Landscape transformations at the dawn of agriculture in southern Syria (10.7–9.9 ka cal. BP): plant-specific responses to the impact of human activities and climate change

Landscape transformations at the dawn of agriculture in southern Syria (10.7-9.9 ka cal. BP): Plant-specific responses to the impact of human activities and climate change

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Abstract

In southwest Asia, the accelerated impact of human activities on the landscape has often been linked to the development of fully agricultural societies during the middle and late Pre-Pottery Neolithic B (PPNB) period (around 10.2-7.9 ka cal. BP). This work contributes to the debate on the environmental impact of the so-called Neolitisation process by identifying the climatic and anthropogenic factors that contributed to change local and regional vegetation at the time when domesticated plants appear and developed in southern Syria (around 10.7-9.9 ka cal. BP). In this work an inter-disciplinary analyses of botanical microremains (pollen and phytoliths) and macroremains (wood charcoal) is carried out along with stable carbon isotope discrimination of wood charcoals in an early PPNB site (Tell Qarassa North, west of the Jabal al-Arab area). Prior to 10.5 ka cal. BP, the results indicate a dynamic equilibrium in the local and regional vegetation, which comprised woodland-steppe, Mediterranean evergreen oak-woodlands, wetland vegetation and coniferous forests. Around 10.5-9.9 ka cal. BP, the elements that regulated the vegetation system changed, resulting in reduced proportions of arboreal cover and the spread of cold-tolerant and wetlands species. Our data show that a reinforcing interactions between the elements of the anthropogenic (e.g. herding, fire-related activities) and climatic systems (e.g. temperature, rainfall) contributed to the transformation of early Holocene vegetation during the emergence of fully agricultural societies in southern Syria.

Keywords

Palaeovegetation; Early Holocene; Climate change; Southwest Asia; Domestication; Archaeobotany; Anthropogenic impact

Highlights

- Multi-proxy analyses reveal diverse vegetation around 10.7-9.9 ka cal. BP.
- Cereals were domesticated in wetter conditions than at present in southern Syria.
- Dynamic equilibrium around 10.7-10.5 ka cal. BP, changes around 10.5-9.9 ka cal. BP.
- RCCs as trigger for the expansion of cold-tolerant and wetland vegetation.
- Increased anthropogenic impacts and RCCs coincided with decreased arboreal cover.

1. Introduction

The Pre-Pottery Neolithic (PPN) represents a key time period to understand the emergence of agriculture in southwest Asia. During the Pre-Pottery Neolithic A (PPNA, 11.6-10.7 ka cal. BP), there is evidence for the development of plant food production activities involving morphologically wild plant species (Willcox et al., 2008), along with the evidence of early control or management of wild animal populations (Ervynck et al., 2001; Vigne, 2013). Subsequently, during the early Pre-Pottery Neolithic B (EPPNB, 10.7-10.2 ka cal. BP), the first morphologically domesticated plants (Tanno and Willcox, 2012) and animal species (Helmer et al., 2005; Peters et al. 2005; Zeder, 2011) appear in the archaeological record, yet the exploitation of morphologically wild species predominated during this time. Agriculture, defined as a subsistence system largely relying on domesticated resources (Zeder, 2015), evolved only around 10.2-9 ka cal. BP, during the middle and late PPNB (Asouti and Fuller, 2012, 2013; Zeder, 2011).

The environmental settings of the PPN period, exception made for the Khiamian period that developed within the last years of the Younger Dryas, were primarily those of the Pre-boreal climatic oscillations (Maher et al., 2011). This period was characterised by rapid warming, with increased mean yearly temperatures of about 7ºC (Alley, 2000), combined with minimum rainfall rates in excess of 350 mm/yr, making it one of the wettest periods in Southwest Asia in the last 25,000 years (Robinson et al., 2006; Weninger et al., 2009). However, early Holocene climate was not stable, and several Rapid Climatic Changes (RCCs) occurred in the eastern Mediterranean at the time when agriculture developed in southwest Asia, c. 10.2 ka cal. BP (Mayewski et al., 2004; Weninger et al., 2009). Such RCCs comprised cold/dry (e.g. 10.2 and 8.2 ka cal. BP) and wet/warm (Levantine Moist Period and Sapropel S1, 10.1-8.6 ka cal. BP) spells. Some of these events seem to have caused considerable changes in the vegetation. For example, maximum *Pistacia* percentages (the so-called "*Pistacia* Phase") were recorded during the Sapropel depositions (around 9-6 ka cal. BP) in several pollen diagrams from the Adriatic and Ionian Sea, Lake Ioannina and Lake Xinias (Greece), Tenaghi Phillippon (Greece), and Ghab (Syria) indicating relatively warm winters and mild summers (Rossignol-Strick 1995; 1999). Reductions in the proportions of evergreen *Quercus* were recorded shortly after the dry 8.2 ka cal. BP event at Tenaghi Phillippon Greece (Pross et al., 2009). During the same time period in the Eastern Mediterranean (close to the Israel coast) pollen records from deep-sea cores indicate maximum values for dry-tolerant *Artemisia* (Laggunt et al., 2011). Yet, the understanding of the effects that early Holocene RCCs caused in the vegetation, and by extension, in the subsistence of the early agricultural groups during the Pre-Pottery Neolithic is still limited (Weninger et al., 2009; Flhor et al., 2016; Berger et al., 2016).

Despite the diverse bioclimatic regions and vegetation zones in southwest Asia (see a short summary in Asouti et al., 2015), the available pollen records indicate a consistent reduction in non-arboreal pollen (NAP) during the early Holocene, and an overall increase in arboreal pollen (AP), characterised, in particular, by the spread of woodland-steppe taxa (*Pistacia* and *Amygdalus*, pistachio and almond) and *Quercus* (oak) woodlands (van Zeist and Bottema, 1977; van Zeist and Woldring, 1978; Rossignol-Strick, 1993, 1995, 1997, 1999; Stevens et al., 2001, 2006; Wright and Thorpe, 2003; Wick et al., 2003; Rosen, 2007; Hajar et al., 2010; Rambeau, 2010). However, the time at which oak-woodlands developed across southwest Asia varied from one region to the other. In the Mediterranean area of the western Levant the spread of deciduous *Quercus* occurred 10.3-8.4 ka cal. BP (Wright and Thorpe, 2003; Rosen, 2007; van Zeist et al., 2009), whereas pollen records from the Irano-Anatolian region including southwest Iran (Zagros area) and central and eastern Anatolia point to a later expansion, around 7.5-4.5 ka cal. BP (Bottema and Woldring, 1984; van Zeist and Bottema, 1977; Stevens et al., 2001; Wick et al., 2003; Djamali et al., 2008; Litt et al., 2009).

Some argued that climatic conditions that would have allowed oak-woodland expansion did not develop in these areas until later (van Zeist and Bottema, 1991; Roberts and Wright, 1993; Rossignol-Strick, 1997). Yet, others have attributed this delay to anthropogenic factors. Several researchers proposed that increased wildfires at the beginning of the Holocene could have contributed to the development of grasslands in central and eastern Anatolia (considered as competitors for oak-seedlings), which would have hindered oak growth and expansion (Wick et al., 2003; Turner et al., 2010). Roberts (2002) suggested that the human activities that developed with the establishment of agriculture in southwest Asia (e.g. land clearance for crop cultivation, burning, animal grazing/browsing, and wood cutting for fuel and lime-plaster manufacture), besides a more marked seasonality and the intensified occurrence of wild fires during the early Holocene, were overall responsible for the late establishment of oak-woodlands in central-eastern Anatolia and the Zagros (see also Turner et al., 2010). Based on wood charcoal analyses, pollen records and observations on modern vegetation in central Anatolia, Asouti and Kabukcu (2014) suggested that semi-arid deciduous oak woodlands in this particular region evolved progressively, for around 3000 years, enhanced by several anthropogenic activities (i.e. selective exploitation of Rosaceae-Maloideae, light-moderate grazing by ruminants and managements of *Quercus* stands) carried out by M/LPPNB groups starting around 9-8 ka cal. BP. They argued that early Neolithic anthropogenic activities contributed to, rather than hampered, the spread of oak-woodland vegetation in the Irano-Anatolian region, and they considered these low-diversity oak-dominated woodlands as one of the earliest anthropogenic vegetation types in southwest Asia.

Nevertheless, the type and scale of the impacts caused by human groups around 10.0 ka cal. BP in southwest Asia was regionally diverse, probably as a consequence of the different environmental conditions and economic activities carried out by local human populations. In the Zagros area, increased proportions of *Plantago lanceolata* (English plantain) in the pollen records has been interpreted as evidence of highly disturbed habitats caused by fires set by local hunters and herders (van Zeist and Bottema, 1977; see also Wasylikowa et al., 2006). In the northern Levant (Ghab area, northwest Syria), Yasuda et al. (2000) recorded an increase of micro-charcoals and the decline of *Quercus* pollen around 10.1-9.5 ka cal. BP, interpreting it as the oldest evidence of large-scale anthropogenic forest clearance or deforestation (see Roberts, 2002 and Meadows, 2005, for an alternative interpretation of the data). In the southern Levant, several authors claimed that agricultural and lime production activities by PPNB groups in areas that nowadays receive low average rainfall for dry-farming (i.e. marginal areas) completely modified the pre-existing landscape and could have led to deforestation (Köhler-Rollefson 1988, Bar-Yosef, 1995; Rollefson 1990, Köhler-Rollefson and Rollefson, 1989, ~~1990~~). Yet, authors such as Blumler (2007) have put into questions that deforestation occurred during the early Holocene in Southwest Asia, since the re-examination of 13 primary pollen datasets from Greece, Turkey, Syria and Israel do not show strong reduction in arboreal cover during this time (e.g. from 90% to 30%). This view is reinforced by pollen records in north-western Turkey and Northern Israel (Golan Heights), where anthropogenic activities (e.g. herding) were identified only during the Early Bronze Age (ca. 4.8 ka cal. BP) (Miebach et al. 2015; Schwab et al. 2004), and slightly later, around 3.8 ka cal. BP, in the Lake Van (eastern Anatolia) (Wick et al., 2003). Asouti et al. (2015) proposed that far from causing degradation, anthropogenic activities could have enhanced woodland-expansion not only in the Irano-Anatolian region but also in the arid area of the southern Levant (e.g. Jordan Rift Valley). High proportions of *Pistacia* wood charcoal and nutshells found at Pre-Pottery Neolithic Wadi el-Hemmeh were interpreted as evidence for the intensive management of these trees as a source of food, fuel and fodder, and along with early Holocene climatic improvements, they would have contributed to the gradual expansion of *Pistacia* woodlands in the area (Asouti et al., 2015).

All perspectives considered, the degree to which early Holocene climate and Neolithic activities shaped local and regional vegetation in southwest Asia remains still an open question. There are as yet no enough data to address the effects of early Holocene RCC in the vegetation across southwest Asia, and depending on the author and the region under study, there are multiple views regarding the impact of Neolithic activities in the landscape (e.g. severe impacts in the form of deforestation, contribution to woodland expansion, no impact in the landscape until later periods). In addition to this, most of the studies so far have focused on the anthropogenic impacts of fully-fledged agricultural societies in southwest Asia (i.e. 10.2 ka cal. BP onwards), and as a result, there is a significant lack of evidence to characterise the environmental setting and anthropogenic impacts that concern the period immediately preceding the emergence of agriculture (e.g. the PPNA and EPPNB, around 11.6-10.2 ka cal. BP), despite animal and plant management activities were already common practice during this time.

2. Aims and scope

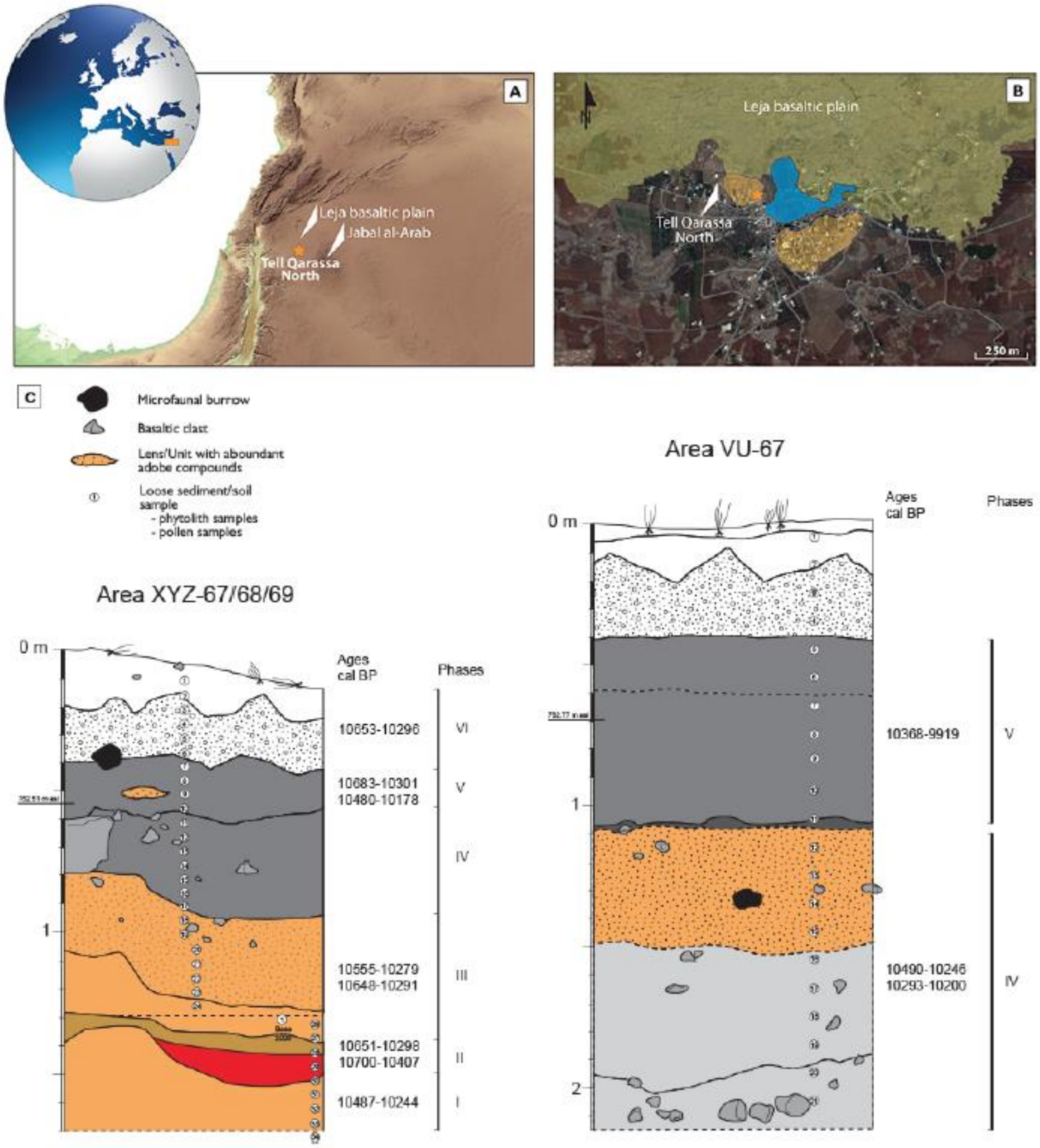
In this study we focus on the local and regional setting of Tell Qarassa North, an EPPNB site located in southern Syria (west of the Jabal al-Arab area). The site was occupied around 10.7-9.9 ka cal. BP (Ibañez et al., 2010), the time at which morphologically domesticated plants first appear in southwest Asia (Tanno and Willcox, 2012; Arranz-Otaegui et al., 2016a). Tell Qarassa provides direct evidence from plant micro and macroremains found in archaeological context, correlated by micro and macrostratigraphic studies and radiocarbon dating (Ibañez et al., 2010b; Balbo et al., 2012; Santana et al., 2012, 2015; Arranz-Otaegui et al., 2016a). The aim of this work is twofold: (i) to use the high-resolution datasets from Tell Qarassa North to reconstruct the complex dynamics of the local and regional vegetation and environmental conditions around 10.7-9.9 ka cal. BP, tracing the evolution of different plant formations at the time when morphologically domesticated cereals appeared and developed in southern Syria; and (ii) to explore the factors that regulate the evolution of plant formations over time considering that changes in the vegetation occur as a result of the complex interaction patterns between the vegetation system and others systems (e.g. climate). To address these issues we carry out, for the first time, an inter-disciplinary study combining pollen, opal phytoliths, wood charcoal remains and stable carbon isotope signature of wood charcoals from archaeological contexts. This work constitutes a substantial contribution to the understanding of environmental conditions at the time of cereal domestication in southern Syria and the climatic and anthropogenic factors that shaped past vegetation prior and during the development of agriculture in southwest Asia.

3. Tell Qarassa North and its current environmental context

The site of Tell Qarassa North was excavated in 2009 and 2010 by a Spanish team (Ibáñez et al., 2009, 2010a, 2010b) as part of the Syrian-French-Spanish archaeological research project around the palaeo-lake of Qarassa (Braemer et al., 2007, 2011). The site is located 25 km to the west of the Jabal al-Arab mountain range (36º49’54’’N-41º27’40’’E, 750 m a.s.l.) and 20 km from the city of Sweida, south Syria (Figure 1a). The early PPNB levels of Tell Qarassa North comprise square shaped wood-made and stone-made architecture (Ibañez et al., 2009; Balbo et al., 2012), ground stone tools such as saddle querns and mortars, imported materials such as obsidian (Ibañez et al., 2009), diverse funerary customs (Santana et al., 2012, 2015), anthropogenic figurines (Ibañez et al., 2014), as well as faunal remains including primarily goat (L. Gourichon in Ibañez et al., 2010a). Tell Qarassa North is one of the two sites in the southern-central Levant (along with Tell Aswad, Tanno and Willcox, 2012) that has provided evidence for the presence of morphologically domesticated-type cereals (Arranz-Otaegui et al., 2016a).

Present-day climate in the Jabal al-Arab comprise cold winters (average temperature of -2 ºC, and snow accumulations in some areas) and hot summers (mean temperatures of around 29 Cº). The area where Tell Qarassa North is located receives a mean annual precipitation of around 350 mm (Chikhali and Amri, 2000; Traboulsi, 2013), and it is characterized by a large basaltic field with many locally interconnected multilayer aquifers that act as water conduits at different depths, allowing the formation of numerous springs, water ponds and lakes (Braemer et al., 2009; E. Iriarte and A. Balbo in Ibáñez et al., 2010a). Tell Qarassa is located in the southern border of a Pleistocene lava field, which is characterised by very scarce soil cover (Figure 1b). To the south of the tell Pliocene basaltic materials are found, which provide rich soils to carry out agricultural activities. To the east of the site, there is evidence of an ancient lake (dated broadly from the late Pleistocene to the mid-Holocene) and towards the south a temporary river is found (Braemer et al., 2009; E. Iriarte and A. Balbo in Ibañez et al., 2009, 2010a).

Figure 1. A) Location of Tell Qarassa North in southwest Asia and B) detail of the surrounding area, including the paleolake (in blue) and the Leja Basaltic plain to the north (in yellow). B) Stratigraphy profiles of excavation areas XYZ and VU at Tell Qarassa North showing site phases and chronology. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article)



The Jabal al-Arab is considered a Mediterranean island within the Irano-Turanian region (Chikhali and Amri, 2000). The current vegetation in the area is rich and diverse with at least 900 species and various endemic taxa. Three main plant communities characterize the study area (Mouterde, 1953): a) to the north (Leja area), a degraded woodland-steppe community of *Pistacia atlantica* (Persian turpentine tree) and *Amygdalus* *korschinskii* (wild almond) is dominant; b) in the central area of the Jabal al-Arab, with altitudes reaching 1000-1500 m a.s.l., an open-woodland community of *Quercus calliprinos* (Palestine oak) and *Crataegus azarolus* (hawthorn) grows, along with *Pyrus syriaca* (Syrian pear), *Pistacia atlantica*, *Acer microphyllum* (small leaf maple) and *Crataegus sinaica* (Sinai hawthorn), the latter indicating the influence of altitude and dryness; in addition, *Quercus ithaburensis* (Mount Thabor's oak) has also been attested in this area (Willcox, 1999); and, c) to the east of the uplands, at an altitude around 700 m a.s.l., with a mean annual rainfall of 80-100 mm, dry-steppe vegetation dominated by *Artemisia* (wormwood) and some Chenopodiaceae (goosefoot) extends.

4. Materials and Methods

The plant macro-remains and micro-remains analysed in this work come from Tell Qarassa North, Zone 1, which comprises two excavation areas: XYZ-67/68/69 (hereafter referred to as area XYZ) and VU-67 (hereafter referred to as area VU) (Figure 1c) (see Balbo et al., 2012; Santana et al., 2015 for micromorphological description of the stratigraphic units). In Table S1 the available C14 dates from Tell Qarassa North are summarised. Area XYZ is dated to 10.7-10.2 ka cal. BP, which is consistent with the EPPNB period in the Levant (Kuijt and Goring-Morris, 2002). In this area, a square-shaped stone structure (space A) and an open patio area (space B) were found. The stratigraphy consists of six phases (Figure 1c; see detailed description in Santana et al., 2015). Phase I corresponds to an occupation phase characterised by beaten earth floors within the stone structures. In phase II a fire event was documented, which enabled the *in situ* preservation of a collapsed roof structure in space A (Balbo et al., 2012). After this fire event, a new phase of occupation was identified which included the construction of a new beaten earth floor (phase III). Area XYZ was abandoned after phase III, leading to the accumulation of a first layer of architectural and colluvial debris (phase IV). A second layer of debris dated to 10.7-10.3 ka cal. BP, including large blocks from the sidewalls, was deposited inside the perimeter both in space A and B (unit 21, phase V). During this time (around 10.5-10.2 ka cal. BP), the abandoned structures were re-used as a funerary area (Santana et al., 2015). Phase VI in area XYZ corresponds to surface layers slightly affected by agricultural activities.

In the VU area, two main occupation phases were attested. A lower phase dated to 10.5-10.2 ka cal. BP, which was characterised by a thin layer of wood charcoal remains, similar to that attested in phase IV of the XYZ area; and an upper phase where a stone-made wall was found associated to human remains. The upper phase was dated to 10.4-9.9 ka cal. BP and it is, probably, contemporary to the funerary phase V in area XYZ (see Santana et al., 2015).

4.1. Pollen analysis

Thirty-four pollen samples were taken from the south-facing profile of square E2 in area XYZ (space A) and twenty-one from the south-facing profile of the excavation area VU. The profiles were sampled from bottom to top at 10 cm intervals, avoiding the mixture of macroscopic visible layers or structures (Figure 1c). The sedimentary accumulation is interpreted as a sequence of aggradational soils (or surfaces) with very low edaphization imprint. The origin of the sediment is interpreted as aeolian and also derived from the reworking of nearby building materials (see detailed descriptions in Santana et al., 2015). Samples from the top of each profile correspond to levels affected by current agricultural activities (samples 1 to 6 from phase VI in area XYZ; samples 1 to 4 from VU, Figure 1c) and they were not included in the analyses. An average of 10 g of sediment was chemically treated to remove the mineral fractions. The method followed for pollen and non-pollen palynomorphs (NPPs) extraction is that described by Burjachs et al. (2003), where palynomorphs were concentrated using Thoulet liquor (Goeury and de Beaulieu, 1979). The final residue was suspended in glycerine and counted until a pollen sum of 250 grains was reached, excluding NPPs and anthropogenic taxa such Cichorioideae and Cardueae (Bottema, 1975; López-Sáez et al., 2003). Slides were examined with a light microscope using a magnification of 400× or 1000×. Pollen types were identified with pollen keys (Moore et al., 1991), pollen atlases (Reille, 1999), and the reference collection of the Archaeobotany Laboratory (CSIC, Madrid, Spain). Cerealia type was defined as Poaceae exceeding 45 μm with a minimum annulus diameter of 8–10 μm (Beug, 2004; López-Sáez and López-Merino, 2005). The majority of NPPs present on the pollen slides were identified and their nomenclature conforms to van Geel (2001). Pollen diagrams were drawn using TGView (Grimm, 2004). To establish the zonation of the pollen sequences, we tested several divisive and agglomerative methods with the program IBM SPSS Statistics 21. Based on the ecological meaning of the obtained zones, five and two local pollen assemblage zones (LPAZs) were constructed respectively for area XYZ and VU on the basis of agglomerative constrained cluster analysis of incremental sum of squares (Coniss) with square root transformed percentage data

(Grimm, 1987). The number of statistically significant zones was determined using the broken-stick model (Bennett, 1996).

4.2. Wood charcoal analysis

The wood charcoal remains analysed in this study were collected from 64 sediment samples processed with machine-assisted flotation (59 from spaces A and B in area XYZ, and five from area VU) (see Arranz-Otaegui, 2016 and Arranz-Otaegui et al., 2016a for details about the sampling and sample processing). The remains corresponded to dispersed wood charcoal fragments found in contexts such as infill of structures, open areas, processing areas, pits, refuse and burial contexts. Wood charcoal was identified using descriptions from several atlases (Fahn et al., 1986; Neumann et al., 2001; Schweingruber, 1990; Vernet, 2001) and the modern wood reference collections housed at the Palaeobotany Laboratory Lydia Zapata (University of the Basque Country, UPV-EHU, Vitoria-Gasteiz), Institute of Archaeology (University College London) and Department of Archaeology, Classics and Egyptology (University of Liverpool). Identifications were carried out with the aid of an incident light microscope (Olympus BX50) with different magnifications (10× to 50×). The majority of the wood fragments analysed at Tell Qarassa North was sized between 2-4 mm. In accordance with Chabal (1989, 1991), rare taxa were always smaller than 4 mm, whilst the most common taxa were found both within 2-4 mm and >4 mm size ranges. Saturation curves were used to establish the minimum number of charcoal fragments to be analysed per sample. These curves are exponential, the higher the number of species represented in a given sample, the higher the number of charcoal fragments that need to be analysed to grant their statistical representativeness. At Tell Qarassa North, saturation curves were used in all samples containing more than 100 wood charcoal fragments and indicated that the identification of 100 wood charcoal fragments was sufficient to ensure taxa representation.

4.3. Stable carbon isotope analysis

Stable carbon isotope analysis was carried out in wood charcoal remains of *Pistacia* sp. (pistachio) and *Amygdalus* sp. (almond) to characterize the water availability conditions of this site (Araus et al., 2014; Fiorentino et al., 2015). The assemblage includes dispersed wood charcoal remains from different contexts processed with flotation (as described above), as well as charcoal remains from a primary deposit, a burnt roof structure, recovered *in situ* (Balbo et al., 2012). The growth-ring curvature of the wood charcoal fragments was evaluated following Marguerie and Hunot (2007). This method provides information to characterise what part of the tree was used (e.g. trunks or branches) and assess whether biases exist in the isotopic content of biologically old (i.e. trunk) or young (i.e. branch) specimens.

Carbonate crusts in charcoals were removed by soaking each charcoal sample separately in 6M HCl for 24 h at room temperature and then rinsing the grain repeatedly with distilled water (DeNiro and Hastorf, 1985; Ferrio et al., 2004). All samples were oven-dried at 60ºC for 24 h before milling to a fine powder for isotope analyses. The stable isotope composition of carbon ($\delta^{13}C$, referred to the VPDB standard) was determined by elemental analysis and isotope ratio mass spectrometry (EA/IRMS) at the Isotope Services of the University of Barcelona (Barcelona, Spain). The overall analytical precision was about 0.1%. Carbon isotope discrimination ($\Delta^{13}C$) of archaeobotanical samples was calculated from grain $\delta^{13}C$ and from the $\delta^{13}C$ of atmospheric CO_2, as follows:

$$\Delta^{13}C(‰) = (\delta^{13}C_{air} - \delta^{13}C_{plant}) / [1 + (\delta^{13}C_{plant} / 1000)]$$

where $\delta^{13}C_{air}$ and $\delta^{13}C_{plant}$ denote air and plant $\delta^{13}C$, respectively (Farquhar et al., 1989). The $\delta^{13}C_{air}$ was inferred by interpolating a range of data from Antarctic ice-core records together with modern data from two Antarctic stations (Halley Bay and Palmer Station) of the CU-INSTAAR/NOAA-CMDL network for atmospheric CO_2 (ftp://ftp.cmdl.noaa.gov/ccg/co2c13/flask/readme.html), as described elsewhere (Ferrio et al., 2005). The whole $\delta^{13}C_{air}$ dataset thus obtained covered the period from 16,100 BCE to 2003 CE (data available at http://web.udl.es/usuaris/x3845331/AIRCO2_LOESS.xls). The provenance, dating as well as the $\delta^{13}C$ and $\Delta^{13}C$ of each sample used in this study and the corresponding $\delta^{13}C_{air}$ are detailed in the Supplemental Information Table S2.

4.4. Phytolith analysis

Seven samples from area XYZ (square E2, south-facing profile) and eleven from area VU (south profile) were selected for phytolith analysis. Samples were obtained from different contexts described in the field as filling deposits, open spaces and funerary areas. The methods used are similar to those developed by Katz et al. (2010). A weighed aliquot of between 30–40 mg of dried sediment was treated with 50 µl of a volume solution of 6N HCl. The mineral components of the samples were then separated according to their densities in order to concentrate the phytoliths using 450 µl 2.4 g/ml sodium polytungstate solution [$Na_6(H_2W_{12}O_{40})$]. Microscope slides were mounted with 50 µl of material. A minimum of 200 phytoliths with recognizable morphologies was examined at 200× and 400× using an Olympus BX41 optical microscope at the Department of Prehistory, Ancient History and Archaeology from the University of Barcelona. The estimated phytolith numbers per gram of sediment are related to the initial sample weight and allow quantitative comparisons between the samples and excavation areas. Phytoliths that were unidentifiable because of dissolution are listed as weathered morphotypes. Multicellular structures (multi-celled or interconnected phytoliths) were also recorded. These latter data may provide information regarding the extent of silification of plant cells, as well as of preservation conditions (Albert and Weiner, 2001; Albert et al., 2008, 2011; Portillo et al., 2014, 2016). Morphological identification was based on modern plant reference collections from the Mediterranean region (Albert and Weiner, 2001; Albert et al., 2008, 2011; Portillo et al., 2014; Tsartsidou et al., 2007) and standard literature (Brown, 1984; Mulholland and Rapp, 1992; Piperno, 1988, 2006; Rosen, 1992; Twiss, 1992; Twiss et al., 1969). The terms used follow the International Code for Phytolith Nomenclature (Madella et al., 2005).

5. Results

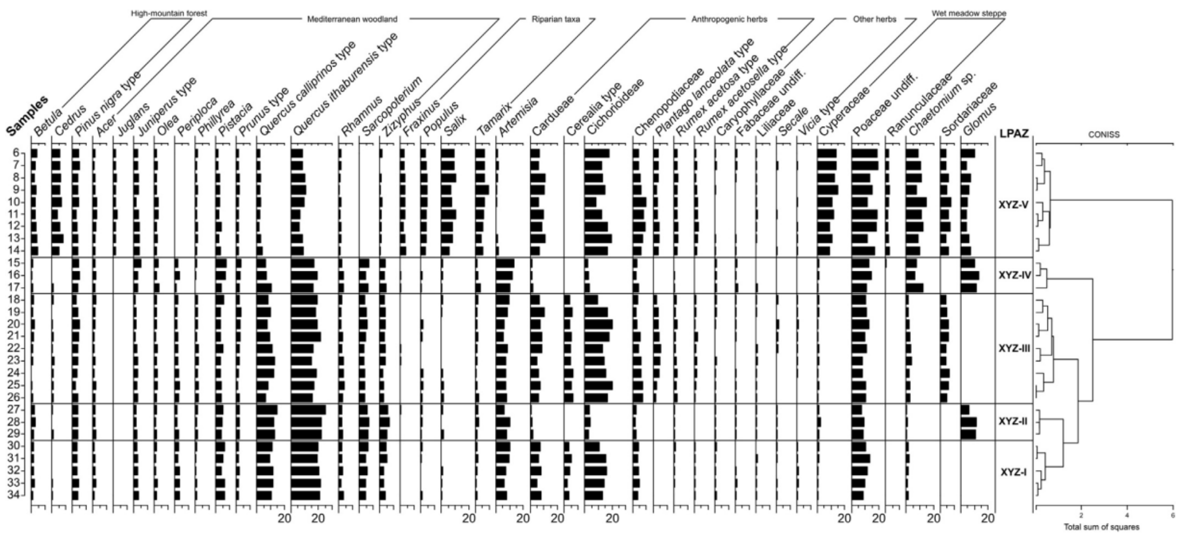
5.1. Pollen analysis

An overall good state of preservation of pollen grains and NPPs was found at Tell Qarassa North. A total of 38 pollen and non-pollen palynomorph types were identified. Total pollen and NPP percentages from area XYZ and VU are given in Figures 2 and 3. The percentage pollen diagrams can be divided into five LPAZ zones in area XYZ and two in area VU, which correspond to phases I-V in area XYZ (LPAZs XYZ-I to XYZ-V) and the lower and upper phases in area VU (LPAZs VU-Lower and VU-Upper).

In area XYZ the oldest phases I to IV show overall high values for *Quercus calliprinos* (7-15%) and *Q. ithaburensis* (15-25%), along with anthropogenic herbs such as Cardueae (5-10%), Cichorioideae (10-20%) and Poaceae (8-13%) (Figure 2). Anthropozoogenous taxa such as *Plantago lanceolata* (2-6%), *Rumex acetosa* (~2%), *R. acetosella* (~2%) and Chenopodiaceae (3-7%) are mainly attested in phase III, associated with maximum values of coprophilous fungi (Sordariaceae 4-6%; *Chaetomium* 4%). Increasing proportions of Cerealia are attested from phase I (around 2.2-5.4%) to phase III (around 3.7-6.5%). Most herbs show continuous presence during phases I to IV, but during destruction phases II and

IV, anthropogenic and zoogenous taxa (Cardueae, Cichorioideae, Chenopodiaceae, *Rumex acetosa*) sharply decrease, and Cerealia, *Plantago lanceolata* and *Rumex acetosella* disappear. In addition, the highest concentration of *Glomus* is recorded during these two destruction phases, whilst Sordariaceae disappear. The only difference between the two destruction phases (II and IV) is the high percentages of *Chaetomium* (6-12%) in the latter. Apart from these, phases I-IV are overall characterized by noticeable percentages of *Juniperus* (1-3%), *Pistacia* (4-7%), *Periploca* (2-4%), *Phillyrea* (1-2%), *Prunus* (2-4%), *Olea* (1-2%), *Rhamnus* (2-4%), *Sarcopoterium* (4-6%) and *Zizyphus* (3-5%) among the shrubs (note that *Pistacia* and *Amygdalus* are commonly under-represented in palynological analyses, e.g. Rossignol-Strick, 1993; Roberts, 2002). Wet meadow steppe taxa (Cyperaceae) show very low values (<2%), whilst *Artemisia* shows its highest percentages during phase IV (6-10%). Values for the rest of taxa, such as *Acer* (1-2%) and *Pinus nigra* (3-5%) remain stable during phases I-IV, whilst *Betula*, *Cedrus*, *Corylus*, *Tamarix*, *Fraxinus*, *Populus* and *Salix* types are rare (<2%) and sporadic.

Figure 2. Pollen and NPP diagram from Tell Qarassa North XYZ.



During phase V (LPAZ XYZ-5), which corresponds to the abandonment and later re-use of the area for funerary purposes, important changes occur in terms of vegetation composition (Figure 2). On the one hand, taxa such as *Olea*, *Pistacia* (2-4%), *Quercus calliprinos* (2-4%), *Q. ithaburensis* (6-11%), *Rhamnus* and *Zizyphus* steadily decline and *Periploca* and *Sarcopoterium* disappear. On the other hand, *Betula* (maximum 4%), *Cedrus* (7%), *Fraxinus* (4%), *Populus* (5%), *Salix* (10%) and *Tamarix* (10%) notably increase, as well as *Juglans*, which is recorded for the first time. Anthropogenic (Cardueae, Cichorioideae) and anthropozoogenic (Chenopodiaceae, *Plantago lanceolata*, *Rumex acetosa*, *R. acetosella*) herbs increase slightly, although Cerealia are absent. Sordariaceae are documented again (4-6%), whereas *Chaetomium* and *Glomus* maintain a continuous presence. Also, wet meadow steppe taxa (Cyperaceae 13-15%; Ranunculaceae 2-3%) show highest values during this time, whilst *Artemisia* drops sharply (<2%).

Figure 3. Pollen and NPP diagram from Tell Qarassa North VU.

In area VU (Figure 3), results for the lower phase (LPAZ VU-Lower) indicate relatively high percentages of arboreal pollen mainly comprising *Quercus ithaburensis* (12-16%), *Q. calliprinos* (5-10%) and *Pistacia* (10-14%), and to lesser extent *Acer*, *Betula*, *Salix* (<4%) and *Pinus nigra* (3-6%). Other trees such as *Tamarix*, *Populus* and *Fraxinus* as well as *Cedrus* are present, but show low percentages (<2%). Shrubs are abundant, with *Prunus* (~3%), *Olea* (~2%), *Periploca* (~2%), *Phillyrea* (1-2%), *Rhamnus* (2-3%), *Sarcopoterium* (3-5%) and *Zizyphus* (3-4%) being the most important taxa. Poaceae (5-12%) are the main herbaceous component. Anthropogenic taxa (Cardueae, Cichorioideae), and anthropozoogenic nitrophilous herbs (*Rumex acetosella*) are also present although with low percentages, similar to those attested during destruction phases II and IV in area XYZ. Hygrophytic taxa (Cyperaceae, Ranunculaceae) are represented by low percentages (~2%), while dry steppe taxa such as *Artemisia* show high values (6-11%), very similar to the evidence attested in phase IV in area XYZ. However, the lower phase of VU show high values of Cerealia (3.3-6.6%), which are similar to those identified during occupation phase III in area XYZ.

During the upper phase of area VU (Figure 3, LPAZ VU-Upper), the results indicate a synchronous decrease of *Pistacia* (4-8%), *Quercus calliprinos* (3-5%) and *Q. ithaburensis* (9-11%), comparable to the decrease observed during phase V in area XYZ. *Acer*, *Pinus nigra* and *Juniperus* maintain similar percentages as those attested during the previous period. *Betula*, *Cedrus* (4-6%), *Fraxinus*, *Populus*, *Salix* (8-11%) and *Tamarix* (4-7%) increase significantly, and *Juglans* (1-2%) appears for the first time. Most of the shrubs (*Prunus*, *Olea*, *Phillyrea*) maintain a continuous and significant presence throughout the zone, although other shrub taxa percentages (*Rhamnus*, *Zizyphus*) display a decreasing trend, and *Sarcopoterium* and *Periploca* disappear. In comparison to the previous phase, anthropogenic and anthropozoogenic taxa such as Cardueae (8-12%), Cichorioideae (9-21%), *Rumex acetosa*, *R. acetosella* and *Plantago lanceolata* (~2%) show an increasing trend, as well as Chenopodiaceae (8-11%), while Cerealia disappear. This is also observed in phase V from area XYZ. *Artemisia* decreases (<1%) whereas Poaceae (13-19%), Ranunculaceae and Cyperaceae (9-13%) significantly increase their values. NPPs indicative of erosion and fire events, as well as pastoral activities (*Chaetomium*, *Glomus*) are at their maximum values in this pollen sequence (23 and 17%, respectively), following synchronous trends.

5.2. Wood charcoal analysis

A total of 5274 wood charcoal fragments were analysed and 14 taxa were identified in areas XYZ and VU (see the main taxa found in Figure 4). It must be noted that there were no significant differences in terms of species representation by phase (i.e. XYZ-I-V) and by type of context (i.e. infill of structure, open areas etc.). Thus, in Table 1 a summary of the ubiquity and absolute counts for area XYZ and VU is given. The results show that *Pistacia* and *Amygdalus* were the most common taxa in all analysed samples, both in terms of ubiquity (between 96.9-98.4% of samples) and absolute counts (between *c.* 30-50%) (Note that these two taxa might be over-represented in the wood charcoal assemblage, Arranz-Otaegui, 2016). In general, the percentages of Anacardiaceae (including *Pistacia*) slightly decreased from 58.7% in area XYZ to 54.4% in area VU, whereas Rosaceae maintained similar proportions (from 34.2 to 35.5%). The rest of taxa were rare both in terms of ubiquity (<35% of samples) and absolute counts (percentage counts <1%). Salicaceae (comprising cf. *Salix*, *Salix*, and cf. *Populus*) was only present in area XYZ (phases I-IV), along with *Tamarix*, *Cedrus libani* and *Fraxinus*, which were also present but in slightly lower proportions (percentage counts <1%). *Quercus* was only identified in area VU (upper phase) and comprised 1.8% of the assemblage. At least one fragment corresponded to evergreen-type *Quercus* (Fig. 4F), although the presence of deciduous *Quercus* cannot be excluded. Other taxa were rare and only found in specific contexts of the excavation area XYZ, such as *Acer* in a pit sample, Chenopodiaceae in the infill of structure and cf. *Rhamnus* associated to a burial.

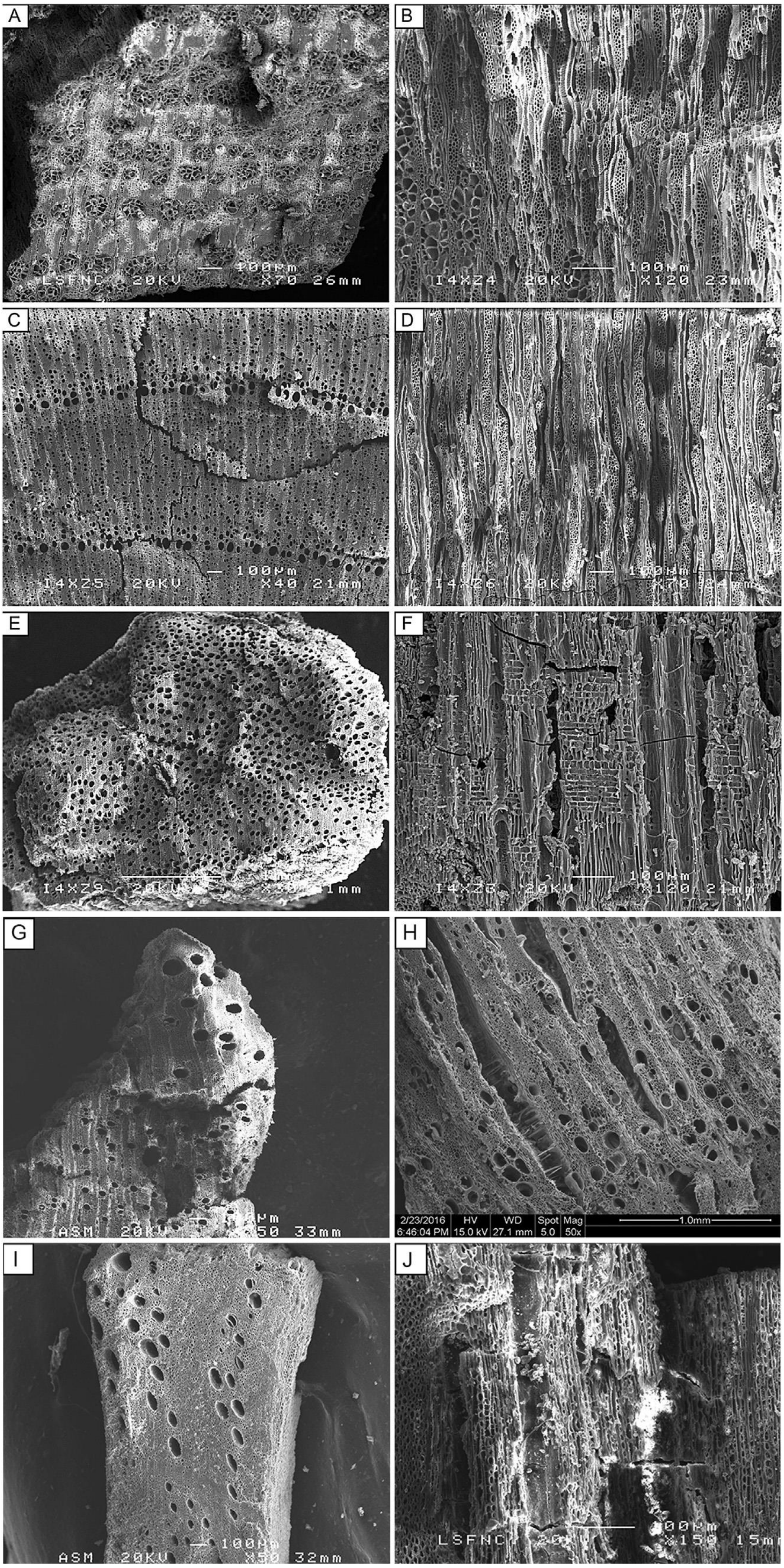
5.3. Isotope analysis on wood charcoal

Carbon isotope discrimination ($\Delta^{13}C$) values for a total of 74 *Pistacia* and 28 *Amygdalus* wood charcoal samples were analysed (Table S2). Curvature was positively assessed in 57 wood charcoal fragments corresponding to scattered remains and 29 samples from the rood structure (Table S2). The results showed the predominance of low curvature fragments (80.7% and 65.5% respectively), followed by medium curvature (12.3% and 10.3% respectively) and strong curvature (7% and 10.3% respectively). There were no significant differences in terms of Δ13C between biologically older (e.g. weak curvature) and younger (moderate or strong curvature) specimens from the same phase (Table S3). In fact, in some cases wood charcoal fragments with strong curvature tended to exhibit lower (phase IV) or higher (phase V) values than the fragments with weak curvature. Considering this we cannot conclude that in our study the age of the wood sampled may bias the Δ13C of the samples analysed. Mean values were plotted for the six phases studied in the XYZ area and the upper and lower phases of the VU area (Fig. 5). In the case of *Amygdalus*, values were near 19‰ through all the period studied, whereas for *Pistacia* values were in general slightly lower (but above 18‰). Both species tended to show lower values in phase IV compared with the other five phases. The mean Δ13C values of the samples of the two species recovered from the roof and corresponding to phase II in XYZ area were clearly lower (nearly 18‰ for *Pistacia* and slightly above 17‰ for *Amygdalus*).

Table 1. Results of the taxonomic analyses of the wood charcoal remains from excavation areas XYZ and VU at Tell Qarassa North.

Taxonomic analysis Scattered remains		**XYZ-67/68/69 (number of samples: 59)**				**VU-67 (number of samples: 5)**				**Total fragments by taxa**			
		counts	*% frag. counts*	presence	*ubiquity (%)*	counts	*% frag. counts*	presence	*ubiquity (%)*	**counts**	***% frag. counts***	**presence**	***ubiquity (%)***
woodland-steppe	*Pistacia* sp.	2556	*56.3*	57	*96.6*	238	*52.8*	5	*100.0*	**2794**	***56.4***	**62**	***96.9***
	Anacardiaceae	108	*2.4*	33	*55.9*	7	*1.6*	3	*60.0*	**115**	***2.3***	**36**	***56.3***
	Amygdalus sp.	1376	*30.3*	58	*98.3*	147	*32.6*	5	*100.0*	**1523**	***30.8***	**63**	***98.4***
	Rosaceae	179	*3.9*	41	*69.5*	13	*2.9*	4	*80.0*	**192**	***3.9***	**45**	***70.3***
oak-woodland	*Acer* sp.	4	*0.1*	1	*1.7*	0	*0.0*	0	*0.0*	**4**	***0.1***	**1**	***1.6***
	Quercus sp.	0	*0.0*	0	*0.0*	8	*1.8*	2	*40.0*	**8**	***0.2***	**2**	***3.1***
coniferous for.	*Cedrus libani*	37	*0.8*	14	*23.7*	0	*0.0*	0	*0.0*	**37**	***0.7***	**14**	***21.9***
wetland and salt marsh	Salicaceae	192	*4.2*	26	*44.1*	0	*0.0*	0	*0.0*	**192**	***3.9***	**11**	***17.2***
	Fraxinus sp.	27	*0.5*	12	*20.3*	0	*0.0*	0	*0.0*	**24**	***0.5***	**12**	***18.8***
	Tamarix sp.	43	*0.9*	20	*33.9*	1	*0.2*	1	*20.0*	**44**	***0.9***	**21**	***32.8***
	Tamaricaceae	13	*0.3*	8	*13.6*	0	*0.0*	0	*0.0*	**13**	***0.3***	**8**	***12.5***
steppe	Chenopodiaceae	2	*0.0*	2	*3.4*	0	*0.0*	0	*0.0*	**2**	***0.0***	**1**	***1.6***
	cf. *Rhamnus*	1	*0.0*	1	*1.7*	0	*0.0*	0	*0.0*	**1**	***0.0***	**1**	***1.6***
	cf. Fabaceae	1	*0.0*	1	*1.7*	0	*0.0*	0	*0.0*	**1**	***0.0***	**1**	***1.6***
Indeterminate		283		49	*83.1*	37	*8.2*	4	*80.0*	**320**		**53**	***82.8***
other (pith, bark)		1		1	*1.7*	0	*0.0*	0	*0.0*	**1**		**1**	***1.6***
Total		4823	*100.0*	59	*100.0*	451	*100.0*	5	*100.0*	**5274**	***100.0***	**64**	***100.0***

Figure 4. The wood charcoal taxa found at Tell Qarassa North: A and B) transverse and longitudinal tangential sections of Pistacia sp.; C and D) transverse and longitudinal tangential sections of Amygdalus sp.; E and F) transverse and longitudinal radial section of Salicaceae cf. Salix; G) transverse section of Fraxinus; H) transverse section of Tamarix; I and J) transverse and longitudinal tangential sections of Quercus (evergreen-type); K) transverse section of Acer; L) transverse section of cf. Fabaceae; M and N) transverse and radial sections (showing scalloped tori) of Cedrus libani; O) transverse section of Rhamnus; P) transverse section of Chenopodiaceae.


A
LSFNC 20KV 100µm X70 26mm
B
I4XZ4 20KV 100µm X120 23mm
C
I4XZ5 20KV 100µm X40 21mm
D
E
F
G
H
2/23/2016 HV WD Spot Mag
6:46:04 PM 15.0 kV 27.1 mm 5.0 50x
1.0mm
I
ASM 20KV 100µm X50 32mm
J

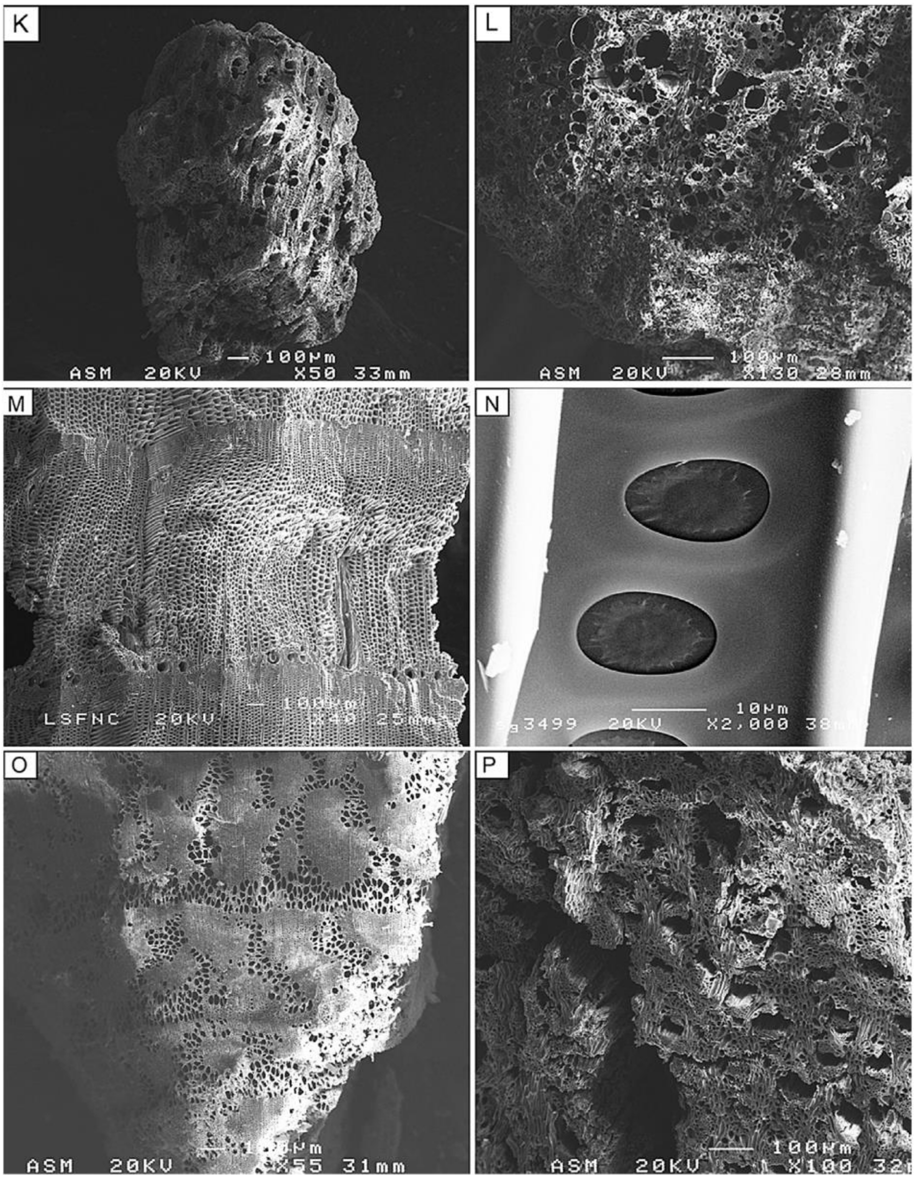
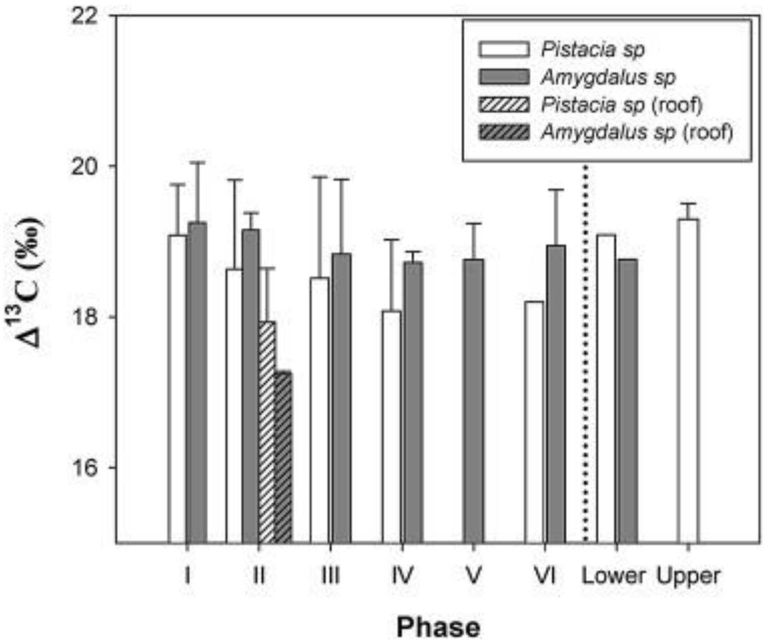


Fig. 4. (continued).

Figure 5. Evolution through time of the carbon isotope discrimination ($\Delta^{13}C$) of *Amygdalus* and *Pistacia*. Phases I to VI correspond to the XYZ area, whereas the lower and upper phases refer to the VU area. Values plotted are means ± SE. Details about the individual samples analysed can be found in Table S2.



5.4. Phytolith analysis

Phytoliths were abundant in all the samples examined (ranging from 1 to 2.6 million phytoliths per gram of sediment in XYZ samples and 0.7 to 1.7 in area VU; Table S4). Overall, the low proportions of weathered phytoliths, together with the presence of multicellular or anatomically or connected phytoliths in most of the samples, are indicative of a good state of preservation of the assemblages. The morphological results indicated that grasses dominated the phytolith record, with around 80% or more of all the counted morphotypes (Figure 6). In addition to dicotyledonous morphotypes, diagnostic phytoliths from the Cyperaceae family (sedges), which are common in wet environments, were noted in both profiles, although to a lesser extent. Grass phytoliths were divided into the different anatomical plant parts in which they were formed (Figure 6). Epidermal cells from grass leaves and stems, including prickles, bulliform cells and stomata, were observed in all the samples in different amounts (between c. 30-65%). The results show that multi-celled concentrations of these plant parts were high in samples related to mud building materials, such as sun-dried adobe compounds (up to 42% in sample 29, in phase II, area XYZ; Table S4 and Figure 7a). Additionally, grass phytoliths derived from their floral parts were abundantly noted in most of the samples (~30% or more of all grass morphotypes).

Inflorescences were characterized mainly by decorated dendritic and echinate long cells in addition to epidermal papillae cells (Figure 7b). Grasses belonged to the Pooideae subfamily which are common in well-watered woodlands and include major cereals. Multi-celled phytoliths from the husks and culms of Pooids, including *Triticum* sp. and *Hordeum* sp. were identified in both profiles (Figure 7c).

Fig. 6. Left: Relative abundances of phytoliths obtained from XYZ and VU samples; Right: anatomical origin of grass phytoliths.

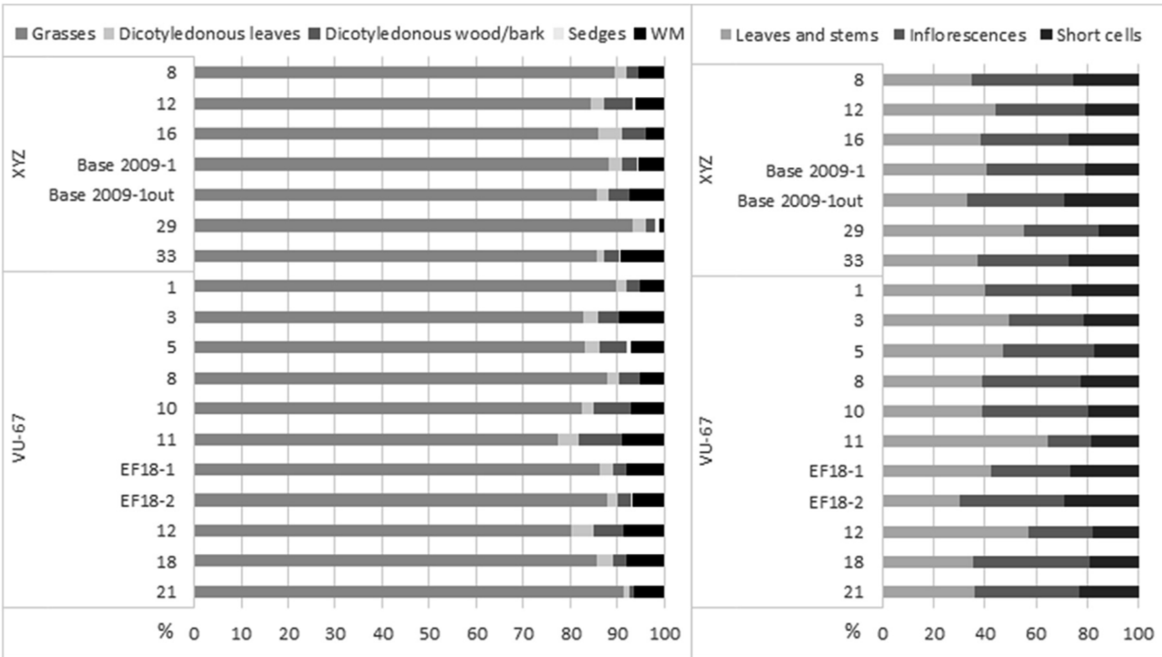
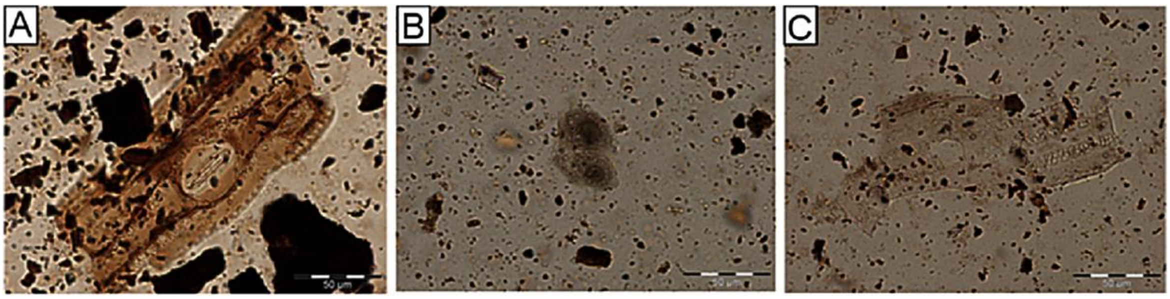


Figure 7. Photomicrographs of phytoliths identified in XYZ samples (scale 400×): A) multicellular structure of long cells with stomata from grass stems (sample 29, phase II); B) epidermal appendage papillae cells (sample 8, phase V); C) multicellular structure of dendritic long cells with short cell rondels from Pooid husk (sample 29, phase II).



6. Discussion

We follow Meadow's approach of system thinking (2008) to characterise past vegetation at Tell Qarassa North and assess its evolution through time. We consider that vegetation represents a system, and it is defined as an interconnected set of elements (e.g. trees, herbs) that are coherently organised to achieve a particular purpose (e.g. to reproduce and survive through time), and that are regulated by different inflows and outflows. In the following lines we describe the elements that define the vegetation system at Tell Qarassa North (section 6.1.), as well as characterise the environmental conditions at the time of cereal domestication (section 6.2.). Following this, we explore the complex patterns of interaction between the local and regional vegetation around Tell Qarassa North and other systems (e.g. climate and human) from 10.7 to 9.9 ka cal. BP (section 6.3.).

6.1. The elements of the vegetation system

According to pollen, wood charcoal and phytolith evidence, from 10.7 to 9.9 ka cal. BP, four main plant formations grew in the area around Tell Qarassa North. These comprised *Pistacia* and *Amygdalus* woodland-steppe, wetland vegetation, Mediterranean open oak-woodlands, and high-mountain coniferous forests (Figure 8).

Wood charcoal remains from archaeological sites represent the remains of local and easily collected wood resources (Smart and Hoffman, 1988). The anthracological assemblage showed that *Pistacia* and *Amygdalus* were the preferred source of fuel during the whole occupation period (10.7–9.9 ka cal. BP) (Table 1). Considering the morphological characteristics of the nutshells found at the site (Arranz-Otaegui et al., 2016a), the remains probably represent *Amygdalus korshinskyi* and *Pistacia palaestina/atlantica.* These species are nowadays leading elements of Irano-Turanian woodland-steppe formations, and grow along with an understory of Poaceae, Chenopodiaceae and other steppic plants (Zohary, 1973). In addition to these, *Q. ithaburensis* is also common in *Pistacia-Amygdalus* woodland and woodland-steppe formations in the Mediterranean and Irano-Turanian borderlands (Zohary, 1973). This association was attested in Bronze Age and Roman sites located in the plains and mountainous areas of Jabal al-Arab, less than 10 km from Tell Qarassa North (Willcox, 1999). In modern pollen rain studies conducted in the eastern Mediterranean and the Middle East values of *Quercus* pollen higher than 20% indicate the local presence of oak forests or maquis, while percentages of the order of 6–8% reflect the regional nature of their origin (e.g. Bottema, 1977; Davies and Fall, 2001; Kaniewski et al., 2011 ; Fall, 2012). At Tell Qarassa North percentages of *Quercus ithaburensis* pollen were up to 25% (Fig. 2), suggesting that this species could have grown in the vicinity. However, the proportions of *Pistacia* pollen found at the site (between 4 and 7% in area XYZ and 4–14% in area VU, Fig. 2; Fig. 3) are indicative of *Pistacia* tree dominance over *Quercus*, especially in *Amygdalus*-closed forest vegetation (Rossignol-Strick, 1995). Considering the remarkable percentages of grasses and steppic plants in the pollen records (Fig. 2 ; Fig. 3) and the non-woody plant macroremains of the site (Arranz-Otaegui et al., 2016a), it is likely that the immediate areas around Tell Qarassa North were characterised by vast open areas with broadly spaced *Pistacia* and *Amygdalus* trees alternating with *Quercus ithaburensis*, shrubby Rosaceae, *Rhamnus* and *Acer*, and extensive patches of grasses and steppe vegetation such as *Capparis, Camelina, Stipa, Trigonella astroites* growing within the scattered trees (Mouterde, 1953 ; Zohary, 1973). This type of vegetation would have been primarily located to the south of the tell, where rich soils that allow agricultural activities were found (Fig. 8A), as well as to the north of the site, in the Leja area. The limited tolerance to water-saturated soils of *Pistacia* and *Amygdalus* (Zohary, 1973) would have made them less common at the eastern foot of the tell due to the existence of a lake (Ibañez et al., 2010a). The prevalence of *Pistacia* and *Amygdalus* woodland-steppe vegetation is found during the early Holocene in inland areas of southwest Asia (Fig. S1, Table S5), from southern-central Syria (Pessin, 2004 ; Deckers et al., 2009) up to the Euphrates area (Roitel, 1997), the Anatolian Plateau (Willcox, 1991; Asouti, 2003 ; Emery-Barbier and Thiébault, 2005), southeast Turkey (Neef, 2003) and the Zagros (van Zeist et al., 1984 ; Riehl et al., 2015); that is, in areas that nowadays correspond to the Irano-Turanian phytogeographical region (Zohary, 1973). An open landscape comprising *Pistacia* forests and steppe vegetation has also been recorded in early Holocene pollen records from Anatolia (Bottema and Woldring, 1984 ; Roberts et al., 2001), southeast Turkey (van Zeist and Bottema, 1977; Wick et al., 2003 ; Litt et al., 2014) and Iran (van Zeist and Bottema, 1977; Bottema, 1986 ; Djamali et al., 2008b) (Fig. S1).

Apart from Irano-Turanian elements, the wood charcoal, pollen and phytolith results reveal that riparian vegetation constituted an important component of the local vegetation at Tell Qarassa North (Table 1, Figures 2 and 3, Table S4). These included hygrophilous taxa such as Salicaceae (*Populus*, *Salix*), *Fraxinus* and *Tamarix*, along with *Ficus* and *Vitex agnus-castus* that were documented within the non-woody plant macroremains (Arranz-Otaegui et al., 2016a), and annual and perennial plants of the Cyperaceae (e.g.

Bolboschoenus glaucus, *Eleocharis* and *Carex*) and Ranunculaceae families. Despite their overall low absolute counts in the wood charcoal assemblage of Tell Qarassa North (Table 1) it is likely they were used as importance source of fuel (Arranz-Otaegui, 2016) and building material (Balbo et al., 2012). Wetland vegetation would have been established around the shores of the ancient lake that was located at the foot of Tell Qarassa North (Figure 8B), as well as in the many water springs and the river fed by the volcanic uplands of the Jabal al-Arab (Ibañez et al., 2010b; Braemer et al., 2009). Riparian trees were commonly used as firewood and were an important element of the vegetation at contemporary sites across southwest Asia (Western, 1971; Lipshschitz and Noy, 1991; Roitel, 1997; Pessin, 2004; Austin, 2007).

The pollen records from Tell Qarassa North show the presence in the area of *Quercus calliprinos* along with a wide range of Mediterranean taxa such as *Olea*, *Rhamnus*, *Periploca*, *Phillyrea*, *Sarcopoterium*, *Ziziphus* and *Acer* (Figures 2 and 3). *Q. calliprinos* is the most important element of the maquis in the south-eastern part of the Mediterranean area (Zohary, 1973), and it is commonly associated with *Pistacia palaestina* at altitudes below 900 m, as attested nowadays in the Hermon area (Aharnovich et al., 2014). Bobek (1963) notes that *Quercus* woodland and woodland-steppe formations commonly replace *Pistacia-Amygdalus* steppe forests in areas where annual precipitation exceed an average of 500 mm. This pattern is observed in the Jabal al-Arab nowadays. Here, the plains (c. 700-900 m a.s.l) with average annual precipitation of around 250-350 mm are characterised by degraded woodland-steppe components, whilst Mediterranean forest vegetation composed primarily of *Q. calliprinos* are restricted to an attitude between 1000 and 1500 m a.s.l. and precipitation above 500 mm (Willcox, 1999). This would indicate that evergreen *Quercu*s woodlands probably existed, at least, in what is known today as the "Mediterranean island" of the Jabal al-Arab (Figure 8C). However, the presence of several Mediterranean species such as *Echinaria capitata, Poa bulbosa, Psilurus incurvus, Taeniatherum caput-medusae* and *Tolpis virgata* within the non-woody plant macroremains of the site (Arranz-Otaegui et al., 2016a) and the identification of evergreen-type *Quercus* in the wood charcoal assemblage (Figure 4F) indicates infiltrations of Mediterranean vegetation close to the site. This is possible considering that moister condition than at present prevailed during the EPPNB in the area (see Balbo et al. 2012, see section 6.2), which would enable these plants to grow at lower altitudes than those nowadays (e.g. 1000 m). The regional evidence shows that typically Mediterranean vegetation was predominant during the early Holocene in the southern Levant. Pollen records from Hula (van Zeist et al., 2009), Dead Sea (Litt et al., 2012), Birkat Ram crate (Schiebel, 2013) and Ammiq wetland (Hajar et al., 2008) point out the prevalence of deciduous *Quercus* forests in the mountain areas of the Golan and the Beqaa (Figure S1). In the coastal areas of modern-day Israel, the wood charcoal evidence around 10.2 ka cal. BP suggests the presence of Mediterranean evergreen *Quercus* forests (Caracuta et al., 2014) and *Pistacia*-*Q. calliprinos* associations (Liphschitz, 1997), similar to the vegetation found nowadays in the same area. In the northern part of the Dead Sea, *Pistacia* forests and halophytic communities (e.g. *Tamarix*) grew at low elevations (i.e. around 250 m b.s.l., Liphschitz, 2010; Western, 1971), whilst in the east, at altitudes around 700 m a.s.l., extensive deciduous *Quercus* woodlands along with some evergreen *Quercus* components were found (Neef, 2004). In the Jordan Valley, *Pistacia* trees (Asouti et al., 2015), and *Juniperus* woodlands (Neef, 2004; Austin, 2007) predominated along with some components of evergreen *Quercus*, indicating that arid areas nowadays characterised as treeless Irano-Turanian steppe and dwarf shrub were moister and more forested than at present.

Mountain vegetation is represented at Tell Qarassa North by the presence of *Cedrus libani*, *Betula* and *Pinus nigra* type, as noted in the wood charcoal and pollen records (Figures 2 and 3, Table 1). These taxa are likely to correspond to the ‘regional’ distance transport of pollen grains from the nearby highland areas (Jabal al-Arab mountain range), or even from more distant regions (e.g. *Betula*), as suggested in the pollen records from Hula (van Zeist et al. 2009). Mixed deciduous and coniferous forests, which grow in the oromediterranean bioclimatic zone of the Syrian and Lebanese mountains, include deciduous oaks, *Pinus nigra*, *Juniperus excelsa* and *J. oxycedrus* reaching up to 1900 m a.s.l (Zohary, 1973). At higher elevations coniferous forests mainly comprise *Pinus nigra*, *Abies cilicica* and *Cedrus libani*, along with various juniper species (*Juniperus excelsa*, *J. drupacea*, *J. phoenicea*) (Zohary, 1973). *Cedrus libani* is now found primarily in the mountainous areas of Lebanon, northern Syria and Turkey (Hajar et al., 2010), although it has also been observed in the Mount Hermon and the northern Golan (Neumann et al., 2007), around 60 km from Tell Qarassa North. Pollen records from Ammiq wetland in Lebanon (Hajar et al., 2008) suggest that coniferous forests with species such as *Cedrus* could have been found during the early Holocene in the Barouk Mountains (Figure S1). The presence of *Cedrus* wood charcoal at the PPNB site of Tell Aswad, in the Damascus Basin, was interpreted as evidence of long-distance transportation of exotic materials (Willcox, 2005). However, *Cedrus libani* can adapt to a wide range of soil types and moisture contents, including semi-arid regions with precipitation between 300 and 600 mm per year (Semerci, 2005), and altitudes above 900 m a.s.l., often between 1500-1800 m a.s.l. (Liphschitz and Biger, 1992; Hajar et al., 2010). At 25 km to the east of Tell Qarassa North the uplands of the Jabal al-Arab rise to 1800 m a.s.l., and they could have constituted a suitable area for the growth of these conifer forests during the early Holocene (Figure 8D).

Figure 8. Reconstruction of the local vegetation around Tell Qarassa North, view towards the south of the site (Author: C. Carlson). A) Woodland-steppe components such as *Pistacia* and *Amygdalus* growing close to the site; B) riparian vegetation growing along the shore of the lake and nearby water ponds; C) evergreen oak stands growing in more distant areas; D) coniferous forests growing in the mountain areas of the Jabal al-Arab (around 25 km from the site).

Overall, the evidence from Tell Qarassa North adds to the mosaic of plant formations attested in southwest Asia during the early Holocene (Fig. S1). The regional wood charcoal and pollen datasets highlighted east-west and north-south gradients in woodland composition not only in the southern Levant (Asouti et al., 2015), but also across southwest Asia. The evidence shows that coastal areas were dominated by

Mediterranean deciduous and evergreen Quercus in the lowlands, and conifer forests at higher altitudes, whilst inland areas were more arid and Pistacia and Rosaceae stands predominated in woodland and woodland-steppe formations (Fig. S1, Table S5). The absence of particular taxa such as deciduous Quercus south of the Dead Sea (Fig. S1) indicates that moisture conditions were not sufficient for this tree to grow in these regions (Asouti et al., 2015), highlighting north-south gradients in the distribution of certain plant communities. This may also apply to Amygdalus, a cold-tolerant species that was rarely attested in the southern Levant during the early Holocene, but predominated along with Pistacia in inland areas starting from southern Syria up to the northern Levant, Anatolia and the Zagros (Fig. S1, Table S5). Early Holocene records show that areas that nowadays receive low precipitation (e.g. Jordan Valley) were considerably moister than at present, and allowed the development of more extensive forests. This pattern is also evidenced at Tell Qarassa North by the presence of evergreen and deciduous Quercus. Notwithstanding that early Holocene vegetationwas not stable and changed in relation to centennial-scale climatic fluctuations and anthropogenic impacts (among other factors), the type of plant formations found during this time broadly match the limits of modern-day phytogeographical regions in southwest Asia.

6.2. The palaeoenviromental conditions at the time of cereal domestication

The analyses of the non-woody plant macroremains (Arranz-Otaegui et al., 2016a) and microremains (Figure 2, 3 6, and 7) from Tell Qarassa North indicate that cereal cultivation was common practice since the earliest occupation phases of the site (i.e.. area XYZ phase I-IV, 10.7-10.5 ka cal. BP). The presence of cereal pollen at Tell Qarassa North suggests cultivation took place in the vicinity, probably in the lands located towards the south of the site (Arranz-Otaegui et al., 2016a; López-Sáez and López-Merino, 2005). The fact that around 30% of the cereal crops bear characteristics of domesticated species (i.e. tough-rachis) indicates that since 10.7 ka cal. BP inhabitants cultivated both wild and domesticated emmer (*T. dicoccoides/dicoccum*), einkorn (*T. boeoticum/urartu/monococcum*), and to a lesser extent barley (*Hordeum spontaneum/vulgare*) (Arranz-Otaegui et al., 2016a). This evidence contrasts with that observed at contemporary sites in the southern-central Levant, where barley is the most common species exploited (see summary in Arranz-Otaegui et al., 2016b).

It is likely that the environmental conditions around Tell Qarassa North were more humid than in the rest of the sites in the southern Levant and allowed the exploitation of wheat over barley. The minimum rainfall requirements for these cereals present at Tell Qarassa North is approximately 200 mm for *Hordeum spontaneum*, 250 mm for *T. urartu*, 300 mm for *T. boeoticum* and 400 mm for *T. dicoccoides* (Willcox, 2005; Heun et al., 2008). The widespread presence of emmer in the assemblage indicates that the minimum annual precipitation around 10.7-9.9 ka cal. BP must have been of around 400 mm. This estimate is confirmed by the habitat requirements of the tree species found at the site. *Q. ithaburensis* is largely dependent on the amount of precipitation and it commonly needs annual average rainfall above 400 mm (Bobek, 1963; Zohary, 1973). *Pistacia atlantica* and *Amygdalus korschinskii* commonly grow in areas with average rainfall 300-400 mm per year (Bobek, 1963). The high $\Delta^{13}C$ values recorded in the charcoal of *Pistacia* and *Amygdalus* from Tell Qarassa North indicate that these trees were growing in relatively wet conditions, prevalent at other early agricultural sites (Araus et al., 2014). In the case of *Pistacia*, the $\Delta^{13}C$ values were similar to those recorded at Epipaleolithic and Neolithic sites in the northern Syria and southeastern Turkey (Araus et al., 2014), including those recorded in the second half of the Holocene (Deckers, 2016). Yet, the values found at Tell Qarassa North were slightly higher than present-day values in the region (Masi et al., 2013; Araus et al., 2014), indicating that cereal domestication took place at a time of moister environmental conditions (i.e. >350 mm, Traboulsi, 2013). It is also noteworthy that *Pistacia* and *Amygdalus* charcoals from the roof structure exhibited lower values in contrast to dispersed wood charcoal remains derived from fuel waste (Figure 5). These results cannot be explained by the biological age of the wood charcoal fragments analysed (i.e. deriving either from trunks or from branches) (Table S3). Moreover the available literature does not conclusively support the effect of age on the Δ13C of the wood charcoal (Tans and Mook, 1980; Leavitt and Long, 1986; Schleser, 1992; Nguyen-Queyrens et al., 1998 ; Fotelli et al., 2009). Instead, it could be that the building materials were gathered in a different location in comparison to fuel resources, probably beyond the agricultural surroundings of the site, in less fertile locations such as those found towards the north, in the Leja area.

6.3. The dynamics of past vegetation around 10.5-9.9 ka cal. BP

For around 200-300 years, plant formation around Tell Qarassa North did not suffer major changes indicating that the whole vegetation system worked in dynamic equilibrium. This means that from 10.7 to 10.5 ka cal. BP the inflows and outflows that regulated the amount and the type of trees present in the area were balanced. The sum of all outflows (e.g. natural death of trees, wood gathering and fire-related activities) equalled the sum of all inflows (e.g. natural reproduction of trees, tree management activities), and therefore, allowed the different plant formation growing around Tell Qarassa North (i.e. woodlands-steppe, oak-woodlands, riparian vegetation and mountain vegetation) to maintain relatively unchanged. However, between c. 10.5 and 9.9 ka cal. BP (phase V in area XYZ, and the upper phase in area VU), several changes occur in some of the outflows and inflows that regulate the vegetation system, in particular in those related to the climate system and the human system, leading to substantial transformations in the local and regional vegetation.

6.3.1. *Changes in the climate system*

The latest occupation phases of Tell Qarassa North dated to between 10.5 and 9.9 k cal. BP (phase V in area XYZ and upper phase in area VU), highlight changes in the proportions of trees that are sensitive to temperature fluctuations. The pollen records show a marked decrease in thermophilous taxa such as *Pistacia*, *Periploca*, *Sarcopoterium* and *Zizyphus* and *Quercus calliprinos* (Figures 2 and 3). This trend is synchronous with the increase in the pollen of mesophilous trees such as *Betula* and *Cedrus*, and the first appearance in the assemblage of typically mesophilous *Junglans* (Figures 2 and 3). The shifts observed suggest that between 10.5 and 9.9 ka cal. BP, cold environmental conditions established around Tell Qarassa North. Regional datasets show that centennial-scale rapid climatic changes occurred during the Holocene in the Mediterranean region, and comprised changes in temperature and rainfall conditions (Mayewski et al., 2004). Based on the Glacial GISP2 non sea-salt (nss) potassium [K^+] concentration record, Weninger et al. (2009) suggested that one of the coldest events during the last 50,000 years occurred at around 10.2 ka cal. BP in the eastern Mediterranean. The 10.2 ka cal. BP event was previously identified in other regions of the Northern Hemisphere (Bond et al., 1997; Rasmussen et al., 2007; Cai et al., 2008), however, so far, it has not been identified in Mediterranean pollen records. This rapid climatic change has been associated to a major interruption in the sequence of settlements in the northern Levant and it has been referred to as possible trigger for the abandonment of several Pre-Pottery Neolithic sites (Borrell et al., 2015). At Tell Qarassa North, the reduction of thermophilous species opposed to mesophilous species is a possible signal of a climatic change contemporary with the 10.2 ka cal. BP event. Most of the mesophilous and thermophilous species that show changes during this time were probably growing at a considerable distance from the site (see section 6.1.), and therefore, human factors can be excluded as possible explanations for their diminution/increase. Furthermore, during other cold rapid climatic changes such as the 8.2 ka cal. BP, a decrease in thermophilous species such as *Quercus calliprinos* has been recorded in several pollen records in the Mediterranean area (Rossignol-Strick, 1999; Pross et al., 2009). Besides, most of the mesophilous and thermophilous species that showed changes during this time were probably growing at a considerable distance from the site (see Section 6.1.), and therefore, human factors can be excluded as possible explanations. Considering this, it is likely that the establishment of colder environmental conditions between 10.5 and 9.9 ka cal. BP acted as an outflow on the flora of the Jabal al-Arab region reducing the extension of thermophilous taxa.

Besides this, temperature fluctuations could have acted as a reinforcing feedback loop, and enhanced further transformations in the local and regional vegetation. Decrease temperatures commonly result in higher snow accumulations and ice melt water, which condition the growth of alluvial fans in valley bottoms, and the rise in the water table of rivers, lakes and water ponds. In Europe, several studies have identified hydrological changes (e.g. floods) as a consequence of the 8.2 ka cal. BP cooling episode (Alley and Agustsfottir, 2005; Hughes et al. 2000; Magny et al., 2003). In the Anatolian Plateau, the expansion of alluvial fans around 9.5 ka cal. BP (Boyer et al. 2006) were referred to as a possible signal of a climatic change contemporary with the cold 9.2 ka cal BP event (Berger et al., 2016). In Cyprus, flood episodes that caused strong upstream erosion (Devillers, 2005), as well as surface erosion and torrential discharges were attested around 8.5 ka cal. BP and 8.1 ka cal. BP (Berger et al., 2016), which could be linked to 8.2 ka cal. BP event. In the Lake Van, high water tables associated to increased sedimentation and mineral content were recorded also around 8.4-8.2 ka cal. BP (Lemcke and Sturm, 1997). Considering that hygrophilous plants represent edaphic communities that depend on ground moisture and water availability (Zohary, 1973), changes in the water table of the nearby water ponds and springs caused by the establishment of colder environmental conditions could have also altered the extent to which this plant formations grew in the vicinity. This hypothesis would explain the synchronous spread of mesophilous species and the development of hygrophilous and meadow steppe attested taxa between 10.5 and 9.9 ka cal. BP at Tell Qarassa North (Figures 2 and 3).

An additional factor that could have contributed to the spread of hygrophilous plants has to do with the other main element that regulates plant growth in the climate system that is rainfall. The isotope record from Tell Qarassa North indicated centurial changes in the isotopic content of the wood charcoal samples studied. In area XYZ, *Pistacia* and *Amygdalus* $\Delta^{13}C$ values decreased from phase I to phase IV, indicating that the second destruction of the site (phase IV) occurred at the time of dry environmental conditions in comparison to earlier occupation phases, and which coincide with maximum values for dry-tolerant *Artemisia* in the pollen samples from phase IV (Figure 2). This period was followed by increased values during the last phases of the site (phase V and VI in XYZ and upper and lower phase in VU), indicating the re-establishment of wet conditions. At Tell Qarassa North, the spread of wetland taxa in phase V of area XYZ and upper phase of area VU is coincidental with the disappearance of *Artemisia* (Figures 2 and 3), a common indicator of dryness in the pollen records (Rossignol-Strick, 1995) and increase in Poaceae (e.g., from 5-12% to 13-19% in area VU, Figures 2 and 3). The increase in Poaceae pollen at the expense of *Artemisia* is suggestive of reduced summer drought or increase summer precipitation. In previous studies, high percentage of Poaceae pollen in deep-core pollen records from the Arabo-Persian Gulf were interpreted as evidence of reduced extreme summer drought around 8.0 ka cal. BP (el-Moslimany, 1983). The evidence would thus indicate that between 10.5 and 9.9 ka cal. BP environmental conditions around Tell Qarassa North not only turned colder, but also moister. This is in accordance with the regional datasets from the Mediterranean area, which indicate that after the 10.2 ka cal. BP, around 10-8.6 ka cal. BP, extremely wet conditions prevailed, referred to as the Levantine Moist Period (LMP). These conditions have been best documented in the Dead Sea (Weninger et al., 2009; Arz et al., 2003b; Migowski et al., 2006), located around 150 km to the west of Tell Qarassa North. The stable carbon isotopes from Soreq Cave (Israel) indicate that during this time regional rainfall could have been twice higher than the present-day average (Bar-Matthews et al., 2000). Recent stable carbon isotope analyses of archaeological plant remains from Neolithic sites in the Middle Euphrates confirm a peak in humid conditions between 10.0 and 8.0 ka cal. BP (Araus et al., 2014). It is thus possible that increased rainfall conditions in the Jabal al-Arab produced changes in the water tables of water ponds and lakes located in the plain, and this could have contributed to the development of wetland vegetation around Tell Qarassa North.

6.3.1. Changes in the human system

The pollen records from Tell Qarassa North show a remarkable decrease in arboreal pollen between 10.5 and 9.9 ka cal. BP (Figures 2 and 3). In area XYZ, *Quercus ithaburensis*, *Quercus calliprinos* and *Pistacia* pollen values decreased from 15-25%

(phases I-IV) to 6-11% (phase V), from 7-15% (phases I-IV) to 2-4% (phase V) and from 4-7% (phases I-IV) to 2-4% (phase V) respectively, and this decrease is also attested in area VU (Figures 2 and 3). Whilst the evidence does not suggest massive deforestation, it does indicate a shift towards an open landscape and overall lower tree cover than in previous periods. The decrease in Mediterranean vegetation comprising thermophilous species such as *Q. calliprinos* could have been triggered by changes in the climate system (section 6.3.1). However, the evidence shows that changes in the arboreal cover occurred at the time of increased evidence for anthropogenic pressures (Figures 2 and 3). This means that plant formation that grew in the immediate vicinity of the site (e.g. *Pistacia*, *Q. ithaburensis*) would have been regulated by additional inflows and outflows associated to the anthropogenic system.

The pollen records for the latest occupation phases of the site (phase V in area XYZ, and upper phase in area VU) indicate a sudden rise in anthropozoogenic taxa (Chenopodiaceae, *Plantago lanceolata*, *Rumex acetosa*, *R. acetosella*), which refer to plants related to grazed pastures (Behre, 1981); coprophilous fungi (Sordariaceae, *Chaetomium*), which commonly develop on dung (van Geel, 2001). This indicates that between 10.5 and 9.9 ka cal BP, coinciding with the development of agropastoral societies in southwest Asia (Asouti and Fuller, 2012, 2013; Zeder, 2011), herding activities intensified in the area around Tell Qarassa North. The preliminary analyses of the faunal remains from Tell Qarassa North revealed the primary exploitation of goat (*Capra* format *aegagrus*) during all the occupations (L. Gourichon in Ibáñez et al., 2010), along with a large spectrum of animal taxa comprising other ungulates like the gazelle, the aurochs, the wild boar and the Mesopotamian fallow deer, and the hare and various species of carnivores and birds as small game (see Table S6). Sheep bones have not been clearly identified and the goat remains show the same size range (though slightly larger in average) that the goat populations from the late Early and Middle PPNB levels of Tell Aswad where evidence of herding was attested (Helmer and Gourichon 2008, 2016). If the domestic status of the goats from Tell Qarassa cannot be asserted from metrical or morphological criteria or kill-off profiles, due to the lack of data, the results provided by the study of NPPs shed new light on this question. The regular occurrence of coprophilous fungi (Sordariaceae) throughout the sequence indicates the prevalence of ungulate dung around and within the habitat that cannot be explained solely by incidental deposits from the intestinal contents of wild animals butchered in the surroundings. In this sense, these data strongly suggest that at least part of the goats were herded near Tell Qarassa North, at a time where early domestication of the bezoar goat was demonstrated in Northern Mesopotamia (Peters et al., 2005). It must be considered that compared to sheep, goats are preferentially browsers and can remove tree seedlings, reducing the rates of natural woodland regeneration (Janis, 2008; Skarpe and Hester 2008). Several researchers suggested that overgrazing was partially responsible for the reduction in plant cover in regions associated to the emergence of sheep/goat pastoralism, resulting in changes in settlement patterns as early as the PPNB (Falconer and Fall, 1995; Grigson, 1995; Köhler-Rollefson, 1988; Köhler-Rollefson and Rollefson, 1990; Simmons, 2000; Tchernov and Horwitz, 1990). Despite it is difficult to test, it is possible that increased herding activities between 10.5 and 9.9 ka cal. BP acted as an outflow and reduced the chances for local trees such as *Pistacia* or deciduous *Quercus* to reproduce. This change, coupled with the shift to colder environmental conditions (section 6.3.1), would have hindered the maintenance of the arboreal cover in proportions similar to those attested in previous phases (i.e. I-IV in area XYZ, and lower-phase in area VU).

Additionally, the evidence between 10.5 and 9.9 ka cal. BP shows a marked increase carbonicolous fungi such as *Chaetomium*, a common indicator of anthropogenic fires (López-Sáez et al., 1998; van Geel et al., 2003; López-Sáez and López-Merino 2007); as well as increased *Glomus* values, which have been associated to erosive processes related to the anthropic dynamics in the immediate environment of archaeological sites (López-Sáez et al., 2000). The evidence thus indicates increased firing activities in the area. The purpose of theses fires is difficult to asses, but fire management is in general associated with hunter-gatherers, pastoralists and cultivators that aim to maintain open savannah-type landscapes with grasslands and trees suitable for agropastoral activities (Roberts, 2002), and Tell Qarassa North the evidence coincided with the time when herding activities intensified and arboreal cover reduced. Regional datasets indicate that grasslands reached maximum values during the early Holocene and dry-season burning was one of the main factors regulating these grass-parkland ecosystems (Turner et al., 2010). Grasses represent competitors for the development of *Quercus* seedlings and they can hamper the expansion of oak-woodlands (see recent review by Asouti and Kabukcu, 2014). In the Mediterranean region, low-intensity ground fires are common in the summer dry season, and favour the development of wild cereal grasses (Zohary and Hopf, 2000; Grove and Rackham 2001). It is thus likely that increased fire-related and herding activities, as well as additional changes in the climate system, all contributed as direct or indirect factors to the decline of the local arboreal cover between 10.5 and 9.9 ka cal. BP.

7. Conclusions

The analyses carried out at Tell Qarassa North show the importance of considering multiple datasets (e.g. plant macro and microremains) to reconstruct past vegetation and environmental conditions in southwest Asia. The multi-proxy analyses at the site have provided high-resolution data to characterise the local and regional vegetation and its evolution at the time when morphologically domesticated cereals appear and developed in southern Syria (10.7-9.9 ka cal. BP). The combination of wood charcoal and pollen evidence indicates that Tell Qarassa North was located within the Irano-Turanian and Mediterranean phytogeographical regions. The local vegetation comprised woodland-steppe components and riparian taxa, whilst Mediterranean oak-woodlands and coniferous forests could have grown at further distance, in the mountain areas of the Jabal al-Arab located to the east of the site. The results overall indicate that considerably moister conditions than at present prevailed around Tell Qarassa North and the Jabal al-Arab, which is consistent with climatic and environmental conditions during the early Holocene (Robinson et al., 2006; Weninger et al., 2009). Furthermore, the evidence shows that the site was located also in amore humid area in comparison to coeval sites in the southern Levant, and could explain why the inhabitants of site exploited predominantly wheat species opposed to barley. Cereal domestication in southern Syria occurred at a time when vegetation, climate and human groups interacted in dynamic equilibrium and the environment was characterised by mild winters (probably frost-free) and hot summers, and an average rainfall of around 400 mm per year.

Slightly later, between 10.5 and 9.9 ka cal. BP, the inflows and outflows that regulated vegetation and that were dependant upon climate and human activities were altered, and resulted in substantial transformations in the local and regional vegetation. Our results provide evidence for the spread of mesophilous and hygrophilous taxa during this time, and suggest the establishment of colder and wetter environmental conditions than today. These fluctuations occurred during a broad time frame (from 10.5 to 9.9 ka cal. BP) and while they cannot be directly correlated with specific RCCs (e.g. the 10.2 ka cal. BP), it is likely that they were triggered by shifts in the inflows and outflows associated to the climate system (e.g. rainfall, temperature). Considering that climatic anomalies vary in time, space, intensity and type of signal, further investigations are needed to compare the shifts observed in this study with records from other regions across southwest Asia. Apart from this, pollen records from Tell Qarassa North showed increased fire-related and herding activities from 10.5 to 9.9 ka cal. BP, which along with changes in the climatic conditions, could have enhanced the spread of grasses and the shift to an open landscape with less arboreal cover. At this regard, more studies are necessary not only to identify the presence of anthropogenic impacts in the wood charcoal and pollen records, but also to fully evaluate how human activities altered local plant formations beyond linear models that link human activities to the decrease of the arboreal cover and deforestation.

Overall, in this work we show that changes in the past vegetation were complex in that they involved elements of different systems acting synergistically, and causing plant-specific responses. This means that single factor explanations (i.e., climatic or anthropogenic) of plant change during the Holocene will fail to recognize the diversity and complexity of the interactions that commonly regulate plant ecosystems.

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Supplementary data

Table S1. Available radiocarbon dates for Tell Qarassa North, area XYZ and VU. Radiocarbon determinations were performed in charcoal samples at Beta Analytic Inc. (Miami, Florida, USA) and Centro Nacional de Aceleradores (Sevilla, Spain). Radiocarbon ages were calibrated with OxCalv4.2.2 (Bronk-Ramsey, 2009) using the IntCal09 calibration curve (Reimer et al., 2009).

Area	Phase/ Group	Space	Unit	Phase Interpretation	Reference	14C BP	cal BP	cal BC	Dated material
XYZ-67/68/69	**I**	B	**52C**	1º Occupation	CNA - 1355	9185±40	10487-10244	8538-8295	*T. dicoccoides/dicoccum*
	II	A	**57**	1º Destruction	CNA - 1065	9300±45	10651-10298	8702-8349	*Pistacia* sp. (Branch BB48)
					Beta - 290929	9340±50	10700-10407	8751-8458	*T. boeoticum/monococcum*
		A	74		-	-	-	-	-
		B	52B		-	-	-	-	-
	III	A	24b;**25**	2º Occupation	CNA - 1353	9252±38	10555-10279	8606-8330	*T. boeoticum/monococcum*
		B	**52**		CNA - 1354	9292±48	10648-10291	8699-8342	*T. boeoticum/monococcum*
	IV	A	24;36;37	2º Destruction	-	-	-	-	-
		B	14		-	-	-	-	-
	V	A	**21**	Abandonment	Beta - 272103	9320±50	10683-10301	8734-8352	Large-seeded Poaceae
		A	**34**;18;5;6	Cemetery	Beta - 262213	9100±60	10480-10178	8531-8229	*T. dicoccoides/dicoccum*
	VI	A	**15**;3;4	Surface layers	Beta - 277177	9300±50	10653-10296	8704-8347	*Triticum* spp.
VU-67		Lower	**14;15**;10	Lower phase	CNA-3129	9192±40	10490-10246	8541-8297	Leguminosae seed
					Beta - 402487	9100±30	10493-10200	8344-8251	Wood charcoal
		Upper	**4;**3	Upper phase	Beta - 274098	9030±60	10368-9919	8419-7970	Leguminosae seed

Table S2. Carbon isotope discrimination ($\Delta^{13}C$) values of the *Pistacia* and *Amygdalus* wood charcoal remains from Tell Qarassa North. Sample reference and location as well as dating, growth-ring curvature and carbon isotope composition ($\delta^{13}C_{sample}$) values are listed for each sample. Spaces A and B belong to the XYZ area, whereas the upper and lower phases refer to the VU area.

Sample Nº	Sample ID	Layer	Growth-ring Curvature	*Pistacia* sp.	*Amygdalus* sp.	Reference	Data BP	%C	$\delta^{13}C_{sample}$ (‰)	$\delta^{13}C_{air}$ (‰)	$\Delta^{13}C$ (‰)
1	Z67 Y67	Space A, phase IV	weak	X				64.71	-24.67	-6.73	18.40
2	Z67D/E 5	Space A, phase IV	weak	X				65.19	-24.88	-6.73	18.61
8	Y68	Space A, phase IV	moderate		X			62.98	-25.08	-6.73	18.82
12	Y67	Space A, phase IV	strong	X				64.81	-23.37	-6.73	17.04
14	Y67 C2	Space A, phase IV	-	X				65.57	-22.79	-6.73	16.44
15	Y67 D2	Space A, phase IV	moderate		X			64.17	-24.88	-6.73	18.62
17	Y68	Space A, phase IV	weak	X				65.53	-25.11	-6.73	18.85
51	Y67 C/D1	Space A, phase IV	strong	X				67.63	-25.07	-6.73	18.82
24	Y67 E2	Space A, phase IV	weak	X				62.06	-24.64	-6.73	18.37
3	Y67	Space A, phase VI	moderate		X	Beta - 277177	9300 ± 50	61.96	-25.59	-6.73	19.35
11	Y67	Space A, phase VI	weak		X	Beta - 277177	9300 ± 50	65.46	-24.86	-6.73	18.58
20	Y67 E2	Space A, phase VI	-		X	Beta - 277177	9300 ± 50	63.43	-25.45	-6.73	19.21
5	Y68	Space A, phase VI	-	X		Beta - 277177	9300 ± 50	63.95	-24.49	-6.73	18.20
6	Y67	Space A, phase VI	weak		X	Beta - 277177	9300 ± 50	63.33	-24.15	-6.73	17.84
10	Y67	Space A, phase VI	moderate		X	Beta - 277177	9300 ± 50	62.98	-25.96	-6.73	19.74
23	Y67 E2	Space A, phase V (cemetery)	strong		X	Beta - 262213	9100 ± 60	64.20	-24.97	-6.72	18.71
13	Y67 C3	Space A, phase V (cemetery)	strong		X	Beta - 262213	9100 ± 60	65.83	-25.66	-6.72	19.43

Sample Nº	Sample ID	Layer	Growth-ring Curvature	*Pistacia* sp.	*Amygdalus* sp.	Reference	Data BP	%C	$\delta^{13}C_{sample}$ (‰)	$\delta^{13}C_{air}$ (‰)	$\Delta^{13}C$ (‰)
18	Y67 E2	Space A, phase V (abandonment)	weak		X	Beta - 272103	9320 ± 50	62.56	-24.87	-6.74	18.60
9	Y67 D3	Space A, phase V (abandonment)	weak		X	Beta - 272103	9320 ± 50	95.05	-24.58	-6.74	18.29
4	V67	Upper phase	weak	X		Beta - 274098	9030 ± 60	64.74	-25.29	-6.70	19.07
7	V67	weaker phase	weak	X		Beta - 402487	9100 ± 30	63.28	-25.30	-6.70	19.09
16	V67	Upper phase	moderate	X		Beta - 274098	9030 ± 60	64.95	-25.53	-6.70	19.32
22	V67	Upper phase	weak	X		Beta - 274098	9030 ± 60	65.22	-25.69	-6.70	19.49
25	V67	weaker phase	weak		X	CNA-3129	9192 ± 40	62.70	-25.00	-6.70	18.76
50	Y67 E3	Space A, phase III	weak	X		CNA1353	9252 ± 38	55.78	-22.57	-6.73	16.21
52	Y67 E4	Space A, phase III	weak		X	CNA1353	9252 ± 38	64.84	-23.61	-6.73	17.29
55	Y67 E1	Space A, phase III	weak		X	CNA1353	9252 ± 38	64.34	-25.78	-6.73	19.56
56	Y68 A4	Space A, phase III	-		X	CNA1353	9252 ± 38	61.79	-25.31	-6.73	19.07
57	Y68 A1	Space A, phase III	weak	X		CNA1353	9252 ± 38	68.08	-24.44	-6.73	18.16
58	Y67 D1	Space A, phase III	weak		X	CNA1353	9252 ± 38	63.20	-25.16	-6.73	18.91
59	Y67 D2	Space A, phase III	weak	X		CNA1353	9252 ± 38	65.53	-25.18	-6.73	18.93
60	Y68 A2	Space A, phase III	weak	X		CNA1353	9252 ± 38	64.87	-24.61	-6.73	18.33
61	Y68 A2	Space A, phase III	weak	X		CNA1353	9252 ± 38	66.20	-24.86	-6.73	18.60
62	Y67 E3	Space A, phase III	weak		X	CNA1353	9252 ± 38	56.57	-23.86	-6.73	17.56
65	Y67 E3	Space A, phase II	-		X	Beta - 290929	9340 ± 50	64.44	-25.18	-6.74	18.91
66	Y67 C3	Space A, phase III	weak	X		CNA1353	9252 ± 38	65.49	-25.34	-6.73	19.10
79	Y67 D3	Space A, phase III	weak		X	CNA1353	9252 ± 38	62.62	-25.28	-6.73	19.04
81	Y67 D2	Space A, phase III	weak	X		CNA1353	9252 ± 38	61.88	-26.50	-6.73	20.31
82	Y67 D3	Space A, phase III	-	X		CNA1353	9252 ± 38	58.14	-22.21	-6.73	15.83

Sample Nº	Sample ID	Layer	Growth-ring Curvature	*Pistacia* sp.	*Amygdalus* sp.	Reference	Data BP	%C	$\delta^{13}C_{sample}$ (‰)	$\delta^{13}C_{air}$ (‰)	$\Delta^{13}C$ (‰)
84	Y67 C/D1	Space A, phase III	weak	X		CNA1353	9252 ± 38	64.62	-24.16	-6.73	17.87
86	Y67 C1	Space A, phase III	weak	X		CNA1353	9252 ± 38	58.06	-22.73	-6.73	16.38
87	Y67 D2	Space A, phase III	weak	X		CNA1353	9252 ± 38	52.43	-24.18	-6.73	17.89
89	Y67 E3	Space A, phase III	-	X		CNA1353	9252 ± 38	57.85	-23.37	-6.73	17.04
90	Y67 E1	Space A, phase III	-	X		CNA1353	9252 ± 38	57.16	-25.12	-6.73	18.87
91	Y67 E3	Space A, phase II, roof	-	X		Beta - 290929	9340 ± 50	61.46	-23.40	-6.74	17.06
94	Y67 E2	Space A, phase II, roof	weak	X		Beta - 290929	9340 ± 50	53.32	-24.37	-6.74	18.07
95	Y67 E2	Space A, phase II, roof	weak	X		Beta - 290929	9340 ± 50	59.98	-24.38	-6.74	18.08
96	Y67 D2	Space A, phase II, roof (post)	weak	X		Beta - 290929	9340 ± 50	55.45	-25.89	-6.74	19.66
75	Y67 E/D1	Space A, phase III (pit)	weak	X		CNA1353	9252 ± 38	64.66	-24.80	-6.73	18.54
76	Y67 E/D1	Space A, phase III (pit)	weak	X		CNA1353	9252 ± 38	60.52	-25.01	-6.73	18.76
54	X68 B1	Space B, phase III	weak	X		CNA1354	9292 ± 48	63.99	-25.85	-6.73	19.63
63	Y68 D5	Space B, phase III	weak	X		CNA1354	9292 ± 48	61.72	-26.85	-6.73	20.67
64	Y68 C5	Space B, phase III	moderate	X		CNA1354	9292 ± 48	64.92	-24.95	-6.73	18.68
77	X69 A1	Space B, phase III	weak	X		CNA1354	9292 ± 48	62.76	-25.46	-6.73	19.22
92	Y68 C4	Space B, phase III	weak	X		CNA1354	9292 ± 48	64.14	-25.75	-6.73	19.52
93	Y68 E4	Space B, phase III	weak		X	CNA1354	9292 ± 48	62.70	-26.52	-6.73	20.33
68	Y68 B5	Space B, phase III	weak	X		CNA1354	9292 ± 48	61.49	-25.66	-6.73	19.42

Sample Nº	**Sample ID**	**Layer**	**Growth-ring Curvature**	***Pistacia* sp.**	***Amygdalus* sp.**	**Reference**	**Data BP**	**%C**	**$\delta^{13}C_{sample}$ (‰)**	**$\delta^{13}C_{air}$ (‰)**	**$\Delta^{13}C$ (‰)**
69	Y68 C5	Space B, phase III	weak	X		CNA1354	9292 ± 48	62.94	-24.51	-6.73	18.22
71	X68 C1	Space B, phase III	weak		X	CNA1354	9292 ± 48	61.63	-25.55	-6.73	19.31
73	X68 E1	Space B, phase III	weak	X		CNA1354	9292 ± 48	62.65	-26.57	-6.73	20.37
83	Y68 B4	Space B, phase III	weak		X	CNA1354	9292 ± 48	62.73	-25.25	-6.73	18.99
67	Y68 C5	Space B, phase I	weak	X		CNA1355	9185 ± 40	63.25	-25.68	-6.72	19.45
70	Y68 E5	Space B, phase I	weak		X	CNA1355	9185 ± 40	63.11	-25.96	-6.72	19.75
72	Y68 D5	Space B, phase I	weak	X		CNA1355	9185 ± 40	63.09	-24.66	-6.72	18.39
74	X68 E1	Space B, phase I	-		X	CNA1355	9185 ± 40	63.95	-25.88	-6.72	19.67
78	X69 A1	Space B, phase I	-	X		CNA1355	9185 ± 40	59.09	-26.25	-6.72	20.05
80	X68 D1	Space B, phase I	moderate		X	CNA1355	9185 ± 40	61.63	-24.61	-6.72	18.34
88	Y68 B4	Space B, phase I	weak	X		CNA1355	9185 ± 40	59.81	-24.86	-6.72	18.60
85	Y68 B4/5	Space B, phase III (pit)	-	X		CNA1354	9292 ± 48	64.36	-25.18	-6.73	18.92
11245	BB29	Space A, phase II, roof	-		X	CNA1065	9300 ± 50	54.65	-23.55	-6.73	17.23
11244	BB28	Space A, phase II, roof	strong		X	CNA1065	9300 ± 50	63.54	-23.61	-6.73	17.28
11212	BB10	Space A, phase II, roof	moderate		X	CNA1065	9300 ± 50	60.57	-23.55	-6.73	17.22
11246	BB30	Space A, phase II, roof	-	X		CNA1065	9300 ± 50	56.08	-24.25	-6.73	17.95
11238	BB24	Space A, phase II, roof	-	X		CNA1065	9300 ± 50	60.97	-23.93	-6.73	17.62
11247	BB31	Space A, phase II, roof	-	X		CNA1065	9300 ± 50	60.17	-24.98	-6.73	18.71

Sample Nº	Sample ID	Layer	Growth-ring Curvature	*Pistacia* sp.	*Amygdalus* sp.	Reference	Data BP	%C	$\delta^{13}C_{sample}$ (‰)	$\delta^{13}C_{air}$ (‰)	$\Delta^{13}C$ (‰)
11248	BB32	Space A, phase II, roof	weak	X		CNA1065	9300 ± 50	59.22	-25.13	-6.73	18.87
11254	BB36	Space A, phase II, roof	moderate	X		CNA1065	9300 ± 50	59.74	-23.61	-6.73	17.28
11266	BB43	Space A, phase II, roof	moderate	X		CNA1065	9300 ± 50	61.04	-25.37	-6.73	19.12
11274	BB48	Space A, phase II, roof	moderate	X		CNA1065	9300 ± 50	62.75	-25.16	-6.73	18.90
11232/3	BB22	Space A, phase II, roof	moderate	X		CNA1065	9300 ± 50	60.16	-24.79	-6.73	18.51
11218	BB12	Space A, phase II, roof	moderate	X		CNA1065	9300 ± 50	61.50	-23.48	-6.73	17.14
11242	BB27	Space A, phase II, roof	weak	X		CNA1065	9300 ± 50	59.02	-23.86	-6.73	17.55
11249	BB33	Space A, phase II, roof	weak	X		CNA1065	9300 ± 50	62.76	-25.27	-6.73	19.02
11263	BB40	Space A, phase II, roof	weak	X		CNA1065	9300 ± 50	57.47	-23.65	-6.73	17.32
11267	BB44	Space A, phase II, roof	strong	X		CNA1065	9300 ± 50	63.78	-23.22	-6.73	16.87
11250	BB34	Space A, phase II, roof	weak	X		CNA1065	9300 ± 50	57.71	-24.12	-6.73	17.82
11221	BB15	Space A, phase II, roof	weak	X		CNA1065	9300 ± 50	60.63	-24.46	-6.73	18.17
11253	BB35	Space A, phase II, roof	weak	X		CNA1065	9300 ± 50	64.27	-24.06	-6.73	17.75

Sample Nº	Sample ID	Layer	Growth-ring Curvature	*Pistacia* sp.	*Amygdalus* sp.	Reference	Data BP	%C	$\delta^{13}C_{sample}$ (‰)	$\delta^{13}C_{air}$ (‰)	$\Delta^{13}C$ (‰)
11228	BB18	Space A, phase II, roof	weak	X		CNA1065	9300 ± 50	63.45	-23.31	-6.73	16.97
11234	BB23	Space A, phase II, roof	weak	X		CNA1065	9300 ± 50	60.88	-24.35	-6.73	18.05
11193	BB4	Space A, phase II, roof	weak	X		CNA1065	9300 ± 50	64.34	-24.08	-6.73	17.77
11277	BB51	Space A, phase II, roof	weak	X		CNA1065	9300 ± 50	56.46	-24.00	-6.73	17.69
11265	BB42	Space A, phase II, roof	weak	X		CNA1065	9300 ± 50	61.24	-23.01	-6.73	16.65
11279	BB53	Space A, phase II, roof	weak	X		CNA1065	9300 ± 50	57.18	-23.86	-6.73	17.55
11260	BB39	Space A, phase II, roof	weak	X		CNA1065	9300 ± 50	57.41	-24.42	-6.73	18.12
11214	BB11	Space A, phase II, roof	weak	X		CNA1065	9300 ± 50	61.20	-24.22	-6.73	17.92
11278	BB52	Space A, phase II, roof	weak	X		CNA1065	9300 ± 50	58.98	-23.55	-6.73	17.22
11256	BB38	Space A, phase II, roof	weak	X		CNA1065	9300 ± 50	61.93	-25.02	-6.73	18.76
11273	BB47	Space A, phase II, roof	weak	X		CNA1065	9300 ± 50	57.67	-23.97	-6.73	17.65
11275	BB49	Space A, phase II, roof	weak	X		CNA1065	9300 ± 50	56.97	-24.22	-6.73	17.92
	BB54	Space A, phase II, roof	strong	X		CNA1065	9300 ± 50	56.30	-24.79	-6.73	18.52
	BB55	Space A, phase II, roof	moderate	X		CNA1065	9300 ± 50	57.32	-23.64	-6.73	17.32

Table S3. Carbon isotope discrimination ($\Delta^{13}C$, ‰) of the charcoal remains recovered in different phases of the Space A (area XYZ) and classified attending their degree of growth-ring curvature. Values presented are means ± SD. Comparisons were performed only for those phases where charcoals from the same genus and different curvatures were recovered as detailed in Table S2. Samples from phases II (Roof) and IV belong to *Pistacia* sp., whereas samples from phases V and VI are of *Amygdalus* sp. Differences across categories of charcoals were tested with ANOVA.

Growth-ring Curvature	**Phase II (Roof)**	**Phase IV**	**Phase V**	**Phase VI**
Weak	17.74 ± 0.60	18.61 ± 0.24	18.44 ± 0.21	18.21 ± 0.52
Moderate	18.05 ± 0.91	/	/	19.54 ± 0.27
Strong	17.69 ± 1.16	17.93± 1.25	19.07 ± 0.50	/
Level of significance	0.654^{ns}	0.395^{ns}	0.252^{ns}	0.086^{ns}

Table S4. Provenance, description of samples and main phytolith results obtained from excavation areas XYZ and VU at Tell Qarassa North.

Area	Sample number	Phase	Phytoliths 1 g of sediment (million)	Phytoliths weathering (%)	Multicelled phytoliths (%)	Description
XYZ-67/68/69	8	V	1.19	5.6	2.3	Dark very fine ashy powdery clayey silt without clasts, including flint, bone and pottery.
	12	IV	1.3	6.2	1.6	Dark very fine ashy powdery clayey silt. The matrix is similar to unit 3, with few scattered small rounded basalt clasts and randomly scattered larger stones. The dominant colour is dark greyish brown.
	16	IV	1.3	3.9	6.6	Dark very fine ashy powdery clayey silt, small rounded basalt clasts and abundance of randomly scattered larger stones.
	Base 2009, 1	III	2	5.4	10.9	Almost exclusively reddish yellow adobe compounds, embedded in a fine matrix of similar colour.
	Base 2009, 1 out	III	1.3	7.5	0.9	Reddish yellow adobe compounds.
	29	II	2.6	1.2	42.3	Ashy with large fragments of charcoal, including carbonized wooden elements, heavily burned adobe and non-wooden plant remains.

	33	I	1	9.1	6.9	Massive homogeneous pulverised reddish yellow adobe including decimetric angular basalt clasts and small basalt clasts.
VU-67	1		1.7	5.2	2.4	Compact clay sediment.
	3		1.2	9.6	2	Clayey silt with small basalt clasts, greyish brown colour.
	5	V	0.84	7.1	0.9	Powdery clayey silt, brown colour.
	8	V	1.4	5.1	4.1	Powdery clayey silt, similar to US 3 but darker.
	10	V	0.72	7.2	0	Powdery clayey silt, similar to US 3 but darker.
	11	V	1.3	9.1	7.3	Dark gray ashy sediments, including adobe compounds.
	12	IV	0.88	8.6	9.1	Yellowish brown sediments, including adobe fragments, ashes, charcoal, bone and lithic artefacts.
	18	IV	0.97	7.9	3	Yellowish brown sediments, including adobe fragments, ashes, charcoal, bone and lithic artefacts.
	EF18-1	IV	1.1	7.9	1.8	Burial EF18, close to cranial remains.
	EF18-2	IV	0.74	6.7	1.2	Burial EF18, under the pit base.
	21	IV	0.95	6.6	2.4	Clayey matrix sediments and basalt clasts, with abundant ashes charcoal fragments, bone and lithic artifacts.

Table S5. Summary of the early Holocene wood charcoal records in southwest Asia. Numbers represent percentage fragment counts by taxa. In some cases the raw datasets were not available, and the presence of taxa was recorded with an X. "Small shrubs" comprise steppic taxa such as *Artemisia, Acacia, Atriplex, Paliurus* etc. "Others" represent rare taxa (e.g., *Vitis*, Leguminosae), as well as cf. identifications of taxa not included in the table (e.g. cf. Labiatae). *Quercus* (E, D) means *Quercus* evergreen and deciduous respectively. Total fragments were calculated excluding indeterminate wood charcoal fragments.

Site		Wadi Faynan 16	Gilgal I (PPNA)	Öküzini (Ia)	Körtik Tepe	Jerf el Ahmar
Date ka cal. BP		12.6-10.2	11.5-11.1	11.6-9.3	11.7-11.4	11.4-10.7
Salicaceae		*15.5*	*22.8*		*x*	*26.0*
Ficus		*6.3*				
Platanus	Wetland					*0.7*
Fraxinus				*x*	*x*	*12.1*
Vitex						
Tamarix		*7.1*	*50.9*	*cf.*	*x*	*9.5*
Chenopodiaceae	Steppe and halophytes	*4.0*	*8.8*			*3.7*
Ephedra		*0.1*				
Small shrubs						*0.7*
Capparis		*1.4*				
Pistacia		*3.2*	*7.0*	*x*	*x*	*14.3*
Amygdalus	Woodland /steppe			*cf.*	*x*	*19.0*
Rosaceae						*1.8*
Rhamnus				*x*	*x*	*4.4*
Maloideae						
Juniperus		*57.5*				
Celtis/Ulmus					*x*	*0.4*
Olea	Oak/juniper woodland					
Quercus (E/D)						
Quercus (E)		*2.2*		*x*		
Quercus (D)				*x*	*x*	*5.5*
Acer				*x*	*x*	
Pinus	Coniferous woodland	*0.1*				
Cedrus						
	Others	*2.7*	*10.5*			*1.8*
Total fragments		2539	57	204	1487	273
		Austin, 2007	Liphschitz, 2010	Emery-Barbier and Thiébault, 2005	Riehl et al., 2012	Roitel, 1997 (see also Pessin, 2004)

Site		Mureybet (phase III-IV)	Göbekli Tepe	Baaz (II-III)	el-Hemmeh PPNA	Jericho (I)
Date ka cal. BP		11.3-10.5	11.2-10.6	11.1-10.2	11.1-10.7	11.1-10.3
Salicaceae		*x*		*91.0*	*7.5*	*15.2*
Ficus					*3.9*	*20.9*
Platanus	Wetland					
Fraxinus		*x*			*1.6*	
Vitex						*0.4*
Tamarix		*x*			*0.6*	*49.4*
Chenopodiaceae					*7.2*	
Ephedra	Steppe and halophytes					
Small shrubs					*1.7*	*9.5*
Capparis					*cf. 0.2*	*0.4*
Pistacia			*63.4*		*70.6*	
Amygdalus			*cf. 36*	*6.1*	*2.0*	
Rosaceae	Woodland/steppe				*0.8*	
Rhamnus					*0.6*	
Maloideae					*0.2*	
Juniperus				*3.0*		
Celtis/Ulmus						
Olea						*0.4*
Quercus (E/D)	Oak/juniper woodland					*2.7*
Quercus (E)					*3.0*	
Quercus (D)		*x*	*0.6*			
Acer						
Pinus	Coniferous woodland					
Cedrus						
	Others					*1.1*
Total fragments		-	164	907	636	c. 263
		Table 7 in Roitel, 1997 (after Willcox)	Neef, 2003	Deckers et al., 2009	Asouti et al., 2015	Western, 1983

Site		Chogha Golan (XI-VII)	Pinarbaşi (A)	Dja’de	Horvat Galil	Mureybet (phase IV)
Date ka cal. BP		11.9-10.7	10.7-10.5	10.7-10.3	10.7-9.9	10.7-9.9
Salicaceae		*33.5*		*37.3*		
Ficus						
Platanus	Wetland			*2.0*		
Fraxinus				*9.7*		
Vitex		*0.3*				
Tamarix		*23.5*		*33.3*		
Chenopodiaceae		*2.0*	*1.6*	*4.6*		
Ephedra	Steppe and halophytes					
Small shrubs		*0.3*	*4.9*	*0.7*		
Capparis						
Pistacia		*34.3*	*1.6*	*6.8*	*66.6*	
Amygdalus		*2.8*	*32.8*	*0.6*		
Rosaceae	Woodland/steppe		*55.7*	*0.5*		
Rhamnus				*0.5*		
Maloideae						
Juniperus						
Celtis/Ulmus						
Olea					*16.7*	
Quercus (E/D)	Oak/juniper woodland					
Quercus (E)					*16.7*	
Quercus (D)				*3.0*		*x*
Acer		*0.3*		*0.4*		
Pinus	Coniferous woodland					
Cedrus						
	Others	*3.1*	*3.3*	*0.4*		
Total fragments		391	61	1116	6	-
		Riehl et al., 2015	Asouti, 2003	Roitel, 1997	Liphschitz, 1997	Table 7 in Roitel 1997, after Willcox

Site Date ka cal. BP		Tepe Abdul Hosein 10.3-9.8	Cafer Höyük 10.3-9.4	Nahal Zippori 3 10.2-9.9	´Ain Ghazal 10.3-8.6	Çatalhöyük (South G) c. 10.3-8.4
Salicaceae		*x*	*x*		*x*	*29.7*
Ficus				*3.7*		
Platanus	Wetland		*x*			
Fraxinus			*x*			*0.2*
Vitex						*0.2*
Tamarix		*x*			*x*	*0.3*
Chenopodiaceae	Steppe and halophytes	*x*				*0.5*
Ephedra						
Small shrubs						
Capparis						
Pistacia		*x*	*x*	*3.3*	*x*	*2.9*
Amygdalus						*2.1*
Rosaceae	Woodland/steppe	*x*	*x*			*0.4*
Rhamnus			*x*			
Maloideae						*1.8*
Juniperus						*0.7*
Celtis/Ulmus			*x*			*56.8*
Olea						
Quercus (E/D)	Oak/juniper woodland			*18.9*		
Quercus (E)				*74.1*	*x*	
Quercus (D)			*x*		*x*	*2.4*
Acer			*x*			
Pinus	Coniferous woodland					
Cedrus						
	Others					*2.1*
Total fragments		-	-	615	-	1311
		Willcox, 1990	Willcox, 1991	Caracuta et al., 2014	Neef, 2004a	Asouti, 2013

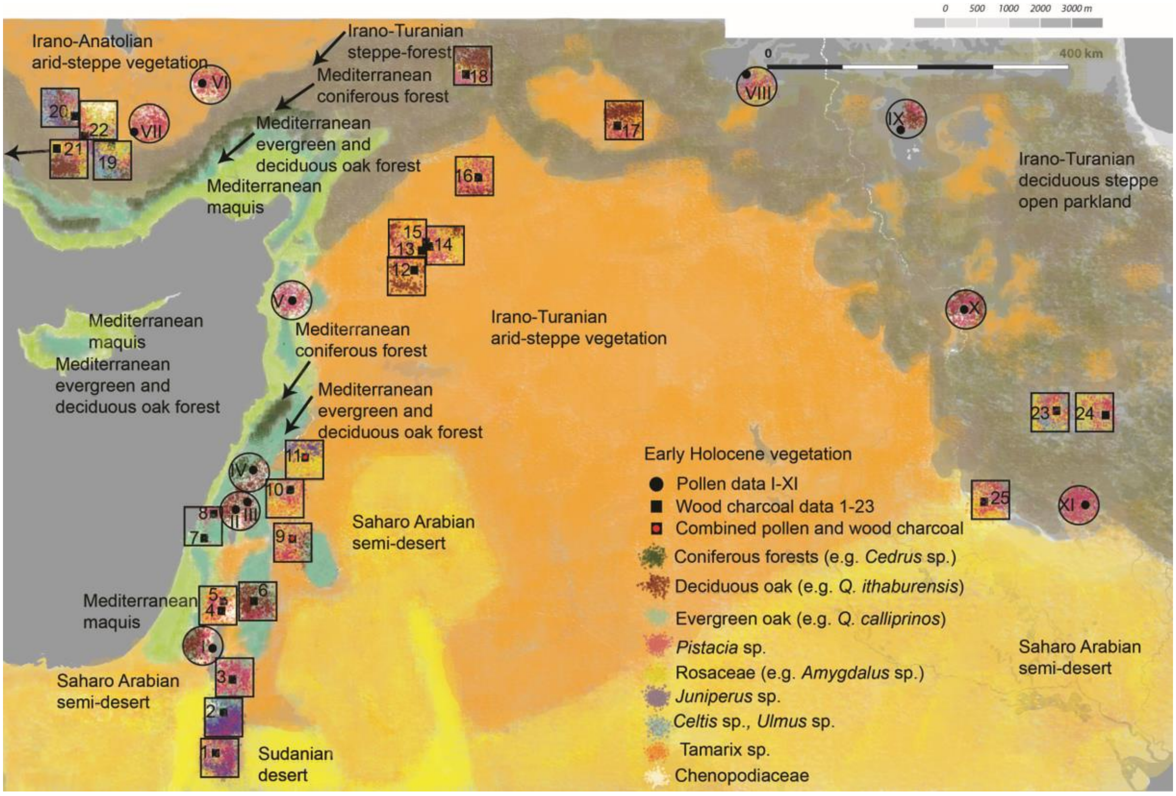
Site Date ka cal. BP		Ganj Dareh 10.2-9.8	el-Hemmeh PPNB c. 10-9	Jericho (II) 10.2-9.5	Tell Aswad II 10.2-9.5	Chogha Golan (VI-I) 10-9.6
Salicaceae	Wetland	*x*	*20.5*	*7.9*	*11.7*	*33.3*
Ficus			*9.0*	*4.9*		
Platanus				*0.5*		
Fraxinus			*34.7*	*7.4*	*29.7*	
Vitex				*0.5*		
Tamarix	Steppe and halophytes		*14.7*	*53.2*	*44.4*	*20.8*
Chenopodiaceae			*6.3*		*2.1*	*1.5*
Ephedra						
Small shrubs			*1.3*	*2.0*		*0.7*
Capparis				*3.4*		
Pistacia	Woodland/steppe	*x*	*6.3*		*1.3*	*39.1*
Amygdalus			*1.1*	*1.0*		*2.3*
Rosaceae		*x*	*0.8*			*0.1*
Rhamnus		*x*		*0.5*	*0.4*	
Maloideae			*0.5*			*cf. 0.1*
Juniperus	Oak/juniper woodland					
Celtis/Ulmus		*?*				
Olea						
Quercus (E/D)				*0.5*		
Quercus (E)			*0.6*			
Quercus (D)						
Acer						
Pinus	Coniferous woodland					
Cedrus					*0.4*	
	Others		*4.0*	*18.2*	*10.0*	*2.1*
Total fragments		-	619	c. 203	478	809
		van Zeist et al., 1984	Asouti et al., 2015	Western, 1983	Pessin, 2004	Riehl et al., 2016

Site		Can Hassan III	Tell Halula (M/L PPNB)	Basta
Date ka cal. BP		9.7-9.4	9.8-9.3	9.5-9.0
Salicaceae	Wetland	*x*	*23.9*	*x*
Ficus				
Platanus			*1.2*	
Fraxinus			*14.2*	*x*
Vitex				
Tamarix	Steppe and halophytes		*30.6*	*x*
Chenopodiaceae			*2.6*	
Ephedra				
Small shrubs			*0.7*	
Capparis	Woodland/steppe			
Pistacia		*x*	*11.0*	*x*
Amygdalus		*x*	*1.9*	*x*
Rosaceae			*0.2*	
Rhamnus				
Maloideae				
Juniperus	Oak/juniper woodland	*x*		*x*
Celtis/Ulmus		*x*	*2.2*	
Olea				
Quercus (E/D)				
Quercus (E)				*x*
Quercus (D)		*x*	*8.1*	
Acer			*0.6*	
Pinus	Coniferous woodland	*x*		
Cedrus				
	Others		*0.6*	
Total fragments		-	2322	-
		Willcox, 1991, Figure 2, p. 142	Roitel, 1997	Neef, 2004b

Table S6. Faunal remains from excavations areas XYZ at Tell Qarassa North (NISP: number of identified specimens). Bone tools were excluded from the counts.

Taxa	**Area XYZ**						**Area VU**			**Total**
	I	**II**	**III**	**IV**	**V**	**VI**	**Lower**	**Upper**	**Surface layers**	
Vulpes sp.	5	11	38	18	12	3	26	1	2	62
Meles meles			6	1	3					4
Felis silvestris		2	5		1		3			4
Canis familiaris			8	1	2	1				4
Carnivore unidentified	5	2	27	6	11		13	1	2	33
Sus f. *scrofa*			5	1	1	1	13		2	18
Dama mesopotamica			1	1	2				1	4
Bos f. *primigenius*	2	2	22	16	7	24	5	8	2	62
Large ungulate	1	1	1	16	37	7	3	5	9	77
Gazella ssp.	15	8	89	38	61	23	67	21	12	222
Capra f. *aegagrus*	15	1	7	27	49	1	38	12	2	129
Capra/Ovis	18	15	15	46	74	18	59	9	14	220
Small ungulate	3	34	232	75	181	21	14	16	18	325
Lepus capensis	2	3	25	6	12	2	8	4		32
Erinaceus concolor			1							0
Anas acuta	1									0
Anas platyrhynchos	1		3		5	1		1	2	9
Anas crecca			1		1					1
A. crecca/querquedula					1			1		2
Anatinae unidentified			4		2		1			3
Aquila f. *chrysaetos*							1			1
Accipitridae		1								0
Alectoris chukar		1	11	1	3	1	5			10
Rallidae			1							0
Otis tarda				1						1
Corvus corone			1		1					1
Birds unidentified	2	1	9	5	4		4			13
Total NISP	101	94	706	264	558	113	409	82	102	1528

Figure S1. Summary of early Holocene pollen (black circles) and wood charcoal (black squares) records (based on Table S5, excluding riparian taxa) in relationship to modern-day phytogeographical regions in southwest Asia (schematic representation based on vegetation maps by Frey and Kürschner, 1989). Dark orange: Irano-Turanian arid steppe; Grey: Irano-Turanian deciduous steppe and open parkland. Light orange: Saharo-Arabian semi-desert vegetation. Yellow: Sudanian desert. Light green: Mediterranean maquis; Turquoise: Mediterranean evergreen and deciduous oak forests; Dark green: coniferous forests. 1. Basta; 2. Wadi Faynan 16; 3. El-Hemmeh; 4. Jericho; 5. Gilgal I; 6. Ain Ghazal; 7. Nahal Zippori 3; 8. Horvat Galil; 9. Tell Qarassa North; 10. Tell Aswad: 11. Baaz Rockshelter; 12. Mureybet; 13. Dja'de; 14. Jerf el Ahmar; 15. Tell Halula; 16. Göbekli Tepe; 17. Körtik Tepe; 18. Cafer Höyük; 19. Can Hassan III; 20. Çatalhöyük; 21. Öküzini Cave; 22. Pinarbaşi; 23. Ganj Dareh; 24. Tepe Abdul Hosein; 25. Chogha Golan. I. Ein Gedi (Litt *et al.*, 2012); II. Hula pollen core (van Zeist *et al.*, 2009); III. Birkat Ram Crate (Schiebel, 2013): IV. Aamiq wetland (Hajar *et al.*, 2008); V. Ghab (Wright and Thorpe, 2003); VI. Eski Acigöl (Roberts *et al.*, 2001); VII. Akgöl (Bottema and Woldring, 1984); VIII. Lake Van (Wick *et al.*, 2003); IX. Lake Urmia (Djamali *et al.*, 2008b); X. Lake Zeribar (van Zeist and Bottema, 1977); XI. Lake Mirabad (van Zeist and Bottema, 1977).



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