In the Kur River Basin, the archaeological charcoal assemblage of Tepe- Malyan, demonstrated a high frequency of *Juniperus* wood, beside the pistachio and almond, as the main sources of firewood during the fourth to second millennia (Miller, 1985). Accordingly, Miller (1985) suggested a progressive deforestation period in SW Zagros during the third millennium. When *Juniperus* has been depleted from the common tree association of the area, due to the increase in economic activities of the prehistoric population. Considering the location and ecological condition of the Rahmatabad site, a relatively similar vegetation composition between these sites is envisaged. Nevertheless, no *Juniperus* has been identified in the Rahmatabad site as evidence of forest exploitation in earlier periods. This results could be interpreted in different ways; a) the presence of *Juniperus* in very local stands close to the Malyan site, which were absent in Rahmatabad vicinity; b) the higher density of forest and therefore availability of fuel around Rahmatabad, which is expectable because of the site location in Pulvar River valley (Tange-Bolaghi). Therefore, people did not need to travel to higher altitudes with *Juniperus* and *Quercus* vegetation to collect wood. c) Bigger population size in Malyan with socio-economic development which created a higher demand for firewood in Malyan (Miller 1985). The last idea is compatible with Jones et al (2018) which argued that the number of archaeological settlements and the population levels in Zagros-Anti-Taurus region during the early Holocene and Neolithic time were not sufficient to change the regional vegetation. This idea is also supported by the presence of the mono-specific assemblage of riparian taxa (*Tamarix*), which shows the in early stages of the occupation during the 4^{th}-5^{th} millennia in Rahmatabad site. Further investigation is needed to develop a comprehensive outline about the Southwestern Zagros vegetation in early Holocene.

The Myrtle charcoal represented in Rahmarabad assemblage since the sixth millennium BC, with the first presence in Pottery Neolithic (Mushki local phase) at of 6217-6028 cal yr BC. This period is correspondent to the 8.2 climatic event. The period of an abrupt decrease in the temperature for 2-4 centuries, which started at 6200 BC. It has been proposed that this climatic event influenced the population replacement and settlement abandonment in Turkey and SW Europe. However, the archaeological evidence did not support a systematic regional scale impacts on human communities by this event, although local impacts were observed (Jones et al. 2018). It has been argued that after 6300 cal BP the drier climate of Iran, compare to other parts of SW Asia, ameliorated with gradual increase in humidity and precipitation. In this regard, and according to the favored ecological condition by *Myrtus*, we suggest that the Pulvar River basin had not been influenced by the 8.2 cooling events and had provided a suitable microclimate for cold-sensitive relict taxa like myrtle.

8. Conclusion

As a contribution to the Paleo-Persepolis project, the present study aimed at studying the regional vegetation dynamics, also in revealing the landscape change and human/anthropogenic activities in the Persepolis basin during Holocene epoch. With a near-continuous history of human occupation (since 7000 BC) in the basin, the anthropogenic impacts also considered in developing an overview of the vegetation change. In this regards, a reference collection (wood and charcoal) and then an anatomical identification key were developed to help the anthracological identifications, which are a novelty in SW of Iran, and to fill the gap in supporting information. The modern woody flora of the basin is very similar to the reconstructed woody flora since the Neolithic period in terms of dominant species. The presence and abundance of *Prunus* (syn: *Amygdalus*) and *Pistacia* species through the last 8000 years is supported by the anthracological survey in Tepe-Rahmatabad site as well as the palynological record. The presence of *Quercus* species (most likely *Q. brantii*), as common taxa in the higher elevations of Zagros Mountains, is also supported by a continuous curve of *Quercus* pollen type during the last ~ 4000 years. Although the archaeological charcoals of Rahmatabad site did not contain the oak wood, findings of acorn remainsdrew back the presence of oak stands in the studied area to the Neolithic period.

The palynological investigations in Maharlou Lake depicts the natural vegetation change, arboriculture, and agricultural activities during the last ~ 4000 years in the study area, which was the heartland of the important Persian kingdoms (especially Achaemenids). This survey showed *Platanus*, *Punica granatum*, *Vitis*, *Ficus*, *Olea*, *Juglans* and *Phoenix dactylifera* have been the main cultivated trees in the southern part of the Persepolis basin and Maharlou Lake watershed. In the present study and with the support of a newly established robust radiocarbon chronology for the reconstructed pollen record, we conclude that the arboriculture peak in Maharlou basin occurred during post-Sasanian Iranian dynasty of Buyids, postdating the similar peak in the nearby Basin of Parishan Lake and relatively at the same time with northern Zagros.

Moreover, we identified the pollen of pomegranate as a formerly unproved arboricultural element in the study area. The considerable distance between Maharlou basin and natural pomegranate stands in Iran, besides the specific palynology of pomegranate, suggest the presence of large-scale pomegranate plantation in nearby orchards. This proposal is supported by the historical information from the Persepolis Fortification Archive (Henkelman, 2013). In accordance with historical information, the present study illustrates the importance of arboriculture in ancient Persia and more specifically for the Achaemenid period. The covariation of indigenous trees (e.g. *Platanus* and Cupressaceae) pollen frequencies with cultivated trees are congruent with the archaeological evidence from the basin and with the hypothesis about ‘Persian gardens’. This change in pollen values, supports the idea of using cypress and plane timber by Sasanian and early Muslim dynasties in the buildings, although, this type of tree cultivation might have been started in the late Elamite period, as shown by the present study.

The highest intensity of arboricultural activities was inferred from correspondent pollen values of the Sasanians to the Early Islamic periods. It showes the prosperity of tree plantation and agriculture in Fars province during Buyids dynasty; which declined by the Mongol invasion (~1220 AD) and never reached the same level during the subsequent periods. As described in historical references (Encyclopedia Iranica) following the Mongols invasion, Ilkhanate (1256-1335 AD) dominated and severly destroyed the natural and man-made landscape of Fars province. Besides the palynological evidence, this historical event is also reflected in the reconstructed fire history of the watershed.

A general increase in the charcoal (micro charcoal and small-sized macro charcoal particles) influx into the lake suggests a regional and large-scale biomass burning during this period. a period of decrease in *Pistacia-Amygdalus* woodlands in Maharlou Lake basin has been postulated during the Parthians period and a few decades after the destructive conquer of Alexander. This event might also been correlated with the macro charcoal inferred fire events between ~ 2200-2000 cal yr BP. The period of pistachio-almond woodland loss would have coincided with the lifestyle change of inhabitants of the basin, likely towards pastoral nomadism. In the same period, the correspondent pollen record represents growth in agriculture and a decrease in herbaceous vegetation. Moreover, this phase of change in vegetation is compatible with the period of the stable hydrological conditions in the Lake basin. Altogether, the reconstructed fire episodes, vegetation, palaeo-hydrology, and the inference about the dominant lifestyle of the basin, suggest a deliberate use of local fires. They most likely occurred as frequent events with scattered and low magnitude fires across the watershed to prepare the land for dry farming.

In the human–climate–environment interactions, the vegetation has a fundamental position to control as well as being affected by natural and anthropogenic environmental change. The most effective ecological factors on the plant communities are the availability of water and moisture. The hydrological stress and long-term imbalance in evapotranspiration/ uptake rate increase the vegetation sensitivity to any change in other factors, and most specifically, the anthropogenic impacts. The pollen and charcoal inferred vegetation dynamics in the present study, appears high compatible with the reconstructed paleohydrology and the sequence of historical events in the basin. However, we suggest that anthropogenic activities have played the leading role in changing the vegetation of the study area, which was enhanced by climatic variations. The 8.2ka and 4.2ka events are among the important abrupt climatic events during the Holocene that have affected the Northern Hemisphere climate and therefor the southwestern part of Asia. The 8.2ka event was a period of decrease in the temperature for 2-4 centuries, which started at 6200 BC. It has been proposed that this climatic event influenced the population replacement and settlement abandonment in Turkey and SW Europe. However, the archaeological evidence did not support a systematic regional scale impacts on human communities by this event, although local impacts were observed. It has been argued that after 6300 cal BP the drier climate of Iran, compare to other parts of SW Asia, ameliorated with gradual increase in humidity and precipitation. The present study shows anthracological evidence from Rahmarabad site representing a typical Mediterranean tree of *Myrtus communis* in the study area and since the sixth millennium BC. In this regard, we suggest that some parts of the study area, like Pulvar River basin, had provided a suitable microclimate for Mediterranean relict taxa like myrtle.

In contrary to 8.2ka event, the 4.2ka has been described as a period of drying by some researchers and as a complex series of dry/wet events by others. In the South East of Iran the impacts of this event on settlement and irrigation systems is shown by geomorphological studies. It has been shown recently that this event covered an interval between 4.3 and 3.8 ka in the Mediterranean Basin. The present palynological study and fire history reconstruction reveal the vegetation changes in Maharlou Lake basin during the last ~ 3700 years. In addition, with the anthracological study of Tepe Rahmatabad we represent older evidence of local changes in landscape and vegetation during the Pre-Pottery Neolithic to Chalcolithic (~ 10000 – 6000 yr BP) periods. Therefore, considering the period of 4.2ka event, the investigated periods by the present study do not overlap with this abrupt climatic event.

Perspectives and future directions

The findings described in this thesis open up a number of additional research topics, which will lead to a better understanding of human–climate–environment nexus in the Persepolis basin and the southwest of Iran in the eastern corner of the Fertile Crescent. In comparison to the nearby basin of Lake Parishan, the seemingly more robust age-depth model of present palynological study supports a delayed start in intensified arboriculture in Maharlou basin. Nevertheless, further palynological investigations, as well as historical and archaeological evidence, are required for supporting this argumentation.

Moreover, in the present study we developed the first fire history reconstruction in the country based on different charcoal proxies (micro- and macro charcoal). We examined the potential of using the macroscopic charcoal count and area to study fire history in Persepolis basin, and showed the advantage of the charcoal area in such studies in semi-arid regions. However, similar surveys in other sites, as well as complementary pedo-anthracological records, are required to build up a comprehensive history of fire occurrence in the area. In this regard, we suggest investigating the other sites that provide older sediment records and possibly with less fluctuation in hydrology and sedimentation rates, compared to the Maharlou Lake.

The present study is an attempt to provide a comprehensive key and reference collections (wood and charcoal) for the Persepolis region. However, complementary surveys with more samples are necessary to cover a wider range of anatomical modifications of the species under different ecological conditions. The identification key and the collections facilitates the study of woody species or charcoal by the anatomical features also the soil charcoal analysis (pedo-anthracology) in future. The intensive modern land use as well as soil erosion in the past made it difficult to perform pedoanthracological survey in the present study. To perform soil charcoal analysis in such landscapes, finding suitable soil charcoal records, conducting a thorough field surveys with test samplings, and sieving soil samples sieved locally are necessary.

As shown by previous studies, the frequency of archaeobotanical surveys and records in the Persepolis region are infrequent. In the present study, we performed an archaeological charcoal analysis, which corresponds to a limited period in antiquity.Considering the restricted spatial and temporal vegetation reconstructions by archaeolobotanicalassemblage, it appears necessary to expand the study to further sites around the region. Additionally, the archaeological charcoal assemblages from other important historical periods (e.g. the Achaemenid Empire) are required to complete this archaeobotanical data.

Supplements

S3 : Chapter 3

Table S33-0-1: Floristic list of trees and shrubs in Persepolis Basin based on literature (Asadi et al 1989-2019; Mozzafarian 2005; Rechinger 1966)

No	Species	Plant Family
1	*Acer monspessulanum subsp. Cinerascens*	Aceraceae
2	*Amygdalus communis*	Rosaceae
3	*Amygdalus eburnea*	Rosaceae
4	*Amygdalus elaegnifolia subsp. Leiocarpa*	Rosaceae
5	*Amygdalus erioclada*	Rosaceae
6	*Amygdalus glauca*	Rosaceae
7	*Amygdalus lycioides var.lycioides*	Rosaceae
8	*Amygdalus reticulata*	Rosaceae
9	*Amygdalus scoparia*	Rosaceae
10	*Andrachne fruticulosa*	Euphorbiaceae
11	*Astragalus baba-alliar subsp. Baba-alliar*	Papilionaceae
12	*Astragalus fasciculifolius subsp. Arbusculinus*	Papilionaceae
13	*Astragalus fasciculifolius subsp. fasciculifolius*	Papilionaceae
14	*Atraphaxis spinosa*	Polygonaceae
15	*beris integrima*	Berberidaceae
16	*Celtis caucasica*	Ulmaceae
17	*Cerasus brachypetela var.brachypetela*	Rosaceae
18	*Cerasus microcarpa subsp.diffusa*	Rosaceae
19	*Cerasus microcarpa subsp.tortusa*	Rosaceae
20	*Citrus aurantifolia*	Rutaceae
21	*Citrus aurantium*	Rutaceae
22	*Citrus deliciosa*	Rutaceae
23	*Citrus limetta*	Rutaceae
24	*Citrus limon*	Rutaceae
25	*Citrus sinensis*	Rutaceae
26	*Clematis ispahanica*	Ranunculaceae
27	*Clematis orientalis*	Ranunculaceae
28	*Colutea persica*	Papilionaceae
29	*Crataegus turkestanica*	Rosaceae
30	*Daphne stapfii*	Thymelaeceae
31	*Dendrostellera lessertii*	Thymelaeceae
32	*Ebenus stellata*	Papilionaceae
33	*Ephedra foliata*	Ephedraceae
34	*Ephedra intermedia*	Ephedraceae

No	Species	Plant Family
35	*Ephedra pachyclada*	Ephedraceae
36	*Ephedra procera*	Ephedraceae
37	*Ephedra strobolacea*	Ephedraceae
38	*Ficus johanis*	Moraceae
39	*Fortuynia bungei*	Cruciferae
40	*Fraxinus rotundifolia subsp.persica*	Oleaceae
41	*Fraxinus rotundifolia subsp.rotundifolia*	Oleaceae
42	*Gymnocarpus decander*	Caryophllaceae
43	*Hertia angustifolia*	Compositeae
44	*Lonicera nummulariifolia*	Caprifoliaceae
45	*Lycium depressum subsp. depressum*	Solanaceae
46	*Malus orientalis*	Rosaceae
47	*Moriera spinosa*	Cruciferae
48	*Morus alba*	Moraceae
49	*Myrtus communis*	Mytraceae
50	*Nerium indicum*	Apocynaceae
51	*Olea europea*	Oleaceae
52	*Otostegia michauxii*	Labiatae
53	*Paliurus spina-christii var spina-christii*	Rhamnaceae
54	*Persica vulgaris*	Rosaceae
55	*Phlomis elliptica*	Labiatae
56	*Pistacia atlantica subsp. Mutica*	Anacardiaceae
57	*Pistacia khinjuk*	Anacardiaceae
58	*Platanus orientalis*	Platanaceae
59	*Populus afghanica subsp.afghanica*	Salicaceae
60	*Populus alba*	Salicaceae
61	*Populus caspica*	Salicaceae
62	*Populus euphratica*	Salicaceae
63	*Prosopis farcta*	Mimosaceae
64	*Prunus*domestica*	Rosaceae
65	*Pteropyrum aucheri*	Polygonaceae
66	*Pteropyrum olivieri*	Polygonaceae
67	*Punica granatum*	Punicaceae
68	*Pyrus glabra*	Rosaceae

No	Species	Plant Family
69	*Pyrus syriaca*	Rosaceae
70	*Quercus brantii*	Fagaceae
71	*Rhamnus persica*	Rhamnaceae
72	*Rhus coriaria*	Anacardiaceae
73	*Rosa beggeriana*	Rosaceae
74	*Rosa canina*	Rosaceae
75	*Rosa damascena*	Rosaceae
76	*Rosa elymatica*	Rosaceae
77	*Rosa foetida*	Rosaceae
78	*Rosa moschata*	Rosaceae
79	*Rubia albicaulis*	Rubiaceae
80	*Rubia florida*	Rubiaceae
81	*Salix acmophylla*	Salicaceae
82	*Salix aegyptica*	Salicaceae
83	*Salix excelsa*	Salicaceae
84	*Salix triandra*	Salicaceae
85	*Salix wilhelmsiana*	Salicaceae
86	*Syringa persica*	Oleaceae
87	*Tamarix szowitsiana*	Tamaricaeae
88	*Vitex psuedo-negundo*	Verbenaceae
89	*Vitis vinifera*	Vitaceae
90	*Zataria multiflora*	Lamiaceae
91	*Ziziphus jujuba*	Rhamnaceae
92	*Ziziphus spina-christii*	Rhamnaceae
93	*Zygophyllum eurypterum subsp. Gontscharowii*	Zygophyllacrar

Table S3-0-2: The studied diagnostic microscopic features according to IAWA (1989)

code	Family	Genus	species	author

growth ring		1- Distinct	
		2- Indistinct	
vessels	Porosity	3- Ring- porous	
		4- Semi Ring- porous	
		5- Diffuse- porous	
	arrangement	6-Tangential	
		7-Diagonal/Radial	
		8-Dendric	
	grouping	9-Solitary	
		10-4 or more	
		11-cluster	
	perforation plate	13-simple	
		14-scalariform (bars no.)	
		19-Reticulate or other	
	intervessel pits	20-Scalariform	
		21-opposite	
		22-alternate	
		23-polygonal	
		size	
	vessel ray pitting	30-distinct border	
		31- reduced border	
		33- 2 sizes in one cell	
	36- Spiral thickening		
	mean diameter of lumina	40-D≤ 50 µm	
		41- 50<D≤100 µm	
		42- 100<D≤200 µm	
		40-D≥ 200 µm	

60- vascular/ vasicentric tracheids		
ground tissue fibers	61- simple to minutely bordered pit	
	62- distinct bordered pit	
	63- pits in radial and tangential walls	
Axial paranchyma	75-absent or extreamly rare	
	apotracheal	
	paratracheal	
Banded paracnchyma	85-> 3 cells in width	
	86-≤ 3 cells in width	
	87-reticulate	
	88-scalariform	
	89-marginal	
Ray width	96- exclusively uniseriate	
	97-cells 1-3	
	98- cells 4-10	
	99- mainly >10 cells	
	100- multiseriate and uniseriate	
101-aggregate rays		
Ray composition	Homogenous	
	Heterogenous	
storied structures	118-all rays storieid	
	120-axial paranchyma and/or vessel elements	
	121- fiber elements	
	123- no. of rays tiers per axial mm	
	non-storied	
Intercellular canals	Axial	
	Radial	
Vessel Connection form	horizontal	
	oblique	

The anatomical images of newly studied species

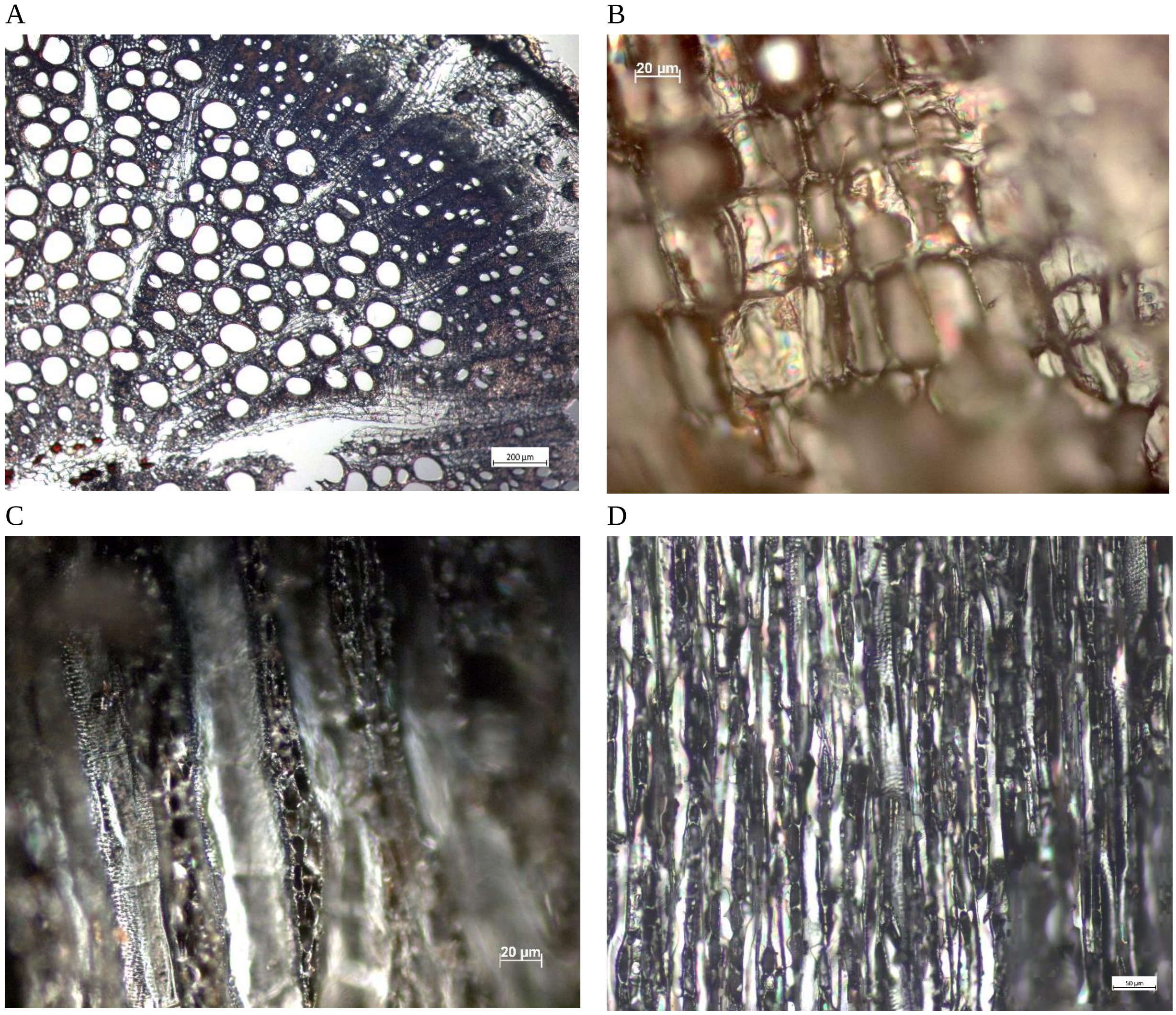


Figure 3-2: A: *Alhagi comelorum*, Transverse section (wood), B: *Alhagi comelorum*, Radial section, rays (charcoal). C: *Alhagi comelorum*, Tangential section-biseriate rays (charcoal), D: *Alhagi maurorum* : Tangential section- ubiseriate rays (charcoal).

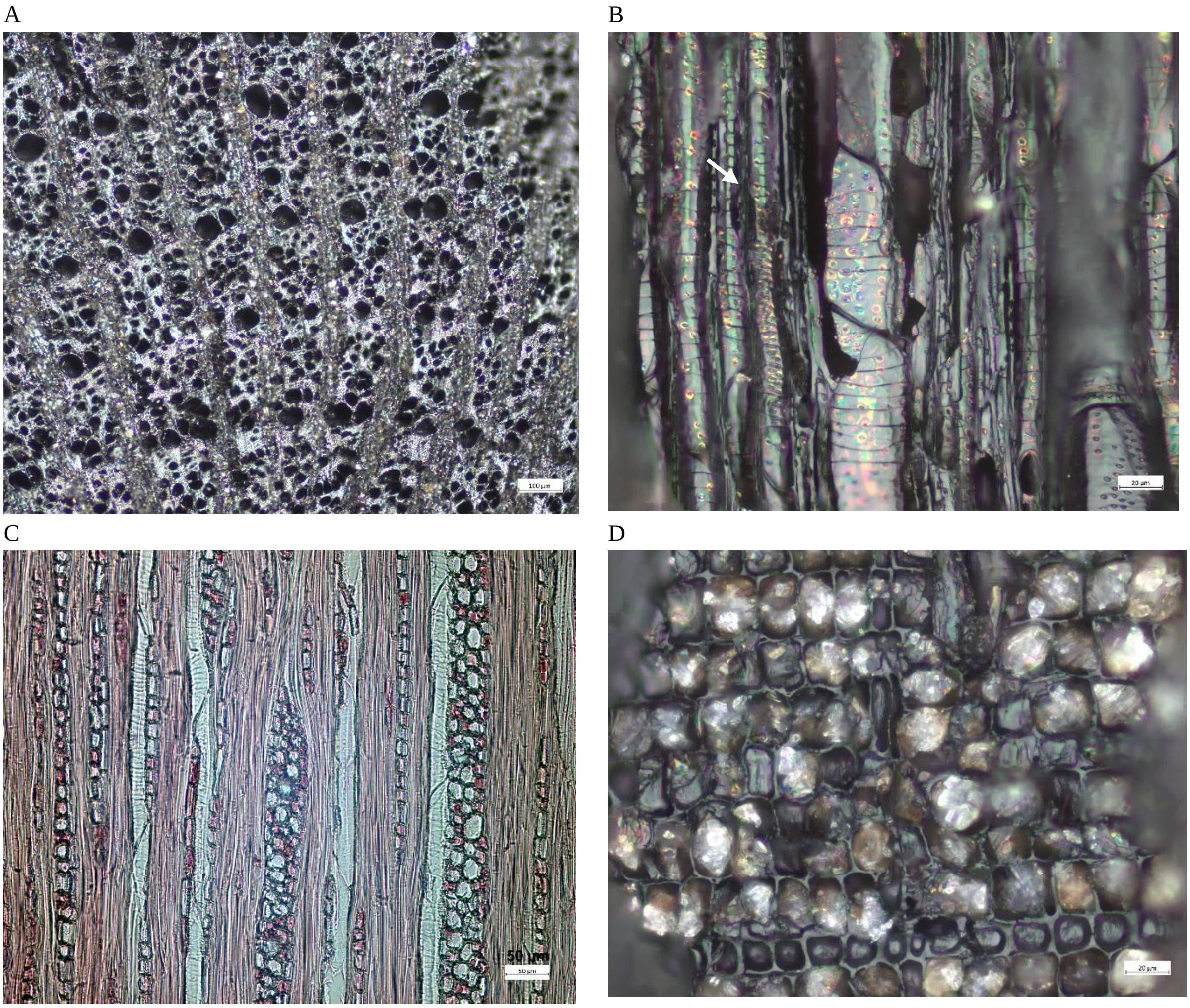


Figure S3-3: *Amygdalus eburnea*, A: Transverse section (charcoal), B: Tangential section, spiral thickening (charcoal) ,C: Tangential section, rays (wood), D: Radial section, rays (charcoal).

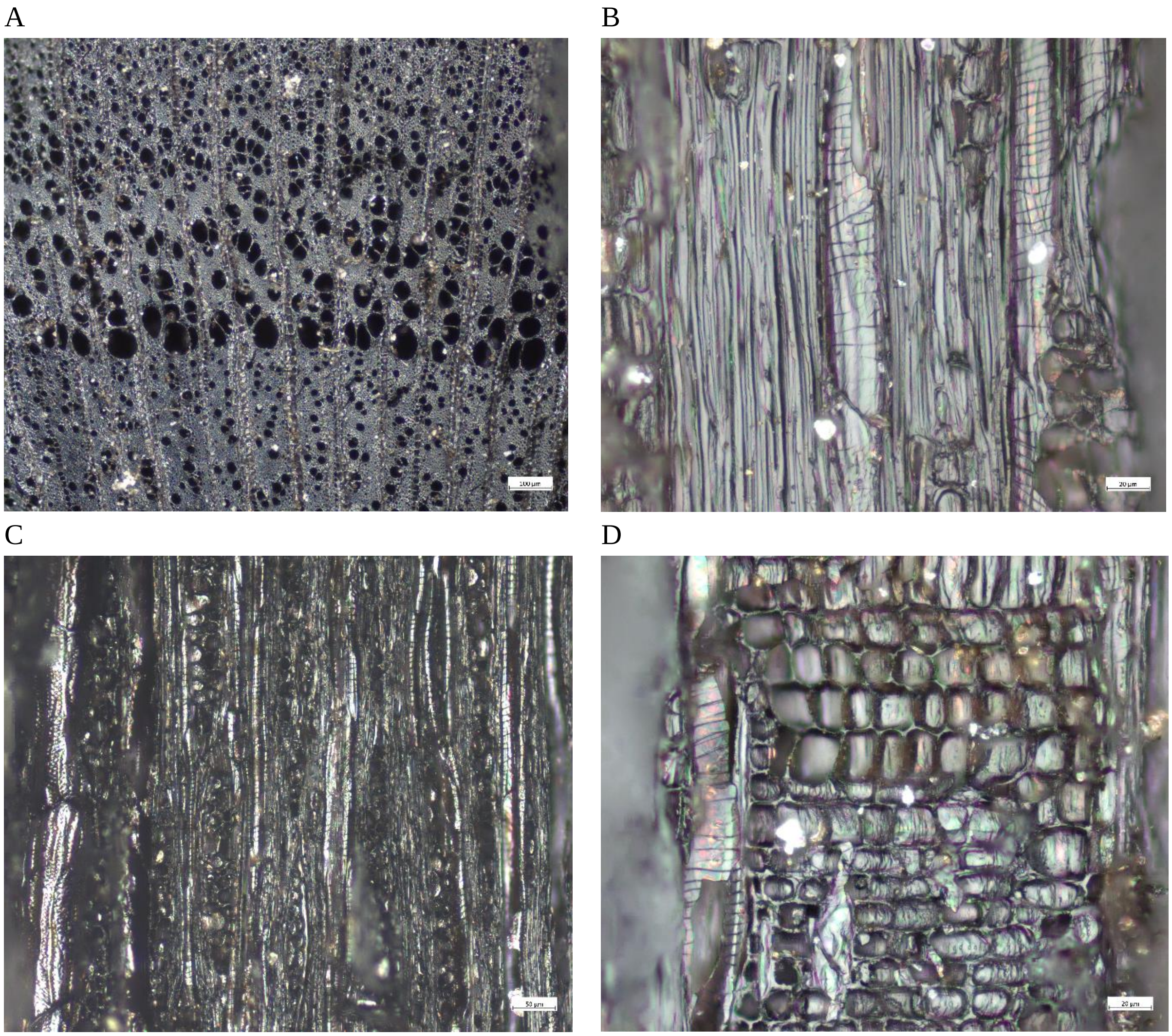


Figure S3-4: *Amygdalus scoparia*, A: Transverse section (charcoal), B: Tangential section, spiral thickening (charcoal) ,C: Tangential section, rays (charcoal), D: Radial section, rays (charcoal).

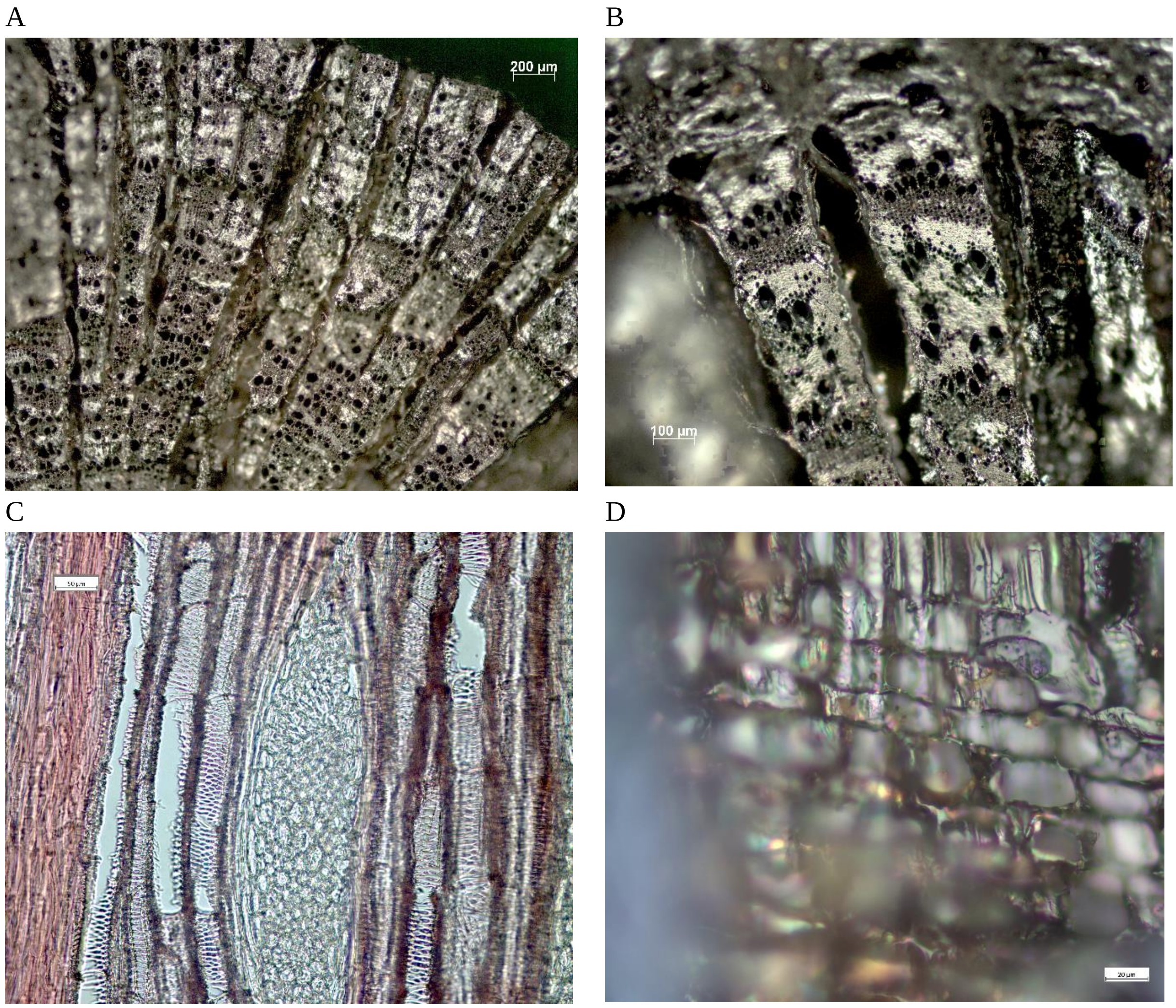
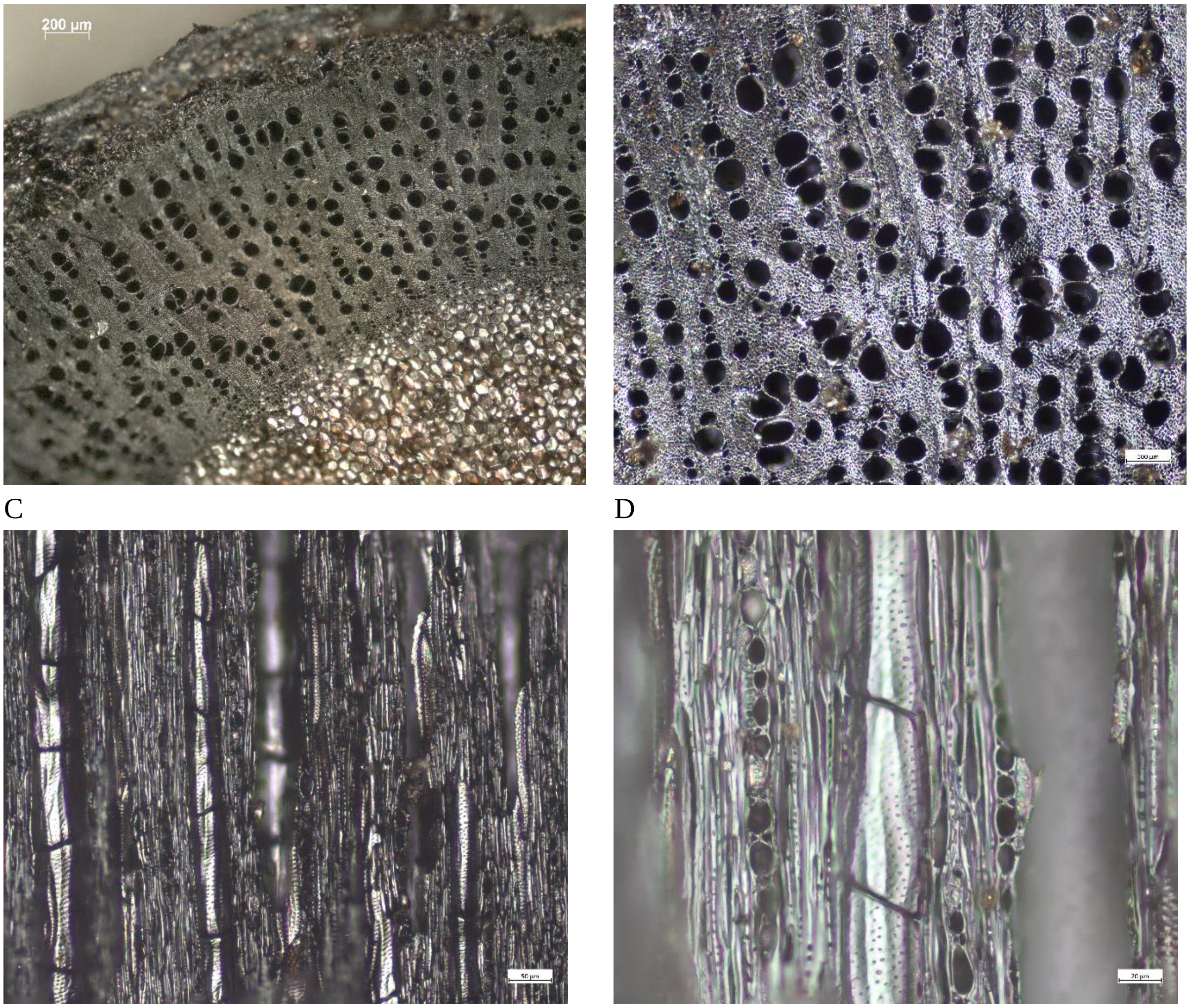


Figure S3-5: A: *Astragalus fasciculifolius*, Transverse section (charcoal), B: *A. glaucacanthus*, Transverse section, apotracheal paranchyma in tangential bands (charcoal), C: *Astragalus fasciculifolius*, Tangential section, ray (wood), D: *Astragalus fasciculifolius*, Radial section, rays (charcoal).

A B



C D

E

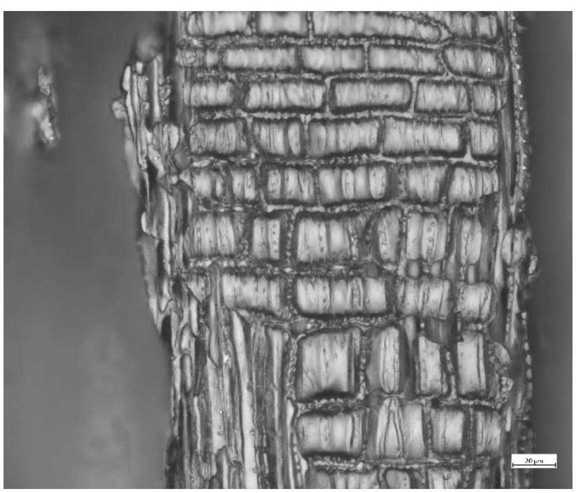


Figure S3-6: *Capparis spinosa*: A, Transverse section (charcoal), B, Transverse section, radial arrangement of vessels (charcoal), C, Tangential section (charcoal), D, Tangential section, uniseriate ray (charcoal), E, Radial section (charcoal).

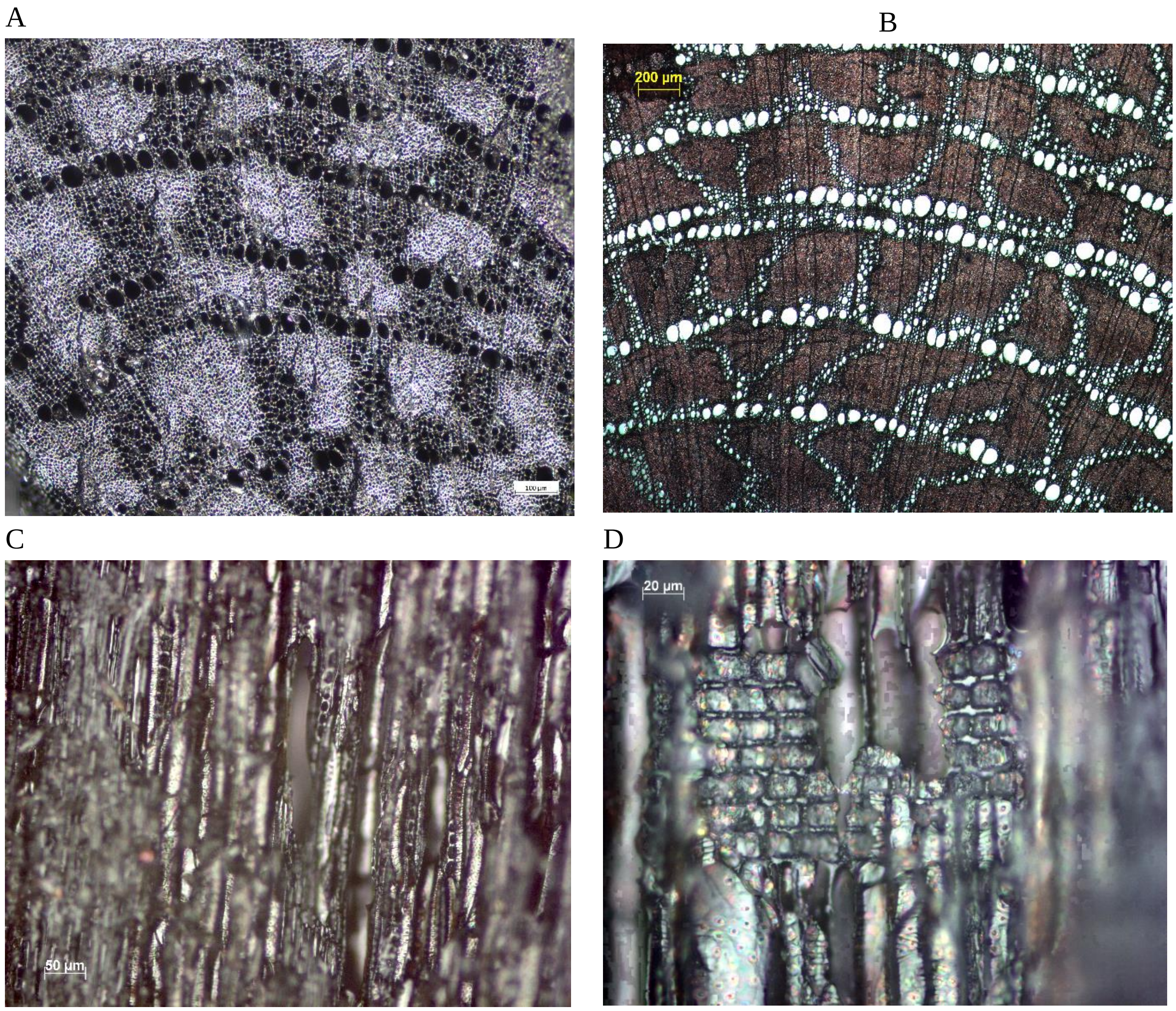
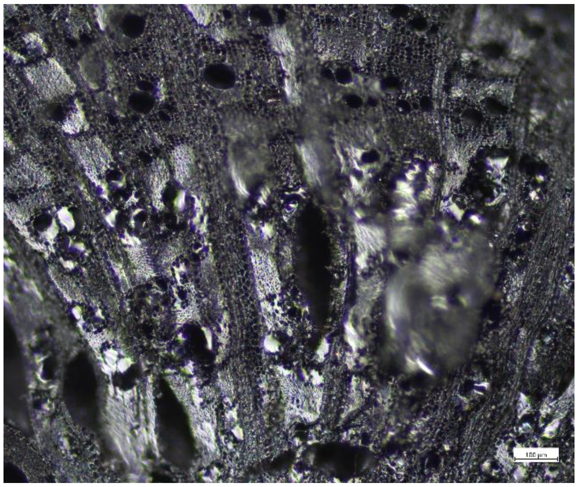
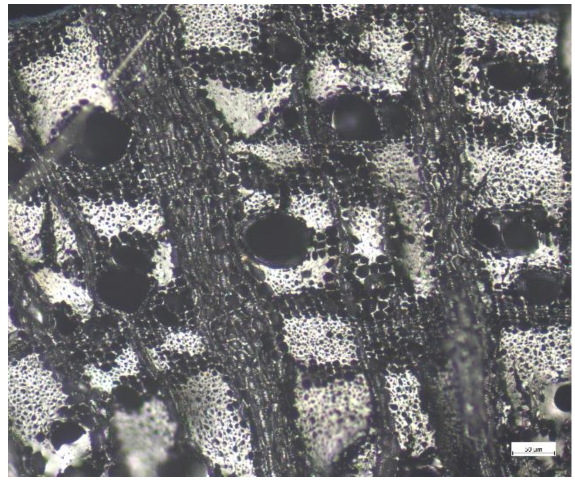


Figure S3-7: *Daphne mucronata*: A, Transverse section (charcoal), B, Transverse section- flame-like arrangement of late vessels, (wood), C: Tangential section (charcoal), D: Radial section (charcoal)

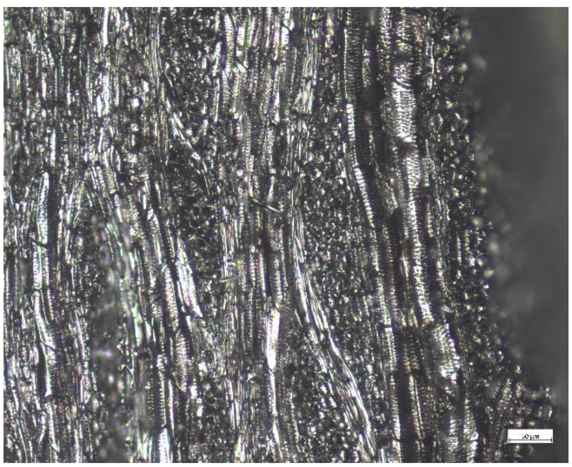
A



B



C



D

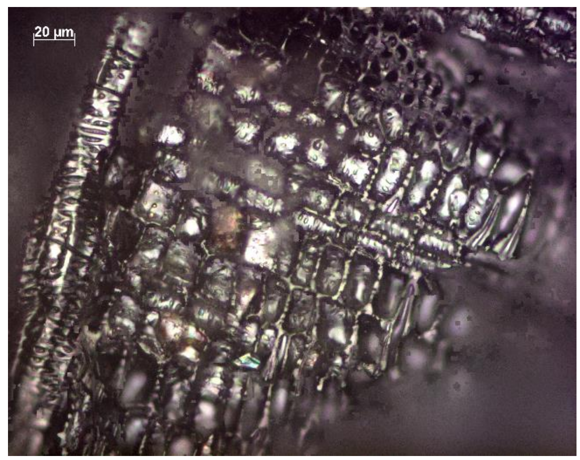


Figure S3-8: *Ebenus stellata*: A, Transverse section (charcoal), B, Transverse section- banded axial parenchyma, (charcoal), C: Tangential section-broad rays (charcoal), D: Radial section (charcoal)

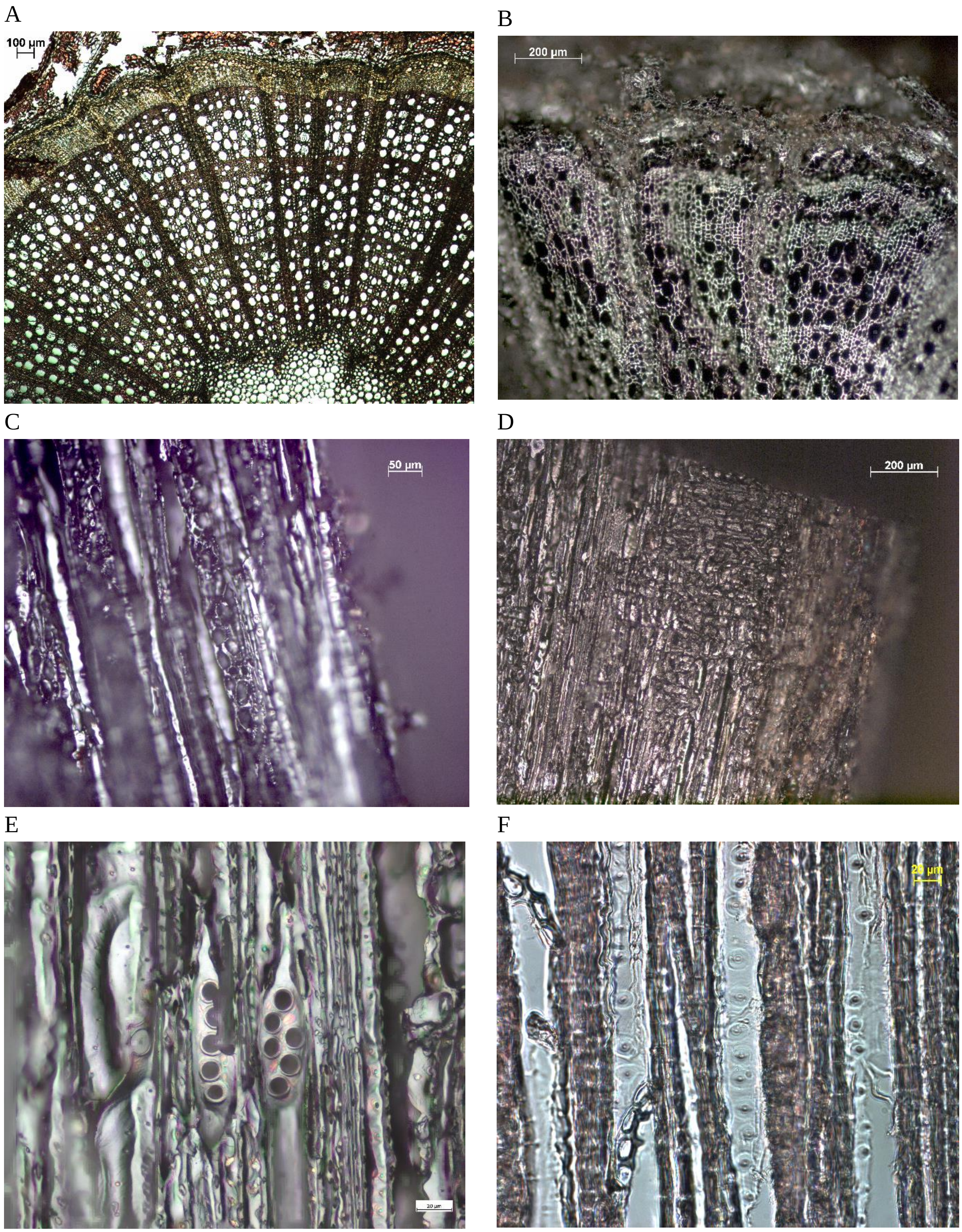
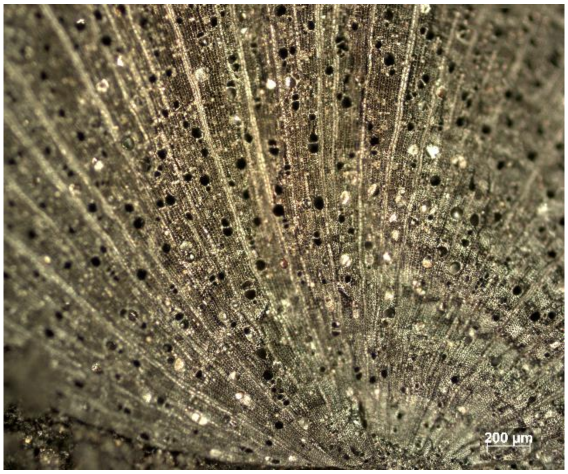
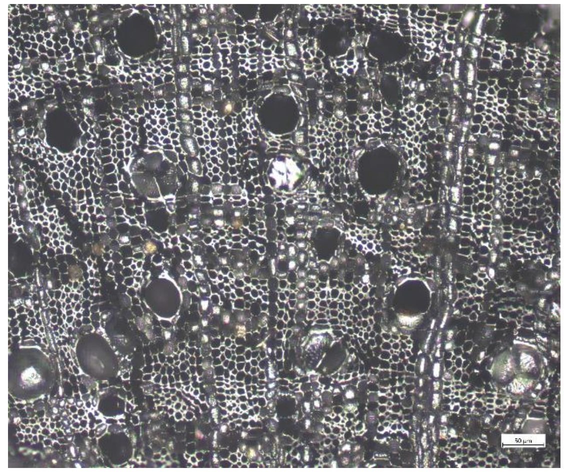


Figure S3-9: *Ephedra foliata*: A, Transverse section (wood), B, Transverse section- banded parenchyma, as year ring borders (charcoal), C: Tangential section (charcoal), D: Radial section (charcoal), E: foraminate perforation plate (charcoal), F: bordered pits (wood)

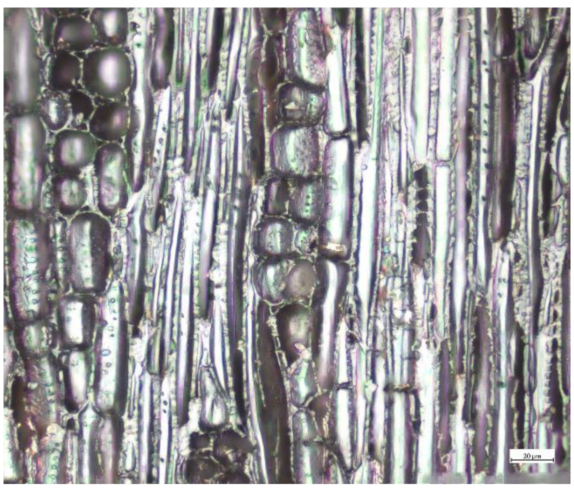
A



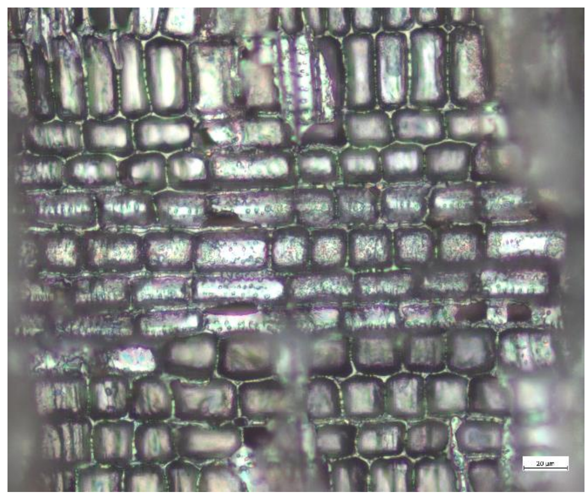
B



C



D



E

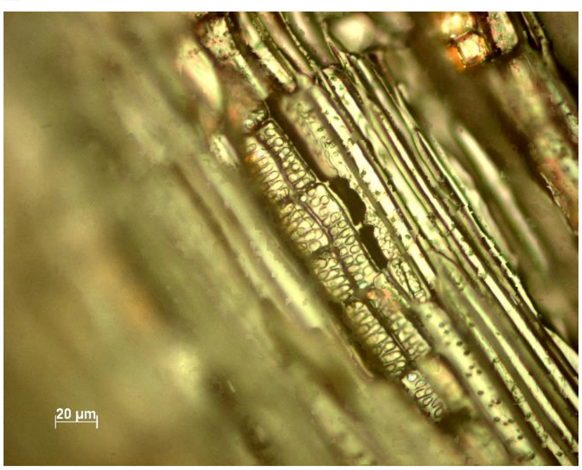
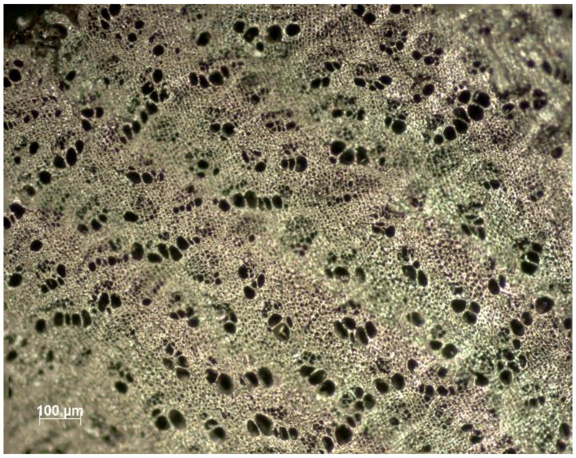
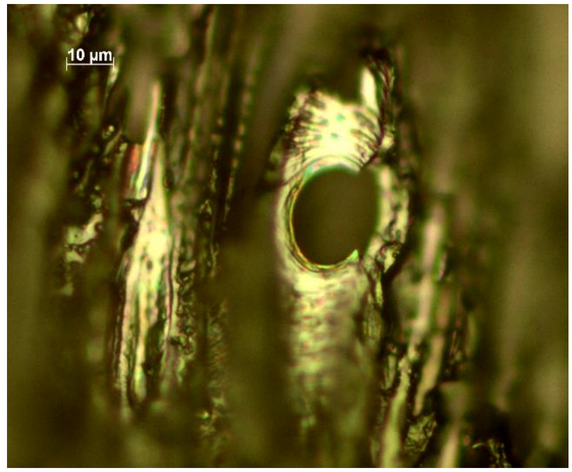


Figure S3-10: *Ficus johanis*: A, Transverse section (charcoal), B, Transverse section- paratracheal parenchyma and tylosis, (charcoal), C: Tangential section (charcoal), D: Radial section (charcoal), E: ray-vessel pits (charcoal).

A



B



C

Figure S3-11: *Halocnemum strobilaceum*: A, Transverse section- included phloem (charcoal), B, Tangential section- simple perforation plate, (charcoal), C: Tangential section- vessel pits (charcoal).

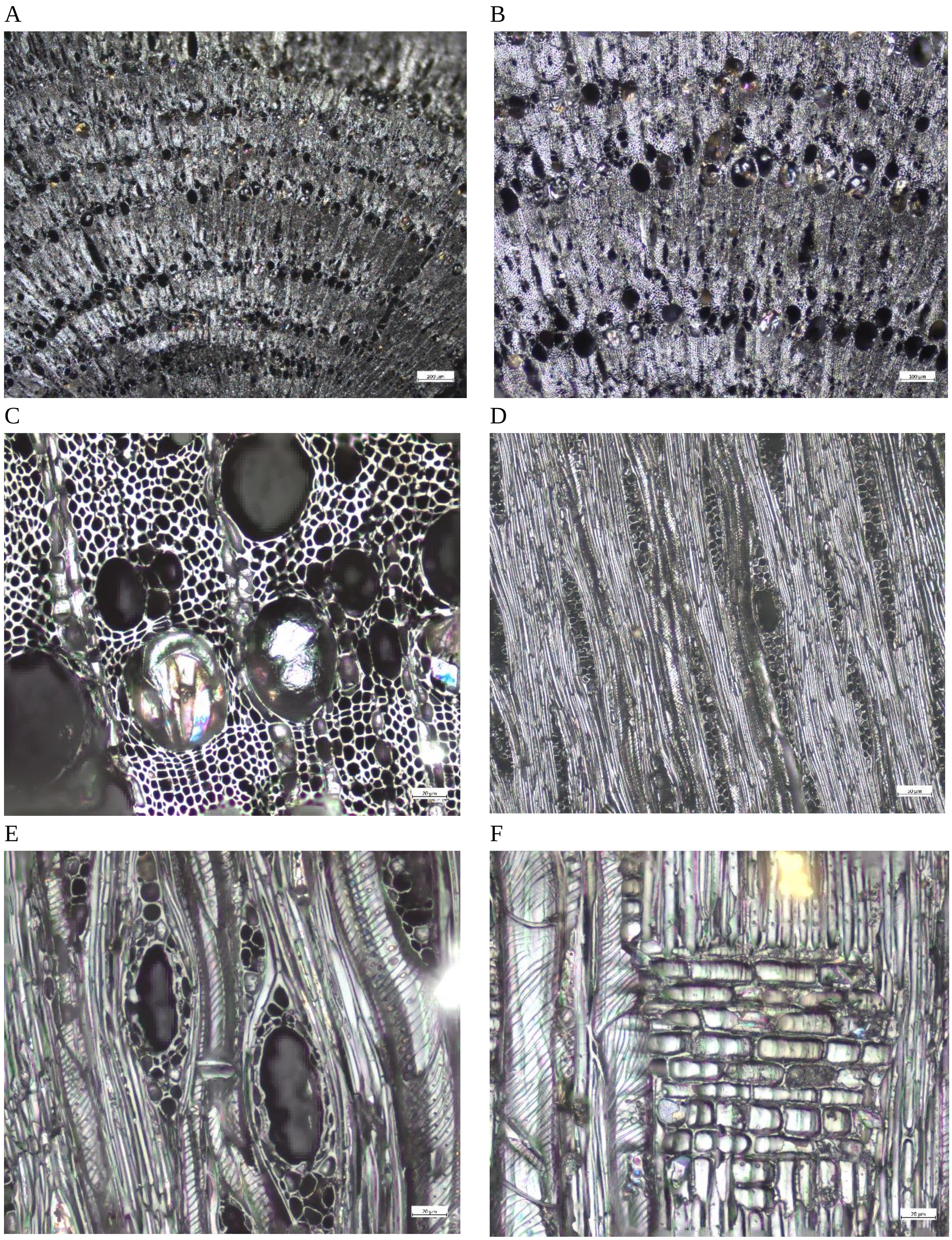


Figure S3-12: *Pistacia atlantica*: A & B, Transverse section (charcoal), C: Transverse section- Tylosis (charcoal), D: Tangential section (charcoal), D: Tangential section (charcoal), E: Tangential section - resin canals, spiral thickening in fibers and vessels with bordered pits (charcoal). F: Radial section (charcoal).

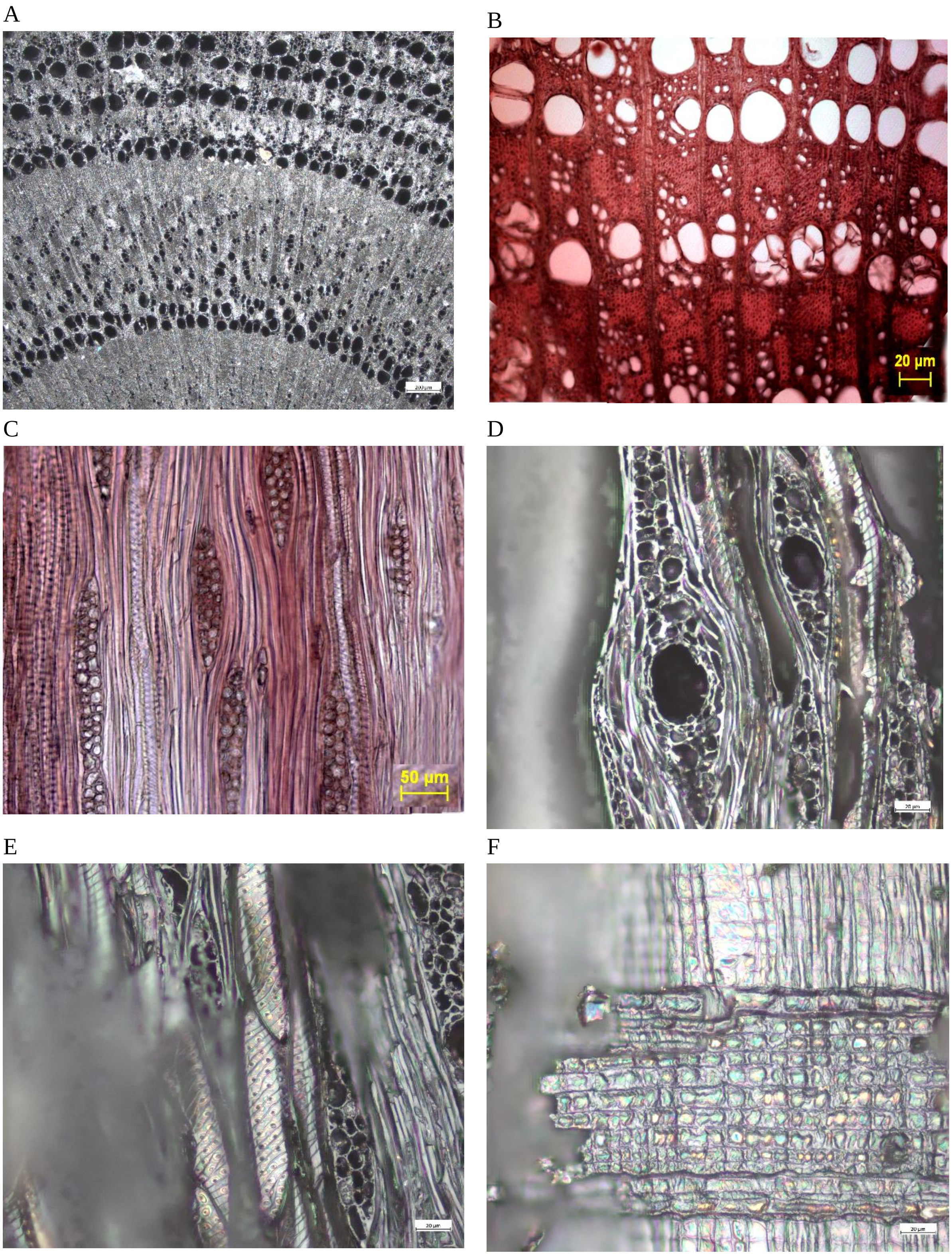


Figure S3-13: *Pistacia khinjuk*: A: Transverse section (charcoal), B: Transverse section- Tylosis (wood), C: Tangential section (wood), D: Tangential section - resin canals, E: Tangential section- spiral thickening and bordered pits (charcoal), F: Radial (charcoal).

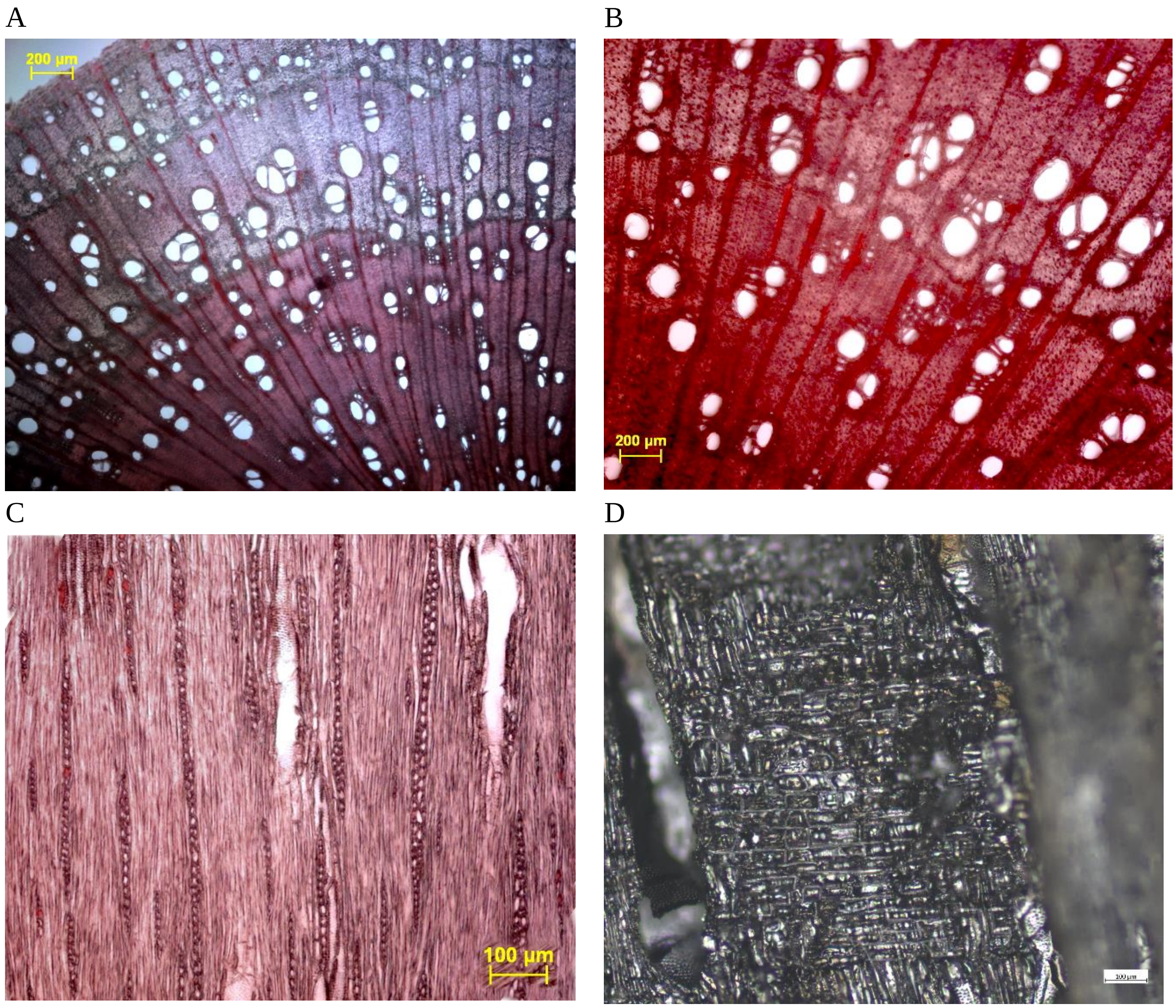


Figure S3-14: *Prosopis farcta*: A & B, Transverse section (wood), C: Tangential section (wood), D: Radial section (charcoal).

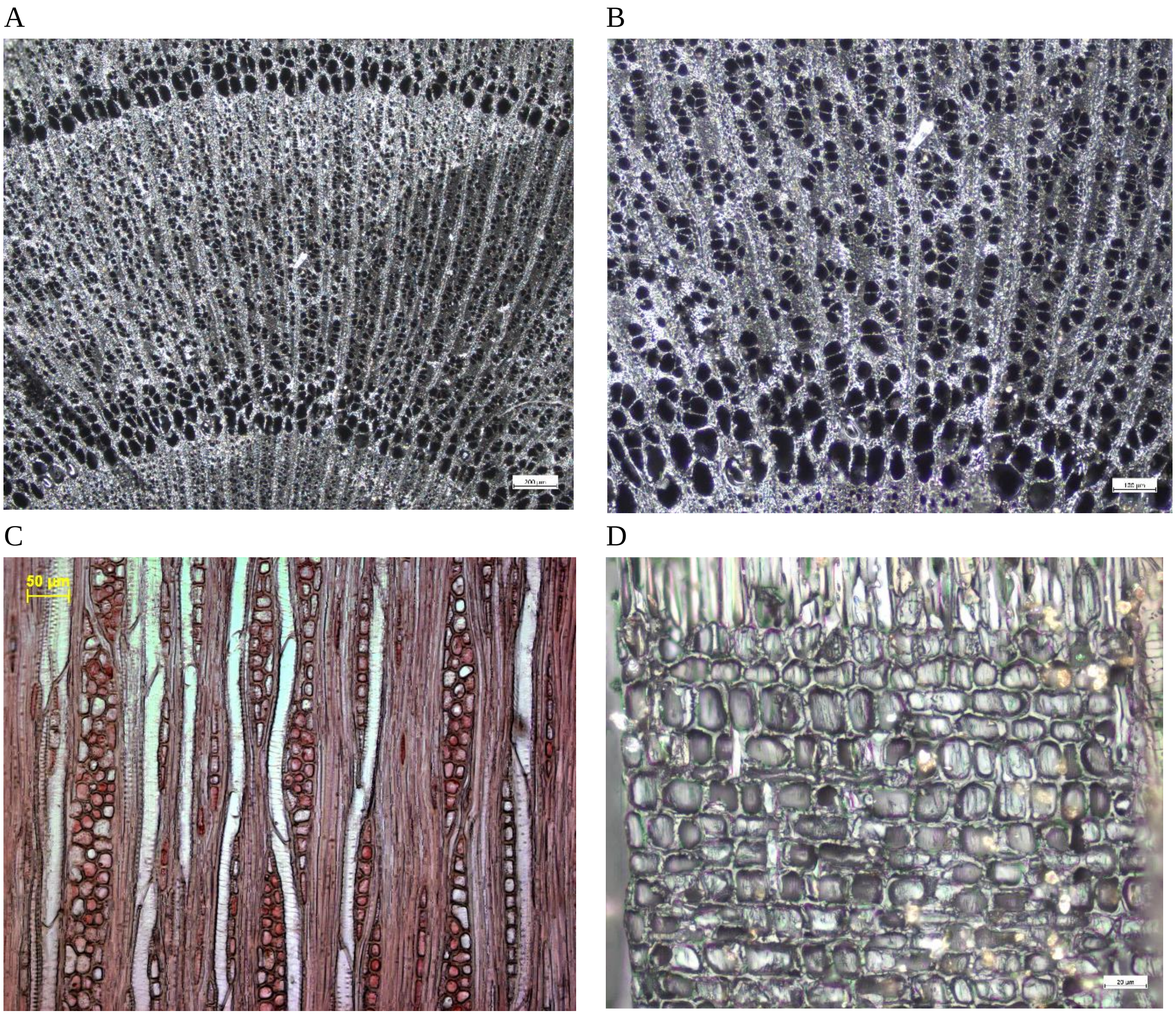


Figure S3-15: *Prunus persica*: A & B, Transverse section (charcoal), C: Tangential section (wood), D: Radial section (charcoal).

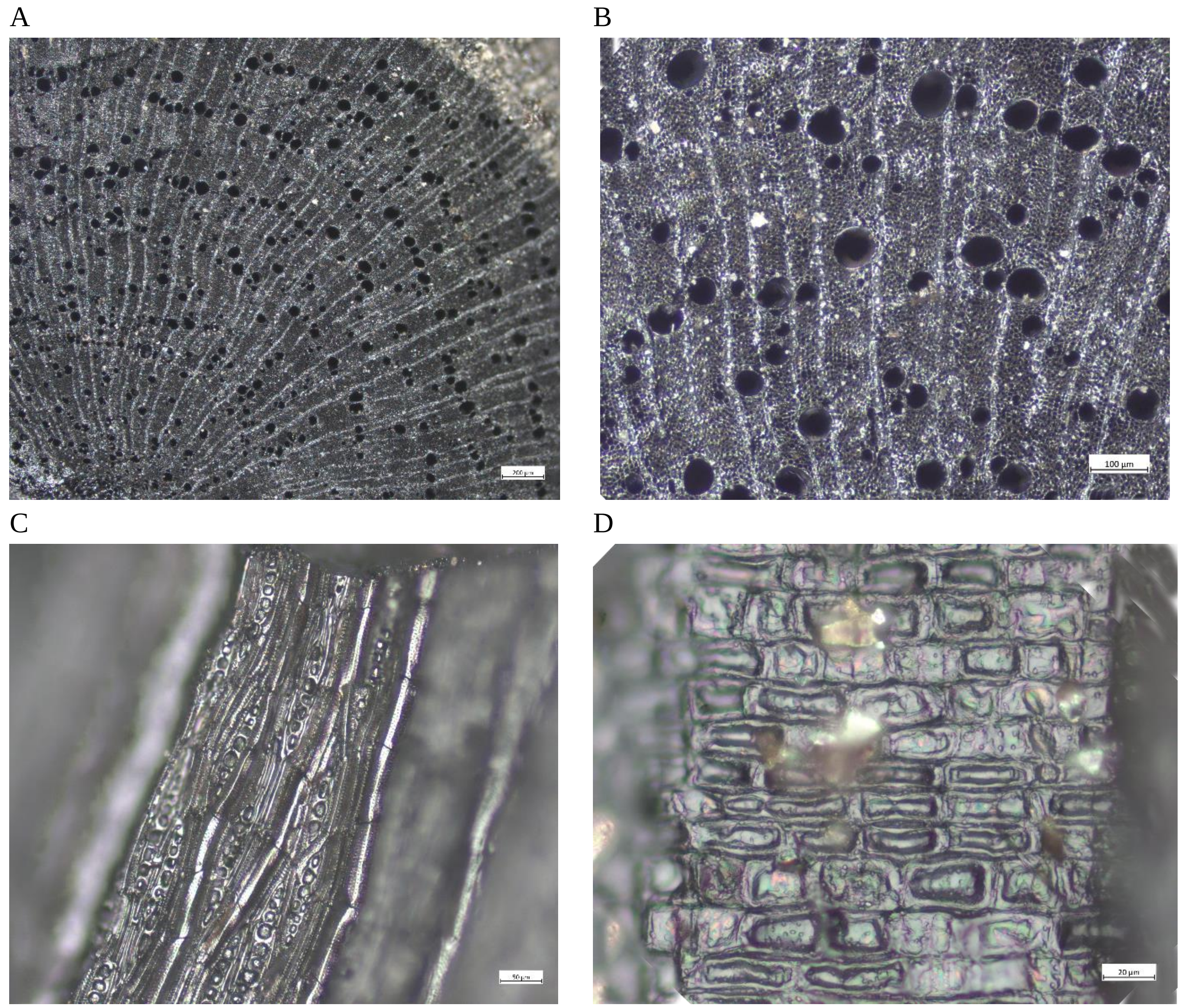


Figure S3-16: *Pteropyrum aucheri*: A & B, Transverse section – solitary vessels (charcoal), C: Tangential section (charcoal), D: Radial section (charcoal).

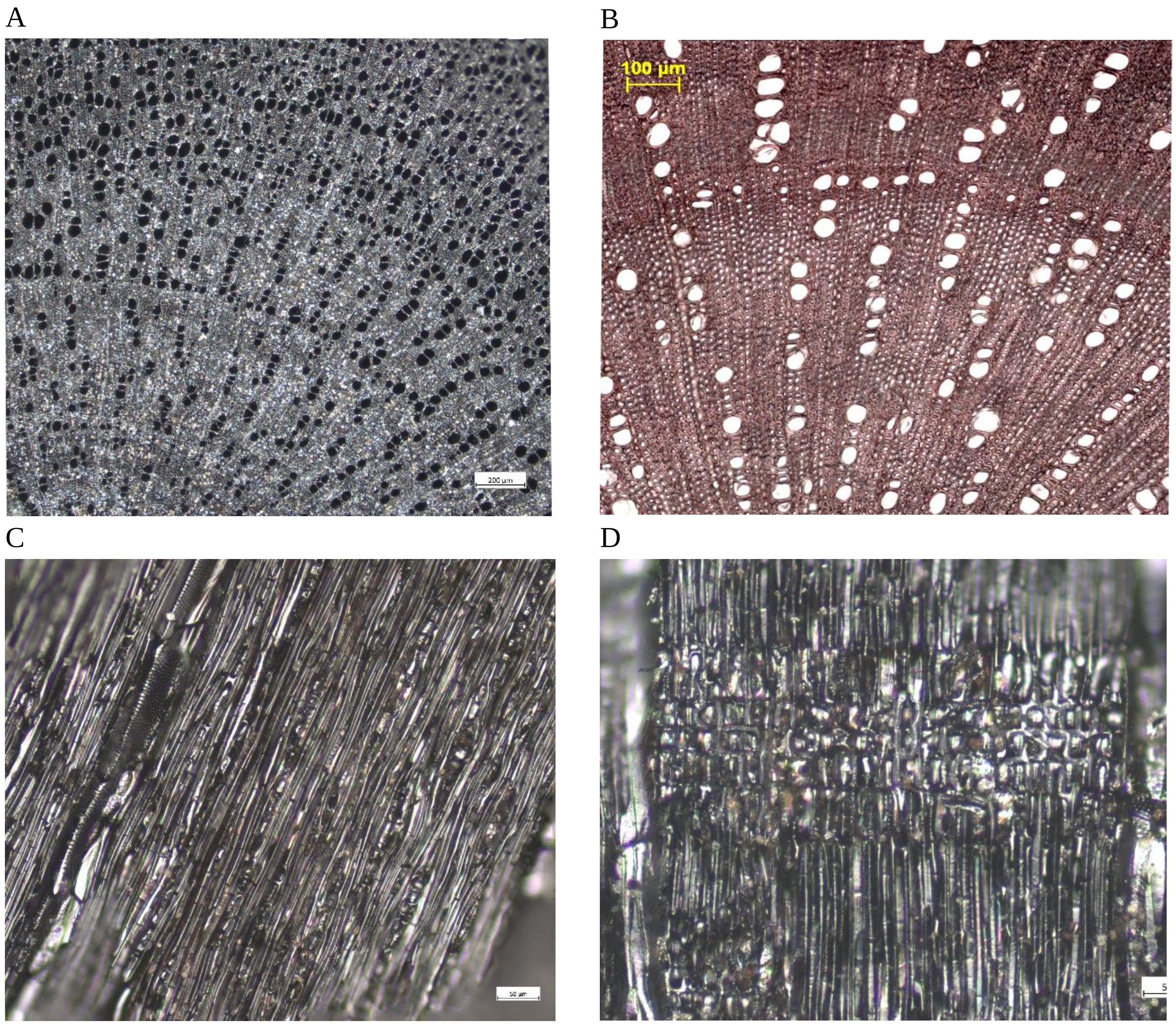
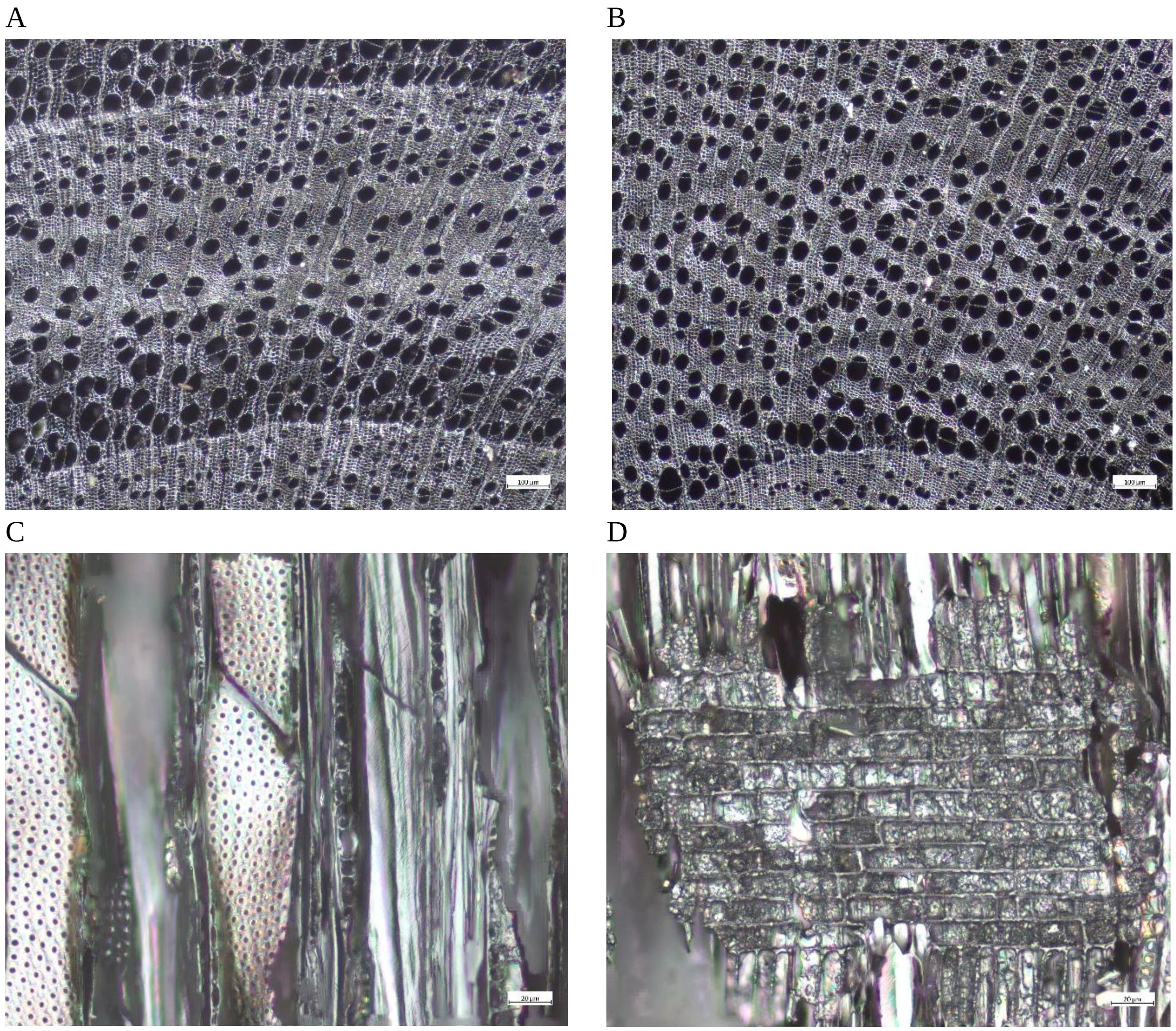


Figure S3-17: *Punica granatum*: A:Transverse section (charcoal), B: Transverse section- vessels in radial files (wood), C: Tangential section- uniseriate rays (charcoal), D: Radial section (charcoal).



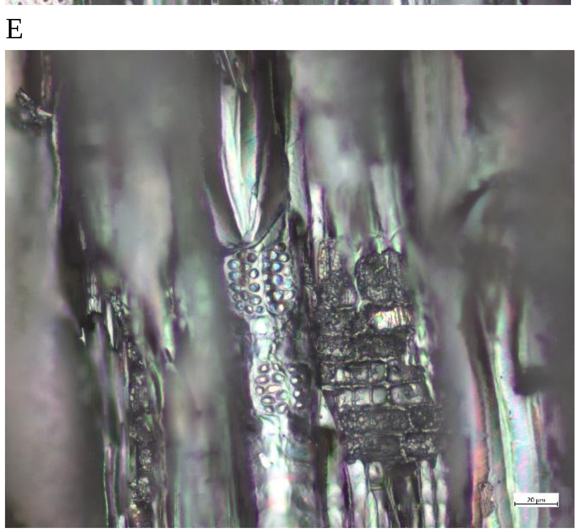


Figure S3-18: *Salix acmophylla*: A & B, Transverse section – vessels in short radial files (charcoal), C: Tangential section- uniseriate rays – bordered vessel pits (charcoal), D: radial section (charcoal), D: Radial section- big ray-vessel pits (charcoal).

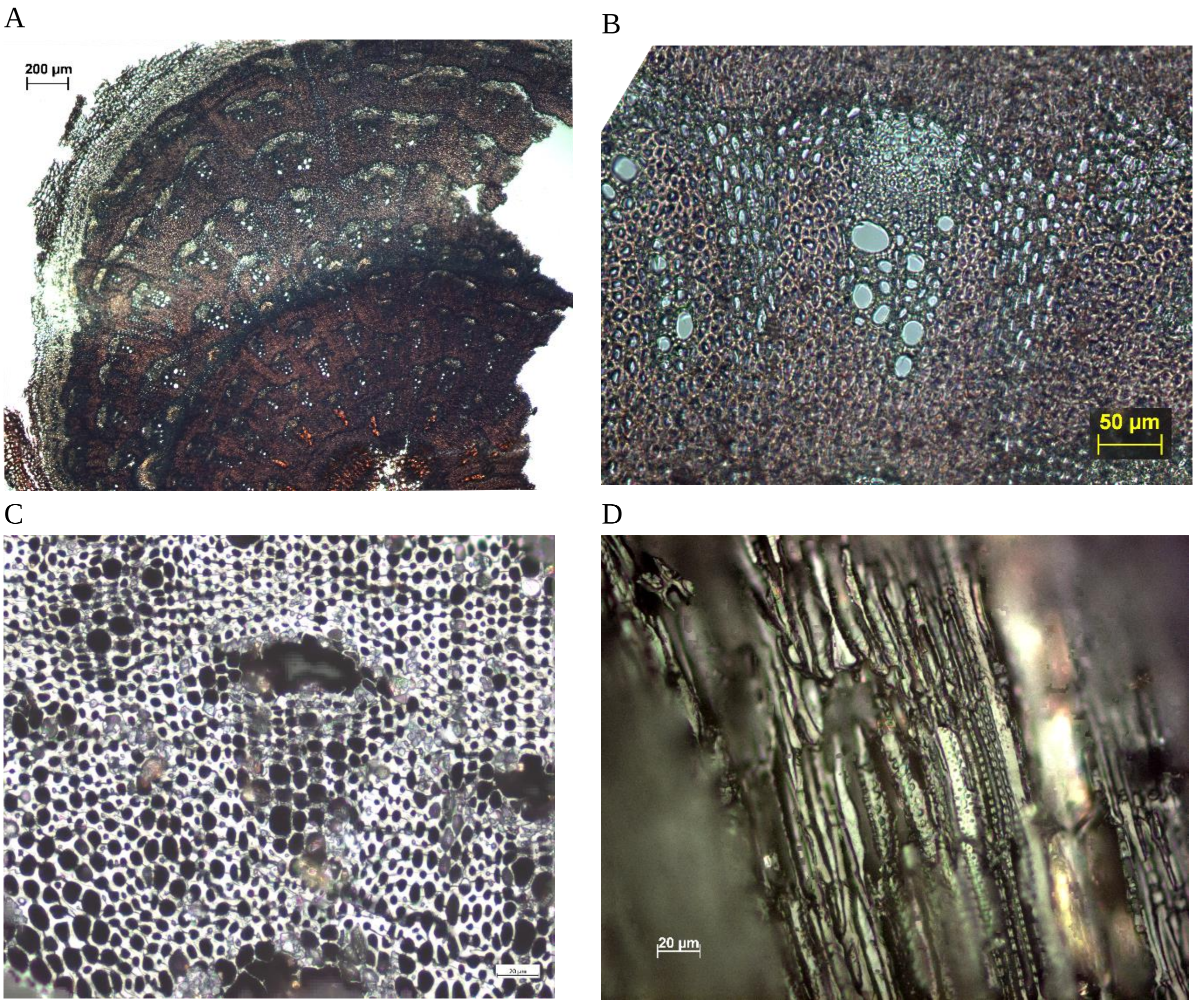


Figure S3-19: *Salsola vermiculata (syn: Caroxylon vermiculatum)*: A: Transverse section - included phloem (wood), B (wood) & C (charcoal): Transverse section – vascular bundle, D: Tangential section- storied fibers and parenchyma (charcoal).

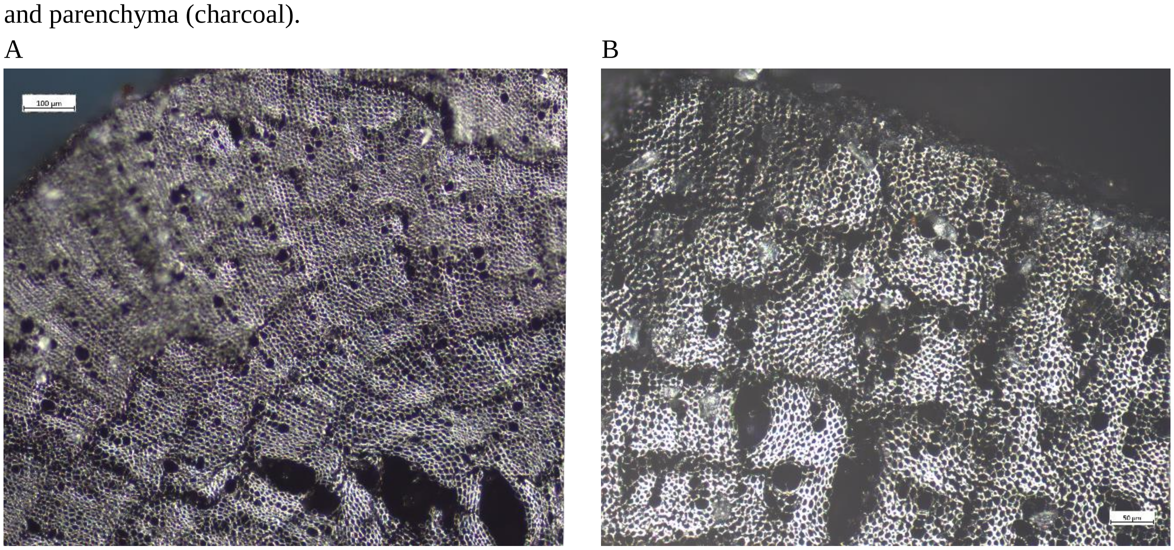
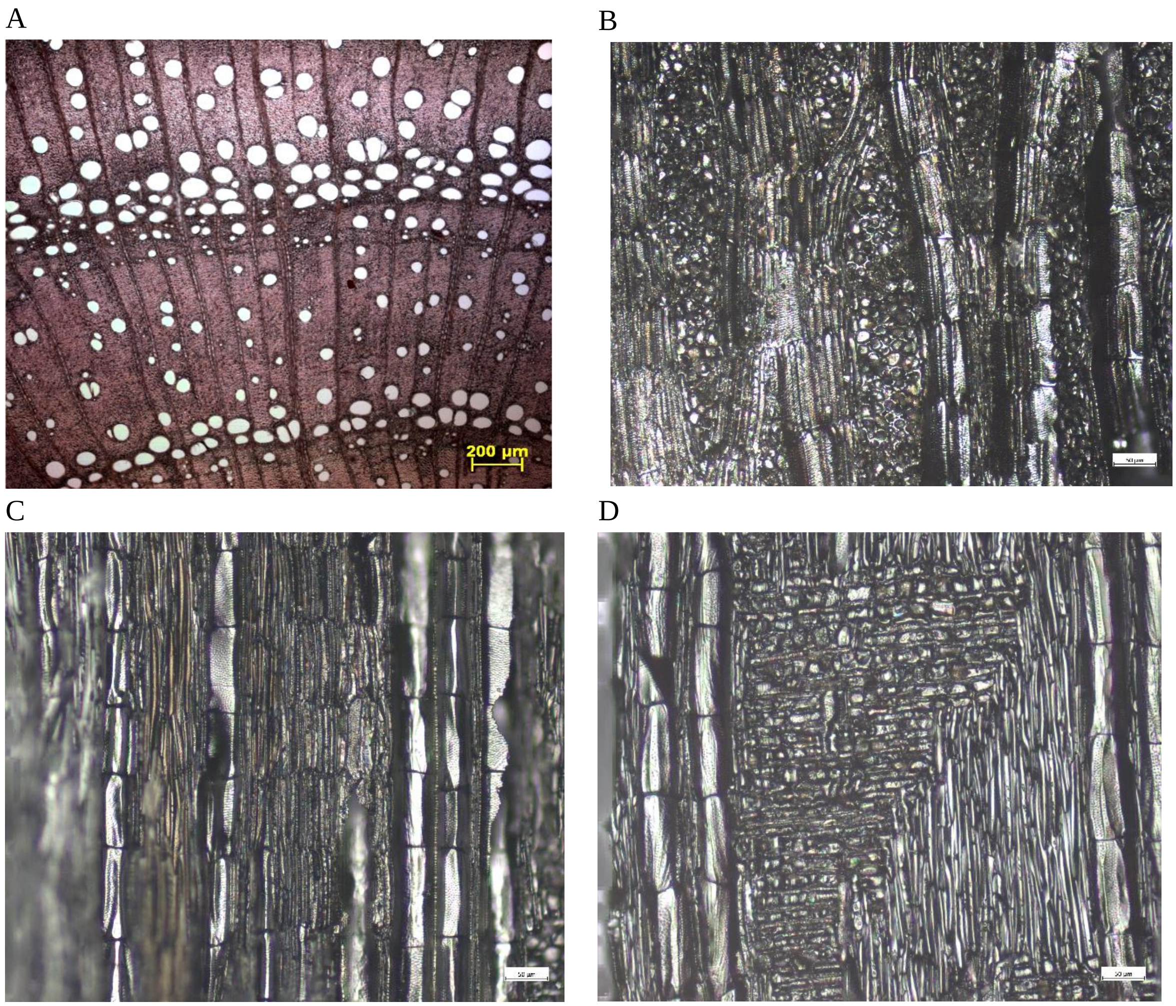


Figure S3-20: *Suaeda chlearifolia:* A & B: Transverse section - included phloem (charcoal)



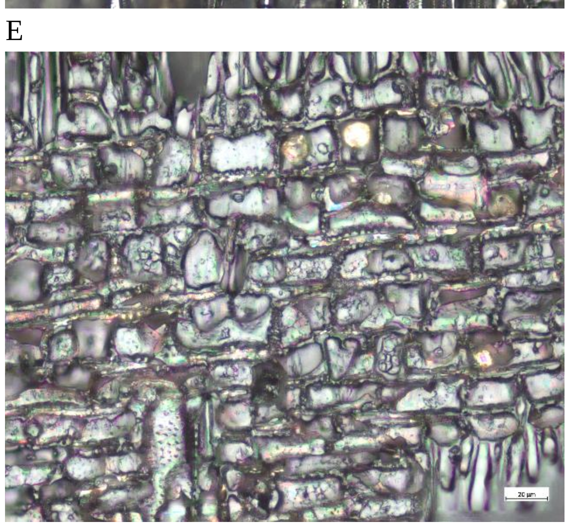


Figure S3-21: *Tamarix arceuthoides*: A: Transverse section (wood), B: Tangential section- large rayes with storied structures (charcoal), C: Tangential section – storied fibers and parenchyma (charcoal), D: Radial section (charcoal), E: Radial section – heterogeneous rays (charcoal).

S4 : Chapter 4

Table S0-3: Identified pollen types in MAH-B record

Pollen- type	Family	Ecological group	Relative abundance
Acacia	Mimosaceae	S	0.000163
Acer	Sapindaceae	A	0.006653
Allophylus	Sapindaceae	S	0.000065
Alnus	Betulaceae	E	0.000163
Amygdalus (syn: *Prunus*)-type	Rosaceae	A	0.003555
Atraphaxis	Polygonaceae	D	0.000293
Berberis	Berberidaceae	A	0.000033
Betula	Betulaceae	E	0.000033
Carpinus	Betulaceae	E	0.000098
Celtis	Ulmaceae	A	0.000033
Combretum aculeatum-type	Combretaceae	S	0.000033
Commiphora	Burseraceae	S	0.000098
Cupressaceae	Cupressaceae	N	0.019892
Dodonaea	Sapindaceae	S	0.004109
Ephedraceae	Ephedraceae	D	0.009066
Fagus	Fagaceae	E	0.000065
Ficus	Moraceae	T	0.000033
Fraxinus	Oleaceae	N	0.003163
Juglans	Juglandaceae	T	0.000946
Lonicera	Caprifoliaceae	A	0.000033
Myrica	Myricaceae	S	0.000848
Olea	Oleaceae	T	0.002674
Pinus	Pinaceae	N	0.000783
Pistacia	Anacardiaceae	A	0.056775
Platanus	Platanaceae	T	0.006294
Phoenix dactylifera	Arecaceae	T	0.000065
Podocarpus	Podocarpaceae	S	0.001207
Pterocarya	Juglandaceae	E	0.000065
Pinuca granatum	Pinaceae	T	0.003228
Calligonum group	Polygonaceae	D	0.003228
Pyrola (tetrad)	Ericaceae	S	0.000424
Quercus	Fagaceae	A	0.141138
Rhamnaceae	Rhamnaceae	A	0.000587
Rutaceae	Rutaceae	A	0.000033
Ricinus	Euphorbiaceae	S	0.000717
Salix	Salicaceae	N	0.000783

Pollen- type	**Family**	**Ecological group**	**Relative abundance**
Tamarix	Tamaricaceae	D	0.002283
Thymeleaceae	Thymeleaceae	A	0.000685
Ulmus	Ulmaceae	N	0.000685
Zygophylum atriplecoides-type	Zygophyllaceae	D	0.001109
Vitis	Vitaceae	T	0.000620
Acanthus	Acanthaceae	B	0.000261
Aconitum group	Ranunculaceae	B	0.000228
Allium-type	Alliaceae	B	0.000163
Amaranthaceae	Amaranthaceae	C	0.168987
Androsace alpina-type	Primulaceae	B	0.000163
Apiaceae	Apiaceae	B	0.010827
Artemisia	Asteraceae	B	0.282048
Asphodelus	Xanthorrhoeaceae	B	0.000033
Astroideae	Asteraceae	B	0.024556
Boraginaceae	Boraginaceae	B	0.000750
Brassicaceae	Brassicaceae	B	0.003750
Bryonia	Cucurbitaceae	B	0.000033
Campanulaceae	Campanulaceae	B	0.000130
Caprifoliaceae	Caprifoliaceae	B	0.000033
Caryophyllaceae	Caryophyllaceae	B	0.001011
Centaurea solstitialis-type	Asteraceae	M	0.008577
Cereal-type	Poaceae	G	0.004729
Chrozophora	Euphorbiaceae	M	0.000033
Cichorioideae	Asteraceae	B	0.005772
Cistaceae	Cistaceae	B	0.000130
Colchicum	Colchicaceae	B	0.000098
Convolvulus	Convolvulaceae	B	0.000587
Cousinia	Asteraceae	B	0.001728
Cuscuta approximata-type	Convolvulaceae	M	0.000554
Cyperaceae	Cyperaceae	H	0.027784
Delphinium	Ranunculaceae	B	0.000033
Echinophora-type	Apiaceae	B	0.005805
Echinops	Asteraceae	M	0.000261
Eremurus-type	Xanthorrhoeaceae	B	0.000098
Erodium	Geraniaceae	B	0.000098
Equisetum	Equisetaceae	H	0.000033
Euphorbiaceae	Euphorbiaceae	X	0.001500
Fabaceae	Fabaceae	B	0.001402
Frankenia-type	Frankeniaceae	X	0.000033

Pollen- type	**Family**	**Ecological group**	**Relative abundance**
Gallium-type	Rubiaceae	B	0.001663
Glaucium	Papaveraceae	B	0.000489
Haplophyllum	Rutaceae	B	0.000130
Helleborus viridis-type	Ranunculaceae	B	0.000033
Helianthemum	Cistaceae	B	0.000033
Hyoscyamus	Solanaceae	B	0.000228
Hypericum	Hypericaceae	B	0.000130
Iridaceae	Iridaceae	B	0.000065
Kohautia- type	Rubiaceae	S	0.000033
Lamiaceae	Lamiaceae	B	0.000130
Leontice-type	Berberidaceae	B	0.000163
Liliaceae	Liliaceae	B	0.000359
Malva sylvestris-type	Malvaceae	W	0.000033
Mentha-type	Lamiaceae	Q	0.000391
Papaveraceae	Papaveraceae	B	0.000457
Pedicularis	Orobanchaceae	B	0.000033
Plantaginaceae	Plantaginaceae	B	0.002152
Plantago coronopus-type	Plantaginaceae	B	0.001859
Plantago major-media-type	Plantaginaceae	B	0.005087
Plantago lanceolata-type	Plantaginaceae	W	0.020479
Plumbagiaceae	Plumbagiaceae	B	0.002870
Polygonum aviculare-type	Polygonaceae	B	0.000391
Poaceae unident.	Poaceae	B	0.037437
Poaceae<30	Poaceae	B	0.072754
Potamogeton	Potamogetonaceae	Q	0.000033
Potentilla	Rosaceae	B	0.000065
Prosopis farcta	Fabaceae	X	0.000848
Ranunculaceae	Ranunculaceae	B	0.001631
Resedaceae	Resedaceae	X	0.000750
Rheum	Polygonaceae	B	0.001109
Riella	Riellaceae	H	0.000196
Rhinanthus group	Orobanchaceae	B	0.000033
Rumex unident	Polygonacaee	W	0.001696
Rumex acetosa-type	Polygonacaee	W	0.001011
Sanguisorba minor-type	Rosaceae	B	0.001272
Sagittaria	Alismataceae	Q	0.000033
Scabiosa	Dipsacaceae	B	0.000228
Scrophulariaceae	Scrophulariaceae	B	0.000293
Sparganium-type	Typhaceae	Q	0.013338

Pollen- type	**Family**	**Ecological group**	**Relative abundance**
Teucrium	Lamiaceae	B	0.000228
Thalictrum	Ranunculaceae	B	0.000033
Tribulus	Zygophyllaceae	X	0.001174
Triticum-type	Poaceae	G	0.001207
Urtica dioica	Urticasse	B	0.000065
Valerianella	Caprifoliacae	B	0.000098
Verbascum	Schrophulariaceae	B	0.000098
Veronica-type	Plngtaginaceae	B	0.000261
Anograma	Pteridaceae	Y	0.000033
Monolet spore	Pteridaceae	Y	0.000033
Trilet spore	Pteridaceae	Y	0.000424
Sporormiella	Fungi spore	FUNG	0.004598

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