Agricultural Patterns in the Aegean in the 4th Millennium BC – An Explanatory Model

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Abstract: Palaeoclimate proxies indicate orbitally induced changes in insolation for the sequence of the mid to the end of the 4th millennium BC. These changes led to polar cooling and advancing glaciers, and have been correlated with Bond event no. 4 or the 5200 BP event, which is considered responsible by some for droughts in wider Mesopotamia, Arabia and Africa. Palynological data from eastern Mediterranean sea-sediment cores suggest relatively arid conditions throughout the whole 4th millennium BC. At other locations like Lake Acigöl in Turkey the second half of this period has been reconstructed as increasingly arid climate. In the Trojan bay a descending sea level for the end of this period has been determined. A settlement hiatus at the archaeological site of Kumtepe (Troad) until roughly 3500 BC supports the argument of unfavourable living conditions. From c. 3300 BC onwards, human impact becomes clearly visible in the charcoal record of the Troad, supporting alternating impact of climate and humans. As a general characteristic of palaeoclimate proxies they often cannot tell in detail how climate change affected ancient societies. Resilience and adaptation, two important aspects in human societies, often cannot be satisfactorily linked with observations of climatic and reconstructed environmental change, because the intermediate agents, such as subsistence behaviour and economy are insufficiently integrated. This contribution aims to provide more insights into these aspects by considering the combined archaeobotanical and stable carbon isotope record as an indication of ancient growing conditions and soil moisture availability for crop plants as the agricultural basis of ancient societies.

Keywords: Mediterranean, climate change, mid-Holocene, archaeobotany, stable carbon isotopes, agricultural modelling

Established agricultural systems of the Final Neolithic or Chalcolithic period are generally considered advanced in terms of technology and the organisation of labour. Disruptive factors in these systems mainly derive from climate and environmental change and/or are closely related to socio-economic developments and/or societal constraints. There are surely more factors, but equally important is the seemingly infinite number of effects they may have. All these factors and multiple effects are interwoven and nearly impossible to be disentangled; therefore transformations of agricultural systems are difficult to explain in a deterministic way.[3]

As archaeologists, we may be able to determine single effects through investigating the material record. At the best we may be aware of certain human actions, but interpretations of the original factors may be relatively biased. This depends on which step in the chain of effects and actions is reflected in the archaeological record.

With this contribution, we aim to improve the understanding of late Neolithic/Chalcolithic agricultural patterns in the Aegean region by considering potentially disruptive factors in agricultural systems (Fig. 1). A short review of the climatic and environmental data available for the 4th millennium BC is followed by a discussion on the archaeobotanical evidence and the regional agricultural potential as indicated by agronomic models.

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[3] Riehl 2009.

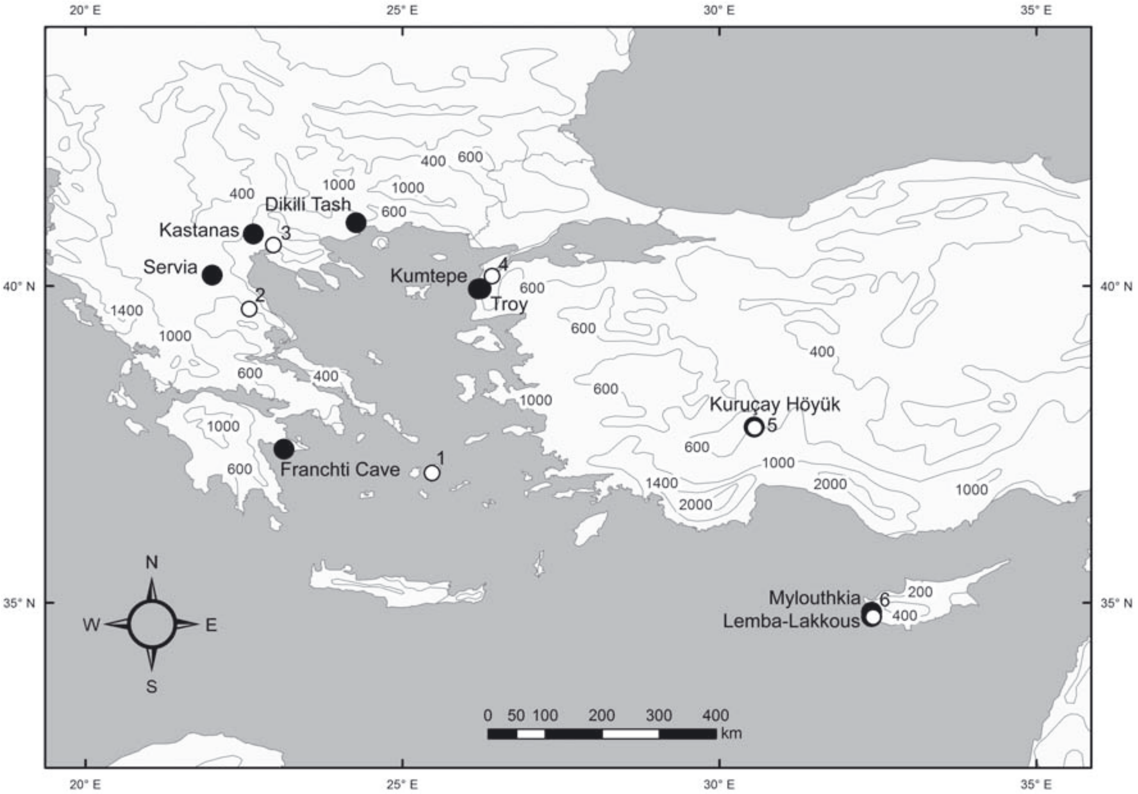

Fig. 1 Map of archaeological sites (black dots) and climate stations (white dots) discussed in the text; Climate stations: 1. Naxos; 2. Larissa; 3. Thessaloniki; 4. Çanakkale; 5. Isparta; 6. Paphos (illustration: S. Riehl).

The Mid-Holocene Palaeoclimate Record

Orbital and solar forcing and the ocean circulation linked to it represent the main parameters of climate change. Evidence suggests moister conditions for the Mediterranean region during the first half of the Holocene,[4] which has also been used as an argument to explain high lake levels in the area.[5] A drying trend followed from the mid-Holocene (around 6000 calBP) on.[6]

The reasons for this development are portended in a marine pollen record from the northern Aegean Sea indicating changes in the coupling to different climate systems throughout the Holocene in this geographic region. The terrestrial climate dynamics in the northern Aegean Sea were largely decoupled from the influence of the Siberian High and probably affected by the monsoon-influenced climate system of the lower latitudes during the early Holocene (9500–7000 calBP). However, after 7000 calBP the winter temperatures correlate with the GISP2 ice core.[7] From the mid-Holocene on, the intensity of the Siberian High exerted strong control on winter climate in the Aegean region.[8] Subsequent research has restated this argument in relation to a multi-centennial winter SST (sea surface temperature) decrease, between 6200–5000 calBP in particular.[9] The interval between 6000–2000 calBP has been described to characterise climatic instability.[10]

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[4] Bar-Matthews et al. 1997; Davis et al. 2003.

[5] Harrison – Digerfeldt 1993.

[6] Roberts et al. 2008.

[7] Rohling et al. 2002.

[8] Kotthoff et al. 2008, 843.

[9] Marino et al. 2009.

[10] Geraga et al. 2010.

Heavy stable oxygen isotopes are enriched at around 5000 and 3000 calBP and, in combination with the micropalaeontological record, support lower sea surface temperatures in the Mediterranean.[11] Temporal reductions in deciduous tree pollen suggest lower terrestrial temperatures and/or stronger aridity.

Non-cyclic events have only been discussed randomly, including evidence for tsunami impact on southwestern Crete at 5660 BP.[12] In contrast, cyclical events, mostly cited in relation to work by Bond et al.,[13] have been analysed more intensively. The 5200 calBP episode was documented in the Greenland ice core records, and Geraga[14] interprets its visibility in the Mediterranean palaeoclimate proxy records with a reduction in the SST records of about 1–2 °C as an overall Mediterranean climatic response to the high-latitude climate system variation. At the same time, east African records document increased aridity around 5200 calBP, which has been associated with a weakening of the monsoonal system through variability in solar activity, changing global circulation patterns, and a teleconnection between high and low latitudes,[15] which underlines the geographic and temporal dispartment of climate effects in the eastern Mediterranean region.

Cold and dry climatic phases are indicated in the benthic foraminiferae records of the Aegean Sea around 5400 and 4300 calBP.[16] Warm and humid climatic conditions have been interpreted for the southeastern Aegean Sea between 5200 and 4200 calBP.[17]

For the Near Eastern region, some geographers link local palaeoclimate proxies at around 5200 calBP to the collapse of the Late Uruk colonies.[18] They refer to interpretations of reduced precipitation leading to unsustainable agricultural production.[19] However, the extent of possible reduction in precipitation is not known for the Aegean region.

Climate modelling has been applied to the Mediterranean region. Brayshaw et al. model slight precipitation and circulation changes. While in northwestern Greece and coastal western Anatolia there is a slight positive modelled change around 6000 calBP, there are slightly negative modelled changes in Thessaly, central eastern Greece and eastern Anatolia.[20] Compared to modern precipitation, no change has been modelled for central Anatolia. The model shows a likely scenario for 6000 BP, but what seems even more important is the visualisation of the regional variation in climate effects we need to be aware of while generalising the Aegean cultural region and its agricultural economy.

Recent evidence for distinct regional differences in climate effects derives from multiple sources. Ehrmann et al.[21] linked the cycles they found in their sediment cores from the northern and southern Aegean Sea to changes of winter/spring intensity of the Siberian High (GISP2 K+ record) and to worldwide Holocene glacial advances. They concluded that substantial differences in sediment grain size between the northern and southern Aegean Sea were caused by different processes and climate regimes controlling sedimentation in the two regions. In the sediment cores analysed, short-term fluctuations superimposed the long-term trends of clay mineral composition and are likely linked to climate variations in the northern and southern Mediterranean borderlands.[22] This is also supported by additional coring results from the Levantine Sea. The similarity of $\delta^{18}O$ values from benthic foraminifers of the southern Aegean Sea and Levantine Basin sug-

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[11] Geraga et al. 2010, 114.

[12] Scheffers – Scheffers 2007.

[13] Bond et al. 1997; Bond et al. 2001.

[14] Geraga et al. 2010, 114.

[15] Kiage – Liu 2006.

[16] Kuhnt et al. 2007.

[17] Triantaphyllou et al. 2009.

[18] E.g. Staubwasser – Weiss 2006.

[19] Weiss 2003.

[20] Brayshaw et al. 2011.

[21] Ehrmann et al. 2007.

[22] Ehrmann et al. 2007, 51.

gests the influence of isotopically identical deep water masses during the middle and late Holocene. Slightly higher $\delta^{18}O$ values are observed in the northern Aegean Sea, which probably shows lower temperatures of North Aegean deep waters.[23]

Sea level changes, indicative of major environmental change, have been investigated in a number of regions in the Aegean. In northwestern Greece, the highest rates of local sea level rise during the Holocene were found until 5500/5000 calBC (up to 12.3m/ka) and the lowest during 4000–500 calBC (0.2–1.4m/ka),[24] which correlates with the observed sea level decrease in the Troad starting between 4000–3000 calBC.[25]

Palynological data is available from a number of sites in Greece and southern Turkey which, according to a recent study, show a shift in inferred plant functional types from temperate mixed forest to xerophytic woodland scrub between 6000 calBP to present.[26] However, a closer look at the vegetation units for 6000 calBP provided on the NOAA server reveals distinct regional differences. According to these records the coastal parts of the area in particular were covered with xerophytic woodland shrub while the higher elevations and interior regions to the north of Greece comprised of cool-mixed forest and the inland region of western Turkey encompassing warm to cool steppes.[27]

Evidence from the northern Aegean indicates high amounts of deciduous tree pollen between 6000 and 4300 BP.[28] Palynological research at Lake Philippi and Lake Kopais was discussed in the 1970s to indicate distinct vegetation differences between northern and southern Greece.[29] The northern pattern constitutes a thick oak forest that had developed by c. 7000 BC without much pioneer scrub. It persisted without discernible change throughout the Neolithic and the Early Bronze Age. In western Greece, Lake Voulkaria shows a pattern similar to northern Lake Philippi.[30] Vegetation patterns, of Kotihi lagoon in northwestern Peloponnese, also seem to fit these patterns.[31] This is in contrast to evidence from the south that shows that the forest was probably substantially reduced with largely treeless plains by the Bronze Age, and perhaps earlier.[32] These data conform to more recent results from the Peloponnese[33]. Greig interprets this pattern as largely anthropogenic due to a higher population pressure in the south although he also considers climatic difference as a factor, arguing that the moister north enabled faster regeneration of tree cover than possible in the south.[34] Supportive evidence comes from olive cultivation which was earlier and more extended in the south than in the north.

Simultaneously, ecological differences in relation to elevation have to be considered, as has been suggested for two sites in northwest Greece near Ioannina.[35] Gramousti Lake and Rezina marsh are only 20km apart, with the former at an elevation of 285m and the latter at 1800m. In the mountainous, more humid region, dense deciduous woodland was predominant while open woodland occurred in the valley. Around 4000 calBP, depletion of vegetation through anthropogenic disturbance is visible in the pollen diagrams from both sites, leading to a relatively uniform herbaceous flora.[36] A general trend noticeable in both pollen diagrams between 6300–5000 calBP

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[23] Kuhnt et al. 2008, 111.

[24] Vött 2007.

[25] Kayan 1992.

[26] Roberts et al. 2011.

[27] Cheddadi 1997.

[28] Kotthoff et al. 2008.

[29] Greig – Turner 1974.

[30] Jahns 2005.

[31] Lazarova et al. 2012.

[32] Greig – Turner 1974, 191.

[33] Jahns 1993.

[34] Greig – Turner 1974.

[35] Willis 1992.

[36] Willis 1992.

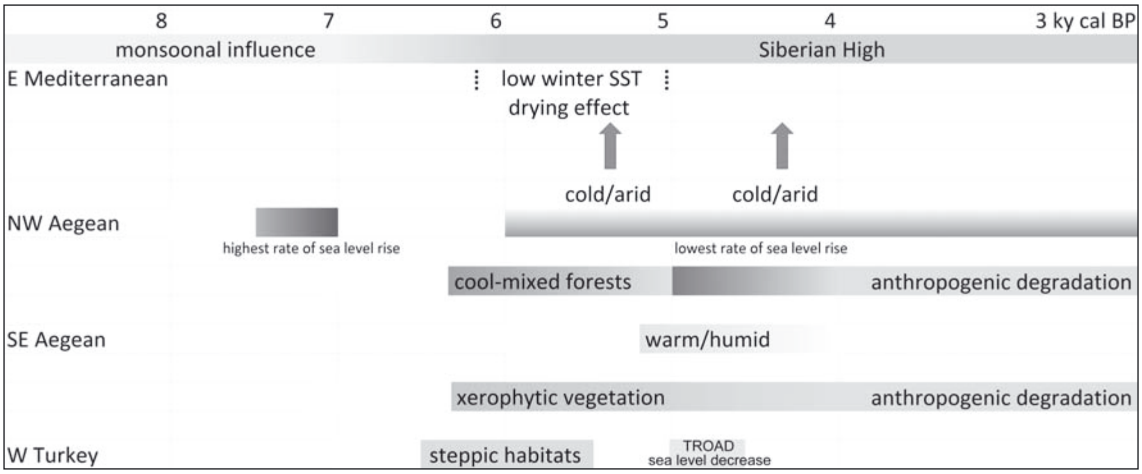

Fig. 2 Climate effects and vegetation development in the Aegean region with focus on the mid-Holocene (illustration: S. Riehl).

is a reduction in tree species, and a re-expansion of woodland after 5000 calBP, which agrees with the cold and arid phases indicated by benthic foraminifera (Fig. 2).

Whether anthropogenic or not, regional differences in vegetation composition were probably linked to the ancient economy in terms of landscape potential and agricultural development.

Greig's interpretation also discusses what was later described as the problem to differentiate between natural and human impact from the mid-Holocene onwards,[37] and subsequently labelled the 'mid-Holocene Mediterranean mélange'.[38] Specific effects of human impact on the environment are to be expected, depending on the settlement density and human economy in the different geographic regions throughout the different periods, as well as on a number of natural response mechanisms, all contributing to a highly complex mosaic of local environments and a high degree of variation in living conditions in the past, almost resistant to any generalisation.

The main goal of this contribution is to consider agricultural patterns against the backdrop of the assumed trend of increasingly arid conditions toward the end of the 4th millennium BC, and the regional differences in climate effects and environmental conditions.

Material and Methods

To achieve the goal stated above, we consider the archaeobotanical evidence from Late Neolithic and Chalcolithic sites in the area, including the stable carbon isotope evidence from Kumtepe and Troy. An agronomic model is used to evaluate potential long-term yields at different locations of the area under investigation.

Archaeobotanical Data

Archaeobotanical research on Late Neolithic/Chalcolithic sites of the Aegean has been published since the 1960s. The regional coverage, however, is very uneven, with most of the sites located in Greece and only few in western Anatolia (Tab. 1).

Certain standards need to be fulfilled in order to use archaeobotanical data for inter-site comparison because they determine the representativeness of each plant assemblage for the site from

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[37] Wilkinson 1999.

[38] Roberts et al. 2011.

which it comes. The criteria applied here are the volume and number of samples along with find density, which usually equals the number of records and number of taxa that provide information on the diversity of the assemblage. High diversity is usually provided by contexts with long-term accumulation of plant remains, while low diversity frequently results from storage contexts.[39] Applying the rigid standards of a requirement of 30 samples per phase[40] would have reduced the comparison to five sites with only three sites from the Late Neolithic/Chalcolithic. Therefore, we used all sites from which more than nine samples were analysed. We excluded sites with very low taxa numbers because of the high probability that only selected species were identified and documented for the original report, limiting comparability. Despite moderate application of archaeobotanical standards, 21 possible data sets were reduced to 10.

In addition to the basic quantitative analysis of the crop assemblages, we applied correspondence analysis to the wild plant taxa to elaborate on possible environmental and/or economic patterns. Correspondence analysis is widely used in archaeobotany and has been applied to a large number of different research questions.[41]

Site	Period	No. of samples	No. of records	< 9 samples, < 500 records < 20 taxa
Dikili Tash	Chalcolithic	224	52375	
Franchthi Cave	Chalcolithic	81	3553	
Kissonerga	Chalcolithic	150	0	X
Kumtepe	Chalcolithic	28	12856	
Kuruçay Höyük	Chalcolithic	47	154445	
Lemba-Lakkous	Chalcolithic	17	1022	
Mylouthkia	Chalcolithic	9	8856	
Pefkakia-Magoula	Chalcolithic	2	0	X
Pyrasos	Chalcolithic	1	585	X
Servia	Chalcolithic	10	9097	
Sesklo	Chalcolithic	2	0	X
Saliagos	Chalcolithic	1	2	X
Argissa-Magoula	Early Bronze Age	4	0	X
Demircihüyük	Early Bronze Age	6	7364	X
Kastanas	Early Bronze Age	40	16782	
Pefkakia-Magoula	Early Bronze Age	3	0	X
Platia Magoula Zarkou	Early Bronze Age	4	1519	X
Sotira Kaminoudhia	Early Bronze Age	53	187	X
Troia II	Early Bronze Age	9	2220	
Troia I	Early Bronze Age	15	3162	
Yenibademli Höyük	Early Bronze Age	15	4,448E+09	X

Tab. 1 Late Neolithic/Chalcolithic and Early Bronze Age sites with archaeobotanical research publications; Zero in the column ‘no. of records’ marks assemblage with presence/absence of records instead of absolute counts; Shaded sites have been used in the analysis, and ‘X’ designates those samples that had to be excluded from comparison, because they did not fulfil archaeobotanical standards. Yenibademili Höyük contained large storage contexts and was excluded.

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[39] Riehl 1999.

[40] Jacomet – Kreuz 1999.

[41] E.g. Jones 1991; Colledge 1998; Bogaard 2004.

Stable carbon isotope analysis on ancient plant remains provides an independent tool for assessing the potential impact of reduced soil moisture in relation to changing agricultural patterns. The method derives from plant physiology and was developed to explore processes during photosynthesis, including water use efficiency in C3 plants.[42] The heavy ^{13}C becomes enriched with the closing of the stomata in the plant during phases of reduced water availability.

In archaeological contexts, the method has been applied at a number of Near Eastern sites that are well-suited for this kind of study due to the semi-arid to arid conditions.[43] In areas where water availability is not the main stress factor for plants, the principle would not apply. Currently, primary research on stable carbon isotope ratios in cereals under Mediterranean conditions are lacking, but recent results on coastal Syrian and Lebanese Bronze Age sites indicate that the $\delta^{13}C$ signal is not a characteristic stress signal of such environments.[44]

We conducted stable isotope analysis on 44 barley grains from Kumtepe and Troy dating to the Late Neolithic/Chalcolithic period and the Early Bronze Age. Measurements were conducted with a Finnigan MAT252 for stable isotope HCNOS analyses at the Central Laboratory of Geochemistry at the University of Tübingen. We consider the $\delta^{13}C$ values within the whole settlement sequence of Troy for understanding the chronological development, and compare the values to other Near Eastern sites to assess the significance of the signals.

The Agronomic Model

Agronomic models inform about potential long-term yield of individual crop species at specific locations and enable the farmer to choose the optimal strategy in crop production. They also help to understand the influence of different factors, natural and anthropogenic, on particular crops.

An agronomic simulation is a simplified model of crop plant growth based on multiple physiological equations and empirical data.[45] An array of agronomic models has been proposed over the last three decades. Some of the models are crop-specific and designed for a single crop plant[46] while others can be applied to a number of different crops.[47]

For this study, we used EPIC (Environmental Policy Integrated Climate), an agro-ecological model that enables the simulation of crop plant growth as a function of environmental factors and agricultural management.[48] Originally, EPIC was developed to calculate the impact of erosion on yields for different periods of time,[49] but it turned out that its principles can be effectively applied to a broader spectrum of assignments.[50] Test studies in different parts of the world demonstrated the robustness of EPIC, usually showing no significant differences between predicted and harvested yields at the 95% confidence level.[51] EPIC operates with a daily time step and involves a series of sub-models:[52] climate and weather, hydrology, erosion, nutrients turnover, soil temperature, tillage, plant growth, crop plant management and economics. One of the advantages of the model is the availability of seven options for water erosion and five options for simulation of evapotranspiration.[53] With these features, EPIC provides the possibility to simulate yields over relatively long periods of time, centuries or even millennia.[54]

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[42] Farquhar et al. 1989.

[43] Araus et al. 1998; Ferrio et al. 2005; Fiorentino et al. 2008; Riehl et al. 2008; Flohr et al. 2011.

[44] Marinova et al. 2012; Riehl et al., in print.

[45] Haan 2002.

[46] Ritchie – Otter 1985; Jones et al. 1986.

[47] Van Keulen et al. 1982; Sharpley – Williams 1990.

[48] Williams 1990.

[49] Williams et al. 1983.

[50] Williams et al. 1989.

[51] Bernardos et al. 2001; Liu et al. 2008; Van der Velde et al. 2009; Srivastava – Geiser 2010.

[52] Williams et al. 1984.

[53] Gassman et al. 2005.

[54] Williams 1995.

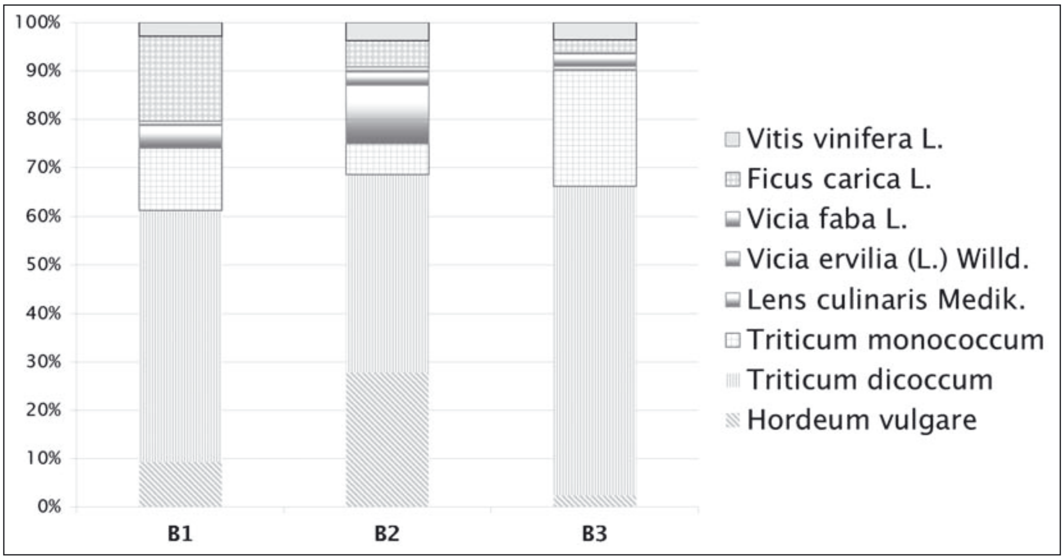

Fig. 3 Crop proportions of the Kumtepe B sequence. Note the higher proportions of pulse crops in Kumtepe B2 and the increase of hulled wheat in Kumtepe B3 (illustration: S. Riehl).

For the EPIC application, we created a data set for locations near the archaeological settlements considered in this study in Access format. These include climate stations at Çanakkale, Isparta, Thessaloniki, Paphos, Naxos and Larissa (http://www.tutiempo.net/en/Climate). For each climate station, two sets of monthly weather parameters were chosen from the past 30 years of continuous meteorological records: the year with minimum sum precipitation and that with maximum sum precipitation. Thereafter these are referred to as a 'bad year' (BY) and 'good year' (GY) respectively. Soil properties were taken from the harmonised world soil database,[55] and from local sources.[56] The simulations were run for two crops, barley and lentil yields for the duration of 100 and seven years and differing starting precipitation values.

Results

Archaeobotanical Patterns

A combined analysis of charcoal and seed remains from Kumtepe and Troy was conducted to answer the question regarding the role of human impact on the mid-Holocene vegetation development in the Troad.[57]

While the site of Kumtepe was not inhabited between 4600 and 3500 calBC and Troy did not yet exist, the dominant species around 3500 calBC belonged to a mixed woodland-type dominated by oak and pine, probably resembling a vegetation type similar to that attested for northern Greece. Human impact became strongly prominent at around 3300 calBC with an increase in sclerophyllous species in Kumtepe B2. These results correlate with palynological results from the northwestern Aegean region as outlined above, and find support in a descending sea level as documented for the Trojan Bay at the end of Kumtepe B[58] (see also Fig. 2). Aridification to an

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[55] Batjes 1995.

[56] Zinke et al. 1986; Boysan – Çimrin 2006; Bilen 2008.

[57] Riehl – Marinova 2008.

[58] Kayan 1992.

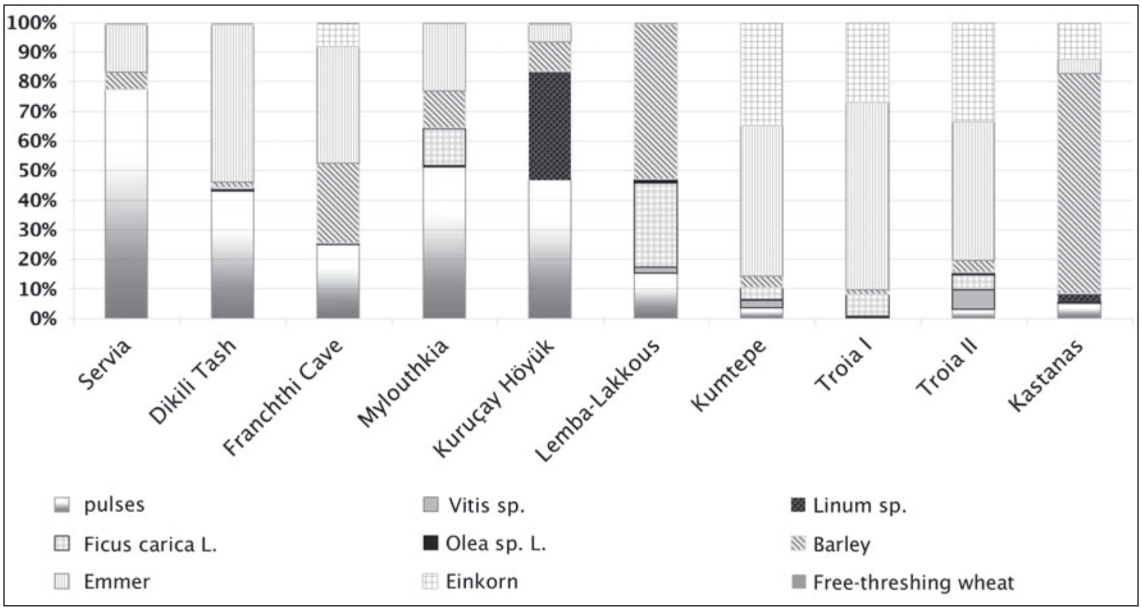

Fig. 4 Crop proportions at Late Neolithic/Chalcolithic and Early Bronze Age sites in the Aegean. The sites appear in relative chronological order with Servia, Dikili Tash and Franchthi Cave starting circa 4500 BC, Mylouthkia and Kuruçay Höyük dating at around 3700 BC, and Lemba-Lakkous and Kumtepe B with the earliest dates at 3500 BC. Troy and Kastanas are Early Bronze Age settlements (illustration: S. Riehl).

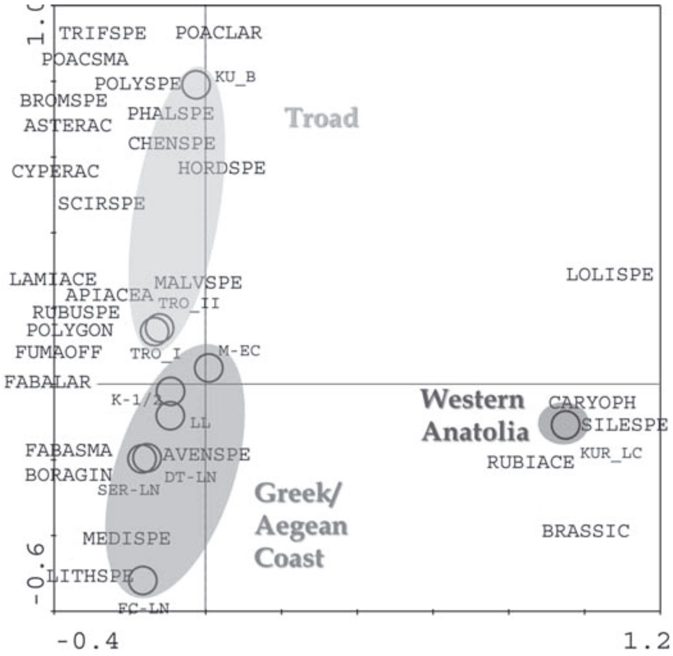

Fig. 5 Correspondence plot of the wild plant assemblages of the ten sites listed in Tab. 1, showing clusters of geographic units (illustration: S. Riehl).

unknown degree may have intensified the anthropogenic impact on the vegetation at the end of the 4th millennium BC.

A distinct pattern becomes obvious when considering crop data of the Kumtepe B sequence. The whole assemblage is dominated by cereals and pulses while lentil is particularly well repre-

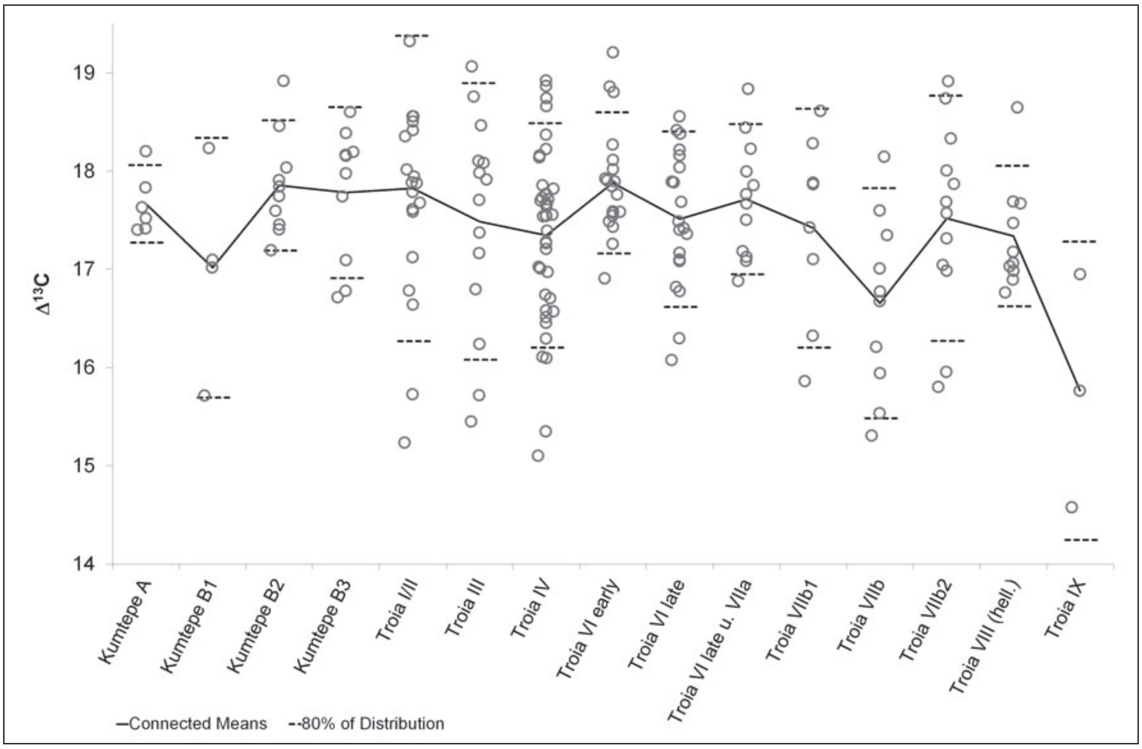

Fig. 6 Stable carbon isotope data of barley grains from different periods at Troy (illustration: S. Riehl).

sented in Kumtepe B2, and hulled cereals increase in Kumtepe B3 and remain in this dominant composition during the Early Bronze Age as recognised at Troy and Kastanas (Figs. 3, 4).

A consideration of ten Aegean archaeobotanical assemblages that fulfil the standards, outlined in the material and methods section, reveals the same pattern as in the Kumtepe B2 assemblage (Figs. 3, 4). Pulse crops are present in high percentages in most of the Chalcolithic sites while hulled cereals such as emmer, einkorn and barley have higher proportions in the two Early Bronze Age sites, but also at Kumtepe B3. The chronological correlation of this development with the proposed palaeoclimate change outlined above raises the question of whether climate change may have been involved in this shift from major components of pulse crops to a cereal-dominated economy.

Correspondence analysis of the wild plant assemblages from these sites displays a geographic pattern rather than a chronological one (Fig. 5). Although the geographic clustering into settlements of the Greek Aegean coast, Kurucay Höyük, and the sites of the Troad indicates environmental diversity of the geographic areas, an environmental change throughout time that would require a clustering of the Late Neolithic/Chalcolithic sites separated from the Early Bronze Age sites is hardly visible which may be alternatively related to the reduced number of Early Bronze Age sites.

Stable Carbon Isotope Data

Stable carbon isotope data on cereal remains may be more informative in relation to increased aridity, because they may provide a direct signal of drought stress in the crop species themselves.

Referring to earlier studies on $\delta^{13}C$ signals at Near Eastern sites, drought stress can be assumed for ^{13}C values below 16‰ that were found at a number of Syrian sites at the transition from the Early to the Middle Bronze Age.[59] Applying this relatively rigid limit to the mean values found at Troy, we may state definite drought stress only during the Roman period (Troia IX). Looking

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[59] Riehl et al. 2008; Riehl et al. 2014.

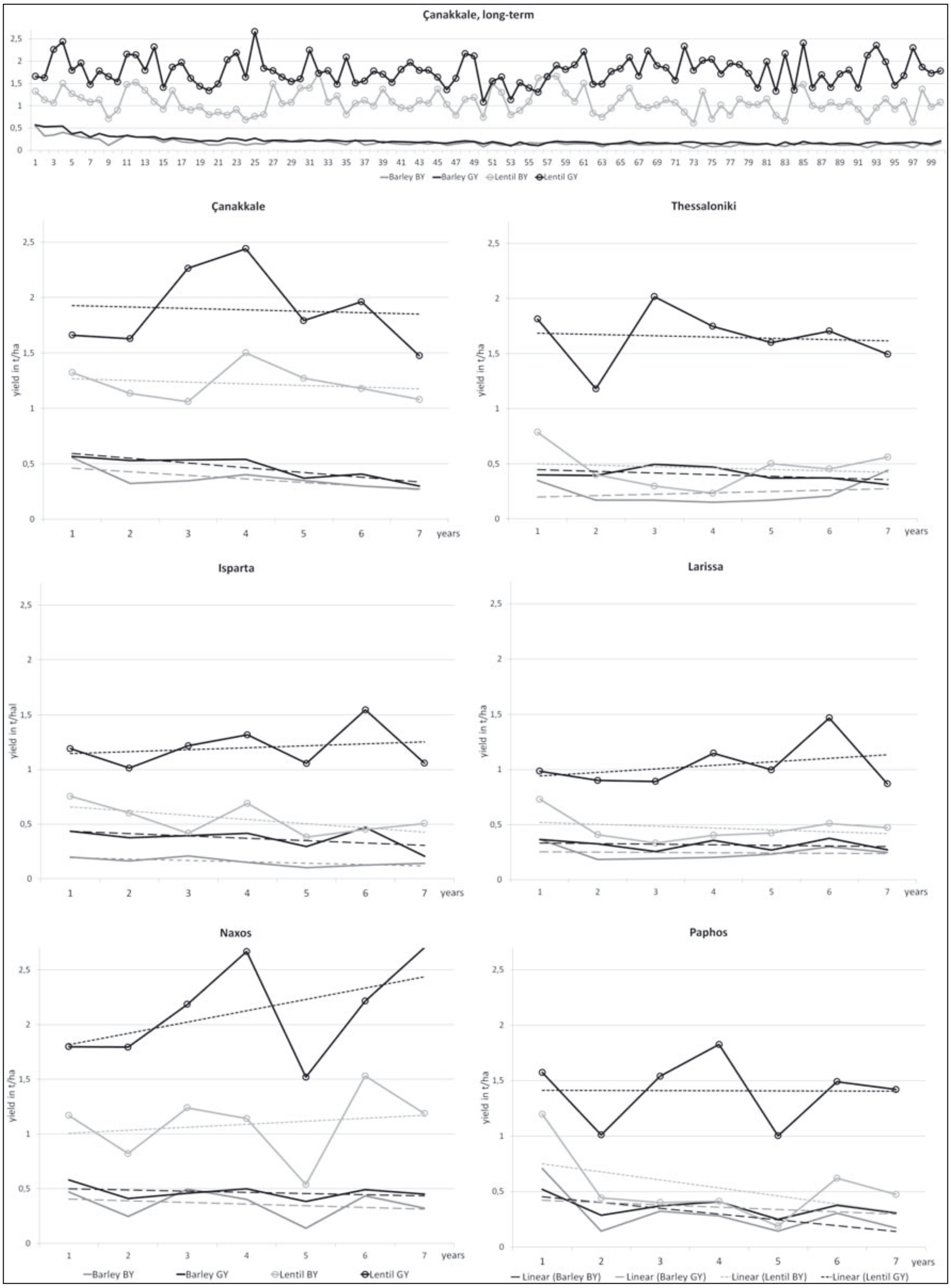

Fig. 7 Yield structure of barley and lentil with different precipitation parameters in the first year, modelled for different climate locations; BY: 'bad year' with minimum sum precipitation, GY: 'good year' with maximum sum precipitation, linear: linear regression (illustration: S. Riehl).

at individual values from the different phases and periods in the Troad, there is, however, a trend of an increasing number of stress signalising values in Kumtepe B3 until Troy IV, although definite stress-indicating values are only present from Troy I/II onward. Kumtepe B1 values cannot be considered, because of too few measurements. A strong drought stress signal during the time considered here is not evident in barley grains from the Troad (Fig. 6).

Agricultural Models

The archaeobotanical and stable carbon isotope evidence alone is not distinctly showing a possible climate impact on the agricultural economy. The modelling of potential yields at different geographic locations may help clarify the local conditions necessary for sufficient crop yield.

Long-term modelling of yields over 100 years shows a general pattern of slightly decreasing yields in all climate stations, depicted here for Çanakkale (Fig. 7, top). While yields of lentil are considerably higher than those of barley, they show strong inter-annual fluctuations and large differences between yields in drier and moister years, in contrast to barley with only a little inter-annual variation and nearly no differences between dry and moist years.

A detailed consideration of the first seven years of the simulations for different locations documents some obvious patterns related to local climate conditions. While regional differences in barley yields are moderate, modelled yields of lentil are considerably higher in coastal areas (Çanakkale, Naxos), and relatively low at locations further inland (Isparta, Larissa).

Considering the linear regressions with reduced precipitation at the beginning of the simulation for seven years (termed as bad year), yields for barley and lentil both decrease, while yields for lentil are generally higher. However, absolute yields for barley and lentil during a bad year are relatively similar from the second year onward at Thessaloniki, Larissa and Paphos while at Çanakkale and Naxos lentil yields with a bad starting year are still higher than barley yields with a good starting year.

The most striking result of the simulation is the strong difference between the high yields of lentil and the relatively low yields of barley with higher precipitation (GY) at the beginning of the simulation. Yields of barley in a good year do not strongly differ from yields in a bad year.

Discussion

The following considerations are based on the assumption that crop plants documented at the different sites are mostly consumed by humans. This also includes the pulses but is in some contrast to the stable isotope data from the Neolithic and Chalcolithic site of Aktopraklık near Bursa in northwestern Anatolia.[60] There, a major component of the diet must have been from C3-plants other than pulses because the $\delta^{15}N$ values are relatively high, suggesting that, aside from the consumption of animal products and meat, the plant component mainly derived from cereals rather than from legumes. With radiocarbon dates between 6400 and 6200 BC, the timing of Aktopraklık is earlier than the periods considered here but also falls into the phase of a RCC event, the 8200 BP event respectively.[61]

Reconsidering our goal as outlined in the introduction, the most striking regional agricultural pattern is the high amounts of pulse crops in the Late Neolithic/Chalcolithic sites that were strongly reduced in favour of barley and hulled wheat during the Early Bronze Age. It is speculated that climate change, i.e., increasing aridity from the mid-Holocene on, may have played a role in this process. The wild plant assemblages do not support this interpretation because they do not indicate a clear chronological clustering, which may be expected if strong climate effects would have affected the composition of the wild plant assemblages.

In general, human impact on vegetation creates similar archaeobotanical results as increasing aridity, making climate impact hardly discernible from human impact in wild plant assemblages.

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[60] Budd et al. 2013.

[61] Weninger et al. 2006.

Such a trend is also visible in the pollen record, and applies to the Troad where human impact on the vegetation occurred at approximately the same time[62] as sea level decrease.[63] The stable carbon isotope evidence from the Troad may correlate with the increasing aridity identified for the palaeoclimate proxy records, but the values do not support a strong drought stress in the plants.

While the archaeobotanical evidence fails to prove a strong link between global climate fluctuations such as the 5200 BP event and agricultural strategies, the incorporation of the agronomic simulations under consideration of a general increase in aridity from the mid-Holocene on helps develop an explanatory model for the observed changes in agricultural patterns.

The extremely high yields of lentil under good moisture conditions in contrast to the modest yields of barley presented the most striking aspect in the model output. As the absolute yields of lentil are higher than those of barley even in bad years, increasing aridity would not explain the shift from pulse crops to cereals observed for the transition from the Chalcolithic/Late Neolithic to the Early Bronze Age. The strong yield differences in lentil between good and bad years, in contrast to barley with relatively similar yields in bad and good years, are more significant because they qualify lentil as a crop with low yield predictability. Agricultural production with a high dependency on lentil would entail the risk of heavy losses in relation to weather fluctuations, while barley yields would be less vulnerable and therefore more predictable. This factor is of high importance under conditions of inter-annual climate variability and increasing aridity, which have been stated for the periods from the mid-Holocene on.[64] Although this climate trend was too weak to produce a strong stress signal in barley, the slight stress increase that is visible may have been enough to cause strong yearly losses in the pulse harvest, leading to a change in the crops preferred for agricultural production.

Such a model of ancient farmers adapting their mode of subsistence or at least their crop spectrum to changing conditions introduces the factor of human perception of the environment, which is unknown for past societies, but undoubtedly a part of the decision making process.[65]

The Aegean crop assemblages presented here suggest a Neolithic tradition of dominating pulse crop cultivation that starts to shift to dominating cereal cultivation from 3500 BC on, probably in relation to increasing aridity, higher variability in mean annual precipitation and a change in environmental perception. This shift probably smoothly progressed, which does not correspond with what we would expect of a RCC (rapid climate change) event as the climate fluctuation around 5200 BP. In terms of diet, this shift can be interpreted as a change from a protein-dominated to a carbohydrate-dominated plant diet. At least in the case of Kumtepe (fallow deer and mussels), hunting and gathering played a major role during the Neolithic while during later periods, including the Early Bronze Age, sheep and goat husbandry increased.[66] Although the earliest date for milk use extends much farther back into the past,[67] decreasing pulse crops at the end of the Chalcolithic period is consistent with Sheratt's classical model[68] of an increased use of secondary products such as milk and cheese to compensate for reduced protein-intake with the shift from pulses to cereals.

Prospective and Conclusions

Because the interrelationship between human societies and landscapes becomes nearly impenetrably complex from the mid-Holocene on, current palaeoclimatological studies considering proxy archives that are not directly associated with archaeological sites can only provide a very rough background

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[62] Riehl – Marinova 2008.

[63] Kayan 1992.

[64] Roberts et al. 2008; Geraga et al. 2010.

[65] Tuan 1990; Ingold, 2011.

[66] Riehl – Marinova 2008.

[67] Evershed et al. 2008.

[68] Sherratt 1981.

pattern of local climate and environmental conditions, regardless how well resolved they are. While immediate reactions to abrupt changes are relatively easy to recognise, long-term processes are much more complicated, involving a large number of natural and cultural variables. Explanatory models of documented changes can become very complicated and regionally specific, particularly, when ancient human perceptions of the environment are involved in the development of economy.

Therefore, each archaeological excavation requires its own environmental archaeology program that cooperates closely with sociocultural anthropology to enable the recognition of concrete, site-specific developmental patterns and an understanding of interdependence of the specific local society within its past natural and cultural landscapes.

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