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HOLOCENE MEDITERRANEAN SPECIAL ISSUE

Pollen-inferred regional vegetation patterns and demographic change in Southern Anatolia through the Holocene

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Abstract

Southern Anatolia is a highly significant area within the Mediterranean, particularly in terms of understanding how agriculture moved into Europe from neighbouring regions. This study uses pollen, palaeoclimate and archaeological evidence to investigate the relationships between demography and vegetation change, and to explore how the development of agriculture varied spatially. Data from 21 fossil pollen records have been transformed into forested, parkland and open vegetation types using cluster analysis. Patterns of change have been explored using non-metric multidimensional scaling (nMDS) and through analysis of indicator groups, such as an Anthropogenic Pollen Index, and Simpson's Diversity. Settlement data, which indicate population densities, and summed radiocarbon dates for archaeological sites have been used as a proxy for demographic change. The pollen and archaeological records confirm that farming can be detected earlier (around 7000 cal. yr. BP) in Anatolia in comparison with other parts of the Mediterranean. Dynamics of change in grazing indicators and the OJCV (*Olea*, *Juglans*, *Castanea*, and *Vitis*) index for cultivated trees appear to match cycles of population expansion and decline. Vegetation and land use change is also influenced by other factors, such as climate change. Investigating the early impacts of anthropogenic activities (e.g. woodcutting, animal herding, the use of fire and agriculture) is key to understanding how societies have modified the environment since the mid-late Holocene, despite the capacity of ecological systems to absorb recurrent disturbances. The results of this study suggest that shifting human population dynamics played an important role in shaping land cover in central and southern Anatolia.

Keywords

Anatolia; Archaeology; Pollen; Demography; Land cover; Vegetation

Introduction

The vegetation history of Anatolia

Southern Anatolia can be broadly divided into three main sub-regions, namely the coastal zone, the Taurus Mountains with intramontane lake basins, and the inner Anatolian plateau (Iyigun et al., 2013). The modern landscape of Anatolia has developed over many millennia

as a result of complex interactions between climate, human land use, natural and anthropogenic fire, and other factors, such as competition and species interactions. The late-Pleistocene landscape of inner Anatolia was characterised by species-rich savannah-type grassland, which was replaced in the early Holocene by *Quercus*-dominated parklands and wood pastures of lower diversity (Asouti and Kabukcu, 2014) in to the mid-Holocene. In the wetter uplands of southwest Turkey, mixed conifer-deciduous forests replaced the *Artemisia*-chenopod steppe of the last glacial period (van Zeist and Bottema, 1991).

Archaeobotanical and archaeozoological evidence demonstrates that plant and animal domestication developed earlier in Southwest Asia than in Europe, in particular within the Levant, showing that this was an important centre of agricultural origins (Colledge et al., 2004; Fuller et al., 2012). The first major human impact on ecosystem dynamics in southern Anatolia is not, however, detectable in pollen records until later in the Holocene (e.g. Eastwood et al., 1998). The so-called Beyşehir Occupation Phase (BOP) (van Zeist et al., 1975; Bottema et al., 1986; 1990; Eastwood et al., 1998; Roberts, 2018), which developed most extensively between 3500 and 1300 cal. yr. BP with varied start dates detected between regions, is distinguished as a period of pronounced anthropogenic land-cover change. This phase began in the second and first millennia BC (~3000 ± 800 cal. yr. BP) with declining forest cover and increasing pasture land, cereals and cultivated trees, such as olive and walnut (Eastwood et al., 1998; Roberts et al., 2018b). In southwest Turkey, Eastwood et al. (2007) identified that increased humidity coincided with pollen evidence for increasing human impact and intensification of agriculture during the BOP. Vegetation changes into the Hellenistic, Roman and early Byzantine periods (Table 1: based on Allcock, 2017) reflected increasing evidence of human activity as documented in numerous studies. For example, Vermoere et al. (2002) identified synchronous periods of late Holocene deforestation and cultivation within pollen records from Turkey, although this was accompanied by dissimilarities in the timing of agricultural phases. The BOP was followed by a period of land abandonment after AD 650 (1300 cal. yr. BP) and re-forestation, notably during the Arab-Byzantine wars of the 7th-10th centuries AD (England et al., 2008; Izdebski, 2013; Roberts et al., 2018a; Roberts et al. 2018a).

Cultural and demographic change in Anatolia

Human demographic change and associated land use has played a key role in shaping Holocene landscape alterations in central and southern Anatolia (Allcock and Roberts, 2014; Allcock, 2017; Roberts et al., 2018a; 2018b). There is evidence of a break in settlement in central Anatolia during the Younger Dryas (Baird et al., 2018), which suggests that populations reacted more slowly to the improved climate that permitted the development of agricultural activity in the early Holocene in surrounding areas, such as the Levant (Roberts et al., 2018b; Palmisano et al., this volume). The Neolithic and related social changes during the early Holocene were associated with periods of population growth (Roberts et al., 2018b). In an assessment of long-term socio-environmental dynamics in central Turkey, Allcock (2017) identified human settlement changes that reflect the transformation of society from rural communities during the Neolithic to complex centralised polities, such as the Hittite, Persian and Roman Empires (Table 1), which builds upon a body of existing literature (e.g. Dalfes et al., 1997; Izdebski et al., 2016). She also highlighted how some periods of social change were associated with climatic or environmental instability, supporting earlier research (e.g. Wilkinson, 1997; McIntosh et al., 2000; Marro and Kuzucuoglu, 2007; Kuzucuoglu, 2015).

The four major settlement cycles described by Allcock (2017) roughly correspond to the Neolithic, Bronze Age, Iron Age-Classical, and Medieval-Modern periods. The most intense period of human occupation in Cappadocia occurred during Late Roman times (4th to 7th centuries AD) with evidence of decreased settlement continuity from the mid-7th century (Roberts et al., 2018a). Between Hellenistic and Late Roman times the numerous cities of southern Anatolia were surrounded by agricultural land (Izdebski, 2013). However, a major demographic decline was identified between AD 650 and 900 in central and southwestern Anatolia associated with social and climatic changes. In the pollen record, this corresponded with a decline in the production of cereal and tree crops, and pastoral activity marking the end of the BOP (Roberts et al., 2018a). This was followed by regional differentiation in land use, such as agro-pastoralism in central Anatolia and cultivation of olives and other tree crops in western Anatolia.

Cultural change and climate

Climate trends in semi-arid regions, specifically variability in precipitation patterns, play an important role in socio-economic and cultural change, as water is a limited resource (Jones et

al., 2006; Dean et al., 2015; Berger et al., 2016). The adoption of agriculture has been linked to the onset of the favourable early Holocene climate, and subsequent periods of drought throughout the Holocene are reflected in archaeological records with evidence of social adaptations to reduced rainfall for crop production (e.g. Staubwasser and Weiss, 2006). A shift in seasonal climate was identified by Lewis et al. (2017), which could be linked to solar-forced climate change beginning ~8600 cal. yr. BP. They describe changing water balance as an important factor influencing observed cultural changes at the Çatalhöyük archaeological site (located in south-central Turkey) in the Late Neolithic/Early Chalcolithic period and provide evidence for wet winter/early spring conditions during the Early Holocene, reduced seasonality and possibly reduced local summer evaporation after 8300 cal. yr. BP (Lewis et al., 2017). Discontinuity in settlement patterns is often correlated with shortage of water, which would have left settlements vulnerable to any changes in climate (Lewis et al., 2017; Roberts, 2018a). The climate of southern Anatolia has altered significantly throughout the Holocene with many studies demonstrating periods of prolonged drought and significant shifts between wet and dry conditions (e.g. Woodbridge et al., 2011; Dean et al., 2015). Three lake sediment oxygen isotope ($\delta^{18}\text{O}$) records derived from carbonates and diatoms (Nar Gölü only) provide an independent framework for Holocene hydro-climatic change, namely Gölhisar in southwest Turkey (Eastwood et al., 2007) and Nar Gölü and Eski Acıgöl in central Anatolia (Dean et al., 2015; Roberts et al., 2001). Similarly to the trends described by Lewis et al. (2017) these records indicate a wetter early Holocene climate.

This study examines vegetation dynamics and human population change across south-central and southwest Anatolia during the last eleven millennia, and addresses two key research questions: 1) what role have changing human populations and past climate trends played in shaping long-term land cover change in southern Anatolia?, and 2) what can be learnt about the impacts of past landscape management through understanding past demographic and vegetation change?

Methods

Pollen-inferred vegetation change

Fossil pollen datasets from 21 records across 14 sites within southern Anatolia have been analysed (Fig. 1 and Table 2) and different approaches employed to identify key patterns of

vegetation change. Most of these records are from the intermontane “lake district” of southwest Turkey, with three from central Anatolia, and only one from the coastal zone. This spatial bias means that human landscape changes in the fertile coastal plains of Pamphylia (around modern Antalya) and Cilicia (around modern Adana) are not registered in regional pollen data. Published pollen records also cover different timespans, with only a few sites spanning the whole Holocene. The limited number of early Holocene pollen records means that regional syntheses of vegetation clusters may not be representative of the case study area’s predominantly intermontane landscape ecology prior to 7000 cal. yr. BP; however, as previously mentioned, major landscape alterations as a result of human activity are typically not detectable until the later Holocene in Anatolia. Cluster analysis and community classification, which involved calculating the median and interquartile range of all pollen taxa within samples that fall into each cluster group (Perez et al., 2015) were used to identify major vegetation groups in Mediterranean-wide modern and fossil pollen datasets (Davis et al., 2013; Leydet et al., 2007-2017). This paper focuses on a sub-set of these sites from Anatolia for continuous 200-year time windows throughout the Holocene. The pollen-based methods employed are described in detail in Woodbridge et al. (in press) and Fyfe et al. (2018), which also involved most of the indices described here. Simpson’s index and non-metric multidimensional scaling (nMDS) have been used to explore patterns of diversity change and major variation in the datasets along with the percentage of Arboreal Pollen (AP%). nMDS is an unconstrained ordination technique providing insights into high-dimensional datasets, and is explained in detail in Legendre and Legendre (1983) and McCune and Grace (2002). When applying nMDS the number of axes are chosen before analysis, which avoids hidden axes of variation unlike other ordination techniques. In this study a two dimensional ordination was chosen and Bray-Curtis dissimilarity was used to calculate the distance matrix for ordination. Simpson’s index has been calculated for each pollen sample using pollen percentage data. This index takes both species richness and evenness into account and is often used to explore diversity change in pollen datasets (e.g. Morris et al., 2014; Woodbridge et al., in press). An API (Anthropogenic Pollen Index: *Artemisia*, *Centaurea*, Cichorioideae, *Plantago*, cereals, *Urtica* and *Trifolium* type) (Mercuri et al., 2013a), an indicator group for cultivated trees (OJC: *Olea*, *Juglans*, *Castanea*) (Mercuri et al., 2013b) with the addition of *Vitis* (OJCV), and a group of pastoral land use indicators (*Artemisia*, Chenopodiaceae, *Plantago lanceolata* and *Plantago major/media*, Asteroideae, Cichorioideae, *Cirsium*-type, *Galium*-type, Ranunculaceae and *Potentilla*-type) (adapted from Mazier et al., 2006) and grazing indicators (*Plantago lanceolata*, *Rumex*

acetosa-type and *Sanguisorba*) (Roberts et al., 2018a) were also calculated to explore changes in the pollen data in relation to human land use. Oleaceae undiff. was grouped with *Olea* within the OJCV index as this taxon is most likely to represent degraded *Olea* grains, and other taxa within the Oleaceae family are routinely differentiated (e.g. *Fraxinus*, *Phillyrea*). Although many of these indicator groups are based on published literature that describe the taxa as ‘anthropogenic indicators’, many of these taxa are not only associated with anthropogenic activity, such as Chenopodiaceae Asteroideae and Cichorioideae, which indicate natural steppe vegetation. The pastoral indicator group was developed using pollen sites in France, so is less informative about landscape change in Anatolia, but has been included to aid comparisons between case study regions within a Mediterranean-wide synthesis (Roberts et al., this volume).

Archaeologically-inferred demographic change

Archaeological data have been obtained for a total of 1426 sites and 3804 excavated or surveyed settlements (occupation periods) (Fig. 1) to construct records of past demographic change using established methods (Palmisano et al. 2017). Archaeological sites have been recorded, where possible, as georeferenced points per time-slice (unprojected WGS84). For the purposes of this paper, we have chosen to deal exclusively with those places identified as human habitation sites or possible habitations, and hereafter then we use the terms ‘site’ and ‘settlement’ interchangeably to refer to this subset. The settlement data covers the time period 9900 to 1100 cal. yr. BP and summed radiocarbon dates extend from 11000 to 6100 cal. yr. BP, as there are no data available covering times prior to or more recent than these periods. A spatial database of archaeological sites has been created through a comprehensive review, standardisation, and synthesis of settlement data from reports and gazetteers relating to 52 archaeological surveys carried out throughout all three sub-regions of southern Anatolia, although there are some notable geographical gaps, such as the Pamphylian coastal plain (see SI 3 for a complete list of references). Although the archaeological surveys carried out in Anatolia show a spatially variable intensity of investigation, most of them fall within the “extensive” category (0.4 to 5 sites per km sq.). Topographic variability is another issue to be considered in the Anatolian context as mountainous fringes and areas with rugged topography are marginal zones that have not commonly received as detailed archaeological attention as lowland areas for a series of practical reasons, such as difficult terrain and dense vegetation cover. Another issue is represented by the gap of the Middle Chalcolithic occupation in

southwest Anatolia and the Burdur plain due to recognition and visibility problems related to either a poor knowledge of Middle Chalcolithic pottery assemblages or colluvium deposits covering floodplain sites (see Vandam, 2015). A major caveat is represented by the estimated size of settlements that in most cases indicate only the overall extent of mounds, but neither the size for a particular chronological phase nor the extent of the surrounding lower town. Therefore, the results derived from the analyses of the estimated settlement sizes have to be interpreted cautiously, as constituting evidence only about the patterns exhibited by relatively large, sedentary farming communities. The methods used in this paper to infer demographic trends from radiocarbon dates and archaeological settlement data build largely on previous works that seek to address issues such as “wealth-bias” of particular site phases (Timpson et al., 2014), the artefacts in SPD plots due to radiocarbon calibration curves (Williams, 2012; Weninger et al., 2015), and temporal uncertainty in archaeological site-phases and periods (see Crema, 2012; Palmisano et al., 2017).

Within the analyses of the archaeological data, the ‘site count’ was calculated and the estimated ‘site sizes’ were summed for 200 year-time steps in order to assess how population changes across time every 200 years. Bearing in mind that archaeological cultures result in larger or shorter time spans according to the dating precision of archaeological artefacts, we applied a probabilistic approach known as aoristic analysis to deal with the temporal uncertainty of occupation periods (Crema, 2012; Palmisano et al., 2017). In addition, to mitigate the discrepancy between wide chronological uncertainties and narrower likely site durations, we applied Monte Carlo methods to generate ‘randomised start of occupation’ periods for sites with low-resolution information (Crema, 2012; Palmisano et al. 2017). The resulting probabilistic distributions of site frequencies through time, based on the aoristic sums and Monte Carlo simulations, provide useful comparisons with the raw site frequency data and the summed settlement sizes. Consequently, the SPD of radiocarbon dates are binned into 200-year time slices to match the time windows used in the analysis of pollen sequences. We also calculated the median of the envelope of the randomised start date of sites, which is the result of a 1,000 randomised start occupation date for sites, and binned this into 200-year time slices.

Palaeoclimate datasets

The palaeoclimate datasets (Fig. 1 and Table 2) derive from lakes in central and southern Anatolia and provide records of $\delta^{18}\text{O}$ inferred hydroclimate (Nar Gölü: Dean et al., 2015, Eski Acıgöl: Roberts et al., 2001 and Gölhisar Gölü: Eastwood et al., 2007). The records have been resampled to the same temporal resolution and converted to z-scores to allow inter-site comparisons and calculation of an average z-score for the region (see Finné et al., this volume, for further details).

Results

Vegetation, climate and demographic trends

The patterns of vegetation cluster group change (Fig. 2) indicate an increase in sclerophyllous parkland (cluster 1.1) and pine steppe (cluster 5.2) after around 8000 cal. yr. BP, which coincides with a decline in deciduous oak parkland (cluster 6.2). However, the limited number of pollen sites in the earlier Holocene make interpretations more restricted for these vegetation cluster groups. One of the most striking trends in the pollen cluster group results is the increase and decline in pasture/wetland (cluster 3.0) between 4500 and 1300 cal. yr. BP. This cluster is dominated by Cyperaceae pollen, and probably reflects a combination of increased upland grazing land, as indicated by the abundance of grass and grazing indicators in this cluster group, and local wetland sedge communities. In the last ~1800 years, there has been a significant expansion in pine woodland (cluster 5.1). The archaeological demographic proxy record indicates that population started increasing in the Early Chalcolithic (~8000 – 7500 cal. yr. BP) and grew substantially during the Bronze Age (~5000 – 3100 cal. yr. BP), which was punctuated by cycles of ‘boom and busts’ throughout the Bronze Age (see Fig. 3). A dramatic increase in population then occurred in the Hellenistic and Roman periods (see Table 1 for a summary of Anatolian archaeological periods).

Pollen indicator groups offer a useful approach to explore key changes in vegetation community dynamics over time in line with cultural shifts. Fig. 4 shows that arboreal pollen (AP%) has varied between 30 and 70% throughout the Holocene with a steady decline from 9000 to 2400 cal. yr. BP and an increase after this time. There is a marked rise in cultivated trees between ~5000 and ~1500 cal. yr. BP demonstrated in the OJCV index. The API indicates an increase in anthropogenic activity from 6500 cal. yr. BP, while grazing pollen indicators steadily increased from 8500 cal. yr. BP and declined in the most recent 1500

years. Simpson's index suggests that diversity increased in the early Holocene with consistent values throughout the records and a recent decline since 1500 cal. yr. BP. Statistically significant relationships between the pollen and archaeological datasets (Table 3) are demonstrated most clearly for the pasture/wetland vegetation cluster (3.0), which shows a strong positive relationship with the demographic proxies, and significant negative relationships between AP% and demographic change, indicating that larger populations were associated with increased pasture/wetland vegetation and a decline in the abundance of trees. A decrease in AP% could lead to decreased evaporation from vegetation and potentially higher run-off. Nevertheless, the Cyperaceae increase suggests lower lake levels, which could indicate drier climatic conditions or possibly human interference with catchment hydrology. There are also highly positive and significant relationships between the demographic proxies and the OJC / OJCV and API indices and grazing indicators, which reflect human land use. nMDS axis scores summarise major variation in the pollen datasets and indicate periods of greater change around 6000 and 2000 cal. yr. BP (Fig. 4). The nMDS scores are significantly correlated (p -value <0.05) with the demographic proxies (Table 3) indicating that major change in the pollen data corresponds with demographic shifts.

When patterns within individual pollen records are examined in more detail, variability between sites is clearly identifiable. The results of two separate analyses are presented in Fig. 5 (sites ordered from left to right reflecting SW to NE location): AP% (shown on the x axis for each site), which indicates how open or closed the landscape is, and the cluster analysis derived 'vegetation clusters' are presented as symbols. Sites on the Anatolian plateau indicate greater abundance of grassland/parkland (1.4) throughout the Holocene (e.g. Eski Acıgöl) while those in the southwest Anatolian Lake District indicate that sclerophyllous parkland (1.1) or woodland dominated the landscape (e.g. Karamık, Beyşehir and Ağlasun). Similar vegetation shifts are shown between records, such as pine woods (5.1) moving to pine steppe (5.2), and several records indicate an increase in pasture/wetland (3.0) from ~4000 cal. yr. BP (e.g. Gölhisar, Ovağöl, Bereket and Pınarbaşı). Grass was abundant in the pollen records during the early Holocene; however, there is no clear relationship between grass abundance and the summed probability distribution (SPD) of radiocarbon dates for this period (Fig. 6). During the Beyşehir Occupation Phase (BOP) there was a clear increase in the OJCV index across most sites from 3500 to 1500 cal. yr. BP, which is also reflected by peaks in the demographic proxies around these times (Fig. 7). The increase in the OJCV index began earliest in the one pollen record available from the coastal zone (Ovağöl).

Within the palaeoclimate datasets (Fig. 4) higher (more positive) z-scores indicate wetter climatic conditions, while lower (more negative) values relate to drier climate. The average z-scores across all three sites show wetter conditions in the early to mid-Holocene (until ~5000 cal. yr. BP), which is followed by drier conditions until ~1500 cal. yr. BP. Values then increase again indicating a shift to wetter climate during Medieval times and then decline signifying a more recent drying phase in the last ~500 years, corresponding to the Little Ice Age. Spearman's rank correlations between the pollen, archaeological and palaeoclimate datasets indicate strong statistically significant negative relationships between all of the climate records and the demographic proxies with r -values up to -0.78 (Table 3). The clearest significant relationships between the climate and pollen datasets are with the pasture/wetland cluster (3.0), which shows a negative relationship indicating that pasture/wetland was more abundant when climate was drier. There are also significant relationships with a number of the pollen indicator groups, such as OJCV, API and grazing indicators, which are all negatively correlated with climate (Table 3). Pollen nMDS scores are significantly correlated with the climate records indicating that major patterns in the pollen datasets reflect climate trends.

Discussion

Demographic change, cultural transitions and landscape dynamics

Although efforts have been made to define a study region with good data coverage and congruence of datasets (pollen, archaeology and climate) the records from different data types may be clustered within some areas and not represented in others. Consequently, patterns are likely to be influenced by sub-regional dissimilarities in climatic, geographic, social and cultural history. The influence of these dissimilarities on the results and interpretations has been taken into account when interpreting patterns within and between the datasets, and sites are also shown individually in addition to the regional synthesis to illustrate site level differences and characteristics (Figs. 5-7). The results presented here have allowed a broad scale comparison of long-term demographic and vegetation change, and they suggest that shifting human population dynamics played an important role in shaping land cover in central and southern Anatolia, as evidenced by the significant positive relationships between anthropogenic pollen indicator groups (API, OJCV and grazing indicators) and

population increases (Fig. 4 and Table 3). Abundance of vegetation cluster 1.4 (parkland/grassland) is evident during the early Holocene (Fig. 3), which coincides with increased burning in the landscape of southern Anatolia, as demonstrated by Turner et al. (2010). The individual pollen records also indicate that grassland cover reached a maximum during the early Holocene (Fig. 6). This early grassland phase could have resulted from a combination of climate change and the influence of human land use, but most studies do not detect clear human impacts on vegetation until the later Holocene in Anatolia. Natural and anthropogenic use of fire, which is restricted by the availability of biomass for burning in drier sites on the Anatolian plateau, could have maintained grasslands, with climate appearing to act as a pacemaker for burning (Turner et al., 2008); however, these relationships require further investigation.

Archaeological trends for the early Holocene inferred from radiocarbon date densities (Roberts et al., 2018b) show a likely increase in population around 10300 cal. yr. BP continuing until ~7500 cal. yr. BP (Fig. 6). This corresponds to the Neolithic and early Chalcolithic periods, when farming and sedentary village life were adopted in this region (Table 1). Previous studies also demonstrate evidence of abundant *Pistacia* in the early Holocene particularly in dry, high elevation areas, which is clearly demonstrated at site Eski Acıgöl (SI 1), and also demonstrated in archaeological charcoal records of burned pistachio wood (Asouti and Kabukcu, 2014). The trends identified by Allcock (2017) for Cappadocia match the wider regional population trajectories identified in the archaeological site survey data (Fig. 3). The Early Bronze Age and Classical (Hellenistic-Roman-Early Byzantine) population peaks are clearly visible in the settlement density data shown in Figs. 3 and 4.

The grassland phase was followed by the development of open oak parkland (~8500 cal. yr. BP) that may have been managed by people (Figs. 4 and 5). According to Asouti and Kabukcu (2014) these semi-arid oak woodlands, associated with increasing abundance of deciduous oak parkland (cluster 6.2), represent one of the earliest anthropogenic vegetation types in Southwest Asia as a consequence of prehistoric landscape practices and was not simply part of the 'natural' Anatolian vegetation. Therefore, this could imply that a pre-Neolithic base-line vegetation was absent in this region; by contrast, Holocene forest cover was much more extensively developed in the uplands of southwest Anatolia. However, the increase in oak parkland also reflects climatic changes and whether or not human populations

would have been large enough to initiate detectable impacts on woodland cover at this time remains a matter of debate.

Throughout the Holocene different vegetation types emerge (Fig. 3), which can be interpreted in relation to changes in land use practices, such as increased sclerophyllous parkland (cluster 1.1) from 8400 cal. yr. BP. Evidence of early farming activity has also been identified in pollen records from archaeological sites, for example, Eastwood et al. (in review) identified very high percentage of *Cerealia* pollen grains deposited over a short time period (~300 years) during the Early Chalcolithic at Çatalhöyük in Anatolia. This early Holocene phase was followed by dominance of clusters 1.1 (sclerophyllous parkland) and 6.2 (deciduous oak parkland) until 4500 cal. yr. BP, and was then followed by an increase in Cyperaceae (shown in cluster 3.0: pasture/wetland) and tree crops indicated by the OJCV index (Fig. 4) from ~5000 cal. yr. BP. Lakes became shallower and dried out during periods of climatic desiccation (Fig. 4) leading to increased Cyperaceae marshland. Cyperaceae also increased due to upland grazing at this time. The increase in the OJCV index that occurred earliest in the one pollen record available from the coastal zone (Ovagöl) suggests that systematic cultivation of tree crops, such as olive, started in the Eu-Mediterranean zone, and only later moved into the interior Oro-Mediterranean zone.

Demographic changes coincide with some, but not all, of the vegetation changes identified in the pollen records. The SPD of radiocarbon dates from archaeological sites only covers the early to mid-Holocene and indicates a steady increase in population between 10400 and 7800 cal. yr. BP, followed by declining population (Fig. 6). Asouti (2017) highlighted a myriad of factors that contributed to land use strategies in Southwest Asia during the early Holocene including natural agencies, such as climatic seasonality, and human factors, such as the experiences, community behaviours and mobility of people. Human land use could be reflected by the increase in parkland/grassland (cluster 1.4) in central Anatolia during this time (Fig. 3), although, the delayed reestablishment of forests in the early Holocene in Turkey has also been attributed to climatic factors (Bottema et al., 1990; van Zeist and Bottema, 1991; Djamali et al., 2010). The relationships between demographic trends, human land use behaviours and vegetation changes are not straightforward and it is uncertain whether human impacts by pre-Neolithic and Neolithic communities were large enough to cause widespread changes in the natural vegetation. Although detectable at an individual site level, such settlements and populations may have been too sparse and low in number to affect

the region-wide landscape and other factors will also have influenced landscape change, such as seasonality of precipitation (Djamali et al., 2010; Lewis et al., 2017).

Oak parkland was maintained in central Anatolia until about 4000 cal. yr. BP, after which time it was largely replaced by pastureland and by tree and cereal crops (Roberts, 2018b). This is demonstrated by the grazing indicator curve and OJCV index, which provides a simple anthropogenic signal, but which can also be influenced by taxa not associated with human land use, such as wild olive (Fig. 4). The Anthropogenic Pollen Index (API) is more difficult to interpret, since the ruderal plant taxa that contribute to this index would have responded to natural (e.g. climatic) as well as human disturbance in this region. Both south-central and southwest Anatolia experienced the Beyşehir Occupation Phase (BOP) of agrarian land use, which also involved arboricultural practice and increases after around 5000 cal. yr. BP before declining again at 1500 cal. yr. BP, indicating that tree crop cultivation, although spatially variable, was most significant during this period.

Initial human impact on regional vegetation in the uplands of southwest Anatolia is detectable somewhat later than on the plateau, most notably in late Chalcolithic times. At Ağlasun, in particular, a decline in deciduous oak woodland and an increase in anthropogenic pollen taxa at around 6000 cal. yr. BP (Fig. 5) has been attributed by Bakker et al. (2012) to clearance by early farming communities. The BOP, most extensively developed between 3500 and 1300 cal. yr. BP, represents the clearest example of human-induced land cover change in southern Anatolia during the Holocene. This phase was followed by a period in many pollen records that indicates ‘rewilding’ of the landscape with an increase in pine trees. This is reflected in the vegetation summary diagram (Fig. 3) showing an increase in pine and mixed woods and decline in open/parkland vegetation. The pine forest and pine woods cluster groups are frequently represented in individual pollen sequences since the mid and late Holocene (e.g. Gölhisar, Gravgaz, and Sogut) in the south-west of the case study region and are also represented in the higher elevation sites (e.g. Beyşehir and Hoyran) towards the north-east of the case study area. Roberts et al. (2018a) concluded that in Cappadocia (central Anatolia) the post-disturbance trajectory also took the regional socio-ecological system to a new and different state, rather than returning to a previous one, in this region dominated by agro-pastoralism (England et al., 2008).

Many previous studies have focussed on shorter time periods (e.g. Izdebski et al., 2015), small scale (i.e. site specific) comparisons between pollen and archaeological records, and identified similar timing in evidence of human occupation and the presence of land use pollen indicators (England et al., 2008). Within the current study there are distinct differences between the pollen sites in the southwest and those on the central Anatolian plateau. The southwest is more mountainous and forested whereas the plateau is drier. During the late Holocene a marked increase in AP% is evident, mainly in the last 1500 years, particularly involving pine woods/forests, which indicates reforestation of areas previously used for agricultural land use. This is also shown in the cluster results (4.0, 5.1 and 5.2: Fig. 3). A decline in population coincides with times of turbulence caused by conflict on the eastern frontier of the Byzantine Empire when much of southern and central Anatolia was deliberately de-populated and militarised (England et al., 2008; Izdebski, 2013; Haldon, 2016).

Significant relationships have been identified between the climate records and the demographic trends (settlement proxy), however, these relationships are complex and reflect many natural and cultural factors. The negative relationship between pasture/wetland and climate implies that when climate is drier, lake levels are lower and more habitats are created that support wetland plants (e.g. Cyperaceae). The synthesised pollen datasets analysed in this study do not appear to show any clear changes during the 9.3 and 8.2 ka climatic events, although they can be recognised in proxy-climate records from sites such as Nar Gölü (Dean et al., 2015). The 4.2 and 3.2 ka climatic events (e.g. Kaniewski et al., 2008) have been linked to societal collapse with centennial-scale drought intervals identified in palaeoclimate records during these periods (e.g. Dean et al., 2015; Massa and Şahoğlu, 2015). Population dynamics drawn from archaeological data seem to corroborate this picture in addition to the strong negative correlations ($r = \sim -0.70$) between palaeoclimate and demographic proxies (Table 3). The fact that some pollen taxa reflect both anthropogenic and non-anthropogenic factors complicates the interpretation of the indicator groups. Flohr et al. (2016) predicted four different potential societal ‘responses’ to sudden climatic change: collapse/decline of societies; long distance migration; adaptation; and no impact. The significant relationships between the OJCV index, API and grazing indicators and the climate records indicate that people may have adapted to long-term climatic shifts, for example, through diversification of subsistence practices. Flohr et al. (2016) suggested that the lack of a large-scale, severe impact that can be detected on Southwest Asian societies can be explained by the existence of

such adaptation strategies and/or by the resilience of early farming communities. In more recent historical periods (the last two thousand years), a number of studies demonstrated that the impact of climatic changes on societal and landscape transformations was relatively limited. Adverse changes in climate conditions did not coincide with major transformations in the landscape and society (Izdebski 2013; Haldon et al. 2014; Izdebski et al. 2016). Rather, a major landscape change, marking the end of the BOP, which took place in southern Anatolia around the 7th century AD has been linked to the collapse of the Eastern Roman (early Byzantine) political and socio-economic system, which required adaptation of social practices and landscapes across Anatolia and much of the eastern Mediterranean. Similar studies of the later historical periods reported lack of clear connections between climatic instability and socio-economic factors as well as landscape change during the Medieval Climate Anomaly (Xoplaki et al., 2016). However, a severe multi-year drought that occurred in Anatolia in the 1590s (AD) led to a prolonged social crisis and expansion of steppe pastures (White, 2011). Several episodes of ‘social crises’ occurred through this and the following century as a consequence of a complex combination of social and cultural factors. The increase in cluster 3.0 (pasture/wetland) between 4500 and 1300 cal. yr. BP is likely to have been due both to climatic desiccation (including the 4.2 and 3.2 ka dry events), and to population rise and the development of pastoralism during Bronze Age to Classical times.

Other factors may also have influenced vegetation patterns, such as geomorphological changes (Kuzucuoğlu et al., 2018) and the impacts of long-term human impact and extreme climatic conditions upon soil properties and thus site-conditions for vegetation growth (e.g. Van Loo et al., 2017, who identified that soil erosion was driven by anthropogenic activities rather than climate change in southwest Turkey). Soil exhaustion in the past may have caused changes in vegetation composition not directly related to human impacts or climate. Furthermore, vegetation recovery following human impact or climate change may be delayed or even halted when specific ‘tipping points’ are not crossed. This might be related to site specific environmental conditions making some sites more resilient than others and resulting in new equilibrium vegetation composition. For example, Kaniewski et al. (2007) stress how contemporary land cover shows strong legacy effects of past human impact.

Landscape management

Understanding past demographic and vegetation change may provide useful information about the impacts of landscape management. Asouti and Kabukcu (2014) highlight how information about the origin and evolution of the Anatolian semi-arid oak woodlands is potentially of importance for reconstructing the changing ecologies and geographical distributions of domesticated crop species. Land use strategies that encourage the establishment and spread of deciduous oaks include sheep herding, controlling competing arboreal vegetation and woodland management (Asouti and Kabukcu, 2014). These practices could have affected landscapes in the mid-Holocene when, as our regional pollen synthesis shows, deciduous oak parkland (cluster 6.2) was more abundant in the landscape; this vegetation type is still abundant in Cappadocia at present. In central Anatolia, this parkland ecosystem also includes economically important tree taxa, such as almond and wild fruit trees that are poorly represented in pollen diagrams (Woldring and Cappers, 2001). According to Gross (2012), poorly-considered development projects are threatening biodiversity in Turkey and wildlife corridors provide opportunity to support conservation progress. Restoring biodiversity to its condition in, for example, earlier stages of the Holocene depends not only on reducing livestock grazing and wood-fuel cutting, but also on incorporating these into a more sustainable system of socio-ecological management such as existed prior to the Iron Age.

Pollen records from Anatolia show clear evidence of environmental recovery following disturbance, most obviously in the post-BOP period. At Nar Gölü in Cappadocia, this included a significant re-expansion of oak woodland and decline in soil erosion after ~1300 cal. yr. BP (England et al., 2008; Roberts et al., in review). In the uplands of southwest Anatolia, the re-wilding process favoured expansion of pine trees rather than the mixed conifer-broad leaf forests of the mid-Holocene (Fig. 3) (see Richardson (2000) for a review of the ecology and biogeography of *Pinus*). The recent dominance of pine has probably been due to a combination of factors including soil loss during and after the BOP, along with continued grazing/browsing pressure from transhumant livestock herding, although open *Juniperus* woodland is also favoured by grazing. The relationships between population, land use and vegetation change are complex and understanding regional trajectories of change can provide information about the characteristics of vegetation resulting from different management practices and changing demographic pressures over time.

Conclusion

This study has highlighted the long-standing human transformation of vegetation in southern Anatolia. The early emergence of Neolithic agriculture meant that the oak parkland ecosystem of central Anatolia co-evolved as a consequence of natural and anthropogenic factors, including burning, grazing and wood cutting, and which may therefore have been maintained as a semi-natural agro-ecosystem. While changing human populations clearly influenced vegetation patterns, they did so in combination with other external controls, such as climate change. Hence the increase in sedge pollen (cluster 3.0: pasture/wetland) between 4500 and 1300 cal. yr. BP is likely to have been due both to climatic desiccation, including the 4.2 and 3.2 dry events, and demographic increase and the creation of upland pastureland during Bronze Age to Classical times. The precise timing of shifts in population and impacts on vegetation patterns do not show regular repetitive patterns over time. Pollen indicator groups such as cultivated trees (OJCV) and grazing indicators display significant positive relationships with demographic trends, especially during the BOP, and highlight how greater production of food would have been required for larger populations. Modern land management could benefit from improved understanding of the regional relationships between land use and vegetation change, and knowledge of how past land use practices promoted the resilience and potential for recovery of certain vegetation types, such as deciduous oak parkland.

References

- Allcock SL and Roberts N (2014) Changes in regional settlement patterns in Cappadocia (central Turkey) since the Neolithic: A combined site survey perspective. *Anatolian Studies* 64: 33-57.
- Allcock SL (2017) Long-term socio-environmental dynamics and adaptive cycles in Cappadocia, Turkey during the Holocene. *Quaternary International* 446: 66-82.
- Asouti E (2017) Human Palaeoecology in Southwest Asia During the Early Pre-Pottery Neolithic (c.9700-8500 cal BCE). Benz M, Gebel HGK and Watkins T (Eds) *The Plant Story Studies in Early Near Eastern Production, Subsistence, and Environment: Neolithic Corporate Identities*. Berlin: Dörte Rokitta-Krumnow.
- Asouti E and Kabukcu, C (2014) Holocene semi-arid oak woodlands in the Irano-Anatolian region of Southwest Asia: natural or anthropogenic? *Quaternary Science Reviews* 90: 158-182.

- Baird D, Fairbairn A, Jenkins E, et al. (2018) Agricultural origins on the Anatolian plateau. *Proceedings of the National Academy of Sciences of the United States of America* 201800163.
- Bakker J, Paulissen E, Kaniewski D, et al. (2012) Man, vegetation and climate during the Holocene in the territory of Sagalassos, Western Taurus Mountains, SW Turkey. *Vegetation History and Archaeobotany* 21: 249-266.
- Berger J-F, Lespez L, Kuzucuoglu C, et al. (2016) Interactions between climate change and human activities during the early to mid-Holocene in the eastern Mediterranean basin. *Climate of the Past* 12: 1847-1877.
- Bottema S, Woldring H and Aytug B (1986) Palynological investigations on the relation between prehistoric man and vegetation in Turkey: the Beyşehir Occupation Phase. In: Demiriz H and Özhatay N (eds) *Proceedings of the 5th OPTIMA Meeting, Istanbul* 315-28.
- Bottema S, Entjes-Nieborg G and van Zeist W (eds.) (1990) *Man's role in the shaping of the eastern Mediterranean landscape*. Rotterdam: A.A. Balkema.
- Colledge S, Connolly J and Shennan S (2004) Archaeobotanical evidence for the spread of farming in the Eastern Mediterranean. *Current Anthropology* 45: 35-58.
- Crema ER (2012) Modelling temporal uncertainty in archaeological analysis. *Journal of Archaeological Method and Theory* 19: 440-461.
- Davis BAS, Zanon M, Collins P, et al. (2013) The European modern pollen database (EMPD) project. *Vegetation History and Archaeobotany* 22: 521-530.
- Dean JR, Jones MD, Leng MJ, et al. (2015) Eastern Mediterranean hydroclimate over the late glacial and Holocene, reconstructed from the sediments of Nar lake, central Turkey, using stable isotopes and carbonate mineralogy. *Quaternary Science Reviews* 124: 162-174.
- Dalfes HN, Kukla G and Weiss H (1997) *Third Millennium BC Climate Change and Old World Collapse*. Berlin: Springer.
- Djamali M, Akhiani H, Andrieu-Ponel V et al. (2010) Indian Summer Monsoon variations could have affected the early Holocene woodland expansion in the Near East. *The Holocene* 20: 813-20.
- Eastwood WJ, et al. (in review) Comparing palynological and archaeobotanical data for early cereal agriculture at Neolithic-Chalcolithic Çatalhöyük, Turkey. *Quaternary Science Reviews*.

- Eastwood WJ, Leng MJ, Roberts N et al. (2007) Holocene climate change in the eastern Mediterranean region: a comparison of stable isotope and pollen data from Lake Gölhisar, southwest Turkey. *Journal of Quaternary Science* 22: 327-341.
- Eastwood WJ, Roberts N and Lamb HF (1998) Palaeoecological and archaeological evidence for human occupation in southwest Turkey: The Beyşehir Occupation Phase. *Anatolian Studies* 48: 69-86.
- England A, Eastwood WJ, Roberts CN, et al. (2008) Historical landscape change in Cappadocia (central Turkey): a palaeoecological investigation of annually-laminated sediments from Nar lake. *The Holocene* 18: 1229-1245.
- Flohr P, Fleitmann D, Matthews R, et al. (2016) Evidence of resilience to past climate change in Southwest Asia: Early farming communities and the 9.2 and 8.2 ka events. *Quaternary Science Reviews* 136: 23-39.
- Fuller DQ, Willcox G and Allaby RG (2012) Early agricultural pathways: moving outside the 'core area' hypothesis in Southwest Asia. *Journal of Experimental Botany* 63: 617-633.
- Fyfe RM, Woodbridge J and Roberts N (2018) Trajectories of change in Mediterranean Holocene vegetation through classification of pollen data. *Vegetation History and Archaeobotany* 27: 351-364.
- Gross M (2012) Turkey's biodiversity at the crossroads. *Current Biology* 22: 503-505.
- Haldon JF (2016) *The empire that would not die : the paradox of eastern Roman survival.* 640-740. Massachusetts: Harvard University Press.
- Haldon J, Roberts N, Izdebski A, et al. (2014) The climate and environment of Byzantine Anatolia: integrating science, history and archaeology. *Journal of Interdisciplinary History* 45:113-161.
- Iyigun C, Türkeş M, Batmaz I et al. (2013) Clustering current climate regions of Turkey by using a multivariate statistical method. *Theoretical and Applied Climatology* 114: 95-106.
- Izdebski A (2013) *A rural economy in transition : Asia Minor from late antiquity into the early Middle Ages.* Warszawa: Fundacja im. Rafała Taubenschlaga.
- Izdebski A, Pickett J, Roberts N and Waliszewski T (2016) The environmental, archaeological and historical evidence for regional climatic changes and their societal impacts in the Eastern Mediterranean in Late Antiquity. *Quaternary Science Reviews* 136: 189-208.

- Izdebski A, Koloch G and Słoczyński T (2015) Exploring Byzantine and Ottoman economic history with the use of palynological data: a quantitative approach. *Jahrbuch der österreichischen Byzantinistik* 65:67-110.
- Jones MD, Roberts CN, Leng MJ and Türkeş M (2006) A high-resolution late Holocene lake isotope record from Turkey and links to North Atlantic and monsoon climate. *Geology* 34: 361-364.
- Kaniewski D, De Laet V, Paulissen E et al. (2007) Long-term effects of human impact on mountainous ecosystems, western Taurus Mountains, Turkey. *Journal of Biogeography* 34: 1975-1997.
- Kaniewski D, Paulissen E, van Campo E et al. (2008) Middle East coastal ecosystem response to middle-to-late Holocene abrupt climate changes, PNAS 105: 13941–13946.
- Kuzucuoğlu C, Kazancı N and Çiner A (Eds) (2018) *Geomorphological Landscapes of Turkey*. Verlag: Springer.
- Kuzucuoğlu C (2015) The rise and fall of the Hittite Empire in central Anatolia: how, when, where, did climate intervene? In: Beyer D, Henry O and Tibet A (eds) *La Cappadoce méridionale de la Préhistoire à la période byzantine*, Institut Français d'Etudes Anatoliennes, Ege Yay., Istanbul 17-41.
- Legendre L and Legendre P (1983). *Numerical ecology*. Amsterdam: Elsevier.
- Lewis JP, Leng MJ, Dean JR et al. (2017) Early Holocene palaeoseasonality inferred from the stable isotope composition of *Unio* shells from Çatalhöyük, Turkey. *Environmental Archaeology* 22: 79-95.
- Leydet M (2007-2017) The European Pollen Database. Available at: <http://www.europeanpollendatabase.net/>. (accessed October 2017).
- Marro C and Kuzucuoğlu C (2007) Northern Syria and upper Mesopotamia at the end of the third mill. BC: did a crisis take place? In: Kuzucuoğlu C and Marro C, *The crisis at the end of the 3rd mill. BC in the middle Euphrates Valley: a reality?* Varia Anatolica, XIX, De Boccard, Paris and Ege Yay/IFEA, Istanbul 583-590.
- Massa M and Şahoğlu V (2015) The 4.2 ka cal. yr. BP Climatic Event in West and Central Anatolia: Combining Palaeo-climatic Proxies and Archaeological Data. In: Meller H, Arz HW, Jung R and Risch R (Eds.) *2200 BC - A climatic breakdown as a cause for the collapse of the old world?* Halle Saale: Landesamt für Denkmalpflege und Archäologie Sachsen-Anhalt, Landesmuseum für Vorgeschichte 61-78.

- Mazier F, Galop D, Brun C et al. (2006) Modern pollen assemblages from grazed vegetation in the western Pyrenees, France: a numerical tool for more precise reconstruction of past cultural landscapes. *The Holocene* 16: 91-103.
- McIntosh RJ, Tainter JA and McIntosh SK (2000) *The Way the Wind Blows: Climate, History and Human Action*. New York: Columbia University Press.
- McCune B and Grace JB (2002) *Analysis of ecological communities*. Oregon: MjM Software Design.
- Mercuri AM, Bandini Mazzanti M, Florenzano A et al. (2013a) Anthropogenic pollen indicators (API) from archaeological sites as local evidence of human-induced environments in the Italian Peninsula. *Annali Di Botanica* 3: 143-153.
- Mercuri AM, Bandini Mazzanti M, Florenzano A, et al. (2013b) *Olea*, *Juglans* and *Castanea*: The OJC group as pollen evidence of the development of human-induced environments in the Italian peninsula. *Quaternary International* 303: 24-42.
- Morris EK, Caruso T, Buscot F et al. (2014) Choosing and using diversity indices: insights for ecological applications from the German Biodiversity Exploratories. *Ecology and Evolution* 4: 3514-3524.
- Palmisano A, Bevan A and Shennan S (2017) Comparing archaeological proxies for long-term population patterns: An example from central Italy. *Journal of Archaeological Science* 87: 59-72.
- Perez M, Fyfe RM, Charman DJ and Gehrels R (2015) Later Holocene vegetation history of the Isles of Scilly, UK: coastal influence and human land use in a small island context. *Journal of Quaternary Science* 30: 764-778.
- Richardson D (2000) *Ecology and Biogeography of Pinus*. UK: Cambridge University Press.
- Roberts N, Allcock SL, Barnett H et al. (in review) Disturbing nature's harmonies? The role of humans and climate upon Holocene sediment flux into a central Anatolian lake catchment. *Geomorphology*.
- Roberts N (2018) Re-visiting the Beyşehir Occupation phase: land-cover change and the rural economy in the eastern Mediterranean during the first millennium CE. Eds: Mulryan M and Izdebski A *Late Antique Archaeology*.
- Roberts N, Cassis M, Doonan O et al. (2018a) Not the end of the world? Post-Classical decline and recovery in rural Anatolia. *Human Ecology*. doi.org/10.1007/s10745-018-9973-2

- Roberts N, Woodbridge J, Bevan A et al. (2018b) Human responses and non-responses to climatic variations during the last Glacial-Interglacial transition in the eastern Mediterranean. *Quaternary Science Reviews* 184: 47-67.
- Roberts N, Reed J, Leng MJ et al. (2001) The tempo of Holocene climatic change in the eastern Mediterranean region: new high-resolution crater-lake sediment data from central Turkey. *The Holocene* 11: 721-736.
- Staubwasser M and Weiss H (2006) Holocene climate and cultural evolution in late prehistoric-early historic West Asia. *Quaternary Research* 66: 372-387.
- Timpson A, Colledge S, Crema E et al. (2014) Reconstructing regional population fluctuations in the European Neolithic using radiocarbon dates: a new case-study using an improved method. *Journal of Archaeological Science* 52: 549-557.
- Turner R, Roberts N and Jones MD (2008) Climatic pacing of Mediterranean fire histories from lake sedimentary microcharcoal. *Global and Planetary Change* 63: 317-324.
- Turner R, Roberts N, Eastwood WJ et al. (2010) Fire, climate and the origins of agriculture: micro-charcoal records of biomass burning during the last glacial–interglacial transition in Southwest Asia. *Journal of Quaternary Science* 25: 371-386.
- Vandam R (2015) The Burdur Plain Survey Project, SW Turkey. In search of the Middle Chalcolithic (5500-4200 BC). In: Steadman SR and McMahon G (Eds.) *The Archaeology of Anatolia: Recent Discoveries (2011-2014) Vol I*. UK: Cambridge Scholar Press, 282-301.
- Van Loo M, Duser B, Verstraeten G et al. (2017) Human induced soil erosion and the implications on crop yield in a small mountainous Mediterranean catchment (SW-Turkey). *Catena* 149: 491-504.
- Vermoere M, Bottema S, Vanhecke L et al. (2002) Palynological evidence for late-Holocene human occupation recorded in two wetlands in SW Turkey. *The Holocene* 12: 569-584.
- Weninger B, Clare L, Jöris O, Jung R and Edinborough K (2015) Quantum theory of radiocarbon calibration. *World Archaeology* 47: 543-566.
- White S (2011) *The Climate of Rebellion in the Early Modern Ottoman Empire*. UK: Cambridge University Press.
- Wilkinson TJ (1997) Environmental fluctuations, agricultural production and collapse: a view from Bronze Age upper Mesopotamia. In: Dalfes HN, Kukla G and Weiss H (eds) *Third Millennium B.C. Climate Change and Old World Collapse, NATO ASI Series 149*, Berlin: Springer-Verlag 67-106.

- Williams AN (2012) The use of summed radiocarbon probability distributions in archaeology: a review of methods. *Journal of Archaeological Science* 39: 578-589.
- Woldring H and Cappers RTJ (2001) The origin of the 'Wild Orchards' of Central Anatolia. *Turkish Journal of Botany* 25: 1-9.
- Woodbridge J, Roberts N and Fyfe R (in press) Pan-Mediterranean Holocene vegetation and land-cover dynamics from synthesised pollen data. *Journal of Biogeography*.
- Woodbridge J and Roberts N (2011) Late Holocene climate of the Eastern Mediterranean inferred from diatom analysis of annually-laminated lake sediments. *Quaternary Science Reviews* 30: 3381-3392.
- van Zeist W and Bottema S (1991) *Late Quaternary vegetation of the Near East*. Michigan: Reichert, pp 156.
- van Zeist W, Woldring H and Stapert D (1975) Late Quaternary vegetation and climate of southwestern Turkey. *Palaeohistoria* 17: 55-143.
- Xoplaki E, Fleitmann D, Luterbacher J et al. (2016) The Medieval Climate Anomaly and Byzantium: A review of the evidence on climatic fluctuations, economic performance and societal change. *Quaternary Science Reviews* 136: 229-252.

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Figures

Fig 1 Locations of modern pollen (grey) and fossil pollen (green) sites, archaeological (blue) and radiocarbon sites (red) and palaeoclimate records (black triangles). The topographic map is shown for the region of south-central Anatolia analysed within this study. Site numbers are provided with the fossil sites (see Table 2 for further information).

Fig 2 Pollen-inferred vegetation cluster groups presented as percentage of pollen samples (time windows) assigned to each vegetation cluster group for sites in south-central Anatolia, and archaeological datasets (11000 cal. yr. BP – modern). The summary diagram shows amalgamated values of broad cluster groups and the grey area highlights a period of low pollen site numbers.

Fig 3 Normalised demographic trends for south-central Turkey based on settlement data (raw count, total area, aoristic weight and randomised start date) for the period 10000-1000 cal. yr. BP with key archaeological periods highlighted.

Fig 4 Pollen indicator groups: arboreal pollen (%AP), sum of *Olea*, *Juglans*, *Castanea* and *Vitis* (OJCV), anthropogenic pollen index (API), summed grazing indicators, non-metric multidimensional scaling (nMDS) axis scores, and Simpson's diversity index averaged for all sites in the study area (11000 cal. yr. BP to modern). Archaeological demographic proxies from settlement data: total estimated area of sites and number of sites (randomised start date) (9900 to 1100 cal. yr. BP). Normalised (z-scores) $\delta^{18}\text{O}$ hydroclimate (palaeoclimate) proxy records with average and standard deviation.

Fig 5 Sum of Arboreal Pollen (%AP) for each fossil pollen site plotted with vegetation cluster groups (symbols) (11000 cal. yr. BP to present). Sites 1 to 18 are located in southwest Anatolia and sites 19 to 22 are located on the Anatolian Plateau.

Fig 6 Poaceae (grass) % for pollen sites covering the early Holocene presented with summed probability distribution (SPD) (11000 to 6000 cal. yr. BP).

Fig 7 OJC (*Olea*, *Juglans* and *Castanea*) index for the period 6000 cal. yr. BP to present for each pollen record presented with archaeological demographic proxies from settlement data: total estimated area of sites and number of sites (randomised duration) (6000 to 1100 cal. yr. BP).

Supplementary Information 1 Percentage of a) *Cerealina* (cereal) pollen types and b) *Pistacia* (pistachio) pollen for each pollen record for the period 11000 cal. yr. BP to present.

Supplementary Information 2 a) Anthropogenic Pollen Index (API) and b) grazing indicators (*Plantago lanceolata*, *Rumex acetosa*-type, *Sanguisorba*) for each pollen record for the period 11000 cal. yr. BP to present.

Supplementary Information 3 Archaeological datasets and references for settlement data used in this study.

Tables

Table 1 Archaeological periods in central and southwest Anatolia (based on Allcock, 2017). The Beyşehir Occupation Phase (BOP) most extensively covers the period from 3500 until 1300 cal. yr. BP.

Table 2 Metadata for fossil pollen and palaeoclimate records from central Anatolia.

Table 3 a) Spearman's Rho correlations between the pollen and archaeological datasets (upper value within each cell: r -value and lower value: p -value) (significant correlations are shaded grey) (9900-1100 cal. yr. BP). b) Spearman's Rho correlations between the pollen, archaeological and palaeoclimate z-score datasets (upper value within each cell: r -value and lower value: p -value) (significant correlations are shaded grey) (for corresponding time periods)

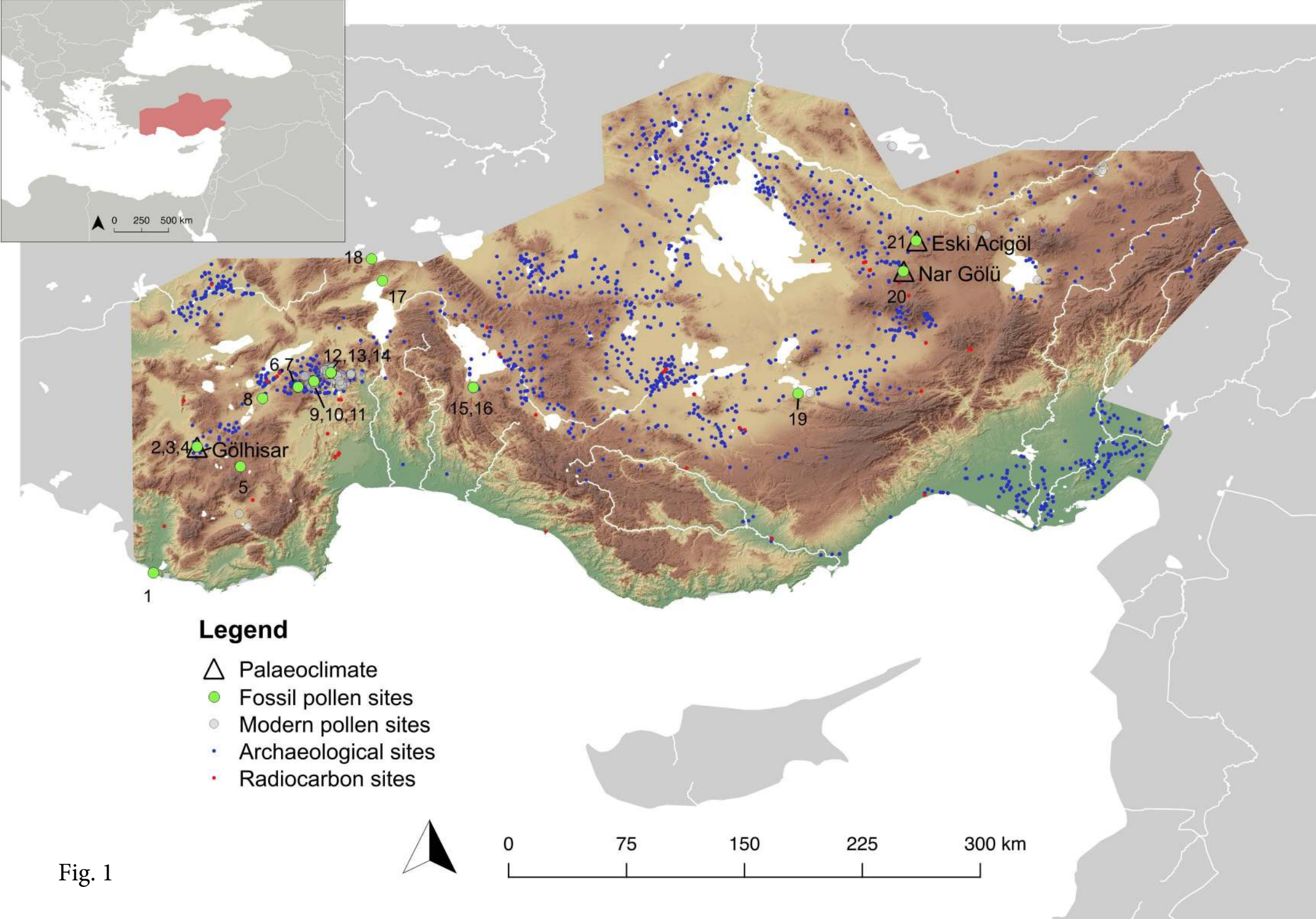


Fig. 1

Fig. 2

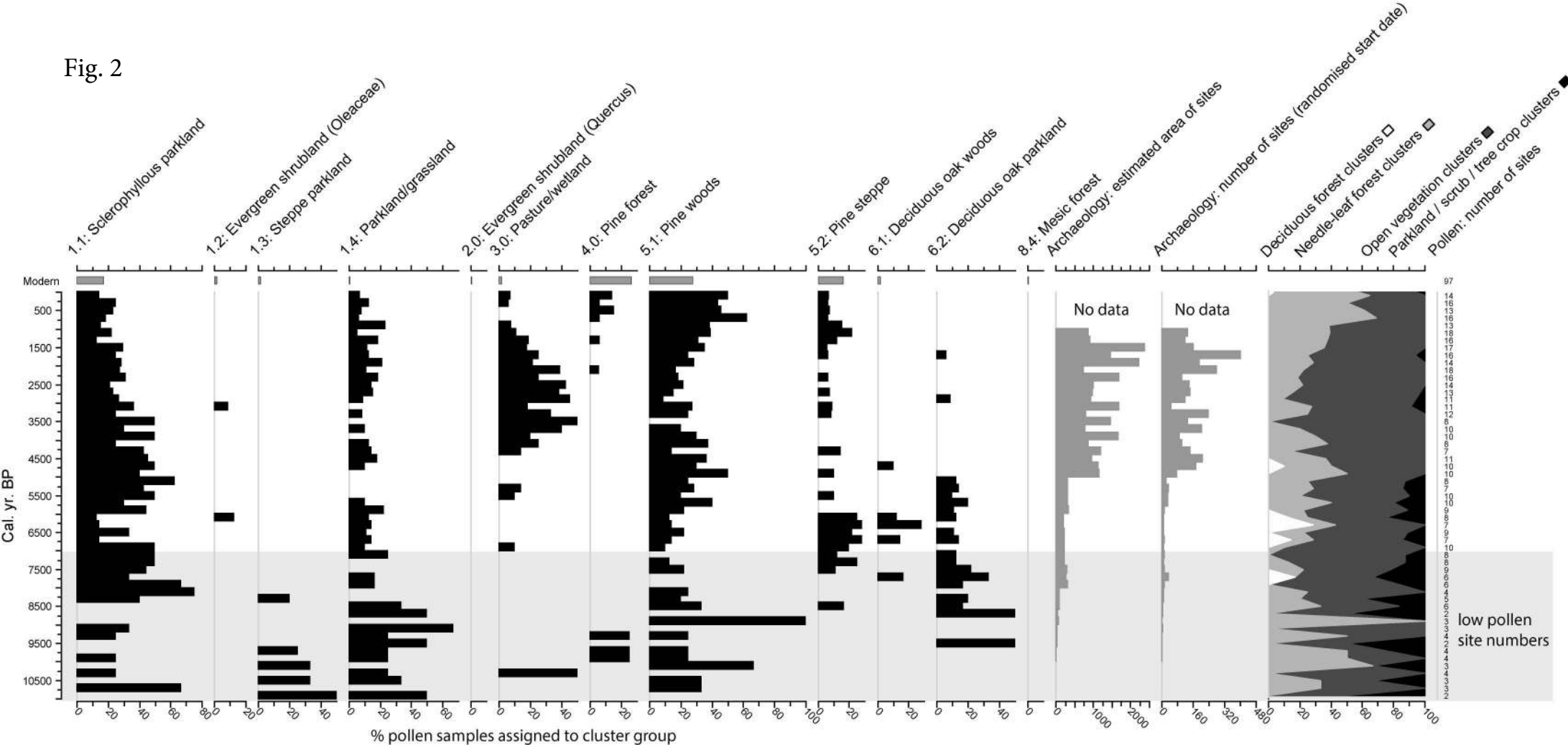


Fig. 3

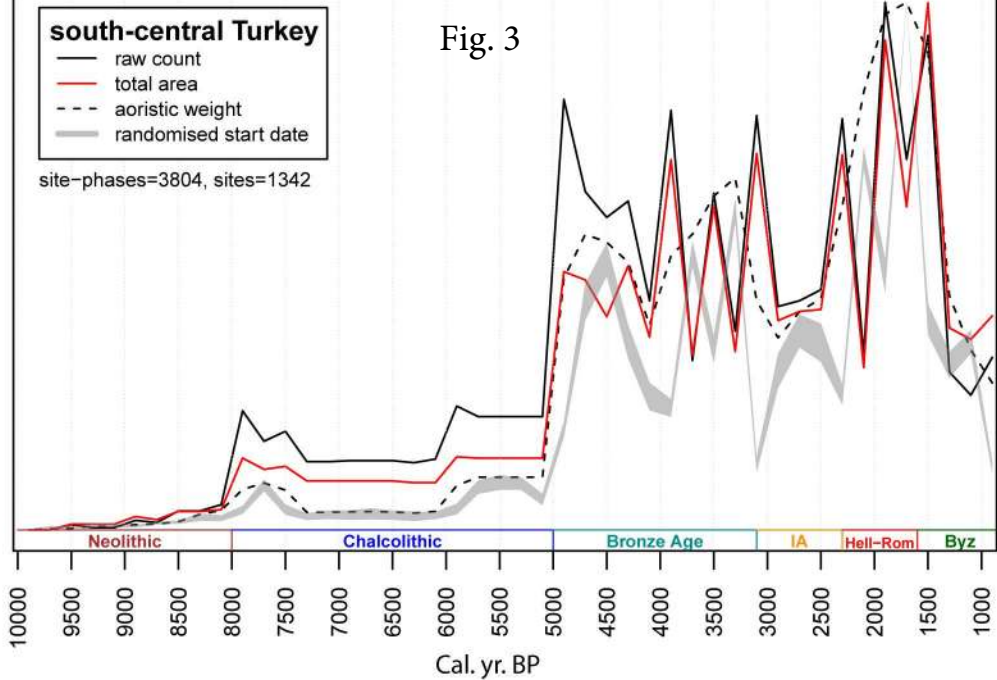
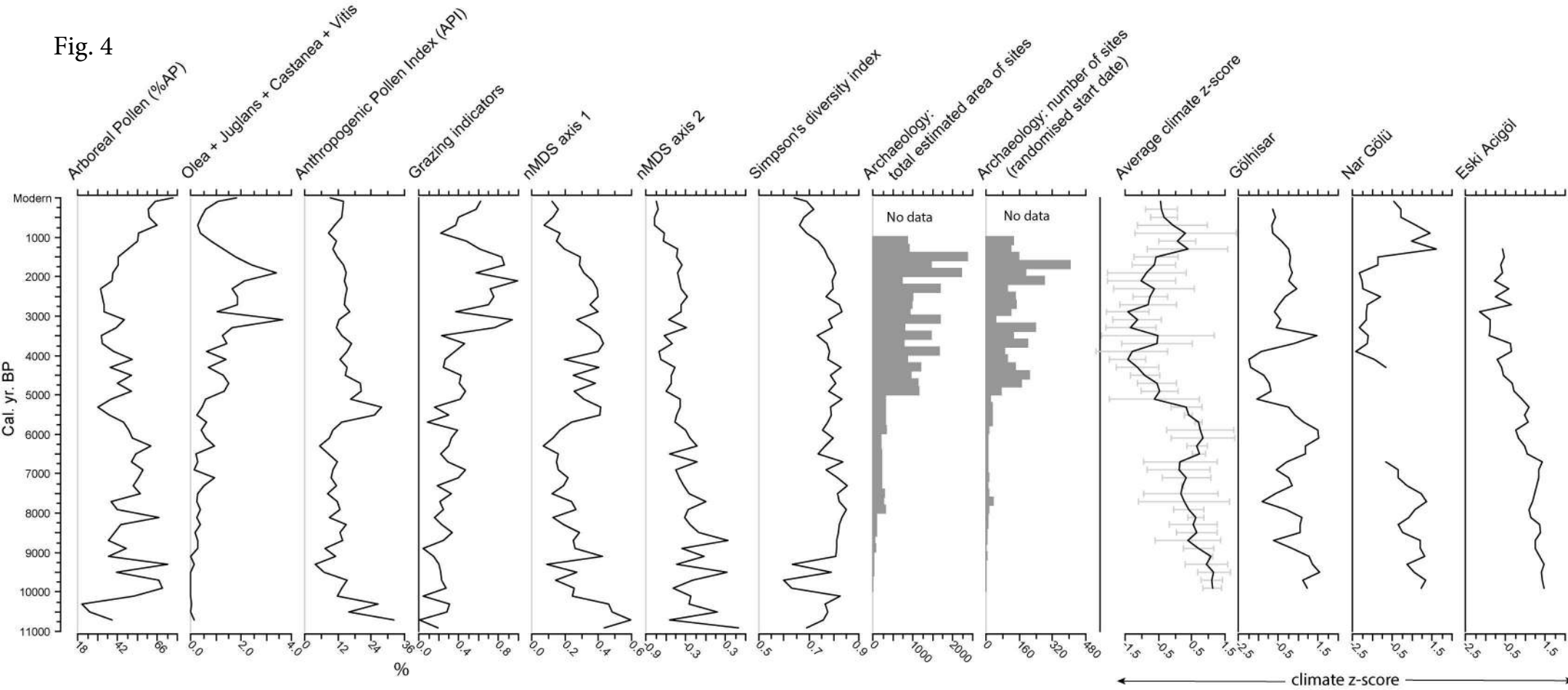


Fig. 4



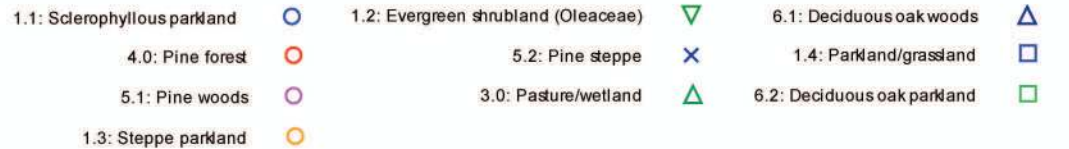
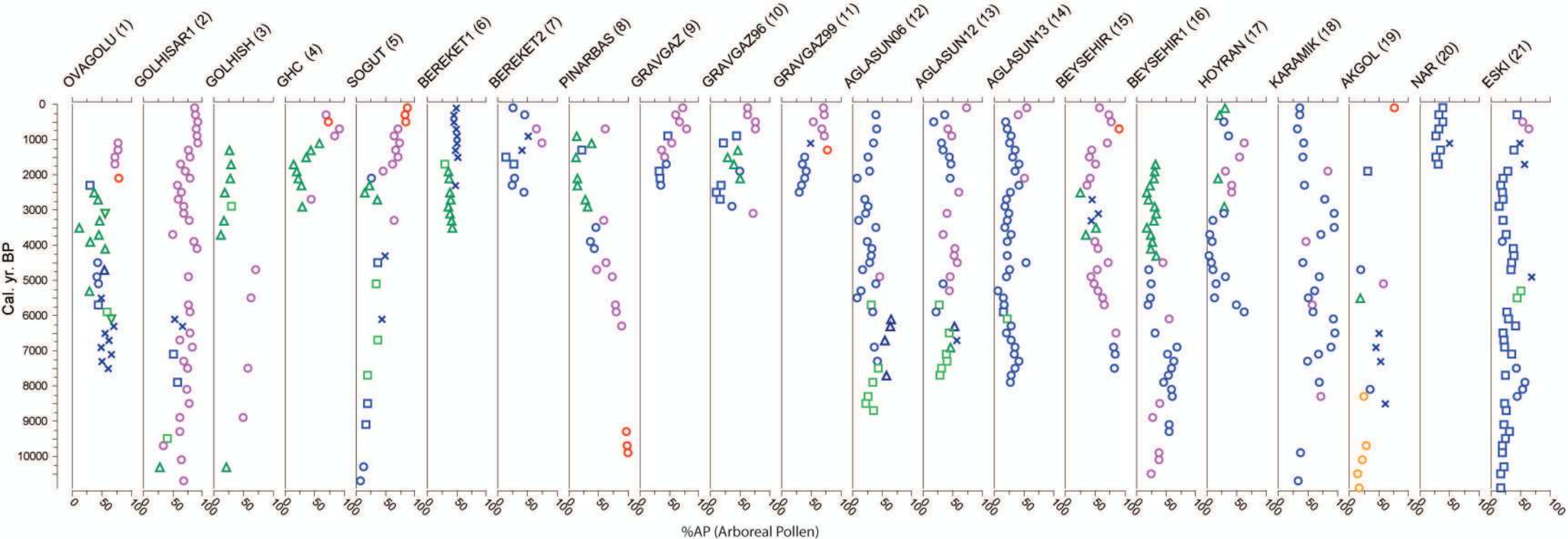


Fig. 5

Fig. 6

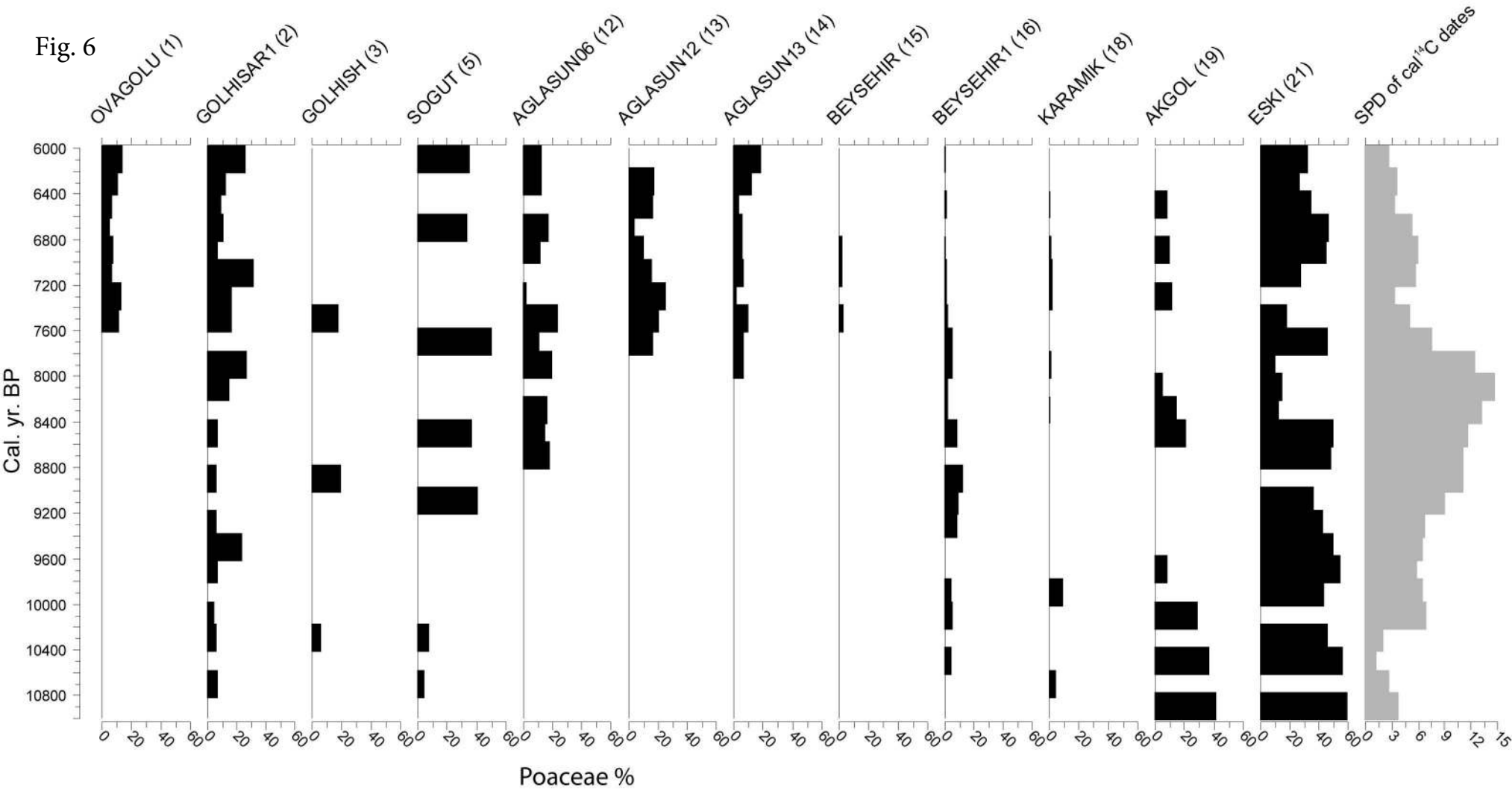


Fig. 7

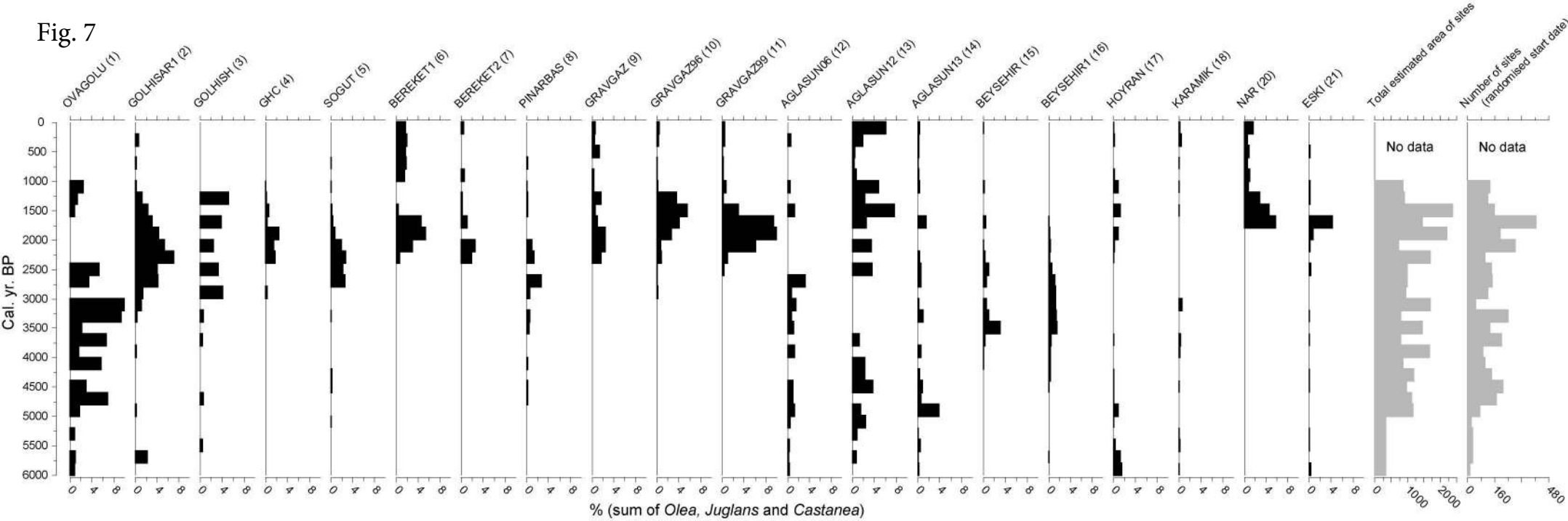


Table 1 Archaeological periods in central and southwest Anatolia (based on Allcock, 2017). The Beyşehir Occupation Phase (BOP) most extensively covers the period from 3500 until 1300 BP.

| Age BP | BC / AD | Period |
|----------------------|--------------------------|---|
| <i>900 - present</i> | <i>AD 1050 - present</i> | Medieval (Islamic) to modern |
| <i>1600 - 900</i> | <i>AD 350 - 900</i> | Byzantine |
| <i>~2000-1600</i> | <i>~50 BC - AD 350</i> | Roman |
| <i>~2300 - 2000</i> | <i>~350 - 50 BC</i> | Hellenistic |
| <i>3100 - 2300</i> | <i>1150 - 350 BC</i> | Iron Age (including Persian) |
| <i>3400 - 3100</i> | <i>1450 - 1150 BC</i> | Late Bronze Age (Hittite Empire) |
| <i>4000 - 3400</i> | <i>2050 - 1450 BC</i> | Middle Bronze Age (including Old Hittite) |
| <i>5000 - 4000</i> | <i>3050 - 2050 BC</i> | Early Bronze Age |
| <i>8000 - 5000</i> | <i>6050 - 3050 BC</i> | Chalcolithic |
| <i>10,300 - 8000</i> | <i>8350 - 6050 BC</i> | Neolithic |
| <i>>10,300</i> | <i>>8350 BC</i> | Pre-Neolithic |

Table 2 Metadata for pollen and climate records from sites in southern Anatolia

| | Code | Site Name | Latitude | Longitude | Elevation | Contributor | Site type | Proxy type | Start and end date | N. time windows | Reference |
|----|-----------|---------------|----------|-----------|-----------|-------------|-----------------------------|--------------------|--------------------|-----------------|--|
| 1 | OVAGOLU | Ova Gölü | 36.26667 | 29.3 | 20 | EPD | small marsh in drained lake | Pollen | 7400-1000 | 30 | European Pollen Database |
| 2 | GOLHISAR1 | Göhlisar | 37.13333 | 29.6 | 951 | Eastwood | lake | Pollen and climate | 10600-200 | 21 | Eastwood W et al. (1999) Quaternary Science Reviews, 18: 671-695. |
| 3 | GOLHISH | Göhlisar Gölü | 37.13333 | 29.6 | 951 | EPD | lake | Pollen | 8800-1200 | 11 | European Pollen Database |
| 4 | GHC | Göhlisar Gölü | 37.13333 | 29.6 | 951 | Eastwood | lake | Pollen | 2600-1000 | 6 | |
| 5 | SOGUT | Sögüt Gölü | 36.9975 | 29.89833 | 1400 | EPD | drained lake | Pollen | 8400-0 | 20 | van Zeist WH et al. (1975) Palaeohistoria, 17: 53-144. |
| 6 | BEREKET1 | Bereket1 | 37.54518 | 30.29506 | 1410 | Kaniewski | marsh | Pollen | 2200-0 | 11 | Kaniewski D et al. (2007) Quaternary Science Reviews 26, 2201-2218. |
| 7 | BEREKET2 | Bereket2 | 37.54518 | 30.29512 | 1410 | Izdebski | marsh | Pollen | 1400-1200 | 2 | Bakker J et al. (2012) Vegetation History and Archaeobotany, 21: 249-266. |
| 8 | PINARBAS | Pinarbasi | 37.46667 | 30.05 | 970 | EPD | lake | Pollen | 4600-800 | 11 | European Pollen Database |
| 9 | GRAVGAZ | Gravgaz | 37.58425 | 30.40358 | 1215 | Izdebski | marsh | Pollen | 1800-0 | 9 | Bakker J et al. (2012) Vegetation History and Archaeobotany, 21: 249-266. |
| 10 | GRAVGAZ96 | Gravgaz96 | 37.58425 | 30.40358 | 1215 | Broothaerts | marsh | Pollen | 3000-0 | 16 | Vermoere M et al. (2002) The Holocene 12: 569-584. |
| 11 | GRAVGAZ99 | Gravgaz99 | 37.58425 | 30.40358 | 1215 | Broothaerts | marsh | Pollen | 2400-0 | 13 | Bakker J et al. (2013) Climate of the Past 9: 57-87. |
| 12 | AGLASUN06 | Aglasun06 | 37.64157 | 30.52029 | 1140 | Broothaerts | stream | Pollen | 8600-200 | 22 | Vermoere M (2004) In: Waelkens M. Studies in eastern Mediterranean archaeology (SEMA 6). Turnhout: Brepols, 1-347. |
| 13 | AGLASUN12 | Aglasun12 | 37.64058 | 30.5225 | 1140 | Broothaerts | stream | Pollen | 7600-0 | 27 | Vermoere M (2004) In: Waelkens M. Studies in eastern Mediterranean archaeology (SEMA 6). Turnhout: Brepols, 1-347. |

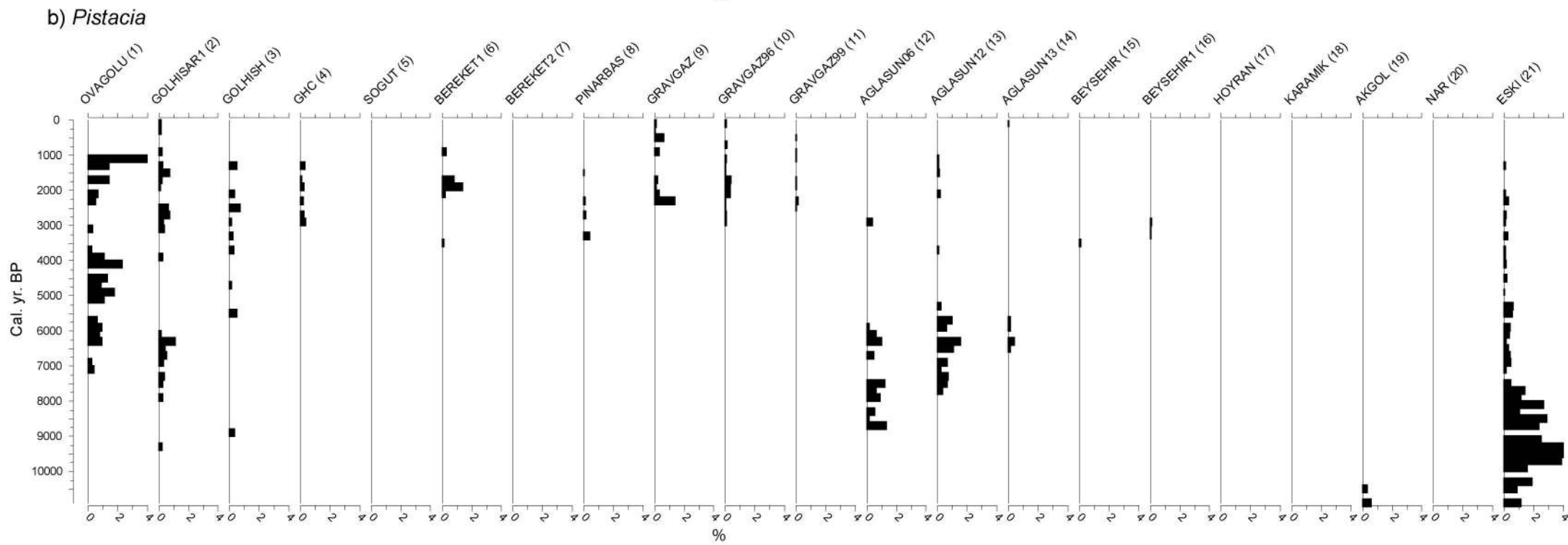
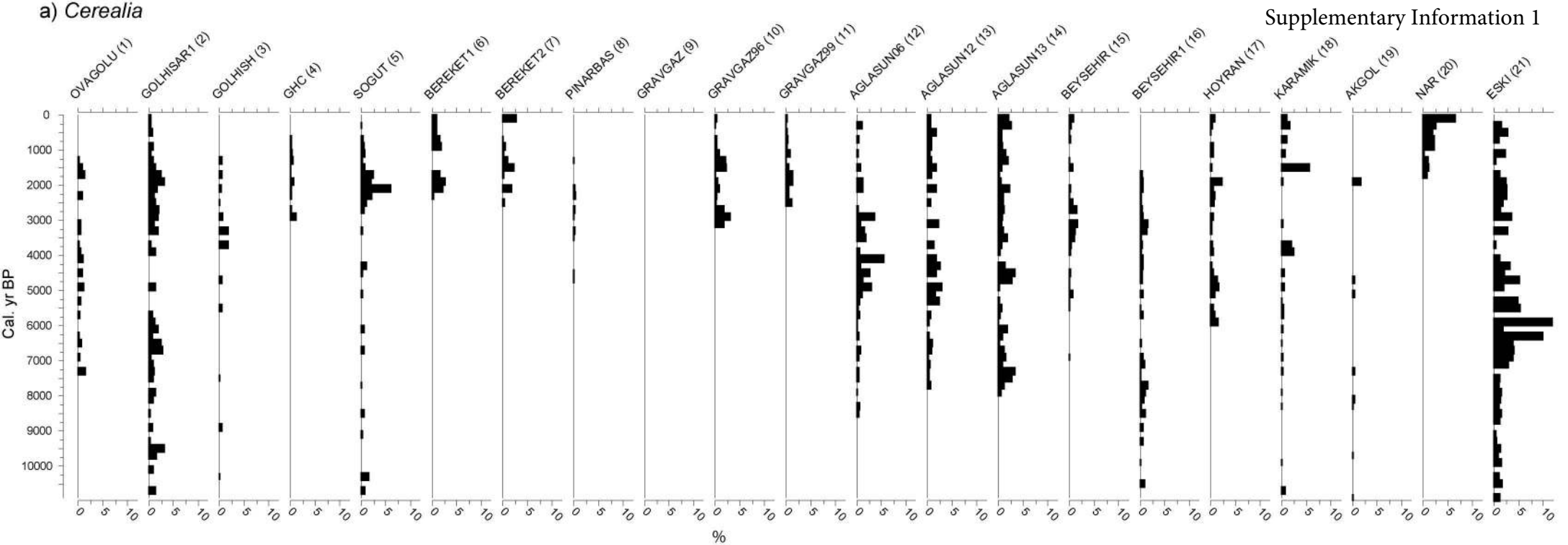
| | | | | | | | | | | | |
|----|-----------|--------------------|----------|----------|------|-------------|--------------------------|--------------------|------------|----|---|
| 14 | AGLASUN13 | Aglasun13 | 37.64258 | 30.52009 | 1140 | Broothaerts | stream | Pollen | 7800-0 | 32 | Vermoere M (2004) In: Waelkens M Studies in eastern Mediterranean archaeology (SEMA 6). Turnhout: Brepols, 1-347. |
| 15 | BEYSEHIR | Beysehir Gölü I | 37.54167 | 31.5 | 1120 | EPD | lake | Pollen | 7400-0 | 22 | European Pollen Database |
| 16 | BEYSEHIR1 | Beysehir 77 II III | 37.54167 | 31.5 | 1120 | Woldring | lake | Pollen | 4600-1600 | 22 | |
| 17 | HOYRAN | Hoyran Gölü | 38.275 | 30.875 | 920 | EPD | lake shore, marsh | Pollen | 5800-0 | 14 | European Pollen Database |
| 18 | KARAMIK | Kararmik Batakligi | 38.425 | 30.8 | 1000 | EPD | marsh, partly open water | Pollen | 9800-0 | 7 | van Zeist W et al. (1975) Palaeohistoria, 17: 53-144. |
| 19 | AKGOL | Akgöl Adabag | 37.5 | 33.73333 | 999 | EPD | lake | Pollen | 10400-1800 | 8 | Bottema S (1987) Pages 295-310 in Aurenche O et al. eds. Chronologies in the Near East. Oxford, United Kingdom. |
| 20 | NAR | Nar Gölü | 38.3403 | 34.45671 | 1363 | Eastwood | lake | Pollen and climate | 1600-0 | 9 | England A et al. (2008) Holocene, 18: 1229-1245. Roberts N et al. (2016) Journal of Quaternary Science. 31: 348-362. |
| 21 | ESKI | Eski Acigol | 38.55028 | 34.54472 | 1270 | Woldring | lake | Pollen and climate | 10800-200 | 44 | Woldring H & Bottema S (2001/2) Palaeohistoria, 43/44. |

Table 3 a) Spearman's Rho correlations between the pollen and archaeological datasets (upper value within each cell: r-value and lower value: p-value) (significant correlations are shaded grey) (9900-1100 BP)

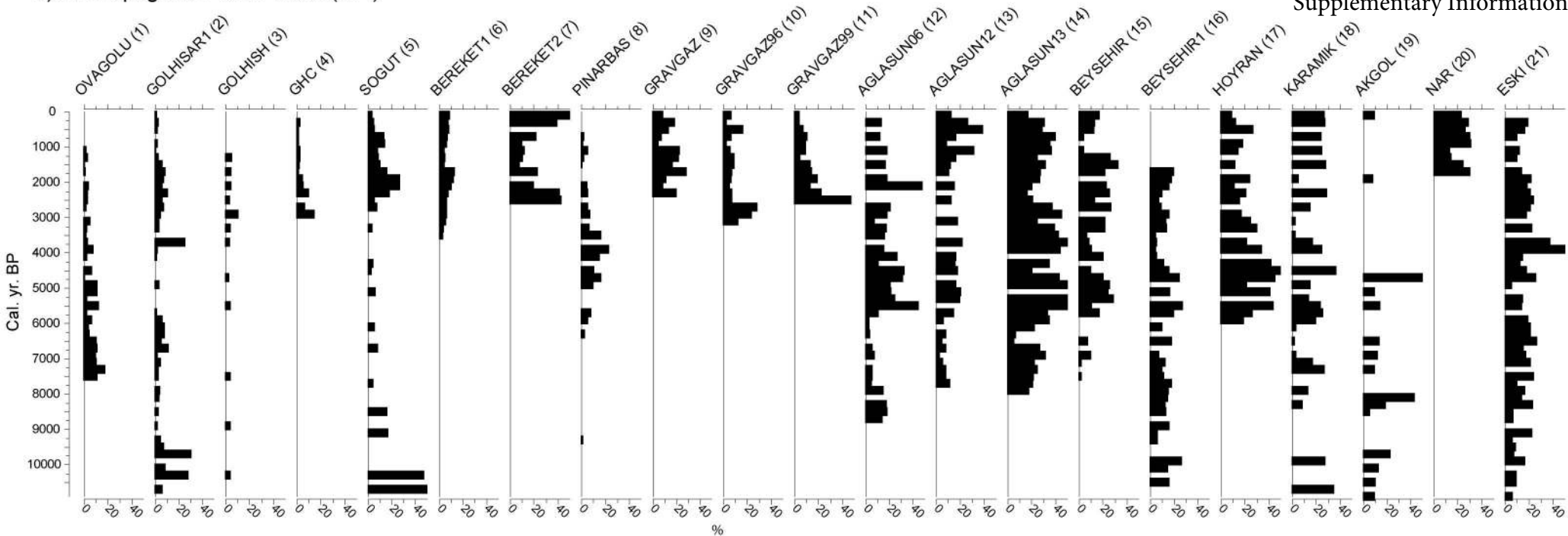
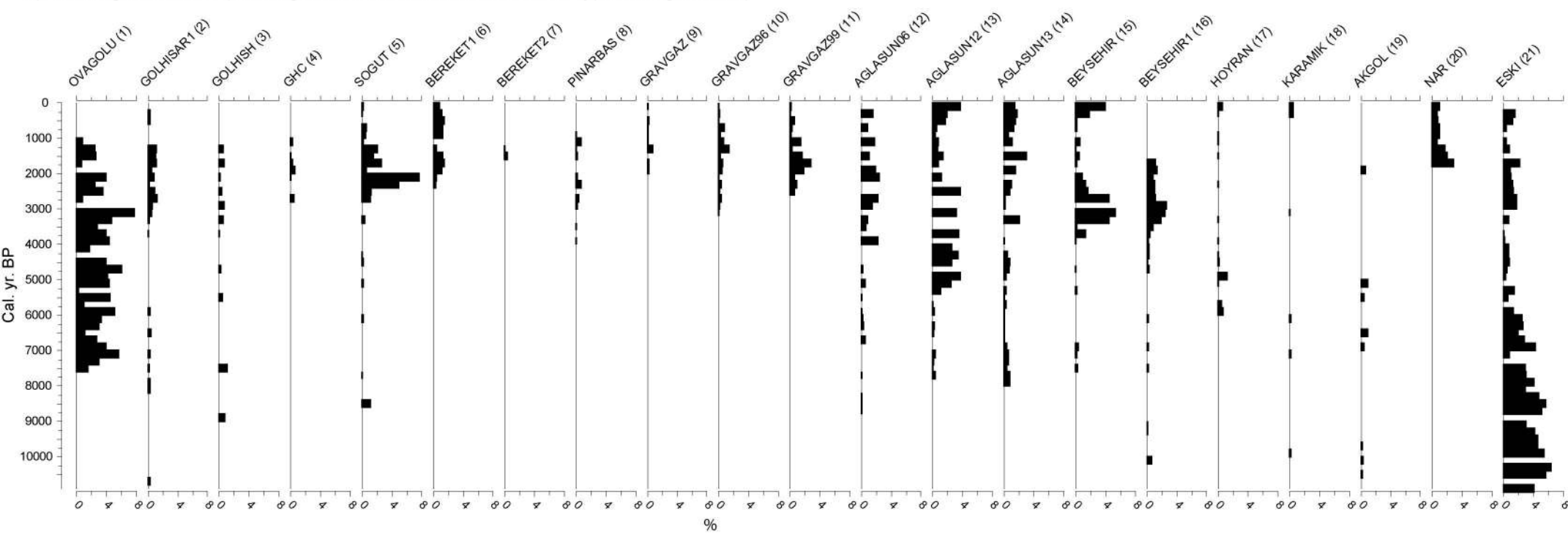
| | <i>Raw count of sites</i> | <i>Total estimated area of sites</i> | <i>Aoristic sum of sites</i> | <i>Number of sites</i> |
|--|---------------------------|--------------------------------------|------------------------------|------------------------|
| 1.1: Sclerophyllous parkland | 0.255 0.091 | 0.263 0.081 | 0.223 0.141 | 0.164 0.281 |
| 4.0: Pine forest | -0.304 0.042 | -0.296 0.048 | -0.208 0.17 | -0.19 0.212 |
| 5.1: Pine woods | 0.303 0.043 | 0.276 0.067 | 0.272 0.07 | 0.23 0.128 |
| 1.3: Steppe parkland | -0.3 0.045 | -0.3 0.045 | -0.292 0.052 | -0.283 0.059 |
| 1.2: Evergreen shrubland (Oleaceae) | 0.095 0.534 | 0.065 0.672 | -0.003 0.987 | -0.077 0.613 |
| 5.2: Pine steppe | -0.005 0.973 | 0.017 0.91 | -0.052 0.732 | -0.031 0.839 |
| 3.0: Pasture/wetland | 0.664 0 | 0.693 0 | 0.73 0 | 0.731 0 |
| 6.1: Deciduous oak woods | -0.1 0.514 | -0.135 0.375 | -0.099 0.519 | -0.069 0.653 |
| 1.4: Parkland/grassland | -0.3 0.045 | -0.288 0.055 | -0.302 0.044 | -0.224 0.139 |
| 6.2: Deciduous oak parkland | -0.396 0.007 | -0.4 0.006 | -0.408 0.005 | -0.396 0.007 |
| Arboreal Pollen | -0.408 0.005 | -0.423 0.004 | -0.455 0.002 | -0.439 0.003 |
| Non-arboreal Pollen | 0.443 0.002 | 0.451 0.002 | 0.5 0 | 0.478 0.001 |
| Oleaceae | 0.783 0 | 0.784 0 | 0.791 0 | 0.807 0 |
| OJC | 0.855 0 | 0.853 0 | 0.863 0 | 0.854 0 |
| OJCV | 0.85 0 | 0.847 0 | 0.857 0 | 0.851 0 |
| API | 0.478 0.001 | 0.454 0.002 | 0.474 0.001 | 0.461 0.001 |
| Grazing indicators | 0.663 0 | 0.656 0 | 0.67 0 | 0.691 0 |
| Regional pastoral indicators | 0.29 0.054 | 0.267 0.076 | 0.242 0.109 | 0.228 0.133 |
| Simpson's diversity index | -0.039 0.798 | -0.039 0.801 | -0.035 0.821 | -0.025 0.869 |
| nMDS axis 1 | 0.473 0.001 | 0.48 0.001 | 0.511 0 | 0.49 0.001 |
| nMDS axis 2 | -0.552 0 | -0.553 0 | -0.491 0.001 | -0.46 0.001 |

Table 3 b) Spearman's Rho correlations between the pollen, archaeological and palaeoclimate z-score datasets (upper value within each cell: r-value and lower value: p-value) (significant correlations are shaded grey) (for corresponding time periods)

| | <i>Göhlisar</i> | <i>Nar Gölü</i> | <i>Eski Acıgöl</i> | <i>Average z-score</i> |
|---|-----------------|-----------------|--------------------|------------------------|
| 1.1: Schlerophyllous parkland | -0.16 0.272 | -0.281 0.083 | -0.138 0.39 | -0.204 0.154 |
| 4.0: Pine forest | 0.073 0.617 | 0.281 0.083 | 0.341 0.029 | 0.28 0.049 |
| 5.1: Pine woods | -0.279 0.052 | 0.018 0.913 | -0.023 0.886 | -0.093 0.519 |
| 1.3: Steppe parkland | 0.183 0.209 | 0.159 0.332 | 0.288 0.068 | 0.246 0.086 |
| 1.2: Evergreen shrubland (<i>Oleaceae</i>) | 0.128 0.38 | -0.202 0.218 | -0.141 0.378 | 0.017 0.908 |
| 5.2: Pine steppe | -0.034 0.817 | 0.043 0.797 | 0.143 0.374 | 0.155 0.283 |
| 3.0: Pasture/wetland | -0.183 0.209 | -0.73 0 | -0.779 0 | -0.677 0 |
| 6.1: Deciduous oak woods | 0.005 0.971 | 0.13 0.431 | 0.163 0.308 | 0.176 0.222 |
| 1.4: Parkland/grassland | 0.25 0.083 | 0.319 0.048 | 0.343 0.028 | 0.396 0.004 |
| 6.2: Deciduous oak parkland | 0.146 0.317 | 0.267 0.1 | 0.452 0.003 | 0.39 0.005 |
| Arboreal Pollen | 0.086 0.559 | 0.451 0.004 | 0.484 0.001 | 0.391 0.005 |
| Non-arboreal Pollen | -0.108 0.459 | -0.481 0.002 | -0.474 0.002 | -0.403 0.004 |
| <i>Oleaceae</i> | -0.175 0.23 | -0.737 0 | -0.644 0 | -0.571 0 |
| <i>OJC</i> | -0.301 0.036 | -0.719 0 | -0.752 0 | -0.692 0 |
| <i>OJCV</i> | -0.3 0.036 | -0.725 0 | -0.752 0 | -0.693 0 |
| <i>API</i> | -0.353 0.013 | -0.528 0.001 | -0.219 0.169 | -0.355 0.011 |
| <i>Grazing indicators</i> | -0.306 0.033 | -0.596 0 | -0.604 0 | -0.645 0 |
| <i>Regional pastoral indicators</i> | -0.332 0.02 | -0.392 0.014 | -0.01 0.952 | -0.205 0.154 |
| <i>Simpson's diversity index</i> | -0.179 0.218 | -0.122 0.46 | 0.036 0.824 | -0.153 0.288 |
| <i>nMDS axis 1</i> | -0.091 0.536 | -0.524 0.001 | -0.53 0 | -0.415 0.003 |
| <i>nMDS axis 2</i> | 0.372 0.009 | 0.268 0.099 | 0.406 0.008 | 0.41 0.003 |
| <i>Raw count of sites</i> | -0.473 0.001 | -0.754 0 | -0.743 0 | -0.778 0 |
| <i>Total estimated area of sites</i> | -0.46 0.001 | -0.696 0 | -0.756 0 | -0.758 0 |
| <i>Aoristic sum of sites</i> | -0.415 0.005 | -0.714 0 | -0.798 0 | -0.775 0 |
| <i>Number of sites</i> | -0.486 0.001 | -0.662 0 | -0.729 0 | -0.7 0 |



a) Anthropogenic Pollen Index (API)

a) Grazing indicators (*Plantago lanceolata*, *Rumex acetosa*-type, *Sanguisorba*)

Supplementary Information 3 Archaeological datasets and references for settlement data used in this study.

| Reference | Season | N. sites |
|------------------------------|---------------|-----------------|
| Abay 2011 | 2003-2009 | 79 |
| Bahar 1997 | 1995 | 22 |
| Bahar 1998 | 1997 | 1 |
| Bahar 1999 | 1997 | 11 |
| Bahar 2001 | 1998-1999 | 21 |
| Bahar 2002 | 2000 | 13 |
| Bahar 2003 | 2001 | 5 |
| Bahar 2004 | 2002 | 3 |
| Bahar 2008 | 2006 | 38 |
| Bahar 2009 | 2007 | 24 |
| Bahar 2014 | 2012 | 18 |
| Baird 2004 | 1995-96 | 85 |
| Baird 2005 | 1995-99 | 19 |
| Balci and Çakan 2016 | 2015 | 10 |
| D'Alfonso 2010 | 2006-2009 | 31 |
| Dökü 2013 | 2012 | 2 |
| Dökü and Baytak 2015 | 2013-2014 | 12 |
| Dökü and Baytak 2016 | 2015 | 11 |
| Erbil 2016 | 2015 | 16 |
| Erbil et al. 2015 | 2014 | 11 |
| French 1965 | 1963-64 | 10 |
| French 1970 | 1958 | 62 |
| Gülçür 1995 | 1993 | 13 |
| Kontani 2012 | 2011 | 18 |
| Kontani 2013 | 2012 | 16 |
| Kulakoğlu <i>et al.</i> 2010 | 2008 | 2 |
| Kulakoğlu <i>et al.</i> 2011 | 2009 | 13 |
| Kulakoğlu <i>et al.</i> 2012 | 2010 | 21 |
| Harmanşah and Johnson 2012a | 2010 | 9 |
| Harmanşah and Johnson 2012b | 2012 | 15 |
| Harmanşah and Johnson 2013a | 2011 | 21 |
| Harmanşah and Johnson 2013b | 2013 | 3 |
| Harmanşah and Johnson 2015 | 2014 | 8 |
| Harmanşah and Johnson 2016 | 2015 | 2 |
| Maner 2014 | 2013 | 13 |
| Maner 2015 | 2014 | 25 |
| Maner 2016 | 2015 | 8 |
| Mellaart 1963 | 1951-1958 | 104 |
| Omura 1993 | 1991 | 7 |
| Omura 1995 | 1993 | 31 |
| Omura 1997 | 1995 | 33 |
| Omura 1998 | 1996 | 23 |
| Omura 2000 | 1999 | 62 |
| Omura 2001 | 2000 | 9 |

| | | |
|--------------------------------|-----------|-----|
| Omura 2003 | 2002 | 9 |
| Omura 2008 | 2003-2006 | 156 |
| Özsait 2003 | 2001 | 17 |
| Özsait and Özsait. 2013 | 2011 | 7 |
| Poblome <i>et al.</i> 2015 | 2014 | 9 |
| Senyurt 1999 | 1997 | 11 |
| Seton-Williams 1954 | 1951 | 143 |
| Vanhaverbeke and Waelkens 2003 | 1993-96 | 131 |

References

- Abay, E. 2011. Preliminary Report on the Survey Project of Çivril, Baklan and Çal Plains in the Upper Meander Basin, Southwest Anatolia. *Ancient Near Eastern Studies* 48, 1–87.
- Baird, D., 2004. Settlement Expansion on the Konya Plain, Anatolia: 5th-7th centuries AD. In: W. Bowden, L. Lavan, and C. Machado (Eds.), *Recent Research on the Late Antique Countryside*. Leiden: Brill, 219–246.
- Baird, D. 2004. Settlement Expansion on the Konya Plain, Anatolia. In: W. Bowden, L. Lavan, and C. Machado (Eds.), *Recent Research on the Late Antique Countryside*. Leiden: Brill, 219-246.
- Baird, D., 2005. The History of Settlement and Social Landscapes in the Early Holocene in the Early Holocene in the Çatalhöyük Area. In: I. Hodder, (Ed.), *Çatalhöyük Perspectives: Themes From the 1995–99 Season*. London: British Institute at Ankara, 55-74.
- Bahar, H. 1997. Doğanhisar, Ilgın, Kadınhanı ve Sarayönü Araştırmaları 1995. In: I. Eroğlu, H. Eren, F. Bayram, F. Kaymaz, N. Tarlan, and A. H. Ergürer (Eds.), *Araştırma Sonuçları Toplantısı* 14. Ankara: T.C. Kültür ve Turizm Bakanlığı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 2, 359–74.
- Bahar, H. 1998. Konya Araştırmaları III: Lykaonia (Konya Merkez Bölgesi). *Selçuk Üniversitesi Edebiyat Fakültesi Dergisi (SEFAD)/Selçuk University Journal of Faculty of Letters* 12, 197–206.
- Bahar, H. 1999. Konya ve Çevresi Yüzeysel Araştırmaları 1997. In: K. Olşen, H. Çakmak, F. Bayram, F. Kaymaz, N. Tarlan, A. Özme, K. Ataş, and H. Dönmez (Eds.), *Araştırma Sonuçları Toplantısı* 16. Ankara: T.C. Kültür ve Turizm Bakanlığı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 2, 23–54.
- Bahar, H. 2001. 1998-1999 Yılı Konya-Karaman İneri Yüzeysel Araştırmaları. . In: K. Olşen, F. Bayram, H. Dönmez, K. Ataş, N. Güder, and N. Toy (Eds.), *Araştırma Sonuçları Toplantısı* 18. Ankara: T.C. Kültür ve Turizm Bakanlığı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 2, 187–204.

Bahar, H. 2002. Konya ve Karaman İlleri YüzeY Arařtırmaları 2000. In: K. Olřen, F. Bayram, A. Özme, H. Dönmez, N. Güder, and N. Toy (Eds.), *Arařtırma Sonuçları Toplantısı* 19. Ankara: T.C. Kültür ve Turizm Bakanlıđı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 2, 257–70.

Bahar, H. 2003. Konya-Karaman YüzeY Arařtırması 2001. In: K. Olřen, F. Bayram, A. Özme, N. Güder, and I. Gençtürk (Eds.), *Arařtırma Sonuçları Toplantısı* 20. Ankara: T.C. Kültür ve Turizm Bakanlıđı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol.2, 171–80.

Bahar, H. 2004. Konya-Karaman Bölgesi YüzeY Arařtırmaları2002. In: K. Olřen, F. Bayram, A. Özme, and N. Ülgen (Eds.), *Arařtırma Sonuçları Toplantısı* 21. Ankara: T.C. Kültür ve Turizm Bakanlıđı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol.1, 203–16.

Bahar, H. 2008. Konya-Karaman YüzeY Arařtırmaları 2006. In: F. Bayram, A. Özme and B. Koral (Eds.), *Arařtırma Sonuçları Toplantısı* 25. Ankara: T.C. Kültür ve Turizm Bakanlıđı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 1, 235–54

Bahar, H. 2009. Konya ve Karaman İlleri ve İlçeleri 2007 Yılı Arkeolojik YüzeY Arařtırması. In: F. Bayram and A. Özme (Eds.), *Arařtırma Sonuçları Toplantısı* 26. Ankara: T.C. Kültür ve Turizm Bakanlıđı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 1, 117–34.

Bahar, H. 2014. Konya-Karaman İlleri ve İlçeleri Arkeolojik YüzeY Arařtırmaları 2012. In: A. Özme (Ed.), *Arařtırma Sonuçları Toplantısı* 31. Ankara: T.C. Kültür ve Turizm Bakanlıđı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 2, 256–71.

Balci, S., and Y. G. Çakan., 2016. Niğde Tarihöncesi YüzeY Arařtırmaları 2015. In: C. Keskin (Ed.), *Arařtırma Sonuçları Toplantısı* 34. Ankara: T.C. Kültür ve Turizm Bakanlıđı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 2, 1–24.

d'Alfonso, L., 2010. Geo-Archaeological Survey in Northern Tyanitis and the Ancient History of Southern Cappadocia. In: L. d'Alfonso, M. E. Balza and C. Mora (Eds.), *Geo-archaeological activities in Southern Cappadocia, Turkey : proceedings of the meeting held at Pavia, 20.11.2008*. Pavia: Italian University Press (Studia Mediterranea, 22), 27–52.

Dökü, F. E., 2013. Uylupınar Yerleşmesi (Erken Kibyra) ve Çevresi YüzeY Arařtırması 2012. In: A. Özme (Ed.), *Arařtırma Sonuçları Toplantısı* 31. Ankara: T.C. Kültür ve Turizm Bakanlıđı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 2, 395-406.

Dökü, F. E., and I. Baytak. 2015. Uylupınar (Erken Kibyra) Yerleşimi 2013-2014 Yılları YüzeY Arařtırmaları. In: C. Keskin (Ed.), *Arařtırma Sonuçları Toplantısı* 33. Ankara: T.C. Kültür ve Turizm Bakanlıđı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 1, 217–40.

Dökü, F. E., and Baytak., I., 2016. 2015 Yılı Uylupınar (Erken Kibyra) Yerleşimi YüzeY Arařtırması. In: C. Keskin (Ed.), *Arařtırma Sonuçları Toplantısı* 34. Ankara: T.C. Kültür ve Turizm Bakanlıđı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 2, 641–70.

Erbil, Y. H., A. Mouton, and S. Yandim - Aydın. 2015. Konya İli Beyşehir İlçesi Fasıllar Anıtı ve Çevresi YüzeY Araştırması Yılı Çalışmaları. 193–206. In: C. Keskin (Ed.), *Araştırma Sonuçları Toplantısı 33*. Ankara: T.C. Kültür ve Turizm Bakanlığı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 2, 193-206.

Erbil, Y. H., 2016. KONYA İLİ, BEYŞEHİR İLÇESİ, FAS ANITI ve ÇEVRESİ 2015 YILI YÜZEY ARAŞTIRMASI SONUÇ RAPORU. Retrieved on the 2nd of May 2018 from the Web: <http://www.ttk.gov.tr/wp-content/uploads/2016/11/8-Konya.pdf>

French, D. H., 1965. Prehistoric Sites in the Göksu Valley. *Anatolian Studies* 15, 177–201.

French, D. H., 1970. Notes on Site Distribution in the Çumra Area. *Anatolian Studies* 20, 139–48.

Gülçür, S. 1995. Some Unknown Aspects of Western Cappadocia: Results of the 1993 Survey. In: H. Çambel (Ed.), *Readings in Prehistory: Studies Presented to Halet Çambel*. Istanbul: Graphis, 149-73.

Kontani, R., H. Sudo, Y. Yamaguchi, Y. S. Hayakawa, F. Kulakoglu, and K. Emre. 2012. Preliminary Report for the Archaeological Survey in Kayseri Province, Turkey (KAYAP), Fourth Season (2011). *Bulletin of the Okayama Orient Museum* 26, 15–29.

Kontani, R., T. Odaka, H. Sudo, Y. S. Hayakawa, Y. Yamaguchi, F. Kulakoglu, K. Emre, S. Ezer, and G. Ozturk. 2013. Preliminary Report for the Archaeological Survey in Kayseri Province, Turkey (KAYAP), the Fifth Season (2012). *Bulletin of the Okayama Orient Museum* 27, 15–42.

Kulakoğlu, F., K. Emre, R. Kontani, H. Tsumura, and S. Ezer. 2010. In: H. Dönmez and C. Keskin (Eds.), *Araştırma Sonuçları Toplantısı 27*. Ankara: T.C. Kültür ve Turizm Bakanlığı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 3, 305–18.

Kulakoğlu, F., K. Emre, R. Kontani, and S. Ezer. 2011. Kayseri Arkeolojik YüzeY Araştırmaları Projesi (Kayap) 2009 Yılı Çalışmaları Sonuç Raporu. In: A. N. Toy and C. Keskin (Eds.), *Araştırma Sonuçları Toplantısı 28*. Ankara: T.C. Kültür ve Turizm Bakanlığı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 3, 409–28.

Kulakoğlu, F., K. Emre, R. Kontani, and S. Ezer. 2012. Kayseri Arkeolojik YüzeY Araştırmaları Projesi (Kayap) 2010 Yılı Çalışmaları. In: A. Özme (Ed.), *Araştırma Sonuçları Toplantısı 29*. Ankara: T.C. Kültür ve Turizm Bakanlığı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 3, 215–36.

Harmanşah O., and Johnson, P., 2012a. Yalburt Yaylası(Ilgın, Konya) Arkeolojik YüzeY Araştırma Projesi, 2010 Sezonu Sonuçları. In: A. Özme (Ed.), *Araştırma Sonuçları Toplantısı 29*. Ankara: T.C. Kültür ve Turizm Bakanlığı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 2, 335-360.

Harmanşah O., and Johnson, P., 2012b. *Yalburt Yaylası Arkeolojik YüzeY Araştırma Projesi (Ilgın, Konya) 2012 Sezonu Arazi Çalışmaları Raporu*. Retrieved on the 2nd of May 2018 from the Web: <https://www.yalburtproject.org/preliminary-reports-and-publications/>

Harmanşah O., and Johnson, P., 2013a. Pınarlar, Mağaralar, ve Hitit Anadolu'sunda Kırsal Peyzaj: Yalbur Yaylası Arkeolojik Yüzey Araştırma Projesi (Ilgın, Konya), 2011 Sezonu Sonuçları." In: A. Özme (Ed.), *Araştırma Sonuçları Toplantısı 30*. Ankara: T.C. Kültür ve Turizm Bakanlığı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 2, 73-84.

Harmanşah O., and Johnson, P., 2013b. *Yalbur Yaylası Arkeolojik Yüzey Araştırması (Ilgın, Konya) 2013 Sezonu Arazi Çalışmaları Raporu*. Retrieved on the 2nd of May 2018 from the Web: <https://www.yalburproject.org/preliminary-reports-and-publications/>

Harmanşah O., and Johnson, P., 2015. *Yalbur Yaylası Arkeolojik Yüzey Araştırma Projesi (Ilgın, Konya) 2014 Sezonu Arazi Çalışmaları Raporu*. Retrieved on the 2nd of May 2018 from the Web: https://issuu.com/omurharmansah/docs/rapor_2014_finalforprint

Harmanşah O., and Johnson, P., 2016. *Yalbur Yaylası Arkeolojik Yüzey Araştırma Projesi (Ilgın, Konya) 2015 Sezonu Arazi Çalışmaları Raporu*. Retrieved on the 2nd of May 2018 from the Web: https://issuu.com/omurharmansah/docs/rapor_2015son_temmuz2016son

Maner, C., 2014. Preliminary Report on the First Season of the Konya-Ereğli (KEYAR) Survey 2013. *Anatolia Antiqua* 22, 343–60.

Maner, C., 2015. Preliminary Report on the Second Season of the Konya-Ereğli Survey (KEYAR) 2014. *Anatolia Antiqua* 23, 249–74.

Maner, C., 2016. "Preliminary Report on the Third Season of the Konya-Ereğli Survey (KEYAR) 2015." *Anatolia Antiqua* 24, 225–52.

Mellaart, J., 1963. Early Cultures of the South Anatolian Plateau, II. *Anatolian Studies* 13, 199–236.

Omura, S. 1993. 1991 Yılı İç Anadolu'da Yürütülen Yüzey Araştırmaları. *Araştırma Sonuçları Toplantısı* 10. Ankara: T.C. Kültür ve Turizm Bakanlığı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, 365–86.

Omura, S. 1995. 1993 Yılında İç Anadolu'da Yürütülen Yüzey Araştırmaları. *Araştırma* In: I. Eroğlu, F. Bayram, H. Eren, N. Ülgen, F. Kaymaz, and A. H. Ergürer (Eds.), *Araştırma Sonuçları Toplantısı* 12. Ankara: T.C. Kültür ve Turizm Bakanlığı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, 215–44.

Omura, S. 1997. 1995 Yılı İç Anadolu'da Yürütülen Yüzey Araştırmaları. . In: I. Eroğlu, H. Eren, F. Bayram, F. Kaymaz, N. Tarlan, and A. H. Ergürer (Eds.), *Araştırma Sonuçları Toplantısı* 14. Ankara: T.C. Kültür ve Turizm Bakanlığı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 2, 283–302.

Omura, S. 1998. 1996 Yılı İç Anadolu'da Yürütülen Yüzey Araştırmaları. In: K. Olşen, H. Çakmak, F. Bayram, F. Kaymaz, N. Tarlan, A. Özme, H. Dönmez, N. N. Kaya, M. Demir, and M. Uyaniker (Eds.), *Araştırma Sonuçları Toplantısı* 15. Ankara: T.C. Kültür ve Turizm Bakanlığı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 2, 41–50.

Omura, S., 2000. Preliminary report of the general survey in Central Anatolia (1999). *Anatolian Archaeological Studies/Kaman-Kalehöyük*, 9, 37–96.

Omura, S., 2001. Preliminary report of the general survey in Central Anatolia (2000). *Anatolian Archaeological Studies/Kaman-Kalehöyük* 10, 37–86.

Omura, S. 2003. Preliminary Report of the General Survey in Central Anatolia (2002). *Anatolian Archaeological Studies/Kaman-Kalehöyük* 12, 37–88.

Omura, S. 2008. 2003-2006 Yıllarında İç Anadolu'da Yapılmış Olan Yüzey Araştırmaları. In: F. Bayram, A. Özme and B. Koral (Eds.), *Araştırma Sonuçları Toplantısı 25*. Ankara: T.C. Kültür ve Turizm Bakanlığı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 2, 213–24.

Özsait, M. 2003. 2001 Yılı Isparta İli Yüzey Araştırmaları. In: K. Olşen, F. Bayram, A. Özme, N. Güder, and I. Gençtürk (Eds.), *Araştırma Sonuçları Toplantısı 20*. Ankara: T.C. Kültür ve Turizm Bakanlığı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol.2, 233–46.

Özsait, M., and N. Özsait. 2013. 2011 Yılı Isparta ve Burdur İlleri Yüzey Araştırmaları. In: Adil Özme (Ed.), *Araştırma Sonuçları Toplantısı 30*. Ankara: T.C. Kültür ve Turizm Bakanlığı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 1, 317–32.

Poblome, J., R. Vandam, B. Neyt, P. Degryse, K. Eekelers, and B. Scott. 2015. The 2014 Archaeological and Geological Surveys in the Territory of Sagalassos. In: C. Keskin (Ed.), *Araştırma Sonuçları Toplantısı 33*. Ankara: T.C. Kültür ve Turizm Bakanlığı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 1, 247–66.

Şenyurt, S. Y., 1999. In: K. Olşen, H. Çakmak, F. Bayram, F. Kaymaz, N. Tarlan, A. Özme, cK. Ataş, and H. Dönmez (Eds.), *Araştırma Sonuçları Toplantısı 16*. Ankara: T.C. Kültür ve Turizm Bakanlığı Kültür Varlıkları ve Müzeler Genel Müdürlüğü Yayın, vol. 1, 451-466.

Seton-Williams, M. V., 1954. Cilician Survey. *Anatolian Studies* 4, 121–74.

Vanhaverbeke, H., and M. Waelkens. 2003. *The Chora of Sagalassos. The Evolution of the Settlement Pattern from Prehistoric until Recent Times*. Turnhout: Brepols.