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The socio-environmental history of the Peloponnese during the Holocene: Towards an integrated understanding of the past

Erika Weiberg [a, *], Ingmar Unkel [b], Katerina Kouli [c], Karin Holmgren [d, e], Pavlos Avramidis [f], Anton Bonnier [g, 1], Flint Dibble [h], Martin Finné [d, e, 1], Adam Izdebski [i], Christos Katrantsiotis [d, e], Sharon R. Stocker [i], Maria Andwinge [d], Kalliopi Baika [j, k], Meighan Boyd [d, e], Christian Heymann [b]

[a] Department of Archaeology and Ancient History, Uppsala University, Box 626, 751 26 Uppsala, Sweden
[b] Graduate School "Human Development in Landscapes", c/o Institute for Ecosystem Research, Kiel University, Olshausenstrasse 75, 241 18 Kiel, Germany
[c] Faculty of Geology & Geoenvironment, National and Kapodistrian University of Athens, Panepistimiopolis, 157 84 Athens, Greece
[d] Department of Physical Geography, Stockholm University, 106 91 Stockholm, Sweden
[e] Navarino Environmental Observatory, Navarino Dunes, Costa Navarino, 24001 Messinia, Greece
[f] Department of Geology Laboratory of Sedimentology, University of Patras, Rio-Patras 26504, Greece
[g] Department of Historical Studies, University of Gothenburg, Box 200, 405 30 Gothenburg, Sweden
[h] Department of Classics, University of Cincinnati, 410 Blegen Library, PO Box 210226, Cincinnati, OH, USA
[i] Department of Byzantine History, Institute of History, Jagiellonian University in Krakow, ul. Golebia 13, 31-007 Krakow, Poland
[j] Département d'Histoire de l'art et Archéologie, Aix-Marseille Université — CCJ UMR 7299, 130 94 Aix-en-Provence, France
[k] Ephorate of Underwater Antiquities, Hellenic Ministry of Culture, 117 42 Athens, Greece

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A B S T R A C T

Published archaeological, palaeoenvironmental, and palaeoclimatic data from the Peloponnese in Greece are compiled, discussed and evaluated in order to analyse the interactions between humans and the environment over the last 9000 years. Our study indicates that the number of human settlements found scattered over the peninsula have quadrupled from the prehistoric to historical periods and that this evolution occurred over periods of climate change and seismo–tectonic activity. We show that societal development occurs both during periods of harsh as well as favourable climatic conditions. At some times, some settlements develop while others decline. Well-known climate events such as the 4.2 ka and 3.2 ka events are recognizable in some of the palaeoclimatic records and a regional decline in the number and sizes of settlements occurs roughly at the same time, but their precise chronological fit with the archaeological record remains uncertain. Local socio-political processes were probably always the key drivers behind the diverse strategies that human societies took in times of changing climate. The study thus reveals considerable chronological parallels between societal development and palaeoenvironmental records, but also demonstrates the ambiguities in these correspondences and, in doing so, highlights some of the challenges that will face future interdisciplinary projects. We suggest that there can be no general association made between societal expansion phases and periods of advantageous climate. We also propose that the relevance of climatic and environmental regionality, as well as any potential impacts of seismo-tectonics on societal development, need to be part of the interpretative frameworks.

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* Corresponding author.
E-mail addresses: erika.weiberg@antiken.uu.se (E. Weiberg), iunkel@ecology.uni-kiel.de (I. Unkel), akouli@geol.uoa.gr (K. Kouli), karin.holmgren@natgeo.su.se (K. Holmgren), p.avramidis@upatras.gr (P. Avramidis), anton.bonnier@antiken.uu.se (A. Bonnier), wfdibble@gmail.com (F. Dibble), martin.finne@natgeo.su.se (M. Finné), adam.izdebski@fundusz.org (A. Izdebski), christos.katrantsiotis@natgeo.su.se (C. Katrantsiotis), shari.stocker@ascsa.edu.gr (S.R. Stocker), maria@andwinge.se (M. Andwinge), kbaika@gmail.com (K. Baika), cheymann@gshdl.uni-kiel.de (C. Heymann).
[1] Present address: Department of Archaeology and Ancient History, Uppsala University, Box 626, 751 26 Uppsala, Sweden.

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1. Introduction

The Mediterranean region is highly sensitive to regional and global climate changes; it is both a biodiversity hotspot and a home to ancient civilisations and, therefore, a key region through which we may study the interwoven forces of long-term interaction between humans and the environment (Mercuri and Sadori, 2014; Roberts et al., 2011; Sadori et al., 2013; Izdebski et al., 2016a). The landscapes of the Peloponnese (Fig. 1), combine these Mediterranean characteristics within a single well-defined region: it was an important center for the establishment and evolution of ancient Greek civilisation, and the history of the peninsula comprises a wide spectrum of early farming communities, palatial economies, and city-states that produced sanctuaries and urban centres, such as those of Mycenae and Olympia; the region is well documented in historical sources, both documentary inscriptions and the literary works of ancient authors. In addition, the environmental changes and climate variability of this region during the Holocene have been studied from multiple sources using geochemistry, sedimentology, stable isotopes, charcoal, pollen and diatom records from lakes, lagoons, wetlands and speleothems.

Until now, however, there have been few attempts to bring together information from the different archives in order to form an integrated long-term narrative of the interactions between humans and the environment in the region. The goal of the present paper is to compile the existing archaeological, palaeoenvironmental and palaeoclimatic data, and to examine how this information may allow us to reconstruct the dynamics of human activity and environmental changes in the Peloponnese (Table B.1). The chronology of this paper will cover a span of some 8000 years, starting in the Neolithic era and concluding in the Frankish period (6800 BC–AD 1460/8750–490 BP) (Table 1). While the principal geographical focus is the Peloponnese, records from neighbouring regions will also be considered in order to enrich the discussion, and to highlight issues of scale and regional variability.

2. Regional setting

The Peloponnese displays significant geologic, geomorphologic and climatic variability with both regional and local patterns. The bedrock is mainly made up of Mesozoic limestone (Fig. B.1), and the major landforms are the result of long-term tectonic activities and catastrophic events (floods, earthquakes, and tsunamis), as well as river sediment influxes and sea level changes (Brückner et al., 2010; Papadopoulos et al., 2014; Vött, 2007); as a result, the landscape varies significantly over short distances. The entire region is rich in limestone caves and sediment archives, such as poljes, coastal lagoons and lakes (Fig. 2).

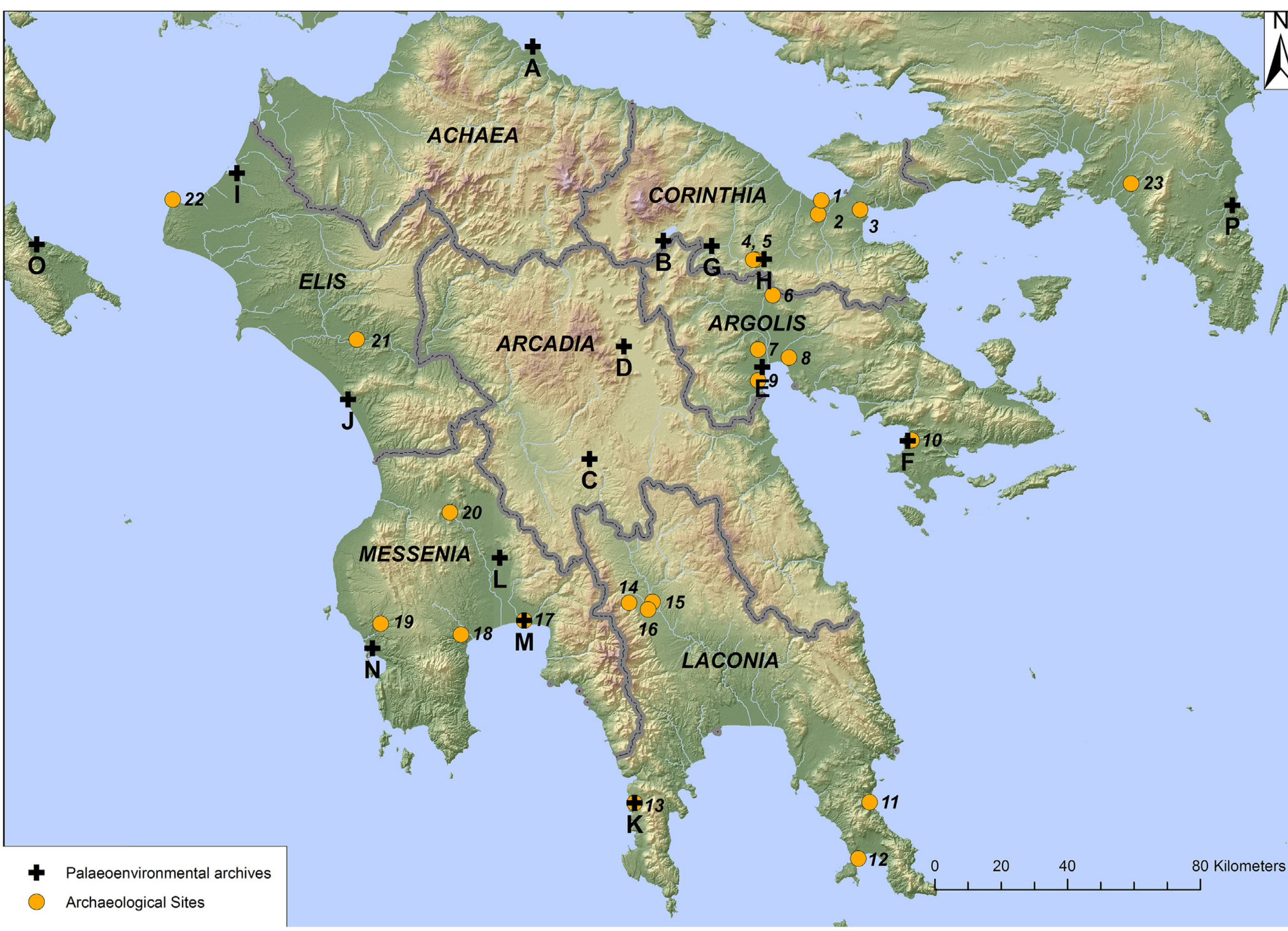


Fig. 1. Map of Southern Greece and the geographical regions of the Peloponnese, with available palaeoenvironmental archives (letters) and archaeological sites (numbers) cited in the paper. A: Aliki/Egion, B: Stymphalia, C: Asea, D: Kapsia, E: Lerna, F: Koiladha, G: Phlious, H: Kleonai, I: Kotychi, J: Kaiafa, K: Alepotrypa, L: Agios Floros, M: Akovitika, N: Osmanaga, O: Alykes/Zakynthos, P: Vravron. 1: Corinth, 2: Lechaion, 3: Isthmia, 4: Nemea, 5: Tsoungiza, 6: Mycenae, 7: Argos, 8: Tiryns, 9: Lerna, 10: Franchthi, 11: Agios Stefanos, 12: Pavlopetri, 13: Alepotrypa, 14: Sparta, 15: Kouphovouno, 16: Mistra, 17: Akovitika, 18: Nichoria, 19: Pylos, 20: Malthi, 21: Olympia, 22: Kyllene, 23: Athens. Supporting information available in Table B.1. The map has been created using the ASTER GDEM, a product of METI and NASA. Illustration by A. Bonnier.

Table 1
Cultural chronology of southern Greece (chronologies based on Bintliff, 2012a; Manning, 2010; Demoule and Perlès, 1993; Perlès, 2001).

Time (BC/AD)	Period		Event	Abbreviations	
AD 1204–1460	Byzantine and Frankish/Late Medieval		Start: Latin conquest of Constantinople.	B, F	
AD 900-1204	Middle Byzantine/Medieval		Start: Consolidation of the Roman (Byzantine) power in the southern Balkans.	B	
AD 641-900	Early Byzantine/Early Medieval		Start: Death of Emperor Heraclius and the collapse of the Late Roman political order.	B	
AD 300–641	Late Antiquity/Late Roman		Start: Founding of the city of Constantinople and the parting of ways between the Western and Eastern parts of the Roman Empire.	LR	
31 BC–AD 300	Roman	Early, Middle	Start: Destruction of Corinth and end of Achaian war.	R	ER, MR
323–31 BC	Hellenistic		Start: Death of Alexander	H	
479–323 BC	Classical		Start: Greek victory over the Persians in the battle of Plataea; Persian invasion of Greece repelled.	C	
750/700–479 BC	Archaic		Start: The first literary sources.	A	
900–750/700 BC	Early Iron Age	Geometric	Start: End of Mycenaean culture.	EIA	G
1075–900 BC		Proto-Geometric			PG
1700–1075 BC	Late Helladic/Mycenaean		Periodization modeled on Minoan Crete, which in turn was modeled on the Old,	LBA	LH I-III
2100–1700 BC	Middle Helladic		Middle and New Kingdom of ancient Egypt.	MBA	MH I-III
3100–2100 BC	Early Helladic			EBA	EH I-III
4500–3100 BC	Neolithic	Final Neolithic	Start: Introduction of a farming economy in Greece.	N	FN
5450–4500 BC		Late Neolithic			LN
5950–5450 BC		Middle Neolithic			MN
6800–5950 BC		Initial and Early Neolithic			IN, EN

The modern climate and weather characteristics are influenced by global-to-hemispheric circulation patterns (Lionello et al., 2006), modulated by smaller scale regional-to-local circulation systems (Maheras and Anagnostopoulou, 2003; Xoplaki et al., 2000). The annual weather pattern is typical of the Mediterranean, with hot, dry summers and mild, wet winters. More than 80% of the annual precipitation falls between October and April, and the water balance is negative between May and September (i.e. evapotranspiration from soil and vegetation exceeds precipitation). Precipitation amounts generally decline towards the east and are orographically influenced by mountain ridges stretching from the north to the south of the central Peloponnese.

Modern vegetation is defined by a high variability over short distances, and has been affected strongly by the cumulative effect of human activities over the last millennia. The variety of plant communities include high alpine vegetation and mountainous coniferous forests with pines, black pines and local fir stands, as well as thermophyllous mixed deciduous woodland, evergreen sclerophyllous and phrygana vegetation (Polunin, 1980).

The natural compartmentalisation of the landscape was an important factor in cultural and historical developments throughout the Peloponnese; both the history and archaeology are defined by a certain level of regionality, and the presence of many micro-regions (Horden and Purcell, 2000). However, there is much evidence for the human strategies developed to transgress these topographic boundaries and to bind the landscape into more-or-less coherent life-worlds. The natural borders of the Peloponnese would at times be a factor in the development of regional differences that set Peloponnesian societies apart from the rest of the Greek mainland and the Aegean sphere at large.

3. Environmental archives used and methods of reconstruction

3.1. Sedimentary archives and data

The selection of sedimentary archives was based on the need for sediment data that would provide a continuous record for at least a few millennia within the temporal scope of this paper. Several of the available records for this period are either fragmented, poorly dated or of low resolution (Table B.1), and we will refer to them only when they are relevant to the subject of this paper. We have summarised the sedimentological, geochemical, palynological and biological records from one lake (Stymphalia: Heymann et al., 2013), two former lakes (Asea and Lerna: Unkel et al., 2014 and Jahns, 1993), one fen (Agios Floros: Katrantsiotis et al. 2015), and four coastal lagoons (Vravron: Triantaphyllou et al. 2010; Kouli 2015, Aliki/Egion: Kontopoulos and Avramidis, 2003, Kotychi: Kontopoulos and Koutsios, 2010; Lazarova et al., 2012; Haenssler et al., 2014 and Alykes/Zakynthos: Panagiotaras et al., 2012; Avramidis et al., 2013) (Fig. 1). Each of the records chosen offer evidence for at least two of the four sedimentary types of datasets.

The stratigraphies and lithologies of these records (Fig. A.4) testify to the varying palaeoenvironmental conditions that must be considered when analysing and comparing the records. These variations are due to different geomorphological processes, including proximity to rivers and river deltas, tectonism, the sediment budget (river/delta or alluvial fan progradation), relative sea level changes and catastrophic events such as floods, earth-quakes and tsunamis (cf. Anthony et al., 2014; Brückner et al., 2010; Papadopoulos et al., 2014; Vött, 2007; Willershäuser, 2014). The fluvial predominance with river sediment supply and river/delta progradation is another parameter which differentiates the depositional environments of the coastal core sites studied here.

Harbours and submerged settlements provide a specific geo-archive that can contribute to a diachronic reconstruction of landscape, environment and coastal/maritime settlements (Marriner and Morhange, 2007). Other geoarchaeological studies have focused on analyses of erosion and sedimentation in a wide variety of landscapes, commonly conducted as part of, or in connection with archaeological field surveys (Table B.1). Unfortunately, many of these lack sufficient chronological resolution, but we will refer to them when they contribute information relevant to the subject of this paper.

Until recently, (inorganic) geochemical proxies have been used only to a very limited degree in sedimentary archives from the Peloponnese, and only single proxies – such as carbonate content, pH values or Mn and Mg – have been used for facies separation (Fuchs et al., 2004; Panagiotaras et al., 2012; Vött, 2009). However the development of high resolution XRF scanning, in combination with Bayesian age-depth modelling of limnic sediments, have provided new methods for extracting information on paleoenvironmental changes in the Holocene period on a decadal to centennial scale (Haenssler et al., 2014; Heymann et al., 2013; Unkel et al., 2014). The chemical elements presented in the studies on Lake Stymphalia (Heymann et al., 2013), the Asea Valley (Unkel et al.,

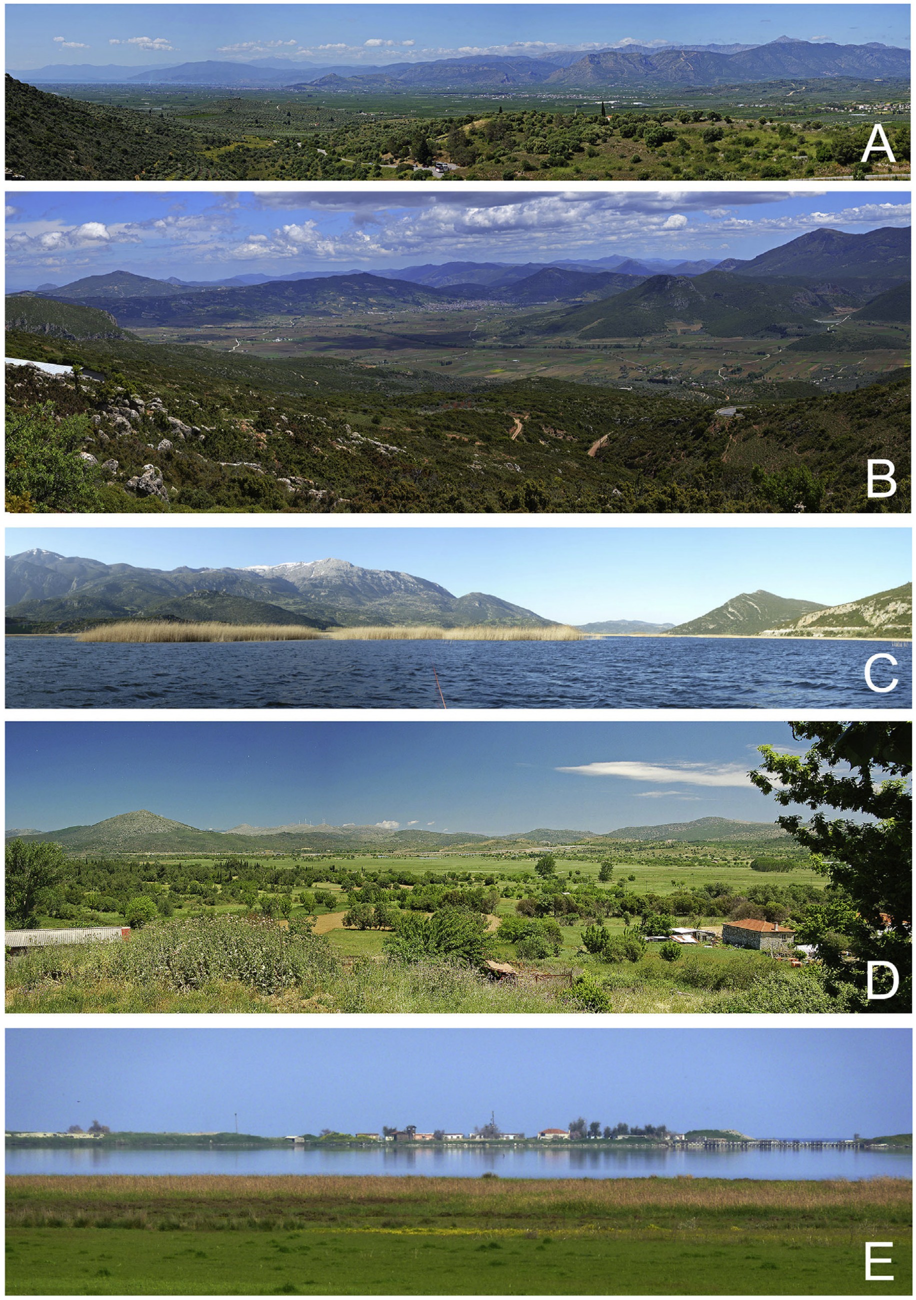


Fig. 2. Five panorama photos illustrating the topographic variation of the Peloponnese from East (top) to West (bottom) as follows: A. View to the Southwest from Mycenae across the Argive Plain with the shores of the bay of Argos in the far left (29.IV.2014); B. View to the East across the Phlious-Nemea Valley, Corinthia, from the hills above the village of Galatas (30.IV.2014); C. View to the Northeast across lake Stymphalia, Corinthia, with the acropolis of Stymphalos to the far left and snow-covered Mt. Ziria (2374 m) in the background (9.IV.2011); D. View to the North from Paparis across the basin of Asea, Arcadia (25.V.2013); E. View to the West across the Kotychi Lagoon, Elis (2.IV.2011). Photos by I. Unkel.

2014), and the Kotychi Lagoon (Haenssler et al., 2014) can be divided into two groups: the carbonate group (indicated by Ca and Sr) precipitated within the lake during summer when evaporation is highest, and the siliciclastic group, composed of clay and clastic minerals (indicated by chemical elements such as Zr and Rb) derived from the lake catchment, which has been proven to work as a proxy for precipitation and run-off in the catchment area (Heymann et al., 2013, and references therein). Elements involved in salt formation (e.g. Cl or Br) may also be used as indicators for changes in marine influence on lagoonal environments (Haenssler et al., 2014). Thus, changes in the ratios of elements which represent different sedimentary processes can be used as proxies for reconstructing changes in the hydrology and temperature of the Peloponnese (Fig. A.2).

We have also based our reconstruction of the Holocene climate and environmental changes in the Peloponnese on biological proxies found in the sediment cores, including pollen and diatoms. In order to enable comparisons between the different records, the pollen diagrams were plotted against time (cal BP), based on the published data from each site (Fig. A.4). For Lake Lerna we used the age-depth model provided by the European Pollen Database (http://www.europeanpollendatabase.net). Arboreal pollen was divided among mountainous, deciduous and Mediterranean vegetation groups, and in addition to the arboreal pollen (AP) sum, a forestation cover index was used to estimate the woodland cover (Kouli, 2012). Agricultural activities may be traced through the fluctuations of cultivated plants (*Olea*, Cerealia-type), as well as the sum of the Pollen Disturbance Index (PDI), which uses selected anthropogenic indicators related to pastoral activities (specifically *Centaurea*, Cichorioideae, *Plantago, Ranunculus acris* type, *Polygonum aviculare* type, *Sarcopoterium, Urtica dioica* type and *Pteridium*) (Kouli, 2015). The sums of synanthropic taxa have allowed us to quantify the overall impact of human activities on vegetation, and include both cultivated plants and secondary indicator species (Bottema and Woldring, 1990). Finally, the H-index (Bottema, 1991; Triantaphyllou et al., 2009) was used as an indicator for pollen-derived humidity.

In contrast to the relatively large number of pollen studies, Holocene diatom records from the Peloponnese are rare, due primarily to the dry and alkaline (carbonate) environment. The first diatom-based study was recently conducted in a 7.5 m long sediment core retrieved from the Agios Floros fen in the eastern-central Messenian plain (Katrantsiotis et al., 2015). The high-resolution diatom analysis complemented by carbon and nitrogen isotopes from bulk sediments contributed to the study of water level shifts, as well as factors behind the hydrological changes which occurred in the Messenian plain during the last ca. 6000 years (Katrantsiotis et al., 2015).

3.2. Caves and speleothem analysis

Cave stalagmites can provide precisely U-series dated archives containing information about long term climate variability (Fairchild and Baker, 2012), and the results from the first speleothem based paleoclimate studies carried out in the Peloponnese were published recently (Finné, 2014; Finné et al., 2015, 2014; Boyd, 2015). Variations in stable isotope composition, petrology, trace elements and growth rates were used to infer changes in precipitation, biologic activity, local environmental changes and human influence.

Kapsia Cave and Alepotrypa Cave (Fig. A.3) are rich in speleothems, and archaeological remains indicate that the caves were used by humans; these sites thus allow us to study both human and climate history within a highly localised area, although the disturbance of the cave environment by humans may also affect the quality of the speleothems as climate archives. Speleothems from Kapsia turned out to be difficult to date by U/Th techniques and there are relatively large uncertainties concerning the age model of the climate record (Finné et al., 2014). The stalagmite analyzed by Finné et al. (2014) grew from approximately 2900–1120 cal BP, but then stopped growing until more recent times. The speleothems from Alepotrypa Cave may be dated with higher precision. Five analysed speleothems, with varying overlap in time, show a similar climate signal for the period 6400–1000 cal BP (Boyd, 2015). One of the speleothems covers the majority of the temporal scope of this paper, but two periods of no (or slow) growth between 8000–6400 and 5500–4600 have not yet been interpreted in any detail. The earlier period may have been due primarily to intensive human activities in the cave, while the latter may potentially be attributed to seismic activity (Boyd, 2015).

3.3. Archaeological and historical archives

The current state of the archaeological and historical records is the result of more than a century of excavations, surface surveys and textual studies (Renfrew and Bahn, 2012). While excavations have focused on vertical stratigraphies and local histories, archaeological surface surveys have been carried out over large or small regions in order to give an overview of human presence, most often from a wide diachronic and horizontal perspective, with an emphasis on site distribution and regional development. Textual studies have involved the analysis of inscriptions, as well as works by ancient and medieval authors. These primary sources, together with modern scholarly reports on different classes of material culture and the synthesis of historical and archaeological narratives, comprise an extensive body of scholarship on the history of human life on the peninsula.

In the present paper we have chosen to focus on the general trends in societal development (Figs. 4–5, A.1) which, we believe, provide the best potential for correlation between the different datasets, and thus the best potential for interdisciplinary communication. We have compiled and assembled site quantities, based on the results of different intensive survey projects, as a first step towards interpreting longer-term social dynamics and their association with past environmental conditions in the Peloponnese (Fig. 3, Table B.1). Although the differences in survey methods, formation processes and archaeological visibility make it difficult to offer exact comparisons of site quantities, both between and within survey projects (Alcock and Cherry, 2004; Pettegrew, 2007), we believe that such an approach is necessary if we are to identify the broader trends in land use and settlement shifts in the Peloponnese. By combining the datasets produced by various survey projects, we are at least able to pinpoint periods of expansion and contraction, even if the exact numbers remain imprecise. While the chronological precision of archaeological data is often coarse, the broad chronological categories offered by both excavated and surface finds allows us to approach and argue for possible links between the sequences offered by palaeoclimatic and palaeoenvironmental datasets. However it should be noted that surface ceramics are often dated broadly, according to art historical categories that encompass uneven time sequences (Table 1; cf. Pullen, 2008); the Archaic and Classical periods, for example, each cover roughly 200 years, while other phases, such as the chronological subdivisions for the Early Helladic period (EHI–III), each cover several centuries of human history in the Peloponnese.

4. Socio-environmental dynamics from the Neolithic to the Frankish period (6800 BC–AD 1460/8750–490 BP)

The process of comparing archaeological and environmental datasets is a challenge, and putting them into an historical context even more so. Even the question of how to present the existing data is far from straightforward: should one arrange it according to geographical principles, for instance a transect from east to west, or a comparison between coastal and mountain sites; or should it appear chronologically. A temporal arrangement achieves the highest consensus between archaeologists and palaeoclimatologists, however it also triggers the next challenge: what are the measurements of time that should be used. Epochs, such as the Early or Late Holocene, are too coarse to reflect cultural changes, while time intervals, for example the Middle and Late Helladic period, may be too brief to capture long-term climatic developments. With these shortcomings in mind, we have decided to discuss both the archaeological and palaeoenvironmental records according to the cultural periods of southern Greece; the chronology is summarised in Table 1. The integrative discussion below is based on an initial review of available evidence (Appendix A), detailing settlement dynamics, socio-political developments and related palaeoclimatological and palaeoenvironmental datasets (Figs. A.1–4).

4.1. The Neolithic period (6800–3100 BC/8750–5050 BP) (Appendix A.1)

The onset of the Neolithic period in the Peloponnese occurred during the later phases of the early Holocene climate optimum, a time when the Eastern Mediterranean region was generally

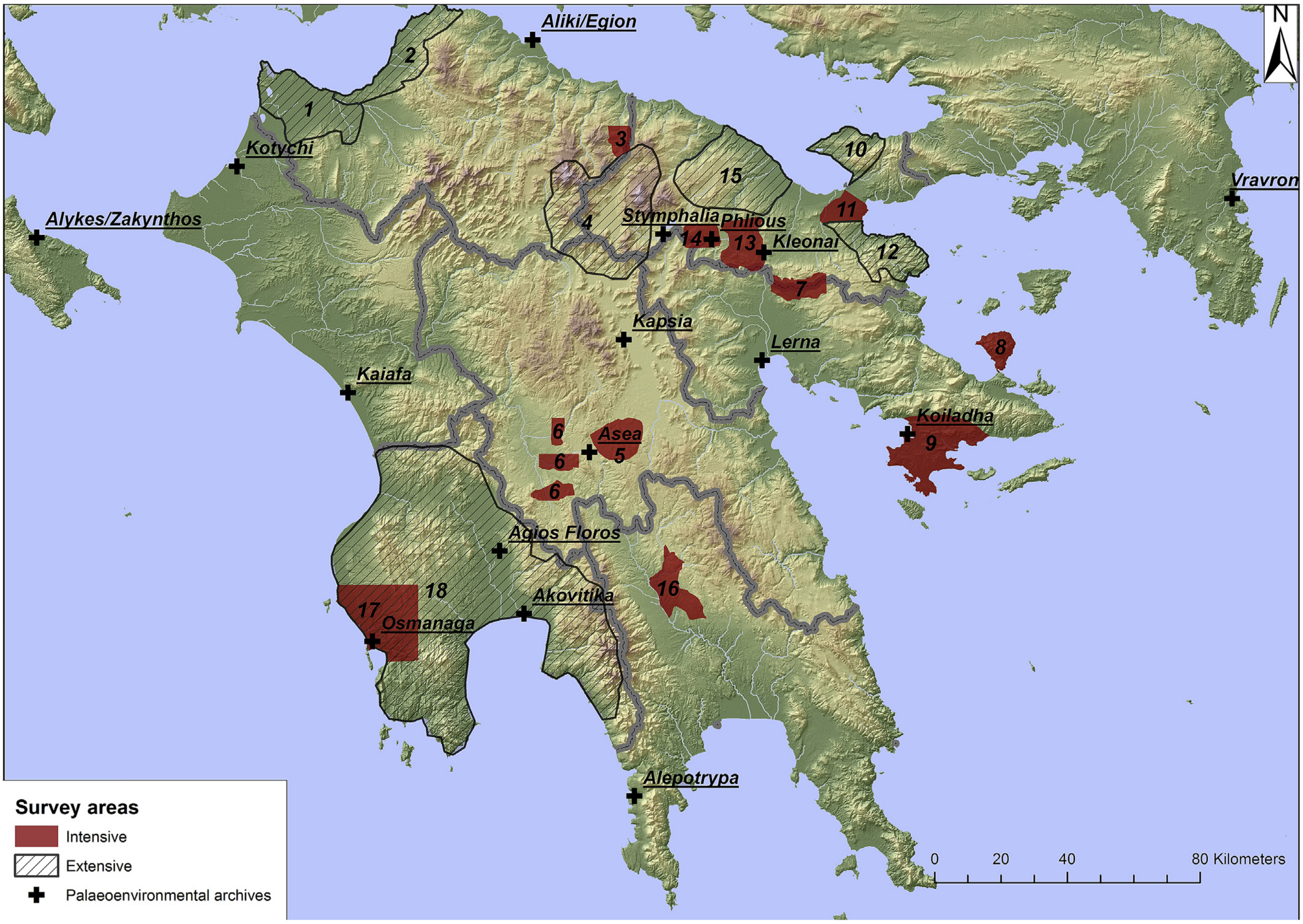


Fig. 3. Areas covered by intensive and extensive archaeological field surveys, visualized in combination with palaeoenvironmental records and geographical regions. 1: Peiros Valley and Western Achaia, 2: Patras *Chora* Survey, 3: Aigialeia Survey, 4: Pheneos and Lousoi Survey, 5: Asea Valley Survey, 6: Megalopolis Survey, 7: Berbati-Limnes Survey, 8: Methana Survey Project, 9: Southern Argolid Exploration Project, 10: Perachora Survey, 11: Eastern Korinthia Archaeological Survey, 12: Saronic Harbours Archaeology Project, 13: Nemea Valley Archaeology Project, 14: Phlious Geoarchaeology Survey, 15: Sikyon *Chora* Survey, 16: Laconia Survey, 17: Pylos Regional Archaeology Project, 18: Minnesota Messenia Expedition. Supporting information available in Table B.1. The map has been created using the ASTER GDEM, a product of METI and NASA. Illustration by A. Bonnier.

dominated by wetter conditions. These wetter conditions were interrupted by a cold and dry interval around 8200 cal BP, often referred to as the 8.2 ka-event (e.g. Finné and Holmgren, 2010; Robinson et al., 2006). The Neolithic onset would have then taken place during favourable climatic conditions, but not ones that would have been distinctly different from the prevailing conditions during the time of the preceding hunter-gatherer societies. The 8.2 ka-event is not very pronounced in the Stymphalia geochemical record (Fig. 4 and A.2; Heymann et al., 2013), and settlement patterns also demonstrate no obvious change. The Early–Middle Neolithic settlements were located on well-watered plains, and were small but with large territories; this pattern may have increased resilience within the communities in the face of any perceived changes in the climate. The gradual increase in both the intensity and spatial distribution of human activity in the later Neolithic period is well attested in the palaeovegetation records, in which the human impact on vegetation patterns gradually overrides the climate-induced plant distribution, as reflected for example in the slow reduction of deciduous trees lasting from just after 7000 BP to modern times (Fig. A.4).

On a local level, however, there are many fluctuations in this trend (Fig. A.4). It is interesting, for instance, to note that an expansion of deciduous oak woodland from around 7200 cal BP (5250 BC), corresponds with a decrease in the indicators of human activity at Lerna, Zakynthos and Kotychi; this expansion is paralleled by regional seismic activities observed from Alykes Lagoon (Avramidis et al., 2013; Vött, 2007). The transition between the Middle and Late Neolithic periods would have occurred around this time and, in many parts of the peninsula, this would have resulted in changes to the land use patterns and a partial shift away from the plains through a diversification of the settlement structure, as well as a fragmentation of the social body. Records from several regions show the first signs of erosion and increased sedimentation during the Neolithic period. The Phlious record (Fuchs et al., 2004; Fuchs, 2007), indicates a gradual intensification of human activities; sedimentation levels appear to have increased between the Early Neolithic and Middle–Late Neolithic periods, at which time we also see a (regionally varied) settlement pattern, featuring an increased number of sites at a greater variety of topographical locations (Fig. 4). The pollen record from Lake Lerna, indicates a low point of arboreal pollen in the Middle Neolithic period, followed by a notable increase during the Late Neolithic period. This pattern compares directly with the archaeological record from the nearby settlement of Lerna, which shows that the Middle Neolithic was a period of intensive activity followed by a settlement hiatus during the Late Neolithic period (Vitelli, 2007; Jahns, 1993). In the Final Neolithic period, however, one may observe the reappearance of a substantial ceramic record, which may correspond to the pronounced dip in arboreal pollen and the increase of cereal cultivation (Fig. 4, A.4). A direct link between these phenomena could, in this case, also potentially help to pinpoint the Final Neolithic activity chronologically within an otherwise very long archaeological period (Maran, 1998). From the generally contemporaneous changes in the archaeological, palynological and seismic records (even if not all recorded in the same area), and the fact that all pollen records are from coastal regions, one may tentatively suggest that the decreased focus on the plains during the Middle–Late Neolithic transition may have been motivated in part by land shortages in the vicinity of Middle Neolithic settlements, perhaps caused by seismically-driven lake- and sea level rise; this in turn would have removed some human pressure from the landscape and enabled the expansion of oaklands. The evidence for increased seismic activity during the Neolithic period may also cause one to reconsider the previous hypotheses, which suggested that erosion and landscape instability were primarily human-induced (cf. Fuchs, 2007).

Evidence for repeated earthquakes may also be found in the Agios Floros fen towards the Final Neolithic period (Fig. 4; Katransiotis et al., 2015). Settlement patterns in this region are not well known, but the most expansive settlement patterns in many parts of the Peloponnese can be found in FN–EH II (4500–2200 BC/6450–4150 BP) (Fig. A.1). The Eastern Mediterranean witnessed generally wetter conditions during this period (Finné et al., 2011; Triantaphyllou et al., 2014), and this trend is supported at a local level by the Alepotrypa cave record; however drier conditons also prevailed at various times within this period (i.e., prior to 5850 cal BP, at 5500–5200 cal BP and at around 4200 cal BP). The Stymphalia record shows a variable picture, but a shift from wetter to drier conditions is recorded towards the end of the Final Neolithic period (Fig. A.2). From an archaeological point of view, the expansion in settlement numbers has been connected to innovations in agricultural technology, which fostered the cultivation of rain-fed fields away from the plains. This explanation would fit with a scenario of wetter conditions.

4.2. Bronze Age and Early Iron Age (3100–700 BC/5050–2650 BP) (Appendix A.2)

Archaeological and environmental datasets both support the notion that the scale of human activity in the Peloponnese increased with the introduction of Bronze Age economies and settlement patterns. In terms of site numbers, the Early Helladic period is characterised by intensive land use, more so than during either the preceding Neolithic or the succeeding Middle Helladic periods. The site numbers would increase again only during the Late Helladic period when, in many areas, settlement densities reached their Bronze Age high point. The Late Helladic period is also when human indicators in the pollen record reach their Bronze Age maximum (Andwinge, 2014). This is most clearly indicated in the Vravron record, which corresponds to the evidence from the archaeological record, in which one may observe settlements of increasing complexity, starting from smaller agricultural communities in the Early Helladic period, and developing into village-like structures in Middle Helladic, and finally a Mycenaean acropolis in the Late Helladic period (Kouli, 2012). There are, of course, geographical variations within this pattern: whereas the archaeological record for some inland regions, such as the Asea valley, suggests no large-scale societal expansion in the Bronze Age (Fig. A.1; Forsén and Forsén, 2003), records from many coastal zones present considerable chronological fluctuations in terms of settlement density and complexity. These fluctuations may in part be attributed to the interconnectedness of the Aegean world, the chronologically varying intensity within pan-Aegean contact networks, and their impact on Peloponnesian lifeworlds that influenced coastal zones more than inland ones (Maran, 1998; Tartaron, 2013).

Evidence for the individual regional trajectories are supported by variations in the palynological record indicating different cultivation strategies. The high *Olea* level at Alykes/Zakynthos during the Final Neolithic period, for example, stands out among the prehistoric records and may reflect local cultivation strategies (Fig. A.4; Avramidis et al., 2013; cf. Maragaritis, 2013). At Kotychi both *Olea* and Cerealia-type reach their peak in the Early Helladic period while, at Lerna, cereal cultivation signs appear to have increased throughout the Final Neolithic period and into the Early Helladic period. This increase might seem to be at odds with the archaeological record, which suggests that human activity levels and economic expansion reached their peak during LH III (Fig. 4, A.1, 1400–1200 BC). In order to explain this apparent inconsistency, we may once again look to the settlement at Lerna, where the Early Helladic period – and especially the EH II period (2700–2200 BC; Wiencke, 2000) – was indeed the peak of habitation, in good agreement with the decrease of arboreal pollen in the second half of the Early Helladic period (Fig. 4, A.4). Due to the coring location, this particular pollen record may not reflect the general trends of the Argive Plain which, during the Late Helladic period, were heavily influenced by the centres at Mycenae and Tiryns, further to the east and northeast.

The impact of climate on societal processes is a recurrent topic of archaeological debate (for discussions on the Greek mainland: Caskey, 1960; Forsén, 1992; Maran, 1998). Scholarly debate regarding the so called 4.2 ka climate anomaly (Davis et al., 2013; Weiberg and Finné, 2013; Wiener, 2014) has given rise to new theories about the content, causes and effects of transformations that occurred around 2200 BC (4150 BP) (Fig. 4). While the palaeoclimate record from Asea shows no evidence of a 4.2 ka climate anomaly (Fig. 4 and A.2; Unkel et al., 2014), the new Alepotrypa Cave record shows a distinct dry period beginning at around 4200 cal BP (2250 BC) and lasting some 200 years (Fig. 4 and A.3), with a dating uncertainty of less than ±50 yrs (Boyd, 2015). The question remains exactly how this event should be linked chronologically to the archaeological record. Based on the conventional archaeological chronology, the two hundred year interval in the Alepotrypa sequence corresponds in time with the end of the EH II period and most of the EH III period (Fig. 4). However, recent radiocarbon series have suggested that late Early Bronze Age dates in the Aegean need to be shifted back in time relative to the traditional chronological frameworks (Renfrew et al., 2012; Wild et al., 2010). Such a chronological shift could suggest that the most significant EH II–III cultural transitions occured prior to and not contemporaneous with the evidence for a changing Peloponnesian climate. There are also chronological uncertainties related to the accelerated sedimentation rates suggesting increased erosion, which have traditionally been assigned to the Early Helladic period and are often considered a significant factor in the cultural transformations that occurred on the Greek Mainland (Andel et al., 1990; Forsén, 1992; Maran, 1998; Zangger, 1993; cf. Butzer, 2005; Weiberg and Finné, 2013), as well as to the residual impact on mainland societies from natural and cultural changes elsewhere in, and beyond, the Aegean (Davis et al., 2013).

Various hypotheses have also been put forth to explain the end of the Bronze Age; one of the most prominent of these is the so called 3.2 ka climate event (Kaniewski et al., 2013), which would have affected the Eastern Mediterranean and may have contributed to the larger scale socio-political transformations that also signalled the end the New Kingdom of Egypt, the Hittite empire, and the Mycenaean palatial culture (e.g. Cline, 2014; Drake, 2012; Monroe, 2009). The record from the Alepotrypa Cave shows a clear dry period extending from 3700 to 2550 cal BP, and within this period there are two shorter phases of extra dry conditions occurring at around 3650 and 3200 cal BP (Fig. 4 and A.3). A sharp and fairly uniform drop in extant evidence of all types is also visible in the archaeological record from the end of the Bronze Age. The paucity of identified, excavated, and published Early Iron Age settlements makes it that much more difficult to understand the human responses to these climatic shifts. The basic typology of settlements from the period (Whitley, 1991) includes stable settlements (those that remained inhabited in subsequent periods, e.g., Athens or Argos), unstable settlements (those that were abandoned during this period, e.g., Nichoria), and unstable settlement systems (a small region where occupation shifted among several sites). If agropastoral production was affected by climate, the unstable settlement systems could potentially be a form of habitat tracking (Weiss, 2014); however, the presence of stable settlements throughout the period suggests a variety of responses.

Furthermore, the Alepotrypa record now indicates that the full trajectory of Late Helladic socio-political developments may have played out during an arid phase. In addition, the record indicates extra dry conditions during both the onset of economic expansion in LH I, and the final demise of palatial administration in LH III (Fig. 4 and A.1). In all, this would suggest that the Mycenaen society was generally well-structured to deal with arid conditions. Complex and multi-scalar trade networks (Tartaron, 2013), may have worked as a buffer against problems in a particular node, but may have also caused the network as a whole – as well as the groups of people depending on its outcomes – to become vulnerable to major disruptions due to any number of external factors.

Despite dense settlement in some regions during the Late Helladic period (Fig. A.1), the period is generally characterised by landscape stability, perhaps because of successful land use strategies that included terracing (e.g. Kvapil, 2012; Zangger et al., 1997). These strategies may have been developed as a response to challenging climate conditions. Isolated short-term sedimentation events dating to the end of the Late Helladic period are recorded in the alluvial deposits of the Phlious Basin (Fig. 4; Fuchs, 2007) and at Tiryns in the Argive Plain, as well as in the torrential stream deposits at Chania and Mycenae (Palaiologou, 2014; Maroukian et al., 1996; Zangger, 1994). These events may suggest lapsed maintenance after the breakdown of the Mycenaean palatial economy, or they may also be related to seismic events. For the most part, however, the very end of the Bronze Age and the beginning of the Early Iron Age are marked by continuous landscape stability and a pronounced decrease in settlement numbers throughout the Peloponnese (Fig. 4 and A.1).

The pattern of *Olea* and Cerealia-type suggest that, following a period of major societal transformation, there was an increased dependence on one of the two cultivars (Fig. A.4). The peak of Cerealia-type in Kotychi during the Bronze Age comes at the Early–Middle Helladic transition, when the level of *Olea* decreases. However at Lerna during the same period, it is *Olea* that reaches its peak, with a corresponding low in Cerealia-type. This pattern reflects a site location close to a cereal field or an olive grove, and could thus be explained as the effect of temporal variations in the use of available cultivation space in the vicinity of the coring site. At Alykes/Zakynthos, the *Olea* peak occurred somewhat earlier (approximately 4500 cal BP) at a time when Cerealia-type disappears from the record. While this pattern – which is repeated in the Early Iron Age – does not imply a full mutual exclusivity, it does suggest a focus on *Olea* during periods of low archaeological visibility. The substantial increase in olive pollen in all records from the first millennium BC (Fig. A.4) (Lazarova et al., 2012; Zangger et al., 1997) demonstrates an intentional shift towards olive cultivation during this period. This increase in Greek olive cultivation matches the evidence for an increase in connectivity and trade – intensifying around 700 BC (2560 BP) – and also emphasizes the importance of olive oil for the urban *polis* culture of the subsequent centuries. It is worth noting, however, that the high levels of *Olea* begin in the Early Iron Age at Lerna, Vravron, and Osmanaga.

Olives, which offer few calories, cannot replace grain for subsistence, and a grain-based diet would have almost certainly continued, although perhaps with less intensive agricultural activities. However, olives are better suited to arid climates and would thus have been the cultivar of choice during arid phases. The interlinked fluctuations of Cerealia-type and *Olea* may thus be seen as evidence of an inherent ability for diversification when the need arose. On the other hand, the low level of centralisation in both late Early Helladic–early Middle Helladic and Early Iron Age societies may have favoured less labour-intensive cultivation strategies, or at least a more diversified economy, given diminished societal control and dwindling population levels.

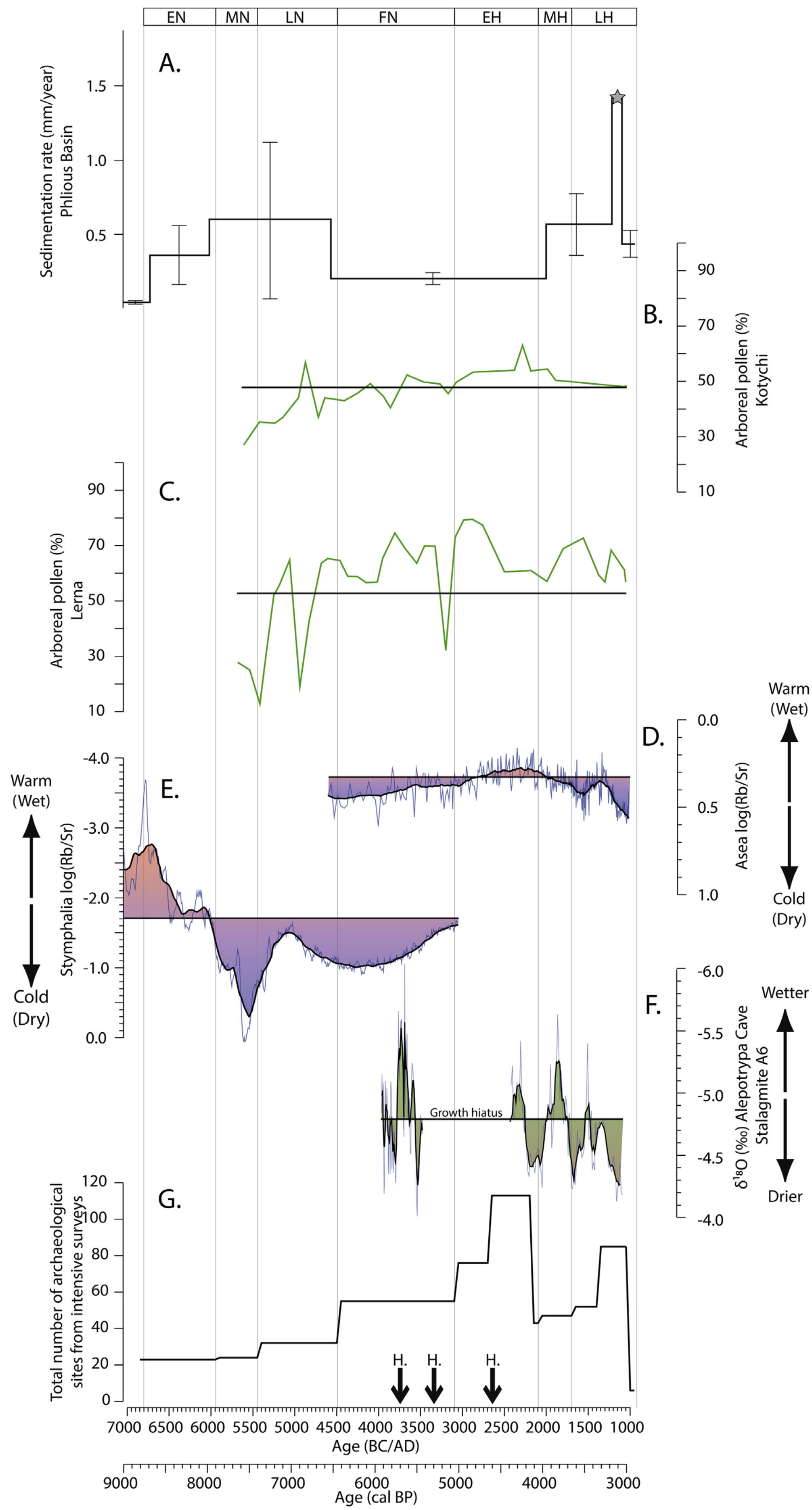
4.3. The Archaic period to the Middle Ages (700 BC–AD 1460/2650–490 BP) (Appendix A.3)

Both the archaeological record and the available pollen archives offer evidence for increased human presence within much of the Peloponnese from the Archaic period onwards. At around 700 BC (2650 BP), the palaeoenvironmental evidence (at Lerna, for example) suggests a sudden drop in arboreal pollen levels (Fig. 5 and A.4), while the average number of settlement sites more than doubles (Cf. Figs. 4 and 5, and A.1). In this instance, there are strong parallels between the vegetation histories and the archaeological evidence for social dynamics.

However, the relationship between the archaeological data and the palaeoclimatic evidence is more complex. Increasingly wet conditions in Alepotrypa between around 600 BC and 150 AD, and in Kapsia from 450 BC until around 100 BC (Fig. A.3), suggest that the Classical and Hellenistic periods would have played out during largely advantageous climatic circumstances, which would in turn have facilitated an expanding agropastoral economy. This is the picture which may, to a large degree, be inferred from surface surveys, archaeobotanical records and pollen data (Fig. 5, A.1 and A.4). However, the diachronic pattern of settlement and agriculture is not uniform across the Peloponnese. In many instances, changes in settlement systems and economic structures may be more closely related to regional political processes and geopolitical shifts, even in those cases where there is a significant link between the archaeological record and palaeoenviornmental data.

Site expansion during the Classical and Early Hellenistic periods (Fig. 5, ca 500–250 BC), is evident especially in the northeastern Peloponnese (cf. site densities for Berbati, Methana, Southern Argolid in Fig. A.1), and may potentially be linked to the wetter conditions attested in both the Kapsia and Alepotrypa records which, when coupled with population growth, would have created favourable conditions for intensive cultivation regimes. In this period we also observe a pattern of rapid urbanisation, which had its origins in the seventh century BC, but which continued on a considerable scale between the sixth and the fourth centuries BC. This increased urban population may have put additional pressure on the land, leading to the use of marginal areas, and the development of complex economic systems that relied on both local production and interregional connectivity (cf. Horden and Purcell, 2000). Changes in the climate may have accelerated these processes, but they would not have been the sole determining cause behind such socio-economic developments.

In fact, the archaeological record for the Hellenistic and Roman periods (ca. 300 BC to AD 300) demonstrates considerable regional variability in settlement dynamics and economic systems, and there seems to have been a clear difference in the settlement trajectories of the eastern and western Peloponnese (Fig. A.1); these


EN
MN
LN
FN
EH
MH
LH
A.
Sedimentation rate (mm/year)
Phlious Basin
1.5
1.0
0.5
B.
Arboreal pollen (%)
Kotychi
90
70
50
30
10
C.
Arboreal pollen (%)
Lerna
90
70
50
30
10
D.
Asea log(Rb/Sr)
0.0
0.5
1.0
Warm
(Wet)
Cold
(Dry)
E.
Stymphalia log(Rb/Sr)
-4.0
-3.0
-2.0
-1.0
0.0
Warm
(Wet)
Cold
(Dry)
F.
δ18O (‰) Alepotrypa Cave
Stalagmite A6
-6.0
-5.5
-5.0
-4.5
-4.0
Growth hiatus
Wetter
Drier
G.
Total number of archaeological
sites from intensive surveys
120
100
80
60
40
20
0
H.
H.
H.
7000 6500 6000 5500 5000 4500 4000 3500 3000 2500 2000 1500 1000
Age (BC/AD)
9000 8000 7000 6000 5000 4000 3000
Age (cal BP)

differences correlate quite well with the suggestion of climate differences between Kapsia and Alepotrypa respectively (Fig. A.3, see further 5.3). After the Early Hellenistic climax in the northeast, we observe a reduction in the number of sites during the Hellenistic and Early Roman periods (ca. 250 BC–AD 100), with only a slight increase during the middle Roman period (after the second century AD), although this was followed by a definite expansion during the Late Roman phase (fourth to seventh centuries AD). In this region, the average number of sites follows the fluctuations in climate, with the chronology of site reduction roughly matching the increasingly dry conditions observed in the Kapsia record between around 100 BC and AD 100 (Fig. 5 and A.3).

In the southern and western Peloponnese, however, we find a different picture from the one provided by the northeastern survey projects. Data from the Pylos Regional Archaeology Project (PRAP) suggests that the number of sites in Messenia initially expanded during the Hellenistic period, with a further increase in rural settlement during the Roman period (Fig. A.1; PRAP, 2015). The Laconia survey demonstrates an expansion of sites in the Late Archaic period, followed by a substantial reduction of site numbers from the Classical and into the Late Classical period, followed by subsequent rural expansion in the Hellenistic phase. Site numbers are once again reduced in the Roman period but do not reach the low levels recorded for the Late Classical period. (Fig. A.1). These observations are further corroborated by the extensive survey data from western Achaia, where we may note comparatively high site numbers during the Hellenistic and Roman phases (Rizakis 1992; Petropoulos and Rizakis, 1994). The archaeological data from the southern and western Peloponnese may thus be understood as corresponding in time to the wet and generally stable conditions seen in the Alepotrypa sequence, even if there is a slightly drier period lasting between AD 1 and AD 125, punctuated by two pronounced short term dry periods (Fig. A.3, 1950–1825 cal BP). In general, there would seem to be definite correspondences between the climate, as recorded in the different palaeoclimate archives, and the archaeological data produced thorough intensive surface survey, at least when linked to specific palaeoclimatic sequences.

However, there are areas in the northeast – such as the Phlious Valley – where, contrary to the common pattern, we may observe an expansion of sites during the Classical period and a continued high number of sites during the Hellenistic and Roman periods (Fig. A.1), even though these developments fall within the dry period recorded at Kapsia. In a region with such varied settlement patterns, the socio-political structures must be regarded as a highly influential factor. The Late Hellenistic and Roman periods (from the second century BC to the fourth century AD) witnessed substantial changes in terms of political authority, and the implementation of Roman rule would have also resulted in new structures of land ownership and changing modes of agricultural production, many of which would have originated in the Hellenistic period (Alcock, 1993); production in the Roman period seems to have been connected more extensively to globalised distribution and consumption networks (Bintliff, 2013).

The transformation of rural settlement patterns during the Roman period may have resulted in a shift towards different topographical contexts. It is possible in particular to identify a concentration of rural sites in lowland zones whereas, in earlier periods, dispersed patterns within wider landscape settings would have been prevalent (Jameson et al., 1994; Wells and Runnels, 1996). The location of these sites may suggest a very specific investment in lowland agriculture during the period of Roman rule, a possibility that is supported by the visible expansion of Cerealia-type pollen in the Lerna and Kotychi archives (Fig. A.4). The fact that both of these archives also present high arboreal pollen levels during the Roman period may suggest that the wooded highlands were used less intensively. It should be stressed that these new land-use patterns in the Late Hellenistic/Early Roman periods seem to have created a much more focused use of the landscape, directed towards lowland cultivation regimes mixed with extensive agropastoral strategies based around larger estates; the western Peloponnese, with their extensive stretches of lowlands, may thus have been better suited to the new patterns of agricultural production (Fig. 1).

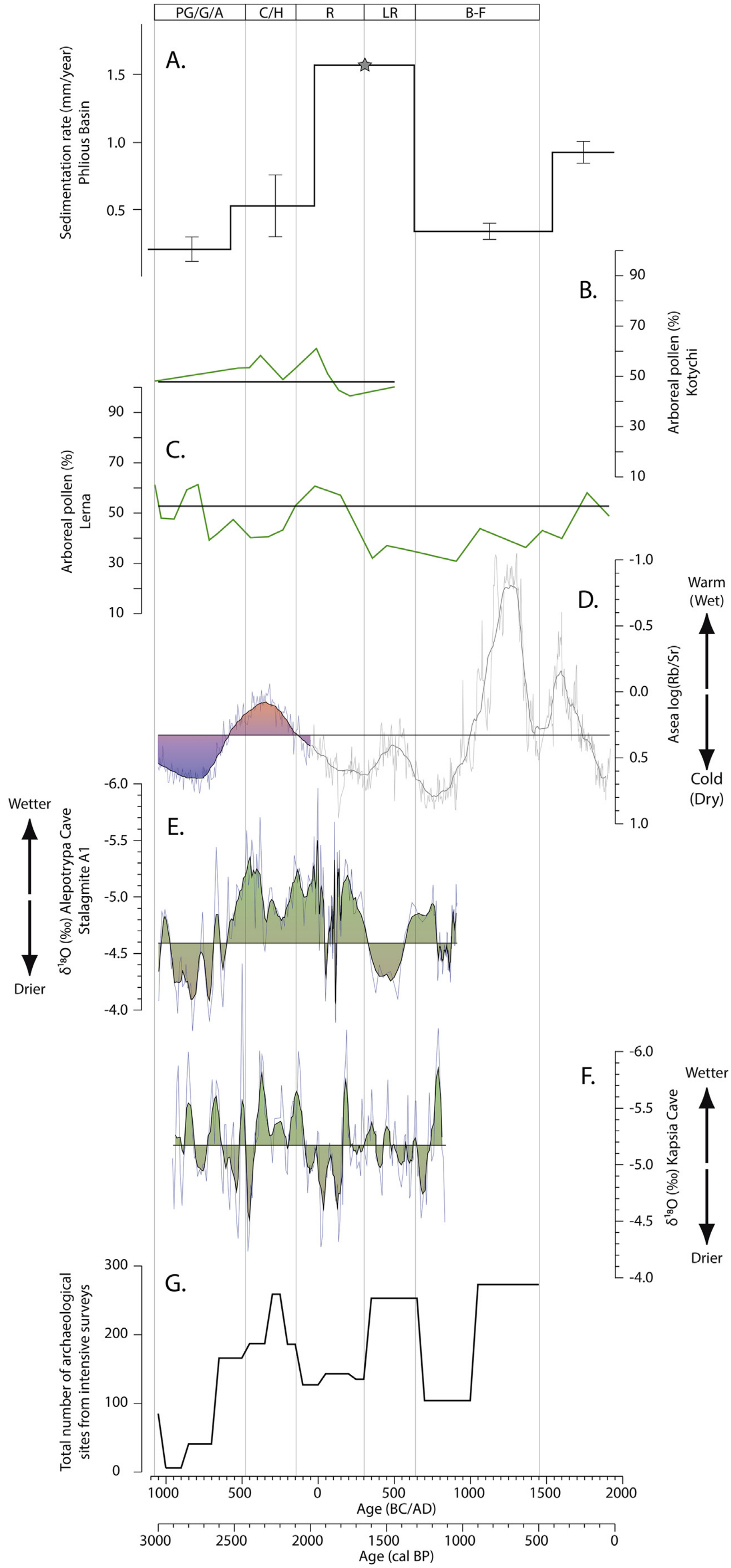
There is, however, some evidence to suggest the presence of hillside and upland farming during the Roman period. Evidence from colluvium sediments in the Phlious basin in the northeastern Peloponnese suggest enhanced sedimentation during the Roman period, following a steady increase of colluvia from Classical times onwards (Fuchs, 2007, Fig. 5). The build-up of colluvium during this period suggests continuing human pressure on both the hill sides and valley floors in the area, reflected in the largely unchanged number of sites in the Phlious Valley. The fact that the area witnessed continued human pressure during a seemingly dry period – as is evident from the Kapsia record – may perhaps be interpreted as an aggravating factor behind the intensifying erosion patterns that occurred during Roman period.

Any discussion of the potential impact of environmental change must consider regional and microregional differences in economic developments and settlement dynamics. While it is certainly possible that changes in the climate may have intensified the socioeconomic changes introduced by political transformations in the region, such generalisations do not necessarily apply across the region as a whole (cf. Stewart, 2014). In order to approach the interaction between humans and the environmental across the region, we require more palaeoenvironmental records from different topographic and ecological settings.

During the late Roman period (sometimes called the late antique or early Byzantine periods), we may again note a correspondence between the palaeoenvironmental and archaeological data. At Lerna, samples dated to around AD 400–600 reveal an increase in cereal pollen, which may reflect the period of settlement intensification around AD 300–600, attested in archaeological survey data from various parts of the Peloponnese (Fig. A.1; see also Bintliff, 2012b; Pettegrew, 2007). In Attica, however, the Vravron pollen record suggests that an increase in cereals occurred only around AD 200–400, and that by AD 500 there was no sign of cereal cultivation (Fig. A.4). From this, along with evidence from the PDI pollen sum, we may infer that agropastoral intensification started earlier in this area, and that the process of decline would have started while the Peloponnesian countryside was still relatively prosperous.

Interestingly, the early Byzantine phase of settlement expansion occurred during a time of substantial climatic fluctuations, judging from the Alepotrypa record and the Kapsia records (Fig. 5 and A.3). Whereas the years between around AD 160–350 were relatively wet – and it was probably after AD 300 that the late antique

Fig. 4. An overview of evidence for soil erosion (A), tree cover (B and C), climate variability (D–F), archaeological sites identified in archaeological surveys (G), and major earthquakes (H) within different parts of the Peloponnese between 9000 and 3000 cal BP (7050 and 1050 BC). Illustration by M. Finné. A. Sedimentation rate in mm/year in Phlious basin (Fuchs, 2007). Bar with star indicates minimum rate. Rates are based on OSL-dated colluvium from foot-slopes; B. Arboreal pollen percentage in Kotychi (Lazarova et al., 2012); C. Arboreal pollen percentage in Lake Lerna (Jahns, 1993); D. log(Rb/Sr) from Asea (Unkel et al., 2014). Black line (and colour shading) 30 point running average; E. log(Rb/Sr) from Stymphalia Lake (Heymann et al., 2013). Black line (and colour shading) 30 point running average; F. $\delta^{18}O$ from Alepotrypa Cave, Stalagmite A6 (Boyd, 2015). Black line (and colour shading) 5 point running average. Shaded slow growth period has not been interpreted in detail (see Boyd, 2015 for details); G. Total number of archaeological sites identified in intensive surveys (see Fig A.1 for original site data); H. Earthquakes inferred by Katrantsiotis et al. (2015). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)


PG/G/A
C/H
R
LR
B-F
A.
Sedimentation rate (mm/year)
Phlious Basin
B.
Arboreal pollen (%)
Kotychi
C.
Arboreal pollen (%)
Lerna
D.
Warm
(Wet)
Cold
(Dry)
Asea log(Rb/Sr)
E.
Wetter
Drier
δ18O (‰) Alepotrypa Cave
Stalagmite A1
F.
Wetter
Drier
δ18O (‰) Kapsia Cave
G.
Total number of archaeological
sites from intensive surveys
Age (BC/AD)
Age (cal BP)

settlement and agropastoral expansion began in southern Greece – this was followed, according to the Kapsia record, by several decades of drier conditions in the eastern Peloponnese; the abrupt transition from wetter to drier conditions would have certainly been felt by the rural populations. Due to the current lack of dating precision for both the archaeological and climate data, it is impossible to evaluate the potential societal impact of these drier conditions. However, it appears that an even more severe drought in Anatolia and the Levant did not lead to a major socio-economic crisis (Izdebski et al., 2016b), and this may have also been the case in southern Greece, which suffered in addition from recurring warfare and invaders from the northern Balkans during this period (Curta, 2013).

It is not possible to draw firm conclusions about correspondances between climatic and socio-economic changes that occurred after around AD 600, especially in light of the opposing signals from the records of Kapsia and Alepotrypa (Fig. 5). These inconsistencies may be attributed to dating problems, but they may also be due to climatic differences between the immediate west coast and the inland/east coast. Thus, while the conditions in Alepotrypa (west coast) seem to have been wet from AD 550 to AD 800, the same period saw drier conditions in the inland and east coast regions (Fig. A.3). Interestingly, it is in the east of the Peloponnese, around the Aegean, that we can see most clearly the expanding late antique economy (in Corinthia in particular, cf. Pettegrew, 2007), which suggests that this area may indeed have been exposed to an adverse change in climate conditions. Thus, the final collapse of the late Roman economy in southern Greece, which occurred sometime after AD 600, may have coincided with the most severe dry episode in the Kapsia record in the last two millennia, which occurred roughly around AD 650–700 (Fig. 5 and A.3). These climatic factors may have discouraged local populations from maintaining their previous agricultural and economic patterns, as well as the political institutions that enforced a social order, which either collapsed or were in the process of major transformation (Brubaker and Haldon, 2011). It is tempting to suggest that the rapid transition to wetter conditions in the 8th century AD (Fig. 5), and the generally wetter conditions on the west coast may have facilitated the Slavic settlements and the creation of new economic patterns in the countryside. This, however, would require a detailed review of all the currently available archaeological evidence on early medieval settlement in Southern Greece; alas, it is not possible to include all of this evidence in the present overview.

During the Middle Byzantine period (AD 1000–1200), there is a very close correspondence between the environmental (pollen) and archaeological-historical records (Fig. 5, A.1 and A.4; cf. Harvey, 1989, as well as Izdebski et al., 2015; Xoplaki et al., 2016). Both suggest agropastoral intensification across many areas of the Peloponnese and Attica. Unfortunately, the speleothems from Kapsia and Alepotrypa stopped growing before AD 1000, leaving us (at present) with no regional palaeoclimate record against which we may compare the socio-economic developments; however, ongoing analyses of the sedimentary records for the post-2500 BP situation at Lake Stymphalia will help to amend this situation.

5. Possibilities and challenges for integrative research

As we have demonstrated in the previous section, there are many possible links between changes in the palaeoenvironmental and archaeological-historical records. Our key results are:

- Archaeological survey records show an average increase of more than 250% in site numbers and human presence in the Peloponnesian landscapes between the prehistoric and historical periods (Cf. Figs. 4 and 5).
- Neolithic expansion from the plains to the uplands, diversified settlement patterns and landscape instabilities occurred within a framework of wetter climate and recorded seismic events.
- The 4.2 ka and 3.2 ka events are recognizable in some of the palaeoclimatic records from the Peloponnese but their chronological fit with the archaeological record remains uncertain.
- Intensification of olive cultivation in historical times may have started as a response to drier conditions in the Early Iron Age.
- The large-scale agricultural and settlement intensification in the Archaic, Classical and Early Hellenistic periods occurred during humid conditions, while the decline in rural settlements during the Roman period may have coincided with a drier phase. Sociopolitical processes were, however, probably the key motivating factors for landscape and settlement transformations.
- During the Hellenistic and Roman periods, we observe shifts in the focus of intensive rural settlement and land use from the east coast to the west, coinciding in time with the longer-term persistence of more favourable (wetter) climatic conditions in the western part of the Peloponnese as compared to the inland regions and, probably, the eastern coast.
- During the Late Roman (Late Antique/Early Byzantine) period, the increased aridity does not appear to have impeded the expanding cereal cultivation and rural settlement inland and in the eastern Peloponnese.
- The Middle Byzantine agricultural expansion provides a good case study for intensive human activity in the landscape and the resulting human impact on the environment.
- Available palaeoclimate records from the Peloponnese do not cover the last millennium. Adding new palaeoclimate records to already available well-dated high-resolution pollen data and written records, especially for the Byzantine climax and its aftermath (AD 800–1460), would allow important studies of the responses of pre-industrial societies to climatic fluctuations.

Keeping these key results and the synthesis as a whole in mind, there are a number of issues that need to be considered, which present both challenges and possibilities for future projects. In the following section we shall discuss three of these issues in detail.

5.1. Chronology

To address the mechanisms of cause and effect within an environmental system, a precise chronology is of fundamental importance. The varying availability of such chronologies, as well as the span of time under consideration will inevitably influence both the resolution of arguments and the number of possible links that one may discern from the analysis and comparison of multivariate datasets. The archaeological narrative for the Neolithic period, for example, is painted with a rather broad brush over approximately 4000 years, and such a margin of error of 100–200 years seems still to allow for a synthesis of human-environment interaction over the whole period. Neither the archaeological nor palaeoenvironmental

Fig. 5. An overview of evidence for soil erosion (A), tree cover (B and C), climate variability (D–F), sites identified in archaeological surveys (G), within different parts of the Peloponnese between 3000 and 1000 cal BP (1050 BC and AD 950). Illustration by M. Finné. A. Sedimentation rate in mm/year in Phlious basin (Fuchs, 2007). Bar with star indicates minimum rate. Rates are based on OSL-dated colluvium from foot-slopes; B. Arboreal pollen percentage in Kotychi (after Lazarova et al., 2012); C. Arboreal pollen percentage in Lake Lerna (Jahns, 1993); D. log(Rb/Sr) from Asea (Unkel et al., 2014). After 2000 cal BP (grey line) the signal in the Asea record is affected by pedogenic processes; E. $\delta^{18}O$ from Alepotrypa Cave, Stalagmite A1 (Boyd, 2015). Black line (and colour shading) 5 point running average; F. $\delta^{18}O$ from Kapsia Cave (Finné et al., 2014). Black line (and colour shading) 5 point running average; G. Total number of archaeological sites identified in intensive surveys (see Fig. A.1 for original site data). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

records can provide firm answers when there is a need for higher-resolution coupling. This is highly relevant for anyone wishing to suggest that intervals of dry climate may have affected the course of events during the periods around 2200 and 1200 BC.

For the environmental and climate sciences, this challenge arises from both the limited availability of high-resolution palaeoarchives and the problems of dating techniques. In ^{14}C dating, one encounters both variations in the carbon cycle – which can, to a large extent, be rectified by calibration – as well as different reservoir effects. Carbonate rock, which dominates the geology of large parts of the Peloponnese, is lacking in ^{14}C and can be easily dissolved. Aquatic plants or shells incorporate this 'dead carbon', which may appear much older than its actual age; ^{14}C dates from coastal sites may be influenced by a similar marine reservoir effect (Ascough et al., 2009; Fernandes, 2013; Olsson, 2009). Although charcoal is often used for ^{14}C dating in both archaeological and palaeoenvironmental studies, the stages of transformation between fresh plant material and a piece of charcoal in an archaeological or sedimentological context may involve several steps of re-deposition and re-working, and the ^{14}C date may not necessarily reflect the time of final deposition (Eckmeier et al., 2009).

For speleothems – which are analysed through Uranium-series dating – the major challenge has been to find specimens of a sufficient quality to obtain precise age estimates. Undisturbed caves, with small entrances, restricted airflow and high humidity are the most suitable for preserving speleothems as good climate archives. Uranium-series dating can then provide ages in calendar years, with small uncertainty intervals, as in the case of Alepotrypa. Larger uncertainties are introduced if the sample contains small amounts of initial uranium or is contaminated by detrital ^{230}thorium, in which case a correction factor must be applied (Hellstrom, 2006). This was the case for the Kapsia Cave stalagmites.

In archaeology, the inconsistencies between radiocarbon dating and conventional chronologies, based on stratigraphies and intercultural cross-referencing, can result in heated debates about competing chronological frameworks; for the Aegean Bronze Age (Bietak, 2003; Manning and Bronk Ramsey, 2003) and the Iron Age (Toffolo et al., 2013) there has been some considerable disparity between the 'high' (radiocarbon) and 'low' (historical) chronologies. The debate surrounding the chronology of the Thera eruption is well-known (Manning et al., 2006); in the Peloponnese, recent radiocarbon analyses of graves from Lerna, in the Argolid, put the beginning of LH I at ca. 1700 cal BC (Lindblom and Manning, 2011; Wild et al., 2010), or roughly 100 years earlier than the conventional chronology (Manning et al., 2006). These controversies not only make it difficult to draw parallels between environmental and archaeological records, but also explain why archaeologists generally prefer to use relative chronological terminologies. These relative chronologies are used for both prehistory and history, and are based primarily on pottery; for some periods (e.g., Late Antiquity) these chronologies are well developed and allow for good site detection, but for periods that are underrepresented in the material record (e.g., LH I or the early Middle Ages) the chronologies remain controversial. Textual records may serve as a complement, but historians have to rely on scattered pieces of textual evidence from various texts written at different moments in time. In the Peloponnese from the Classical to the Roman periods, textual evidence from literary sources is sporadic, often written by non-local historians, and the epigraphic record is also highly fragmentary.

5.2. Tectonics and seismicity

Western Greece and the Peloponnese are among the most seismically active regions in the Mediterranean (Papazachos and Papazachou, 1997) since they are located very close to the convergence of the African and Eurasian plates and thus experience rapid and intense ground deformations (Lagios et al., 2007). Seismic activity may thus have been as important as climate variability in the formation of the Peloponnesian landscapes. Theories about tsunami catastrophism in the Eastern Mediterranean have increased in recent decades (Stewart and Morhange, 2009; Vött et al., 2009, 2011; Willershäuser, 2014) and the notion that coastal areas and ancient cities were influenced by sea level rise, tsunami events and marine transgression is becoming more common (e.g. Kontopoulos and Avramidis, 2003; Brückner et al., 2010; Pavlopoulos et al., 2012; Apostolopoulos et al., 2014).

Due to tectonic activity and changes in the relative sea-level, a number of coastal sites in the Peloponnese, dating from the Palaeolithic to the Medieval periods, are presently under water, including Early Helladic Pavlopetri (Gallou and Henderson, 2012), Classical-Byzantine Lechaion (DIA, 2015), and Frankish Kyllene (FIA, 2015). High-energy impacts, including tsunami events, have been recorded in sedimentological sequences from some of these locations as well as from other coastal lagoons and plains on the western shore of the Peloponnese and the nearby island Cefalonia (Hadler et al., 2012, 2013; Röbke et al., 2013; Vött et al., 2011; Willerhäuser, 2014). Consequently, the submerged continental shelf, which has been largely neglected due to its inaccessibility, should be taken into account in future paleoenvironmental studies.

Seismic events should also be taken into account when considering changes in settlement dynamics, for instance during the Middle–Late Neolithic and Final Neoltihic–Early Helladic transitional periods, when repeated earthquakes were recorded in the Agios Floros area of the central Messenian plain (Katrantsiotis et al., 2015). Archaeological research into the local effects of seismicity and earthquakes has been more frequent in recent years (e.g. Palaiologou, 2014; Maroukian et al., 1996), and it has been suggested that earthquakes may have contributed to the end of the Mycenaen palatial era (Nur and Cline, 2000; Cline, 2014).

5.3. Regional variability

The considerable differences in geomorphology within the Peloponnese have led to a variety of local climatic patterns and vegetation characteristics across the peninsula. Thus, when attempting to investigate the causal relationships between human activity and the environment, evidence should preferably be derived from the same locality. The present article has highlighted some interesting variations within the pollen records themselves, as well as differences between the pollen records and archaeological and historical evidence, which further supports the notion of micro-regional trajectories. Such variations should serve as a warning against making generalisations from pollen records, which provide evidence of a local, rather than a regional nature. Of the few climatic/environmental records available, most are located near archaeological sites (Fig. 1), but those sites may not always be representative of trends within the larger region, nor will they necessarily reflect the full temporal span of the record. The Alepotrypa archaeological record, for example does suggest a mostly Neolithic habitation of the interior and exterior of the cave (Boyd, 2015), while the settlement by Lake Stymphalia is primarily a Classical-Hellenistic city (Heymann et al., 2013). The Asea valley has been covered by an archaeological survey (Forsén and Forsén, 2003) but the results show only very limited activity in the valley during the Bronze Age, with more intensive use only during historical periods (Fig. A.1). While the geochemical records reflect a limited geographical area – albeit larger than the pollen records – speleothems are generally used as an index for climate over large regions. Other investigations have demonstrated that regional concerns are important on an Eastern Mediterranean scale (Finné et al., 2011; Izdebski et al., 2016b; Roberts et al., 2011; Xoplaki et al., 2016), but the present article extends this caution to a relatively small region such as the Peloponnese.

Differences between the records from the Alepotrypa and Kapsia caves (Fig. 5 and A.3) may also be due to a number of factors not related to climatological change. First of all, the dating uncertainties, especially in the record from the Kapisa Cave, may contribute significantly to the inconsistencies between the two records. The records may also be affected by more site-specific variables such as the thickness and properties of the bedrock, which will affect both the smoothing and the lagging of climate signals, as well as the human impact both within the cave and on the vegetation cover above the cave. It should also be noted that, in this particular case, we are attempting to compare a coastal site with an inland intermountain site; there is an altitude difference of some 700 m between the two. Furthermore, the moisture transport is mainly west (or south-west) to east, which means that moist air has to travel inland and over mountains to reach Kapsia, which may have lead to a reduction in moisture content.

6. Perspectives

If we are to engage in a meaningful interdisciplinary discussion on socio-environmental history, it is essential that we provide detailed analyses of as many parameters as possible describing the societies, the environment, and the climate of the past; we must be aware of both the shortcomings and potentials of our datasets when deciding how they may best be correlated. While it is unlikely that the challenges of dating will be overcome in the immediate future, they remain an inherent part of our evidence; if we can make ourselves aware of the limitations associated with each body of evidence, we are better able to develop novel ways of integrating and comparing scientific, archaeological and historical chronologies and datasets.

The discussions of socio-environmental dynamics in this paper should thus be viewed as hypothetical; the associations between datasets that we have proposed here need to be tested in future studies. Even with good palaeoenvironmental data and a wealth of archaeological information, chronological links must be assessed in terms of the scale of mutual impact of societies, environment, and climate on one other, as well as the resilience of each (Folke, 2006). In terms of environment and climate, a modern analogue approach (Magny et al., 2012) might help us to assess the scale of past changes, even if some environmental parameters are not fully known or understood; however when analysing human societies of the past from a modern perspective there is always the danger of anachronistic reasoning. Of course, socio-environmental systems differ from purely ecological ones (Holling, 2001; Redman and Kinzig, 2003); any interpretations will need to incorporate human agency into the outcome of events, including the consideration of how people of the past may have perceived and acted on the environmental and climatic changes around them. It is generally easier to confirm the impact of humans on their environment (mainly land coverage) than the other way round. Integrated palaeoclimate and palaeoenvironmental reconstructions might allow us to widen these discussions in order to facilitate a science based, bi-directional approach; by establishing firm evidence for climate-induced changes in the environmental record, we may be able to create stronger links with the archaeological record.

It is clear from the synthesis above, and from the review below (Appendix A) that, while there is a wealth of site-specific archaeological evidence from the Peloponnese, as well as information regarding palaeoenvironmental dynamics, we still require a greater quantity of locally-derived data on climate evolution. This, of course, is an ongoing process, and an increasing number of palaeoenvironmental studies – as well as interdisciplinary integrative studies and research institutions, such as the Navarino Environmental Observatory (www.navarinoneo.gr) – promise to improve the situation significantly during the coming years and to lay the ground for further multidisciplinary efforts, in which close collaboration between natural scientists, archaeologists, and historians will be essential. The rich history of the Peloponnese, in combination with its active archaeological and palaeoenvironmental communities, highlights the peninsula as a key region for such future research.

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Appendix A: Review of the archaeological and palaeoenvironmental records from the Peloponnese

A.1. The Neolithic period (6800–3100 BC/8750–5050 BP)

A.1.1. Archaeological record

At the beginning of the Neolithic period, there was a transition from hunter-gatherer societies (common to the Mesolithic period) towards the establishment of permanent farming villages by people moving westward from the Near East; it is at around this time that we see the introduction of domesticated plants and animals (Zeder, 2008). Franchthi, a cave and open-air site in the southern Argolid, was used throughout the Mesolithic-to-Neolithic transition, and the evidence from the site supports the general picture of an influx of new inhabitants into the Peloponnese. During the earliest Neolithic period, these people would have brought with them the first domesticated species of plants and animals (Hansen, 1992, 1991). A major cultural shift took place around 6500 BC, when activities inside the cave decreased in favour of an expanding, open-air settlement near the shore. This change coincides with the appearance of a more diverse material culture and practices characteristic of Neolithic societies, including technical advances and a wider suite of domesticates (Perlès, 2001).

The main settlement pattern in the Early and Middle Neolithic Peloponnese seems to have consisted of one large multi-period site in each topographically distinct region – distributed quite evenly throughout the landscape – complemented by smaller, subsidiary sites with less continuous activity (Cavanagh, 2004; Johnson, 1996; Perlès, 2001). Settlements such as Kouphovouno in Laconia (Mee et al., 2014), where no other Early–Middle Neolithic sites are recorded, delineate a pattern of large unoccupied territories of around 30 km^2 surrounding each regional center (Cavanagh, 2004). Although the Early and Middle Neolithic societies inhabited a sparsely populated landscape with fairly remote neighbours, they were held together by socio-economic interdependencies evident in the uniformity of material culture, which suggests a certain amount of exchange and social interaction (Mee, 2007). This uniformity began to fragment in the Late and Final Neolithic periods, as illustrated by an increased emphasis on local ceramic traditions and a gradual decrease in ceramic quality (Demoule and Perlès, 1993; Mee, 2007; Mee et al., 2014). These shifts coincided with an increase in the number of sites, beginning in Late Neolithic (e.g., Laconia) and amplified in the Final Neolithic period (e.g., Berbati-Limnes, Southern Argolid) (Fig. A.1).

Neolithic farmers practiced small-scale, mixed farming, with closely integrated crop cultivation and animal husbandry. Isotopic analyses of plant and animal remains from Middle and Late Neolithic Kouphovouno, Laconia (Vaiglova et al., 2014), show that this farming economy consisted of intensively managed cultivation of free-threshing wheat, possibly earmarked for human consumption, along with more extensive cultivation of hulled barley for fodder, and garden-style cultivation of pulses. Flocks of sheep diminished in size during the Late Neoltihic period in favour of smaller, more diversified herds (also Halstead, 2000). Innovations throughout the Neolithic provided further grounds for economic diversification; secondary products, such as milk and wool, were exploited and, in conjunction with advances in plough technology, animals started to be used for traction and transport (Halstead and Isaakidou, 2011; Sherratt, 1981). These innovations would have enabled larger fields and rain-fed crops to be cultivated away from the plains (Johnson, 1996). This is consistent with the larger diversity in site types during the Late and Final Neolithic period, including caves that were possibly supra-regional ritual locations, such as the Alepotrypa cave in Mani (Mee et al., 2014; Tomkins, 2009).

A.1.2. Palaeoenvironmental record

The Neolithic period was a time of rapid sea level rise and high seismic activity, as we may infer from the changing sedimentation rates and the intrusion of marine waters in near-coastal records. The exact timing of peak activities differs among the sites studied. At Alykes Lagoon, large changes are documented at around 7200 cal BP and 6400 cal BP (Avramidis et al., 2013; Vött, 2007). At Kotychi Lagoon in coastal Elis, a short-lived sequence of coastline progradation and barrier accretion occurred around 8000 cal BP (Haenssler et al., 2014). Pronounced lagoonal conditions developed around 6300 cal BP, concurrently with a period of circum-Mediterranean lagoon formation. Seismic activity may also be observed in the geochemical studies of sediment cores from the Messinian plain in the south, indicating a rapid and significant rise in sea level, a landward displacement of the shoreline, and the flooding of the plain around 5000 cal BP (Engel et al., 2009). Pollen and diatom records from the Agios Floros fen also indicate a shift in lake levels in the central Messenian plain at around the same time (Papazisimou et al., 2005; Katrantsiotis et al., 2015). In particular, two decade-long periods of rapid development of deep lake conditions with an open water environment and high accumulation rates were recorded at around 5700 and 5300 cal BP (Katrantsiotis et al., 2015). These short-lived phases were probably triggered by seismic activities causing basin subsidence and rapid changes in the water flow of the nearby karst springs, although abrupt climatic change with enhanced precipitation cannot be excluded as a contributory cause (Katrantsiotis et al., 2015).

The longest climate record in the Peloponnese with the highest resolution comes from Lake Stymphalia (Fig. A.2; Heymann et al., 2013). Evidence from this record indicates that there may have been a shift to cooler conditions between around 8500 cal BP and 7500 cal BP, most probably a response to the so called 8.2 ka event in the North Atlantic (Heymann et al., 2013). Summer conditions became drier between 7500 and 7000 cal BP, with peak dry conditions occurring around 7000 cal BP. Between 6100 and 5000 cal BP, the proxies indicate a drying trend and modest warming at Lake Stymphalia. The sedimentary record from the Asea valley (Fig. A.2; Unkel et al., 2014) only begins around 6500 cal BP, and it shows relatively stable environmental conditions with moderate evaporation from the lake until about 4000 cal BP.

The Alepotrypa Cave record starts around 6400 cal BP, and shows drier-than-average conditions until around 5800 cal BP, when a rapid shift to wetter conditions seems to have occurred (Fig. A.3). These wetter conditions continued until 5500 cal BP, although they were punctuated by two brief arid phases at 5650 and 5570 cal BP. A longer period of arid conditions began quite abruptly at 5500 cal BP and lasted until 5200 cal BP. However a period of slow speleothem growth between 5430 cal BP and 4600 cal BP may have been related to seismic activity rather than to the drier climate (Boyd, 2015; cf. Katrantsiotis et al., 2015). The isotope record of the only stalagmite from Alepotrypa with continuous growth during this period suggests that wetter conditions continued until 4400 cal BP.

Evidence from the pollen record indicates a mosaic plant landscape that alternated between open vegetation areas with evergreen Mediterranean taxa, a significant amount of mixed thermophilous oak forests and mountainous forests in high altitudes, as well as the clear impact of different types of human activities on local vegetation (Fig. A.4). Open xeric vegetation during the Early Neolithic may be inferred from the records of Osmanaga (Kraft et al., 1980) and Alykes on Zakynthos Island (Avramidis et al., 2013). After around 8200 cal BP, the Alykes pollen sequence reveals the development of an herb landscape with sclerophyllous Mediterranean elements, pine trees and open oak-dominated mixed deciduous forested areas (Avramidis et al., 2013). A similar pattern is documented at Lerna (Jahns, 1993), Kleonai (Atherden et al., 1993), and in the fragmented record of the Osmanaga lagoon (Kraft et al., 1980). The increasing trend of forest cover index suggests that an expansion and (partial) closure of the deciduous oak woodland may have occurred around 7200 cal BP in Lerna and, to a lesser extent, in Alykes and Kotychi (Fig. A.4; Avramidis et al., 2013; Lazarova et al., 2012). The closure of woodland vegetation coincides with a short-lived decline in the pollen associated with agricultural activities but, shortly after 6500 cal BP, the vegetation pattern at Lerna indicates that cereal cultivation and animal husbandry increased once again (Fig. A.1). Given the local impact of human activities on vegetation, at least during the Neolithic period (Kouli, 2015), we may wish to attribute the fluctuations in the record from Lerna to the temporal fluctuations in human activities near the coring site (Kouli, 2015). Similarly, levels of *Olea* at Alykes during this period reach a prominent peak between 6200 and 5200 BP (Avramidis et al., 2013), whereas the other records show only low quantities.

A.2. Bronze Age and Iron Age (3100–700 BC/5050–2650 BP)

A.2.1. Early Helladic/Early Bronze Age (3100–2100 BC/5050–4050 BP)

The beginning of the Early Helladic period is characterized by small settlements situated in a variety of environments, including marginal and highland regions, and supported by a mixed economy of cereal cultivation, horticulture and animal husbandry that continued throughout the period (Pullen, 2011a). In regions that lacked settlement expansion during the Final Neolithic period – including Methana, the Southern Argolid, the Nemea valley and the Pylos region (Fig. A.1) – there is evidence for increasing activity. This pattern is partially broken around 2700 BC (the beginning of the EH II subphase) when archaeological evidence from the northeast Peloponnese suggests a decrease in the number of small settlements, and the development of larger regional centers, usually one in each topographically distinct region, similar to the pattern that occurred during the Early–Middle Neolithic periods; for the most part, these centers remained inhabited with few or no interruptions throughout the remainder of the Bronze Age (Weiberg and Finné, 2013; Wiencke, 1989). Among the most well-documented locations are Lerna and Tiryns in the Argolid (Wiencke, 1989; Rutter, 2001) and Tsoungiza in the Corinthia (Pullen, 2011a).

This altered settlement pattern may reflect a process of urbanisation, represented in the archaeological record by organized settlement plans, fortifications, the use of seals for administrative purposes, and the appearance of monumental buildings. Among the latter, the so called ‘corridor houses’ at Lerna and Akovitika, and the monumental ‘Rundbau’ at Tiryns, are the most conspicuous elements of a new set of supra-regional correspondences. All these factors are indicative of communal organisation, planning, and a certain amount of centralised control, which has been variously identified as a heterarchy, a chiefdom or a proto-state (Maran, 1998; Maran and Kostoula, 2014; Nilsson, 2004; Pullen, 2011b). The two final centuries of this phase, were characterised by accelerated cultural transformation in an increasingly interconnected world that spanned the Aegean and the western Anatolian littoral, incorporating most parts of the Peloponnese (Broodbank, 2013; Maran, 1998; Rahmstorf, 2011; Şahoğlu, 2005).

This expansive phase ended with a period of comprehensive socio-political transformation at the end of EH II (Forsén, 1992; Maran, 1998); the EH III communities were smaller and more fragmented than their predecessors (Weiberg and Finné, 2013; Wiersma, 2014). There was a decline in human impact on the landscape, and the extant material culture is more ephemeral. Differences in artifact types and settlement patterns – including a decrease in the size, distribution and organisation of sites – are clearly visible (Fig. A.1). While EH II was defined to some extent by its communal focus, there was a move to a more household-oriented society during EH III. Freestanding apsidal houses, in which the apse was reserved for storage, became the primary form of domestic architecture, replacing the agglomerative rectangular houses of the EH II period (Pullen, 2008).

A.2.2. Middle Helladic/Middle Bronze Age (2100–1700 BC/4050–3650 BP)

In some parts of the Peloponnese, such as the Argolid, the material culture and social structure of the Middle Helladic period developed seamlessly from its predecessor. After the decrease in settlement numbers at the end of EH II, settlement patterns remained fairly stable during the transition from the Early to the Middle Helladic periods. In Messenia and Laconia, however there is little or no evidence from EH III (Fig. A.1; Rutter, 2001); in these regions, the earliest post-EH II material appears *de novo* in MH I, at newly established sites, often small and short-lived, located in remote and sometimes defensible locations away from the coast (Stocker, 2004, 2003; Rambach, 2007). At the other end of the period, sites such as Tsoungiza in the Argolid – which was abandoned after the Early Helladic period and subsequently deserted until the Middle Helladic period when it was reoccupied – can be used to define MH III (Rutter, 2007). In all regions, however, there were sites where habitation continued throughout much of the Bronze Age, and these remain important for our understanding of continuity and change during the Middle Helladic period as a whole, and the transition to the Late Helladic period. Some of the most well-documented Middle Helladic sites in the Peloponnese include Nichoria and Malthi in Messenia (McDonald and Wilkie, 1992; Valmin, 1938), Aghios Stephanos in Laconia (Zerner, 2008), and Asine in the Argolid (Nordquist, 1987).

The level of political complexity and social stratification during the first half of the Middle Helladic period appears to have been low (Wiersma, 2014). Much of the available evidence suggests that societies operated at a local village scale, with low levels of central administration or social hierarchy. Changes in the ceramic repertoire at the beginning of the period are indicative of outside influences, new ceramic traditions, or culinary shifts. Potting traditions, however, changed slowly throughout MH I–II and most vessels were produced locally (Rutter, 2007); patterns of exchange during this period were regional, especially in Laconia and Messenia. This slow pace of change accelerated rapidly in MH III when there was a pronounced move towards social complexity (Galaty and Parkinson, 2007; Wright, 2008); in this period, both Mycenae and Tiryns emerged as administrative centers. At Pylos, surface survey suggests that a number of small sites coalesced on the acropolis and spread into the area of the lower town. As the number of settlements increased throughout the Peloponnese, nucleated centers became larger and people began to occupy more marginal areas (Fig. A.1). These patterns point to an increase in population and an accompanying intensification in agricultural production (Wright, 2008).

A.2.3. Late Helladic/Late Bronze Age (1700–1075 BC/3650–3025 BP)

The transition between the Middle and Late Helladic periods is marked by a move from simple social orders to an increasingly competitive social environment; this is most evident in the mortuary realm (Boyd, 2002; Fitzsimons, 2011; Voutsaki, 2010, 1998). The LH II period also marks the beginning of a new phase of expansion, as well as the inception of the Mycenaean palatial system; based on the funerary evidence, the material culture gradually becomes more formalised, suggesting increasing levels of centralisation and societal complexity, which would have provided new arenas for conspicuous consumption and competitive displays of resources (Fitzsimons, 2011).

Palaces of a monumental and heavily-decorated nature first become evident in the LH III period. These centres constituted the socio-political hubs of an economic system that lasted some two hundred years (approximately 1400–1200 BC). The archaeological evidence reveals a diversified economy (Bennet and Halstead, 2014; Galaty and Parkinson, 2007), and it seems clear that the palatial authorities were able to mobilise specific resources through a series of agreements, which included the taxation of outlying settlements, direct production, share-cropping, dependent individuals, and the procurement of other resources via payments (Galaty et al., 2011). Some resources were also intended for export, and the evidence testifies to high-level and long-distance economic diplomacy, as well as short-distance connectivity and lower-level trade (Tartaron, 2013). Both the palaces and the monumental tholos tombs attest the ability of the Mycenaean elites to mobilise large amounts of skilled and unskilled labour (Darcque, 2005). Considerable labour investments would have been required for environmental engineering projects such as the drainage system at Lake Kopais; the dam at Kofinas near Tiryns; the large, underground cisterns at the Athenian Acropolis, Mycenae, and Tiryns; the Mycenaean road network, which was supported by preserved terraces and bridges; and the creation of artificial harbours, such as that at Pylos (Hope Simpson and Hagel, 2006).

These constructions, which may generally be dated to the 14th–13th centuries BC (LH IIIA–B), coincide with the centuries of the Late Helladic period that feature the highest archaeological visibility. In the northeast Peloponnese, these centuries are defined by a distinct rise in settlement numbers, especially as compared with the sparsely occupied Middle–early Late Helladic landscape (Fig. A.1, e.g. Berbati-Limnes and Southern Argolid). In those places where the main expansion occurred during the (late) Middle Helladic period, the existing patterns appear to have continued without further intensification into the Late Helladic period (Fig. A.1, e.g. Pylos region and Laconia), while, in other areas, the whole of the Bronze Age is defined by low settlement numbers relative to the periods before and after (Fig. A.1, e.g. Asea valley). Increases in settlement numbers were, however, reversed again when the Mycenaean palaces were destroyed around 1200 BC. Although Mycenaean culture survived for some time afterward (Maran, 2011), life on the Greek mainland was, once more, reduced to small-scale societies.

A.2.4. Early Iron Age (1075–700 BC/3025–2650 BP)

The beginning of the Early Iron Age is defined by a sharp decrease in archaeological evidence, settlements, settlement size, and presumably population (Snodgrass, 2000). Higher order administrative centers, landscape engineering, monumental architecture, and writing all disappeared; trade and connectivity were reduced in scale and frequency. There is no clear consensus on the cause of these transformations, and the causal explanations proposed thus far have encompassed a wide variety of both natural and cultural phenomena (e.g., Cline, 2014; Drews, 1993; Dickinson, 2006). With a few exceptions, the excavated sites – primarily funeral – are generally fewer and poorer compared to those of the Late Helladic period. The lack of settlement evidence from excavation, which is mirrored in regional surveys of the landscape (Fig. A.1), conspire to render our knowledge of the period somewhat vague. The centralisation visible in Late Helladic material culture shifts increasingly towards regionalism, which makes it difficult to draw general conclusions from the few excavated settlements (e.g., Nichoria). The chronology of this period is largely defined by ceramic typologies containing geometric motifs, and the Early Iron Age is often subdivided into the Proto-Geometric and Geometric periods.

The quantity of archaeological evidence from southern Greece increases significantly from 750 BC onwards – during the late Geometric period (Whitley, 2001) – indicating a dramatic increase in the number of settlements and sanctuaries (Fig. A.1). Towards the end of this period, Corinth and Sparta begin establishing overseas colonies, and we see the reappearance of writing and monumental architecture in the form of epic poetry and temple construction. The Panhellenic sanctuaries –Isthmia, Nemea, and Olympia were all located on the Peleponnese – started to become important centers at this time, bringing together worshippers, athletes, craft specialists, elites, and civic representatives from throughout the Mediterranean (Snodgrass, 1986).

A.2.5. Palaeoenvironmental record

Sediment cores from Aliki/Egion covering the last 5000 years testify to rapid environmental changes due to seismic activities, including six tsunami events. Although these events are not precisely or independently dated, four of them have been tentatively placed at 4720, 3000, 2500 and 2000 cal BP (Kontopoulos and Avramidis, 2003). The sedimentary record from the Kotychi lagoon also indicates substantial geomorphological instability between 5200 and 3500 cal BP (Fig. A.2; Haenssler et al., 2014). The diatom and isotope records from the Agios Floros fen indicate rapid and moderate lake level rise at around 4600 cal BP, which might be connected to karst springs and/or the seismic activity of the nearby fault system (Katrantsiotis et al., 2015). After 4500 cal BP, the record suggests the development of terrestrial conditions in the central Messenian plain, which may be attributed to more arid climate conditions and the consequent drying up of the karst springs. This is in agreement with the general picture from the Eastern Mediterranean, where drier conditions began to dominate after around 4600 cal BP (Katrantsiotis et al., 2015; Finné et al., 2011; Magny et al., 2011); on the other hand it does not correspond to the Alepotrypa Cave record (Fig. A.3; Boyd, 2015), where slow stalagmite growth is replaced by more rapid growth around 4600 cal BP and generally wetter conditions. At 4200 cal BP (4184 cal BP ±34 years) there began a period of aridity lasting some 200 years. Conditions seem to have become gradually wetter again from around 4000 cal BP (3984 cal BP) and a distinct wet period followed, lasting from 3850 to 3700 cal BP. This period shifted into a prolonged period of arid conditions which lasted between 3700 cal BP and 2550 cal BP. During this span of 1100 years, there is evidence for two especially pronounced dry spells, one around 3650 cal BP, and a second around 3200 cal BP which is also the driest period recorded in the Alepotrypa Cave. This long arid period is also interrupted by two short wet spells centered around 3550 and 2950 cal BP.

The Asea record (Fig. A.2) suggests relatively stable climatic/environmental conditions for the Early and Middle Helladic period, with no indications of any significant climate event around 4200 cal BP, the so-called 4.2 ka event (Unkel et al., 2014). There may however have been a phase of more humid and potentially cooler conditions towards the end of the Late Helladic period, lasting until the Middle Geometric period (Unkel et al., 2014), followed by a relatively dry or warm period which would have reached its peak in the Hellenistic period around 2300 cal BP (350 BC).

Pollen assemblages from the Bronze Age Peloponnese would have been affected by humans, and we cannot therefore use them as a principal index for the reconstruction of climate. However the pollen-based humidity index (H-index) from our records (Fig. A.4), suggests that a ‘humid’ Early Helladic period was followed by a more ‘arid’ Late Helladic period; this is especially evident in the record from Lerna, where the low point for humidity is centred around 4200 cal BP. Hydrologically unstable periods may be concluded from the fluctuations of pollen calculated humidity (H-index) in Lerna and Vravron. The H-index fluctuates significantly between 3200 and 2500 cal BP, exhibiting profound minima (e.g., at 3200 cal BP) and maxima values.

The plant landscape in the Bronze Age is otherwise comparable to that of the Neolithic period, and can be described as a floral mosaic where, in the lowland plains, open Mediterranean evergreen pine woods alternated with maquis shrublands and open diverse grasslands, while in the Peloponnesian uplands, there were thermophilous mixed deciduous oak woodlands and altitudinal forests. The records from Lerna and Vravron present a slightly different pattern (Fig. A.4). In these two locations, a decline of mixed deciduous oak woodlands and a concurrent expansion of evergreen Mediterranean vegetation may be observed, starting from the Early Helladic period and continuing throughout the Early Iron Age. This is quite probably a sign of increased human pressure in the area. The pollen record from Alykes shows that cereal cultivation switches over to an olive culture around 4500 cal BP (Fig. A.4). At Kotychi, olive and cereal cultivation both reach their peak during the Early Helladic period (Fig. A.4), while at Osmanaga, olive cultivation is more evident during the Late Helladic (Zangger et al., 1997). At Lerna, cereal cultivation appears less intensive during the Bronze Age than in the Neolithic, while olive culture becomes more important in the Middle Helladic as well as towards the end of Late Helladic period after 3200 cal BP. In nearby Attica, cultivation is primarily devoted to cereals, although there is some evidence for minor olive culture. The evidence from both Lerna and Vravron suggests that agricultural activities intensified in the Early Iron Age, and there was a shift towards olive cultivation (Jahns, 1993; Kouli, 2012) (Fig. A.4). In the Messenian plain, the records from Akovitika point to the re-establishment of maquis vegetation and show a very low human impact, with no signs of olive cultivation after the fall of the kingdom of Pylos (Engel et al., 2009). During the Geometric period, however, a strong signal of olive cultivation appears in the records from Osmanaga in Navarino bay (Zangger et al., 1997) and Kotychi lagoon (Lazarova et al., 2012).

A.3. The Archaic period to the Middle Ages (700 BC–AD 1460/2650–490 BP)

A.3.1. Archaic, Classical and Hellenistic period (700–146 BC/2650–2096 BP)

During the Archaic period (700–480 BC), we find evidence for the emergence of clear civic identities; these are most apparent in the public construction of monumental urban temples and non-urban sanctuaries. Over the course of this period civic construction expands to include urban infrastructure, fortifications, entertainment venues, and governmental buildings. These cities, or *poleis* (city-states), were defined by a body of land-owning citizen farmers who contributed to a diversified agropastoral economy.

The Classical and Hellenistic periods (479–146 BC) represent two of the most expansive phases of Greek history, during which the presence of urban and semi-urban *polis*-communities began to intensify. This intensification was initially evident at wealthier centers such as Corinth and Argos, although it soon spread across central and southern Greece (Hansen and Nielsen, 2004). Several urban *poleis* (e.g., Megalopolis) were political foundations that brought citizens from smaller settlements into a new urban environment. Classical *poleis* were incorporated into broader geopolitical frameworks, including the 'leagues' (*koina*), which comprised several communities that shared a common foreign policy and military defence, and often integrated different microecologies as well as their resources (Bonnier, 2014; Mackil, 2013). The Achaian league, for example, became a significant political and economic power in the Peloponnese during the third century BC.

The development of specialised craft industries provides evidence for social stratification and a cosmopolitan elite. Standardised forms of material culture – as well as increasing trade, and the increase in Mediterranean-wide colonisation – indicate a high level of connectivity between the Greek urban communities. A shift from glume wheat to the less-bulky and more portable free-threshing wheat in the archaeobotanical record (Halstead, 2014; Sallares, 1991) may have been related to this increase in connectivity, and the need to feed a non-rural populace. The high frequency of trade in foodstuffs and the intensive cultivation of non-staple crops were important buffers against the risks of interannual variability in rainfall, and could provide support for a struggling *polis* (Garnsey, 1988; Horden and Purcell, 2000).

The rural expansion in the Classical and Early Hellenistic periods – during which settlement density reached its peak in many parts of the Peloponnese (Fig. A.1) – reflects a growing population coupled with an economy firmly rooted in a citizen-farmer ideology, as well as a growing demand for outside food resources. Subsequent contraction in the (later) Hellenistic or early Roman periods in the northeastern Peloponnese is more problematic. Substantial socio-economic changes are evident from around 250 BC, but it is difficult to determine whether the settlement and site trends signify a decline in population, or merely reflect profound changes in the socio-political order.

A.3.2. Roman period (146 BC–AD 330/2096–1620 BP)

The Roman period in the Eastern Mediterranean is commonly dated from the battle of Actium in 31 BC, although Roman power in the Peloponnese had been established from as early as the second century BC (Alcock, 2002; Engels, 1990; Rizakis, 1996), and in 27 BC, the peninsula was incorporated into the Roman province of Achaea. Under Roman rule, land allotments were divided according to the practice of centuriation, which measured out equal portions of land using a system of baselines, the outlines of which may still be found in the modern landscape (Romano, 2003). At the same time, the ancient sources suggest a widespread desolation, with ruined cities and depopulated landscapes, especially those in the upland regions of Arkadia (Pausanias 8.18.7–8; 8.17.6; Strabon 8.8.2). Polybios (36.17.5) suggests that the population of the Peloponnese had already started its decline during the Hellenistic period. These passages, taken together, would seem to suggest a reduction in both settlements and agricultural activity in the Early Roman period. However, it is important to stress that these images of depopulation may, to some degree, represent a literary device designed to illustrate the moral and political decline of Greece, especially as compared with the illustrious (Classical) past (Alcock, 1993).

The archaeological record to a certain extent supports the notion of a depopulated landscape, and the recurring pattern of settlement contraction, may suggest a restructuring of the cultivation regime, or production systems and patterns of land ownership that involved the abandonment of dispersed holdings in favour of larger estates (Alcock, 1993). A reduction in the number of sites and the contraction of settlements may be observed in many parts of the Peloponnese (Fig. A.1). Given the intensity of urban transformation at Roman Corinth, we may perhaps wish to interpret rural contraction in the Corinthia as a consequence of changes in land ownership and farming practices rather than complete regional depopulation. Certainly the construction of fountain houses and the Hadrianic aqueduct, which provided water to the city from Lake Stymphalia, highlight significant improvements within the management of urban resources (Lolos, 1997).

There are also regions where one finds evidence for the intensification of land use and an expansion of rural settlement, for example in the Pylos area (Fig. A.1). In the northwestern Peloponnese, in the territory surrounding Patrae, an expansion of rural settlement began in the Hellenistic period and reached its peak during the Roman period (Bintliff, 2012a; Petropoulos and Rizakis, 1994). The material remains from urban sites, and the investment in urban infrastructure, suggest the need for a more nuanced understanding of 'stagnation' or 'decline' during the Roman period (Alcock, 1993).

A.3.3. Byzantine and Frankish period (330–AD 1460/1620–490 BP)

During the Late Antique and Medieval periods, southern Greece saw two major periods of economic expansion. The first occurred at the beginning of the Byzantine era (AD 330–600), and may have resulted from the growing demand for agricultural produce in the new imperial capital of Constantinople, and the general economic prosperity enjoyed in the Eastern parts of the Later Roman Empire (Bintliff, 2012b; Izdebski, 2013). The second period of growth reached its peak between the eleventh and thirteenth centuries AD, when Byzantine civilisation in Greece was at its height. Developments in southern Greece during this period were part of a wider trend within the Byzantine Balkans (primarily Greece and Bulgaria) and Anatolia (Harvey, 1989; Xoplaki et al., 2016). The 200–300 years that separate these two peak periods of growth are sometimes referred to as the Byzantine 'Dark Age,' and are characterised by a relatively simple material culture. This period is much less visible, both in the archaeological record and the textual sources, than either the Late Antique or the Middle Byzantine periods (Curta, 2013). The later Middle Ages were a time of gradual economic contraction, especially with respect to agricultural exploitation (Lock, 1995); Greek society must also have suffered considerably from the Black Death (Izdebski et al., 2015).

In the earlier period (Late Antiquity), the Peloponnese provides evidence for a growing number of rural settlements (Fig. A.1), as well as the creation of new sites in previously uninhabited locations, and an intensification of agricultural activities. The increase in the quantities of ceramic finds is so great when compared with the preceding (early Roman) period, that one may reasonably doubt whether the ceramic record accurately reflects the scale of the settlement and agricultural expansion that occurred between these periods. Alternatively, the expansion in Late Antiquity and the succeeding decline in the early Medieval period may to some extent be ascribed to the unusual visibility of Late Roman ceramics (Pettegrew, 2007). Similarly, although there is no doubt that the Peloponnese and Attica participated in the Middle Byzantine economic expansion, the evidence from this period is much smaller compared to that of Late Antiquity. The two most important surveys in this respect are those from Laconia and Berbati-Limnes (Fig. A.1, Table B.1), where the first signs of settlement expansion are visible from around AD 800, with a marked acceleration from AD 1000, and an impressive climax around AD 1200. This trend of increasing population and settlement activity is supported by the construction of churches in the Peloponnese, with the largest number being built during these centuries (cf. Gerstel, 2015); it is also visible on some of the excavated sites, such as the northeast gateway of the Palace of Nestor (Davis and Stocker, 2013). After the fall of Constantinople in AD 1204, and the creation of the Latin princedoms in Greece, the economic situation in the Peloponnese began to deteriorate slowly. The major change in settlement patterns arising as a result of the Frankish conquest is the construction of stone towers and other fortifications (castles) in order to control the newly-conquered countryside (Lock, 1986). A reorientation of trade networks towards Western Europe also led to the creation of new harbours and exchange centres, such as the harbour-city of Glarentza (Kyllene) in the Frankish principality of Morea, Elis (FIA, 2015; Athanasoulis, 2013).

A.3.4. Palaeoenvironmental record

The Alepotrypa Cave record (Fig. A.3) indicates a gradual return to wetter conditions between 2650 and 2400 cal BP, after nearly 1100 years of mainly drier conditions (Boyd, 2015). Conditions remain wetter from 2550 to 1650 cal BP, but with a drier spell centered at 2300 cal BP and one at 1900–1800 cal BP. The latter shows especially large isotopic fluctuations with two episodes of enrichment indicating dry conditions at 1900 and 1850 cal BP. Drier conditions prevail from 1650 cal BP until 1400 cal BP when wetter conditions return. A rapid shift towards drier conditions occurs at 1150 cal BP which lasts until 1050 cal BP when wetter conditions return once again. Speleothem formation in Alepotrypa stops at 1037 cal BP.

The speleothem record from Kapsia Cave (Fig. A.3), starting from around 950 BC (2900 cal BP, bearing in mind the age uncertainties; **see 3.2**), embraces 3.5 cycles of rapid transitions from drier to wetter conditions, followed by a slow drying trend and then a rapid dry–wet transition (Finné et al., 2014). The cycles occur at roughly 950–400 BC, 400 BC–AD 150, and AD 150–650, followed by a final transition from dry to wet around AD 700. Within these cycles, each lasting about five centuries, are shorter periods of wetter and drier conditions with generally wetter conditions centered at 850 BC, 700 BC, 500 BC, 400–100 BC; AD 160–300 and AD 770. The Kapsia sequence often resembles the record from Alepotrypa; the similarities are most clear during the period between 2400 and 1800 cal BP, with wetter conditions recorded in Kapsia between 2350 and 2050 cal BP (400–100 BC) followed by two distinct dry phases at 1900 and 1800 cal BP in line with Alepotrypa. It should be noted that the sequence from Kapsia has a less robust chronology than the record from Alepotrypa. This means that, while we can see general similarities between the records, the exact timings are difficult to assess, especially in the Kapsia sequence, and it is possible that this record needs to be adjusted chronologically to Alepotrypa. However, the differences between these two records may also be due to site-specific variations, for example the properties of bedrock and the level of human impact; they may also be due to actual differences in climate rather than dating uncertainties (see further **5.2**). The speleothem from Kapsia stopped growing around AD 830 (1120 BP), which matches Alepotrypa quite closely. The wet period between 2550 and 1650 cal BP attested in the cave records is supported by evidence from the diatoms and isotopes in the Agios Floros fen, which suggest the onset of wetter climate conditions with marked seasonality in the central Messenian plain after 2500 cal BP (Katrantsiotis et al., 2015).

Vegetation patterns during Classical and Hellenistic times are characterised by an opening of forest cover and an expansion of maquis, possibly as a result of increasing human pressure on the landscape (Fig. A.4). This type of landscape was dominant, at least in the northeastern Peloponnese and Attika (Atherden et al., 1993; Jahns, 2003, 1993; Kouli, 2012; Kouli et al., 2009). A temporal increase of altitudinal forests may be observed in the Lerna and Vravron records, while agricultural activities are represented by intense olive and moderate cereal cultivation. Evidence for *Olea* cultivation is also found in the western and southern Peloponnese (Engel et al., 2009; Lazarova et al., 2012; Zangger et al., 1997). The expansion of mixed deciduous oak and altitudinal forest, accompanied by the abandonment of olive cultivation practices may be observed at the end of the Classical period in Attica, and during the Roman period in the Argolid and northwest Peloponnese. In Lerna, cereal cultivation increases markedly around 950 cal BP (Fig. A.4, Jahns, 1993), while in Attica cultivation practices also include olive and walnut (Kouli, 2012). Signs of olive cultivation are also evident in Osmanaga Lagoon, around AD 1000–1200 (950–1150 BP) (Zangger et al., 1997).

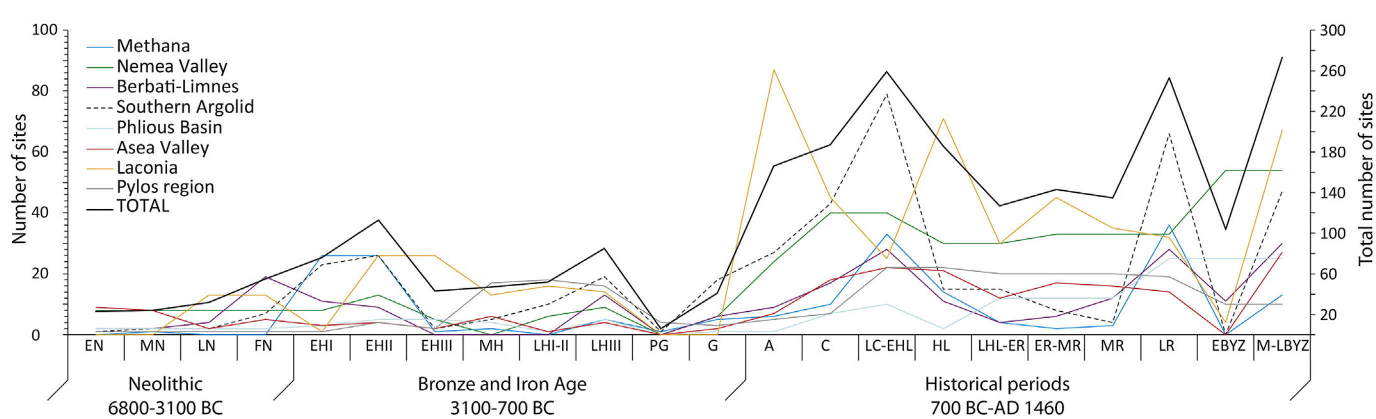


Fig. A.1. Overview of the number of sites recorded in eight intensive field surveys, generalised by period in the relative chronology (not weighted against actual time span; for details see Table 1 and B.1). Illustration by A. Bonnier and M. Finné.

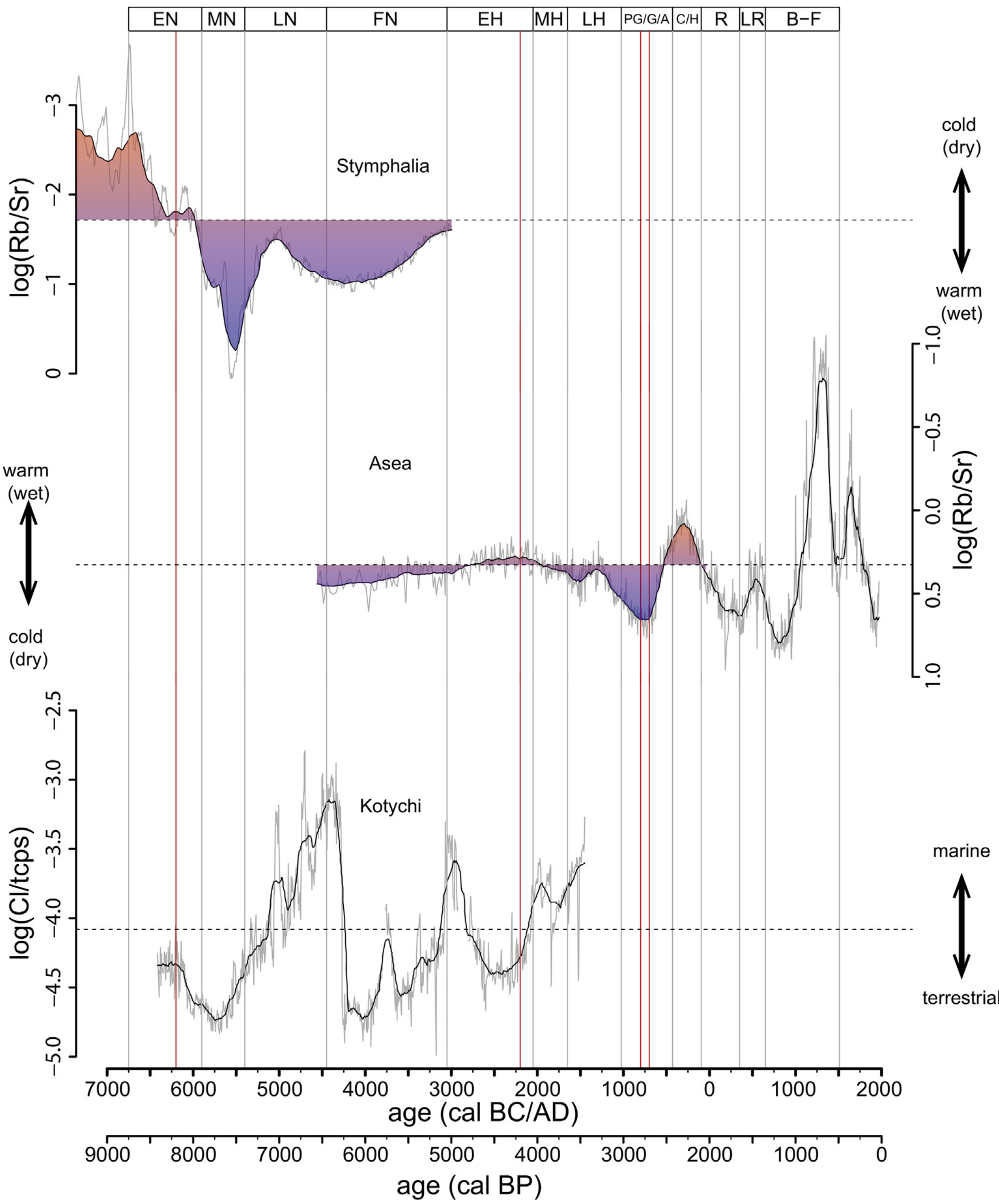


Fig. A.2. Comparison of selected geochemical palaeoclimate records of the last 9000 years BP discussed in the text. From top to bottom: Rb/Sr ratio from Lake Stymphalia (Heymann et al., 2013), and from the Asea valley (Unkel et al., 2014); Chlorine (Cl) as indicator for marine influence at Kotychi lagoon (Haenssler et al., 2014). Grey vertical lines and boxes at the top of the graph indicate cultural periods in southern Greece (compare Table 1), red vertical lines indicate well-known climate events for comparison (8.2 ka and 4.2 ka events, solar minimum 2.8–2.7 ka BP). The XRF data is plotted as log-ratios using the natural logarithm. Illustration by I. Unkel.

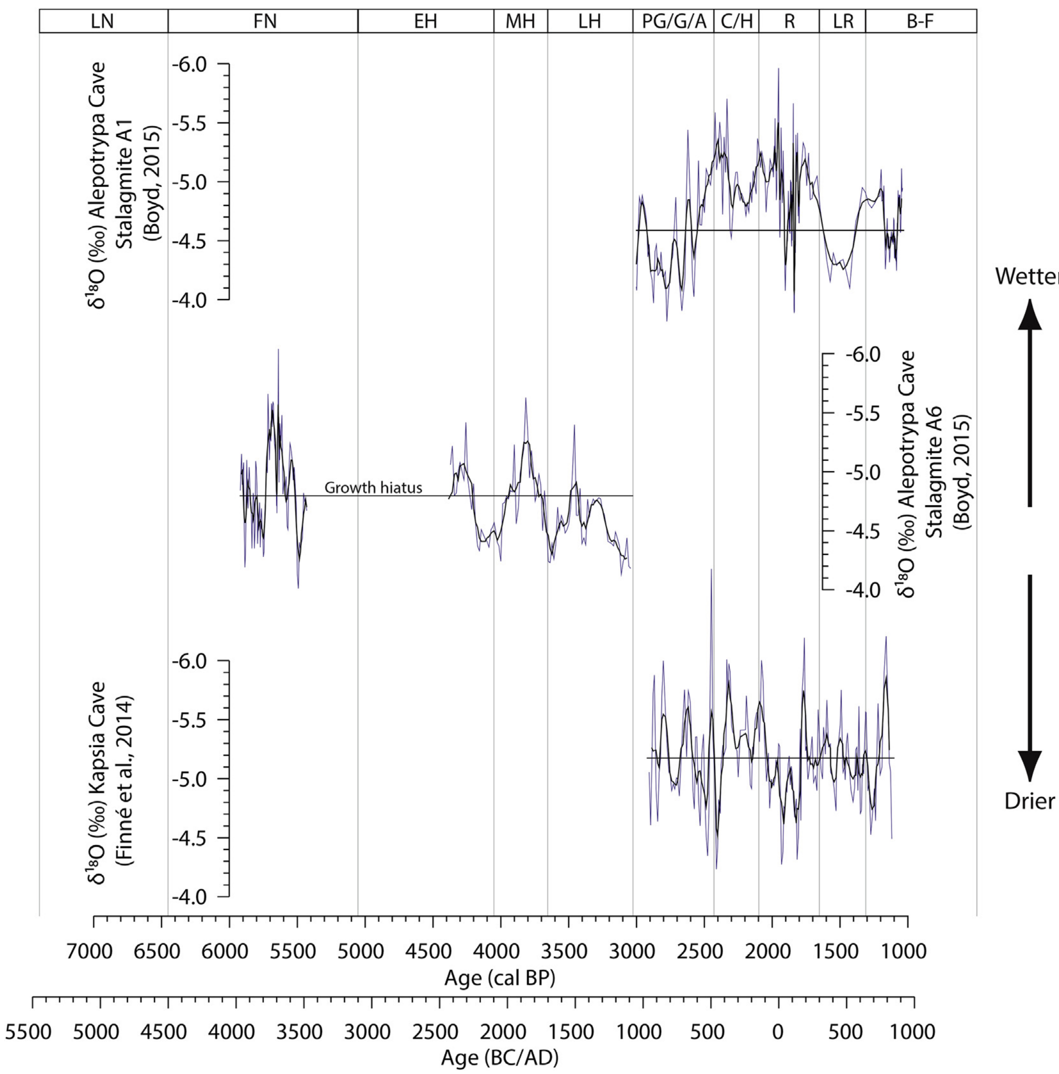
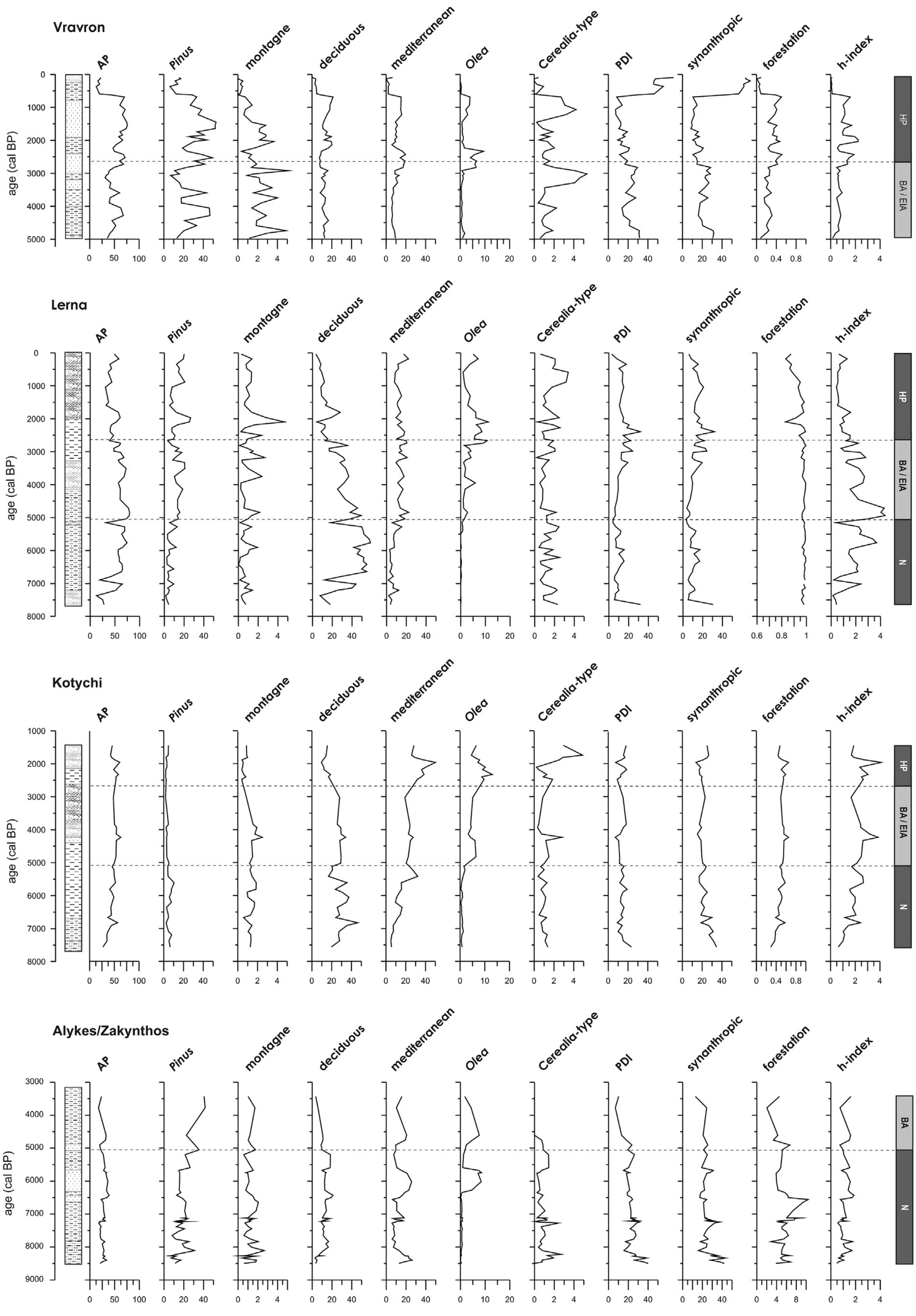


Fig. A.3. Comparison of $\delta^{18}O$ values in stalagmites from Alepotrypa Cave (top two) and Kapsia Cave (bottom). More negative $\delta^{18}O$ values (up) are interpreted to reflect more precipitation, and vice versa. In the case of Alepotrypa Cave both stalagmites (A6 and A1) overlap in the period from 5900 to 3050 cal BP, showing a similar $\delta^{18}O$ signal. However, only stalagmite A6 is presented in this paper as it has a more robust chronology for the period. Black lines in all graphs represent 5 point running average. Records arranged from west to east. Illustration by M. Finné.


Vravron
Lerna
Kotychi
Alykes/Zakynthos
AP
Pinus
montagne
deciduous
mediterranean
Olea
Cerealia-type
PDI
synanthropic
forestation
h-index
age (cal BP)
HP
BA / EIA
N
BA
silt
loam
clay
sandy silt
f. sand

Appendix B. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.quascirev.2015.10.042.

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Fig. A.4. Summary pollen diagrams of selected plant groups from Vravron, Lake Lerna, Kotychi and Alykes/Zakynthos. Montagne: *Abies*, *Fagus*, *Betula* and *Picea*. Deciduous: *Quercus robur* type, *Carpinus/Ostrya*, *Acer*, *Corylus*, *Ulmus*, *Salix*, *Juglans* and *Platanus*. Mediterranean: *Quercus ilex* type, *Pistacia*, *Phillyrea*, *Fraxinus ornus*, *Rhamnus* and Ericaceae. PDI sum: *Centaurea*, Cichorioideae, *Plantago*, *Ranunculus acris* type, *Polygonum aviculare* type, *Sarcopoterium*, *Urtica dioica* type and *Pteridium*. Synanthropic plants: *Olea*, *Juglans*, *Castanea*, *Vitis*, Cerealia-type, Asteroideae, Chenopodiaceae, Cichorioideae, Leguminosae, *Plantago*, *Rumex*, Urticaceae. Forestation: broadleaved tree versus PS excluding bisaccates ratio. H-index: Arboreal taxa excluding *Pinus* versus *Artemisia*, Chenopodiaceae, Asteraceae and Poaceae ratio. Lithology of the records is after Triantaphyllou et al., 2010 (Vravron); Jahns, 1993 (Lerna); Kontopoulos and Koutsios, 2010 (Kotychi); Panagiotaras et al., 2012 (Alykes/Zakynthos). Illustration by K. Kouli.

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