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### ► To cite this version:

Lyudmila Shumilovskikh, Morteza Djamali, Jacques-Louis de Beaulieu, Philippe Ponel, Jebrael Nokandeh, et al.. Woodland use in treeless landscapes? A compilation of botanical data from NE Iran during the Sasanian Empire. *Quaternary International*, 2023, 659, pp.34-44. 10.1016/j.quaint.2023.02.013 . hal-04132128

**HAL Id: hal-04132128**

**<https://amu.hal.science/hal-04132128>**

Submitted on 19 Jun 2023

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# Woodland use in treeless landscapes? A compilation of botanical data from NE Iran during the Sasanian Empire

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## ARTICLE INFO

### Keywords:

Pollen  
Fungal spores  
Insects  
Carpology  
Wood anatomy  
Palaeoecology

## ABSTRACT

The Gorgan Plain (NE Iran) is largely treeless today but it possibly was not in the past. We use palaeobotanical data from radiocarbon-dated sediments and archaeological excavations to investigate the extent and use of woodland under the Sasanian Empire (224–651 CE). Palynology, anatomical studies of charred and uncharred wood, insects and botanical macroremains have shed new light on this question. Palynological research points to natural origins of the open steppe vegetation in the Gorgan Plain contrasting to carpological and wood anatomy studies indicating wide use of trees and shrubs during the Sasanian period. As it shown by charcoal data, local sources provided enough firewood for kilns in short-term use, but were insufficient for supplying fortification garrisons which required additional supplies from the Hyrcanian forests. These forests provided the main source of firewood for sites located close to the Alborz Mountains. Cultivation of trees was widespread during the Sasanian era for fruits, shadow and possibly moriculture for silk production. Palaeobotanical records are still very rare in the Gorgan Plain. New data are a desideratum to gain further insights into woodland use before, during and after the Sasanian Empire.

## 1. Introduction

Eurasian forests have been intensively exploited by humans over millennia. Especially in the climatic ecotone zones such as forest-steppe, overuse of woodlands can lead to the demise of forest cover. There is clear evidence for such over-exploitation from a range of territories. Pollen data in the forest-steppe zone in the Eastern European Plain (Novenko et al., 2015, 2016; Shumilovskikh et al., 2018, 2019; Lukanina et al., 2022) demonstrate that the first destructions of the forests occurred in the Iron Age, leading to total deforestation for agriculture in many areas within the last 300–500 years. Eastern Mediterranean records from Turkey point to similar developments (van Zeist and Bottema, 1991; Shumilovskikh et al., 2016b). The records show that natural deciduous oak forests were cleared at c. 800 BCE and that intensive agriculture and animal grazing led to increased soil erosion, resulting in a marked change of the vegetation. But not all forest-steppe regions were necessarily affected by deforestation. Pollen data from the forest-steppe

in the southern Urals (Stobbe et al., 2015) or northern Mongolia (Schlütz et al., 2008) have shown that the open to semi-open landscapes here were of natural origins, while in western Iran they are supposed to be the result of a agro-sylvo-pastoral management in the late Holocene (van Zeist, 1967; Djamali et al., 2010).

The Gorgan Plain (NE Iran) located at the southeastern corner of the Caspian Sea represent a typical forest-steppe environment. It represents a transition between forests on the northern slopes of the Alborz Mountains and the Turkmen steppe. The Gorgan Plain is characterised by Quaternary alluvial and loess deposits resulting in fertile soils (Asadi et al., 2013). It is not surprising that today the Gorgan Plain is intensively exploited for agriculture of mainly wheat and soya. However, the question arises if the open landscape is of natural or anthropogenic origins.

The Gorgan Plain has a long settlement history (e.g. Abbasi, 2011; Arne, 1945; Sauer et al., 2013; Thornton, 2013; Wilkinson et al., 2013). Just a few sites are known from the Neolithic, but the number of

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settlements increased substantially at the beginning of the Bronze Age (ca. Early 3rd millennium BC) before decreasing again in the first half of the 2nd millennium BC. The plain appears to have been more densely occupied again in the Iron Age III period (ca. 8th–6th centuries BC). The territory of the Gorgan Plain was subsequently under the control of Achaemenid (ca. 549–330 BCE), Macedonian and Seleucid (ca. 330–247 BCE), Parthian (247 BCE – 224 CE) and Sasanian (224–651 CE) Empires.

To judge by the preserved monuments, human impact may have reached a maximum under the Sasanian Empire. It was one of the largest and most powerful empires in the late antique world, stretching from Mesopotamia to modern Pakistan and from Central Asia to the Arabian Peninsula. Large fortified cities, small urban centres, numerous towns, long canals, defensive walls and forts were constructed to protect imperial assets (Sauer et al., 2013, 2022; Simpson, 2017). The largest known Sasanian city on the Gorgan Plain, Dasht Qal'eh, was an extraordinarily large megalopolis, comparable in size to some of the late antique world's major cities (Sauer et al., 2013, 2022). To protect its northern borders on the Gorgan Plain, and the Caspian coastal plain further west, massive walls were constructed, representing a visual symbol of the impressive power of the Sasanian state. The Gorgan and Tammisheh Walls were made of fired mud-bricks (Sauer et al., 2013). Our estimates suggest that perhaps as many as two hundred million bricks, of c. 20 kg each, were needed to construct the Gorgan Wall (Sauer et al., 2022). For this purpose, thousands of brick kilns were built along the construction site for the long-wall. In the loess landscapes of the Gorgan Plain, material for brick-production existed in limitless supplies, while fuel could be a limiting factor. A growing population would have required more food, probably leading to an increase of agriculture and pasture. Potentially both factors would have put pressure on woodlands.

In order to shed light on questions of the extent of natural woodland and Sasanian woodland use and management, we compile and analyse existing data from the Gorgan Plain (Fig. 1). The data include pollen, fungal spores, botanical macroremains, insects, wood and geochemical

evidence from off-site and on-site archives previously published elsewhere. We investigate (1) woodland use and management during the Sasanian era and (2) natural vs. anthropogenic landscape openness of the Gorgan Plain.

### 1.1. Geographical setting

The Gorgan Plain is characterised by a Mediterranean xeric to oceanic bioclimate with the dry season lasting as long as three to four months (Akhani et al., 2010). The Caspian Sea is the major source of moisture, transported by dominant north-eastern and north-western winds (Khalili, 1973). The Alborz Mountains prevent moisture transport into the central parts of Iran, causing orographic rainfall on the northern slopes of the mountains and abrupt changes in the precipitation regime along a south-north gradient from 1300 mm over the Alborz Mountains to 600–700 mm in the piedmont and down to 200 mm on the Turkmen steppe. Precipitation decreases also with distance from the Caspian Sea in a west-east gradient from 500 mm at Gorgan to 350 mm at Gonbad-e Kavus (Djamali et al., 2011; Sagheb Talebi et al., 2014).

Reflecting the precipitation regime, the natural vegetation of the Gorgan Plain is represented by Hyrcanian forests on the northern slopes of the Alborz Mountains and the Irano-Turanian steppes in the lowlands (Gerasimov, 1964; Zohary, 1973). Open vegetation is represented by dry steppe of *Artemisietea herbae-albae iranica* type, Irano-Turanian psammophilous vegetation and saltland vegetation of the *Salicornietea*. The arboreal communities in the Gorgan Plain consist of *Tamarix* on saline and moist soils and bushes of *Acer monspessulanum*, *Berberis*, *Paliurus spina-christi*, *Crataegus*, *Cerasus*, *Rubus* in the transition zone between forest and steppe. The Hyrcanian forest is represented by arboreal communities with *Acer*, *Alnus*, *Celtis australis*, *Cornus sanguinea*, *Diospyros lotus*, *Ficus carica*, *Parrotia persica*, *Pterocarya fraxinifolia*, *Vitis sylvestris*, *Zelkova carpinifolia* in the lowlands, *Acer*, *Carpinus betulus*, *Carpinus orientalis*, *Euonymus*, *Fraxinus*, *Ilex*, *Pyrus*, *Quercus castaneifolia*,

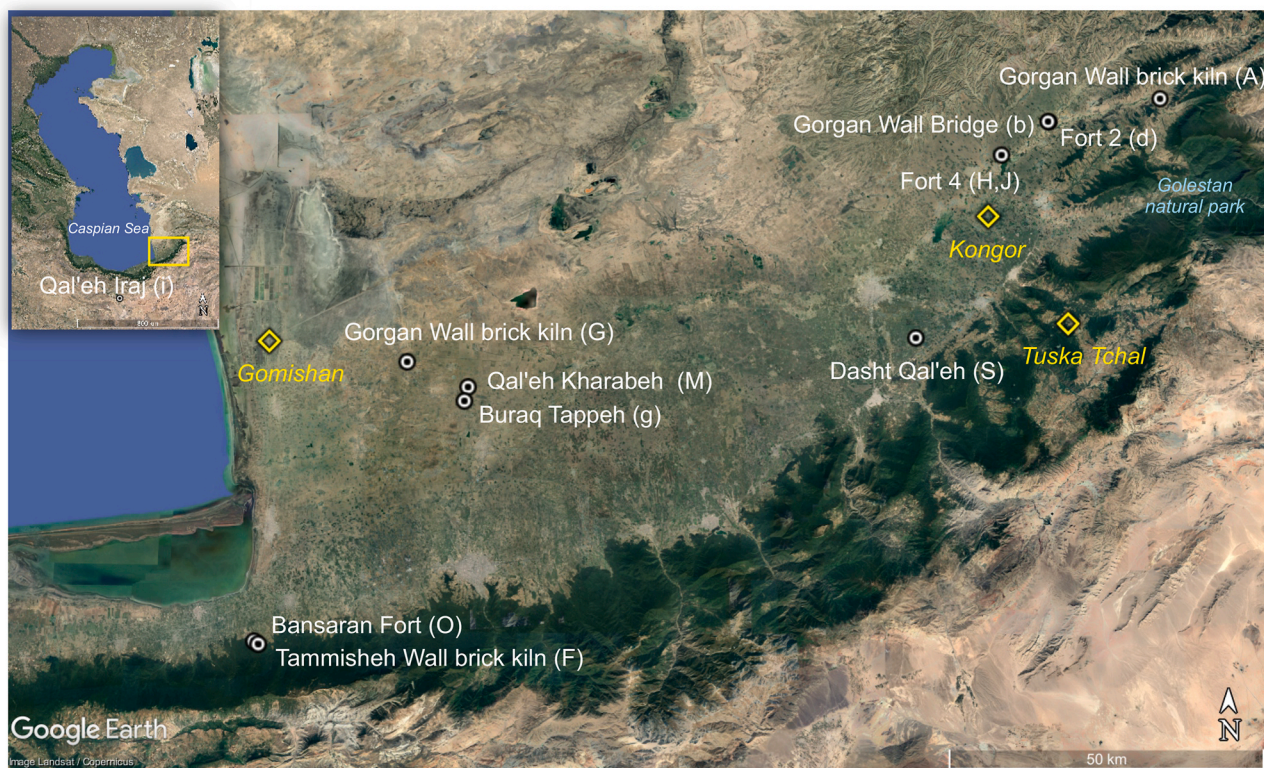


Fig. 1. Map of the Gorgan Plain with location of sites studied (based on Google Earth satellite image, 07.2022). White circles – on-site records, yellow diamonds – off-site records.

*Q. macranthera*, *Rhamnus*, *Sorbus*, *Tilia*, *Ulmus* on the northern slopes of Alborz-Kopeh Dagh, and *Juniperus*, *Paliurus spina-christi*, *Haloxylon* at the transition to the steppe of the Central Iranian Plateau in the south. *Alnus*, *Salix* and *Eleagnus angustifolia* grow along the river valleys in the forest and steppe zones (Akhani, 1998; Djamali et al., 2009; Akhani et al., 2010; Sagheb Talebi et al., 2014). The grasslands or grass-dominated vegetation is also found in the ecotones between the Hyrcanian forest and Irano-Turanian steppes in higher elevations e.g. in the Golestan National Park (Akhani and Ziegler, 2002).

Although annual precipitation above 200 mm would allow formation of forest patches on the Gorgan Plain, today the landscapes are largely treeless and intensively exploited for agriculture and pastoral activities. Precipitation patterns seem to be the major determining factor in the geographical distribution of different agro-pastoral practices with rain-fed cultivation concentrated in the piedmont plains, irrigated wheat cultivation on the alluvial plains and grazing further to the north especially in the Turkmen Steppe (Wilkinson et al., 2013). Our own observations of vegetation on the Gorgan Plain have shown that a variety of cultivated trees is present, such as fig tree, white mulberry, orange tree, grapevine, walnut, pomegranate, peach, pear, cherry, plane tree, cypress and pine. Woody species also grow along the roads and between fields, represented by spiny and inedible species developed in response to overgrazing, including *Alhagi persarum*, *Paliurus spina-christi*, *Rubus* and *Capparis*.

## 2. Material and methods

This study is based on data obtained mainly during the excavation seasons of 2005–2008 and 2014–2016 (Sauer et al., 2013, 2022). They are represented by both off-site and on-site investigations.

The off-site palynological record Kongor (Shumilovskikh et al., 2016a) was obtained from the eastern part of the Gorgan Plain (Fig. 1). Lake Kongor (93 m a.s.l.) is a temporary lake located c. 20 km north-east of the ancient city of Dasht Qal'eh, the regional urban centre during the Sasanian period. Today, the area is intensively exploited for agriculture of mainly wheat and soya beans and for pasture. The site is not connected to any significant stream and is fed by groundwater and direct precipitation. Beside different ruderal and wetland herbs, the local arboreal vegetation around the lake is composed of wild *Salix*, *Populus* and *Rubus* and planted *Pinus*, *Ficus carica*, *Morus alba*, *Prunus*, *Juglans*

*regia*, and *Vitis vinifera*. The sediment core was extracted from Kongor Lake (37°21'21" N, 55°23'27" E, 93 m a.s.l.) via a semi-cylindrical chamber corer in 2012 and dated with 9 samples of plant macroremains and bulk samples using the AMS-radiocarbon method (Shumilovskikh et al., 2016a). In order to reconstruct vegetation and environmental changes, multi-proxy analyses were carried out on the sediment core Kongor, including pollen, non-pollen palynomorphs (fungal spores, algae, animal and plant remains), carpology, insects and wood anatomy analyses, XRF-scanning for element intensities, total phosphorus and biomarkers (Shumilovskikh et al., 2016a). For the purpose of this study, the diagram plots selected curves which contribute most to our understanding of vegetation changes (Fig. 2).

Carpological and wood anatomy studies in on-site archives were carried out during the excavations of 2014–2016 (Sauer et al., 2022). The material was collected in different ways. In some trenches charcoal was manually collected by archaeologists during the archaeological excavations. In some trenches, flotation or sieving using sieves with meshes 3.15, 0.71 and 0.25 mm were employed to obtain the material for macroremains analysis. The methods applied are listed in Table 1. Full data were published by Poole and Gale (2013), Shumilovskikh et al. (2022), Shumilovskikh and Talon (2022). For the purpose of this work, we use only data from the Sasanian era. These data are compiled in Table 1, showing which individual taxa were present at each site as well as preserved remains of wood and fruits/seeds or their fragments.

In order to explore geographical patterns in woodland use, we present charcoal data in pie charts featuring three dominant components (Fig. 3): steppe vegetation include Chenopodioideae, *Juniperus*, monocots, *Tamarix* and *Ziziphus*; Hyrcanian forest - *Acer*, *Alnus*, *Carpinus*, *Fraxinus*, *Juglans/Pterocarya*, *Quercus*, *Salix/Populus*, *Ulmus*, *Ulmus/Zelkova* and *Zelkova*; and possibly cultivated trees - *Juglans*, *Pistacia*, *Platanus*, Maloideae and Prunoideae.

## 3. Results and interpretation

### 3.1. Regional vegetation and human impact revealed by palynology

Pollen data from Lake Kongor reveal a dominance of Amaranthaceae, *Artemisia* and Poaceae over the last 6000 years (Fig. 2), while arboreal pollen (AP) does not exceed 20%. These results strongly suggest that this part of the Gorgan Plain was not covered by forests but remained open

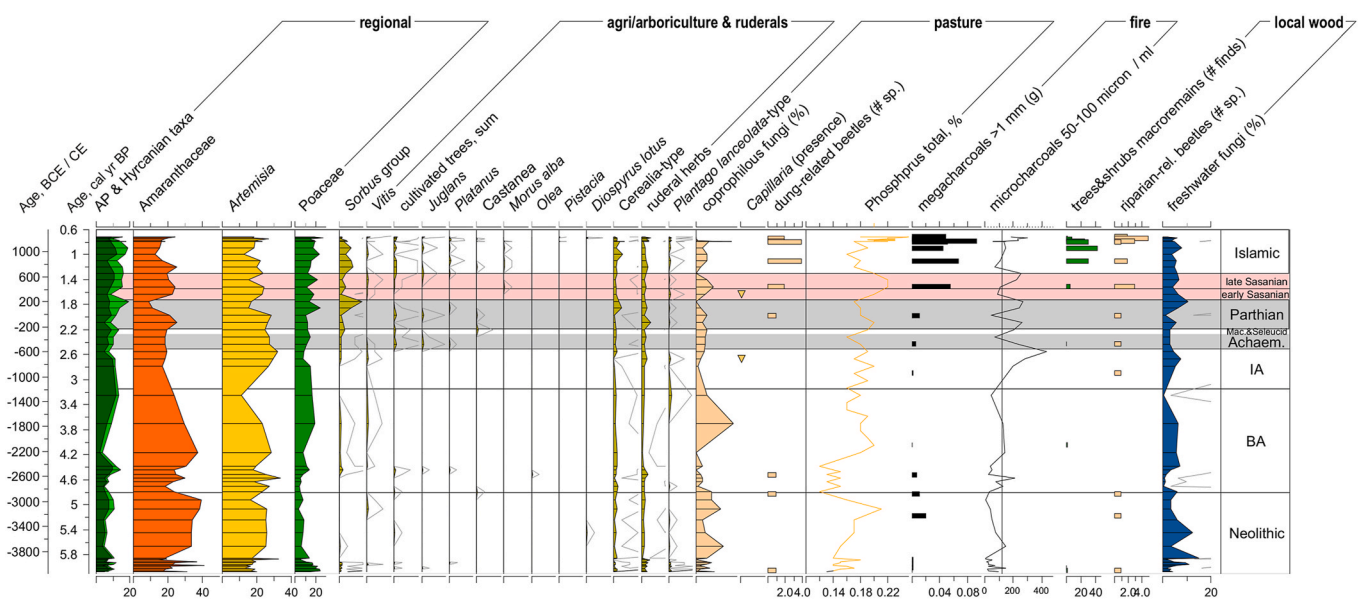


Fig. 2. Pollen diagram from Lake Kongor showing selected curves reflecting forest dynamics (based on Shumilovskikh et al., 2016a). Kongor pollen data are presented in percentages from the total sum of minimum 300 terrestrial pollen; AP = arboreal pollen; coprophilous and riparian beetles – in number of species; megacharcoal (>1 mm) – in gram/sample; microcharcoal is represented by concentration of fragments of 50–100  $\mu\text{m}^3$ .

**Table 1**

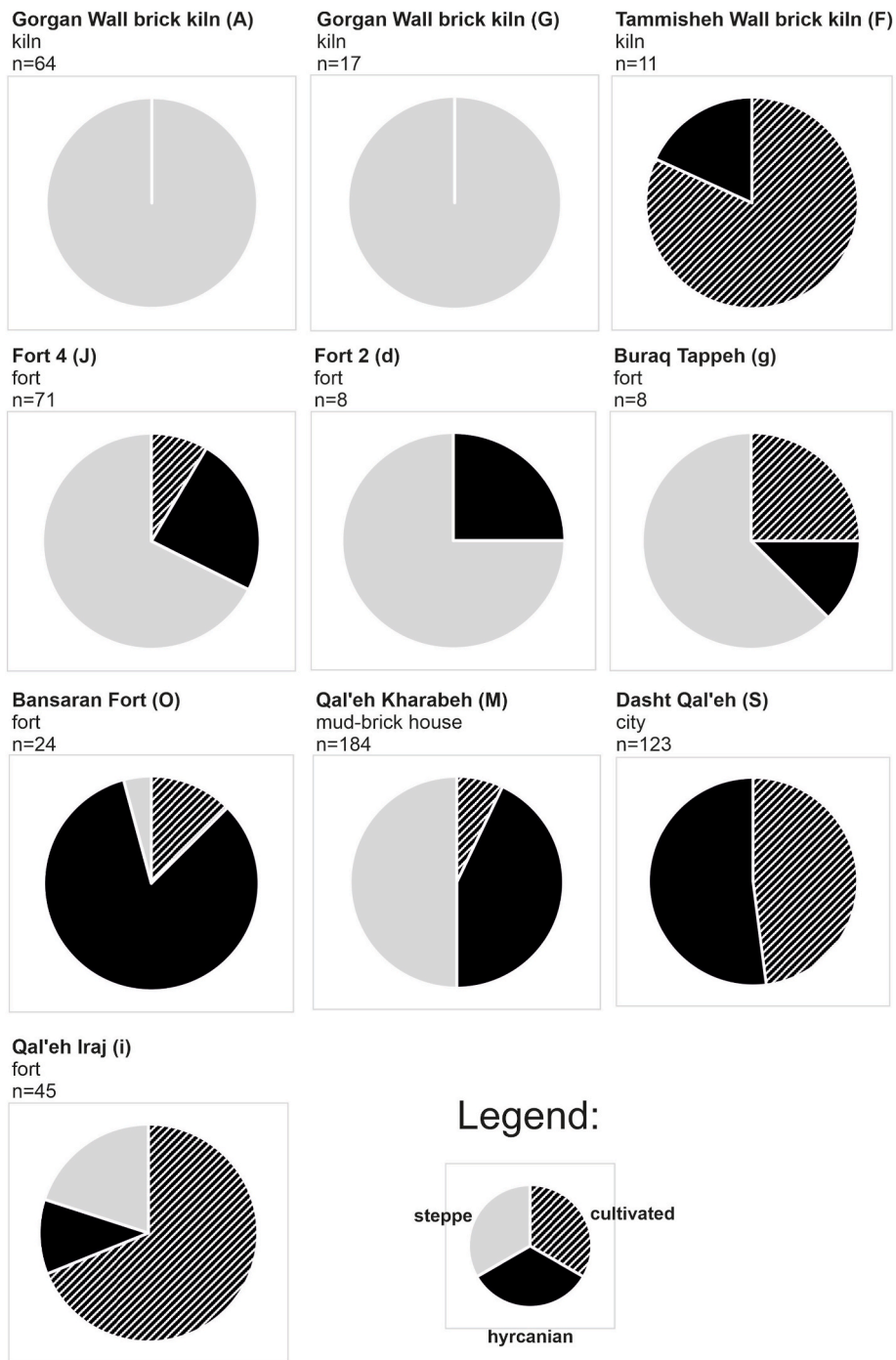
List of identified taxa of wood fragments and fruits/seeds/nutshell from contexts of the Sasanian period obtained during excavation seasons 2005, 2007, 2008–2009, 2016 (after [Poole and Gale, 2013](#), [Shumilovskikh et al., 2016a](#); [Shumilovskikh et al., 2022](#); [Shumilovskikh and Talon, 2022](#)).

	Site	Gorgan Wall	Tammisheh Wall	Gorgan Wall	Fort 4	Qal'eh Kharabeh	Bansaran Fort	Dasht Qal'eh	Gorgan Wall Bridge over the Sari Su River	Fort 2	Buraq Tappeh	Qal'eh Iraj	Kongor Lake
	Trench Feature	A kiln	F kiln	G kiln	H, J fort	M house in campaign base	O fort	S city	b water reservoir	d fort	g fort	i fortress	– lake
	Method	hand	hand	hand	hand	hand	hand	hand	sieving	flot.	flot. + hand	hand	sieving
Identified taxon	Family												
<i>cf. Acer</i>	Sapindaceae						wood						
<i>Alnus</i>	Betulaceae				wood			wood		wood			
<i>Carpinus</i>	Betulaceae		wood			wood	wood	wood					
<i>Capparis spinosa</i>	Capparaceae								seed <sup>a</sup>				
Chenopodioideae	Amaranthaceae			wood		wood				wood	wood		
<i>Ficus carica</i>	Moraceae								fruit <sup>a</sup> , wood <sup>a</sup>				
<i>Fraxinus</i>	Oleaceae									wood			
<i>cf. Hippophae</i>	Elaeagnaceae											wood	
<i>Juglans</i>	Juglandaceae		wood							nutshell			
<i>Juniperus</i>	Cupressaceae				wood				wood, wood <sup>a</sup>				
Maloideae	Rosaceae					wood		wood				wood	
Monocots										nodi			
<i>Morus alba</i>	Moraceae												fruit <sup>a</sup> , wood <sup>a</sup>
<i>Morus nigra</i>	Moraceae								fruit <sup>a</sup>				
<i>cf. Morus</i>	Moraceae											wood	
<i>Quercus</i>	Fagaceae				wood	wood	wood	wood					
<i>Paliurus</i> ( <i>Ziziphus</i> ) <sup>b</sup>	Rhamnaceae	wood			wood	wood	wood						
<i>Pistacia</i>	Anacardiaceae					wood	wood						
<i>Platanus</i>	Platanaceae									wood		wood	
<i>Platanus/Fagus</i>	Platanaceae/ Fagaceae				wood								
Prunoideae	Rosaceae												
Rosaceae	Rosaceae												floral parts <sup>a</sup> endocarp <sup>a</sup>
<i>Rubus</i>	Rosaceae								endocarp <sup>a</sup> wood <sup>a</sup>			wood wood	
<i>Salix</i>	Salicaceae												
<i>Salix/Populus</i>	Salicaceae				wood	wood		wood					
<i>Sambucus</i>	Adoxaceae								endocarp <sup>a</sup>				endocarp <sup>a</sup>
<i>Tamarix</i>	Tamaricaceae				wood	wood					wood	wood	
<i>Ulmus/Zelkova</i>	Ulmaceae				wood	wood		wood			wood	wood	
<i>Vitis</i>	Vitaceae								seed, seed <sup>a</sup>	seed		wood	
<i>Zelkova</i>	Ulmaceae					wood							

Method indicates hand = manual collection of charcoals by archaeologists, flot. = flotation or sieving.

<sup>a</sup> Indicates non-charred findings.

<sup>b</sup> [Poole and Gale \(2013\)](#) tentatively identified *Ziziphus*; as this genus, however, is in not represented in the vegetation of the Gorgan Plain, it probably is *Paliurus*, which belongs also to the Rhamnaceae family and grows widely across the Gorgan Plain.



**Fig. 3.** Pie-charts of charcoal ratios of the sites. Steppe taxa include *Chenopodiaceae*, *Juniperus*, monocots, *Tamarix* and *Ziziphus*; hyrcanian - *Acer*, *Alnus*, *Carpinus*, *Fraxinus*, *Juglans/Pterocarya*, *Quercus*, *Salix/Populus*, *Ulmus*, *Ulmus/Zelkova* and *Zelkova*; cultivated - *Juglans*, *Pistacia*, *Platanus*, *Maloideae* and *Prunoideae*.

steppe.

During the era of the Persian Empires, a slight decrease of Hyrcanian forest indicators from the Achaemenid to the Sasanian era implies deforestation. However, there is no evidence for drastic forest devastation in this part of the Gorgan Plain. The plantation of cultivated trees such as walnut and the plane tree started around 500 BCE, the time when the Achaemenid Empire was established. During the Late Sasanian period (5th to 7th century CE), an increase in *Juglans*, *Platanus* and *Vitis* as well as the first occurrence of *Morus alba* suggest that grapevine, walnut, white mulberry and plane were cultivated on the Gorgan Plain. In the Islamic period, cultivation of trees continued and new species were planted in the vicinity of the lake, such as pistachio (*Pistacia*) and

persimmon (*Diospyros*) (Fig. 2). We also observe an increase in the *Sorbus* group, indicating either an expansion of wild Rosaceae, like *Rubus*, or cultivation of trees from this family, for example peach, pear, apple etc.

Cerealia-type and ruderals percentages remain low until the 8th century BCE with only one phase with slightly higher values in a wet phase during the Early Bronze Age, suggesting possible agricultural activities in the region. After the 8th century BCE, an increased amount of the Cerealia-type and ruderals points to establishment of agricultural activities in the surroundings of the Kongor Lake. Although Cerealia-type reaches a temporary minimum during the Sasanian era, the ruderal herbs remain high, which points to agricultural or pastoral

activity in the eastern Gorgan Plain at a greater distance from the lake.

High concentrations of phosphorus and spores of coprophilous fungi throughout the profile (Fig. 2) suggest that animals (wild or domesticated) frequented the shores of Kongor Lake since the end of the Neolithic era. It is possible that people and animals were attracted by the water. Dung-related beetles indicate intensified pastoral activities for the last 2000 years. A peak in the coprophilous fungi and in phosphorus indicate that pastoral activities increased during the Sasanian period (4th-7th centuries CE) and in the high Middle Ages (12th-13th centuries CE).

The microcharcoal concentration record indicates that fire activities increased around 800 BCE (Fig. 2). Contemporary evidence for a shift to moist conditions (Shumilovskikh et al., 2016a) as well as higher settlement activities during the Iron Age suggest humans as a major cause of fire. The maximum of megacharcoal around the 5th century CE is contemporary with the construction of the Gorgan Wall and suggests intensified human occupation of the area. From then onwards, the concentration of megacharcoal in the sediment remains high, indicating

that fires were lit frequently on the shores of the lake at least until the 13th century CE, when the record ends.

### 3.2. Local vegetation around water bodies

#### 3.2.1. Kongor Lake

In contrast to the pollen record suggesting open environments, botanical macroremains, beetles and freshwater fungi indicate local presence of trees and shrubs.

Botanical macroremains are present in the upper part of the core (1.7–0.7 cal ka BP/250–1250 CE) indicating presence of *Morus alba*, *Sambucus*, *Rubus caesius* and *Rubus fruticosus* in the lake surroundings (Fig. 4).

The majority of beetle species found during ~2–0.78 cal ka BP (50 BCE–1170 CE) is associated with grasslands, steppes and open landscapes. However, some species indicate the presence of riparian ecosystems close to the lake. *Trepanes octomaculatus* and *Tachyura haemorrhoidalis* are widespread riparian ground beetles. *Haltica tamaricis*



Fig. 4. Selected plant remains documented in Kongor Lake and Trench b: fruit of *Morus alba* (Kongor Lake), fruit of *Morus nigra* (Trench b), fruit of *Ficus carica* (Trench b), seed of *Capparis spinosa* (Trench b), seed of *Vitis vinifera* (Trench b), floral parts of Rosaceae (Trench b), endocarp of *Sambucus* sp. (Kongor Lake), endocarp of *Rubus caesius* (Kongor Lake), endocarp of *Rubus fruticosus* (Kongor Lake). Scale bar 1 mm.

and *Phyllodecta* are common taxa found on riverine forest bushes and trees such as willow. *Trypophloeus alni* is associated with alder. *Cyphon* is a very common genus found on herbaceous plants, shrubs and trees close to the shores of lakes and rivers. The only *Scolytus* reminds one of the European *Scolytus* that lives on woody Rosaceae such as *Prunus*, *Malus* and so on (Shumilovskikh et al., 2016a).

Freshwater lignicolous fungi *Megalohypha aqua-dulces*, *Xylomyces chlamydosporus*-type, *Zopfiella* cf. *submersa*, *Sporoschisma saccardoii*-type, *Dictyosporium heptasporum* and *Dictyosporium digitatum* are present throughout the record, indicating that there was degrading wood and therefore trees or shrubs growing on, or near, the sampling site over the last 6000 years (Shumilovskikh et al., 2017b). This does not necessarily mean that there were forests. Shrubby *Artemisia* or Chenopodioideae could provide possible substrates for their development in the lower part of the record.

### 3.2.2. Local vegetation around the water reservoir at the Gorgan Wall bridge over the Sari Su River

Trench b contained further archives with preservation of water-logged material. Archaeobotanical investigations of the sediment infill of the reservoir provided unprecedented insights into the vegetation formed in and around the pond (Shumilovskikh et al., 2022). Carpological analysis shows that there was water (*Potamogeton*, *Zannichellia palustris*, *Ruppia maritima*) and wetland (*Typha*, *Cyperus longus*, *Myosoton aquaticum*, *Salicornia europaea*, *Mentha aquatica*) taxa, indicating a reservoir with deep standing water. According to radiocarbon samples it was created in Sasanian times, probably in the sixth century CE (Sauer et al., 2022).

In the surroundings of the reservoir, there were *Salix* in wetlands, *Rubus* and *Capparis spinosa* in ruderal habitats and *Juniperus* in drier areas. Possibly, some Rosaceae trees, such as *Prunus*, *Malus*, *Crataegus* or similar wild trees and shrubs, grew on the shores, as indicated by floral parts (Fig. 4). Fruits and wood fragment of *Ficus carica* (Fig. 4) suggest that also fig trees may have been planted at the edge of the pond. *Morus nigra* (Fig. 4) can grow wild, but it is also possible that it was planted for shadow. The grapevine documented by charred fruits (Fig. 4) may have been planted close to the water reservoir, but we cannot exclude that the fruits were brought either by travellers or by the water in the river. In the light of all this evidence, we may imagine that an artificial oasis was created in this river valley.

### 3.3. Charred woody taxa from settlements and kilns

Overall, 30 taxa of trees, shrubs and monocots were detected by carpological and wood anatomy studies (Table 1). The majority of woody taxa (22) were detected by analysis of charcoal collected manually during archaeological excavations: cf. *Acer*, *Alnus*, *Carpinus*, Chenopodioideae, *Fraxinus*, cf. *Hippophae*, *Juglans*, *Juniperus*, Maloideae, cf. *Morus*, *Quercus*, *Paliurus*, *Pistacia*, *Platanus*, *Platanus/Fagus*, Prunoideae, *Salix*, *Salix/Populus*, *Tamarix*, *Ulmus/Zelkova*, *Vitis*, and *Zelkova*. Nutshell fragment of *Juglans*, monocots nodi and seeds of *Vitis* are attested by charred remains obtained via flotation.

#### 3.3.1. Kilns

During the excavation seasons of 2005 and 2006, charcoal samples were recovered from the firing chambers of three Sasanian brick kilns: one next to the Tammisheh Wall (Trench F), one in the west (Trench G) and one in the east (Trench A) of the Gorgan Wall. In the arid environments of the Gorgan Wall, charcoal from both Gorgan Wall kilns is represented by *Paliurus* and Chenopodioideae (Table 1). The assemblage recovered from the firing chamber of the Tammisheh Wall kiln, located close to the forested slopes of the Alborz Mountains, was composed of *Juglans*, *Juglans/Pterocarya* and *Carpinus* (Table 1; Fig. 3; Poole and Gale, 2013).

#### 3.3.2. Fortifications

Excavations within the barracks in Fort 4 showed that it was built for accommodating soldiers. Our estimates, based on the number of rooms and their size, suggest that about 2000 persons could have been accommodated in this fort (Sauer et al., 2013, 2022), the largest on the wall, and perhaps some 20–30,000 on the entire wall. The fort was provided with storage pits and ovens. The large garrison will have required much fuel for cooking and heating. Based on a range of calibrated radiocarbon dates, the fort was occupied probably from the 5th century to the early or mid- 7th century (Sauer et al., 2022). The charcoal assemblage recovered from Fort 4 (Trenches H and J) during the 2006 and 2007 excavation seasons is more diverse than that recovered from the kilns. It is mainly represented by wood from arid environments, such as *Paliurus*, *Tamarix* and *Juniperus*. Wood from riparian forests growing along rivers, channels or lakes (*Alnus*, *Salix/Populus*, *Platanus*) and the eastern Hyrcanian forests (*Quercus*, *Ulmus/Zelkova*) is represented to a much lesser extent. In general, the prevalence of local wood in the assemblage is evident, but wood from species growing on mountain slopes were occasionally supplied as well.

Fort 2 (Trench d), located to the east of Fort 4, was excavated in 2014–2016. The excavation revealed a series of rooms within the barracks, including a storage room full of large vessels, several storage pits, ovens and fire-places, which must have been used for cooking and heating (Sauer et al., 2022). Charcoal fragments recovered here are represented by monocots, possibly grasses from the wetlands, and chenopods (Chenopodioideae) indicating arid areas. *Fraxinus* and *Alnus* indicate wood supply from wetlands possibly close to the Hyrcanian forests.

Buraq Tappeh (Trench g), a fort near Qaleh Kharabeh (Trench M), is located in the western part of the Gorgan Plain and on the Old Gorgan River. Charcoal is represented mainly by trees growing in an arid environment, such as chenopods (Chenopodioideae) and tamarisks (*Tamarix*). Elm (*Ulmus*) charcoal suggest wood supply from Hyrcanian forests, while plane (*Platanus*) could originate from riparian vegetation or cultivations (Shumilovskikh et al., 2017a).

The Bansaran Fort (Trench O), at the foot of the densely forested Alborz Mountains, is one of two forts in the vicinity of Tammisheh Wall. A three-aisled hall in the Bansaran Fort has no parallels in any of the forts along the Gorgan Wall, suggesting perhaps that this monument functioned as a high-status monument and may have been part of a palace (Sauer et al., 2013). Three radiocarbon dates of charcoal from its foundation layers point to occupation contemporary with that of the forts on the Gorgan Wall. Evidence for hornbeam, oak and maple in the charcoal assemblage indicates use of wood from the local Hyrcanian forests during the Sasanian occupation. Pistacio (*Pistacia*), growing in drier areas to the north, could be cultivated or wild.

Qal'eh Iraj fortress (Trench i) is located to the south of Alborz Mountains (Fig. 1). Like Fort 2 and Buraq Tappeh, it is dated to the 5th to 6th centuries CE (Sauer et al., 2022). The charcoal assemblage is presented by ten taxa (Table 1). It is dominated by potentially cultivated species (Fig. 3). Plane tree, grape and mulberry may have been planted in the surroundings of the fort for fruits, shadow or possibly moriculture. Prunoideae and Maloideae could be wild or domesticated. *Tamarix* and cf. *Hippophae* indicate clear evidence for wood from arid environments. The lowest representation have *Ulmus/Zelkova*, *Salix* and *Salix/Populus* associated with wetlands or Hyrcanian forests.

#### 3.3.3. Domestic contexts

Ovens, hearths and fire-places in domestic contexts were used for food preparation and heating. Excavation within the campaign base of Qal'eh Kharabeh (Trench M), in the west of the Gorgan some 2 km north of Buraq Tappeh and the Old Gorgan River (Fig. 1), revealed a small house perhaps functioning as a supply facility, where food was prepared, perhaps for the occupants of the numerous tents that once appear to have filled the interior of the large compound. Even if the circumstances are not clear from the contexts, the house was destroyed



by a fire (Sauer et al., 2013). The assemblage of charcoal recovered was rather diverse. The dominance of tamarisks and willow/poplar, accompanied by chenopods and *Paliurus*, points to the use of local wood from riparian forests in arid environments. Similarly, high amounts of *Ulmus/Zelkova*, accompanied by oak and zelkova, suggest use of wood from the Hyrcanian forests. Finds of *Pistacia*, Maloideae and possibly *Morus* could indicate use of cultivated plants.

#### 3.3.4. City of Dasht Qal'eh

Comparable in size with major metropolises of the ancient world, **Dasht Qal'eh** is the largest city of the Sasanian era known on the Gorgan Plain. It may have been intended for a population of perhaps around 100,000 inhabitants, although estimates of ancient urban populations always involve a large margin of error (Sauer et al., 2013). It is located in the southern part of the Gorgan Plain, close to the Alborz Mountains (Fig. 1). The vicinity of Hyrcanian forests is clearly reflected in the charcoal assemblage from Dasht Qal'eh. Intriguingly, the assemblage is dominated by Maloideae, which cannot be identified to genus and include cultivated and wild species of apple, pear, hawthorn, quince, white beam tree, European mountain ash, medlar, cotoneaster etc. (Schweingruber, 1990). The next most frequent genera are *Carpinus*, *Ulmus/Zelkova* and *Quercus*; wood from the nearby Hyrcanian forests is evidently strongly represented. Riparian and wetland woods are represented by alder and willow/poplar. Taking into account the modern treeless environment surrounding Dasht Qal'eh, the data reveal Hyrcanian forests as the main source of firewood.

## 4. Discussion

### 4.1. Sasanian woodland use

Due to its orographic and climatic diversity, the flora of the Gorgan Plain and the neighbouring Alborz Mountains is very rich (Akhani et al., 2010). The total species number in the Golestan Natural Park located in the eastern Hyrcanian forests (E of Mazandaran, NW of Khorasan and N of Semnan provinces), for example, exceeds 1200 species with 40 species of trees and 60 of shrubs (Akhani, 1998). As can be seen in comparison to our data containing about 30 arboreal taxa, one third of this rich arboreal flora is represented in our samples. One reason for it is the low number of samples, and further investigations are required to improve taxonomical diversity of the trees and shrubs recovered. Another reason is the rather low taxonomical resolution of identifications based on the anatomical features of the wood. In most cases, it is possible to identify charcoal to genus level. However, some genera have similar anatomical features, so that poor preservation of the material hinders identification to lower taxonomic levels. In the case of Rosaceae, the identification goes often to the sub-family level, Prunoideae and Maloideae, both containing numerous wild and cultivated species (Schweingruber, 1990). Nevertheless, even our fragmentary data shed significant new light on the use of trees and woodlands on the Gorgan Plain during the Sasanian era.

#### 4.1.1. Firewood

Charcoal data of the Sasanian era are available from nine sites in the eastern, western and southern part of the Gorgan Plain and one to the south of Alborz Mountains, Qal'eh Iraj (Fig. 3). Two of the records are represented by less than ten finds, two of them have more than one hundred specimens. Such differences in the size of the assemblages pose limitations on our analysis of the data and do not as yet enable us to identify clear patterns in woodland use. More and larger data sets are required to evaluate our preliminary results.

We observe two trends in charcoal representation. Firstly, charcoal assemblages from sites located at less than 10 km distance from the Alborz Mountain are composed largely of Hyrcanian and possibly cultivated taxa. Dominance of Hyrcanian taxa suggests that the forests could cover more ground in the southern Gorgan Plain than they do

today. All other sites situated along the Gorgan Wall have a considerable number of trees and shrubs from steppe environments. This trend underlines the concept of the importance of local sources of firewood.

Secondly, our data demonstrate dependence of charcoal assemblages on the function of the site/monument and its duration of use/occupation. Thus, charcoal from kilns along the Gorgan Wall is represented only by local arid wood, and on the Tammisheh Wall, by Hyrcanian/cultivated wood. As Poole and Gale (2013) noted, the charcoal in kilns represents shrub and tree branches, because they burn at higher temperatures. Even if it is impossible to establish precisely how often kilns were used (Sauer et al., 2013), we may assume that fired mud-brick production required wood over a period of a few weeks during the dry season. In this case, local sources could provide enough firewood. In contrast to the kilns, charcoal from forts and hinterland facilities are more diverse and include some charcoal from the Hyrcanian forest, evidently drawing on a larger area for wood and timber supply. Fortifications were in use much longer than kilns and had substantial numbers of occupants, requiring continuous supply of firewood for cooking and for heating in the cold season. In the case of the treeless landscapes of the Gorgan Plain, they were dependent on wood from more distant areas. An especially rich charcoal assemblage, with 43% of wood from Hyrcanian forests, is found in a mud-brick house in Qal'eh Kharabeh (Trench M; Fig. 3). This indicates that this house benefitted from a regular supply of wood from the Alborz Mountains possibly together with other goods.

Charcoal recovered in deposits in Fort 2 is represented by monocots and chenopods (Chenopodioideae) indicating possible use of dung fuel. This is also suggested for Fort 4, where occupation horizons of a house contained ruderal plants such as *Galium*, *Rumex* and Chenopodioideae (Shumilovskikh et al., 2022). Dung use as fuel is often suggested for areas where livestock/domesticated animals are present and climate allows drying and stockpiling of the resource (Miller, 1984, 1996; Spengler, 2019). In the Gorgan Plain today this is definitely the case (Shumilovskikh et al., 2022). There was a dry steppe environment already in the Sasanian period according to pollen record Kongor and the presence of large numbers of cattle, sheep and goats at the time is attested by archaeozoological studies in the area (Mashkour et al., 2022).

Our interpretations of the woodland use are biased by our own experience and knowledge. One cannot be completely sure for what purposes woodland and trees were used. Charcoal records provide direct evidence of burned wood, but do not indicate what exactly was burned – firewood, construction timbers, wooden tools or artefacts. Furthermore, many species could be used for multiple purposes. For example, walnut was exploited for its nuts, and its wood was also used as fuel or for wooden furnishings. Another example is plane tree, which can be planted for shadow and later used for fuel. Baskets, floor and roof covers are often made of willow branches, and they also make good firewood.

#### 4.1.2. Construction timber

There is no direct evidence for the use of wood in construction in the Gorgan Plain due to poor preservation conditions. However, the discovery of postholes, ethnographic evidence and practical considerations leave no serious doubt that timber was used in construction, perhaps more selectively in the steppe zones than in the vicinity of the Alborz Mountains (Sauer et al., 2022). It is likely that wood was not frequently used for construction of buildings, but as supplementary material for covering roofs (Sauer et al., 2013, 2022). Going beyond the Gorgan Plain, the only systematic study of timber identification has been conducted at the Sasanian Palace of Qal'a-ye Dokhtar as well as the Late Sasanian-early Islamic monument of Sarvestan in Fars, SW Iran (Djamali et al., 2017, 2021). These studies provided evidence for the use of Mediterranean cypress (*Cupressus sempervirens* L.) in palatial and religious architecture. *Cupressus sempervirens* is growing naturally in the Hyrcanian forest and was possibly planted in Sasanian gardens.

#### 4.1.3. Tree fruits in sasanian-era diet

Palynological studies across the Sasanian Empire indicate that arboriculture then reached a second apogee, following a first maximum under Achaemenid rule (Shumilovskikh et al., 2017a). Worth noting in particular is the widespread increase of walnut plantations. Our own investigations at Fort 2 (Shumilovskikh et al., 2022) indicate that in addition to cereals, grapevine and walnut made up part of the diet. *Vitis* pips were not only found in Trench b (the artificial water reservoir on the Sari Su River), charred grape seeds came also to light in the fill of two of the storage vessels in Fort 2. Most likely, however, they were not part of the original contents of the vessels, but were embedded in occupation debris used to fill of the vessels and raise the surface, after the vessels had gone out of use. Two fragments of nutshells of *Juglans* were found in occupation layers of Sasanian age, suggesting that walnuts were also consumed at the site.

#### 4.1.4. Trees for recreation

Charcoal assemblages from Qal'eh Kharabeh and Buraq Tappeh provide evidence for *Platanus* and possibly *Morus* use for fire. Plane trees and black mulberries grow naturally along the river valleys in the entire eastern Mediterranean region and beyond. Both have broad leaves and were therefore very popular for the shadow they provide. Plantations of plane can be traced back to the Late Bronze Age and was popular across the ancient world (van Zeist and Bottema, 1991). In the Gorgan Plain, an increase of plane pollen at the time of the Achaemenid to Sasanian Empires (Fig. 2) suggests that this species was then cultivated. It seems that both walnut and plane trees were beloved and venerated by Iranians and were exported to the east and the west from their major cultivation centre in Persia (Potts, 2018). *Morus nigra* seeds found in the water reservoir on the Sari Su suggest that black mulberry trees grew, naturally or in plantations (e.g. lining alleys to provide shadow and/or fruits), on the shores of the reservoir.

#### 4.1.5. Silk production?

Evidence for *Morus alba* at Lake Kongor is interesting. Since the leaves of the white mulberry tree represent the only food source for silkworms, the primary producer of silk, the presence of pollen, fruits and wood of this tree may indicate moriculture on the Gorgan Plain. The early Islamic geographers of the 9th-10th centuries CE, such as Yaqubi (died 897/898), Ibn al-Faqih (9th-10th centuries), Ibn Hawqal (died 978) and Istakhri (9th-10th centuries), attest production of silk at Djurdjan (Serjeant, 1946), coinciding with continuous presence of *Morus alba* in the Kongor core (Fig. 2). Based on an age-depth model for the sediment core Kongor, the earliest evidence for pollen of *Morus alba* occurs around the 5th century CE, suggesting that sericulture and production of raw silk on the Gorgan Plain might go back at least to the period of the Sasanian Empire (Shumilovskikh et al., 2016a).

#### 4.2. Woodland use in treeless landscapes?

Contrasting to evidence of woodland use, pollen record from the Lake Kongor point to open steppe vegetation being dominant on the eastern Gorgan Plain at least since the mid-Holocene. Although the climatic conditions varied over the last 6000 years (Shumilovskikh et al., 2016a; Shumilovskikh, 2022), the precipitation regime did, however, not change to the extent that it would have had a strong impact on forest growth. We may conclude that people settled in the treeless landscapes of the Gorgan Plain and had to develop strategies to deal with its dry climate. This reconstruction is in line with pollen-based reconstruction of the vegetation history on the core TM (Leroy et al., 2013). The core was obtained from the lagoon to the west of Gomishan (– 23/– 27m a.s.l.), near the south-eastern corner of the Caspian Sea (Fig. 1). Today, the area is characterised by lowland halophilous vegetation with the only one salt-tolerant tree species *Tamarix ramosissimum*. The reconstructions suggest that open steppe and salt marshlands dominated the area over the last 3500 years (Leroy et al., 2013).

Evidence of woodlands close to water bodies on the Gorgan Plain is coming from botanical macroremain and insect data from Lake Kongor and the water reservoir on the Sari Su River (Trench b). Local vegetation includes so-called azonal vegetation represented by riparian forests with *Alnus*, *Rubus*, *Salix* and *Sambucus*. Other important components of Sasanian woodlands include potentially cultivated trees such as *Ficus carica*, *Morus alba*, *Morus nigra* and *Vitis vinifera* (see discussion below). Travel accounts from the 19th century also refer to much woodland on the Gorgan Plain. Overall, the carpological and wood anatomy data attest that people living on the Gorgan Plain during Sasanian times did burn wood of a wide range of tree species (Table 1), implying logging of trees in the Hyrcanian forests. Yet despite the supposedly strong human impact on the forests, pollen records located today in treeless environments demonstrate that an open landscape has dominated the area for millennia, although Tuska Tchal record indicates strong deforestation.

The pollen record Tuska Tchal (Fig. 1) indicates heavy human impact under the Sasanian Empire. The core was obtained from a peat bog at Tuska Tchal (1,037m a.s.l.) located in the heart of the eastern Alborz Mountains (partly published in Shumilovskikh et al., 2017a). The wetland is located between cultivated lands (mainly *Nicotiana*) and the Hyrcanian forest dominated by *Quercus castaneifolia* and *Carpinus betulus*. The high-resolution pollen record indicates forest clearance during the late Parthian and Sasanian period for walnut, grape, plane and cereal plantations. After the end of Sasanian rule, settlement activity decreased and forest rapidly recovered. This is further evidence for active use of the Hyrcanian forests at the time. Even if extensive clearance of the vast forest on mountain slopes would also have been far from easy, perhaps woodland management was regulated in the Sasanian Empire.

A comparison of pollen records before, during and after the Sasanian Empire (Shumilovskikh et al., 2017a) suggests that across Persia tree cultivation intensified during the time of the Persian Empires, notably those of the Achaemenids and Sasanians. Palaeobotanical data support the idea of strong investment in arboriculture during the Sasanian Empire (Djamali et al., 2010; Shumilovskikh et al., 2017a). On the Gorgan Plain, plantations of grapevine, walnut, plane, fig, mulberry, Prunoideae and Maloideae may have been quite common. The data cannot answer the question how the plantations were managed. However, our two principal sample sites at Lake Kongor and on the Sari Su River were definitely surrounded by trees including cultivated species. If we assume that these data are typical for the Gorgan Plain more broadly, small gardens may well have been established also around a variety of other natural hollows and artificial water reservoirs, transforming parts of the northern Gorgan Plain into a flourishing garden.

## 5. Conclusion

Palaeobotanical data provide new insights into woodland use during the Sasanian era and shed significant new light on the landscape history and the extent of woodland cover on the today largely treeless Gorgan Plain, to the southeast of the Caspian Sea. Although palynological research points to natural origins of the open steppe vegetation in the Gorgan Plain, carpological and wood anatomy studies provide evidence for extensive use of trees and shrubs during the Sasanian period. Charcoal data indicate that local sources provided enough firewood for kilns in short-term use, but were insufficient for fortifications which required additional supplies from the Hyrcanian forests. These forests provided the main source of firewood for sites located close to the Alborz Mountains. Cultivation of trees was widespread during the Sasanian Empire for fruits, shadow and possibly moriculture for silk production. Palaeobotanical records are still in short supply on the Gorgan Plain. New data are required to gain further insights into woodland use during the Sasanian era.

## Author contributions

LS: Formal analysis, Conceptualisation and first draft of the

manuscript; P P: Formal analysis; JLB: palynological data Tusca Tchal; Morteza Djamali, PP, JLB, JN, HOR, ES: fieldwork and work on the final version of the manuscript.

## Data availability

Pollen data are available in PANGAEA: <https://doi.org/10.1594/PANGAEA.907390>; raw data from macroremain analysis are published in Shumilovskikh et al. (2022), from anthracological analysis in Poole and Gale (2013) and Shumilovskikh and Talon (2022).

## Funding

The study was partially supported by the European Research Council project PERSIA (grant 295375).

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

## Acknowledgement

We thank two anonymous reviewers for their kind valuable comments helping us to improve the manuscript. We are also grateful to Dr Mohammadreza Nemati for enabling us to take samples at Qal'eh Iraj.

## References

- Abbasi, G., 2011. Final Report of the Archaeological Excavations at Narges Tappeh, Gorgan Plain, Iran. Gorgan, Golestan Cultural and Heritage Organization and Golestan Higher Education Institute (in Persian).
- Akhani, H., 1998. Plant biodiversity of golestan national Park. *Stapfia* 53, 1–411.
- Akhani, H., Ziegler, H., 2002. Photosynthetic pathways and habitats of grasses in Golestan National Park (NE Iran), with an emphasis on the C4-grass dominated rock communities. *Phytocoenologia* 32, 455–501.
- Akhani, H., Djamali, M., Ghorbanalizadeh, A., Ramezani, E., 2010. Plant biodiversity of Hyrcanian relict forests, N Iran: an overview of the flora, vegetation, palaeoecology and conservation. *Pakistan J. Bot.* 42, 231–258.
- Arne, T.J., 1945. Excavations at Shah Tepe, Iran. *Elanders Boktryckeri Aktiebolag, Stockholm, Göteborg*.
- Asadi, S., Moore, F., Keshavarzi, B., 2013. The nature and provenance of Golestan loess deposits in northeastern Iran. *Geol. J.* 48, 646–660.
- Djamali, M., de Beaulieu, J.-L., Campagne, P., Andrieu-Ponel, V., Ponel, P., Leroy, S.A.G., Akhani, H., 2009. Modern pollen rain-vegetation relationships along a forest-steppe transect in the Golestan National Park, NE Iran. *Rev. Palaeobot. Palynol.* 153, 272–281.
- Djamali, M., Miller, N.F., Ramezani, E., Akhani, H., Andrieu-Ponel, V., de Beaulieu, J.-L., Berberian, M., Guibal, F., Lahijani, H., Lak, R., Ponel, P., 2010. Notes on the arboricultural and agricultural practices in ancient Iran based on new pollen evidence. *Paleorient* 36, 175–188.
- Djamali, M., Akhani, H., Khoshravesh, R., Andrieu-Ponel, V., Ponel, P., Brewer, S., 2011. Application of the Global Bioclimatic Classification to Iran: implications for understanding the modern vegetation and biogeography. *Ecol. Mediterr.* 37, 91–114.
- Djamali, M., Chaverdi, A.A., Balatti, S., Guibal, F., Santelli, C., 2017. On the chronology and use of timber in the palaces and palace-like structures of the Sasanian Empire in “Persis” (SW Iran). *J. Archaeol. Sci.: Report* 12, 134–141.
- Djamali, M., Capano, M., Askari-Chaverdi, A., Faucherre, N., Guibal, F., Northedge, A., Rashidian, E., Tuna, T., Bard, E., 2021. An absolute radiocarbon chronology for the World Heritage site of Sarvestan (SW Iran); a late Sasanian heritage in early Islamic era. *Archaeometry* 64, 545–559.
- Gerasimov, I.P., 1964. Atlas Mira. AN SSSR-GUGK SSSR, Moscow (in Russian).
- Khalili, A., 1973. Precipitation patterns of central elburz. *Theor. Appl. Climatol.* 21, 215–232.
- Leroy, S.A.G., Kakroodi, A.A., Kroonenberg, S., Lahijani, H.K., Alimohammadian, H., Nigarov, A., 2013. Holocene vegetation history and Sea level changes in the SE corner of the Caspian Sea: relevance to SW Asia climate. *Quat. Sci. Rev.* 70, 28–47.
- Lukanina, E., Shumilovskikh, L., Novenko, E., 2022. Vegetation and fire history of the East-European forest-steppe over the last 14,800 years: a case study from Zamostye, Kursk region, Russia. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 605, 111218 <https://doi.org/10.1016/j.palaeo.2022.111218>.
- Mashkour, M., Khazaeli, R., Amiri, S., Fathi, H., Doost, S.B., Mohaseb, A., Debue, K., Radu, V., Davoudi, H., Ruchonnet, A., Laleh, H., Nokandeh, J., Omrani Rekavandi, H., Nemati, M., Sauer, E., 2022. Archaeozoology of Sasanian and Islamic sites from the Gorgan Wall to the Tehran Plain. In: Sauer, E.W., Nokandeh, J., Omrani Rekavandi, H. (Eds.), *Ancient Arms Race: Antiquity's Largest Fortresses and Sasanian Military Networks of Northern Iran*. A Joint Fieldwork Project by the Iranian Center for Archaeological Research, the Research Institute for Cultural Heritage and Tourism and the University of Edinburgh (2014-2016), British Institute of Persian Studies Archaeological Monographs Series VII. Oxbow Books, Oxford, pp. 647–698.
- Miller, N.F., 1984. The use of dung as fuel: an ethnographic example and an archaeological application. *Paleorient* 10, 71–79.
- Miller, N.F., 1996. Seed eaters of the ancient Near East: human or herbivore. *Curr. Anthropol.* 37, 521–528.
- Novenko, E.Y., Tsyganov, A.N., Volkova, E.M., Babeshko, K.V., Lavrentiev, N.V., Payne, R.J., Mazei, Y.A., 2015. The Holocene paleoenvironmental history of central European Russia reconstructed from pollen, plant macrofossil, and testate amoeba analyses of the Klukva peatland, Tula region. *Quat. Res. (Orlando)* 83, 459–468.
- Novenko, E.Y., Tsyganov, A.N., Rudenko, O.V., Volkova, E.M., Zuyganova, I.S., Babeshko, K.V., Olchev, A.V., Losbenev, N.I., Payne, R.J., Mazei, Y.A., 2016a. Mid- and late-Holocene vegetation history, climate and human impact in the forest-steppe ecotone of European Russia: new data and a regional synthesis. *Biodivers. Conserv.* 25, 2453–2472.
- Poole, L., Gale, R., 2013. Charcoal. In: Sauer, E., Omrani Rekavandi, H., Wilkinson, T., Nokandeh, J., et al. (Eds.), *Persia's Imperial Power in Late Antiquity: the Great Wall of Gorgan and Frontier Landscapes of Sasanian Iran*. Oxbow Books, Oxford, pp. 581–590.
- Potts, D.T., 2018. Arboriculture in ancient Iran: walnut (*Juglans regia*), plane (*Platanus orientalis*) and the “Radde dictum”. *Dabir* 6, 101–109.
- Sagheb Talebi, K., Sajedi, T., Pourhashemi, M., 2014. Forests of Iran. In: *A Treasure from the Past, a Hope for the Future, Series: Plant and Vegetation*, vol. 10. Springer, Dordrecht.
- Sauer, E., Omrani Rekavandi, H., Wilkinson, T., Nokandeh, J., et al., 2013. *Persia's Imperial Power in Late Antiquity: the Great Wall of Gorgan and Frontier Landscapes of Sasanian Iran*. British Institute of Persian Studies Archaeological Monographs Series II. Oxbow Books, Oxford.
- Sauer, E.W., Nokandeh, J., Omrani Rekavandi, H., 2022. *Ancient Arms Race: Antiquity's Largest Fortresses and Sasanian Military Networks of Northern Iran*. A Joint Fieldwork Project by the Iranian Center for Archaeological Research, the Research Institute for Cultural Heritage and Tourism and the University of Edinburgh (2014-2016). In: *British Institute of Persian Studies Archaeological Monographs Series VII*. Oxbow Books, Oxford.
- Schlüt, F., Dulamsuren, C., Wieckowska, M., Mühlenberg, M., Hauck, M., 2008. Late Holocene vegetation history suggests natural origin of steppes in the northern Mongolian mountain taiga. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 261, 203–217.
- Schweingruber, F., 1990. *Mikroskopische Holzanalyse. Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft, Birmensdorf*.
- Serjeant, R.B., 1946. Material for a history of Islamic textiles up to Mongol conquest. *Art Islam.* 11/12, 98–145.
- Shumilovskikh, L.S., Hopper, K., Djamali, M., Ponel, P., Demory, F., Rostek, F., Tachikawa, K., Bittmann, F., Golyeva, A., Guibal, F., Talon, B., Wang, L.-C., Nezamabadi, M., Bard, E., Lahijani, H., Nokandeh, J., Omrani Rekavandi, H., de Beaulieu, J.-L., Sauer, E., Andrieu-Ponel, V., 2016a. Landscape evolution and agrosylvo-pastoral activities on the Gorgan Plain (NE Iran) in the last 6000 years. *Holocene* 26, 1676–1691.
- Shumilovskikh, L.S., Seeliger, M., Feuser, S., Novenko, E., Schlüt, F., Pint, A., Pirson, F., Brückner, H., 2016b. The harbour of Elaia: a palynological archive for human environmental interactions during the last 7500 years. *Quat. Sci. Rev.* 149, 167–187.
- Shumilovskikh, L.S., Djamali, M., Andrieu-Ponel, V., Ponel, P., de Beaulieu, J.-L., Naderi-Beni, A., Sauer, E., 2017a. Palaeoecological insights into agri-horti-cultural and pastoral practices before, during and after the Sasanian Empire. In: Sauer, E. (Ed.), *Sasanian Persia: between Rome and the Steppes of Eurasia*. Edinburgh University Press, Edinburgh, pp. 51–73.
- Shumilovskikh, L.S., Ferrer, A., Schlüt, F., 2017b. Non-pollen palynomorphs notes: 2. Holocene record of *Megalohypha aqua-dulces*, its relation to the fossil form genus *Fusiformisporites* and association with lignicolous freshwater fungi. *Rev. Palaeobot. Palynol.* 246, 167–176.
- Shumilovskikh, L.S., Novenko, E., Giesecke, T., 2018. Long-term dynamics of East-European forest-steppe ecotone. *J. Veg. Sci.* 29, 416–426.
- Shumilovskikh, L.S., Rodinkova, V., Rodionova, A., Troshina, A., Ershova, E., Novenko, E., Zazovskaya, E., Sycheva, S.A., Kiselev, D., Schlüt, F., Schneeweiß, J., 2019. Insights in the late Holocene vegetation history of the East European forest-steppe: case study Sudzha (Kursk region, Russia). *Veg. Hist. Archaeobotany* 28, 513–528.
- Shumilovskikh, L.S., 2022. Vegetation history on the Gorgan Plain. In: Sauer, E.W., Nokandeh, J., Omrani Rekavandi, H. (Eds.), *Ancient Arms Race: Antiquity's Largest Fortresses and Sasanian Military Networks of Northern Iran*. A Joint Fieldwork Project by the Iranian Center for Archaeological Research, the Research Institute for Cultural Heritage and Tourism and the University of Edinburgh (2014-2016), British Institute of Persian Studies Archaeological Monographs Series VII. Oxbow Books, Oxford, pp. 719–724.
- Shumilovskikh, L.S., Bittmann, F., Paetzold, D., 2022. Archaeobotanical studies on the Gorgan Plain. In: Sauer, E.W., Nokandeh, J., Omrani Rekavandi, H. (Eds.), *Ancient Arms Race: Antiquity's Largest Fortresses and Sasanian Military Networks of Northern Iran*. A Joint Fieldwork Project by the Iranian Center for Archaeological Research, the Research Institute for Cultural Heritage and Tourism and the University of Edinburgh (2014-2016), British Institute of Persian Studies Archaeological Monographs Series VII. Oxbow Books, Oxford, pp. 705–719.
- Shumilovskikh, L.S., Talon, B., 2022. Woodland use. In: Sauer, E.W., Nokandeh, J., Omrani Rekavandi, H. (Eds.), *Ancient Arms Race: Antiquity's Largest Fortresses and Sasanian Military Networks of Northern Iran*. A Joint Fieldwork Project by the

- Iranian Center for Archaeological Research, the Research Institute for Cultural Heritage and Tourism and the University of Edinburgh (2014-2016), British Institute of Persian Studies Archaeological Monographs Series VII. Oxbow Books, Oxford, pp. 699-705.
- Simpson, J., 2017. Sasanian cities: archaeological perspectives on the urban economy and built environment of an empire. In: Sauer, E. (Ed.), *Sasanian Persia: between Rome and the Steppes of Eurasia*. Edinburgh University Press, Edinburgh, pp. 21-50.
- Spengler, R.N., 2019. Dung burning in the archaeobotanical record of West Asia: where are we now? *Veg. Hist. Archaeobotany* 28, 215-227.
- Stobbe, A., Gumnior, M., Röpke, A., Schneider, H., 2015. Palynological and sedimentological evidence from the Trans-Ural steppe (Russia) and its paleoecological implications for the sudden emergence of Bronze Age sedentarism. *Veg. Hist. Archaeobotany* 24, 393-412.
- Thornton, C.P., 2013. The Bronze Age in Northeastern Iran. In: Potts, D.T. (Ed.), *The Oxford Handbook of Ancient Iran*. Oxford University Press, Oxford, pp. 179-202.
- Van Zeist, W., 1967. Late quaternary vegetation history of western Iran. *Rev. Palaeobot. Palynol.* 2, 301-311.
- Van Zeist, W., Bottema, S., 1991. *Late Quaternary Vegetation of the Near East*. Reichert, Wiesbaden.
- Wilkinson, T.J., Omrani Rekavandi, H., Hopper, K., et al., 2013. The landscapes of the gorgan wall. In: Sauer, E.W., Omrani Rekavandi, H., Wilkinson, T.J., et al. (Eds.), *Persia's Imperial Power in Late Antiquity: the Great Wall of Gorgan and Frontier Landscapes of Sasanian Iran*. Oxbow Books, Oxford, pp. 24-132.
- Zohary, M., 1973. *Geobotanical Foundations of the Middle East*. Fischer, Stuttgart, Amsterdam.