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Early Holocene woodland vegetation and human impacts in the arid zone of the southern Levant

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Abstract
Palynological archives dating from the Pleistocene–Holocene transition are scarce in the arid zone of the southern Levant. Anthracological remains (the carbonized residues of wood fuel use found in archaeological habitation sites) provide an alternative source of information about past vegetation. This paper discusses new and previously available anthracological datasets retrieved from excavated habitation sites in the southern Levant dating to the Pre-Pottery Neolithic (PPN) period. The available evidence indicates the existence of distinct arboreal floras growing in different ecological niches, which occupied areas that today are either treeless or very sparsely wooded. The anthracological data provide independent confirmation of the hypothesis that early Holocene climate in the southern Levant was significantly moister than at present. Clear North–South and East–West precipitation and associated woodland composition gradients are evidenced. Far from deducing widespread anthropogenic degradation of the regional vegetation, it is suggested that woodland expansion in the semi-arid interiors of the Levant may be attributed to the intensive management of *Pistacia* woodlands for food, fuel and pasture.

Keywords
anthracology, early Holocene, human impact, Pre-Pottery Neolithic, southern Levant, woodland vegetation

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Introduction

Across Southwest Asia, the Pleistocene–Holocene transition was characterized by abrupt shifts in critical climate variables including precipitation, temperature and seasonality, which exerted significant impacts on water and vegetation resources (Orland et al., 2012; Rambeau, 2010; Roberts et al., 2001; Robinson et al., 2011; Rosen, 2007). These provided the setting for major economic and socio-cultural transformations that unfolded during this period including regionally diverse pathways to sedentism, the onset of food production and, by the mid-8th millennium cal. BC, the establishment and spread of mixed agro-pastoral economies reliant on plant and animal domesticates (Arbuckle and Atici, 2013; Asouti and Fuller, 2012, 2013; Martin and Edwards, 2013; Zeder, 2008, 2009). The nature and scale of the impacts of climate change on terrestrial habitats, especially woodlands and grasslands, varied greatly between the different bioclimatic regions of Southwest Asia. The greatest divergence has been observed between the Irano-Anatolian region and the Mediterranean littoral. In the Irano-Anatolian region, the slow pace of the expansion of deciduous *Quercus* after the end of the Younger Dryas (YD) (~12.7–11.5 ka cal. BP) lagged behind the rapid rise in temperature and precipitation that occurred at the start of the Holocene and was not completed until the mid-Holocene. By contrast, in the Levantine Mediterranean Woodland Zone, *Quercus* woodlands recovered rapidly after the end of the YD, without, however, reaching the maxima recorded during the Bølling-Allerød interstadial (~15–13 ka cal. BP) (for a recent comprehensive overview see Asouti and Kabukcu, 2014). This might have been caused by human impacts on Mediterranean woodlands due to vegetation firing and clearance for cultivation (see discussion in Rosen, 2007; Turner et al., 2010; Wright and Thorpe, 2003).

Reconstructions of the floristic composition, ecology and geographical distribution of late Pleistocene and early Holocene woodland vegetation in Southwest Asia have been traditionally based on data produced by pollen analyses (see overviews by Rambeau, 2010; Rosen, 2007). However, Southwest Asian terrestrial pollen sequences are plagued by problems of poor pollen preservation. Pollen-bearing sediments are predominantly found in large lake basins receiving supra-regional pollen rain and are often characterized by the absence of well-preserved organic matter and macrofossils suitable for radiocarbon dating. Thus, both the spatial and the temporal resolutions of the available pollen sequences are often compromised. From an ecological viewpoint, there are other issues too, concerning the representativeness of the Southwest Asian pollen assemblages: several woodland taxa that are native to the region are either poor and/or erratic pollen producers–dispersers (e.g. *Pistacia, Juniperus*) or are insect-pollinated (e.g. Rosaceae,

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Figure 1. Map showing the major landscape units of the southern Levant.

Maloideae). They are thus under-represented or altogether absent from the regional pollen sequences. The absence of well-preserved and dated pollen archives with which to reconstruct late Pleistocene and early Holocene palaeovegetation habitats is particularly acute in the arid zone of the southern Levant, especially east of the Jordan Rift Valley and to the south of the Dead Sea basin (Rambeau, 2010).

The aim of this paper is to present a comprehensive overview of the anthracological datasets currently available from late Pleistocene and early Holocene habitation sites located in the arid zone of the southern Levant, with particular emphasis on the Pre-Pottery Neolithic (PPN) (~9500–6700 cal. BC). Our key objectives are: (a) to reconstruct the vegetation catchments managed by the PPN inhabitants of this area through time and (b) to examine the nature of the temporal variations observed in the composition of the anthracological assemblages, and whether these may be tied to anthropogenic (clearance/pasture) and/or climate impacts on early Holocene woodland cover, composition and ecology. Following data presentation and discussion, we place the anthracological results in their broader regional context by comparing them to palaeoclimatic and other palaeovegetation archives that are available for this period. This comparison points to the existence of divergent woodland ecologies and trajectories of vegetation change across the different bioclimatic regions of Southwest Asia. In the arid zone of the southern Levant, *Pistacia* semi-arid grasslands predominated, occupying what are presently classed as treeless Irano-Turanian and Saharo-Arabian biomes to the east of the Jordan Rift Valley and south of the Dead Sea Basin. Towards the end of the PPN, these grasslands were replaced by *Pistacia*-dominated wood pastures, with a significant component of small-seeded legumes, as a result of their increasing management by sedentary late PPNB communities. Our work demonstrates that integrated analyses of archaeobotanical (charcoal, seed) archives provide a powerful tool for reconstructing prehistoric human–vegetation interactions and the complexity of vegetation succession patterns in semi-arid environments. Anthracology in particular emerges as the sole viable alternative to palynology for reconstructing local arboreal floras (given also that the study of wood phytoliths that may be ubiquitous in archaeological contexts such as hearths does not produce taxon-specific identifications of trees and shrubs). It can also generate high-resolution reconstructions of vegetation habitats that are all but extinct from these areas, which are firmly anchored to radiometric archaeological chronologies (Asouti and Austin, 2005; Asouti and Kabukcu, 2014). For these reasons, anthracology should become a priority for palaeoecological research in Southwest Asia.

Topography, climate and modern vegetation of the southern Levant

For the purpose of this paper, we have adopted the definition of the southern Levant proposed by Soto-Berelov et al. (2012) as the geographical region situated between latitude 29°30′ N to 33°N and longitude 34°17′ E to 36°15′E encompassing the modern political entities of Israel, Palestine and Jordan. Its diverse topography includes five major landscape units arrayed W-E: the coastal plains extending along the Mediterranean Sea, the Central Hills (rising to an altitude of 1200 m a.s.l.), the Jordan Rift Valley (extending from Lake Tiberias in the north through to the Dead Sea, Wadi Arabah and the Red Sea in the south), the Jordanian Plateau Region (rising to an altitude of 1650 m a.s.l.) and the Eastern Desert (Figure 1). Topography bears a strong effect on the regional distribution of precipitation gradients, with rainfall decreasing from W-E, and N-S, with the lowest values (<100 mm p.a.) observed in the southern part of the Rift Valley and the Eastern Desert (Figure 2). Temperature variation is principally affected by elevation and latitude, with the lowest temperatures observed in the southern highlands of the Plateau Region and the highest (up to 50°C) in the Wadi Arabah (Soto-Berelov et al., 2012).

The major bioclimatic regions and associated vegetation ecologies of the southern Levant have been described by Zohary (1962, 1973), Kürschner (1986) and Al-Eisawi (1996) (see Figures 2 and 3 for maps of the distribution of the major present-day bioclimatic zones and rainfall gradients, respectively). Mediterranean mixed evergreen woodlands, maquis, batha and steppe-batha vegetation are found in areas receiving 350–1000 mm of annual rainfall. In the low altitude plains and valleys of the Mediterranean zone (>400 mm p.a.), *Quercus ithaburensis, Quercus aegilops, Quercus boissieri* and *Quercus infectoria* abound. In areas receiving <400 mm p.a., deciduous oak is substituted by *Pistacia atlantica, Amygdalus, Rhamnus palaestina* and *Retama raetam* in association with

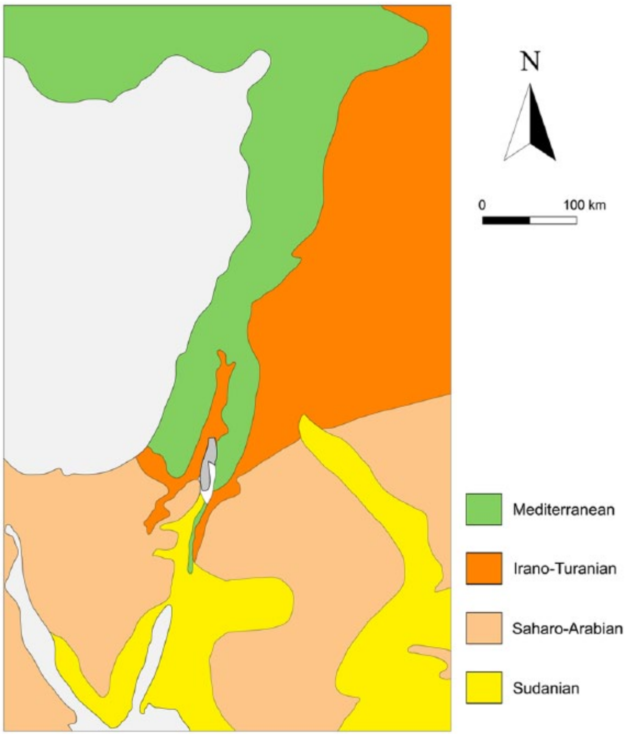

Figure 2. Present-day distribution of the major bioclimatic zones of the southern Levant (modified after Zohary, 1973).

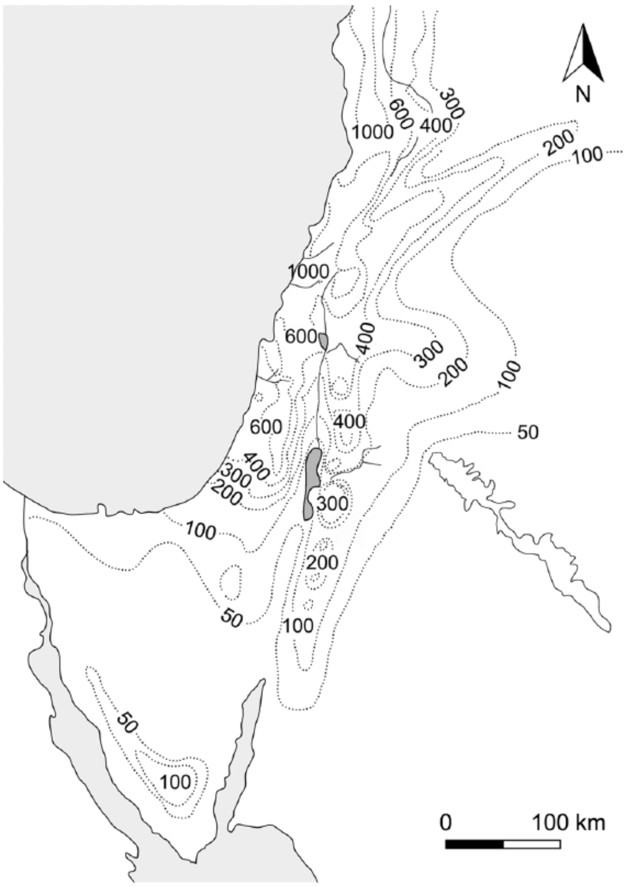

Figure 3. Present-day distribution of rainfall gradients in the southern Levant.

grasslands. In the Central Hills above 300 m a.s.l., the dominant association is that of *Pinus halepensis* with *Quercus calliprinos, Pistacia palaestina, Arbutus andrachne, Laurus nobilis, Cercis siliquastrum* and *Acer syriacum*. Evergreen maquis consists of *Quercus coccifera/calliprinos* growing alongside *Pistacia palaestina, Juniperus phoenicea, Pyrus syriaca, Rhamnus palaestina, Amygdalus communis* and *Crataegus azarolus*. Irano-Turanian xeromorphic dwarf shrub steppe and steppe forest vegetation (~200–350 mm p.a.) is presently characterized by shrubs such as *Artemisia herba-alba, Retama raetam, Ziziphus lotus, Noaea mucronata* and *Anabasis syriaca*, while scattered *Pistacia atlantica* and *Juniperus phoenicea* stands may grow in moister localities at higher altitudes with an

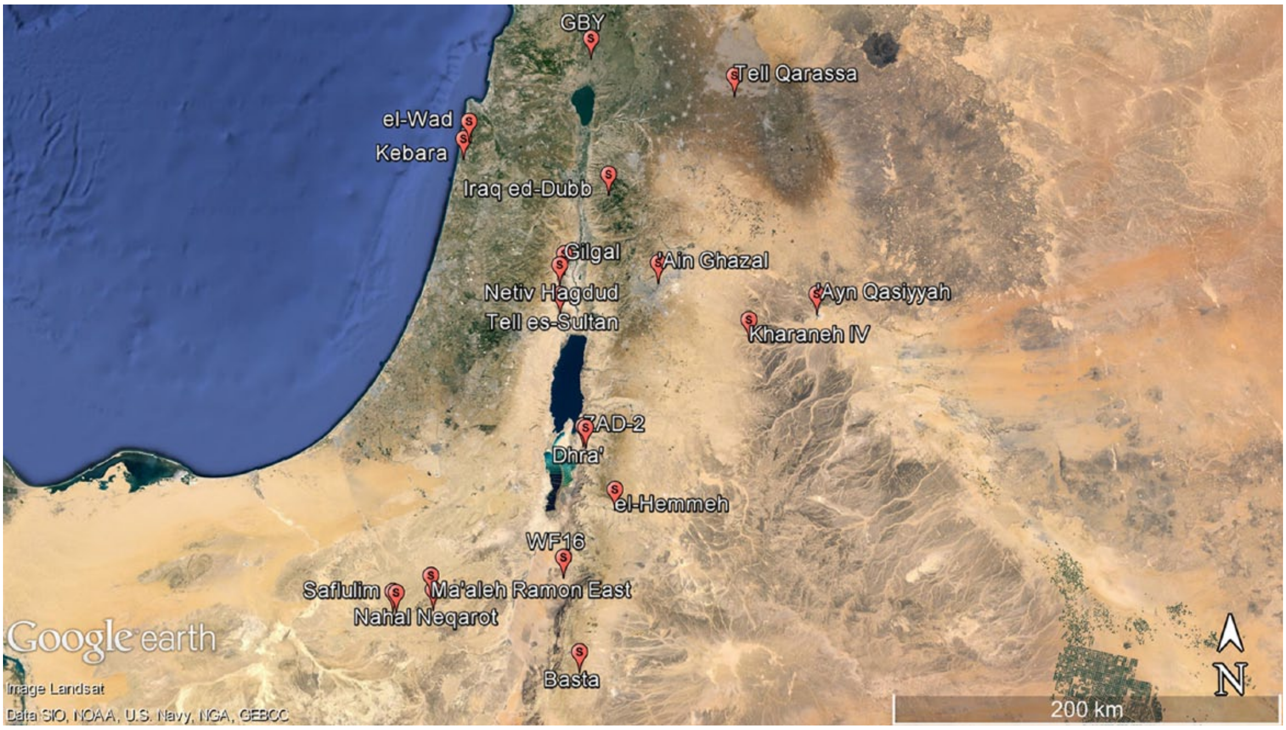

Figure 4. Map showing the location of the archaeological sites mentioned in the text.

understorey of steppe vegetation. Kürschner (1986) has argued that the Irano-Turanian dwarf shrublands represent the most regressive stages of semi-arid *Quercus ithaburensis–Pistacia atlantica* associations. Across the Saharo-Arabian region (extending along the Rift Valley, and in the Jordanian Eastern Desert and the Negev) (~50–100 mm p.a.) vegetation cover becomes very thin and consists mostly of shrubs and herbs including *Artemisia herba-alba, Achillea fragrantissima, Phlomis, Astragalus, Stipa* and *Trigonella*. Sudanian elements are found in the hottest parts of the region in the Jordan Rift Valley, under a similar rainfall regime (~50–100 mm p.a.) growing on alluvial, saline, sandy, marl and hammada soils. They include *Acacia* spp., *Balanites aegyptiaca, Calotropis procera, Maerua crassifolia, Salvadora persica, Haloxylon persicum, Ochradenus baccatus* and *Zygophyllum dumosum. Acacia* thorn woodlands occupy the wadi beds dissecting the southern part of the Rift Valley. Juniper forests, dominated by *Juniperus phoenicea* and *Cupressus sempervirens*, grow on the southern highlands at altitudes above 1000 m a.s.l. in association with *Pistacia atlantica, Rhamnus palaestina, Crataegus azarolus, Artemisia herba-alba* and *Amygdalus korschinskii*. East of the Rift Valley, especially on wadi beds characterized by more stable water flows that are also relatively free from agricultural and pastoral pressures, denser and more diverse riparian vegetation may occur (Mithen et al., 2007). Riparian taxa include *Tamarix, Salix, Populus, Phragmites* and *Nerium*. Isolated stands of *Pistacia atlantica, Pistacia khinjuk, Quercus calliprinos* and *Amygdalus korschinskii* may also be found on sandstone outcrops amidst treeless steppe and transitional desert areas because of water trapped in the subsoil by non-absorbent sandstone (Danin, 1995: 181).

The anthracological record

Over the last 40 years, anthracology, the study of the charred wood macro-remains originating in stratified archaeological deposits, has been increasingly used as a source of data for reconstructing early Holocene terrestrial vegetation habitats in Southwest Asia. This has been the case especially in Syria, in south-central and eastern Anatolia, and the Zagros (e.g. Asouti, 2005, 2013; Asouti and Hather, 2001; Asouti and Kabukcu, 2014; Deckers and Conard, 2011; Emery-Barbier and Thiébault, 2005; Kabukcu, 2015; Kabukcu and Asouti, in press; Martinoli, 2005; Riehl et al., 2012; Roitel and Willcox, 2000; Willcox, 1992, 1999). In the southern Levant, there are few published charcoal datasets dating from the late Pleistocene and the early Holocene. Anthracological analyses are available from Upper Palaeolithic and Natufian sites in the Negev (Baruch and Goring-Morris, 1997) and five PPNA–Early PPNB sites: Tell es-Sultan (Jericho) (Western, 1971, 1983), WF16 (Austin, 2007), Tell Qarassa (Arranz, 2011), and el-Hemmeh (including a LPPNB/PPNC facies) and Dhra' (both reported in the present paper). Neef (2004a, 2004b) has also published preliminary anthracological results from M-LPPNB 'Ain Ghazal and late PPNB Basta. Epipalaeolithic sites include Kharaneh IV and Ayn Qasiyyah in the Azraq Basin (Asouti and Kabukcu, in press) while waterlogged wood remains have also been reported from Lower Palaeolithic Gesher Benot Ya'aqov (GBY) (Goren-Inbar et al., 2002), Natufian el-Wad (Lev-Yadun and Weinstein-Evron, 1994) and the Kebara cave (Baruch et al., 1992) (for the location of all sites mentioned in the text, see Figure 4).

Table 1 presents in summary form the currently available anthracological data from all sampled sites located in the Irano-Turanian and Saharo-Arabian bioclimatic regions of the southern Levant. *Pistacia* is present at all sites (except for Nahal Neqarot). *Juniperus* (a cold-tolerant species) has a more restricted distribution to southern sites including Nahal Neqarot and Ma'aleh Ramon in the Central Negev Highlands, and WF16 and Basta on the foothills of the eastern Jordanian highlands. By contrast, deciduous *Quercus* (a Mediterranean woodland indicator) has been positively identified only from 'Ain Ghazal in the north. Similarly, members of the Rosaceae family (*Amygdalus*/*Prunus*) have been reported as co-dominant with *Pistacia* only from Tell Qarassa North in southern Syria. *Olea* (a typical Mediterranean taxon) has been identified in charcoals retrieved from PPN layers in Tell es-Sultan (Jericho). Riparian taxa (Salicaceae, *Fraxinus, Tamarix*) indicative of wadi woodland habitats have also been identified from several sites (see Table 1 and references therein).

A more detailed anthracological study providing insights into the evolution and temporal changes of early Holocene woodland vegetation from a single ecological catchment has been obtained

Table 1. Published anthracological assemblages from late Pleistocene and early Holocene sites in the southern Levant (taxa frequencies are expressed as percentage fragment counts, except for 'Ain Ghazal and Basta (explained below)).

	Nahal Neqarot[a]	WF16[b]	Ma'aleh Ramon[a]	Abu Salem[a]	Saflulim[a]	Ramat Harif[a]	el-Hemmeh (PPNA)[c]	Dhra'[d]	Tell Qarassa N[e]	Tell es-Sultan[f]	'Ain Ghazal[g]	Basta[g]	el-Hemmeh (LPPNB/PPNC)[c]
Pinus					0.72								
Juniperus	82.72	57.58	40									65.5	
Pistacia		3.16	58	99.95	61.59	99.62	70.71	+	59.48		<3	72.7	6.30
Quercus deciduous											>43		
Quercus evergreen		2.17					2.99	+	+		<3	3.7	0.65
Rhamnus	9.69	0.12	0.2	0.03		0.03	0.63						
Amygdalus/Prunus			0.2	0.02			2.84		37.25	+		10.9	1.94
Maloideae							0.16			+	+		0.48
Olea										+			
Punica										+			
Ceratonia										+			
Capparis		1.38								+			0.48
Leguminosae		0.67						+		+			
Ephedra	6.28	0.12	1.2			0.35		+					
Chenopodiaceae	0.79	3.99	0.4				7.24	+		+			6.30
cf. Asteraceae													1.13
cf. Labiatae													1.94
Ziziphus/Paliurus					37.66		1.73			+			1.29
Zygophyllum		0.26											0.48
Salicaceae		15.51					7.56	+	0.65	+	+	+	20.52
Tamarix	0.26	7.14					0.63	+		+	+	+	14.70
Fraxinus							1.57	+		+	+	+	34.73
Platanus										+			
Ficus		6.31					3.94	+		+			9.05
Total ID charcoal fragment count	382	2534	500	6620	138	6766	635	26	153	~160	~1300	~1535	619

Data sources: [a]Baruch and Goring-Morris (1997); [b]Austin (2007); [c]Asouti et al. (this paper); [d]Asouti, previously unpublished charcoal identifications produced for ^{14}C dating of hand-picked specimens; [e]Arranz (2011, personal communication, 2014); [f]Western (1971, 1983), hand-picked charcoals; [g]Neef (2004a, 2004b). 'Ain Ghazal: ubiquity scores (percentage presence) were calculated by combining hand-picked and flotation samples; Western (1983) reported the presence of some oak charcoals from PPN deposits at Jericho, without specifying if they are evergreen or deciduous; Basta: ubiquity scores (percentage presence) were re-calculated on the basis of a sample population including only flotation samples that contained charcoal (other quantification methods employed by Neef in the analysis of the Basta charcoals, such as percentage frequency measured by volume (ml) and percentage ubiquity calculated on the basis of all archaeobotanical samples including those that did not contain charcoal, were not taken into account for the purpose of the present study).
+denotes presence in hand-picked charcoal assemblages (indicated in the table) or uncertainty in the precise quantitative value of the frequency/presence values.

from el-Hemmeh, a Neolithic site located in Wadi al-Hasa, east of the Jordan Rift Valley, at a distance of ~30 km south-east of the Dead Sea basin. The sampled sequence includes a PPNA habitation (dated at c. 9120–8570 cal. BC) and a LPPNB/PPNC habitation dated to the late 8th and early 7th millennia cal. BC (Makarewicz et al., 2006). The tabulated anthracological data are presented as raw/percentage fragment counts and ubiquity (sample presence) in Table 2 (SEM microphotographs of select charcoal specimens are presented in Figures 5–9). *Pistacia* charcoal dominates the PPNA anthracological assemblage (>70%). While species identification is not possible on the basis of wood anatomy alone, White (2013) has identified the few whole *Pistacia* nutlets found among the seed botanical remains as *Pistacia atlantica*. It is therefore likely that the *Pistacia* charcoals belong to the same species. The rest of the assemblage comprises mostly riparian woodland taxa (Salicaceae, *Fraxinus, Tamarix*) and Chenopodiaceae shrubs. Minor components include fig (*Ficus carica*–type), evergreen oak (*Quercus*) and a range of semi-arid deciduous Rosaceae trees and shrubs such as *Amygdalus, Prunus*-diffuse porous type (possibly wild cherry), Maloideae (pear/hawthorn family), *Rhamnus* and *Ziziphus/Paliurus spina-christi*. The ubiquity (presence across samples) of *Pistacia*, riparian woodland taxa, Chenopodiaceae and, to a lesser degree, *Ficus* suggests that they were routinely collected as firewood during the PPNA. Table 3 presents a comparison of the fragment counts and sample presence of carbonized wood and non-wood remains of *Pistacia, Amygdalus* and *Ficus* for all sampled PPNA contexts. While *Ficus* pips and *Pistacia* nutshell were found in almost all contexts, *Amygdalus* nutshell was present in only one sample (White, 2013). The excellent preservation of *Pistacia* nutlets (with several surviving in whole form) and the presence of the small and fragile *Pistacia* attachment stems accord well with the ubiquity and frequency of *Pistacia* charcoal in the PPNA anthracological assemblage. Overall, the available evidence suggests that *Pistacia* trees and shrubs were intensively managed for the collection of nuts and firewood. The low ubiquity and percentage frequency values of *Amygdalus* probably reflect the low intensity of use of almond wood fuel and nut. *Amygdalus* wood is hardy and charcoal tends to preserve well, even in adverse depositional and post-depositional environments (Asouti, 2005, 2013; Asouti and Kabukcu, 2014). While fig (*Ficus*) charcoal is present with much lower frequencies compared with *Pistacia*, the presence of charred *Ficus carica* mericarp fragments with pips still attached to them and the ubiquity of *Ficus* druplets indicate that fig fruits were also collected as food during the PPNA (White, 2013).

The LPPNB/PPNC anthracological assemblage is dominated by riparian woodland taxa (*Fraxinus*, Salicaceae, *Tamarix*). Riparian taxa account for >70% of all positively identified specimens. Compared with the PPNA, *Pistacia* values drop from >70% to ~6% (being of almost equal frequency to Chenopodiaceae). However, *Pistacia* charcoal is ubiquitous, being present in

Table 2. Quantified charcoal data (raw/percentage fragment counts and sample presence) grouped by phase (PPNA, LPPNB) from the site of el-Hemmeh.

	PPNA			PPNB		
	Fragment count	%	Sample presence	Fragment count	%	Sample presence
Quercus (evergreen)	19	2.99	4	4	0.65	1
Pistacia	449	70.71	10	39	6.3	13
Amygdalus	13	2.05	3	7	1.13	4
Prunus (diff. porous)	5	0.79	2	5	0.81	4
Maloideae	1	0.16	1	3	0.48	2
Rhamnus	4	0.63	2			
Ficus	25	3.94	7	56	9.05	17
Fraxinus	10	1.57	4	215	34.73	18
Salicaceae	48	7.56	9	127	20.52	18
Tamarix	4	0.63	4	91	14.7	17
Chenopodiaceae	46	7.24	8	39	6.3	10
Ziziphus/Paliurus	11	1.73	2	8	1.29	2
cf. *Zygophyllum*				3	0.48	2
cf. *Capparis?*				3	0.48	3
cf. Asteraceae				7	1.13	5
cf. Labiatae				12	1.94	5
Total	635	100	11	619	100	20

Table 3. Comparison table of *Pistacia, Ficus* and *Amygdalus* wood and non-wood charcoal counts from the PPNA habitation at el-Hemmeh (non-wood charcoal counts derived from White, 2013).

	No. of items	Sample presence ($n = 11$)
Wood		
Pistacia	449	10
Amygdalus	13	4
Ficus	25	7
Non-wood		
Pistacia atlantica whole nutlet	5	4
Pistacia atlantica nutshell fragments	492	10
Pistacia atlantica attachment	19	4
Amygdalus nutshell fragments	2	1
Ficus carica druplet	598	11
Ficus carica mericarp	11	2

13 out of the 19 sampled contexts. This suggests that *Pistacia* trees and shrubs were growing in the environs of the LPPNB/PPNC settlement, just as it was the case during the PPNA. Other taxa that saw a reduction in their frequencies compared with the PPNA are evergreen *Quercus* and members of the Rosaceae (*Amygdalus, Prunus*, Maloideae). The proportions of the Chenopodiaceae remained stable while the frequency and ubiquity of *Ficus* increased. *Ziziphus/Paliurus, Zygophyllum* and charcoals tentatively identified as Asteraceae (*Artemisia*?) and Labiatae occurred in very low frequencies.

In order to explore further the temporal variation observed in charcoal sample composition, multivariate analyses were carried out including Correspondence Analysis (CA) and Principal Components Analysis (PCA). CA and PCA were performed with R statistical software (version 2.15.0). Due to the variable types, limited quantity and low resolution of the quantitative data available from other sites, it was only possible to undertake this analysis with the anthracological assemblage derived from el-Hemmeh, which could be integrated with the results of the published seed botanical study (White, 2013). Figure 10 presents the results of CA on the first two ordination axes based on abundance (raw fragment counts). The first two axes account for just over 60% of the observed taxonomic variation. The strong chronological separation between PPNA and LPPNB/PPNC charcoal sample composition is evident. All PPNA contexts cluster on the left-hand side of axis 1, being closely associated with *Pistacia*, evergreen *Quercus* and *Rhamnus*. LPPNB PPNC contexts are more widely spread along the second axis, with the separation of *Fraxinus* from Salicaceae and *Tamarix*. This might suggest that, despite the overall predominance of riparian woodland taxa in LPPNB PPNC samples, there is also a great degree of context-related variation (e.g. the possibility that *Fraxinus* charcoal might have entered the sampled population through the episodic inclusion of charred timber remains in the anthracological assemblage). The ecological separation between semi-arid and riparian woodland taxa is also confirmed by the results of PCA for the same sample set (Figure 11). A strong correlation is indicated between *Pistacia*, evergreen *Quercus* and Chenopodiaceae while *Rhamnus, Prunus* and Maloideae appear to form a distinct group. Again the patterning of taxa such as *Amygdalus, Fraxinus* and *Ficus* does not appear to be explained very well with the available dataset. It may be that the erratic representation of these taxa was due to context-related variation (e.g. charcoals of these taxa were deposited through the burning and discard of structural timber, or they may represent the remains of short-term, episodic fuel wood use). In order to evaluate more precisely the range of potential vegetation catchments from which wood was collected in the past, multivariate analyses were also applied on raw seed counts of wild grasses and small-seeded legumes from 27 contexts for which both seed and charcoal counts were available (excluding

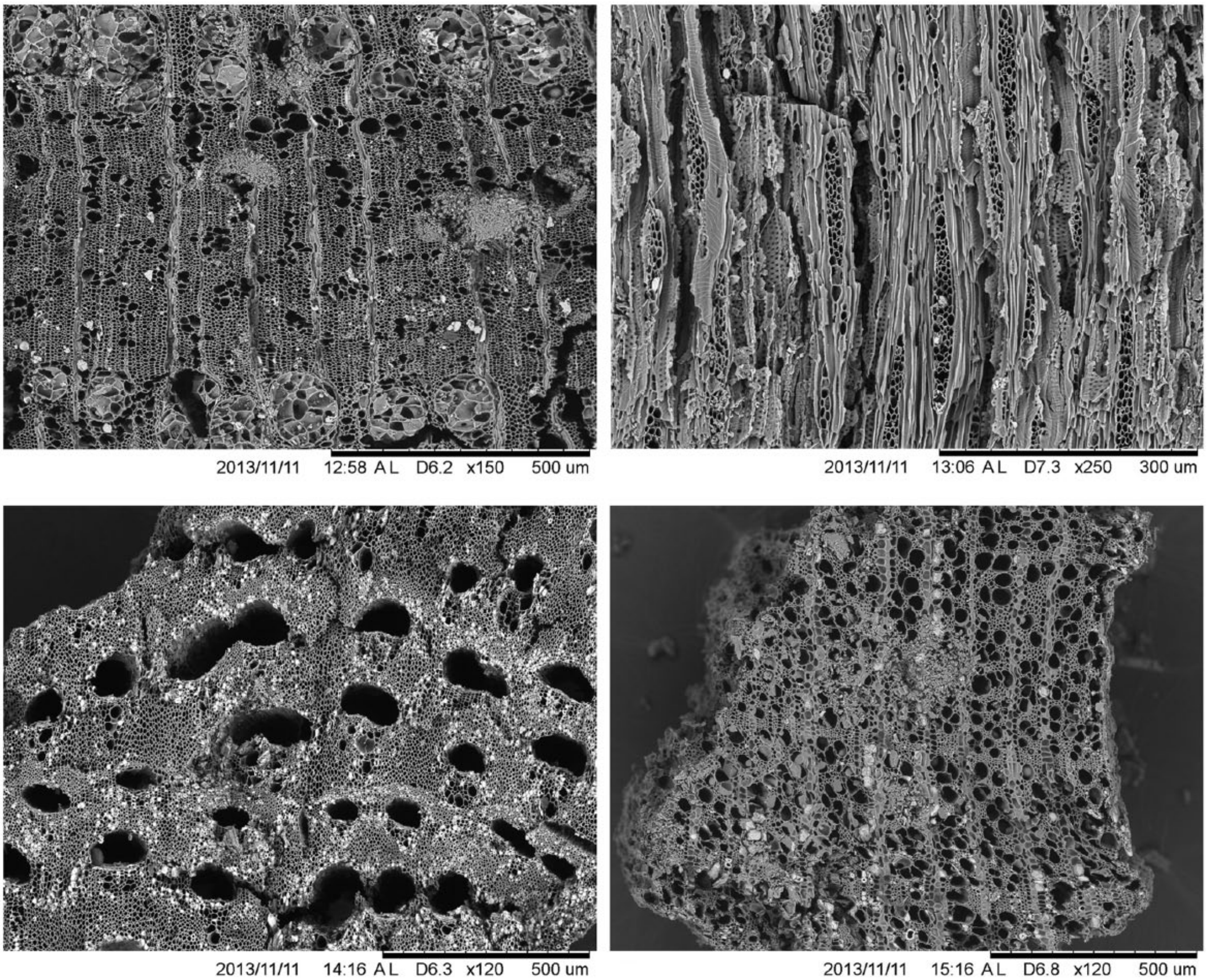

Figure 5. SEM microphotographs of wood charcoal specimens from el-Hemmeh – top row: *Pistacia* Transverse Section (TS) (left), Tangential Longitudinal Section (TLS) (right); bottom row: Chenopodiaceae (TS) possible *Salsola* type (left), *Amygdalus* (TS) semi-ring porous type (right).

contexts for which there were no seed data; both cultivated taxa and wild taxa with very low counts such as *Fumaria, Artemisia, Gallium* and so on were also excluded; cf. White, 2013). The results of CA (Figure 12; the first two axes account for 62% of the observed variation) indicate the association of *Pistacia* with evergreen *Quercus, Rhamnus* and wild grasses. The chronological separation between PPNA and LPPNB/PPNC contexts is also evident. All LPPNB PPNC samples cluster on the left-hand side of axis 1 with small-seeded legumes. PCA applied to the same dataset (Figure 13) also points to the association of *Pistacia* with evergreen *Quercus* and wild grasses.

Discussion

Regional vegetation and climate

The combined anthracological record from the south Levantine arid zone indicates that during the early Holocene, *Pistacia* woodlands extended to the east and south of the Jordan Rift Valley, occupying areas that at present are almost completely devoid of arboreal vegetation. *Pistacia* is the dominant taxon in almost all the PPNA (and earlier) sites that have been sampled for charcoal analysis in this part of the Levant, with the exception of Nahal Neqarot, Ma'aleh Ramon and WF16. The prevalence of *Juniperus* at Nahal Neqarot can be explained by its date to the Last Glacial Maximum in conditions that were too cold and arid for the establishment of *Pistacia* woodland, while its coexistence with *Pistacia* at Ma'aleh Ramon (dated to the YD) suggests that local conditions were not prohibitive for tree growth during the 11th millennium cal. BC (Baruch and Goring-Morris, 1997). In WF16, the preference for *Juniperus* rather than *Pistacia* (whose nutshell was ubiquitous in the archaeobotanical samples) and the riparian taxa that abounded in its environs may reflect a preference for juniper old wood for timber and fuel, including driftwood sourced from highland areas (Austin, 2007). As it stands at present, the ecological representativeness of the WF16 charcoal assemblage remains to be verified by the analysis of a more substantial charcoal sample population.

The ubiquity of *Pistacia* charcoal in PPNA and LPPNB anthracological assemblages (particularly at sites with multi-period assemblages such as el-Hemmeh) suggests significantly higher (compared with present-day) early Holocene precipitation levels across the arid zone of the southern Levant. According to published regional vegetation surveys (Kürschner, 1986; Zohary, 1962, 1973), associations of *Pistacia palaestina–Quercus calliprinos* are presently encountered only in areas with 300–350 mm of annual rainfall, while *Pistacia atlantica* can withstand somewhat drier conditions (250–300 mm p.a.). Increased precipitation likely characterized not only the lowland plains but also higher elevations on the escarpment and the Jordanian plateau. This interpretation is supported by the presence of evergreen *Quercus, Rhamnus*, Rosaceae (including both *Amygdalus* and *Prunus*) and Maloideae (on ecological grounds the latter likely including *Crataegus, Pyrus*) in the anthracological record. Overall, climate conditions were probably moister (~200–350 mm p.a.) than at present

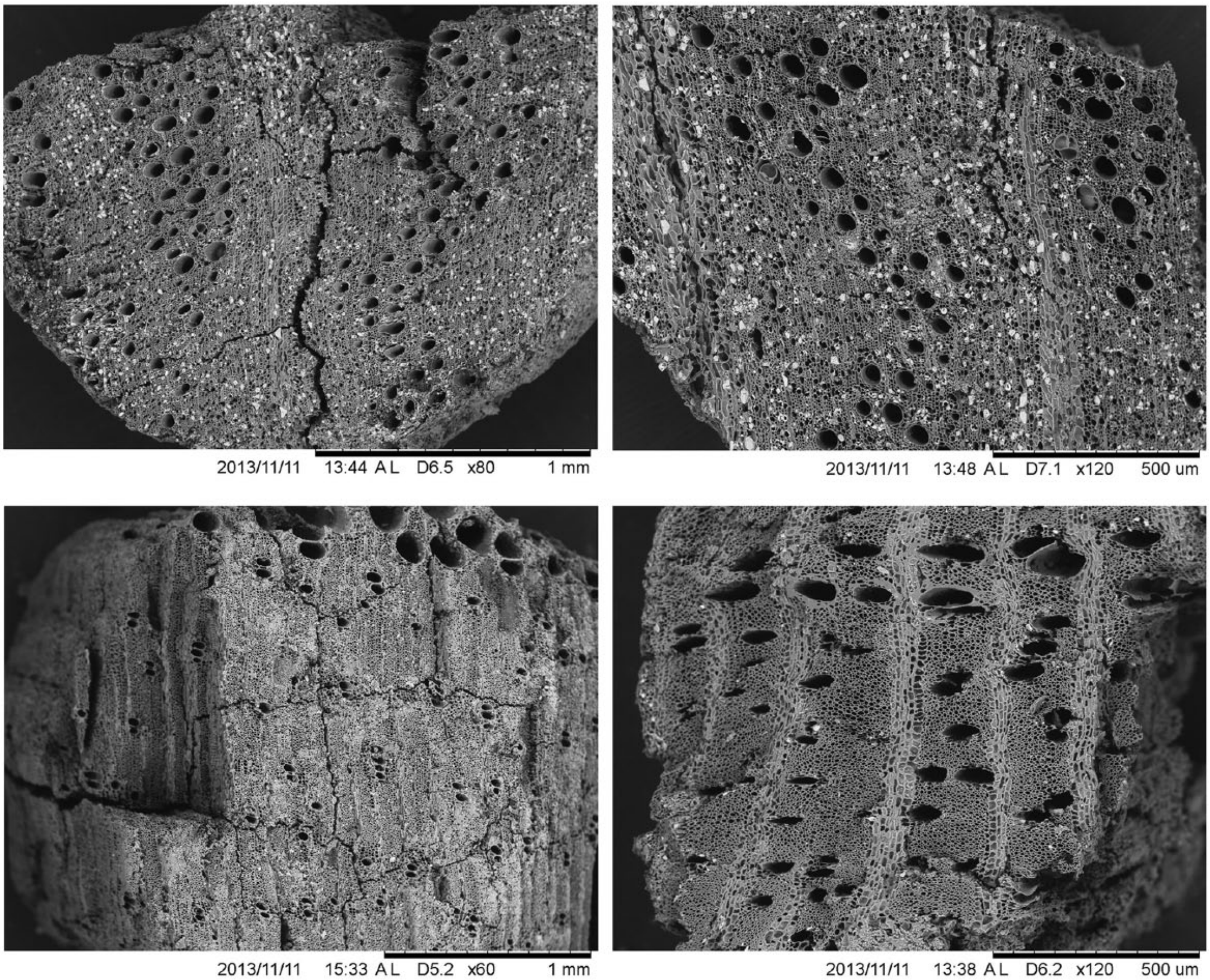

Figure 6. SEM microphotographs of wood charcoal specimens from el-Hemmeh – top row: *Quercus* (TS) evergreen type; bottom row: *Fraxinus* (TS) (left), *Tamarix* (TS) (right).

across the areas that today are classified as 'treeless' Irano-Turanian dwarf shrubland and steppe. This proposition finds additional support in other regional palaeovegetation and palaeoclimatic records, which point to the existence of a more varied and spatially extensive arboreal cover and an overall moister, if seasonally unstable, climate regime during the early Holocene (cf. Black et al., 2011; Emery-Barbier, 1995; Hunt et al., 2004; Orland et al., 2012; Rambeau et al., 2011).

At the regional scale, the available regional palaeovegetation archives suggest that in the northern (Irano-Anatolian) and western (Mediterranean) parts of Southwest Asia *Quercus* woodlands were gradually spreading after the end of the YD through to the mid-Holocene (Asouti and Kabukcu, 2014; Bottema, 1991; Bottema and Van Zeist, 1981; Rosen, 2007; Wright and Thorpe, 2003). The geographical distribution of the anthracological and pollen records indicates the existence of N-S and E-W gradients in woodland composition. Deciduous oaks are important ecological indicators of the Mediterranean and the Irano-Anatolian bioclimatic regions. Significantly, deciduous *Quercus* charcoal is completely absent from all sites located in the southernmost parts of the Levantine arid zone (i.e. south of the Dead Sea basin), while evergreen *Quercus* charcoal appears only sporadically in their anthracological assemblages. This pattern also appears to be verified by more recently obtained pollen evidence at the site of Ein Gedi on the western shores of the Dead Sea, where the low percentages of *Quercus ithaburensis*–type pollen during the early Holocene have been interpreted as indicative of long-distance transport from highland localities (Litt et al., 2012). This geographical pattern suggests that, despite the early Holocene rapid climate amelioration, conditions in the arid zone of the southern Levant were still too dry to permit deciduous oak establishment, hence casting doubt on Zohary's (1973) suggestion of including a narrow strip east of the Dead Sea basin to the Mediterranean (or the Mediterranean steppe maquis) biome. The presence of evergreen *Quercus* in this area is likely to denote the intrusion of drier elements of Mediterranean floras into Irano-Turanian biomes as a result of early Holocene climate improvement. The presence of deciduous *Quercus* at moister localities on higher elevations further north (especially on limestone and terra rossa substrata) indicates the southernmost extent of this taxon in the arid zone of the southern Levant. Deciduous *Quercus* dominated the anthracological assemblage of LPPNB 'Ain Ghazal located at an altitude of ~700 m a.s.l. near the modern city of Amman (cf. Neef, 2004a), while *Quercus ithaburensis*–type pollen is also well represented during the early Holocene in the Birkat Ram pollen sequence from the Golan Heights (Schiebel, 2013).

The presence of evergreen *Quercus* is often interpreted as a classic indicator of the anthropogenic disturbance of 'climax' Mediterranean vegetation, with the substitution of deciduous semi-arid woodland by maquis vegetation that is more resistant to fire and overgrazing. However, evergreen *Quercus* could also have formed natural components of woodlands growing in areas receiving low and/or seasonally erratic rainfall. Its charcoal is present at all sampled early Holocene sites located on

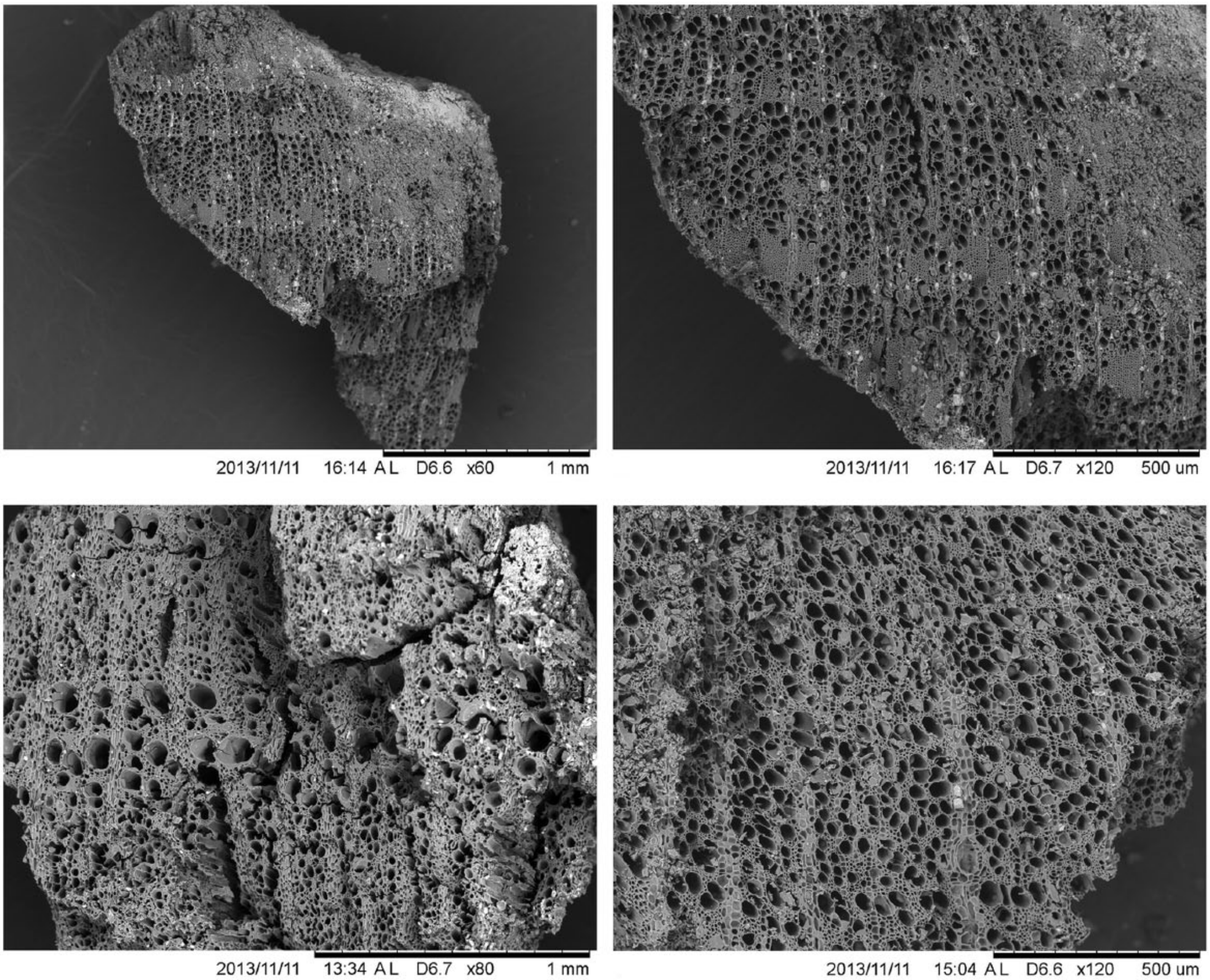

Figure 7. SEM microphotographs of wood charcoal specimens from el-Hemmeh – top row: *Rhamnus* (TS); bottom row: *Amygdalus* (TS) ring porous type (left), *Prunus* (TS) diffuse porous type (right).

the escarpment east of the Jordan Rift Valley (el-Hemmeh, Dhra', WF16, Basta) but is absent from the Negev sites where conditions were too dry for evergreen oaks. The archaeobotanical evidence thus confirms the existence of a south Levantine N-S gradient from moister to more drought-tolerant woodland habitats during the early Holocene, which accords well with modern vegetation observations by Zohary (1973). Interestingly, evergreen *Quercus* is absent from EPPNB Tell Qarassa, which is located in a comparatively moister area in southern Syria. Its charcoal appears with very low frequencies only in samples dating from the beginning of the 8th millennium cal. BC (Arranz, personal communication, 2014). If confirmed by further analysis, this pattern suggests that in the northern half of the south Levantine Irano-Turanian arid zone evergreen oaks spread only secondarily, possibly as a response to vegetation clearance and grazing/browsing pressures in the course of the 9th millennium. Conversely, the reduction in the frequency of evergreen oak charcoal (despite the known resistance of this taxon to browsing pressures) in the LPPNB /PPNC samples from the site of el-Hemmeh might signify a shift to drier climate conditions, whose impact was particularly felt in more fragile ecotones to the south and east of the Jordan Rift Valley. A subtler early Holocene N-S gradient is also suggested by the relatively high proportions of the Rosaceae (*Amygdalus* and *Prunus*) in PPN charcoal samples from Tell Qarassa (Arranz, 2011). In conjunction with the high values recorded for *Pistacia*, they point to the abundance of mixed *Pistacia*–Rosaceae woodlands in comparatively moister Irano-Turanian biomes in the north during the early Holocene. To date, the sole site with evidence pertaining to the easternmost distribution of the Mediterranean woodland biome during the early Holocene is Tell es-Sultan. Samples provisionally dated to the PPN have revealed the presence of typical Mediterranean maquis taxa such as *Olea, Ceratonia* and other Leguminosae (Fabaceae) (Western, 1971, 1983). The presence of *Quercus* (evergreen and/or deciduous) in its anthracological assemblage provides additional support for its inclusion in the Mediterranean woodland biome.

The evidence for woodland management and anthropogenic vegetation impacts

The integrated anthracological and seed botanical evidence from el-Hemmeh, alongside the available modern vegetation analogues, provides the most complete dataset for a preliminary assessment of the ecology and spatio-temporal transformations of early Holocene *Pistacia* woodlands in the arid zone of the southern Levant. Multivariate analyses indicate the association of *Pistacia* with evergreen *Quercus* and Poaceae (Gramineae). Woodland vegetation was probably characterized by an open structure and low-density canopy, comprising widely spaced *Pistacia* trees with a thin understorey of evergreen *Quercus* and Chenopodiaceae shrubs, and a ground cover rich in grasses. Other relatively rare and unevenly distributed charcoal taxa such as

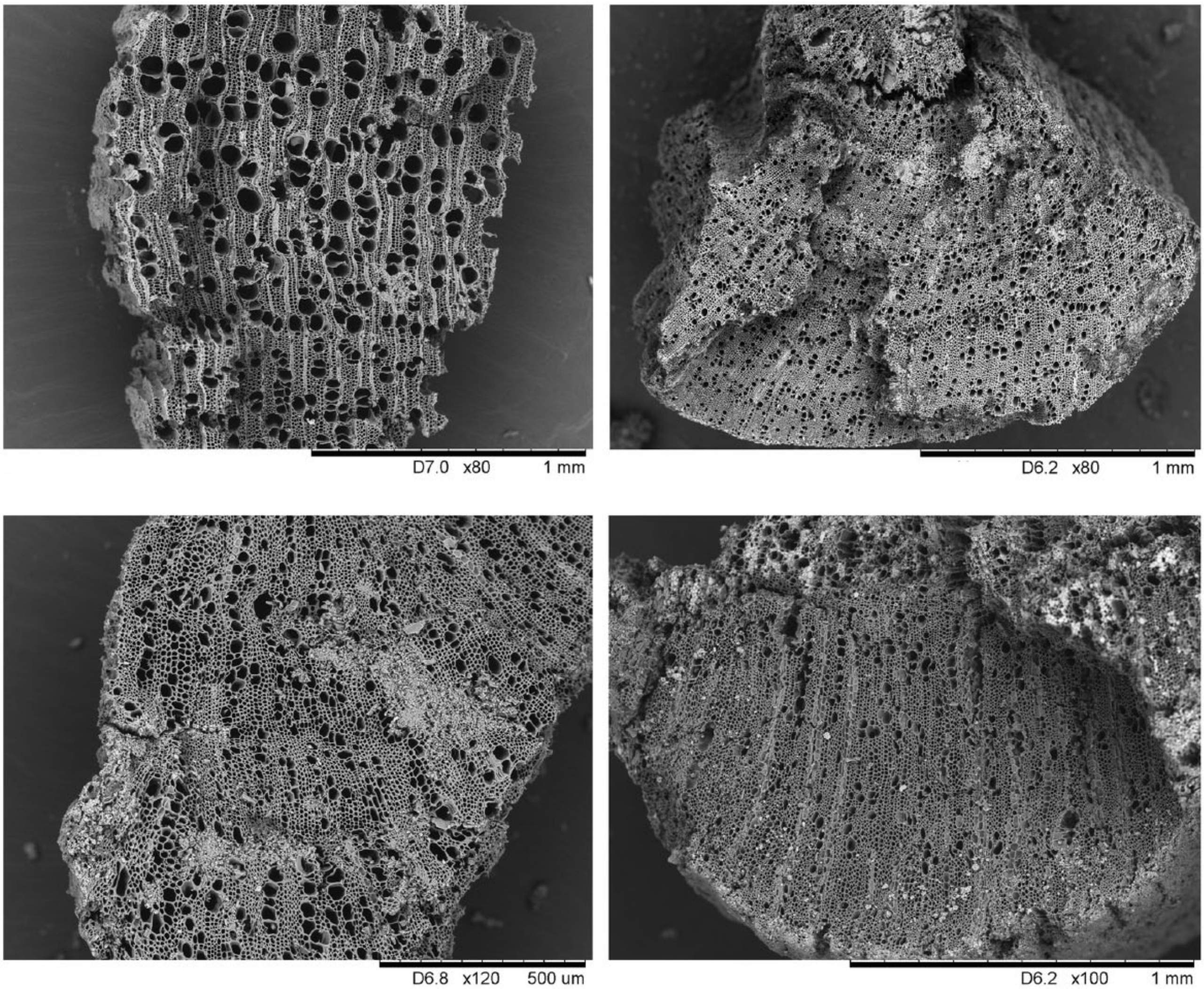

Figure 8. SEM microphotographs of wood charcoal specimens from el-Hemmeh – top row: *Ziziphus/Paliurus* (TS) (left), cf. *Zygophyllum* (TS) (right); bottom row: cf. *Labiatae* (TS) (left), cf. *Asteraceae* (Artemisia) (TS) (right).

Amygdalus, Prunus, Maloideae and *Rhamnus* might have originated in woodland catchments similar to Zohary's (1973) and Kürschner's (1986) 'Mediterranean woodland' growing on terra rossa and yellow soils. Alternatively, they could have formed elements of moist woodland steppe habitats (sensu Hillman, 2000) growing at higher altitudes. The openness of *Pistacia* stands in semi-arid grasslands could have been maintained through time by management strategies such as pruning, coppicing and pollarding and the regular firing of the ground vegetation that would have stimulated grass growth. Due to the small size (>1 to <2 mm) of the recovered charcoal particles, it was not possible to obtain direct evidence for woodland management practices through the analysis of wood curvature, calibre and preserved terminal rings. To date, no such evidence has been reported from other sites. However, the use of fire as a vegetation management tool during the early Holocene in the southern Levant has been previously proposed based on the study of micro-charcoal and phytolith archives (Turner et al., 2010).

The above limitations aside, the high frequencies of *Pistacia* charred wood and nutshell in the el-Hemmeh PPNA archaeobotanical assemblages suggest that *Pistacia* woodlands were routinely managed as a source of fuel and food during this period. This conclusion accords well with previously published archaeobotanical studies indicating the prominence of *Pistacia* nut harvesting at several PPNA and EPPNB sites including WF16 (Kennedy, 2007), 'Iraq ed-Dubb (Colledge, 2001), Netiv Hagdud (Kislev, 1997), ZAD-2 (Edwards et al., 2004) and Tell es-Sultan (Hopf, 1983). Figs were also common at Gilgal I (Kislev et al., 2006), 'Iraq ed-Dubb (Colledge, 2001), Netiv Hagdud (Kislev, 1997), Dhra' (Colledge et al., 2008), Tell Aswad I (Van Zeist and Bakker-Heeres, 1985) and Tell es-Sultan (Hopf, 1983; Western, 1971). These datasets testify to the significant contribution of tree crops to the south Levantine PPNA–EPPNB subsistence economies. While making a case for the 'domestication' of *Pistacia* and *Ficus* in the PPNA is doubtful (see especially the arguments for and against fig domestication by Kislev et al. (2006) and Denham (2007), respectively), the integrated anthracological and seed botanical evidence suggests that *Pistacia* nuts were not simply collected from the wild as part of opportunistic strategies procuring occasional delicacies or dietary supplements. Instead, both *Pistacia* nut and fuel/timber wood production appear to have formed an integral part of the south Levantine PPN subsistence economies.

Anthracological evidence dating to the LPPNB is currently available only from two sites in the arid zone of the southern Levant: Basta and el-Hemmeh. While at Basta riparian taxa have a rather limited presence, the el-Hemmeh anthracological record points to a shift in the focus of fuel selection from the semi-arid *Pistacia*-dominated grasslands that were primarily exploited during the PPNA, to the riparian woodland biome that abounded on the banks of Wadi al-Hasa during the LPPNB/PPNC. This shift in the composition of the anthracological assemblage suggests that LPPNB/PPNC small-scale mixed (cereal and pulse) horticulture focused on the riparian woodland biomes that were intensively

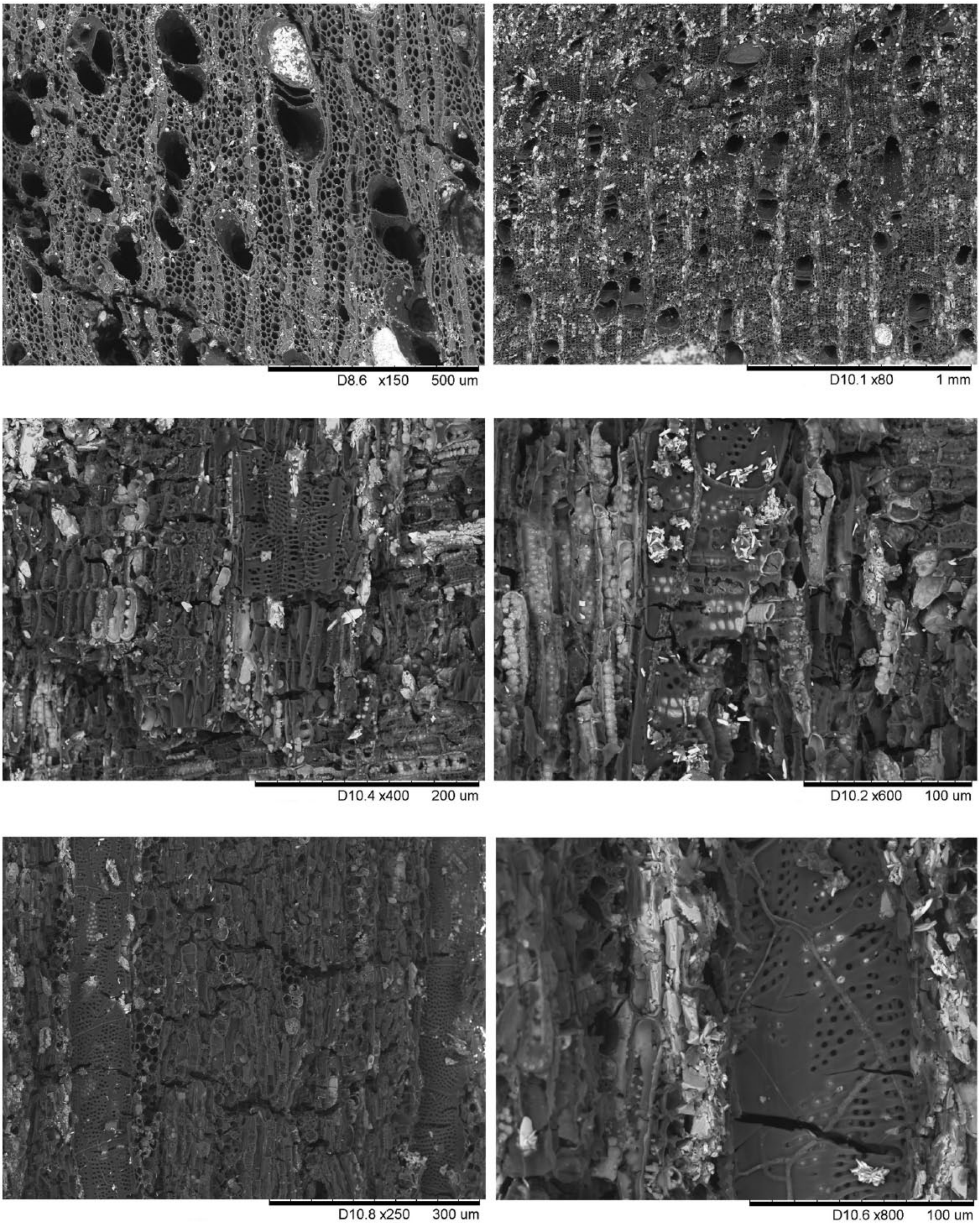

Figure 9. SEM microphotographs of wood charcoal specimens from el-Hemmeh – top row: *Ficus* (TS); middle row: *Ficus* (Radial Longitudinal Section, with signs of fungal hyphae in vessel elements indicating burning as deadwood); bottom row: *Ficus* (TLS, showing rays and fungal hyphae on vessel walls indicating the burning of deadwood).

managed. Wadi woodlands were dominated by typical riparian taxa such as *Fraxinus*, Salicaceae and *Tamarix*. While Chenopodiaceae probably formed a stable component of understorey shrub vegetation in semi-arid grassland and moist steppe woodland habitats during both periods of Neolithic habitation, they are also likely to have grown in marshes, abandoned channels and saline substrata at the edges of riparian woodlands alongside *Ziziphus/Paliurus* and *Zygophyllum*.

The results of multivariate analyses at el-Hemmeh indicate the strong association of small-seeded legumes with LPPNB/PPNC charcoal samples dominated by riparian taxa (Figure 11). Small-seeded legumes are a favoured forage choice for caprine livestock;

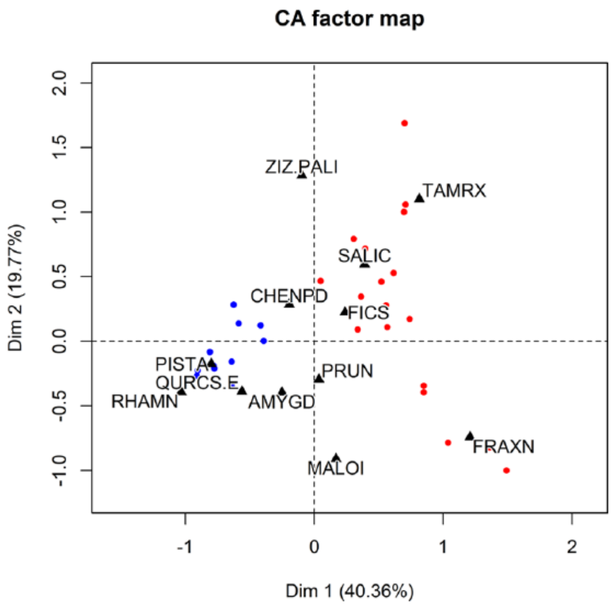

Figure 10. R Correspondence Analysis plot of 30 PPNA and LPPNB PPNC contexts from the site of el-Hemmeh (excluding 1 PPNA context that contained only 1 identified charcoal fragment; including only taxa that were positively identified to genus or family level). Dark (blue) dots represent PPNA contexts and light (red) dots LPPNB/PPNC contexts.

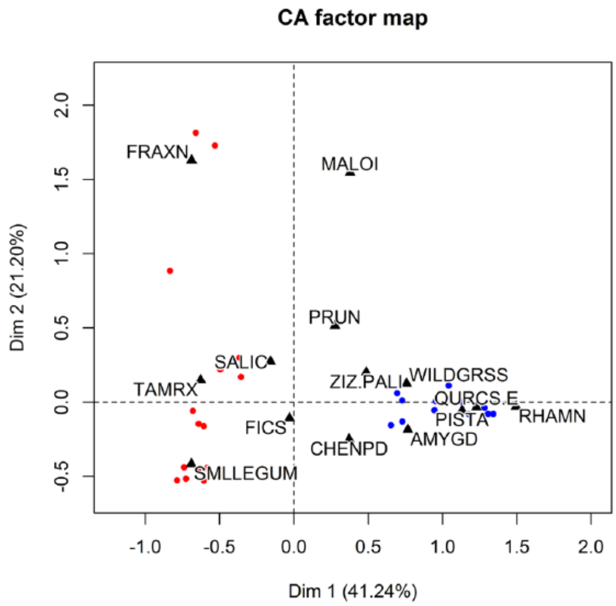

Figure 12. R Correspondence Analysis plot of 27 PPNA and LPPNB/PPNC contexts from the site of el-Hemmeh, for which both wood charcoal and wild seed taxa counts were available (including only taxa that were positively identified to genus or family level). Dark (blue) dots represent PPNA contexts and light (red) dots LPPNB/PPNC contexts.

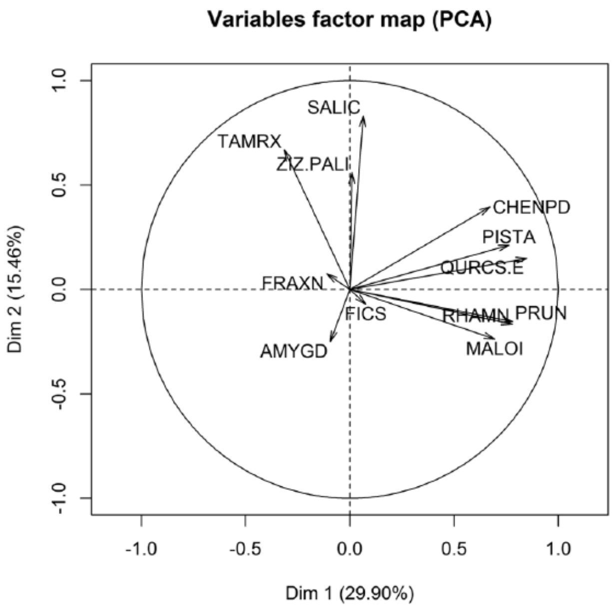

Figure 11. R Principal Components Analysis plot of 30 PPNA and LPPNB/PPNC contexts from the site of el-Hemmeh (excluding 1 PPNA context that contained only 1 identified charcoal fragment; including only taxa that were positively identified to genus or family level).

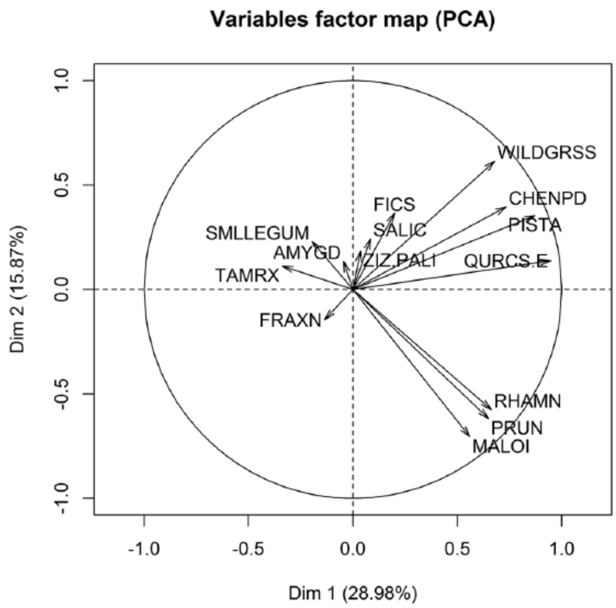

Figure 13. R Principal Components Analysis plot of 27 PPNA and LPPNB/PPNC contexts from the site of el-Hemmeh, for which both wood charcoal and wild seed taxa counts were available (including only taxa that were positively identified to genus or family level).

this association suggests that one of the main pathways for their inclusion in the archaeobotanical record was through the burning of dry dung as fuel. The use of dung fuel at el-Hemmeh is also suggested by the sporadic occurrence of charred dung fragments in LPPNB/PPNC botanical samples (White, 2013). Given the ubiquity of wood charcoal and the limited evidence for the use of dung fuel during this period, there is no reason to conclude that firewood had become a scarce resource as a result of 'deforestation' caused by *Pistacia* woodcutting or goat browsing. Neef (2004b) reached similar conclusions from his analysis of the Basta plant macrofossils, where he also found no evidence for the degradation of the local *Pistacia–Juniperus* woodlands. Considered together, the el-Hemmeh and Basta archaeobotanical records contradict arguments previously proposed by Köhler-Rollefson and Rollefson (1990) for widespread deforestation caused by anthropogenic impacts in the territories of the south Levantine LPPNB 'mega-sites'. These earlier arguments were based on rather limited evidence obtained from another well-known south Levantine LPPNB 'mega-site', 'Ain Ghazal. Both el-Hemmeh and Basta were located in much drier ecological zones to the south. Thus, it is reasonable to assume that their vegetation catchments would have been even more fragile and susceptible to environmental degradation compared with the relatively well-watered and more densely wooded environs of 'Ain Ghazal. However, it should also be emphasized that these earlier hypotheses were generated from rather limited excavated areas and will almost certainly be revised by further archaeobotanical work at 'Ain Ghazal (Rollefson, personal communication, 2013; see also Campbell, 2010). One possible explanation for the lack of evidence for a more substantial ecological footprint of these large and long-lived, sedentary LPPNB communities is that anthropogenic impacts on their vegetation catchments were mitigated by the adoption of woodland management strategies, which ensured the sustainability of valuable fuel, leaf fodder and timber resources.

Although the available evidence does not support the hypothesis of large-scale deforestation, the archaeobotanical record also points to the existence of more subtle late PPN anthropogenic vegetation impacts. The LPPNB/PPNC seed botanical samples from el-Hemmeh did not contain classic disturbed wetland/marsh habitat indicators such as *Scirpus maritimus, Phragmites, Carex, Typha* and *Bolboschoenus* (White, 2013). Instead, they were dominated by cosmopolitan grass taxa such as *Phalaris* (cf. Haslam, 2003: 90) alongside small-seeded legumes. This, alongside the clustering of LPPNB/PPNC charcoal samples with small-seeded legumes, evidenced by multivariate analysis, suggests that large-scale vegetation changes were probably at play during this period, involving the progressive replacement of semi-arid grasslands by a herbaceous ground cover dominated by small-seeded legumes. The general consensus in rangeland ecology research is that grazing and browsing pressures tend to favour the proliferation of forbs (e.g. Asteraceae, Labiatae, Fabaceae) at the expense of annual and perennial graminoids (e.g. Poaceae, Cyperaceae) (Díaz et al., 2007; Noy-Meir et al., 1989). Moreover, small-seeded legumes may expand their habitat ranges as a result of their dispersal through caprine dung deposition in pastures (Ghassali et al., 1998). Hence, the observed shift from Poaceae (PPNA) to small-seeded legumes (LPPNB/PPNC) at el-Hemmeh may signify the increasing conversion of semi-arid grassland habitats into intensively grazed rangelands during the late PPN. The low frequency and high ubiquity values of *Pistacia* charcoals in the LPPNB/PPNC charcoal samples alongside the evidence for the harvesting of *Pistacia* nuts that continued into this period might also indicate the collection of less *Pistacia* firewood, which could have derived from fewer, larger and older *Pistacia* trees with crowns established well above the browsing line. Such individuals could have formed wide-spaced, even-aged, old-growth *Pistacia* wood pastures characterized by low to nil rates of natural regeneration due to the browsing of *Pistacia* young shoots, seedlings and saplings by goats. The integrated charcoal and seed macro-botanical evidence thus points to complex vegetation succession patterns from semi-arid grasslands to wood pastures resulting from the ecological impacts of herding activities on the grassland biomes of the southern Levant in the transition from PPNA cultivator-forager to LPPNB late PPN mixed agro-pastoral economies.

Conclusion

The potential of anthracology in the southern Levant has been attested since the first publication by AC Western (1971) of her analysis of the wood charcoal macro-remains from Kathleen Kenyon's excavations at Tell es-Sultan. However, more than 40 years later its application in the region remains piecemeal. Given the limited potential for pollen studies in the arid zone of the southern Levant, anthracological analyses need to be undertaken much more extensively, especially on assemblages derived from late Pleistocene and early Holocene habitation sites. Anthracology is a relatively inexpensive method that can provide high-resolution, detailed reconstructions of vegetation catchments and woodland management strategies even for sites at which charred macrofossil density and preservation are less than ideal. el-Hemmeh is such a sub-optimal site. It has been suggested in the literature that high rates of charcoal fragmentation (evidenced in the case of el-Hemmeh by the general absence of charcoal particles >2 mm from the analysed samples) may result in assemblages that are not representative of the relative proportions of fuel wood taxa used in the past and thus of fuel choice and associated woodland ecologies (cf. Chrzavzez et al., 2014). However, at el-Hemmeh, both charcoal sample composition and relative taxa proportions are consistent with the broad regional pattern evidenced from other sites. This is due to the fact that the absence of >2 mm fractions was counterbalanced by the systematic sampling, sub-sampling and analysis of charcoal macrofossils from stratified archaeological deposits that represented in their majority 'dispersed contexts' (sensu Chabal et al., 1999) accumulated in the long-term. This systematic work, alongside the integration of anthracological and seed archaeobotanical datasets, produced the evidence that permitted reconstructing in unprecedented detail local PPN woodland composition, ecology and structure.

Limited as it is, the regional anthracological record suggests that early Holocene vegetation and climate (especially precipitation) were very different from their present-day and historical counterparts across the arid zone of the southern Levant. In its southern half, vegetation was dominated by *Pistacia* savanna woodlands, including along the eastern flanks of the Jordan Rift Valley a distinct component of evergreen *Quercus* following an N-S gradient from moister to more arid habitats. Along this transect, so-called Mediterranean deciduous *Quercus* woodland, *Pistacia–Amygdalus–Rhamnus–Prunus*–Maloideae moist woodland steppe and *Juniperus–Pistacia* steppe woodlands were established in moister and/or cooler localities with suitable soil substrata.

The available terrestrial pollen sequences from the Mediterranean zone suggest that mixed deciduous and evergreen oak–*Pistacia* woodlands prevailed throughout the prehistoric periods because of the higher annual rainfall values and the presence of extensive vegetation refugia in this area (cf. Van Zeist and Bottema, 2009; Van Zeist et al., 2009; Wright and Thorpe, 2003). The Mediterranean Woodland Zone probably extended to the western flanks of the Dead Sea basin and the Jordan Rift Valley, as suggested by the anthracological finds of Tell es-Sultan (Western, 1971). Further north, on the Irano-Anatolian foothills and mid-elevation slopes, Rosaceae-dominated grasslands prevailed at the onset of the Holocene, including a small but distinct component of deciduous *Quercus* (Asouti and Kabukcu, 2014). Across the hilly flanks of the northern and eastern Fertile Crescent, the post-glacial expansion and establishment of deciduous *Quercus* woodlands was not completed until mid-Holocene times. Increasing grazing of grasslands by sheep, the clearance of competing arboreal vegetation and the routine management of deciduous oaks for fuel, fodder and timber during the 9th–7th millennia cal. BC provided deciduous oaks with the competitive advantage over grasses and the Rosaceae (Asouti and Kabukcu, 2014). During this period, the arid zone of the southern Levant witnessed the dramatic expansion of *Pistacia* woodlands that dominated regional vegetation from the beginning of the Holocene through to the end of the PPN in the mid-7th millennium cal. BC, as a result of the combined impacts of climate improvement and increasing herding activities on the landscape, especially with the widespread adoption of sheep herding during the LPPNB/PPNC (Martin and Edwards, 2013). Thus, the picture emerging from the south Levantine archaeobotanical record adds an important new dimension to previous climate-focused interpretations of the early Holocene *Pistacia* expansion observed in sapropel pollen sequences from the Eastern Mediterranean (cf. Rossignol-Strick, 1999). In light of this evidence, it is also clear that previous theories about widespread anthropogenic environmental degradation in the southern Levant due to Neolithic deforestation must be revised.

Palaeoenvironmental research on integrated archaeobotanical (charcoal, seeds) assemblages is still minimally applied in Southwest Asia. This is even more the case in the southern Levant where anthracological analyses have been undertaken at very few sites. Furthermore, region-wide seed botanical studies are narrowly focused on the questions of early plant domestication and the evolution of early 'weed' floras and agroecologies. Much more sampling and analyses need to be undertaken (including the exploration of co-variation between wood charcoal and seed/fruit botanical taxa from closely controlled archaeobotanical assemblages) at multiple sites located in different bioclimatic zones, in order to map more precisely the ecological diversity and the spatial and temporal transformations of late Pleistocene and early Holocene woodland vegetation across Southwest Asia. Given the limitations of pollen analysis, particularly in arid and semi-arid environments, the wider application of anthracology is paramount for generating high-resolution reconstructions of the palaeoecology and environmental history of Southwest Asian terrestrial biomes at this critical threshold in the prehistory of the region. A better understanding of the evolution and regional differentiation of Southwest Asian woodland ecologies is required in order to reconstruct the complexity and directionality of the ecological footprint of the diverse foraging and farming resource management strategies that framed the Neolithic transition.

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References

Al-Eisawi D (1996) *Vegetation of Jordan*. Cairo: UNESCO Regional Office for Science and Technology for the Arab States.

Arbuckle BL and Atici L (2013) Initial diversity on sheep and goat management in Neolithic south-western Asia. *Levant* 45(2): 219–235.

Arranz A (2011) Analysis of archaeological plant macroremains from Tell Qarassa North (Syria). An example of early agriculture and woodland use in the Near East. *Quaternary Studies* 1: 3–17.

Asouti E (2005) Woodland vegetation and the exploitation of fuel and timber at Neolithic Çatalhöyük: Report on the wood-charcoal macro-remains. In: Hodder I (ed.) *Inhabiting Çatalhöyük: Reports from the 1995–99 Seasons*. Cambridge: McDonald Institute for Archaeological Research, pp. 213–258.

Asouti E (2013) Woodland vegetation, firewood management and woodcrafts at Neolithic Çatalhöyük. In: Hodder I (ed.) *Humans and Landscapes of Çatalhöyük: Reports from the 2000-2008 Seasons*. Los Angeles, CA: Cotsen Institute of Archaeology, pp. 129–162.

Asouti E and Austin P (2005) Reconstructing woodland vegetation and its exploitation by past societies, based on the analysis and interpretation of archaeological wood charcoal macroremains. *Environmental Archaeology* 10: 1–18.

Asouti E and Fuller DQ (2012) From foraging to farming in the southern Levant: The development of Epipalaeolithic and Pre-pottery Neolithic plant management strategies. *Vegetation History and Archaeobotany* 21: 149–162.

Asouti E and Fuller DQ (2013) A contextual approach to the emergence of agriculture in Southwest Asia. Reconstructing early Neolithic plant-food production. *Current Anthropology* 54(3): 299–345.

Asouti E and Hather J (2001) Charcoal analysis and the reconstruction of ancient woodland vegetation in the Konya basin, south-central Anatolia, Turkey: Results from the Neolithic site of Çatalhöyük East. *Vegetation History and Archaeobotany* 10: 23–32.

Asouti E and Kabukcu C (2014) Holocene semi-arid oak woodlands in the Irano-Anatolian region of Southwest Asia: Natural or anthropogenic? *Quaternary Science Reviews* 90: 158–182.

Asouti E and Kabukcu C (in press) Palaeoecology and plant use at Kharaneh IV and Ayn Qasiyyah: The wood charcoal. In: Maher LA and Richter T (eds) *At the Oasis: A Palaeolandscape Perspective on the Prehistory of the Azraq Basin, Jordan. Volume I: Epipalaeolithic Foragers in Azraq Project 2008-2014*. Oxford: CBRL Monographs.

Austin P (2007) The wood charcoal macroremains. In: Finlayson B and Mithen S (eds) *The Early Prehistory of Wadi Faynan, Southern Jordan* (Levant Supplementary Series 4). Oxford: Oxbow, pp. 408–419.

Baruch U and Goring-Morris AN (1997) The arboreal vegetation of the central Negev highlands, Israel, at the end of the Pleistocene: Evidence from archaeological charred wood remains. *Vegetation History and Archaeobotany* 6(4): 249–259.

Baruch U, Werker E and Bar-Yosef O (1992) Charred wood remains from Kebara cave, Israel; preliminary results. *Bulletin de la Société Botanique de France, Actualités Botaniques* 139: 531–538.

Black S, Robinson SA, Fitton R et al. (2011) Palaeoenvironmental and limnological reconstruction of Lake Lisan and the Dead Sea. In: Mithen S and Black E (eds) *Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley*. Cambridge: Cambridge University Press, pp. 113–127.

Bottema S (1991) Développement de la végétation et du climat dans le bassin Méditerranéen oriental à la fin du Pléistocène et pendant l'Holocène. *L'Anthropologie* 95: 695–728.

Bottema S and Van Zeist W (1981) Palynological evidence for the climatic history of the Near East 50.000–6.000 BP. In: Cauvin J and Sanlaville P (eds) *Préhistoire du Levant*. Paris: CNRS, pp. 111–132.

Campbell D (2010) Modelling the agricultural impacts of the earliest large villages at the pre-Pottery Neolithic–Pottery Neolithic transition. In: Finlayson B and Warren G (eds) *Landscapes in Transition*. Oxford: Oxbow, pp. 173–183.

Chabal L, Fabre L, Terral J-F et al. (1999) L'anthracologie. In: Bourquin-Mignot C, Brochier J-E, Chabal L et al. (eds) *La botanique*. Paris: Errance, pp. 43–104.

Chrzavzez J, Théry-Parisot I, Fiorucci G et al. (2014) Impact of post-depositional processes on charcoal fragmentation and archaeobotanical implications: Experimental approach combining charcoal analysis and biomechanics. *Journal of Archaeological Science* 44: 30–42.

Colledge S (2001) *Plant Exploitation on Epipalaeolithic and Early Neolithic Sites in the Levant* (BAR, International Series 986). Oxford: Archaeopress.

Colledge S, Finlayson B and Kuijt I (2008) Dhra' summary: 2008. *CBRL Bulletin* 2008: 61–63.

Danin A (1995) Man and the natural environment. In: Levy TE (ed.) *The Archaeology of Society in the Holy Land*. London: Leicester University Press, pp. 24–37.

Deckers K and Conard NJ (2011) Vegetation and wood-use from the Pleistocene to the Holocene in the foothills of the eastern Anti-Lebanon. In: Deckers K (ed.) *Holocene Landscapes through Time in the Fertile Crescent*, Subartu 28. Turnhout: Brepols, pp. 1–15.

Denham TP (2007) Early fig domestication, or gathering of wild parthenocarpic figs? *Antiquity* 81: 457–461.

Díaz S, Lavorel S, McIntyre S et al. (2007) Plant traits responses to grazing: A global synthesis. *Global Change Biology* 13: 313–341.

Edwards PC, Meadows J, Sayej G et al. (2004) From the PPNA to the PPNB: New views from the southern Levant after excavations at Zahrat adh-Dhra' 2 in Jordan. *Paléorient* 30(2): 21–60.

Emery-Barbier A (1995) Pollen analysis: Environmental and climatic implications. In: Henry DO (ed.) *Prehistoric Cultural Ecology and Evolution: Insights from Southern Jordan*. New York: Plenum Press, pp. 375–384.

Emery-Barbier A and Thiébault S (2005) Preliminary conclusions on the Late Glacial vegetation in south-west Anatolia (Turkey): The complementary nature of palynological and anthracological approaches. *Journal of Archaeological Science* 32(8): 1232–1251.

Ghassali F, Osman AE and Cocks PS (1998) Rehabilitation of degraded grasslands in north Syria. The use of awassi sheep to disperse the seeds of annual pasture legumes. *Experimental Agriculture* 34: 391–405.

Goren-Inbar N, Werker E and Feibel CS (2002) *The Acheulian Site of Gesher Benot Ya'aqov: The Wood Assemblage*. Oxford: Oxbow.

Haslam SM (2003) *Understanding Wetlands*. London: Taylor & Francis.

Hillman GC (2000) The potential vegetation under modern climatic conditions. In: Moore AMT, Hillman GC and Legge AJ (eds) *Village on the Euphrates: From Foraging to Farming at Abu Hureyra*. Oxford: Oxford University Press, pp. 49–72.

Hopf M (1983) Appendix B: Jericho plant remains. In: Kenyon KM and Holland TA (eds) *Excavations at Jericho, volume 5: The Pottery Phases of the Tell and Other Finds*. London: British School of Archaeology in Jerusalem, pp. 576–621.

Hunt CO, Elrishi HA, Gilbertson DD et al. (2004) Early Holocene environments in the Wadi Faynan, Jordan. *The Holocene* 14: 921–930.

Kabukcu C (2015) *Prehistoric vegetation change and woodland management in central Anatolia: Late Pleistocene-mid Holocene anthracological remains from the Konya Plain*. Unpublished PhD Thesis, University of Liverpool.

Kabukcu C and Asouti E (in press) The anthracological remains from Boncuklu höyük, a 9th millennium cal BC site in the Konya Plain of south-central Anatolia, Turkey. In: Baird D (ed.) *From Foragers to Farmers in Central Anatolia: Excavations at Boncuklu, volume 1*. London: British Institute at Ankara.

Kennedy A (2007) The plant macrofossils. In: Finlayson B and Mithen S (eds) *The Early Prehistory of Wadi Faynan, Southern Jordan* (Levant Supplementary Series 4). Oxford: Oxbow, pp. 420–428.

Kislev ME (1997) Early agriculture and palaeoecology of Netiv Hagdud. In: Bar-Yosef O and Gopher A (eds) *An Early Neolithic Village in the Jordan Valley*. Cambridge, MA: Peabody Museum of Archaeology and Ethnology, Harvard University, pp. 209–236.

Kislev ME, Hartmann A and Bar-Yosef O (2006) Early domesticated fig in the Jordan valley. *Science* 312: 1372–1374.

Köhler-Rollefson I and Rollefson G (1990) The impact of Neolithic subsistence strategies on the environment: The case of 'Ain Ghazal, Jordan. In: Bottema S, Entjes-Nieborg G and Van Zeist W (eds) *Man's Role in the Shaping of the Eastern Mediterranean Landscape*. Rotterdam: Balkema, pp. 3–14.

Kürschner H (1986) *Contributions to the Vegetation of Southwest Asia* (Beihefte zum Tübinger Atlas des Vorderen Orients, Reihe A (Naturwissenschaften), Nr. 24). Wiesbaden: Dr Ludwig Reichert Verlag.

Lev-Yadun S and Weinstein-Evron M (1994) Late Epipalaeolithic wood remains from el-Wad Cave, Mount Carmel, Israel. *New Phytologist* 127: 391–396.

Litt T, Ohlwein C, Neumann FH et al. (2012) Holocene climate variability in the Levant from the Dead Sea pollen record. *Quaternary Science Reviews* 49: 95–105.

Makarewicz C, Goodale N, Rassmann P et al. (2006) el-Hemmeh: A multi-period pre-Pottery Neolithic site in the Wadi al-Hasa, Jordan. *Eurasian Prehistory* 4: 183–220.

Martin LA and Edwards Y (2013) Diverse strategies: Evaluating the appearance and spread of domestic livestock in the southern Levant. In: Dobney K, Shennan S, Colledge S et al. (eds) *The Origins and Spread of Stock-Keeping*. London: Left Coast, pp. 49–82.

Martinoli DC (2005) *Plant food economy and environment during the Epipalaeolithic in southwest Anatolia: An investigation of the botanical macroremains from Öküzini and Karain B*. PhD Thesis, University of Basel. Available at: http://edoc.unibas.ch/272/1/DissB_7223.pdf.

Mithen SJ, Austin P, Kennedy A et al. (2007) Neolithic woodland composition and exploitation in the Southern Levant: a comparison between archaeobotanical remains from WF16 and present day woodland at Hammam Adethni. *Environmental Archaeology* 12: 49–70.

Neef R (2004a) PPNB settlements: Vegetation and climate. A comparison between PPNB 'Ain Ghazal and Basta. In: Bienert HD, Gebel HGK and Neef R (eds) *Central Settlements in Neolithic Jordan*. Berlin: ex Oriente, pp. 289–299.

Neef R (2004b) Vegetation and plant husbandry. In: Nissen HJ, Muheisen M and Gebel HGK (eds) *Basta I: The Human Ecology*. Berlin: ex Oriente, pp. 187–218.

Noy-Meir I, Gutman M and Kaplan Y (1989) Responses of Mediterranean grassland plants to grazing and protection. *Journal of Ecology* 77: 290–310.

Orland IJ, Bar-Matthews M, Ayalon A et al. (2012) Seasonal resolution of Eastern Mediterranean climate change since 34 ka from a Soreq Cave speleothem. *Geochimica et Cosmochimica Acta* 89: 240–255.

Rambeau MC (2010) Palaeoenvironmental reconstruction in the southern Levant: Synthesis, challenges, recent developments and perspectives. *Philosophical Transactions of the Royal Society A* 368: 5225–5248.

Rambeau MC, Finlayson B, Smith S et al. (2011) Palaeoenvironmental reconstruction at Beidha, southern Jordan (ca. 18,000-8,500 BP): Implications for human occupation during the Natufian and Pre-pottery Neolithic. In: Mithen S and Black E (eds) *Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley*. Cambridge: Cambridge University Press, pp. 45–268.

Riehl S, Benz M, Conard NJ et al. (2012) Plant use in three pre-Pottery Neolithic sites of the northern and eastern

Fertile Crescent: A preliminary report. *Vegetation History and Archaeobotany* 21: 95–106.

Roberts N, Reed J, Leng MJ et al. (2001) The tempo of Holocene climatic change in the eastern Mediterranean region: new high-resolution crater-lake sediment data from central Turkey. *The Holocene* 11: 719–734.

Robinson S, Black S, Sellwood B et al. (2011) A review of palaeoclimates and palaeoenvironments in the Levant and Eastern Mediterranean from 25,000 to 5000 years BP: Setting the environmental background for the evolution of human civilisation. In: Mithen S and Black E (eds) *Water, Life and Civilisation: Climate, Environment and Society in the Jordan Valley*. Cambridge: Cambridge University Press, pp. 71–93.

Roitel V and Willcox G (2000) Analysis of charcoal from Abu Hureyra. In: AMT, Hillman GC and Legge AJ (eds) *Village on the Euphrates: From Foraging to Farming at Abu Hureyra*. Oxford: Oxford University Press, pp. 544–547.

Rosen AM (2007) *Civilizing Climate: Social Responses to Climate Change in the Ancient Near East*. Lanham, MD: Altamira Press.

Rossignol-Strick M (1999) The Holocene climatic optimum and pollen records of sapropel 1 in the eastern Mediterranean, 9000–6000 BP. *Quaternary Science Reviews* 18(4–5): 515–530.

Schiebel V (2013) *Vegetation and climate history of the southern Levant during the last 30,000 years based on palynological investigation*. PhD Thesis, Mathematisch-Naturwissenschaftlichen Fakultät, Rheinischen Friedrich-Wilhelms-Universität. Available at: http://hss.ulb.uni-bonn.de/2013/3270/3270.htm.

Soto-Berelov M, Fall PL and Falconer SE (2012) A revised map of plant geographical regions of the Southern Levant. In: *Proceedings of the Geospatial Science Research Symposium GSR2*, Melbourne, December. Available at: http://www.academia.edu/2519552/A_revised_map_of_plant_geographical_regions_of_the_Southern_Levant.

Turner R, Roberts N, Eastwood WJ et al. (2010) Fire, climate and the origins of agriculture: Micro-charcoal records of biomass burning during the last glacial – Interglacial transition in Southwest Asia. *Journal of Quaternary Science* 25: 371–386.

Van Zeist W and Bakker-Heeres JH (1985) Archaeobotanical studies in the Levant 1. Neolithic sites in the Damascus Basin: Aswad, Ghoraifé, Ramad. *Palaeohistoria* 24: 165–256.

Van Zeist W and Bottema S (2009) A palynological study of the Acheulian site of Gesher Benot Ya'aqov, Israel. *Vegetation History and Archaeobotany* 18: 105–121.

Van Zeist W, Baruch U and Bottema S (2009) Holocene palaeoecology of the Hula area, northeastern Israel. In: Kaptijn W and Lucas P (eds) *A Timeless Vale. Archaeological and Related Essays on the Jordan Valley in Honor of Gerrit van der Kooij on the Occasion of His 65th Birthday. Archaeological Studies Leiden University volume 19*. Leiden: Leiden University Press, pp. 29–64.

Western AC (1971) The ecological interpretation of ancient charcoals from Jericho. *Levant* 3: 31–40.

Western AC (1983) Appendix F. Catalogue of identified charcoal samples. In: Kenyon K and Holland TA (eds) *Excavation at Jericho. Volume 5: The Pottery Phases of the Tell and Other Finds*. London: British School of Archaeology in Jerusalem, pp. 770–773.

White CE (2013) *The emergence and intensification of cultivation practices at the Pre-pottery Neolithic site of el-Hemmeh, Jordan: An archaeobotanical study*. PhD Thesis, Boston University (ProQuest publication no. 3529031).

Willcox G (1992) Timber and trees: Ancient exploitation in the Middle East: Evidence from the plant remains. *Bulletin of Sumerian Agriculture* 6: 1–31.

Willcox G (1999) Charcoal analysis and Holocene vegetation history in southern Syria. *Quaternary Science Reviews* 18: 711–716.

Wright HE Jr and Thorpe J (2003) Climatic change and the origin of agriculture in the Near East. In: Mackay AW, Battarbee RW, Birks HJ et al. (eds) *Global Change in the Holocene*. London: Hodder Arnold, pp. 49–62.

Zeder MA (2008) Animal domestication in the Zagros: An update and directions for future research. In: Villa E, Gourichon L, Choyke A and Buitenhuis H (eds) *Archaeozoology in the Near East VIII*. Lyon: Archéorient, Maison de l'Orient et de la Méditerranée, pp. 243–277.

Zeder MA (2009) The Neolithic macro-(R) evolution: Macroevolutionary theory and the study of culture change. *Journal of Anthropological Archaeology* 17: 1–63.

Zohary M (1962) *Plant Life of Palestine, Israel and Jordan*. New York: Ronald.

Zohary M (1973) *Geobotanical Foundations of the Middle East*. Stuttgart: Gustav Fischer Verlag.