Title: *Identification of woodland management practices and tree growth conditions in archaeological fuel waste remains: a case study from the site of Çatalhöyük in central Anatolia, Turkey*

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Abstract: This paper presents the results of dendroanthracological analyses conducted on the anthracological assemblage retrieved from Neolithic and Chalcolithic occupations excavated at Çatalhöyük (central Anatolia, Turkey). Besides standard botanical identification of the charcoal macroremains, a range of anatomical features were also recorded including the presence of fungal decay, traumatic growth, tyloses and discontinuous growth rings. The qualitative assessment of growth ring curvature (following Marguerie and Hunot 2007) was supplemented by quantitative estimations of minimum wood diameter (following Paradis et al. 2013) alongside sequential ring width measurements. Botanical identifications, dendroanthracological features and quantitative measurements obtained from individual charcoal fragments, were analysed using multivariate statistical techniques. These permitted assessing the relative importance of wood size, type and species in prehistoric fuel selection, and obtaining a detailed view of environmental and management impacts on prehistoric woodland growth conditions. The results of this work indicate the deep antiquity of woodland management practices in the semi-arid continental regions of Southwest Asia dating as early as the Neolithic period.

Keywords: dendroanthracology, charcoal analysis, woodland management, Neolithic, Çatalhöyük

1. Introduction

Beginning with its earliest applications, anthracology has been increasingly concerned with the question of human impacts on woodland environments (Western 1969, Salisbury and Jane 1940). Some early work focused on taxon identifications and shifts in the relative proportions of taxa used as fuel, thereby indicating shifts in woodland composition (e.g., Chabal 1992, Chabal 1994 and Chabal 1997 see also review by Asouti and Austin 2005). Contemporary anthracology seeks to reconstruct woodland management practices through the integrated study of taxon identifications, estimates of the minimum diameter of wood and the condition of fuelwood (cf., Dufraisse 2008, Marguerie and Hunot 2007). The importance of wood size and condition in fuelwood selection is also confirmed by various ethnographic and experimental accounts (cf., Asouti and Austin 2005, Alix and Brewster 2005, Dufraisse et al. 2007, Henry and Théry-Parisot 2014, Théry-Parisot et al. 2010) which demonstrate that the calibre and condition (e.g., deadwood, green/seasoned wood) of the wood collected as fuel can be as important determinants of fuel selection as the (real or perceived) burning qualities of the different tree or shrub species. In addition to this, woodland management practices such as coppicing, pollarding, shredding, transplanting and other silvicultural applications exert long-lasting impacts on the structure and composition of woodland vegetation. Thus detecting the wood anatomical signatures of such practices in archaeological fuel wood waste remains is a topic of perennial interest in anthracology. Cyclical cutting, control of species composition and structure are documented in a wide range of broadleaved woodlands in Europe and Southwest Asia (cf., Peterken 1981, Rackham 2001, Asouti and Kabukcu 2014) and, more rarely, in slow-growing coniferous woodlands (Asouti and Kabukcu 2014: Fig. 13). This paper presents the results of the systematic application of a wide range of techniques employed in anthracology for assessing woodland growth conditions, and preferences with regard to species, size and condition of fuel logs, to secondary fuel wood waste and *in situ* hearth charcoals from Çatalhöyük. The excellent preservation of this large, multi-period anthracological assemblage rendered Çatalhöyük an ideal case study for testing, in a systematic manner, the applicability of these approaches.

In anthracology, the identification of woodland management practices (commonly limited to the detection of coppicing) focuses primarily on quantitative and/or qualitative estimations of wood calibre. It is argued that the preservation of a uniformly narrow range of stem diameters constitutes evidence of coppicing, which is frequently found in charcoal assemblages derived from construction timber and charcoal production kiln fires (e.g., Nelle, 2002, Dufraisse 2008). On the other hand, woodland management practices for domestic fuelwood production include a diverse array of harvest strategies, which invariably result in the production of equally diverse wood diameter classes. Furthermore, as fuelwood waste is subject to a series of taphonomic filters, including conditions in various fire installations and post-depositional alterations, the minimum wood diameters reconstructed from charcoal remains may be smoothed, thus limiting the value of diameter estimations as a tool for reconstructing past woodland management practices. In addition, detailed evaluations of growth-ring width series have been predominantly applied to timbers from historical buildings and kiln charcoal fuel; by contrast, their application to fuelwood remains has been piecemeal (Billamboz 2003, Deforce and Haneca 2015). The Çatalhöyük anthracological assemblages, including a representative assemblage of well-preserved fuel waste remains from different hearth types accumulated over long periods of time, present a unique opportunity to test the applicability of these methods for assessing charcoal taphonomy and reconstructing prehistoric domestic fuel wood production and use.

It is often difficult to differentiate between the impacts of woodland management practices such as coppicing, pollarding, shredding, lopping, etc. and environmental impacts on wood anatomy (e.g., through fluctuations in rainfall and ground moisture, defoliation caused by browsing, disease and pests, fire damage, etc.). This situation is further compounded by intra-specific variation that characterises the wood anatomical structure of seedlings, shoots (long and short) and stems. Various studies of managed woodlands (e.g., Rozas 2003, Corcuera et al. 2006, Schweingruber 2007, Copini et al. 2010, Altman et al. 2013, Deforce and Haneca 2015) have demonstrated that management practices impact on wood anatomy by enhancing or hindering annual growth (expressed as fluctuations in growth-ring width) independent of environmental fluctuations. For example, coppicing often involves mixtures of coppice stools and standards (large, mature trees). Generally, shoots growing from cut down coppice stools have wider growth rings and larger vessel diameter compared to seedlings. After a cycle of thinning, the remaining trees experience improved growth conditions with an abrupt increase in ring width (referred to as "growth release periods"; cf. Schweingruber et al. 1990, Corcuera et al. 2006, Altman et al. 2013, Schweingruber 2007). This growth release is sustained for 5-10 years during which time ring width remains substantially higher than average growth years. By contrast, in the years leading up to a cycle of thinning, a majority of the sprouts and stems of coppice stools display reduced growth rates, due to high canopy density causing increased competition for light and nutrients. This is described as a "growth suppression period" (cf. Schweingruber et al. 1990, Rozas 2003, Bleicher 2014). Pollarding, pruning and browsing will result in a sudden reduction of growth rate due to trauma and defoliation and subsequent return to normal growth, (Thiébault 2006, Schweingruber 2007: 139). Characteristic anatomical features associated with trauma and stress include series of successive very narrow growth rings with missing latewood, false rings, callus and scar tissue, collapsed vessels, fibres, tracheids, and traumatic canals/gum deposits. In the context of prehistoric Southwest Asia, such features had never been systematically recorded in anthracological research before their large-scale application to the wood charcoal assemblage from Çatalhöyük, which provided a unique window into the nature of environmental and human impacts on prehistoric woodland growth conditions and ecology.

2. Regional setting

Çatalhöyük is located in the Konya plain, south-central Anatolia (Figure 1). The present-day continental climate of the Anatolian Plateau gives rise to a predominantly semi-arid steppe vegetation also impacted by millennia of human settlement and economic activities, especially pastoral production (Fırıncıoğlu et al. 2007) (Figure 2). The Konya basin floor (~1000 m a.s.l.) is formed by the now dry bed of the late Pleistocene Konya palaeolake (Driessen 1970) and is surrounded by mountain ranges. During the Holocene, extensive alluvial deposits carried by the Çarşamba and May rivers entering the Konya Plain from the north-facing slopes of the Taurus mountains to the south of the plain, created fan-shaped landforms deposited directly on the former palaeolake bed (Boyer et al. 2007). The Çarşamba and Selerecki alluvial fans were host to the Neolithic settlements of Çatalhöyük and Can Hasan III respectively.

The Neolithic höyük (Çatalhöyük East mound) is one of the largest in Southwest Asia (~13 ha) and was occupied between ~7.1-6ka cal BC (Figure 3). It was formed by superimposed rectilinear mudbrick structures, built in agglutinated 'neighbourhoods' that typify the late aceramic and ceramic Neolithic habitations of central Anatolia (Düring 2006). Successive excavations at the site have identified several occupation phases: 12 levels (I-XII) as identified by Mellaart's excavations and 14 phases (G-T) in the South Area, 5 phases (F-J) in the North area and 7 phases in the TP Area (M-S) identified by the Hodder excavations (Hodder 2014). The Chalcolithic Çatalhöyük West mound lies just 300 metres to the west of the Neolithic mound and dates to ~6ka-5.5ka cal BC (Marciniak and Czerniak 2007) (Figure 3).

3. Material and methods

3.1 Sample selection and laboratory analysis methods

As the main objective of the study was to characterise fuel use and management practices, samples for analysis were selected from 2 groups of contexts: *in situ* burning deposits and secondary midden/waste disposal areas. From a fuel use perspective, short-lived contexts and/or primary deposition contexts (e.g. hearths, fire spots) are likely to represent the remains of their last episode of use, thus providing a unique snapshot of fuel use practices and also holding great potential for understanding the different combinations of fuel types used. On the other hand, deposits accumulated in the long term (e.g., middens, building infills and other contexts containing dispersed charcoal scatters; cf. Chabal 1992, Chabal et al. 1999) are likely to contain charred fuel refuse derived from multiple episodes of discard. In the context of Çatalhöyük, it has been argued that the daily cleaning and disposal of fuel waste would have resulted in a mostly homogenous accumulation of year round fuel use, thus reflecting long-term fuel preferences and consumption patterns through the lifetime of the site (Asouti 2005, 2013).

In the present study, wood charcoal fragments were analysed from a total of 93 contexts (50 midden, 43 hearths and firespots) representing all excavated phases in the Çatalhöyük East and West mounds from which charcoals were available for analysis. The “dispersed charcoal” assemblage from Çatalhöyük East mound (Neolithic) comprises 39 midden contexts (encompassing phases South G-T and TP) yielding 2306 identified and 337 indeterminate fragments. No verifiable midden samples were available from South N; therefore this phase is not represented in the present study. A further 39 primary fire features were also analysed from South P, South Q, South R and South S from Çatalhöyük East, which yielded 953 identified and 49 indeterminate fragments. From the West mound (Chalcolithic) anthracological assemblage 11 “dispersed charcoal” contexts were analysed, including midden-like deposits, building infill and floor deposits. A further 4 primary fire features were analysed from West mound resulting in 53 identified and 3 indeterminate fragments. Due to the low resolution of the phasing and the low density of the charcoal materials observed in the West mound assemblage, it is presented here as a single phase.

Charcoal fragments were sorted with the aid of a GXMMZS0745TL-R Zoom stereomicroscope. Depending on their size, wood charcoals were either hand- or pressure-fractured with a carbon steel razor blade in order to produce a fresh section in all three anatomical planes (transverse, radial longitudinal and tangential). Each section was examined under a high power, epi-illuminating BF/DF Brunel ICM 110M metallurgical microscope at magnifications of x50, xl00, x200, x400 and x500. Botanical identifications (commonly to genus or family level) were made by using published identification manuals, dichotomous wood anatomy keys and wood anatomical descriptions of specimens from Southwest Asia and Europe (Western 1969, Fahn et al. 1986, Schweingruber 1990, Greguss 1955, 1959, Akkemik and Yaman 2012, Crivallero and Schweingruber 2013). Furthermore, archaeological charcoals were compared to the modern wood charcoal reference collection and the thin sections wood reference collection held in the Archaeobotany Laboratory of the University of Liverpool. For each botanically identified specimen the presence/absence of the following features was also recorded: pith, bark, tyloses, fungal hyphae, resin canals, gum deposits, callus/scar tissue, boreholes, collapsed vessels or tracheids, narrow growth rings, false growth rings, tension/reaction wood, radial cracks and mineral deposits. These are discussed in greater detail below.

3.2 Dendroanthracological **analysis methods**

3.2.1 Diameter estimation and calibre of wood

The ring curvature estimation criteria originally developed by Marguerie (1992) and Marguerie and Hunot (2007) classify growth rings into three groups: Curvature Degree (CD) 1: weakly curved rings; CD 2: moderately curved rings; and CD 3: strongly curved rings. The definition of curvature classes is based on the observation that small branches and twigs have strongly curved growth rings while moderately large stems have CD 2 and large mature stems CD 1 growth rings. This method for the assessment of wood diameter has been criticised by some authors as insufficient; curvature degree determination is done based on arbitrarily set classifications and can be misleading in specimens with abnormally narrow growth rings (see especially discussion in Paradis et al. 2013). However, a significant practical advantage of the CD method is that it can be performed quickly and concurrently with standard botanical identifications. It therefore provides an expedient tool for assessing overarching trends in charcoal taphonomy. In the present study, CD (1-3) classification was recorded for each identified specimen.

In order to produce more precise estimations of minimum wood diameter ranges, the “trigonometric tool” of radius calculation developed by Paradis et al. (2013) was also applied to select specimens from each sampled context (see also Fig. 4). The trigonometric method of calculating wood radius provides a minimum estimate of the radial distance from the notional pith (i.e. from the centre) to the outermost preserved growth ring on a given specimen. In the present paper this method of estimation was used following the guidelines set out by Paradis et al. (2013) and a minimum diameter estimation was achieved by multiplying the radius calculation (i.e. distance from pith) by 2. While it is acknowledged that such a calculation assumes perfectly symmetric growth, the method nevertheless provides a satisfactory summary assessment of the range of wood diameters preserved in a given anthracological assemblage.

The application of the trigonometric tool requires the detection and demarcation of two rays in the transverse section, preferably across a width of >4mm in order to ensure reliability of results (Paradis et al. 2013). In the present study the purpose of the diameter calculations was first to test the reliability of qualitative diameter estimations and secondly to provide a more precise method of assessing wood diameter in order to evaluate growth ring-width measurements (e.g., for discriminating between fast-growing shoots and saplings, vs. slow-growing trunk wood). Four of the most ubiquitous taxa (i.e. taxa present in a majority of samples per phase) across the assemblage (*Quercus*, *Celtis*, *Ulmus* and *Fraxinus*) were selected for quantitative diameter estimation and recording sequentially measured growth ring-width. These taxa were selected because of the requirement to have diameter estimations covering all or most phases of occupation. Another reason for selecting them was the ease of observations of their rays on the transverse section, and the size of the preserved fragments (normally >4mm). By contrast taxa such as Salicaceae and *Juniperus* have very narrow rays, that may be difficult to discern and photograph at the required resolution with a stereozoom microscope, especially in small specimens and/or characterised by high degree of degradation (e.g., collapsed vessels and fibres as was frequently the case with Salicaceae at Çatalhöyük; or wavy growth ring boundaries as was the case with *Juniperus* which was also characterised by very short rays, normally 2-4 cells high). For all these reasons Salicaceae and Juniperus were excluded from quantitative diameter estimation measurements. The transverse sections of *Quercus*, *Celtis*, *Ulmus* and *Fraxinus* specimens preserving at least 3 growth rings and 2 clearly visible rays were photographed using a 5-megapixel digital microscope camera attached to a zoom stereomicroscope at magnifications x7-x45. From each charcoal sample, up to 10 fragments (>5mm) were selected for study.

Tyloses are overgrown parenchyma cells which spread through pitting on vessel walls filling in the vessel cavity (Wilson and White 1986: 207-211, Taylor et al. 2002). In certain taxa, these are normally absent or in low numbers in the sapwood (i.e., the outer part of the stem wood tissue situated closest to the bark). Thus recording their presence (across the majority of the woody tissue observed) can provide a measure of which part of the stem is most commonly present in the anthracological assemblage. In most taxa, the transition zone from sapwood to heartwood is reportedly brief, represented by 1-2 growth rings (Wilson and White 1986: 208). However, if trees are felled during their active growth season then tyloses may develop in the sapwood as well, or as a result of physical injury (trauma) (Murmanis 1975, Schweingruber 2007). To overcome issues with the presence of traumatic tyloses formation and/or to avoid recording of the heartwood-sapwood transitional zone, tyloses in the present study were recorded as “present” only when they were observed across the majority of the specimen TS surface (across all vessels; i.e., 90-100% of vessels in all growth rings observed; see also Figure 5). Tyloses, presence/absence of pith and bark were routinely recorded for all identified specimens as an additional means of evaluating specimen calibre (i.e., as stem, heartwood or sapwood, twig or branch wood).

3.2.2 Condition of wood

Wood is subject to decay as a result of fungal, bacterial and insect attacks leading to the decomposition of woody tissue, which leaves behind signs of degradation (Blanchette 2000, Schweingruber 2007). Fungal hyphae and mycelium can be identified during microscopic observation of the specimens (Marguerie and Hunot 2007, Moskal-del Hoyo et al. 2010). In addition, insect boreholes and some types of bacterial degradation can also be observed.

Recent ethnoarchaeological work by Henry and Théry-Parisot (2014) suggests that in addition to the presence of fungal mycelia and insect boreholes, wood that has been subject to severe degradation (e.g., rotting) may also display collapsed vessels (hardwoods) and tracheids (gymnosperms). Radial cracks may result from seasoning/drying of fuel wood and can become further pronounced as a result of burning (Théry-Parisot and Henry 2012). Prior and Alvyn (1983) have also observed that the incidence of radial cracks is higher in taxa with very wide rays (e.g., oak). In this study, the presence of radial cracks were recorded when these were present across all growth rings under observation. Heavy mineral deposits on wood charcoal fragments and/or permineralisation may more strictly relate to post-depositional processes resulting from prolonged burial of charcoal fragments in acidic soils (Rebollo et al. 2008). The presence of deadwood, collapsed anatomical features, and radial cracks were regularly recorded for all identified anthracological specimens.

3.2.3 Ecophysiological tree-ring attributes

Compression wood (conifers) or tension wood (hardwoods) is formed under severe mechanical stress (e.g., wind exposure) prevailing during the growth season (Timell 1986, Schweingruber 2007: 127-137). The resulting eccentricity of growth rings and the formation of reaction wood are specifically related to mechanical stress. Eccentric growth was recorded with observations on the transverse section. These observations in coniferous wood were verified by observations of helices on cells (40°-45° angles) observed the radial longitudinal sections (as reported in Marguerie and Hunot 2007). Open wounds (e.g., from bark stripping) will cause increased cell formation and cell wall thickening, as well as a change in fibre direction, all of which result in the accumulation of scar tissue. Callus tissue formation and radial overgrowth are commonly observed during the re-growth and recovery of the tree following events such as bark scarring caused by cutting, lightning, fire, bark stripping, frost and hail damage, twigs and/or needle shedding etc. (Schweingruber 2007: 139-178; 188). Similarly, traumatic resin canals in conifers (gymnosperms) and traumatic gum ducts in angiosperms (hardwoods/broadleaves; e.g., members of the Rosaceae and Anacardiaceae families such as *Amygdalus* and *Pistacia*) can also be formed in response to ecological factors including spring frost and other extreme weather conditions, and defoliation by insects (Schweingruber 2007: 85, 182, 187). *Juniperus*, the only coniferous taxon identified in the Çatalhöyük assemblage, does not normally form resin canals; therefore their presence is considered to be an indication of environmental and/or biological disturbance-related stress.

3.3 Data analysis and statistical methods

Dendroanthracological features recorded as categorical variables were analysed using Multiple Correspondence Analysis (MCA) and Multiple Factor Analysis (MFA) (R, version 3.1.1, package ‘FactoMineR’). MCA as an ordination technique is particularly suited to the analysis of multiple categorical variables, and results in a reduction of dimensions in a complex dataset (Greenacre and Pardo 2006). The dendroanthracological dataset was analysed by treating individual charcoal specimens as data points (with a unique identifier) in order to examine the co-occurrence of individual dendroanthracological features and taxa. In addition to examining the distribution of individuals, it is also possible to evaluate the relationships between categories and supplementary variables (e.g. phase, context type) in the resulting biplots of the MCA. These are interpreted similarly to the results of CA, by taking into account the 2-dimensional representation of individuals plus variables, eigenvalues, contribution to dimensions by categories, and cos2 values (Husson et al. 2011: 127-169).

Multiple Factor Analysis (MFA) was applied to per-sample charcoal taxon counts, and per-sample counts of the presence of each dendroanthracological feature, thus comprising a data matrix of taxon composition and dendroanthracological features. The aim was to explore the main components of the samples with regard to the co-occurrence of taxon abundance and the qualitative attributes of specimens (i.e., presence of fungal hyphae, tyloses, etc.) MFA relies on principles similar to Principal Components Analysis (PCA) in ordination, but it allows for distinct groups of variables to be evaluated separately (Bécue-Bertaut and Pagès 2008, Escofier and Pagès 2008). This permits the simultaneous evaluation of inertia in a dataset where a number of different observations have been made on the same individuals (i.e., samples/units). Thus the results remain unaffected by differences in the quantification of distinct groups of variables (Escofier and Pagès 2008: 149-205).The results are evaluated similarly to PCA, whereby a map of variables (factors) represented in 2-dimensional space, reflects the nature of the relationship between different sets of variables. The plot of variables (and groups of variables) signifies a perfect correlation between variables if the arrows representing them overlap. A perfectly inverse relationship between variables is inferred when the arrows of two variables are at a 180° angle (i.e., they form a straight line). No significant relationship is deduced when the angle between the two variables is at 90°. These geometric representations are interpreted by taking into account the correlation between the estimate and the original dataset, and the contribution of individual variables to dimensions.

4. Results

A range of 21 different taxa were identified in the Çatalhöyük East and West mound assemblages, adding to the growing body of anthracological analysis from other late-Pleistocene and Holocene archaeological sites in south-central Anatolia (Asouti 2005, 2013). As this paper focuses primarily on the assessment of dendroanthracological methods and the reconstruction of prehistoric woodland management practices, a detailed discussion of the taxon composition of the anthracological assemblages will be presented elsewhere. Here it I sufficient to note that the earliest occupation levels at Çatalhöyük comprise predominantly Ulmaceae remains, with a later switch to deciduous *Quercus*. In the mid to late-Neolithic levels *Juniperus* becomes the more commonly used fuelwood, with a renewed surge of Ulmaceae during the later TP and West mound sequences. In turn, these broad shifts in the fuel economy likely reflect not only changes in woodland vegetation, but also spatial and temporal changes in subsistence-related economic activities in the landscape (Kabukcu 2015, Asouti and Kabukcu 2014).

4.1 Wood calibre and diameter estimations

Qualitative dendroanthracological analyses at Çatalhöyük yielded a large dataset of a broad array of dendroanthracological features (see Table 1 for a summary). The results of CD growth ring classification indicate that across all contexts the majority of the fragments are characterised by moderately curved rings (CD2). The distributions of CD classes were similar across all sampled phases. The highest frequencies of CD1 fragments (weakly curved, likely indicating largest diameter ranges) amongst all taxa are observed for *Quercus*, it should be noted however CD1 fragments were observed in very low numbers (Table 1). Furthermore, a majority of the fragments from *Quercus*, along with *Juniperus* and *Ulmus*, belong to CD2 (moderately curved). This distribution of CD classes suggests the presence of medium/large calibre wood from these taxa. By contrast fruit/nut bearing taxa such as *Amygdalus*, *Pistacia*, Maloideae and *Celtis* consist predominantly of CD3 specimens, suggesting their use mostly in the form of smaller sized branches and twigs. These observations are in agreement with previous qualitative observations on the same taxa from Çatalhöyük (see Asouti 2005, 2013). In addition *Juniperus*, Ulmaceae, Salicaceae and *Fraxinus* include numerous fragments that were not assigned a CD class due to their small size and/or poor preservation, or the specific qualities of their wood anatomy. The latter was often the case with *Juniperus* that does not have clearly visible rays in the transverse section and contains mostly narrow growth rings, sometimes including false rings, or naturally wavy ring boundaries. Salicaceae growth ring boundaries were often indistinct, particularly in dead/decayed wood; thus estimating CD for Salicaceae fragments (even large ones) was often not feasible. Interestingly, some primary fuel waste debris contexts (fire spots) from South P (mid-Neolithic) contained proportionally higher numbers of twigs preserving pith and/or bark, which suggests that the preservation conditions in some of these contexts were particularly favourable. One such outdoor burning context (17082) contained a large number of Ulmaceae and Salicaceae twigs alongside Leguminosae and *Artemisia* fragments with pith and bark partially preserved.

Across all categories of qualitative features recorded, the most frequently observed feature was the presence of tyloses in both dispersed and primary fuel waste deposits (1802 and 620 observations respectively) (see Table 1). Alongside the prominent presence of CD2 specimens, the high frequency of tyloses in the assemblage suggests the preservation of heartwood in higher quantities.

Quantitative diameter estimation techniques were applied to a sub-sample of the specimens which were recorded through qualitative dendroanthracological analyses (CD classes) (see Figure 6). These included 150 specimens belonging to *Quercus*, *Fraxinus*, *Ulmus* and *Celtis* from midden contexts covering all phases of the Çatalhöyük East mound sequence and the West mound assemblage, plus 32 specimens of the same taxa from primary fuel waste contexts from South P, Q and R. Interestingly, in midden contexts *Fraxinus*, *Ulmus* and *Celtis* are represented with a wider range of diameter sizes compared to their representation among primary fire features. While *Quercus* fragments are also represented with a wide diameter range in midden contexts, some fire features provided very large diameter size estimations for this taxon (>400mm). However, generally, for all taxa to which quantitative dendroanthracological analyses were applied, large diameter sizes (>200mm) were rare; these rare measurements most likely represent the limit of validity for trigonometric tool diameter estimations (Paradis et al. 2013).

Lastly, a direct comparison of the results of qualitative (CD classes) and quantitative (trigonometric tool) diameter estimation methods facilitates the evaluation of the potential of the former for approximating the size and calibre of the wood preserved as charcoal in the archaeological deposits. Figure 6 shows that, despite the presence of outliers, there is a clear separation in the ranges of values represented by different CD classes for *Fraxinus* and *Celtis*. For all taxa, CD3 (strongly curved) covers approximately a minimum diameter range of 3.5 to 40mm (excluding outliers at 107mm and 184mm). There seems to be a wider range of measurements and more overlap between CD2 and CD1. CD2 represents specimens ranging from 8mm to 189mm (excluding outliers at 281mm, 219mm and 4mm) while CD1 covers a range from 14mm to 425mm (with a theoretical upper-end of 425mm, assuming that ranges >250mm are not reliable as suggested by Paradis et al. 2013). One of the possible explanations for this overlap in diameter sizes could have to do with the extremely narrow growth rings observed on some specimens, which could alter the growth ring morphology (and therefore the curvature of the growth ring) regardless of diameter. In addition to this, it is possible to observe a discrepancy between CD1 classifications for *Ulmus* and *Quercus* and their corresponding trigonometric tool diameter estimations: in Ulmus, and to a lesser extent in Quercus CD1 classifications appear to underestimate diameter compared to the trigonometric tool (see Figure 6). A possible explanation for this may lie in the wood anatomical characteristics of growth suppression, resulting in narrower and flatter growth ring boundaries (e.g., Figure 7.4). In turn, this situation might arise more frequently in taxa that were subjected to browsing and/or wood cutting pressures over a number of years.

4.2 Condition of wood

Evidence for fungal decay of wood prior to charring is abundant in the assemblage, with observations of fungal hyphae very common in both discarded fuel waste and in situ burning deposits (see Table 1). On the other hand, potential indicators of more severe fungal degradation such as collapsed vessels/tracheids and insect bore holes were less frequently observed. This combination of features suggests that if deadwood was collected, these logs were either monitored in order to ensure controlled drying (e.g., seasoning of cut wood) and/or if naturally occurring deadwood was collected, then the period of decay was limited to a shorter duration (1-2 years). In addition, radial cracks and mineral deposits were also rarely observed. The low occurrence of mineral deposits in charcoal agrees with the overall state of charcoal fragments at the site, suggesting that weathering of charcoal fragments were not severely detrimental to preservation.

4.3 Woodland growth conditions indicators

Evidence for ecological stress and/or trauma to woody tissue was fairly common in the assemblage (see Table 1). Resin canals/gum ducts, narrow growth rings, false/discontinuous growth rings were found in similar proportions in dispersed and primary fuel waste contexts. Through time resin canals, narrow and discontinuous rings were more commonly observed in the later phases at Çatalhöyük, predominantly due to the fact that these features were observed generally in *Juniperus* specimens (which are more abundant in the later phases). Other growth anomalies such as tension/reaction wood, knot wood, and scar/callus tissue were recorded at much lower frequencies across the assemblage.

In order to assess the variability of growth-ring width present in the assemblage, average, median, maximum, minimum and delta (i.e., delta=minimum ring width subtracted from maximum ring width) ring width measurements for each specimen are plotted against diameter measurements (see Figure 8). They demonstrate that there is a great degree of variability in average, minimum, maximum and median growth ring width, which do not display a strictly unilinear relationship to diameter sizes. A majority of the specimens exhibit average and median ring width <1mm, while a second group (comprising fewer individuals) contains median and average ring width of 1-2mm. Ring-width values are slightly lower in larger diameter specimens. This is commonly observed in aging large trunks whereby growth-ring width is slightly reduced (e.g., by a magnitude of 0.5 mm), however basal area increment remains high. At the same time, the greatest range of variability and delta values in ring width is observed in the <100mm diameter sizes. This distribution of ring width values in smaller diameter specimens suggests that a range of different ecological conditions are represented for specimens of this calibre. Particularly, some specimens with very high ring width values and delta values point to abrupt fluctuations in growth that take place within a short period. Some examples of such specimens, such as those in Figure 7, show the vigorous growth in the first 2-5 years of growth, followed by a sudden and lasting plateau in growth. Alongside such specimens are other specimens with more evenly distributed ring width values and minor fluctuations. Other specimens display average growth rates followed by a sudden abrupt increase in ring width, suggesting response to thinning in the canopy.

4.4 Results of multivariate analyses

The Çatalhöyük charcoal taxon and dendroanthracological datasets collected by the present study were investigated using Multiple Correspondence Analysis (MCA). All charcoal fragments on which dendroanthracological observations were made were included in the analysis as individual data points, while the presence/absence of dendroanthracological features were treated as categorical variables. The first two dimensions account for 24% of the variation observed in the dataset (see Supplementary Table 1a-b). The main factors are curvature degree, pith, bark, tyloses, trauma canals, fungal hyphae and false rings. The factor map (Figure 9) reveals associations between the occurrence of some dendroanthracological features and taxon representation. Traumatic resin canals, false rings and reaction wood are closely associated with Juniperus. On the other hand, in the lower right hand-side of the biplot CD3 (strongly curved, smaller diameter), pith and bark are more closely associated with *Tamarix*, *Capparis*, Leguminosae, *Rhamnus*, Chenopodiaceae, *Artemisia*, Maloideae, Anacardiaceae, *Pistacia*, and *Amygdalus,* and some Salicaceae and Ulmaceae. CD1, although recorded in very low numbers across the assemblage, is more closely associated with taxa which more frequently display tyloses, fungal hyphae, collapsed vessels, mineral deposits and radial cracks. Although there is a high degree of clustering in the centre of the biplot *Quercus*, *Ulmus* and *Celtis* appear to be more closely associated with tyloses, fungal hyphae and collapsed vessels. The MCA biplot confirms some of the descriptive results of the dendroanthracological analysis: there seems to be no significant difference in the range of dendroanthracological features observed in specimens derived from dispersed contexts and fire features. The second dimension of the MCA plot displays predominantly the temporal patterning in the assemblage, with the early-middle phases concentrated in the lower part of axis 2, and the later phases in its upper part. This temporal patterning appears to be due to the co-variation in botanical identifications and the presence/absence of dendroanthracological features. For instance, the presence of tyloses are more restricted to angiosperms such as *Quercus* and *Ulmus*; whereas false growth rings, bore holes and trauma canals are more commonly found in *Juniperus*.

The plot of individuals resulting from this MCA is presented in Figure 10a. Individual specimens were coded according to phase and context type in order to evaluate the presence of temporal and/or context-related (spatial) patterning. Specimens are characterised by similar dendroanthracological qualities regardless of context type, while phases are also more or less evenly represented in both axes. Figure 10b is a biplot of individuals from select taxa: although there is some overlap most *Juniperus* specimens are confined to the right-hand side of axis 1, while most *Quercus* fragments are spread on the left-hand side of axis 1. In order to investigate the dendroanthracological composition of each sample, per-sample counts of dendroanthracological features were converted into a data matrix comprising the sums of the observations recorded for each feature. The resulting 57 samples (with sufficient number of specimens per sample) from midden and fire feature contexts were investigated using Multiple Factor Analysis (MFA). This technique allowed for the treatment of the two datasets (charcoal taxon counts and dendroanthracological features counts) as separate groups; thus inertia within groups could be calculated independently. The first two dimensions account for 65% of the variation observed in the dataset (Figure 11, see Supplementary Table 2a-d). The charcoal dataset and the dendroanthracological dataset contribute equal weights in dimension 1. The main components of the dataset in dimension 1 are tyloses, fungal hyphae, CD3, *Juniperus* and *Quercus* and in dimension 2 Ulmaceae, *Quercus*, CD3 and pith. Confirming the results of MCA, variations in taxon abundance appear to be closely related to variations in the frequency of dendroanthracological features on a sample-by-sample basis. Dimension 1 of the dendroanthracological dataset and dimension 1 of the charcoal taxon count dataset reflect inertia in the same direction, with a relatively narrow angle, thus suggesting a close relationship between the two datasets. Dimension 2 for both datasets is also closely correlated. The main variation in taxon composition is reflected in the nearly perfect inverse relationship between *Juniperus* and *Quercus*, predominantly along dimension 1. The main significant components of dimensions 1 and 2 (Figure 11) demonstrate that *Quercus* is more closely linked to CD1 and tyloses, while Salicaceae and *Ulmus* are associated with collapsed vessels, fungal hyphae and radial cracks. Ulmaceae and *Artemisia* appear to be more significantly related to pith and CD3.

5. Discussion

Wood calibre estimation (both qualitative and quantitative), in combination with the recording of various dendroanthracological features and ring width measurements suggests the presence of twigs, shoots, saplings and developed branch and trunk wood in the fuel assemblage. The variability observed in ring-width values alongside observations of short-ring series in some specimens support the presence of growth suppression in some saplings/shoots (see Figure 7). As reported elsewhere, coppice shoots (or other shoots in response to cutting) tend to result in vigorous growth in the early years of the shoot development (above average for seedling growth) followed by a sudden reduction in growth rate due to competition in the canopy (Deforce and Haneca 2015, Copini et al. 2010, Bleicher 2014). On the other hand, following thinning, remaining saplings and larger trees in managed woodlands may display increased growth rates as a result of reduced competition of nutrients and moisture. There are some specimens in the Çatalhöyük assemblage which likely display such patterns. However, more observations, systematic ring width measurements and a more detailed quantitative wood anatomy study are necessary in order to evaluate these patterns fully. Alternatively, these ring width signatures might indicate the response of individual trees to episodes of thinning of the understorey vegetation in denser woodland stands. Selective thinning of the understorey and the protection of individual trees might also have allowed the development of larger diameter trunks that could have been managed for use as timber. As both *Ulmus* (shade-tolerant, riparian) and *Quercus* (shade-intolerant, semi-arid) specimens display similar variability in growth increment in small to medium diameter categories, it is likely that its underlying causes relate to anthropogenic impacts rather than solely episodes of natural disturbance.

Growth ring width measurements available for *Celtis* indicate that this taxon might have been impacted in similar ways, although a larger dataset is necessary for confirming this pattern. Ecologically, *Celtis* could have grown in both semi-arid woodlands (including Rosaceae-dominated and *Quercus*/*Juniperus*-dominated stands) as well as riparian and/or wetland edge habitats (see Çetik 1985: 254, Asouti and Kabukcu 2014). At Çatalhöyük this is a distinct possibility, considering also the overall wider growth ring width ranges observed for *Celtis* compared to deciduous oaks. The *Celtis* ring width ranges are also more similar to those observed for *Ulmus* and *Fraxinus*. Overall the pattern of ring width measurements observed for *Quercus*, *Ulmus* and possibly *Celtis* too, is more suggestive of woodland management impacts resulting in alternating periods of reduced and enhanced woodland productivity, rather than environmental (e.g., seasonal moisture deficiency) impacts. Observations of scar/callus tissue and radial overgrowth on specimens from the same taxa provide additional confirmation for the existence of impacts on wood anatomy resulting from intentional cutting, pruning and/or debarking. Additional impacts associated with severe defoliation (i.e. successive very narrow and discontinuous (false) growth rings) suggest that both dryland and riparian woodlands were potentially affected by herbivore browsing, although not on a routine basis as their presence was not common in the studied assemblage.

The frequent occurrence of narrow and discontinuous growth rings and traumatic canals in *Juniperus* at Çatalhöyük and also throughout the sampled Konya plain anthracological sequence (including late-Pleistocene Pınarbaşı and early-Holocene Boncuklu; Kabukcu 2015, Asouti and Kabukcu 2014) suggests that, on the whole, *Juniperus* stands grew under considerable environmental stress well into the Holocene. As already mentioned, due to the inapplicability of diameter measurements to this taxon, growth ring width was not systematically measured for *Juniperus* specimens. However, *Juniperus* ring width has been observed to be consistently narrow across all sampled early to mid-Holocene phases. Average growth ring width data available from dendroanthracological samples at Çatalhöyük previously analysed by Newton (1996) and the limited measurements undertaken by Asouti (2013) have indicated very low average ring width values throughout the sampled phases (ranging between 0.25-0.77mm). Newton also noted that the Çatalhöyük juniper specimens she examined, derived exclusively from carbonised timbers with ages ranging between 160-500 years, were generally slow growing (21cm maximum recorded diameter). Newton observed that this growth rate is significantly slower than the rates observed in dendroanthracological specimens obtained from Chalcolithic, Bronze Age and Iron Age sites in Anatolia, while it is also slower when compared to modern juniper populations from southern Anatolia (Newton 1996: 24-25).

In the ecological literature it is reported that the main driver of continuously narrow growth rings (indicating slow growth rates) in *Juniperus* are dry and hot climate conditions during the spring and early summer (Lipschitz et al. 1979, Sass-Klaassen et al. 2008, Liang et al. 2011, Esper et al. 2014). This is due to the fact that the majority of the radial growth in junipers consists of early wood tracheids, which are formed predominantly in spring and early summer. Thus, consistently dry and hot growth seasons will result in very slow growth rates, in addition to a higher frequency of false rings, somewhat independently of average annual precipitation levels. Compared to junipers, the dendroanthracological features of the examined *Quercus* specimens do not indicate equally slow growth rates. This situation likely reflects the ability of deciduous oaks to regulate fluctuations in annual water balance more effectively. Various case studies indicate that the deeper root system of oaks enables them to use more effectively winter precipitation of the previous year, hence allowing relatively uninterrupted early wood formation (Villar-Salvador et al. 1997, Manetti 2002, Cherubini et al. 2003, Corcuera et al. 2004). Junipers on the other hand do not respond in a similar way to increased winter rainfall. Together these anthracological observations on the dendroanthracological properties of *Juniperus* and *Quercus* charcoals provide direct evidence of the pronounced seasonality of early Holocene climate in central Anatolia, which was likely characterised by distinctly dry and hot late spring/summer seasons and winter-focused precipitation. This interpretation is in overall agreement with the central Anatolian (Dean 2014) and other regional palaeoclimatic records (cf. Djamali et al. 2010, Orland et al. 2012).

As presented in the results, the majority of charcoal fragments were classified as CD2 and CD3 (moderately and strongly curved rings respectively) while few fragments were classified as CD1 (low curvature). This distribution of growth ring morphology also agrees with diameter estimation measurements made using the trigonometric tool. Furthermore, the abundance of tyloses in frequently used fuel taxa such as *Quercus* and Ulmaceae, is indicative of the ubiquity of heartwood remains in the anthracological assemblage. More rarely, the transition from heartwood to sapwood and/or sapwood *per se* were also preserved. As indicated by the MCA of the per-specimen observations of dendroanthracological features, and MFA on per-sample composition of taxon abundance and number of observations of dendroanthracological features, a close association exists between CD1, the presence of tyloses and *Quercus*. The descriptive results of curvature degree classification on the other hand show that most of the *Quercus* fragments were classified as CD2 and CD3. Thus, the association of CD1 with *Quercus* demonstrates that when low ring curvature is observed, this is more likely to occur in *Quercus* fragments. The same applies to the presence of tyloses, which further supports the possibility that a majority of the *Quercus* fragments preserved at Çatalhöyük represent heartwood remains. The possible indication following from these observations is that as a result of the fuel use practices at Çatalhöyük (including log-splitting, use of logs in fires and burning efficiency) the great majority of sapwood and the larger diameter portions of the logs originally put into fire are consistently under-represented in the anthracological assemblage. Conversely, smaller diameter portions of fuel wood are consistently over-represented, most likely due to the near-complete combustion of sapwood during burning, in addition to the supplementary use of small-calibre wood (twigs, branches, shoots, etc.) For this reason, the diameter size-classes represented in the anthracological assemblage are skewed towards the preservation of the smaller diameter portions of fuel wood. In the case of Çatalhöyük, it is uncertain whether calibre estimation techniques alone are capable of representing an accurate estimation of the original calibre of the logs harvested and used as fuel wood. These results and interpretations will be further tested by future experimental work in order to evaluate more precisely the preservation potential of different diameter size-classes in anthracological assemblages derived by various hearth types and burning environments.

Lastly, the high frequency of observations of fungal decay in wood prior to charring in the assemblage suggests a distinctive preference for the collection of dry deadwood and/or seasoned wood as fuel. As the results of MFA suggests, samples with a more prominent riparian woodland component (e.g. Salicaceae, *Ulmus*) also tend to contain more evidence for the presence of fungal hyphae and collapsed vessels, both features relating to moderate fungal decay. This inertia in the assemblage could point to the higher deadwood productivity of riparian woodlands used by the prehistoric inhabitants of Çatalhöyük.

6. Conclusions

As highlighted by research into the wood anatomical characteristics of trees in managed woodlands, qualitative and quantitative wood anatomy offers the most suitable tools for the detection and characterisation of woodland management practices. Their applications in anthracology, as briefly reviewed, have so far been limited, particularly on assemblages deriving from predominantly domestic fuel waste. As presented, the results of minimum diameter estimations and ring width measurements demonstrate the possible wood anatomical signatures of management activities and/or controlled cutting cycles in both semi-arid (*Quercus*) and riparian (*Ulmus*) woodlands during the occupation of Çatalhöyük. These inferences concerning woodland management at Çatalhöyük will be tested formally through a future study of growth-ring width patterns in situ carbonised timber specimens from this site. In addition, future work would greatly benefit from measurements of early wood vessel/tracheid size and vessel density, in order to address additional questions regarding the modelling of levels of ground moisture availability and growth season aridity. Moreover, multivariate analyses of the dendroanthracological datasets highlighted the potential taphonomic filters and differential preservation rates of wood calibre classes at Çatalhöyük. Thus, the utility of wood calibre measurements for reconstructing preferred fuel wood diameter and volume and woodland management strategies is questioned.

Further insights into the ecological conditions of woodlands include observations on *Juniperus* remains, demonstrating that this taxon, across all phases of occupation, generally contained more abundant signs of ecological stress, as indicated by the frequent presence of narrow/false rings, traumatic canals and deformed tracheids. With the exception of some taxa that are naturally resistant to fungal infestation (e.g., *Juniperus*) a great majority of the specimens from Çatalhöyük displayed signs of pre-burning decay including fungal hyphae, collapsed vessels and boreholes, suggesting that they were either collected as deadwood and/or stored (on and/or off-site) for a period of time for seasoning prior to burning.

In the context of anthracological research in Southwest Asia, the present study represents the first instance of the systematic, large-scale application of dendroanthracological analyses on wood fuel remains. For arid and semi-arid environments in particular, the utility of well-dated archaeological charcoal sequences for reconstructing woodland composition and the spatial distribution of prehistoric woodland catchments is further emphasised by the preservation limitations of off-site pollen sequences. However, the full interpretative potential of anthracological assemblages as the material residues of people-environment interaction lies in the fact that carbonised wood fuel remains embody the ecological signatures (i.e., the growth conditions and life histories) of the individual trees and shrubs collected as fuel, and of the woodland ecologies they have derived from. Thus, not only taxon presence and frequencies but also the form, function and environmental attributes of woodland growth conditions, and the ways in which they were impacted by human activities, can also be recorded through the analysis of qualitative or quantitative dendroanthracological features. Anthracology provides a unique set of analytical tools with which to disentangle the varied phases of the complex feedback cycles between vegetation, climate conditions and prehistoric woodland management and landscape use practices. In this sense archaeological wood fuel remains represent a category of archaeobotanical data that are exceptionally well-suited for reconstructing the origin and long-term histories of intentionally modified, anthropogenic landscapes.

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Dendrological features		Dispersed contexts		Fire features	
		Count	%	Count	%
	1	137	8.0%	13	2.3%
	2	850	49.4%	319	57.2%
	3	733	42.6%	225	40.4%
	N/A	1048	N/A	437	N/A
Pith		195	7.0%	125	12.6%
Bark		41	1.5%	59	5.9%
Tyloses		1802	65.1%	620	62.4%
Traumatic resin canals/gum ducts		599	21.6%	144	14.5%
Fungal hyphae		1335	48.2%	610	61.4%
Narrow growth rings		424	15.3%	177	17.8%
Radial cracks		145	5.2%	22	2.2%
Collapsed vessels		180	6.5%	37	3.7%
Boreholes		44	1.6%	2	0.2%
Scar/callus tissue		30	1.1%	1	0.1%
Mineral deposits		166	6.0%	75	7.5%
Reaction wood		44	1.6%	9	0.9%
False rings		45	1.6%	10	1.0%
Knots		193	7.0%	60	6.0%
Total number of analysed wood charcoal fragments		**2768**		**994**	

Table 1: Summary of dendroanthracological observations (numbers of fragments exhibiting individual features, i.e., presence of feature) obtained from wood charcoal fragments from dispersed contexts and fire features at Çatalhöyük East and West mounds.

Figures

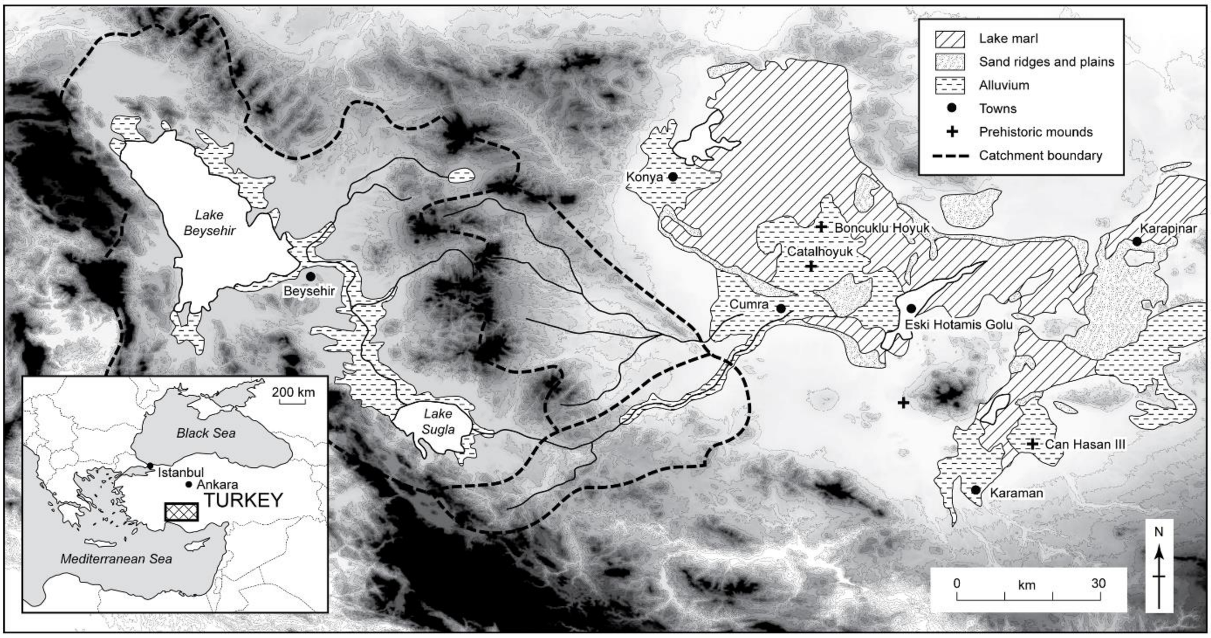

Figure 1 Map of the Konya plain and the Çarşamba river catchment area showing the locations of prehistoric mounds and main landscape units.

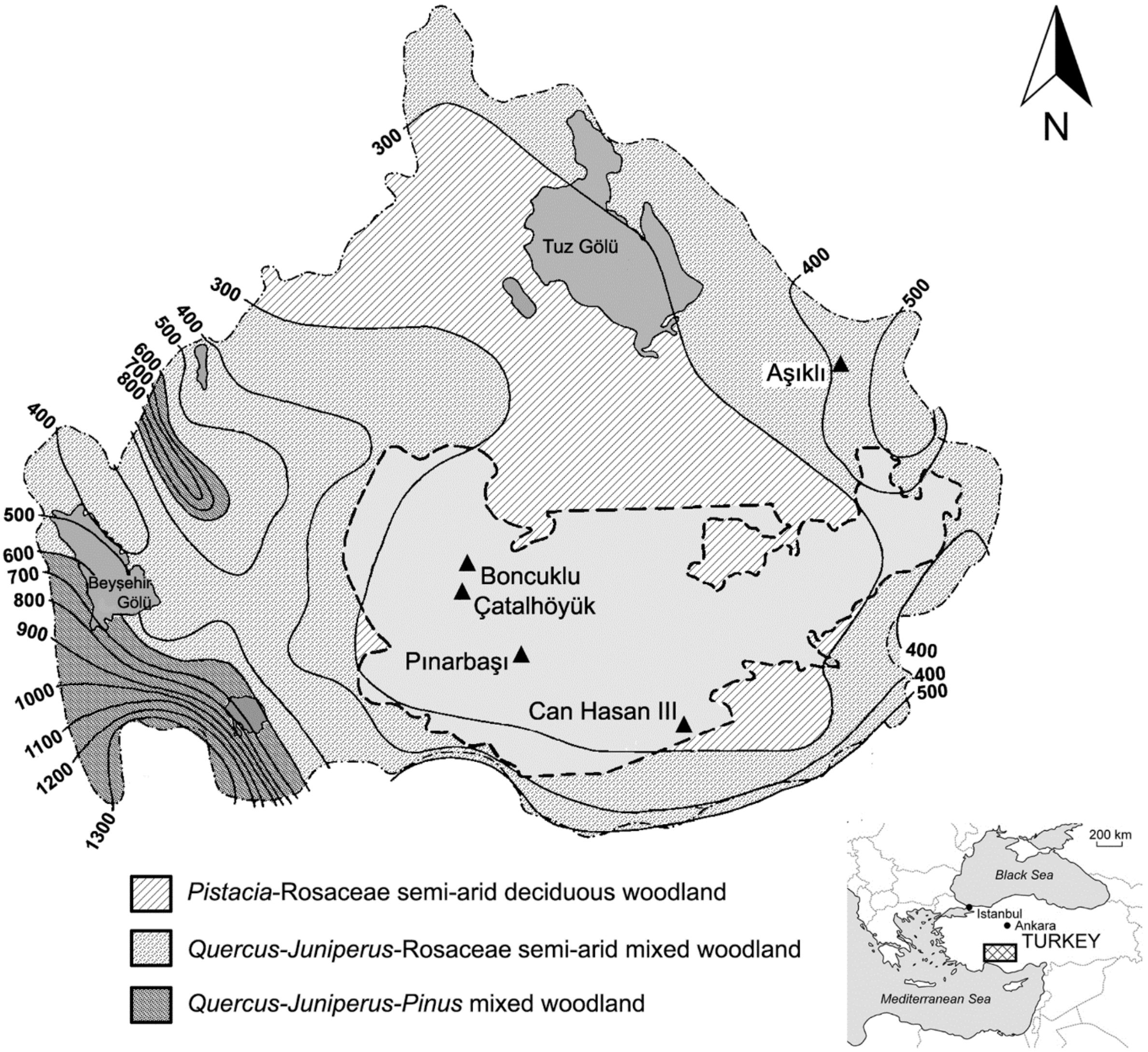

Figure 2 Schematic map of major rainfall gradients and associated vegetation zones in the Konya plain (after Asouti and Kabukcu 2014, Fig. 8).

Figure 3 Map of the Çatalhöyük East and West mounds, showing the location of all excavated areas.

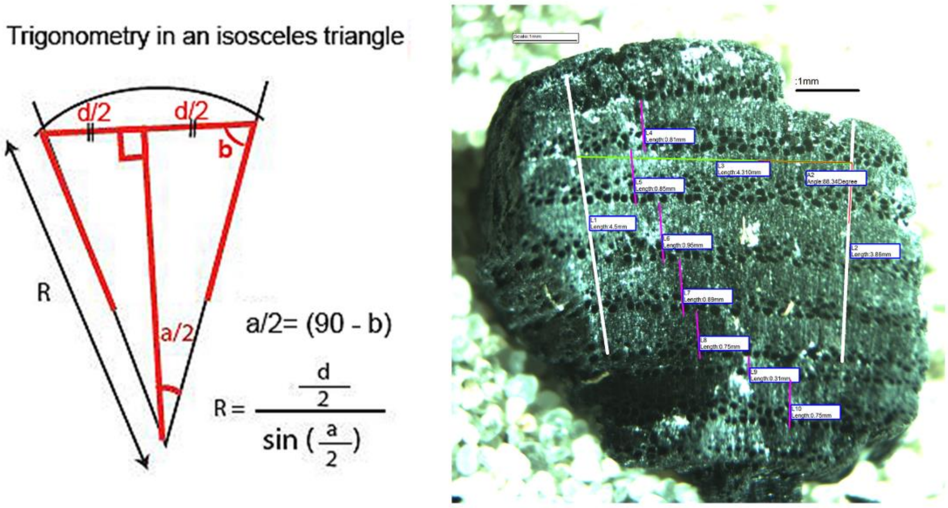

Figure 4: Method of calculation of estimated radius of curvature (R); minimum estimated diameter = 2xR.

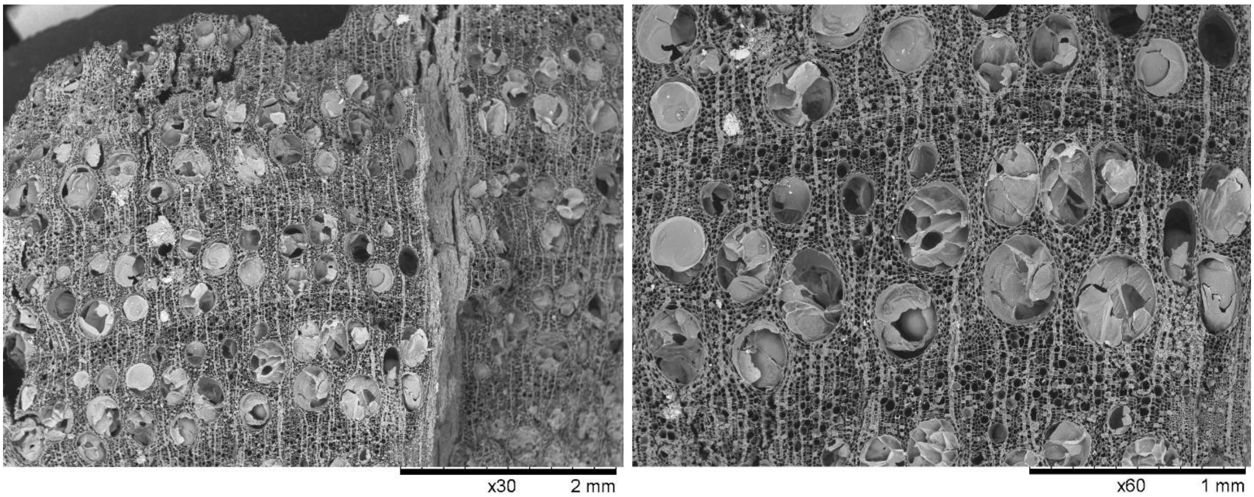

Figure 5 *Quercus* specimen showing tyloses.

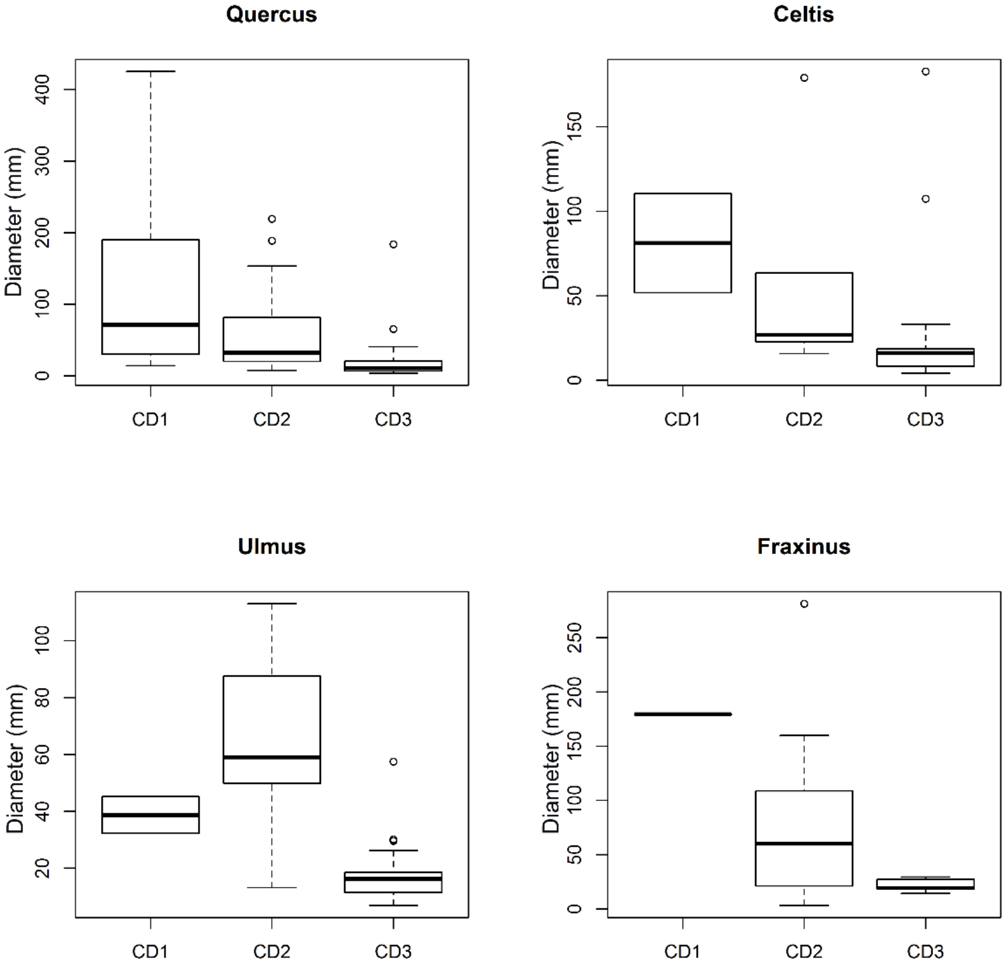

Figure 6: Boxplots showing range of diameter measurements for *Quercus*, *Ulmus*, *Celtis* and *Fraxinus*, calculated with the trigonometric tool (y axis) for specimens classified in Marguerie and Hunot (2007) Curvature Degrees (CDs) classes 1-3 (1: weakly curved, 2: moderately curved, 3: strongly curved) (x axis).

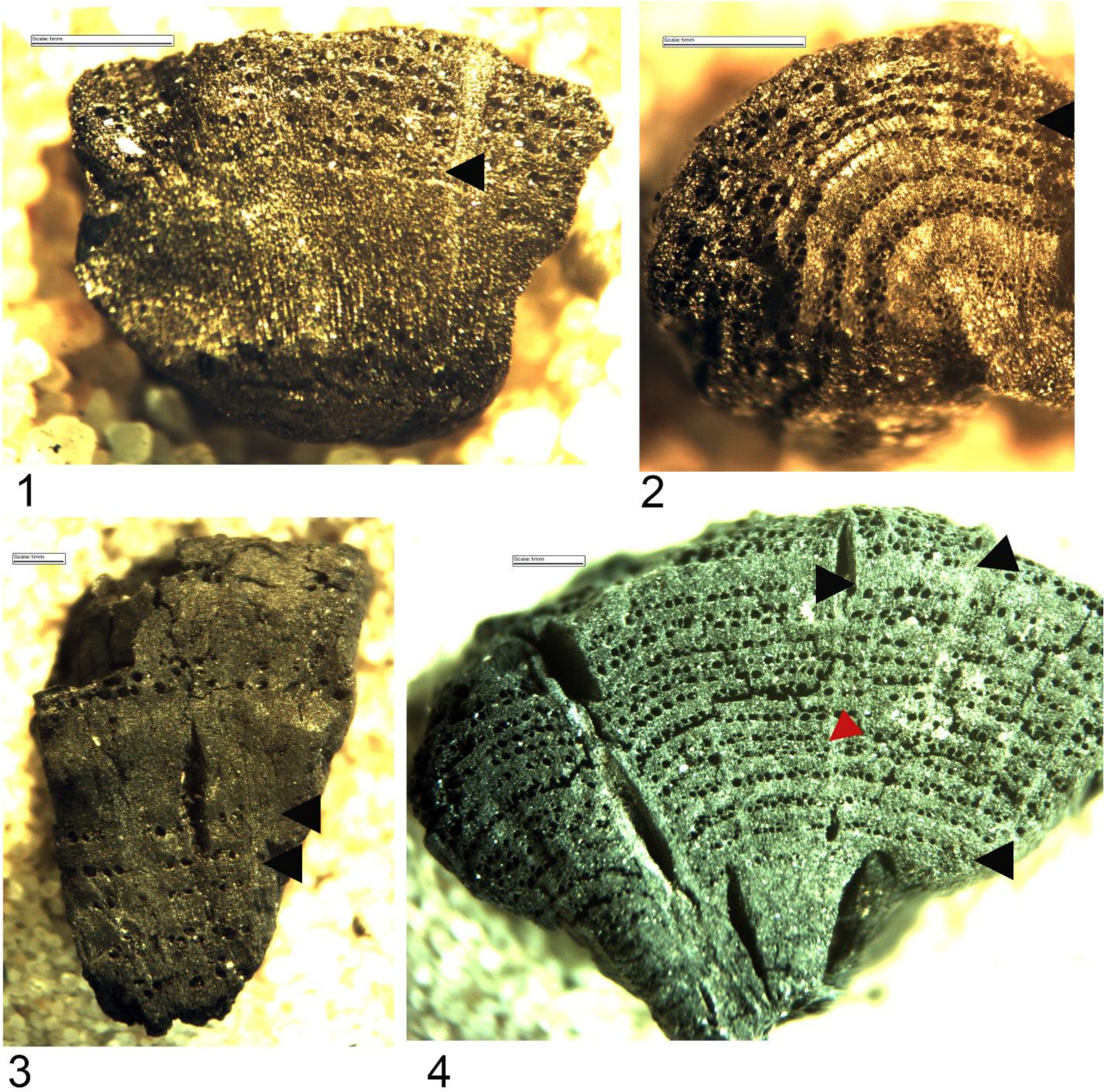

Figure 7: Growth ring width variability observed in specimens from Çatalhöyük (zoom stereomicroscope digital images; scale 1mm).

1. *Quercus*, fragment of heartwood, arrow indicates sudden growth reduction.

2. *Quercus*, short shoot, growth reduction indicated by arrow.

3. *Quercus*, adult stem wood, lower arrow denotes the beginning of early wood in year with limited radial growth; upper arrow denotes the beginning of abrupt growth improvement.

4. *Quercus*, shoot or dwarfed stem wood; lower black arrow indicates beginning of growth reduction. Red arrow indicates discontinuous ring, upper arrow marks one year of improved growth; note also vigorous growth in the early years.

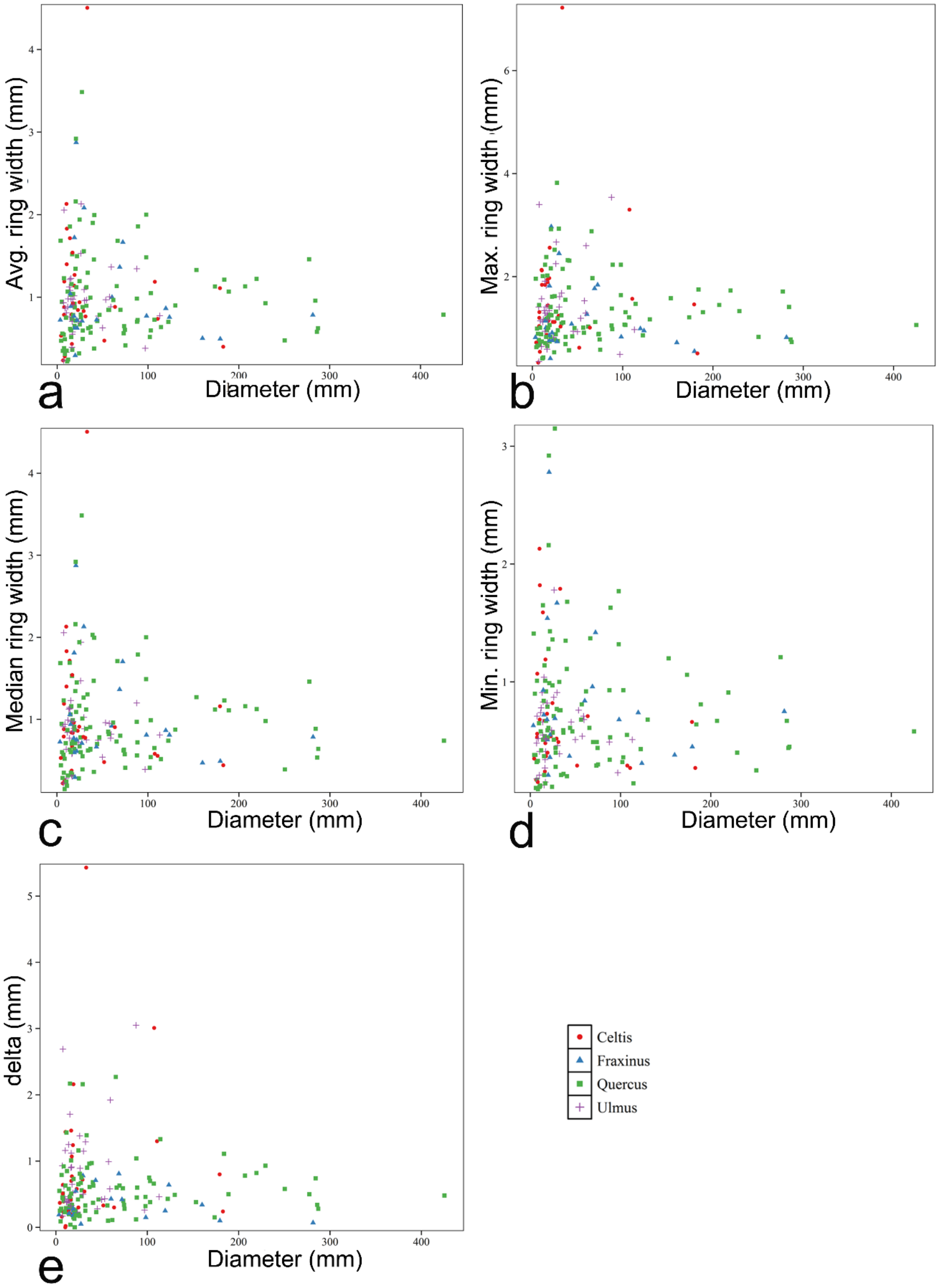

Figure 8: Scatter plot of average (a), maximum (b), median (c), minimum (d) and delta (e) ring width and diameter measurements for each specimen from Çatalhöyük.

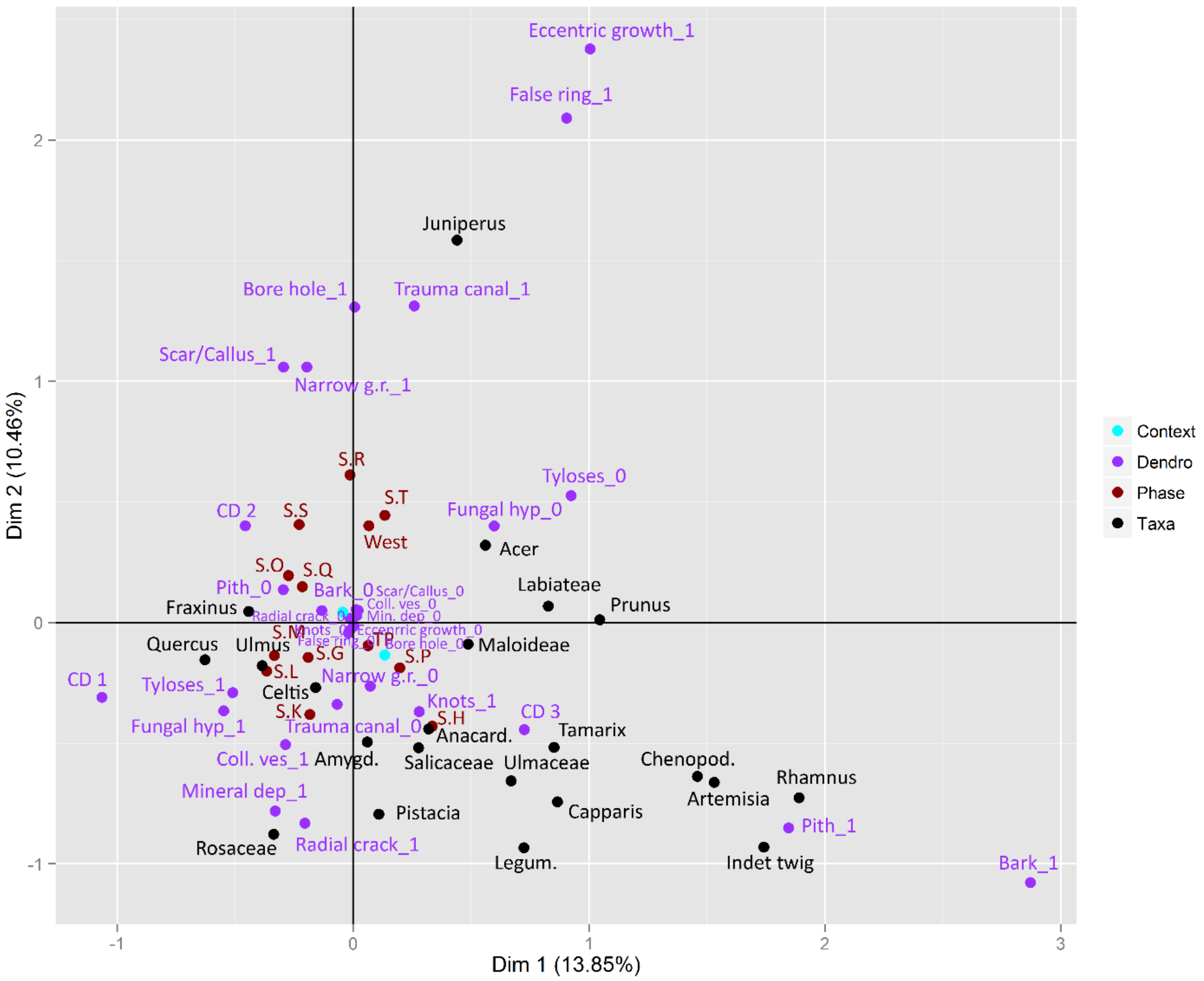

Figure 9: Plot of variables (Dimensions 1 and 2), MCA run on dendroanthracological features recorded for Çatalhöyük specimens

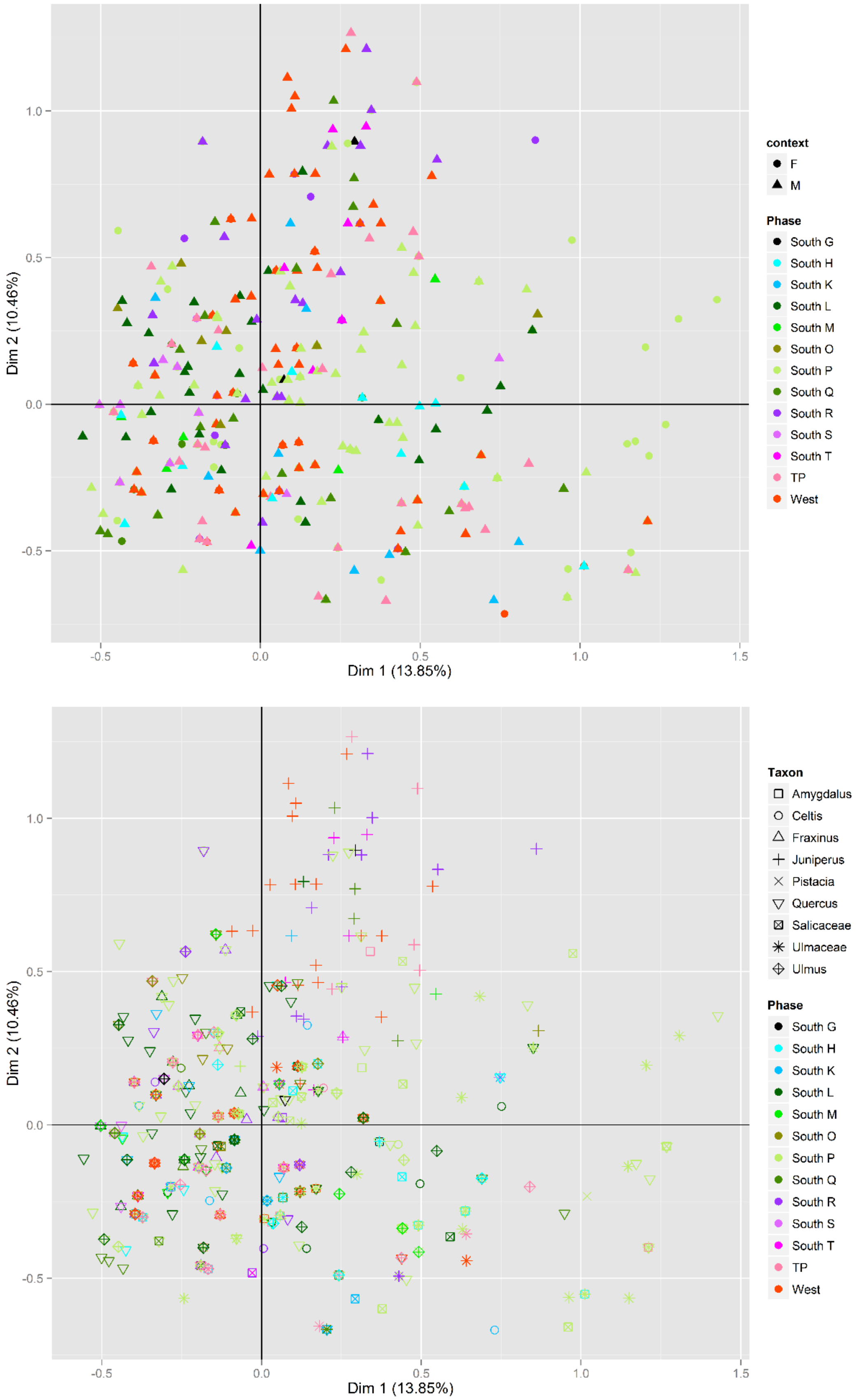

Figure 10: Plot of individuals, MCA

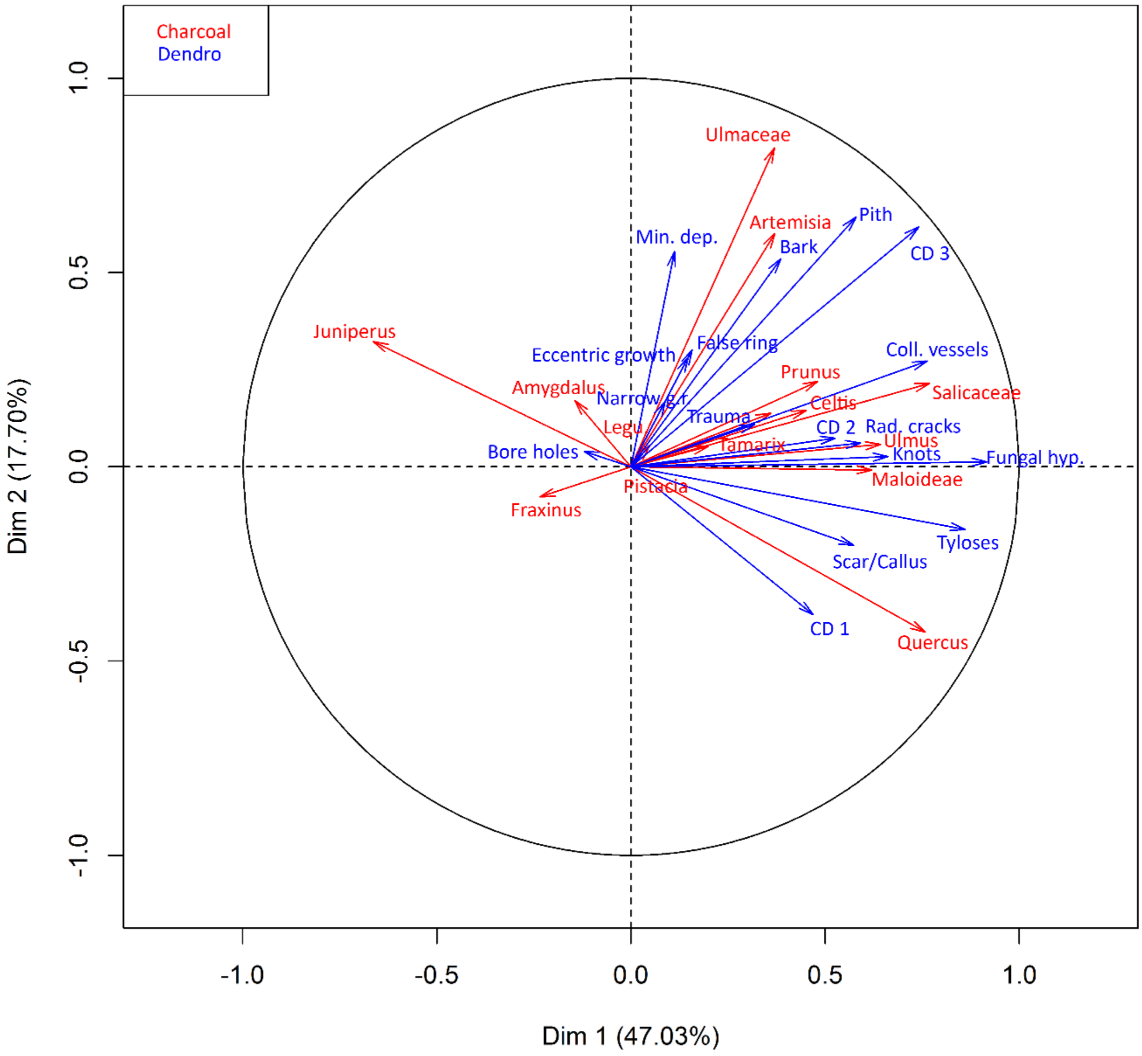

Figure 11: Plot of variables (Dimensions 1 and 2), MFA run on per sample wood charcoal taxon and dendroanthracological feature presence counts from Çatalhöyük (dispersed and primary fuel waste deposits)

	eigenvalue	% of variance	cumulative % of variance
Dim 1	0.15	13.85	13.85
Dim 2	0.11	10.46	24.31
Dim 3	0.08	7.41	31.72
Dim 4	0.08	7.24	38.96
Dim 5	0.07	6.81	45.77
Dim 6	0.07	6.53	52.30
Dim 7	0.07	6.35	58.65
Dim 8	0.06	6.08	64.72
Dim 9	0.06	5.81	70.54
Dim 10	0.06	5.44	75.98
Dim 11	0.06	5.18	81.16
Dim 12	0.05	4.78	85.94
Dim 13	0.05	4.27	90.21
Dim 14	0.04	3.99	94.20
Dim 15	0.03	3.13	97.33
Dim 16	0.03	2.67	100.00

Supplementary Table 1a: Results of MCA run on dendroanthracological features recorded for Çatalhöyük wood charcoal specimens: eigenvalues and percentage of variance.

	Contribution to dimensions					**cos^2**				
	Dim 1	**Dim 2**	**Dim 3**	**Dim 4**	**Dim 5**	**Dim 1**	**Dim 2**	**Dim 3**	**Dim 4**	**Dim 5**
CD1	3.37	0.38	2.50	**11.66**	**17.51**	0.0799	0.0068	0.0318	0.1445	0.2042
CD2	4.84	4.95	1.09	0.13	2.15	0.2208	0.1708	0.0267	0.0031	0.0483
CD3	**10.00**	4.93	0.28	0.91	0.00	0.3819	0.1422	0.0057	0.0182	0.0000
Pith_0	3.39	0.95	0.01	0.32	0.04	0.5454	0.1158	0.0007	0.0270	0.0032
Pith_1	**21.21**	**5.96**	0.05	2.01	0.25	0.5454	0.1158	0.0007	0.0270	0.0032
Bark_0	0.75	0.14	0.01	0.25	0.02	0.3788	0.0534	0.0039	0.0650	0.0061
Bark_1	**16.34**	3.05	0.32	**5.37**	0.54	0.3788	0.0534	0.0039	0.0650	0.0061
Tyloses_0	**13.72**	**5.88**	0.07	0.60	0.84	0.4718	0.1527	0.0014	0.0108	0.0142
Tyloses_1	**7.57**	3.24	0.04	0.33	0.46	0.4718	0.1527	0.0014	0.0108	0.0142
Knots_0	0.01	0.02	0.07	1.74	0.03	0.0037	0.0065	0.0183	0.4445	0.0078
Knots_1	0.16	0.37	1.47	**36.67**	0.69	0.0037	0.0065	0.0183	0.4445	0.0078
Trauma canal_0	0.16	**5.47**	1.91	0.00	0.03	0.0175	0.4452	0.1105	0.0002	0.0017
Trauma canal_1	0.63	**21.14**	7.40	0.01	0.12	0.0175	0.4452	0.1105	0.0002	0.0017
Scar tissue_0	0.00	0.00	0.07	0.06	0.06	0.0003	0.0089	0.1099	0.0875	0.0889
Scar tissue_1	0.01	0.53	**9.20**	**7.50**	**8.10**	0.0003	0.0089	0.1099	0.0875	0.0889
Narrow gr. ring_0	0.19	3.32	2.03	1.36	0.57	0.0215	0.2792	0.1205	0.0790	0.0312
Narrow gr. ring_1	0.78	**13.36**	**8.14**	**5.47**	2.29	0.0215	0.2792	0.1205	0.0790	0.0312
Reaction wood_0	0.01	0.07	0.04	0.08	0.03	0.0144	0.0806	0.0343	0.0669	0.0248
Reaction wood_1	0.64	4.75	2.85	**5.69**	2.24	0.0144	0.0806	0.0343	0.0669	0.0248
False rings_0	0.02	0.11	0.00	0.12	0.03	0.0169	0.0901	0.0000	0.0684	0.0162
False rings_1	0.75	**5.27**	0.00	**5.79**	1.45	0.0169	0.0901	0.0000	0.0684	0.0162
Boreholes_0	0.00	0.02	0.26	0.04	0.17	0.0000	0.0236	0.2247	0.0322	0.1383
Boreholes_1	0.00	1.39	**18.69**	2.75	**12.52**	0.0000	0.0236	0.2247	0.0322	0.1383
Radial cracks_0	0.01	0.16	0.66	0.01	0.83	0.0027	0.0449	0.1282	0.0027	0.1489
Radial cracks_1	0.11	2.52	**10.15**	0.22	**12.83**	0.0027	0.0449	0.1282	0.0027	0.1489
Mineral deposits_0	0.02	0.14	0.65	0.03	0.98	0.0071	0.0396	0.1264	0.0049	0.1742
Mineral deposits_1	0.30	2.22	**10.01**	0.40	**15.02**	0.0071	0.0396	0.1264	0.0049	0.1742
Collapsed vessels_0	0.01	0.05	1.14	0.36	1.08	0.0048	0.0148	0.2455	0.0757	0.2151
Collapsed vessels_1	0.20	0.84	**19.57**	**6.18**	**18.66**	0.0048	0.0148	0.2455	0.0757	0.2151
Fungal hyphae_0	**7.73**	4.57	0.67	2.06	0.22	0.3281	0.1464	0.0153	0.0457	0.0045
Fungal hyphae_1	**7.07**	4.18	0.62	1.88	0.20	0.3281	0.1464	0.0153	0.0457	0.0045

Supplementary Table 1b: Results of MCA run on dendroanthracological features recorded for Çatalhöyük wood charcoal specimens: contribution of variables to dimensions, and cos^2 values.

	eigenvalue	% of variance	cumulative % of variance
comp 1	1.724	47.03	47.03
comp 2	0.649	17.70	64.72
comp 3	0.430	11.74	76.46
comp 4	0.287	7.82	84.28
comp 5	0.134	3.65	87.93
comp 6	0.096	2.61	90.54
comp 7	0.076	2.07	92.61
comp 8	0.058	1.58	94.19
comp 9	0.040	1.08	95.26
comp 10	0.036	0.98	96.24
comp 11	0.028	0.77	97.01
comp 12	0.020	0.54	97.55
comp 13	0.018	0.50	98.05
comp 14	0.016	0.44	98.50
comp 15	0.013	0.36	98.85
comp 16	0.010	0.28	99.14
comp 17	0.007	0.20	99.34
comp 18	0.006	0.16	99.49
comp 19	0.004	0.12	99.61
comp 20	0.003	0.08	99.70
comp 21	0.002	0.07	99.76
comp 22	0.002	0.06	99.82
comp 23	0.002	0.04	99.87
comp 24	0.001	0.04	99.90
comp 25	0.001	0.03	99.94
comp 26	0.001	0.03	99.96
comp 27	0.000	0.01	99.98
comp 28	0.000	0.01	99.99
comp 29	0.000	0.01	99.99
comp 30	0.000	0.00	100.00

Supplementary Table 2a: Results of MFA run on Çatalhöyük per sample (dispersed and primary fuel waste contexts) wood charcoal taxon and dendroanthracological counts: eigenvalues and percentage of variance.

	Contribution to dimensions				
	Dim.1	**Dim.2**	**Dim.3**	**Dim.4**	**Dim.5**
Dendro	50.83	38.97	30.85	31.44	31.52
Taxa	49.17	61.03	69.15	68.56	68.48

Supplementary Table 2b: Results of MFA run on Çatalhöyük per sample (dispersed and primary fuel waste contexts) wood charcoal taxon and dendroanthracological counts: contribution of groups to dimensions.

	Contribution to dimensions				
	Dim.1	**Dim.2**	**Dim.3**	**Dim.4**	**Dim.5**
Pith	3.48	**11.40**	0.84	5.02	**10.23**
Bark	0.31	1.60	0.45	1.62	2.30
Tyloses	**19.28**	1.79	8.18	**20.77**	0.46
Traumatic canals	0.47	0.15	9.58	0.34	1.85
Fungal hyphae	**12.35**	0.01	1.99	0.53	0.03
Narrow gr. rings	0.01	0.14	1.04	0.04	9.11
Radial cracks	0.45	0.00	0.14	0.73	0.10
Collapsed vessels	0.52	0.18	0.00	0.02	0.00
Boreholes	0.00	0.00	0.04	0.02	0.07
Scar callus tissue	0.01	0.00	0.02	0.00	0.00
Mineral deposits	0.01	0.92	0.04	0.00	0.98
Reaction wood	0.00	0.01	0.01	0.00	0.01
False rings	0.00	0.04	0.06	0.02	0.36
Knots	0.21	0.01	0.04	0.90	0.14
CD1	0.61	1.06	1.94	1.34	3.07
CD2	1.42	0.08	6.49	0.08	0.08
CD3	**11.68**	**21.58**	0.00	0.02	2.73
Juniperus	**15.16**	9.52	**60.34**	2.09	0.98
Quercus	**20.61**	**17.26**	4.75	**45.16**	0.00
Amygdalus	0.02	0.07	0.29	0.06	0.03
Pistacia	0.00	0.01	0.25	0.18	0.88
Prunus	0.01	0.01	0.00	0.00	0.00
Maloideae	0.08	0.00	0.01	0.07	0.27
Salicaceae	7.19	1.49	0.03	0.26	**27.64**
Ulmaceae	2.36	**31.02**	1.83	3.46	2.09
Ulmus	2.38	0.05	0.43	4.41	0.17
Celtis	0.80	0.22	0.16	**10.49**	2.29
Fraxinus	0.31	0.09	0.91	2.11	**33.95**
Tamarix	0.00	0.00	0.00	0.00	0.00
Artemisia	0.18	1.25	0.13	0.00	0.16
Leguminosae	0.05	0.02	0.01	0.26	0.01

Supplementary Table 2c: Results of MFA run on Çatalhöyük per sample (dispersed and primary fuel waste contexts) wood charcoal taxon and dendroanthracological counts: contribution of variables to dimensions.

Dim.1 main components			Dim.2 main components		
	correlation	**p value**		**correlation**	**p value**
Fungal hyphae	0.9162	0	Ulmaceae	0.8208	0
Tyloses	0.8606	0	Pith	0.6433	0
Salicaceae	0.7691	0	CD3	0.6179	0
Collapsed vessels	0.7632	0	*Artemisia*	0.6012	0
Quercus	0.7576	0	Mineral deposits	0.554	0
CD3	0.7412	0	Bark	0.5361	0
Radial cracks	0.6616	0	*Juniperus*	0.3228	0.0143
Ulmus	0.6426	0	False rings	0.3008	0.023
Maloideae	0.6199	0	Reaction wood	0.2822	0.0335
Knots	0.5908	0	Collapsed vessels	0.273	0.0399
Pith	0.5796	0	CD1	-0.3803	0.0035
Scar tissue	0.5736	0	*Quercus*	-0.4253	0.001
CD2	0.5256	0			
Prunus	0.4809	2.00E-04			
CD1	0.4688	2.00E-04			
Celtis	0.4513	4.00E-04			
Bark	0.3854	0.0031			
Artemisia	0.3706	0.0045			
Ulmaceae	0.3693	0.0047			
Leguminosae	0.36	0.0059			
Traumatic canals	0.3178	0.016			
Juniperus	-0.664	0			

Supplementary Table 2d: Results of MFA run on Çatalhöyük per sample (dispersed and primary fuel waste contexts) wood charcoal taxon and dendroanthracological counts: significant components of the first two dimensions.