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Woodland modification in Bronze and Iron Age central Anatolia: An anthracological signature for the Hittite state?

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Abstract

The Bronze and Iron Ages of central Anatolia encompass a period of significant social and political change. In contrast to the well-documented changes in the social landscape, the environmental landscape for the region at this time is poorly understood. The limited temporal and spatial coverage from environmental records means it is difficult to understand the finer details of environmental change, especially in relation to the archaeology of specific sites. This paper offers a complete and continuous diachronic wood charcoal assemblage for the Middle Bronze Age to Late Iron Age from Kaman-Kalehöyük in central Anatolia. Results show a significant decline in taxa richness from the Middle Bronze Age to the Late Iron Age, particularly during the Hittite Empire period. The decline in richness is followed by a dramatic increase in pine use from the beginning of the Iron Age. The timing and exploitation of key taxa in Kaman-Kalehöyük assemblage do not match that indicated in the regional pollen data but rather show a clear local signature chronologically matched to the Hittite Empire.

Keywords: Wood charcoal; Kaman-Kalehöyük; Turkey; woodland modification; Bronze Age; Iron Age; deforestation

1.0 Introduction

The central Anatolian plateau was a key region of cultural development throughout prehistory, yet its detailed environmental history is relatively poorly understood compared to adjacent regions, especially during the Bronze Age (BA) (~3,000 – 1,200 BC) and Iron Age (IA) (~1200 - 300 BC) (Dörfler, et al., 2011). Today, the barely forested central Anatolian landscape exhibits many characteristics of an anthropogenically modified landscape produced by millennia of agricultural and pastoral use (Asouti and Kabukcu, 2014, Marsh and Kealhofer, 2014). Much of the region is agricultural land dominated by crops and pastures, the latter supporting large livestock herds which have acted in concert with cultivation to produce a landscape of open treeless steppe with few observable pockets of woodland cover (Condé, et al., 2002).

In contrast to the current landscape, regional pollen records indicate the establishment of open deciduous oak (*Quercus* spp.) woodland early in the Holocene across much of southwest Asia, including central Anatolia, until the mid-Holocene (Roberts, et al., 2011b). Oak cover in central Anatolia reached its maximum ~ 3,000 – 5,000 BC, after which it declined drastically (Roberts, et al., 2011b, Woldring and Cappers, 2001) matching the general pattern established in Syria, Iran and Georgia (Roberts, 2002).

While palynological research has outlined the broad vegetation history of central Anatolia, the BA and IA remain poorly understood particularly in regards to the role of humans in modifying the landscape. Current knowledge relies largely on widely spaced pollen cores and climate data (Allcock, 2013, Roberts, et al., 2001, Wick, et al., 2003, Woldring and Bottema, 2002) supplemented by rare anthracological (wood charcoal analysis) studies (Asouti, 2013, Asouti and Kabukcu, 2014, Marston, 2009, Miller, 2010).

As demonstrated in published cases from the broader region, anthracology is a powerful tool by which localised changes in ancient tree cover may be understood and disentangled (Asouti and Austin, 2005, Miller, 1985, Willcox, 2002). However, when analysing the BA and IA, anthracology's potential has not been widely utilised in central Anatolia despite this period being one in which population, settlement, and landscape were undergoing significant and interconnected phases of change (Allcock and Roberts, 2014, Rosen, 2007).

This paper details the anthracological investigation of BA and IA settlement at Kaman-Kalehöyük, located in the heart of the central Anatolian highlands. A continuous occupation sequence from the Late Early Bronze Age (EBIII) until the Late Iron Age (LIA) (c. 300 BC) allows the exploration of woodland history during several significant cultural and environmental phenomena, including the local impact of purported major deforestation sequences described elsewhere (Djamali, et al., 2008, Eastwood, et al., 1998, England, et al., 2008, Vermoere, et al., 2000). The period under study also includes a major 3.2-3.0 ka BP (c. 1,250 – c. 1,050 BC) drought event (Allcock, 2013, Mayewski, et al., 2004) which corresponded with the sudden collapse of the Hittite state in central Anatolia (Weiss, 1982). This major socio-political event, which saw a region superpower disappear from history for several millennia, was part of a sequence of political centralisation from the EBIII and was followed by a period of societal fragmentation - the so-called Anatolian "Dark Age" - after which centralised political authority re-emerged into the Classical Period (Bryce, 2005a). Given this context, the analysis aims to determine whether the patterns of woodland change at Kaman-Kalehöyük match that seen elsewhere in the eastern Mediterranean and evaluate the extent to which they were caused by the onset and impacts of anthropogenic woodland modification or patterns of climatic change.

2.0 Materials and Methods

2.1 The site and its cultural context

Located in Kırşehir Province 110 km southeast of the Turkish capital, Ankara, Kaman-Kalehöyük (39°21’ 46” N, 33°47’ 12” E at 1, 070m ASL) is positioned near the centre of the central Anatolian highlands (Fig. 1) (Ishimaru and Kashima, 2000, Sayhan, 2000). The site is approximately 30km from the Kızılırmak River, and is situated in an area dominated by an agricultural economy and surrounded by abundant natural resources, including rich agricultural soils, mountains containing a variety of geological resources and several watercourses, including Aktan Dere.

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Kaman-Kalehöyük is an 18m high artificial settlement mound approximately 280m in diameter. Excavated since 1986, the settlement is thought to have begun in the Neolithic or Chalcolithic, Kaman-Kalehöyük's excavated deposits have been grouped into five strata, each separated into a number of sub-phases and occupation levels corresponding to the regional cultural sequence which are abbreviated according to Yakar (2011) and can be found in Table 1 (see Omura, 2011). These show a largely continuous occupation spanning from at least EBIII to the LIA and Hellenistic Period, with a hiatus prior to reoccupation in the Medieval and Post-Medieval Periods.

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Kaman-Kalehöyük preserves a complex settlement sequence dominated throughout by domestic-scale architecture consisting of mudbrick buildings with stone foundation walls, cut through by numerous pits (Omura, 2011). Analysis has demonstrated that many pits were originally used for agricultural storage, being filled with rubbish once their primary use had ended (Fairbairn and Omura, 2005). Agriculture was a major focus for the site's economy throughout its occupation, with abundant evidence for crop and animal production, alongside small-scale domestic industries such as cloth and pottery production, the latter using raw materials derived from local sources (Bong, et al., 2008, 2010, Kealhofer, et al., 2008). Material culture largely reflected domestic activities, with relatively few exotic and ostentatious finds, though gold items, seals, and a cuneiform tablet have been rarely recovered. Several occupation phases show evidence of some form of large-scale architecture, most clearly in the Hittite period when a central masonry building and associated grain silos indicate centralised control of grain supply (Fairbairn and Omura, 2005). Large buildings in the Middle Iron Age (MIA) and LIA, including a megaron-like structure, and large crop storages also suggest some form of political centralisation during that period (Omura, 2011). Importantly, occupation at Kaman-Kalehöyük appears to have continued during the Late Bronze Age (LBA) to Early Iron Age (EIA) transition, which marks a major rupture it Anatolian settlement patterns (Allcock and Roberts, 2014) when the Hittite state collapsed as part of a phase of regional scale socio-political change (Bryce, 2005b, Drews, 1993).

2.2 Environmental setting

Situated in the temperate semi-arid steppe of the central Anatolian highlands, Kaman-Kalehöyük has a climate characterised by summer droughts and winter rains/snow with temperatures varying between -25℃ and 40℃ (Ertuğ-Yaras, 1997, MGM, 2014, Roberts, 1995, Ünal, et al., 2003). At c. 380mm, the modern average rainfall for the region (Fig. 1) is above the minimum required for reliable arable farming (MGM, 2014), which continues to be important in the local economy. For the study period, lake isotope records indicate a drying climate from ~4,500 BC after a wet early Holocene with two drought events from 2,200-2,000 BC and 1,200-1,000 BC respectively (Mayewski, et al., 2004, Roberts, et al., 2011a, Weninger, et al., 2009) .

Central Anatolia is currently dominated by open agricultural habitats, steppe grassland, and while it supports steppe-forest elements of both Xero-Euxinian and Irano-Turanian types these only make up ~4% of the landscape (Condé, et al., 2002, Zohary, 1973). Although steppe-forest contains many taxa it is characterised by dominant associations of deciduous oak (*Quercus* spp.), juniper (*Juniperus* spp.), terebinth (*Pistacia* spp.), and hawthorn (*Crataegus* spp.), mixed with small herbs and shrubs, including spiny members of the legume family (Fabaceae/Leguminosae) (Zohary, 1973). On mountain slopes (above 1,100m), sparse forests of pine (*Pinus* spp.) can be observed, while willow/poplar (*Salix*/*Populus*), ash (*Fraxinus* sp.) and elm (*Ulmus* sp.) dominate riparian locations such as streams and lakes (Condé, et al., 2002, Davis, 1965-1985, Zohary, 1973).

Turkey oak (*Q. cerris*) is commonly found in less disturbed woodlands, the closest to the site being 45km to the northeast in a protected and well drained valley, while pubescent oak (*Q. pubescens*) occurs in open oak woodland of which the closest is 30km to the northeast (Akdeniz, et al., 2004, Akman, 1995, Kargıoğlu, et al., 2008). Pine and juniper occur in a modern planted forest near Bala some 60km to the northwest. Baran Dağ to the south of the site has some planted members of the Rosaceae family present on its higher slopes; however, this area remains subject to grazing and is consequently sparsely treed. Planted riparian taxa can be found along the course of Aktan Dere and other more substantial waterways within 5km of the site.

Pollen data show the gradual establishment (peaking ~5,000 BC to 3,000 BC) of open oak woodland in the high plateau of central Anatolia, matching the taxonomic composition of the small pockets of indigenous woodland visible today (Asouti and Kabukcu, 2014, Issar and Zohar, 2007, Riehl, 2009). Pine, cedar (*Cedrus libani*), terebinth, and juniper (*Juniperus exelsa*) also established themselves in their appropriate ecological zones (Cordova, 2007, Davis, et al., 1988, Djamali, et al., 2009b). From 3,000 BC onwards, pollen records generally show a decline in oak in Anatolia and the Near East (Connor, et al., 2004, Roberts, 2002). This decline not only matches increasing aridity in the region but also matches the shift to highly urbanised, politically centralised, and agriculture dependent societies in the Anatolian region (Allcock and Roberts, 2014, Arıkan, 2014, Riehl, et al., 2008, Roberts and Rosen, 2009). This pattern is evident in other parts of southwest Asia and Mediterranean regions where archaeobotanical investigations demonstrate dramatic human impacts to the landscape, resulting in a substantial loss of woodland cover (Klinge and Fall, 2010, Longford, et al., 2009, Miller, 1985, Miller, 1988, Willcox, 1974).

2.3 Sampling

Following standard anthracological methods, this analysis aimed to evaluate which tree species were utilised during each occupation phase at Kaman-Kalehöyük as a means of evaluating changes in available wood resources and thus tree cover. Samples were selected from a series of rubbish deposits recovered from re-used agricultural storage pits found commonly in the settlement sequence. Previous anthracological research has clearly indicated that pit assemblages contain a diverse range of wood charcoals derived from a variety of human actions and are suitable for evaluating general patterns of wood use through time (Asouti and Austin, 2005, Thery-Parisot, et al., 2010, Thiébault, 2002). In this case, pits were selected for analysis that were clearly defined and not subject to reworking, thus representing sealed depositional contexts. A total of 54 pit contexts from six occupation phases from the Middle Bronze Age (MBA) to LIA were analysed (Table 1). Samples from well-sealed pits from the EBIII and transitional strata at Kaman-Kalehöyük (IVa and IVb) were not available for analysis. Ten samples from the other major strata were included with the exception of Hittite Empire Period (Stratum IIIa), for which only 4 were available.

All samples were subject to a standard archaeobotanical recovery technique, being recovered using an Ankara-type flotation tank fitted with a <0.25mm flotation mesh and a 1mm base mesh (Nesbitt, 1995). After Keepax (1988) a sub-sample of a minimum 100 fragments from the >2mm sample fraction of each sample was identified. To explore sample variability and adequacy of sample size, 11 samples that had 200 fragments were examined as well as six samples that had 1,000 fragments (see rarefaction analysis below). Sub-sampling was undertaken using a riffle box/geological sample splitter (van der Veen and Fieller, 1982).

2.4 Identification

All fragments were manually broken to expose fresh transverse, tangential and radial sections. For taxonomic identification, fragments were observed under a reflected light microscope (Olympus BX60, SZX16, and ZX61) at magnifications up to 1,000x. A JOEL NeoScope JCM5000 desktop scanning electron microscope (SEM) was used for high quality image capture.

Taxonomic identification was achieved using a reference collection of the dominant taxa of Turkey housed at The University of Queensland, Australia in conjunction with standard identification keys of European and South West Asian woodland taxa (Hather, 2000, Heiss, 2009, Schoch, et al., 2004, Schweingruber, 1990, Schweingruber, et al., 2006). The identified taxa were also grouped into appropriate analytical groups according to habitat preference based on the ecological literature (see Table 3 caption).

2.5 Quantification and statistical analysis

Identified taxa were quantified using ubiquity, absolute abundance and percentage abundance, all considered to be good proxies for the relative abundance of utilised taxa (Asouti and Austin, 2005, Smart and Hoffman, 1988). Weight data were not used to quantify the Kaman-Kalehöyük wood charcoal assemblage as a pilot study (Wright, 2010) showed that weight data tracked count data (Asouti and Austin, 2005, Deckers and Pessin, 2010, cf. Nelle, et al., 2010).

Correspondence analysis (CA) was conducted on the charcoal abundance data to examine the association between plant taxa across stratigraphic units (Smith and Munro, 2009). CA was used to identify major changes in taxonomic composition in the assemblages through time; these changes were then subject to additional statistical testing. Significant temporal trends in species abundance were identified using a chi-square test for linear trend (Lyman, 2008).

Rarefaction analysis was used to compare taxonomic richness (total number of non-overlapping taxa within each phase) across samples of different sizes (100, 200, and 1,000 fragments) using the Paleontological Statistics (PAST) software package (Hammer, et al., 2001). Rarefaction analysis was conducted to ensure any patterns detected in the data were not a result of different sampling efforts (Bush, et al., 2004, Koellner, et al., 2004), that is different sample size, between archaeological contexts and periods. Temporal trends in taxonomic richness – with values rarefied down to comparable sample sizes – were assessed using Spearman's rank order correlation coefficient.

3.0 Results

11,900 fragments were analysed, of which 95% were identified to one of 18 taxa (Table 2). All unidentifiable fragments contained insufficient diagnostic characteristics for identification or were poorly preserved. The number of unidentifiable fragments per sample remained consistent across analysed phases, with little variation observed. Following Asouti (2003), percentage abundance counts were calculated excluding the unidentifiable fragments.

3.1 Identified taxa

Of the 11,345 fragments identified, deciduous oak was the dominant taxon, and appeared in all contexts and occupation phases (Table 2). Despite not appearing in all contexts, pine is the next most abundant taxon in the wood charcoal assemblage followed by willow/poplar. Besides deciduous oak, only members of the Salicaceae (willow/poplar) family appear in all contexts (see Table 2). The remaining taxa do not make any significant contribution to the wood charcoal assemblage, with no single taxon exceeding more than 6% of the assemblage in any phase (Table 2).

Six taxa (oak, pine, willow/poplar, Rose Family Indet. and Maloideae) appear in all phases, while three (holly, olive and fig) taxa only appear in Iron Age samples (Table 2). In contrast, only plum and reed only occur in BA phases. Several specimens belonging to the Rosaceae family could be identified (e.g., sub-family Maloideae and the genus Prunus), whereas the majority could only be identified to family level who's potential candidates in this category include Amygdalus, although it is rare in close vicinity to the site today. The LBA contains the least number of taxa (n=7) while the MBA I-III and LIA phases contain the most taxa (n=16). Using the site totals from Table 2, we observe that ubiquity is very tightly correlated with absolute fragment counts (log-transformed) (r = 0.92, p <0.001). It follows that – as in the case of fragment weights – ubiquity generally tracks count data. We therefore focus our analyses on the count data.

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3.2 Plant communities

Five distinct analytical groups were represented in the wood charcoal assemblage based on habitat preferences and structure (Table 3). Two taxa, oak and pine, are kept separate from other taxa as they dominate, with a tendency to be mono-specific in their respective vegetation communities in the region (Kaya and Raynal, 2001, Woldring and Cappers, 2001). The bulk of other species are found in the fringes or woodland transition zones (Davis, et al., 1988, Djamali, et al., 2009b).

The riparian vegetation community contains hydrophilic taxa, including, willow/poplar, elm, reed, tamarisk and ash. All remaining taxa, including the Rose Family Indet., can represent open vegetation elements commonly occurring on the periphery of woodland zones and in the woodland understory (Asouti, 2003, Asouti and Kabukcu, 2014, Riehl and Marinova, 2008). These taxa are referred to as minor taxa with the exception of olive, fig and holly, which are grouped separately as exotic (Table 3). Juniper and maple are included in the minor taxa group and appear as isolated large trees. Both can be occasionally found in open oak woodland, pine forests, or mixed forest, although rarely together (Asouti, 2003, Condé, et al., 2002, Kaya and Raynal, 2001). Fig and olive are native to the Mediterranean region and probably indicate trade species. Although both are capable of growing in central Anatolia, neither is a part of the native flora of central Anatolia with the cold winters precluding them from being indigenous taxa in the region. Both genera prefer the warmer coastal conditions of the Mediterranean region and extreme winters are known to harm mature trees (Davis, 1965-1985, Davis, et al., 1988). Holly is considered a Euxine element and most probably originated from the Black Sea region where it is found today (Davis, 1965-1985, Davis, et al., 1988) and, with fig and olive, probably represent traded items.

"INSERT TABLE 3 AND CAPTION HERE"

3.3 Assemblage analysis

Correspondence analysis of taxonomic abundance was used to explore the temporal variability in the taxonomic composition of the wood charcoal assemblage. Fig. 2 plots CA axes 1 and 2, which account for 55.3% and 14.6% of the variance in taxonomic abundance, respectively. Contexts within phases group together and are therefore more similar to each other than to contexts in other phases. Aside from the LIA samples, which are characterised by greater variability than other phases, the phases are aligned in near-perfect temporal order along axis 1, which documents the transition from taxa-rich contexts in the MBA I-III to taxa-poor assemblages with abundant pine in the IA. There is a clear separation of BA and IA samples on axis 1, with all BA samples having a positive loading while all IA samples have negative loading (Fig. 2). CA axis 2 is positively loaded by taxa that do not occur in all contexts such as olive, fig, and ash, among others, while being negatively loaded by oak and willow/poplar which do occur in all contexts (see ubiquity in Table 2).

"INSERT FIG. 2 AND CAPTION HERE" 2 COLUMN FITTING COLOUR ON WEB

The diachronic ordering of samples in the CA was further analysed in Fig. 3 using the analytical taxonomic groupings detailed in Table 3, with the differences in the abundance of the three dominant taxa (oak, pine and willow/poplar) being readily apparent. Oak is clearly dominant across all occupation phases while pine shows a marked increase from the oldest to the youngest phase and willow/poplar the opposite, matching their position on CA axis 1. The remaining taxa show a similar pattern of diachronic decline, with the exception of the Rose family which displays a similar pattern to oak. The most obvious shift in abundance occurs in pine, which is very rare in the BA (Kaman-Kalehöyük stratum IIIc to IIIa) but becomes the second most dominant taxon in the IA (Kaman-Kalehöyük stratum IId-IIa), almost equalling the abundance of oak.

Oak is the dominant taxon across all phases peaking at 78.71% in the Hittite Empire period (IIIa). A chi-square test for linear trend, conducted on a 2 by 6 contingency table (oak versus non-oak across all six phases), shows that the increase in oak from the MBA I-III to the LBA and its subsequent decline to the LIA are significant (χ^2_{trend} = 117.455, $p < 0.001$ and χ^2_{trend} = 151.132, $p < 0.001$ respectively). Pine peaks in the MIA and all other vegetation groups decline steadily from BA to IA. This shift towards pine parallels that observed in the correspondence analysis (Fig. 2). A chi-square test for linear trend (2 x 6 contingency table) shows that the increase in pine relative to all other taxa is highly significant (χ^2_{trend} = 1,892.979, $p < 0.001$). Highly significant results are also observed for the decline in riparian taxa (χ^2_{trend} = 455.421, $p < 0.001$) and minor taxa (χ^2_{trend} = 313.253, $p < 0.001$).

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3.4 Taxonomic richness

Samples from the MBA I-III and LIA show the highest taxonomic richness, with 15 out of 18 taxa present, while LBA samples only have seven out of 18 taxa (see Table 2). Despite there being a similar number of taxa in both the MBA I-III and the LIA, the two phases have a dissimilar range of taxa (see Table 2 and Fig. 4). EIA and IA samples show decreased taxonomic richness, but not to the extent of the Hittite Empire. The MBA IV (Old Hittite Kingdom) period contains 15 of the 18 identified taxa; however, its samples generally show reduced taxonomic ubiquity compared to the MBA I-III (Table 2).

Table 2 and Fig. 1 indicate a decline in taxa richness in the samples from the LBA but do not take into account different sampling effort between contexts. To determine whether the decline in taxa richness is a real trend and not a product of sample size bias, samples of greater than 100 fragments were rarefied to 92 specimens and the taxa richness was compared (Fig. 4). Rarefaction analysis was conducted on 17 samples and is illustrated in Fig. 4 (see also Supplementary Table 1 and Supplementary Fig. 1). The rarefied samples show that the pattern of decline in taxonomic richness in the LBA, which appears to be sustained well into the Iron Age, was not a product of differing sample size. Spearman's rank-order correlation coefficient indicates that this decline is significant ($r_s = -0.714$, $p = 0.058$). The rarefaction analysis also shows that among those samples from more taxa-rich contexts (>5 taxa), 100 fragments may be insufficient to obtain a complete representation of utilised taxa (see also Supplementary Table 1 and Supplementary Fig. 1).

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4.0 Discussion

The spread of deciduous oak woodlands and mixed forests into the Anatolian plateau is well reported in much of the literature to the mid-Holocene (Asouti and Kabukcu, 2014, Roberts, 2002), however, the nature of woodland utilisation for the BA and IA has been generally overlooked (cf. Longford, et al., 2009, Marston, 2009, Miller, 2010). Despite this paucity of research, a regional picture of changing patterns in woodland cover can be found in palaeoenvironmental proxies from the region (see Figs. 5 and 6 as summary diagrams) which allow a reconstruction of the history of vegetation exploitation at Kaman-Kalehöyük to be placed in its regional setting.

Wood charcoal analysis of BA and IA contexts at Kaman-Kalehöyük demonstrates increasing exploitation of broadleaf woodland with a corresponding decrease in taxa richness (Figs. 2, 3, and 4) during the MBA IV and LBA. The decrease in taxa richness is immediately followed by a highly significant increase in exploitation of pine during the EIA which is sustained until the end of the First Millennium BC.

The level of taxonomic richness (Fig. 4), especially the presence of minor woodland taxa in conjunction with the dominance of oak in the MBA (Fig.3), indicate the landscape likely consisted of a well-established open oak woodland (Woldring and Bottema, 2002, 100 y, 1973) matching that indicated by Asouti and Kabukcu (2014:170,175) in areas of characterised by less anthropogenic disturbance. In the LBA (Hittite Empire) there is a significant decline in the number of taxa exploited, possibly indicating that the well-established woodland of earlier periods was under significant anthropogenic pressure. The simultaneous increase in oak use in the same period also matches observations by Asouti and Kabukcu (2014:175) of scrub oak overtaking areas that have been intensively utilised for firewood and the like. This reduction in taxonomic richness, which begins in the MBA IV (Old Hittite

Kingdom), could be the result of an expansion of agricultural or grazing land at the expense of riparian woodland, possibly in conjunction with clearance of minor woodland taxa via grazing and wood fuel collection (Djamali, et al., 2009a, Flynn, et al., 2009, Marston, 2012, Miller, 1997). Contemporaneous evidence from storage structures at Kaman-Kalehöyük indicates that the Hittite period saw increased political and economic control over grain redistribution (Fairbairn and Omura 2005). Interpreted in this light, the anthracological data for Hittite land clearance suggest that Kaman-Kalehöyük's farmers were also modifying their production systems, perhaps also responding to state demands, whether directly through political instruction or indirectly through demand from large conurbations (Atıcı, 2005).

Today, two species of anatomically indistinguishable deciduous oak (*Q. cerris* and *Q. pubescens*) are found in similar landscapes to that of Kaman-Kalehöyük, with the nearest stands some 30km to the northwest (Akdeniz, et al., 2004, Akman, 1995, Kargıoğlu, et al., 2008). However, the dominance of deciduous oak (evergreen oak was not present) in the Kaman-Kalehöyük assemblage suggests that significant stands of oak woodland persisted close to the site throughout the study period. The pollen data for the broader region (Fig. 5) is inconsistent but that of Eski Acıgöl, some 110 km to the south, indicates a persistent but low level of oak cover but certainly not the dominance that the Kaman-Kalehöyük wood charcoal data suggest. Beyşehir Gölü (250 km southwest) shows a barely perceptible oak presence in the BA and a slight, but low level, increase in oak in the IA, opposite of the pattern shown in the Kaman-Kalehöyük data. The conclusion is, neither of these patterns are a good match for the Kaman-Kalehöyük data (to the extent that the Kaman-Kalehöyük data are reflective of the local woodland composition). The far more distant Lake Van data (800km east) is a better match for the oak data from Kaman-Kalehöyük indicating significant differences in local chronologies of woodland change.

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The pine found in the Kaman-Kalehöyük assemblage was probably derived from black pine (*P. nigra*) or Scots pine (*P. sylvestris*), which are indistinguishable on the basis of their wood anatomy. Both pine species are still relatively common in the region, although the nearest observed stands are all planted and are some 50-60 km to the northwest near Bala. The wood charcoal data show pine increasing in the IA while barely registering a presence in the BA. It is clear from Fig. 6 that the Kaman-Kalehöyük pine exploitation data show no strong agreement with the reported data from contemporaneous pollen cores from central Anatolia. Instead, the pollen data indicate that, at least in Eski Acıgöl and Beyşehir Gölü records (Fig. 6), pine was more dominant than oak in the region for the entire study period, although the pollen data may be skewed by the prodigious ability for pine to produce vast quantities of pollen that travel considerable distances (Richardson, 2000). Neither Eski Acıgöl nor Beyşehir Gölü show a contemporaneous sudden increase in presence to match the increased exploitation at the start of the EIA in the Kaman-Kalehöyük data. Again, only the Van data show any similarity in the low levels of pine present in the BA period although the Van data shows no similarity for the IA.

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The onset of the Iron Age is accompanied by a dramatic increase in pine use (Figs. 2, 3 and 6) and we consider four potential mechanisms that could account for this:

1. Pine colonised areas previously occupied by oak;
2. Pine was imported from further afield to supplement the wood resource repertoire;
3. Climate change encouraged the spread of pine in the region, increasing its presence in the landscape;
4. Previously avoided or underutilised sources of pine were now exploited.

Pine can be a successful coloniser of disturbed land, even highly alkaline soils exposed after fire or clearance (see *Pinus sylvestris* as an example) (Keeley and Zedler 2000:234). However, this is an unlikely scenario as oak also responds well to land clearance, often re-sprouting after felling while pine is generally slow in colonising alkaline soils like those in the region (Asouti and Kabukcu, 2014, Eastwood, et al., 1998). The continued dominance of oak suggests that the woodland around the site had not resulted in the complete opening of the landscape required for taxa such as pine to flourish and is contra the pollen data shown in Figs. 5 and 6 (Keeley and Zedler, 2000).

It is possible that pine was transported to the site from farther afield than in previous periods. If this is the case, we would expect its incorporation into the assemblage to result from construction with the waste being used for fuel supplementation, because it is unlikely that pine – an inferior fuel source compared to oak (Marston, 2009) – would be sourced from long distances purely for fuel and there is no evidence for an increase in dung fuel use, which is usually associated with fuel scarcity (Miller, 1984, Miller, 1985). However, the archaeology of the site to date does not support a significant increase in buildings in the EIA utilising pine. Newton and Kuniholm (2001) consistently found that oak was the main construction material in the EIA, although more detailed analysis of construction materials needs to be undertaken for a conclusive argument to be made.

From the third millennium BC, the increase in pine chronologically matches the fall of the Hittite empire as well as the 3.2-3.0 ka BP (c. 1,250 – c. 1,050 BC) climatic event that brought widespread drought throughout the region (Kuzucuoğlu, et al., 2011, Roberts, et al., 2001, Rosen, 2007). The climatic event is characterised by humidity values lower than the periods pre and post the LBA (Allcock, 2013, Allcock and Roberts, 2014, Kuzucuoğlu, 2010, Rosen, 1997). Climate change has often been suggested as causal of changes in arboreal cover, but ecological data on the preferred range and habitat of oak indicates that even with a drying climate, the central Anatolian steppe would still support open oak woodland (Jones and Roberts, 2008, Roberts, et al., 2001, Sagona and Zimansky, 2009). Additionally, the persistence of pine in the Kaman-Kalehöyük assemblage into the LIA is counter intuitive to a surge in pine driven by drought. Despite the climate change event observed in the climate data from across Anatolia, the results from Kaman-Kalehöyük support Roberts et al.'s (2001) argument that climate alone is insufficient in causing the shift from oak to pine at Kaman-Kalehöyük and, as such, climate change can be seen as a contributory factor rather than the primary cause of the change.

Interestingly, as the climate improved into the IA there was not a concomitant increase in riparian taxa (which are sometimes pioneers), indicating that continued human impact played a major role in landscape transformation at the site. There is a drop in the abundance of riparian taxa in the Early Iron Age, suggesting that riparian woodland in the local area had declined. Nevertheless, the presence of willow/poplar in all phases indicates the continued existence of a riverine or riparian forest along banks and gullies of the local water sources (Fairbairn, et al., 2002, Longford, et al., 2009, Riehl and Marinova, 2008, Russell, et al., 2007). Considering the close proximity of waterways to the site and the ability of riparian taxa to colonise rapidly, the decline in riparian taxa supports the notion that constant human pressure on riverine areas surrounding the site limited the ability for these species to maintain woodland cover in the face of human harvesting pressure.

The pollen data from both Eski Acıgöl and Beyşehir Gölü indicate pine forests were in existence close to the site in the BA but were underexploited or avoided compared to oak and riparian woodlands either due to their location prohibiting their common use or a specific avoidance of pine. In particular, if pine did exist on the slopes of Baran Dağ just to the south of the site, then its lack of exploitation could be explained by the significance and sacred nature attributed to mountains by the Hittites, as proposed by Haas (1982) and supported by Popko (1994). If indeed mountains were sacred and places of importance to the Hittite (contra Ullmann, 2010), then the underutilisation of the woodland resources on them is a reasonable premise (Gorny, 1989, Gorny, 2006a, Gorny, 2006b). The demise of the Hittite Empire at the end of the Bronze Age and cessation of Hittite cultural practices could explain why pine sees a sudden and significant increase in use in the Early Iron Age.

The continued dominance of oak throughout the Iron Age does not support the conclusion that there was complete replacement of oak woodland in the area close to Kaman-Kalehöyük during the Iron Age. Rather, the decline in minor taxa combined with the continued exploitation of oak indicates a possible shift from well-established minimally disturbed oak woodland described by Zohary (1973) and Davis (1965-1985) to the more low-diversity highly disturbed oak-dominated woodlands described by Asouti and Kabukcu (2014). This indicates that the highly modified anthropogenic open oak woodland described and observed by Asouti and Kabukcu (2014) may well have been established at Kaman-Kalehöyük during the Hittite Empire period (LBA). At the same time, across much of southwest Asia and Europe there is sufficient evidence to suggest that deforestation often accompanies urbanisation, increased agricultural activities, and possibly state formation (Badal, et al., 1994, Baruch, 1990, Böse and Brande, 2010, Fall, et al., 2002). However, the pattern from Kaman-Kalehöyük does not support the level of deforestation indicated elsewhere in the southwest Asian region during the BA and IA, for example northern Syria and southern Turkey (Deckers and Riehl, 2007), instead demonstrating that woodland continued to exist and was used as the major fuel. Rather, the Kaman-Kalehöyük data clearly indicate an anthracological signature that is most clearly linked to the emergence and expansion of the Hittite state characterised by woodland modification, perhaps in concert with expanding agricultural practices, rather than complete deforestation.

5.0 Conclusion

This paper detailed the anthracological investigation of Kaman-Kalehöyük in the central Anatolian highlands during the BA and IA in order to evaluate the extent and nature of Kaman-Kalehöyük's woodland in this period. In particular, the paper aimed to establish the presence and change in dominant tree taxa during the occupation sequence.

Results indicate that deciduous oak woodland was present throughout the entire sequence, though several significant changes in woodland composition did occur. The first and most obvious of these changes was a significant and dramatic increase in the use of pine from the onset of the IA coinciding with the decline of the Hittite Empire at the end of the BA. The second change was the clear and significant reduction in taxa richness from the MBA I-III to the LBA, indicating a local anthracological signature for the Hittite state. This reduction in taxa richness was followed by a more subtle increase from the EIA through to the LIA.

The interpretation that these changes indicate that the activities of the inhabitants of the site, especially during the Hittite occupation, had substantial impact on the surrounding environment is reasonable. The Hittite signature for the LBA is one of intensive harvesting of the extant open woodland to the point where taxa richness was significantly affected while also avoiding pine which the pollen data clearly show was present in the region. Despite the notable impact on taxa richness, deciduous oak never disappears from the record indicating that despite the intensity of Hittite harvesting, collection of oak did not result in complete removal of deciduous oak from the available resource repertoire. Thus, the nuance contained in the Kaman-Kalehöyük assemblage does not directly match the regional pollen data but rather show Kaman-Kalehöyük is characterised by a local exploitation pattern reflecting specific cultural and economic practices.

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6.0 References

Akdeniz, H., Keskin, B., Yılmaz, İ., Oral, E., 2004. Bazı Arpa Çeşitlerinin Verim ve Verim Unsurları ile Bazı Kalite Özellikleri Üzerinde Bir Araştırma, Tarım Bilimleri Dergisi 14, 119-125.

Akman, Y., 1995. Forest vegetation in Turkey (Türkiye Orman Vejetasyonu), Ankara University Publications, Ankara.

Allcock, S.L., 2013. Living with a changing landscape: Holocene climate variability and socio-evolutionary trajectories, central Turkey, School of Geography, Earth and Environmental Sciences, Plymouth University, p. 375.

Allcock, S.L., Roberts, N., 2014. Changes in regional settlement patterns in Cappadocia (central Turkey) since the Neolithic: a combined site survey perspective, Anatol. Stud. 64, 33-57.

Arıkan, B., 2014. Macrophysical Climate Modeling, economy, and social organization in Early Bronze Age Anatolia, J. Archaeol. Sci. 43, 38-54.

Asouti, E., 2003. Woodland vegetation and fuel exploitation at the prehistoric campsite of Pinarbaşi, south-central Anatolia, Turkey: the evidence from the wood charcoal macro remains, J. Archaeol. Sci. 30, 1185-1201.

Asouti, E., 2013. Woodland vegetation, firewood managment and woodcrafts at Neolithic Çatalhöyük, in: Hodder, I. (Ed.), Humans and Landscapes of Çatalhöyük: Reports from the 2000-2008 Seasons, UCLA Press, Cotsen Institiute of Archaeology, Los Angeles, pp. 129-162.

Asouti, E., Austin, P., 2005. Reconstructing woodland vegetation and its exploitation by past societies, based on the analysis and interpretation of wood charcoal macro-remains, Environ. Archaeol. 10, 1-18.

Asouti, E., 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, Veg. Hist. Archaeobot. 10, 23-32.

Asouti, E., Kabukcu, C., 2014. Holocene semi-arid oak woodlands in the Irano-Anatolian region of Southwest Asia: natural or anthropogenic?, Quat. Sci. Rev. 90, 158-182.

Atıcı, L., 2005. Centralized or Decentralized: The Mode of Pastoral Economy at Early Bronze Age Kaman-Kalehöyük, Anatol. Archaeol. Stud. 14, 119-128.

Badal, E., Bernabeu, J., Vernet, J., 1994. Vegetation changes and human action from the Neolithic to the Bronze Age (7000-4000 B.P.) in Alicante, Spain, based on charcoal analysis, Veg. Hist. Archaeobot. 3, 155-166.

Barnes, B.V., Zak, D.R., Denton, S.R., Spurr, S.H., 1998. Forest Ecology, 4th ed., John Wiley & Sons, Inc., New York.

Baruch, U., 1990. Palynological evidence of human impact on the vegetation as recorded in the late Holocene lake sediments in Israel, in: Bottema, S., Entjes, G., Van Zeist, W. (Eds.), Man's Role in the Shaping of the Eastern Mediterranean Landscape, Balkema, Rotterdam, pp. 283-293.

Bong, W.S.K., Matsumura, K., Nakai, I., 2008. Firing Technologies and Raw Materials of Typical Early and Middle Bronze Age Pottery from Kaman-Kalehöyük: A Statistical and Chemical Analysis, Anatol. Archaeol. Stud. 17, 295-311.

Bong, W.S.K., Matsumura, K., Yokoyama, K., Nakai, I., 2010. Provenance study of early and middle bronze age pottery from Kaman-Kalehöyük, Turkey, by heavy mineral analysis and geochemical analysis of individual hornblende grains, J. Archaeol. Sci. 37, 2165-2178.

Böse, M., Brande, A., 2010. Landscape history and man-induced landscape changes in the young morainic area of the North European Plain -- a case study from the Bäke Valley, Berlin, Geomorphol. 122, 274-282.

Bryce, T., 2005a. The Kingdom of the Hittites, Oxford University Press, Oxford.

Bryce, T., 2005b. The Last Days of Hattusa: The Mysterious Collapse of the Hittite Empire, Archaeology Odyssey 8.

Bush, A.M., Markey, M.J., Marshall, C.R., 2004. Removing Bias from Diversity Curves: The Effects of Spatially Organized Biodiversity on Sampling-Standardization, Paléobiol. 30, 666-686.

Condé, S., Richard, D., Leclère, A., Sotolargo, B., Pinborg, U., 2002. Biogeographical regions in Europe: The Anatolian region - the biogeographical transition to Asia, European Environment Agency, Sweden.

Connor, S.E., Thomas, I., Kvavadze, E.V., Arabuli, G.J., Avakov, G.S., Sagona, A., 2004. A survey of modern pollen and vegetation along an altitudinal transect in southern Georgia, Caucasus region, Rev. Palaeobot. Palynol. 129, 229-250.

Cordova, C.E., 2007. The Degradation of the Ancient Near Eastern Environment, Blackwell Reference Online, Oxford.

Davis, P.H., 1965-1985. Flora of Turkey and the East Aegean Islands, Edinburgh University Press, Edinburgh.

Davis, P.H., Mill, R.R., Tan, K., 1988. Flora of Turkey, Edinburgh University Press, Edinburgh.

Deckers, K., Pessin, H., 2010. Vegetation development in the Middle Euphrates and Upper Jazirah (Syria/Turkey) during the Bronze Age, Quat. Res. 74, 216-226.

Deckers, K., Riehl, S., 2007. Fluvial environmental contexts for archaeological sites in the Upper Khabur basin (northeastern Syria), Quat. Res. 67, 337-348.

Djamali, M., Beaulieu, J.-L., Miller, N.F., Andrieu-Ponel, V., Ponel, P., Lak, R., Sadeddin, N., Akhani, H., Fazeli, H., 2009a. Vegetation history of the SE section of the Zagros Mountains during the last five millennia; a pollen record from the Maharlou Lake, Fars Province, Iran, Veg. Hist. Archaeobot. 18, 123-136.

Djamali, M., de Beaulieu, J.L., Campagne, P., Andrieu-Ponel, V., Ponel, P., Leroy, S.A.G., Akhani, H., 2009b. Modern pollen rain–vegetation relationships along a forest–steppe transect in the Golestan National Park, NE Iran, Rev. Palaeobot. Palynol. 153, 272-281.

Djamali, M., de Beaulieu, J.L., Miller, N.F., Andrieu-Ponel, V., Lak, R., Sadeddin, M., Akhani, H., Fazeli, H., 2008. Vegetation history of the SE section of Zagros

Mountains during the last five millennia; a pollen record from the Maharlou Lake, Fars Province, Iran, Veg. Hist. Archaeobot. 18, 123-136.

Dörfler, W., Herking, C., Neef, R., Pasternak, R., von den Driesch, A., 2011. Environment and Economy in Hittite Anatolia, in: Genz, H., Mielke, D.P. (Eds.), Insights into Hittite History and Archaeology, Peeters, Walpole, pp. 99-124.

Drews, R., 1993. The end of the Bronze Age: Changes in warfare and the catastrophe CA. 1200 B.C., Princeton University Press, Princeton.

Earth, G., 2014. Google Earth: Map Data @ 2014 AND Image Landsat.

Eastwood, W.J., Roberts, N., Lamb, H.F., 1998. Palaeoecological and Archaeological Evidence for Human Occupance in Southwest Turkey: The Beyşehir Occupation Phase Anatol. Stud. 48, 69-86.

England, A., Eastwood, W.J., Roberts, N., Turner, R., Haldon, J.F., 2008. Historical landscape change in Cappadocia (central Turkey): a palaeoecological investigation of annually laminated sediments from Nar lake., Holocene 18, 1229-1245.

Ertuğ-Yaras, F., 1997. An Ethnoarchaeological Study of Subsistence and Plant Gathering in Central Anatolia (Turkey), Econ. Bot. 54, 155-182.

Fairbairn, A., Asouti, E., Near, J., Martinoli, D., 2002. Macro-botanical evidence for plant use at Neolithic Çatalhöyük, south-central Anatolia, Turkey, Veg. Hist. Archaeobot. 11, 41-54.

Fairbairn, A., Omura, S., 2005. Archaeological Identification and Significance of *ÉSAG* (Agricultural Storage Pits) at Kaman-Kalehöyük, Central Anatolia, Anatol. Stud. 55, 15-23.

Fall, P.L., Falconer, S.E., Lines, L., 2002. Agricultural Intensification and the Secondary Products Revolution along the Jordan Rift, Hum. Ecol. 30, 445-482.

Flynn, D.F.B., Gogol-Prokurat, M., Nogeire, T., Molinari, N., Richers, B.T., Lin, B.B., Simpson, N., Mayfield, M.M., DeClerck, F., 2009. Loss of functional diversity under land use intensification across multiple taxa, Ecol. Lett. 12, 22-33.

Gorny, R.L., 1989. Environment, Archaeology, and History in Hittite Anatolia, Biblic. Archaeol. 52, 78-96.

Gorny, R.L., 2006a. The 2002-2005 Excavation Seasons at Çadir Höyük. The Second Millennium Settlement, Anatol. 32, 29-54.

Gorny, R.L., 2006b. Çadir Höyük and Çaltepe: Are they the Hittite City of Zippalanda and the Holy Mt. Daha, The Oriental Institute News and Notes 188.

Haas, V., 1982. Hethitische Berggötter & Harritische Steindämonen: Riten, Kulte & Mythen, Kulturgeschichte der antiken Welt, Philipp von Zabern Verlag, Mainz.

Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001. AST: Paleontological statistics software package for education and data analysis, Palaeontol. Electron. 4, 1-9.

Hather, J., 2000. The Identification of the Northern European Woods: A Guide for archaeologists and conservators, Archetype Publications Ltd, London.

Heiss, A.G., 2009. Anatomy of European and North American woods - An interactive identification key. Version 2009-05-14.

Hongo, H., 2003. Continuity or Changes: Faunal Remains from Stratum IId at Kaman-Kalehöyük, in: Fischer, B., Genz, H., Jean, E., Köroglu, K. (Eds.), From Bronze to Iron Ages in Anatolia and its Neighbouring Regions, Ege Yayinlari, Istanbul, pp. 257-269.

Ishimaru, K., Kashima, K., 2000. Geomorphological Environment and the Distribution of Archaeological Sites in the Region of Kaman-Kalehöyük, Central Turkey, Anatol. Archaeol. Stud. 9, 167-176.

Issar, A.S., Zohar, M., 2007. Climate Change: Environment and History of the Near East, 2nd ed., Springer, Berlin.

Jones, M.D., Roberts, N., 2008. Interpreting lake isotope records of Holocene environmental change in the Eastern Mediterranean, Quat. Int. 181, 32-38.

Kargıoğlu, M., Cenkci, S., Serteser, A., Evliyaoğlu, N., Konuk, M., Kök, M.Ş., Bağcı, Y., 2008. An Ethnobotanical Survey of Inner-West Anatolia, Turkey, Hum. Ecol. 36, 763-777.

Kaya, M.A., Raynal, D.J., 2001. Biodiversity and conservation of Turkish forests, Biol. Conserv. 97, 131-141.

Kealhofer, L., Grave, P., Marsh, B., Matsumura, K., 2008. Analysis of Specialized Iron Age Wares at Kaman-Kalehöyük, Anatol. Archaeol. Stud. 17, 201-223.

Keeley, J.E., Zedler, P.H., 2000. Evolution of life histories in *Pinus*, in: Richardson, D.M. (Ed.), Ecology and Biogeography of *Pinus*, Cambridge University Press, Cambridge, pp. 219-249.

Keepax, C.A., 1988. Charcoal analysis with particular reference to archaeological sites in Britain, Archaeology, University of London, London.

Klinge, J., Fall, P., 2010. Archaeobotanical inference of Bronze Age land use and land cover in the eastern Mediterranean, J. Archaeolog. Sci. 37, 2622-2629.

Koellner, T., Hersperger, A.M., Wohlgemuth, T., 2004. Rarefaction Method for Assessing Plant Species Diversity on a Regional Scale, Ecogr. 27, 532-544.

Kuzucuoğlu, C., 2010. Climate and environment in times of cultural changes from the 4th to the 1st mill. BC in the Near and Middle East, in: Cardarelli, A., Cazzella, A., Frangipane, M., Peroni, R. (Eds.), Reasons for Changes of Societies Between the End of the IV and Beginning of the 1st Millenium BC, Scienze delle Antichita, Rome, pp. 141-163.

Kuzucuoğlu, C., Dörfler, W., Kunesch, S., Goupille, F., 2011. Mid- to late-Holocene climate change in central Turkey: The Tecer Lake record, Holocene 21, 173-188.

Litt, T., Krastel, S., Sturm, M., Kipfer, R., Örcen, S., Heumann, G., Franz, S.O., Ülgen, U.B., Niessen, F., 2009. Lake Van Drilling Project 'PALEOVAN', International Continental Scientific Drilling Program (ICDP): results of a recent pre-site survey and perspectives, Quaternary Science Reviews 28, 1555-1567.

Longford, C., Drinnan, A., Sagona, A., 2009. Archaeobotany of Sos Höyük, northeast Turkey, in: Fairbairn, A., O'Connor, S., Marwick, b. (Eds.), New Directions in archaeological science, ANU E Press, Canberra, pp. 121-136.

Lyman, R.L., 2008. Quantitative Paleozoology, Cambridge University Press, Cambridge.

Marsh, B., Kealhofer, L., 2014. Scales of impact: Settlement history and landscape change in the Gordion Region, central Anatolia, The Holocene 24, 689-701.

Marston, J.M., 2009. Modeling wood acquisition strategies from archaeological charcoal remains, Journal of Archaeological Science 36, 2192-2200.

Marston, J.M., 2012. Agricultural strategies and political economy in ancient Anatolia, American Journal of Archaeology 116, 377-403.

Matsumura, K., Omori, T., 2008. The Iron Age Chronology in Anatolia Reconsidered: The Results Of The Excavations At Kaman-Kalehöyük, in: Matthiae, P., Pinnock, F., Nigro, L., Marchetti, N. (Eds.), the 6th International Congress on the Archaeology of the Ancient Near East, Harrassowitz Verlag, Sapienza.

Mayewski, P.A., Rohling, E.E., Stager, J.C., Karlén, W., Maasch, K.A., Meeker, L.D., Meyerson, E.A., Gasse, F., van Kreveld, S., Holmgren, K., Lee-Thorp, J., Rosqvist, G., Rack, F., Staubwasser, M., Schneider, R.R., Steig, E.J., 2004. Holocene climate variability, Quaternary Research 62, 243-255.

MGM, 2014. Meteoroloji Genel Müdürlüğü, MGM, Ankara.

Miller, N.F., 1984. The Use of Dung as Fuel : an Ethnographic Example and an Archaeological Application, Paléorient 10, 71-79.

Miller, N.F., 1985. Palaeoethnobotanical evidence for deforestation in ancient Iran: a case study from urban Malyan, Journal of Ethnobiology 5, 1-19.

Miller, N.F., 1988. Ratios in Paleoethnobotanical Analysis, in: Hastorf, C.A., Popper, V.S. (Eds.), Current Paleoethnobotany: Analytical Methods and Cultural Interpretations of Archaeological Plant Remains, The University of Chicago Press, Chicago, pp. 72-85.

Miller, N.F., 1997. The Macrobotanical evidence for vegetation in the Near East, c. 18 000/16 000 B.C to 4 000 B.C, Paléorient 23, 197-207.

Miller, N.F., 2010. Botanical Aspects of Environment and Economy at Gordion, Turkey, University of Pennsylvania Press, Philadelphia.

Nelle, O., Dreibrodt, S., Dannath, Y., 2010. Combining pollen and charcoal: evaluating Holocene vegetation composition and dynamics, Journal of Archaeological Science 37, 2126-2135.

Nesbitt, M., 1995. Recovery of archaeological plant remains at Kaman-Kalehöyük, in: Mikasa, T. (Ed.), Essays on Anatolian Archaeology: Bulletin of the Middle Eastern Culture Center in Japan, Harrassowitz, Weisbaden, pp. 115-130.

Newton, M.W., Kuniholm, P.I., 2001. Dendrochronological Invetsigations at Kaman-Kalehöyük: Dating the Early Iron Age Level IId, Anatolian Archaeological Studies 10.

Omori, T., Nakamura, T., 2006. Radiocarbon Dating of Archaeological Materials Excavated at Kaman-Kalehöyük: Initial Report, Anatolian Archaeological Studies 15, 263-268.

Omori, T., Nakamura, T., 2007. Radiocarbon Dating of Archaeological Materials Excavated at Kaman-Kalehöyük: Second Report, Anatolian Archaeological Studies 16, 111-123.

Omura, S., 2011. Kaman-Kalehöyük excavations in Central Anatolia, in: Steadman, a., McMahon, G. (Eds.), The Oxford Handbook of Anatolian Archaeology., Oxford University Press, Oxford, pp. 1095-1111.

Popko, M., 1994. Zippalanda: ein Kultzentrum im hethitischen Kleinasien, Texte der Hethiter, Carl Winter Universitätsverlag, Heidelberg.

Richardson, D.M., 2000. Ecology and Biogeography of *Pinus*, Cambridge University Press, Cambridge.

Riehl, S., 2009. Archaeobotanical evidence for the interrelationship of agricultural decision-making and climate change in the ancient Near East, Quaternary International 197, 93-114.

Riehl, S., Bryson, R., Pustovoytov, K., 2008. Changing growning conditions for crops during the Near Eastern Bronze Age (3000-1200 BC): the stable carbon isotope evidence, Journal of Archaeological Science 35, 1011-1022.

Riehl, S., Marinova, E., 2008. Mid-Holocene vegetation change in the Troad (W Anatolia): man-made or natural?, Vegetation History and Archaeobotany 17, 297-312.

Roberts, N., 1995. Climatic forcing of alluvial fan regimes during the Late Quaternary in the Konya Basin, south central Turkey, in: Lewin, J., Macklin, M.G., Woodward, J.C. (Eds.), Mediterranean Quaternary River Environments, A.A. Balkema, Rotterdam, pp. 2017-2217.

Roberts, N., 2002. Did prehistoric landscape management retard the post-glacial spread of woodland in Southwest Asia?, Antiquity 76, 1002-1010.

Roberts, N., Brayshaw, D., Kuzucuoğlu, C., Perez, R., Sadori, L., 2011a. The mid-Holocene climatic transition in the Mediterranean: Causes and consequences, The Holocene 21, 3-13.

Roberts, N., Eastwood, W.J., Kuzucuoğlu, C., Fiorentino, G., Caracuta, V., 2011b. Climatic, vegetation and cultural change in the eastern Mediterranean during the mid-Holocene environmental transition, The Holocene 21, 147-162.

Roberts, N., Reed, J.M., Leng, M.J., Kuzucuoğlu, C., Fontugne, M., Bertaux, J., Woldring, H., Bottema, S., Black, S., Hunt, E., Karabiyikoglu, M., 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, 721-736.

Roberts, N., Rosen, A., 2009. Diversity and Complexity in Early Farming Communities of Southwest Asia: New Insights into the Economic and Envronmental Basis of Neolithic Çatalhöyük, Current Anthropology 50, 393-402.

Rosen, A., 1997. Environmental Change and Human Adaptational Failure at the End of the Early Bronze Age in the Southern Levant, in: Dalfes, H.N., Kukla, G., Weiss, H. (Eds.), Third Millennium BC Climate Change and Old World Collapse, Springer-Verlag, Berlin, pp. 25-38.

Rosen, A.M., 2007. Civilizing climate: social responses to climate change in the ancient near East, Altimira Press, Lanham.

Russell, T., Cutler, C., Walters, M., 2007. Trees of the World, Hermes House, London.

Sagona, A., Zimansky, 2009. Ancient Turkey, Routledge, Abingdon.

Sayhan, S., 2000. Geologic and Geomorphologic Characteristics of Kaman and its Surroundings, Anatolian Archaeological Studies 9, 193-200.

Schoch, W., Heller, I., Schweingruber, F.H., 2004. Wood Anatomy of Central European Species.

Schweingruber, F.H., 1990. Anatomy of European Woods, Haupt, Stuttgart.

Schweingruber, F.H., Börner, A., Schulze, A.-D., 2006. Atlas of Woody Plant Stems: Evolution, Structure, and Environmental Modifications, Springer-Verlag, Berlin.

Smart, T.L., Hoffman, E.S., 1988. Environmental Interpretation of Archaeological Charcoal, in: Hastorf, C.A., Popper, V.S. (Eds.), Current Paleoethnobotany: Analytical Methods and Cultural Interpretations of Archaeological Plant Remains, The University of Chicago Press, Chicago, pp. 167-205.

Smith, A., Munro, R.N., 2009. A Holistic Approach to Examining Ancient Agriculture: A Case Study from the Bronze and Iron Age Near East, Curr. Anthropol. 50, 925-936.

Thery-Parisot, I., Chabal, L., Chrzavzez, J., 2010. Anthracology and taphonomy, from wood gathering to charcoal analysis. A review of the taphonomic processes modifying charcoal assemblages, in archaeological contexts, Palaeogeogr., Palaeoclim., Palaeoecol. 291, 142-153.

Thiébault, S., 2002. Methodological approaches, palaeoecological results and wood uses, in: Thiébault, S. (Ed.), Charcoal Analysis, Methodological Approaches, Palaeoecological Results and Wood Uses. Proceedings of the 2nd International Meeting in Anthracology, Paris, September 2000. BAR International Series 1063, Archaeopress, Oxford.

Ullmann, L., 2010. Movement and the Making of Place in the Hittite Landscape, School of Arts and Sciences, Columbia University, New York.

Ünal, A., Kindap, T., Karaca, M., 2003. Redefining the Climate Zones of Turkey using Cluster Analysis, International Journal of Climatology 23, 1045-1055.

van der Veen, M., Fieller, N., 1982. Sampling Seeds, Journal of Archaeological Science, 287-298.

Vermoere, M., Smets, E., Waelkens, M., Vanhaverbeke, H., Librecht, I., Paulissen, E., Vanhecke, L., 2000. Late Holocene Environmental Change and the Record of Human Impact at Gravgaz near Sagalassos, Southwest Turkey, Journal of Archaeological Science 27, 571-595.

Weiss, B., 1982. The Decline of Late Bronze Age Civilization as A Possible Response to Climatic Change, Climatic Change 4, 173-198.

Weninger, B., Clare, L., Rohling, E.J., Bar-Yosef, O., Böhner, U., Budja, M., Bundschuh, M., Feurdean, A., Gebel, H.-G., Jöris, O., 2009. The impact of rapid climate change on prehistoric societies during the Holocene in the Eastern Mediterranean, Documenta praehistorica 36, 7-59.

Wick, L., Lemcke, G., Sturm, M., 2003. Evidence of Lateglacial and Holocene climatic change and human impact in eastern Anatolia: high-resolution pollen, charcoal, isotopic and geochemical records from the laminated sediments of Lake Van, Turkey, The Holocene 13, 665-675.

Willcox, G., 2002. Evidence for ancient forest cover and deforestation from charcoal analysis of ten archaeological sites on the Euphrates, in: Thiebault, S. (Ed.), Charcoal Analysis, Methodological Approaches, Palaeoecological Results and Wood Uses. Proceedings of the 2nd International Meeting in Anthracology, Paris, September 2000. BAR International Series 1063, Archaeopress, Oxford, pp. 141-145.

Willcox, G.H., 1974. A Histroy of Deforestation as Indicated by Charcoal Analysis of Four Sites in Eastern Anatolia, Anatolian Studies 24, 117-133.

Woldring, H., Bottema, S., 2002. The Vegetaton History of East-Central Anatolia in Relation to Archaeology: The Eski Acigöl Pollen Evidence Compared with the Near Eastern Environment, Palaeohistoria 44, 1-34.

Woldring, H., Cappers, R., 2001. The Origin of the Wild Orchards of Central Anatolia, Turkish Journal of Botany 25, 1-9.

Wright, N.J., 2010. Subsistence abuse: habitual misuse of woody taxa, central Anatolia, Turkey, The University of Queensland, The University of Queensland, Unpublished.

Yakar, J., 2011. Anatolian Chronology and Terminology, in: Steadman, S.R., McMahon, G. (Eds.), The Oxford Handbook of Ancient Anatolia (10,000-323 BCE), Oxford University Press, Oxford, pp. 56-93.

Zohary, M., 1973. Geobotanical Foundations of the Middle East, Gustav Fischer Verlag, Stuttgart.

Fig. 1. A – Kaman-Kalehöyük in relation to sites mentioned in text (redrawn from Google Earth, 2014 Map Data © 2014 AND Image Landsat). B – Topography of the area surrounding the site and key features mentioned in text (redrawn from Sayhan, 2000). C – Annual rainfall for the Kırşehir region from 1971 to 2013, dashed line indicates the 42 year mean rainfall (MGM, 2014).

Fig. 2. Correspondence analysis plot of all samples where Axis 1 accounts for 55.3% of the variance within the samples and axis 2 describes 14.6% of the variance.

Fig. 3. Percentage abundance for all taxa across all samples where samples are ordered by phase with the oldest at the bottom and the dashed line indicates the division between the BA and IA. Taxa are ordered by vegetation zone/structure as per Table 3.

Fig. 4. The number of taxa at 92 fragments compared to the observed amount of taxa for those samples where 1000 were analysed.

Fig. 5. Oak (Quercus) wood charcoal data from Kaman-Kalehöyük compared to pollen records from Eski Acıgöl, Lake Van, and Beyşehir Gölü (original data published by Litt, et al., 2009, Roberts, et al., 2001, Wick, et al., 2003, Woldring and Bottema, 2002) The chronology for Eski Acigol is based on Roberts, et al. (2001), Lake Van chronology is the revised chronology based on Litt, et al. (2009) while the Kaman-Kalehöyük phases follow Table 2.

Fig. 6. Pine (*Pinus*) wood charcoal data from Kaman-Kalehöyük compared to the pollen records from Eski Acıgöl, Lake Van, and Beyşehir Gölü (sources and chronology as detailed in Fig. 5).

Table 1: Approximate dates for the occupation phases and sample information for Kaman-Kalehöyük (*Hongo, 2003, Matsumura and Omori, 2008, Omori and Nakamura, 2006, Omori and Nakamura, 2007, Omura, 2011, Yakar, 2011).

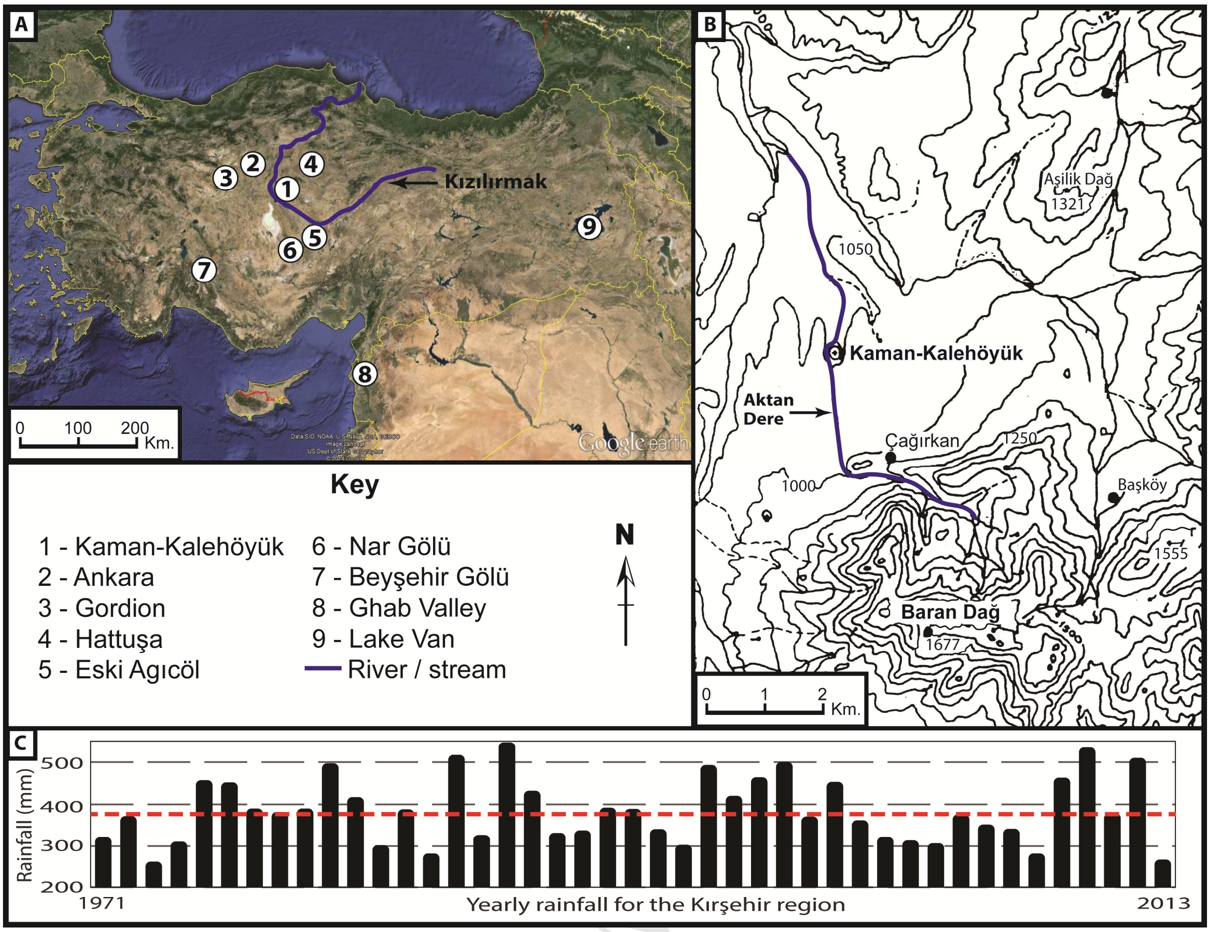
Period	No. of samples analysed (fragments identified)	Site Stratum	Anatolian cultural phase (abbreviation used in text)	Approximate dates *
Medieval/ Post-Medieval	NA	Ia	Ottoman	c. 1,450 – 1,650 AD
	NA	Ib	Byzantine	c. 1,000 – 1,150 AD
Iron Age	10 **(1835)**	IIa	Late Iron Age to Hellenistic **(LIA)**	c. 650 – 300 BC
	10 **(1841)**	IIc	Middle Iron Age **(MIA)**	c. 800 – 650 BC
	10 **(2102)**	IId	Early Iron Age **(EIA)**	c. 1,200 – c. 800 BC
Late Bronze Age	4 **(1390)**	IIIa	Hittite Empire Period **(LBA)**	c. 1,500 – 1,200 BC
Middle Bronze Age	10 **(2104)**	IIIb	Old Hittite Kingdom Period **(MBA IV)**	c. 1,650 – 1,500 BC
	10 **(2073)**	IIIc	Assyrian Colony Period **(MBA I-III)**	c. 2,000 – 1,650 BC
Early Bronze Age	NA	IVa	Transitional Early Bronze Age **(EBA)**	c.2,000 BC
	NA	IVb	Early Bronze Age III **(EBIII)**	to c.2,000 BC

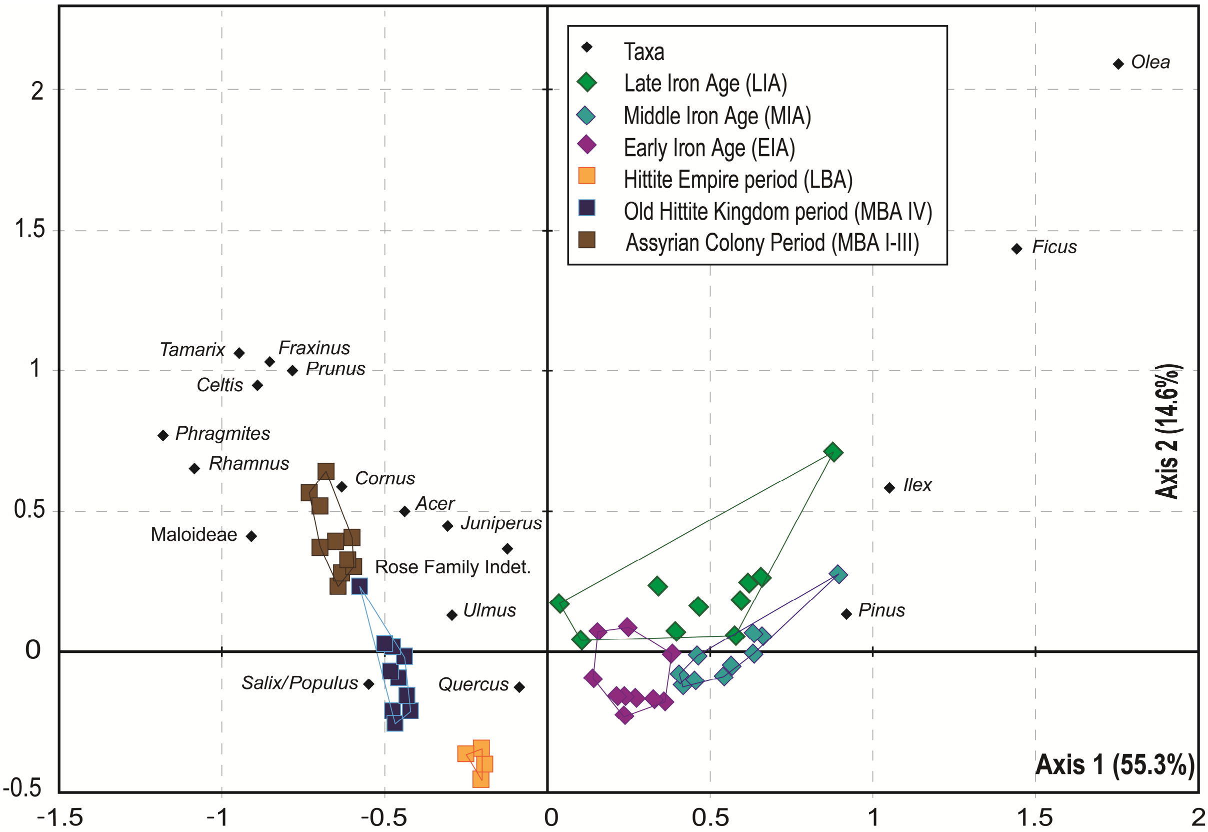
Table 2: Percentage abundance (%*f*), absolute count (A*f*) and ubiquity (U) for pit contexts across the analysed strata (Kaman-Kalehöyük phases in parentheses). Shaded squares indicate presence.

	Taxon		Phase																		Totals		
			Late Iron Age (IIa)			Middle Iron Age (IIc)			Early Iron Age (IId)			Late Bronze Age (IIIa)			Middle Bronze Age IV (IIIb)			Middle Bronze Age I-III (IIIc)					
	English Name	Latin	%*f*	U	A*f*	%*f*	U	A*f*	%*f*	U	A*f*	%*f*	U	A*f*	%*f*	U	A*f*	%*f*	U	A*f*	%*f*	U	A*f*
	Oak	*Quercus*	46.2	10	848	51.8	10	953	63.3	10	1,331	78.7	4	1,094	63.1	10	1,327	57.7	10	1,197	59.5	54	*6,750*
	Pine	*Pinus*	37.7	10	692	40.0	10	737	25.0	10	526	4.2	4	58	1.8	10	38	0.5	3	11	18.2	47	*2,062*
Riparian	Willow/Poplar	*Salix/Populus*	4.7	10	87	3.0	10	56	6.8	10	142	12.2	4	169	21.5	10	453	14.1	10	292	10.6	54	*1,199*
	Elm	*Ulmus*	1.1	5	20	1.1	4	21	0.6	8	13	0.9	2	12	2.2	8	47	1.7	10	35	1.3	37	*148*
	Tamarisk	*Tamarix*							0.2	3	5				0.1	2	2	0.8	9	16	0.2	14	*23*
	Reed	*Phragmites*													0.7	6	14	1.4	9	29	0.4	15	*43*
	Ash	*Fraxinus*	0.3	3	6	0.1	1	1	0.0	1	1				0.3	6	6	1.5	10	31	0.4	21	*45*
Minor	Rose Family indet.	Rosaceae	3.7	10	67	2.3	10	42	2.2	9	47	1.9	3	26	2.7	10	57	4.8	10	99	3.0	52	*338*
	Apple sub-family	Maloideae	1.1	8	20	0.9	7	17	0.2	4	4	1.7	3	24	2.6	10	55	5.3	10	110	2.0	35	*230*
	Plum	*Prunus*																1.5	9	31	0.3	9	*31*
	Dogwood	*Cornus*	0.5	2	10	0.1	1	2	0.1	1	2				1.1	10	23	1.3	10	27	0.6	23	*64*
	Hackberry	*Celtis*	0.7	2	13				0.5	4	11				0.9	10	19	5.1	9	106	1.3	25	*149*
	Buckthorn	*Rhamnus*	0.2	2	3										1.0	7	22	1.6	10	33	0.5	19	*58*
	Juniper	*Juniperus*	0.8	3	15	0.4	4	8	0.4	2	9	0.5	2	7	0.8	9.0	17	1.5	10	31	0.8	30	*87*
	Maple	*Acer*	1.0	7	19				0.3	5	7				1.1	8	24	1.2	8	25	0.7	28	*75*
Exotic	Holly	*Ilex*	0.5	2	9				0.2	1	4										0.1	3	*13*
	Fig	*Ficus*	1.3	2	24	0.1	1	2													0.2	3	*26*
	Olive	*Olea*	0.1	1	2	0.1	1	2													0.0	2	*4*
	Totals		**100**	**10**	**1,835**	**100**	**10**	**1,841**	**100**	**10**	**2,102**	**100**	**4**	**1,390**	**100**	**10**	**2,104**	**100**	**10**	**2,073**	**100**	**54**	***11,345***
	# of Taxa		**15**			**11**			**13**			**7**			**14**			**15**			***18***		

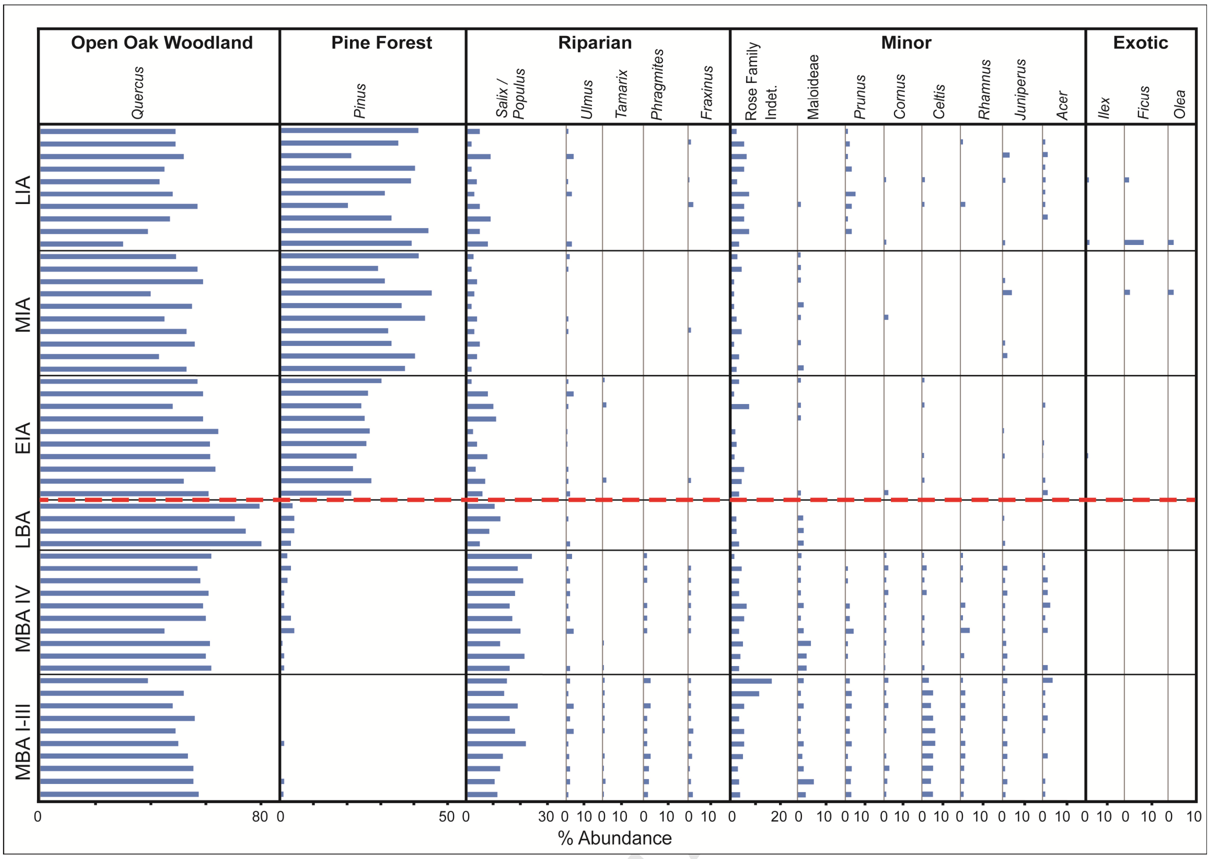
Table 3: Shows the analytical groups of the identified taxa based on their habitat preference and/or structural quality which are used in text. Table adapted from (Asouti, 2003, Asouti and Austin, 2005, Asouti and Hather, 2001, Barnes, et al., 1998, Condé, et al., 2002, Davis, 1965-1985, Davis, et al., 1988, Deckers and Pessin, 2010, Riehl and Marinova, 2008, Roberts, et al., 2001, Russell, et al., 2007).

Analytical Groups	Key Taxa		Habitats
Open Oak Woodland	Deciduous Oak	*Quercus*	Well drained, upland slopes and foothills. Plateaus and mountain slopes 800m to 2,000m
Pine Forest	Pine	*Pinus*	Well drained upland slopes. Mountain slopes 1,100m to 2,700m
Riparian	Willow/Poplar	*Salix/Populus*	River banks, wet valleys and gullies, and lake sides
	Elm	*Ulmus*	
	Tamarisk	*Tamarix*	
	Reed	*Phragmites*	
	Ash	*Fraxinus*	
Minor Taxa (shrubs, fringe)	Rose Family Indet.	Rosaceae	Steppe and flat areas, rocky foothills, outcrops and dry plains. Open well drained, gullies. Mountain slopes, high plateaus
	Apple sub-family	Maloideae	
	Plum	*Prunus*	
	Dogwood	*Cornus*	
	Hackberry	*Celtis*	
	Buckthorn	*Rhamnus*	
	Juniper	*Juniperus*	
	Maple	*Acer*	
Exotic	Holly	*Ilex*	Euxine element, humid woodland
	Fig	*Ficus*	Rocky outcrops and fast flowing streams. Humid rocky areas
	Olive	*Olea*	Limestone slopes and crags. Warmer coastal conditions

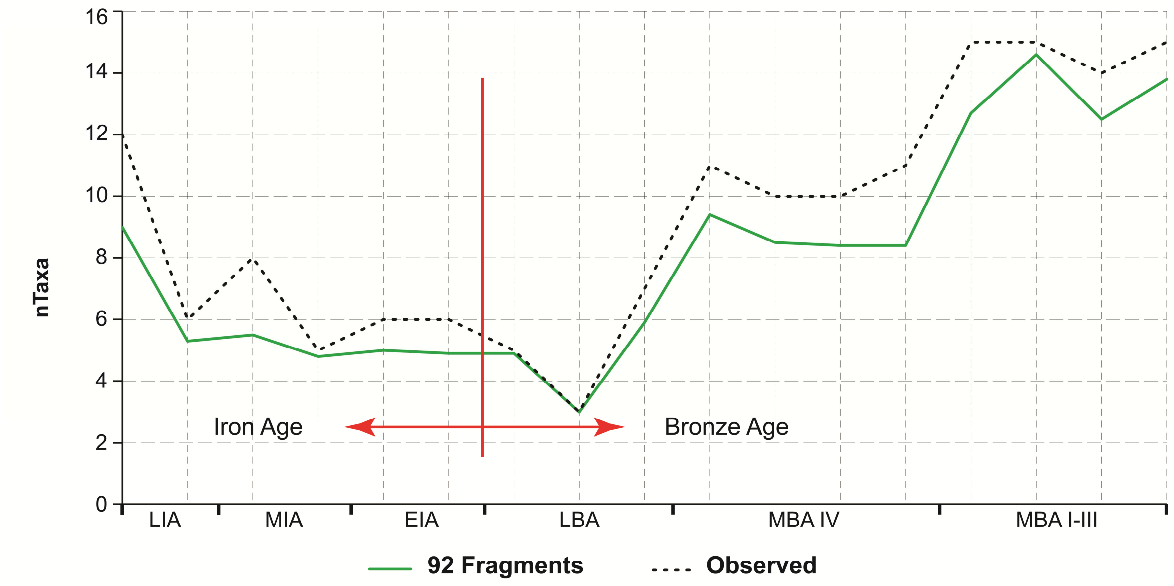

A
Kızılırmak
0 100 200 Km.
Key
1 - Kaman-Kalehöyük
2 - Ankara
3 - Gordion
4 - Hattuşa
5 - Eski Agıcöl
6 - Nar Gölü
7 - Beyşehir Gölü
8 - Ghab Valley
9 - Lake Van
River / stream
N
B
Aşilik Dağ
1321
1050
Kaman-Kalehöyük
Aktan Dere
Çağırkan
1250
1000
Başköy
1555
Baran Dağ
1677
0 1 2 Km.
C
Rainfall (mm)
500
400
300
200
1971
Yearly rainfall for the Kırşehir region
2013



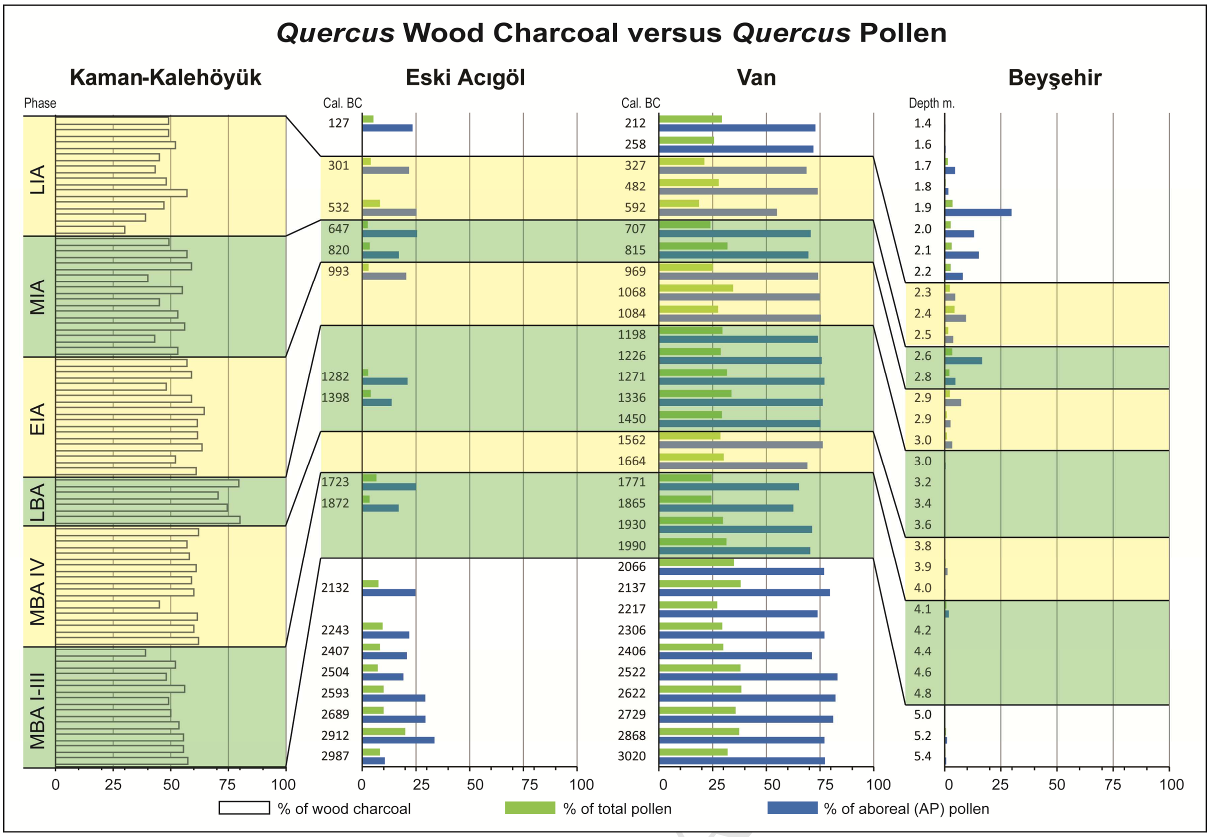
Taxa
Late Iron Age (LIA)
Middle Iron Age (MIA)
Early Iron Age (EIA)
Hittite Empire period (LBA)
Old Hittite Kingdom period (MBA IV)
Assyrian Colony Period (MBA I-III)
Olea
Ficus
Tamarix
Fraxinus
Prunus
Celtis
Phragmites
Rhamnus
Cornus
Acer
Juniperus
Maloideae
Rose Family Indet.
Ulmus
Ilex
Pinus
Salix/Populus
Quercus
Axis 1 (55.3%)
Axis 2 (14.6%)
2
1.5
1
0.5
0
-0.5
-1.5
-1
-0.5
0
0.5
1
1.5
2

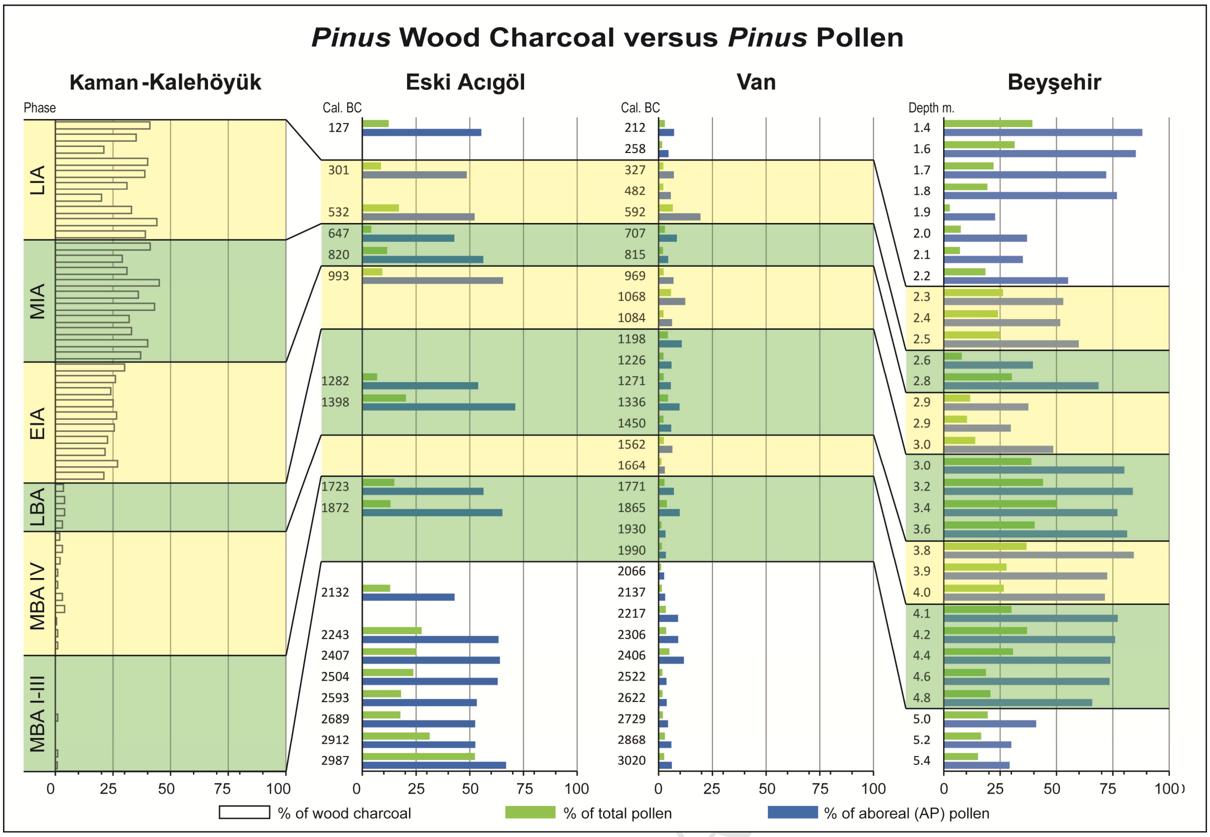


Open Oak Woodland
Pine Forest
Riparian
Minor
Exotic
Quercus
Pinus
Salix / Populus
Ulmus
Tamarix
Phragmites
Fraxinus
Rose Family Indet.
Maloideae
Prunus
Cornus
Celtis
Rhamnus
Juniperus
Acer
Ilex
Ficus
Olea
LIA
MIA
EIA
LBA
MBA IV
MBA I-III
% Abundance



16
14
12
10
8
6
4
2
0
nTaxa
Iron Age
Bronze Age
LIA
MIA
EIA
LBA
MBA IV
MBA I-III
92 Fragments
Observed


Quercus Wood Charcoal versus *Quercus* Pollen
Kaman-Kalehöyük
Eski Acıgöl
Van
Beyşehir
Phase
Cal. BC
Cal. BC
Depth m.
LIA
MIA
EIA
LBA
MBA IV
MBA I-III
% of wood charcoal
% of total pollen
% of aboreal (AP) pollen


Pinus Wood Charcoal versus *Pinus* Pollen
Kaman-Kalehöyük
Eski Acıgöl
Van
Beyşehir
Phase
Cal. BC
Cal. BC
Depth m.
LIA
MIA
EIA
LBA
MBA IV
MBA I-III
127
301
532
647
820
993
1282
1398
1723
1872
2132
2243
2407
2504
2593
2689
2912
2987
212
258
327
482
592
707
815
969
1068
1084
1198
1226
1271
1336
1450
1562
1664
1771
1865
1930
1990
2066
2137
2217
2306
2406
2522
2622
2729
2868
3020
1.4
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.8
2.9
2.9
3.0
3.0
3.2
3.4
3.6
3.8
3.9
4.0
4.1
4.2
4.4
4.6
4.8
5.0
5.2
5.4
0 25 50 75 100
0 25 50 75 100
0 25 50 75 100
0 25 50 75 100
% of wood charcoal
% of total pollen
% of aboreal (AP) pollen

Woodland modification in Bronze and Iron Age central Anatolia: An anthracological signature for the Hittite state?

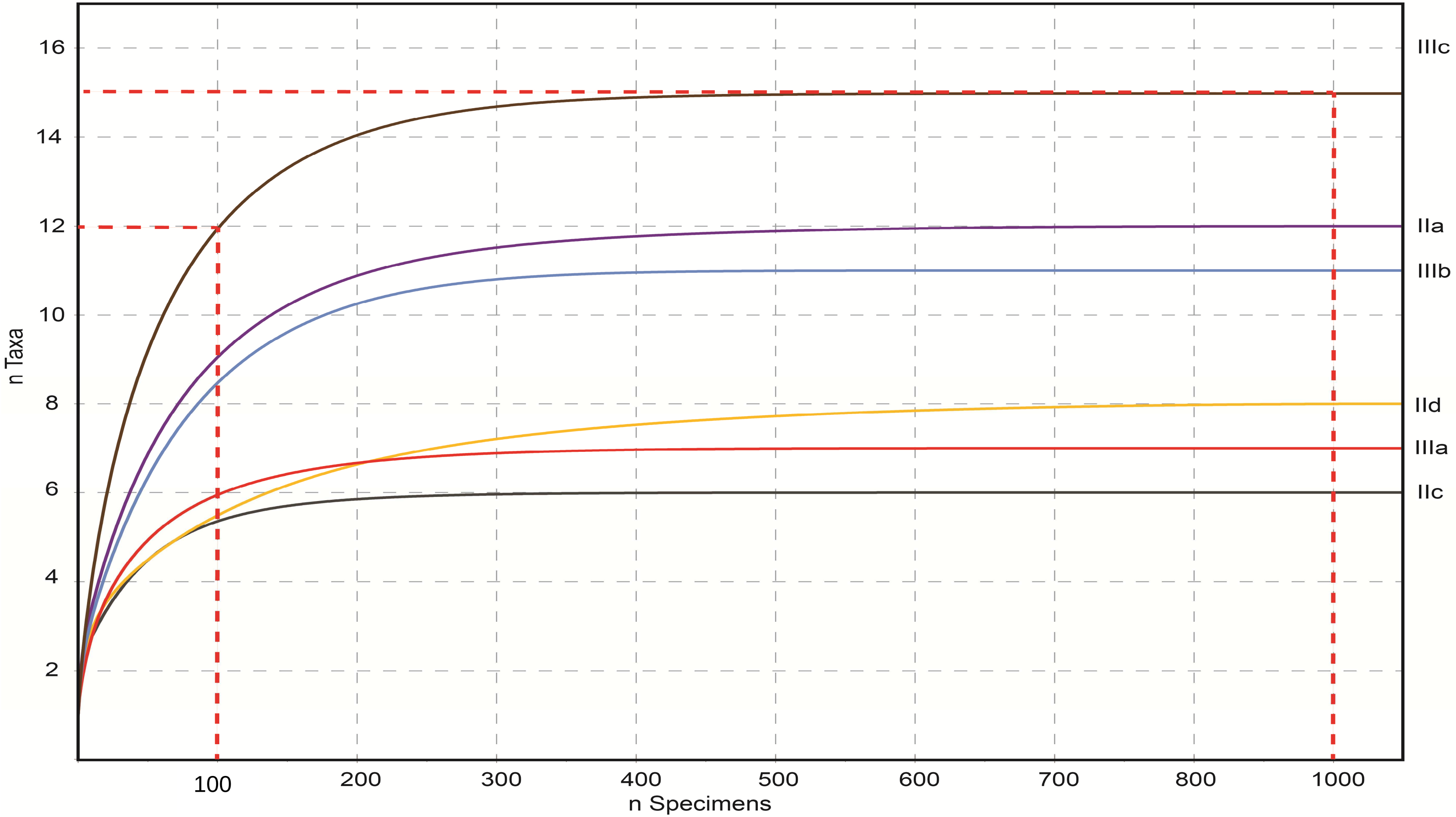
Nathan J. Wright[a], Andrew S. Fairbairn[a] and J. Tyler Faith[a] and Kimiyoshi Matsumura[b]

HIGHLIGHTS

- We analyse 54 wood charcoal contexts from Kaman-Kalehöyük Turkey.
- Taxa richness declines during the Late Bronze Age and into the Iron Age
- A shift to pine occurs at the beginning of the Iron Age
- Oak is dominant throughout the sequence
- An anthracological signature for the Hittite occupation is detected

Supplementary Table 1: Rarefied data for those samples where more than 200 fragments were analysed. Rarefaction was used for comparing richness in samples of different sizes (Bush et al. 2004). This table shows the estimates of how many taxa are expected to be found in a sample with a smaller total number of individuals. Typically rarefication of the larger samples down to a sample size equivalent to the smallest occurs, which in this case is 92 fragments.

Number of fragments	Kaman Stratum																
	IIa	**IIc**	**IId**	**IId**	**IId**	**IId**	**IIIa**	**IIIa**	**IIIa**	**IIIb**	**IIIb**	**IIIb**	**IIIb**	**IIIc**	**IIIc**	**IIIc**	**IIIc**
50	6.8	4.5	4.5	4.3	4.2	3.9	4.4	2.9	4.9	7.1	6.6	6.3	6.3	9.7	11.2	9.9	10.6
75	8.1	5.0	5.0	4.6	4.7	4.5	4.8	3.0	5.5	8.4	7.7	7.5	7.5	11.5	13.3	11.5	12.6
92	**9.0**	**5.3**	**5.5**	**4.8**	**5.0**	**4.9**	**4.9**	**3.0**	**5.9**	**9.4**	**8.5**	**8.4**	**8.4**	**12.7**	**14.6**	**12.5**	**13.8**
150	10.2	5.7	6.2	5.0	5.6	5.6	5.0	3.0	6.4	10.5	9.6	9.6	9.6	14.2	15.0	13.5	14.9
187	10.9	5.9	6.6	5.0	6.0	6.0	5.0	3.0	6.7	11.0	10.0	10.0	10.2	14.6	15.0	14.0	15.0
250	11.3	5.9	7.0						6.8				10.6	15.0			
500	11.9	6.0	7.7						7.0				11.0	15.0			
750	12.0	6.0	8.0						7.0				11.0	15.0			
950	12.0	6.0	8.0						7.0				11.0	15.0			
Difference (max-92)	3.2	0.7	2.5	0.2	1	2.1	0.1	0	1.1	1.4	1.5	1.6	2.6	2.3	0.4	1.5	1.2



Supplementary Fig. 1: Rarefaction curves for the six samples, one from each phase, with 1000 fragments analysed. The red dashed lines offer an example of the differences in taxa observed at different sampling efforts. In this case, 15 taxa could be expected to be observed at 900 fragments sampled while approximately 12 would be expected at 100 fragments sampled.