Quaternary Science Reviews xxx (2015) 1–20

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

The environmental, archaeological and historical evidence for regional climatic changes and their societal impacts in the Eastern Mediterranean in Late Antiquity

Adam Izdebski [a], [*], Jordan Pickett [b], Neil Roberts [c], Tomasz Waliszewski [d]

[a] *Institute of History, Jagiellonian University in Krakow, ul. Golebia 13, 31-007 Krakow, Poland*
[b] *Art and Archaeology of the Mediterranean World, University of Pennsylvania, Philadelphia, PA 19104, USA*
[c] *School of Geography, Earth and Environmental Sciences, Plymouth University, Plymouth PL4 8AA, UK*
[d] *Polish Centre of Mediterranean Archaeology and the Institute of Archaeology, University of Warsaw, ul. Nowy Świat 4, 00-497 Warsaw, Poland*

ARTICLE INFO

Article history:
Received 30 March 2015
Received in revised form
9 July 2015
Accepted 17 July 2015
Available online xxx

Keywords:
Anatolia
Levant
Eastern Mediterranean
Late antiquity
Roman empire
Byzantium
Arab conquests
Climatic change
Societal impact of climate change

ABSTRACT

This paper examines the evidence for climatic changes in the Eastern Mediterranean for the period 200–800 AD and offers hypotheses on the role of climatic fluctuations in the societal developments that occurred in this region at the end of Antiquity. The geographical focus of the paper includes Anatolia and the Levant, two major regions of the Eastern Roman Empire that are rich in environmental, historical and archaeological data. The paper starts with the review of current research on the economic, settlement and vegetation history of the Eastern Mediterranean in Late Antiquity, which provides the necessary framework for the study of potential climate impacts. The core of the article is devoted to the analysis of the palaeoclimatic evidence, which is divided in two groups. The first one encompasses the direct evidence, that is palaeoclimate proxies and the textual record of extreme weather events, while the second includes indirect information on climate, in particular multi-proxy studies that include pollen analysis, archaeological evidence, and the historical evidence of subsistence crises. We conclude that during our study period there occurred three periods of substantially different climatic conditions. A late Roman drought ~350–470 AD was followed by a dramatic shift to much wetter climatic conditions. These in turn changed into increasing dryness after ~730 AD in Anatolia and ~670 AD in the Levant. The lack of chronological precision in the dating of the archaeological evidence and of some climatic records makes it impossible at present to make conclusive observations regarding the societal responses to these climatic fluctuations. Nonetheless in all probability, the extended and – in some areas - severe late Roman drought did not cause any major social upheaval or economic decline in Anatolia or the Levant, although it appears to have contributed to a change in patterns of water use in the cities. In contrast, the increased availability of moisture after ~470 AD does appear to have contributed to the expansion of rural settlement and agriculture into environmentally marginal terrain, including semi-arid areas such as the Negev. In this way climate probably contributed to the general economic prosperity of the late Roman Empire in the east of the Mediterranean basin. The end of this late Roman world system came about finally in mid-7th c. and, at least in Anatolia, is not directly associated with any shift in climatic conditions. Aridity during early Medieval times may be one of the main factors behind the gradual long-term decline of settlement on the marginal lands in the Levant following Islamic conquest.

1. Introduction

Among the scholars specializing in the study of history and archaeology of Late Antiquity (ca. 3rd-7th c. AD), one may observe a growing awareness of the fact that during this period the Eastern Mediterranean not only experienced an impressive economic and cultural floruit, but it also witnessed significant fluctuations in climate. Among the first to observe that climate may have changed in the 5th-6th c. AD was Koder (1996, 1994), a few years later his work was followed by Hirschfeld (2004) who discussed the archaeological and textual evidence for a rise in humidity in 5th-6th-c. Palestine. Recently, Izdebski (2011) proposed that an increased

---

[*] Corresponding author.
E-mail address: adam.izdebski@uj.edu.pl (A. Izdebski).

http://dx.doi.org/10.1016/j.quascirev.2015.07.022
0277-3791/

availability of water derived from precipitation contributed to the economic expansion in the countryside across Anatolia, the Levant and Mesopotamia, while Witakowski (2010) argued that a trend towards drier conditions in the 6th-7th c. AD brought about the collapse of the intensive rural settlement in northern Levant (a similar hypothesis has been put forward by Coulton (2012) for a part of South-Western Anatolia, but for the 8th c.). At the same time, in a review paper discussing palaeoclimate data from the Mediterranean and Europe, McCormick et al. (2012a) concluded that Late Antiquity was indeed characterised by significant instability of climate compared to the previous period. This potential for the study of the links between climate and society has been further discussed concerning the case of Anatolia by Haldon et al. (2014).

In the context of this growing number of hypotheses about how climate could influence the course of the societal changes in the Eastern Mediterranean during Late Antiquity, this paper adopts a different, more comprehensive approach (Izdebski et al., this issue). First of all, it aims at reviewing all of the existing evidence on climate change in the period of 200–800 AD/1750-1350 cal BP. In order to observe both shorter and longer-term developments, we consider a period beginning a hundred years before the traditional starting date for Late Antiquity (ca. AD 300), and ending some hundred years after the traditional dates for the end of this period (ca. AD 650–700).[1] Our discussion includes all types of palaeoclimate data, be it historical (unusual weather events and subsistence crises attested in the written sources), archaeological (responses to the changes in the amount of precipitation visible in the extant material record), and environmental (palaeoclimate data, such as stable isotopes, as well as referring to other environmental proxies, such as pollen-based reconstructions). It is only after establishing the course of climatic changes that occurred in our study period, as well as their spatial extent, that we discuss the potential links between climate and social change. Thus, in the final section of this paper, we review hypotheses about the impact of climate on the society in Anatolia and the Levant in Late Antiquity that can be proposed on the basis of the existing evidence. In order to provide the necessary background information, we begin our article by a short overview of the historical events, the settlement history of our region, and of the key environmental processes.

The geographical foci of this paper are Anatolia and the Levant, which are rich in data on both past climate and society. Together with Egypt they formed the heartland of the Eastern Roman Empire in Late Antiquity, and several palaeoclimate sites, as well as archaeological projects, are located in various parts of these two regions. Egypt, on the other hand, while endowed with a rich archaeological and historical record (it is the only region of the Mediterranean that possesses an exhaustive record of everyday life thanks to the papyri), remains a special case that cannot easily be analysed together with our two study regions. On the one hand, Egyptian agriculture depends entirely on the Nile floods, which in turn are determined by a climate system that operates over Eastern Africa and the Indian Ocean, and which is only indirectly linked to the climate system of the Mediterranean (Lionello, 2012). In particular, the Nile flood is determined by summer rainfall of monsoonal origin, whereas moisture availability and river regimes in the rest of the Eastern Mediterranean are controlled by winter-season cyclonic precipitation. What is more, the fact that the social and economic life of late antique Egypt is known to us in incredible detail as compared to other regions of the Eastern Empire makes it particularly difficult to arrive at conclusions that apply to both Egypt and the rest of the empire (for the history of Egypt in our period, see Bagnall, 1993). Looking westwards, Greece and the Balkans had a very different political and economic history to the rest of the Eastern Mediterranean. Whereas Anatolia and the Levant enjoyed relative peace and stability until the 7th c. AD, the Balkans were constantly devastated by ‘barbarian’ raids and migrations from the 5th c. AD. In addition, while there is abundant archaeological record from Greece for our study period, palaeoclimate evidence from here is rather sparse. Also, for reasons of brevity, we exclude Cyprus from our survey of archaeological evidence. Finally, we do not include archaeological or environmental data from the Sassanian Empire, located at the eastern limit of our study region, as we want to focus on a culturally and politically uniform world of the Roman Empire, which facilitates greatly our comparison of the environmental and societal processes.

2. Background

2.1. Social and economic history of Anatolia and the Levant in AD 200–800

Our study period begins with the 3rd century AD, which after the successful reigns of the Severan dynasty saw the so-called Crisis of the Third Century, which lasted from the death of Alexander Severus in AD 235 until the accession to the throne of Diocletian in AD 284. During this period, the Roman Empire faced numerous devastating wars both in Europe and in the Middle East, and the imperial throne was contested every few years by competing emperors and usurpers from different parts of the empire (Ziolkowski, 2011). Diocletian finally managed to re-install order and stability throughout his long reign, and despite some re-occurring conflicts between military and political leaders competing for the throne, the 4th c. AD can be considered an era of consolidation. It was during this period that the new political-economic structure of the Eastern Mediterranean came into being, with the foundation of the empire's new capital, Constantinople, in AD 330, which completely re-organised the economic networks in the East (Cameron, 1993). In AD 395, the political division between the western and eastern parts of the empire became permanent, and from that moment on the Balkans, Anatolia, Levant and Egypt constituted a separate political entity, that is the Eastern Roman Empire. Contrary to its western counterpart, the Eastern Empire fared relatively well during the 5th c. AD, except for the Balkan provinces which suffered almost continuous warfare with the Huns and the Goths. It is during this peaceful century (which also saw the further elaboration of the Christian creed) that the economic consequences of the founding of Constantinople became fully visible. Not only did the city receive large grain shipments from Egypt, but it also attracted the agricultural surplus, through trade and taxes, from other parts of the East. In addition, the growing interest on the part of the imperial government in collecting taxes in cash rather than in kind encouraged increasing monetization of the entire economy, and provided a further incentive for economic expansion (Banaji, 2007).

In the 6th c., during the reign of Justinian I which lasted almost half of this century, the Eastern Empire undertook a program of large-scale political and military expansion, which resulted in prolonged (although often successful) wars both in the western part of the Mediterranean and on the Persian frontier. However,

---

[1] Late Antiquity is not the only name used in archaeological and historical scholarship for the period of ca AD 300–650. Other names include early Byzantine (in particular with regard to the Levant), late Roman or early Christian period. For the period after AD 650, names commonly used include early medieval, early Islamic, or—in Anatolia - early Byzantine. The actual confusion is even greater, since each archaeological project tends to define the actual chronological limits of these periods in different ways; at times, the differences amount even to a hundred years. In this paper, we avoid the use of culture- or religion-specific names (such as early Byzantine or early Islamic) and use instead the general terms, Late Antiquity and the early Middle Ages. We also attempt at translating the periods used by specific archaeological projects into this general framework.

Please cite this article in press as: Izdebski, A., et al., The environmental, archaeological and historical evidence for regional climatic changes and their societal impacts in the Eastern Mediterranean in Late Antiquity, Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.07.022

whereas the military expeditions were conceived towards the end of the prosperous era of the 5th-early 6th c., the empire had to cope with their consequences after the outbreak of the pandemic known as the "Justinianic plague" in AD 541. Moreover, the conflict with the Persian Empire culminated in the great war of the early 7th c., which resulted in an economic and demographic depletion of both belligerent states. These and other factors paved the way for the Arab conquest of the Middle East. Within a few years, the recently Islamicised Arabs managed to overtake all of Syria, Palestine and Egypt, and thus after AD 642 the Eastern Roman Empire was left only with Anatolia and the remnant territories in the Balkans and the West (Howard-Johnston, 2010). As a consequence, the empire, conventionally called Byzantium after that date, had to undergo profound changes in order to cope with the new situation. Byzantium's heartland, Anatolia, became the arena of Arab-Byzantine warfare for many decades from the mid 7th c., with Constantinople itself besieged in AD 668 and again in AD 717–718 (Haldon, 1997; Jankowiak, 2013). Whereas life in central Anatolia, in particular, became insecure at this time, in Syria and Palestine the new Arab regime of the Umayyads, based in Damascus, involved a large degree of continuity and political stability.

2.2. Rural settlement in Anatolia and the Levant in Late Antiquity

The period we discuss in this paper is now widely recognised as the era of a large-scale intensification of the rural settlement in several regions of the Mediterranean, in particular in its eastern part (Bintliff, 2012; Decker, 2009). In Anatolia, this phenomenon is visible in almost all archaeological surveys and excavations that focus on Late Antiquity (for a detailed list, see Table 1 in the Appendix) (Izdebski, 2013a, pp. 13–21, 2013b). Thus, we see it on the Mediterranean coast, in regions such as Isauria (Varinlioğlu, 2007) and Lycia (Kolb, 2008), in the Aegean (e.g., Lohmann, 2004) or on the Black Sea coast (Doonan, 2004). It is also present in the data from many inland regions, both in the mountains of South-Western Anatolia (e.g., Coulton, 2012) or on the central plains (e.g., Baird, 2003). The late antique rural settlement is remarkable for a large number of architectural finds - which has to do with the construction of new sites and expansion of the existing ones, as well as with the building of village churches. Moreover, the chronology of these sites is usually relatively well understood thanks to the fact that the generations-long research on the Late Roman ceramics makes it possible to identify with considerable certainty sherds of a late antique origin. This period's settlement pattern is also characteristic for the increasing nucleation: in the Hellenistic and Early Roman periods, villages and dispersed settlements, including small hamlets, co-existed within the same landscape; in Late Antiquity, villages became the dominant settlement type in the Anatolian countryside, which may have to do with the agricultural intensification and specialisation, requiring a more concentrated organisation of rural labour (cf. Wickham, 2005, pp. 443–465). Whereas beyond doubt the expansion trend culminated almost everywhere in the 5th-6th c. AD, the fate of the dense late antique rural settlement from the 7th c. onwards remains unclear. The early medieval ceramics are not so well understood as those of Late Antiquity, and thus the post-Roman rural settlement is much less visible; many surveys are simply unable to tell what happened with the late antique sites after the period when they reached their climactic phase. In fact, when we consider only the archaeological evidence, in all Anatolia there are only one or two clear cases of substantial settlement continuity (Balboura and perhaps also Sagalassos, both in SW Anatolia), plus only three cases (two of them excavations) of abandonment convincingly dated to the 7th c. This is very little compared to around fifteen sites or surveyed areas that offer evidence for the late antique intensification (Izdebski, 2013a, pp. 21–45).

In contrast to the image we get for Anatolia, extensive surveys and excavations conducted during the last decades in the Levant have provided a much more nuanced knowledge about the rural settlement (Chavarría, Lewit, 2004, pp. 16–21). In many regions, the late antique period seems to have been one of village growth, persistence of farmsteads and emergence of large settlements, neither villages nor cities, that are conventionally named towns (again, see Table 1 in the Appendix for a detailed list). The prosperity of Palestine and Transjordan during the 5th-6th c. is often referred to as a kind of 'success story' (Kennedy, 2000, p. 609), although already towards the end of this period there appeared signs of impoverishment in the cities, which are variously interpreted by modern scholars (Waliszewski, 2014, pp. 243–245).

The most famous among the regions which experienced the late antique prosperity is the Syrian Limestone Massif, which lies in a heavily urbanized area between the great cities of Antioch and Apamea-on-the-Orontes. Rapid settlement expansion started here already in the 2nd-3rd c. AD, initiating developments that transformed lands unsuitable for cultivation into a prosperous agricultural landscape (Tate, 1992). A substantial demographic growth in ca. AD 330–550 (culminating in AD 450–530) was connected with an increase in the size of settlements and individual farms. Stagnation set in around AD 550–610; the ultimate decline took place in the 9th-10th c., and was related to the increasing warfare between Byzantium and the caliphate (Eddé, Sodini, 2005). Even more detailed data are provided by several ground surveys that have been conducted in Palestine. In Upper Galilee, 106 sites were recorded for the Hellenistic period, with 170 for the Roman (98 of them newly established in this period) and 194 sites for the late antique period (again, 72 new sites). However, only 13 sites are attested for the Early Islamic period, which suggests that a dramatic decline occurred during the 7th-8th c. AD (Frankel et al., 2001, pp. 108–117). Results of a survey in Gaulanitis (Golan Heights) point to a similar population dynamics (143 early Roman and 173 late

Table 1
Key historical events in Anatolia and the Levant, AD 200–800.

Year AD	Key events and reigns
253–284	Military and political crisis of the Roman Empire
313	End of persecutions against Christians
330	Foundation of Constantinople as a new imperial capital in the East
395	Final division of the Roman Empire in two separate political entities, the Western and the Eastern Empires (the former later becomes Byzantium)
526–565	The reign of Justinian I - the height of the military and political power of the Eastern Roman Empire
541	The outbreak of the Justinianic Plague
602–628	The great war between Persia and the Eastern Roman Empire
636–642	The Arab conquest of Syria and Palestine
644–750	The Umayyad caliphate in Syria (Damascus), with repeated Arab raids and military campaigns into Byzantine Anatolia
750	The Abbasid revolution: the caliphate's capital transferred from Damascus to Baghdad by the new dynasty, with Iraq now becoming the centre of political and economic life

Please cite this article in press as: Izdebski, A., et al., The environmental, archaeological and historical evidence for regional climatic changes and their societal impacts in the Eastern Mediterranean in Late Antiquity, Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.07.022

antique sites; Ma'oz, 1993; Bar, 2004). Here, the number of settlements also declined gradually between the 7th and 9th c., after which the region became deserted. Samaria (Zertal, 2004, 2008, p. 59, pp. 90–91) and Judea (Bar, 2004) followed the same trajectory, with a more than twofold increase in site numbers between the early Roman and late antique periods; the population numbers achieved in Late Antiquity were never again to be matched until the modern times. Finally, moving to the south, also marginal regions, such as the Negev, saw a major settlement expansion, with site numbers increasing almost tenfold (from 111 to 958) between the Roman and late antique-early Islamic periods (Avner and Carmi, 2001, p. 1204). Contrary to the areas mentioned above, it seems that this 'green revolution' in the Negev lasted well into the 7th-9th c. AD, although the towns clearly declined by the latter part of this period (Rosen, 2000).

In summary, in both Anatolia and in the Levant there occurred a similar phase of rural settlement expansion that almost everywhere culminated in the 5^{th}-6th c. AD. From the 7th c. onwards, however, the regional development trajectories started to diverge. In fact, within both Anatolia and the Levant we observe a deep contrast between their western and eastern parts. Whereas in Anatolia the eastern and central regions seems to have experienced a sharp decline in settlement density, there is some evidence to suggest no major drop in settlement numbers for at least one region in the west. This pattern is even clearer for the Levant; here, however, it was the west, that is the heavily urbanized, fertile coastal plain, that experienced a marked decline, while the recently colonized regions east of the north–south mountain chains and the Jordan river show signs of substantial continuity of the late antique population levels (Lucke et al., 2012). In other words, it seems that the previously homogeneous and prosperous rural world of the late antique Eastern Mediterranean more or less collapsed across the central zone stretching from Gaza to Cappadocia, while the western and eastern "peripheries" survived the 7th c. rather intact (although it is very likely that our knowledge of the early medieval developments in both Levant and Anatolia will significantly change in the near future). In this context, one of the aims of this article is to explore to what extent these cycles of growth and contraction were in any way temporally correlated with, or actually at least partially caused by, the changes in regional climatic conditions.

2.3. *Palaeo-environmental evidence for land-use change in late antiquity*

The period AD 200–800 was the final phase of the rural agrarian system of Antiquity in the Eastern Mediterranean, and it is clearly reflected in palaeoenvironmental records, just as it is in historical texts and archaeological material. In both Anatolia and the Levant, from the Late Bronze Age onwards (and in particular after the beginning of the Hellenistic period) the characteristic vegetation and form of land-use was the Beyşehir Occupation Phase (BOP) (Bottema et al., 1986; Bottema and Woldring, 1990; Eastwood et al., 1998). It was characterized by cereal cultivation, arboriculture (olive, vine, fruits and nuts) and a significant presence of pastoral activities. Such a combination of agricultural practices resulted in the creation of a specific anthropogenic landscape that is visible in pollen data coming from various parts of the Eastern Mediterranean from as early as the second millennium BC until the mid-first millennium AD. This vegetation pattern was first identified in the pollen record of Lake Beyşehir in South-Western Anatolia; the presence of similar pollen assemblages dated to the same period in other pollen sites from this part of Turkey led to the creation of the notion of a more widespread land-cover pattern characteristic of the entire area during much of the Late Holocene. It is now clear that this phase occurred not only in Anatolia, but – in modified form - across the entire Eastern Mediterranean, in particular from the Hellenistic period onwards (after the 4th c. BC) (Eastwood, 2006; Haldon et al., 2014; note 27, and Izdebski, 2013a, p. 131 note 54, contain detailed lists of pollen sites which record the BOP). Thus, apart from many sites in northern, south-western and central Anatolia, the BOP has been identified at numerous sites located in the Levant such as the Golan Heights (Neumann et al., 2007), the Sea of Galilee (Baruch, 1986), the Dead Sea (Leroy, 2010; Neumann et al., 2010), or Wadi Faynan in Jordan (Hunt et al., 2007), as well as on Cyprus (Kaniewski et al., 2013). Moreover, pollen assemblage zones similar to the BOP are also visible in data coming from the Caucasus region, from both Iran (Djamali et al., 2009) and Georgia (de Klerk et al., 2009). This widespread presence of the BOP, especially during the final phases of Antiquity, suggests that it became the standard mode of agriculture for the Hellenistic-Roman societies that developed following first Alexander the Great's and then Rome's conquests.

Interestingly, at many sites, Late Antiquity seems to represent a climax in the development of the BOP, with anthropogenic indicators achieving their highest proportionate values for the entire period of Antiquity. At the same time, however, Late Antiquity also saw the end of the BOP, except for a few specific cases. What is most interesting is that this termination was not a uniform phenomenon that occurred everywhere at the same moment. Even if we account for the dating error inherent in the pollen core chronologies based on radiocarbon dates, the differences between sites are still large enough to conclude that the end of the BOP was a complex process lasting from the 2nd c. AD until at least the 8th c. AD, or even considerably later (Izdebski, 2013a; Haldon et al., 2014). At least in Anatolia, there are convincing arguments for concluding that the precise end date for the BOP in the majority of sites had to do with political and economic processes, rather than with natural factors (Izdebski, 2013a, pp. 145–201). It is not certain, however, whether this was also the case everywhere across the Eastern Mediterranean, even though, for instance, in Southern Levant olive cultivation became considerably reduced in the early Islamic period as compared to Late Antiquity (Waliszewski, 2014, pp. 93–97). It must be borne in mind that like all land-use patterns, the BOP depended on natural factors as well as human ones, including climatic changes. Thus, one of the objectives of this article is to attempt at distinguishing between the influence that people exerted on vegetation and the role that climate fluctuations occurring in the period of AD 200–800 played in the termination of the BOP. This is a yet another reason to focus on Anatolia and the Levant, which together provide the major part of the Eastern Mediterranean pollen record.

3. The data on climatic changes in late antiquity and their consequences

3.1. *Direct evidence*

3.1.1. *Palaeoclimate proxies*

The synthesis of proxy climate data presented here focuses on well-resolved palaeoclimate data series from western-central Anatolia and the Levant, along with a brief comparison with data sets from further afield. We have selected sequences that are relatively well dated by multiple ^{14}C or U–Th ages, or by varve chronologies, and which have a mean sampling interval better than ~50 years. We also focus initially on proxies that can be related unambiguously to past climatic conditions, rather than the wider spectrum of evidence (e.g. pollen data) which would have been influenced by climate, but which was also affected by other controls, such as human impact. These primary climate proxies include chemical/isotopic analysis of cave speleothems, and lake and

Please cite this article in press as: Izdebski, A., et al., The environmental, archaeological and historical evidence for regional climatic changes and their societal impacts in the Eastern Mediterranean in Late Antiquity, Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.07.022

marine sediment cores, which have responded primarily to changes in effective moisture availability, incorporating both precipitation and, via evaporative losses, temperature as well. On the other hand, there are very few direct records of temperature changes *per se* from the Eastern Mediterranean region. It is therefore difficult to know if the so-called "Roman Warm Period" (RWP) in Anatolia and the Levant was as warm as (or warmer than) Medieval times or the 20th-century, although temperature syntheses for northern hemisphere mid-latitudes in the last two millennia support the occurrence of warmer than average summers during much of the first three centuries AD (Ljungqvist, 2010; Büntgen et al., 2011). This is consistent with a range of qualitative evidence from the Eastern Mediterranean region; for example, the cultivation of olive trees and vines at elevations higher than their current climatic limit in areas such as southwest Anatolia during Classical times (see Roberts, 1990; and England et al., 2008; for further discussion). The written record (discussed below) provides further information about conditions during specific years, including severe winter weather (cold, snow, freezing). One potential proxy record of winter snowfall in central Anatolia derives from a comparison of $\delta^{18}O$ measurements on biogenic silica and endogenic carbonate from Nar lake (Dean et al., 2013) (# 3 on Fig. 3). Lake carbonates are precipitated in early summer whereas the Si_{bio} is formed mainly from diatoms, many which bloom earlier in the year and which may therefore incorporate isotopically-light water deriving from snowmelt. The $\delta^{18}O_{carb}$ and $\delta^{18}O_{diatom}$ curves track each other quite closely for most of the last 1700 years (after allowing for fractionation offsets), but diverge around AD 320–360, 420–530 and again ~700 (see Fig. 4a). The anomalously light $\delta^{18}O_{diatom}$ values at these times may have been the result of more winter snowfall or a longer period of snow cover. Although these isotopic offsets could have other explanations (e.g. related to problems of detrital Si contamination), they would be broadly consistent with the overall cooling trend inferred from European

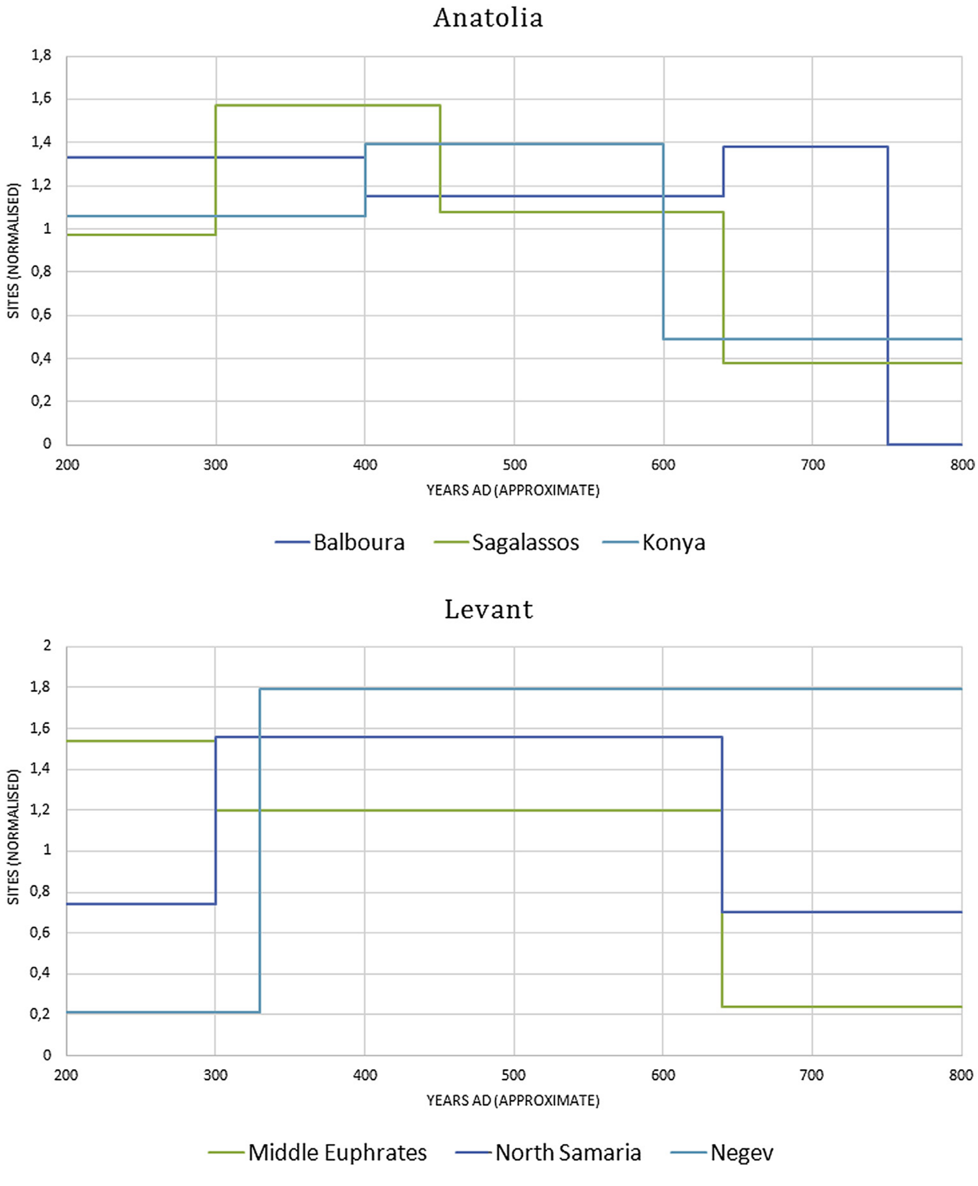


Fig. 1. Site numbers (normalised) per period in selected areas of Anatolia and the Levant according to archaeological field survey data (based on site data from the primary studies: Balboura: # 7 on Fig. 2 below; data: Coulton, 2012, table 7.1, p. 170; Sagalassos: # 8 on Fig. 2 below; data: Vanhaverbeke, 2003, Fig. 14, p. 147; Konya: # 9 on Fig. 2 below; data: Baird, 2003, Fig. 3, p. 225; Middle Euphrates: # 14 on Fig. 2 below; data: Waliszewski, 2011, 225; North Samaria: # 25 on Fig. 2 below; data: Zertal, 2004, 59, and Zertal, 2008, 90–91; Negev: # 34 & 35 on Fig. 2 below; data: Avner and Carmi, 2001, Fig. 1 on p. 1204).

Please cite this article in press as: Izdebski, A., et al., The environmental, archaeological and historical evidence for regional climatic changes and their societal impacts in the Eastern Mediterranean in Late Antiquity, Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.07.022

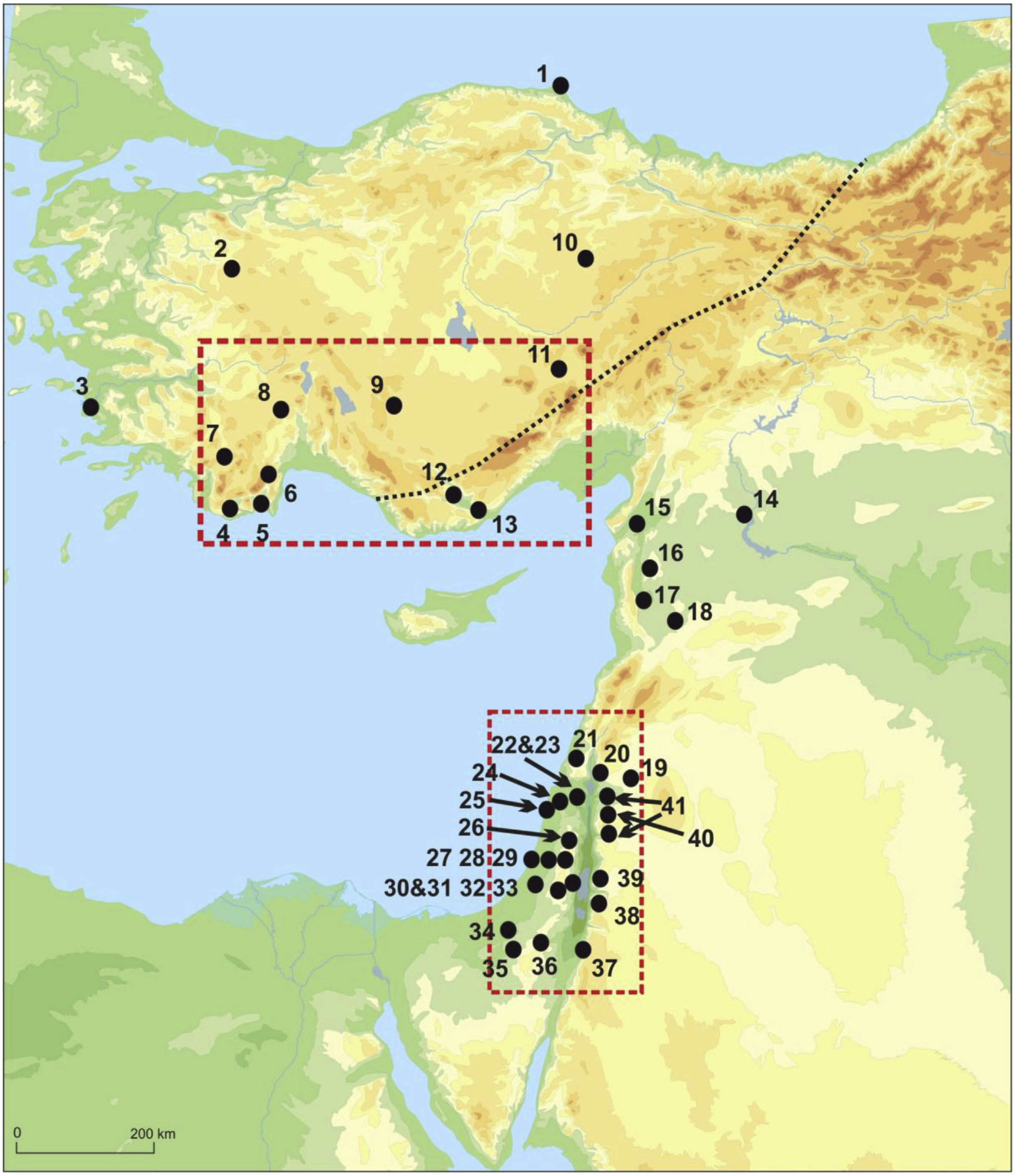


Fig. 2. Archaeological sites and survey areas in Anatolia and the Levant with the approximate Byzantine-Arab border ca. 670 AD (for numbers, see Table 1 in the Appendix). Red boxes show the sub-regions represented on the synthetic diagram (Fig. 7, see below). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

tree rings during the 4th-6th centuries (Büntgen et al., 2011).

The coldest decade of the first millennium AD was almost certainly from AD 536–545. This is clearly evident in narrow tree rings from many sites world-wide, and was associated with the AD 536 Dust Veil event that was probably caused by a major volcanic eruption (Larsen et al., 2008) or a cometary/asteroid impact (Baillie, 1994). The unusual weather conditions were recorded by contemporary chroniclers such as Procopius and Cassiodorus (Arjava, 2005), and led to crop failure, unripened fruit and sour wine, although a bumper harvest the previous year seems to have ensured that famine was avoided (Gunn, 2000; Stathakopoulos, 2004, p.265 ff.). This short-lived climatic cooling triggered by higher atmospheric aerosol (e.g. dust) concentrations may in turn have contributed to the onset of the first Justinian plague pandemic in AD 541–542 (Keys, 1999).

Proxy records for variations in effective moisture across Anatolia and the Levant are much better than those for palaeotemperatures. In particular, there are high-resolution studies of

Please cite this article in press as: Izdebski, A., et al., The environmental, archaeological and historical evidence for regional climatic changes and their societal impacts in the Eastern Mediterranean in Late Antiquity, Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.07.022

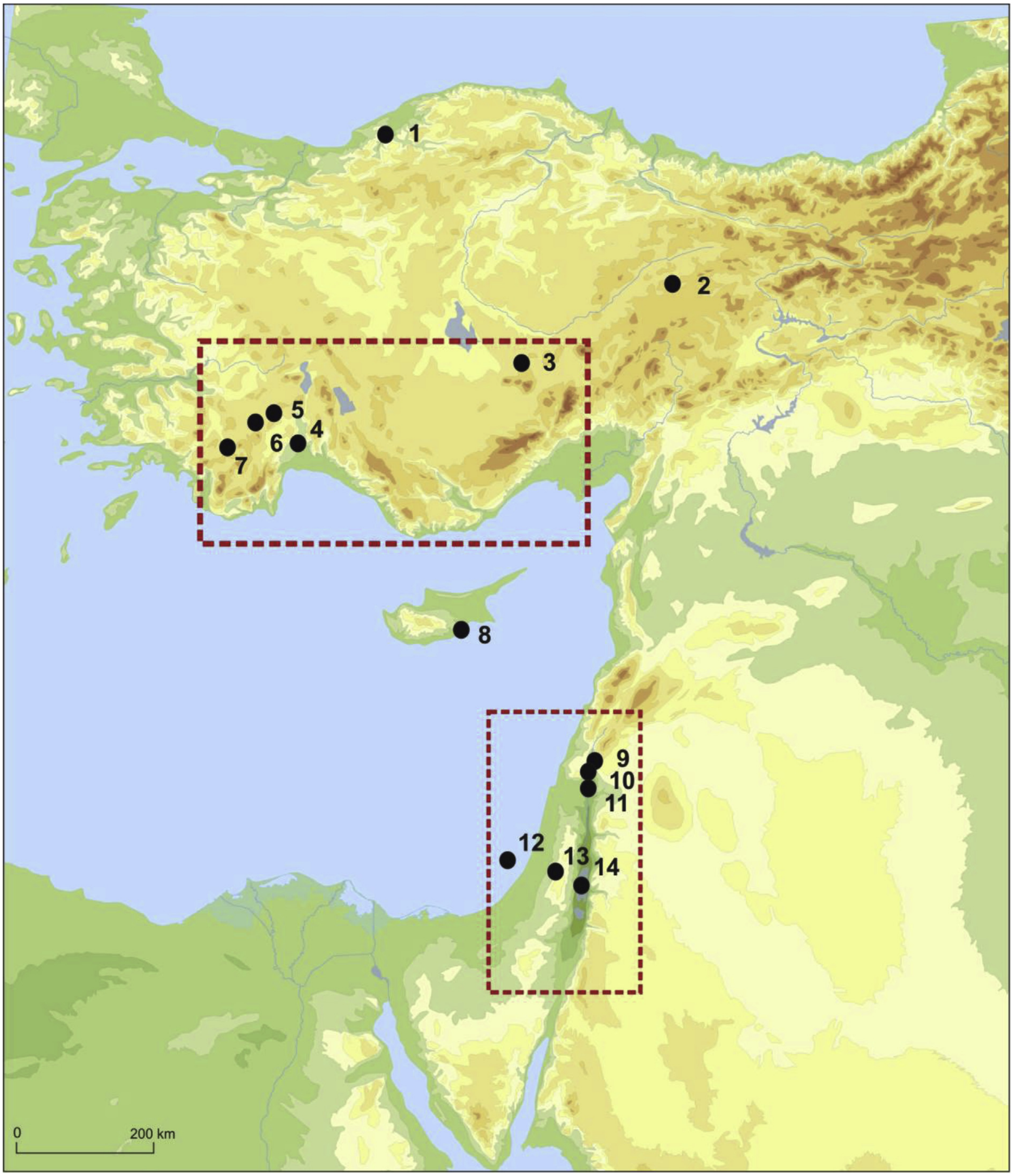


Fig. 3. Paleoenviornmental sites in Anatolia and the Levant discussed in this paper(for numbers, see Table 2 in the Appendix). Red boxes show the sub-regions represented on the synthetic diagram (Fig. 7, see below). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

cave carbonates (speleothems) from Soreq in Israel (# 12 on Fig. 3) and Sofular in northwest Turkey (# 1 on Fig. 3) (Orland et al., 2009; Göktürk et al., 2011), and of annually-laminated sediments (varves) from Nar lake in Cappadocia (Jones et al., 2006), all of which are well-dated and moisture-sensitive. All three records have been analysed via geochemical methods including the stable isotope ratios of carbon and oxygen, while Nar lake cores have also been analysed for biological indicators such as diatom assemblages (Woodbridge and Roberts, 2011). These sequences are supplemented in Fig. 5 by less highly-resolved and less well-dated records from Tecer lake in central Anatolia (# 2 on Fig. 3) (carbonate geochemistry and sedimentology; Kuzucuoğlu et al., 2011) and from two shallow marine cores off the southern Levant coast (# 11 on Fig. 3) (stable isotopes; Schilman et al., 2001). It should also be noted that the Soreq record, which includes separate laser-ablation measurement of light and dark carbonate bands, only has a high temporal sampling interval prior to ~520 AD.

A first key question is how well these five records agree with each other, in terms of the pattern and timing of inferred changes in moisture balance. Response times to climate change vary between

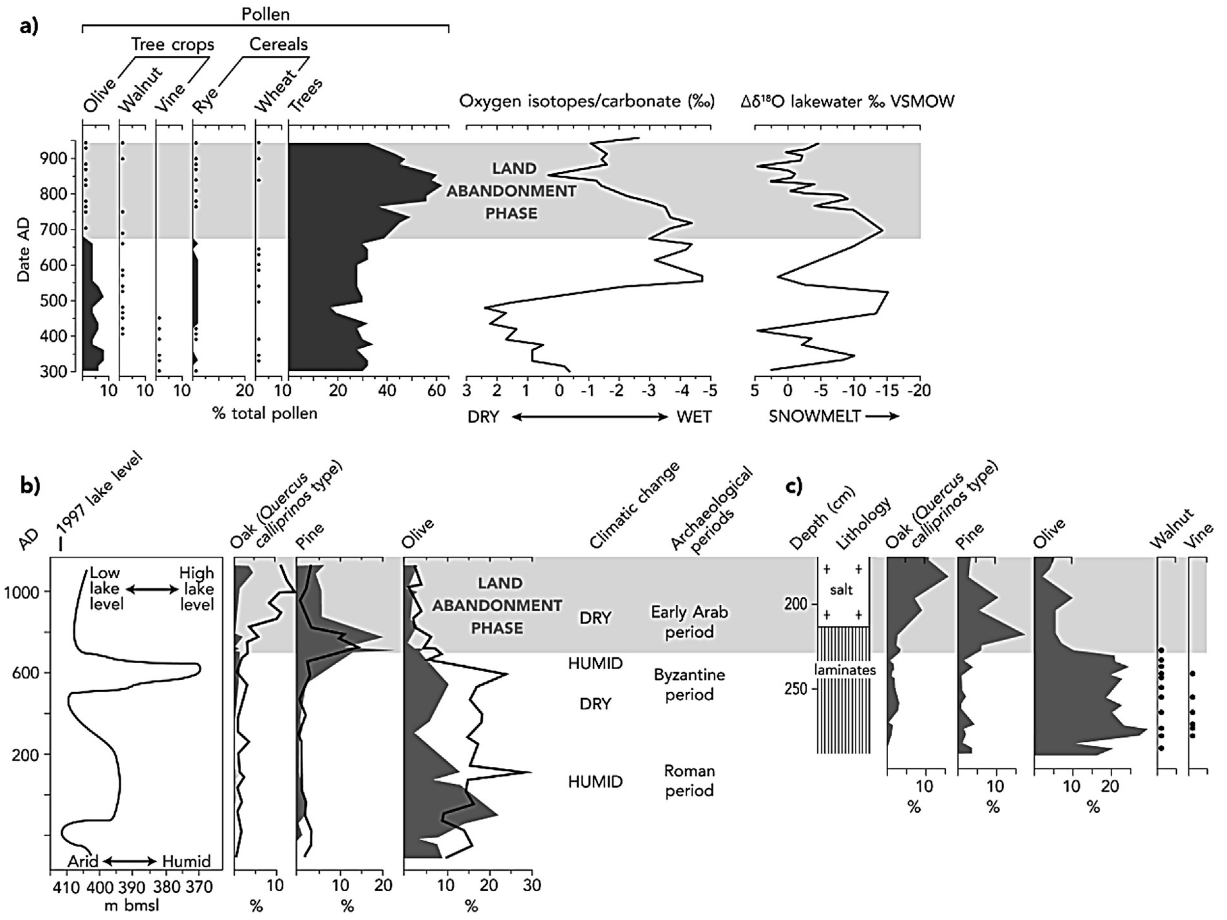


Fig. 4. Multi-proxy records of changes in climate and pollen-inferred land cover during the first millennium AD. a) Nar lake, central Anatolia (data from Jones et al., 2006; England et al., 2008; Dean et al., 2013); b) and c) Dead Sea records, from Ein Feshkha (b. black line), Ze'elim (b. shaded curves) and core DS7-1SC (c.) (modified from Migowski et al., 2006; Neumann et al., 2007;and Leroy, 2010).

different natural archives and there may also be internal threshold effects, especially for lake systems. For instance, Nar lake water has a mean residence time today of 8–11 years, which means that its response to climatic conditions would have been averaged over a decadal time interval (although this too may have changed in the past, being longer during times of low water level, and shorter when lake levels were high). Consequently, the Nar $\delta^{18}O$ record will not have registered year-to-year weather variations in the way that tree rings can. The non-laminated sediment cores from Tecer lake and off the Levantine coast were subject to turbation (mixing) effects, smoothing their records and generating multi-decadal mean values. In other records, such as Lake Gölhisar in southwest Anatolia (# 6 on Fig. 3), which has both pollen and stable isotope data (Eastwood et al., 2007), sediment mixing has meant that the Late Holocene climate signal is probably averaged over an even longer time period, and therefore only makes it possible to identify multi-centennial climate trends.

The climate time series shown in Fig. 5 lie on a northwest-southeast transect from close to the Black Sea to near the Nile delta (Fig. 3), and it is consequently far from obvious, *a priori*, that the different sites must have experienced the same climate histories over the last two millennia. Indeed for the period of instrumental weather measurements since the mid-19th century, winter precipitation shows an inverse spatial correlation between northwest Anatolia and the southern Levant, partly linked to the North Atlantic–or Mediterranean - Oscillation (see Roberts et al., 2012, Fig. 1). In fact, although not identical, the five records in Fig. 5 show a broad similarity in the pattern of fluctuations over time between drier and wetter climates. Although there are some apparent offsets in the timing of climate shifts between sites, these appear to be largely within the error of dating uncertainty; for example Soreq is dated by U–Th ages within a standard error no better than ±110 years (Orland et al., 2009). It is therefore entirely plausible that climate shifts occurred synchronously across the whole region, although it is certainly possible that there were some lag and lead effects. The Levant and Anatolia do not seem to have experienced an anti-phase climate see-saw relationship during the 1st millennium AD; nor did they during the last millennium (Roberts et al., 2012). However, macro-regional climatic changes that we describe below in more detail would obviously have had consequences that varied locally, given that the study area is strongly differentiated in terms of elevation, proximity to the sea, and other important factors.

Prior to ~300 AD, all records show a phase of relatively wet (and probably warm) climatic conditions, marking the latter part of the RWP. A relatively wet climate during the RWP is also indicated from ^{14}C-dated shorelines around the Dead Sea (# 13 on Fig. 3), reflecting high water levels in this terminal lake system and positive water balance in the Jordan river catchment (Enzel et al., 2003; Bookman et al., 2004; see Fig. 4b). After ~300 AD there was a gradual decrease in effective moisture in both Anatolia and the Levant, reaching a minimum between AD 350 and 470, depending on the individual record. This dry phase is marked by increasingly positive isotopic values in lake, cave and marine sediments, by aragonite

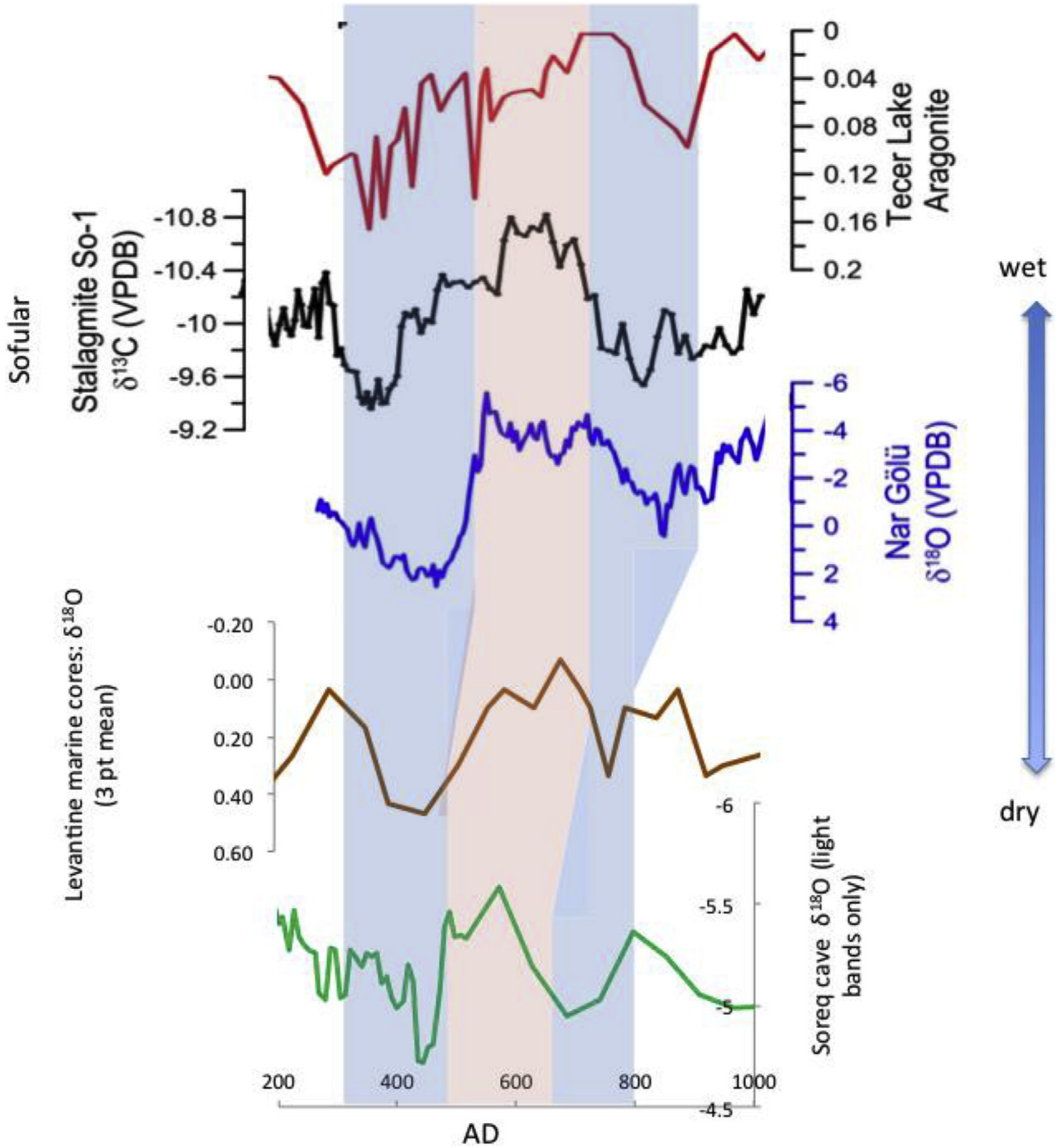


Fig. 5. Proxy records of hydro-climatic change in Anatolia and the Levant, 200–1000 AD, with the drier and wetter periods marked for each record (see Table 2 in the Appendix for sources).

precipitation in Tecer lake, and by a predominance of salt-tolerant diatoms in Nar lake. The occurrence of an important period of drought conditions at this time across the wider Eastern Mediterranean is supported by evidence for low water levels in a number of other lakes in the region including the Dead Sea and Marmara Gölü (western Anatolia; Besonen and Roosevelt, in review). Most sequences indicate that this dry (and probably colder) phase lasted 100–150 years, although the Soreq cave isotope data suggest that within it there may have been a shorter interval of about 40 years during the mid-5th c. when the drought was most intense. This late Roman drought phase ended abruptly in a number of proxy-climate sequences; for instance at Nar lake and Soreq cave, the subsequent dry-to-wet climatic transition (AD 470–560) was both rapid and of high amplitude. The Dead Sea level also rose abruptly during early Byzantine times, although some ^{14}C dates (e.g. Bookman et al., 2004) puts this lake high-stand and inferred maximum wetness earlier than the records shown in Fig. 5. This transition was probably one of the most dramatic climatic shifts to affect the Eastern Mediterranean during the last 2500 years, hinting at a large-scale re-organisation of atmospheric circulation. The AD 536 Dust Veil event and subsequent decade of cold temperatures are most likely to have occurred towards the end of this larger-scale climatic shift.

The following late antique wet phase lasted for around two centuries, peaking during the 6th and 7th c. It overlapped in time with a period of renewed agrarian prosperity and an expansion of rain-fed and runoff farming into dryland regions such as the Negev (see below). In some regions, such as Cappadocia, this seems to have been among the most favourable climatic phase for rural settlement and agriculture since Neolithic times. During the 8th-c. precipitation levels gradually decreased, reaching a minimum in most records at or just after 800, although in Anatolia at least, this dry phase was much less severe than the late Roman “mega-drought”. At Soreq the inferred rainfall minimum is dated slightly earlier (AD 660–780), although this may be due to lower sampling resolution and dating precision for this part of the speleothem record. Isotopic analysis of both dark and light carbonate laminae at Soreq has allowed changes in seasonality to be evaluated (Orland et al., 2009). Between the 1st and 8th centuries there was a

Please cite this article in press as: Izdebski, A., et al., The environmental, archaeological and historical evidence for regional climatic changes and their societal impacts in the Eastern Mediterranean in Late Antiquity, Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.07.022

progressive decrease in maximum $\delta^{18}O_{\mathrm{dark-light}}$ values, interpreted as an increasing seasonal contrast (i.e. drier summers or shorter wet seasons). In contrast to Anatolia, estimated rainfall levels in the southern Levant by AD 800 may have been as low as, or even lower than, they were in the 5th c. (Orland et al., 2009, Fig. 6C). This would seem to be in accord with evidence from the Dead Sea, where a long-lasting lake low-stand occurred after the Byzantine period and continued at least until the 9th c. (Bookman et al., 2004; Migowski et al., 2006). In summary, while there was an overall decline in effective rainfall between the high point of Roman imperial rule in the 2nd c. and the time of Arab invasions and conquests (7th c. onwards), this was not a progressive decline over the intervening time period. Instead it involved two downward steps in precipitation, firstly centred on the 4th c. and secondly on the later 7th and 8th c., separated by a period of much more favourable climate centred on the 6th and early 7th c.

3.1.2. Textual evidence on weather and climate

For the purpose of this paper, we prepared a list of all weather events that occurred in Anatolia and the Levant in our study period (AD 200–800). The list is based on a database prepared by a team led by McCormick in 2012, which was used by them for a study on the role of climate fluctuations in the history of the Roman Empire (McCormick et al., 2012a). The database covers the years 100 BC - AD 800 and almost all of its material for the Eastern Mediterranean in the period of AD 300–800 comes from an earlier study by Telelis. In his publications, Telelis gathered and analysed the written evidence on weather events coming from a wide variety of Greek sources plus a substantial amount of the same data from the oriental sources (Syriac, but also Arabic) for the Eastern Mediterranean in the period of AD 300–1500 (Telelis, 2008, 2004). The resulting list of weather events, as well as detailed diagrams, are provided in the Appendix.

As is visible on Fig. 6, climatic trends visible in the Anatolian and Levantine textual data surveyed by Telelis are not always the same; more importantly, they do not correspond very well with the trends that are visible in the palaeoclimate proxies (see Section 3.1.1). This is due to several factors, which may have to do with both the unequal coverage of areas and periods by the existing textual record, and with the sensitivity of the late antique texts to the actual climatic fluctuations (which is not constant, but rather varies with literary genres and periods). Thus, the imbalance of the textual record with regard to both regions is evident, for instance, in the fact that very few events are recorded for Anatolia in comparison to the Levant for the period AD 650–800. Another problem we face when interpreting the textual record, is its bias for the relatively extreme, and in some cases, short-lived weather events. This is most obviously in the case of floods and excessive rains, which should not be used as a reliable basis for estimating mean precipitation levels. On the other hand, droughts might potentially carry greater significance from the climatological point of view. However, while droughts recorded in the Levant during the later 7th and 8th c. match proxy evidence for climatic desiccation, those for the later 5th and 6th c. do not.

This and other problems that make it impossible to fully integrate the late antique-early medieval textual record with palaeoclimate proxies are not surprising, if we consider the fact that in the vast majority of pre-modern texts the information on weather events or natural disasters cannot be interpreted simply as a record of an extreme weather event that took place at a given point in time at a specific location (as is possible for the archival historical evidence for the early modern period in Europe, cf. Pfister et al., 1999). Rather, the role that such events have in these texts is completely different: the occurrence of natural catastrophes is used as an argument in favour of a certain view in political or religious controversies, which means that testimonies of such events almost always serve an ideological purpose. Consequently, they should first of all be understood as a rhetorical tool used to persuade the reader to accept a certain opinion, rather than as a piece of information about actual weather conditions (Janiszewski, 1997, 2000).

Finally, it should also be noted that neither the database prepared by McCormick and others, nor Telelis's survey took full account of all the existing written sources from the period of AD 200–800, but focused only on those texts that promised to yield the largest amount of weather-related testimonies. Thus, Telelis based his work on the annalistic and narrative sources, that is the lives of saints, works of both classical-style and ecclesiastical historiography, and universal chronicles (Telelis, 2008, 2004). Consequently, the results shown on Fig. 6 do not reflect all the existing written material from our period, but only a significant part of this textual corpus. If we look beyond the texts analysed by Telelis and later by McCormick and others, we find that there exist sources that offer additional information about the climatic conditions in Late Antiquity. This applies in particular to the sermons, which are preserved in large numbers and which often reflect more or less directly the socio-economic and sometimes even natural conditions that existed at the time of their composition and delivery (Cunningham and Allen, 1998; Allen et al., 2009). Among these sources, there are several texts that mention drier conditions in Anatolia and Northern Syria in the period of AD 350–400, which together deserve further and more detailed study. For instance, Basil the Great's sermon *In time of famine and drought* (published in, *Patrologia Graeca* 31,303–328) describes an unusually cool and dry winter followed by a very dry and warm summer (for an analysis of this sermon, see Holman, 2001, pp. 76–83).

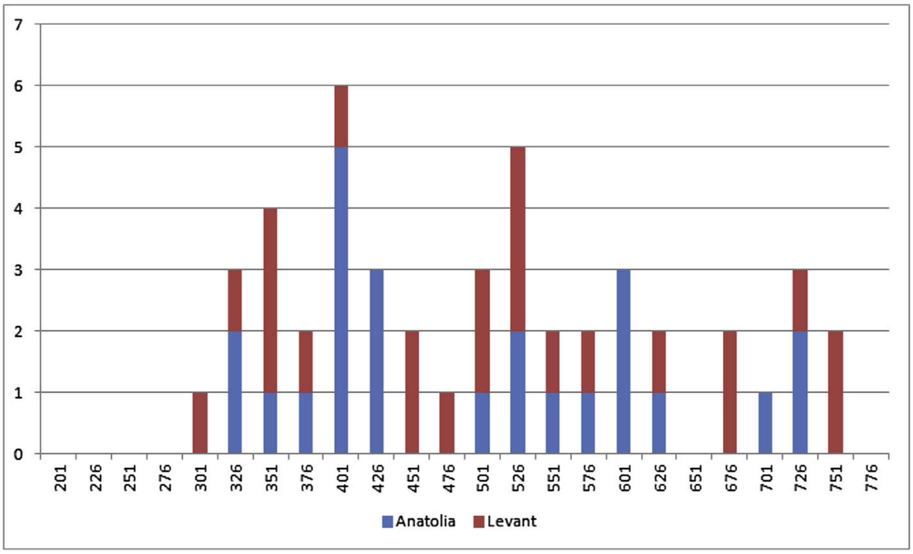
3.2. Indirect evidence

3.2.1. Palaeoenvironmental data

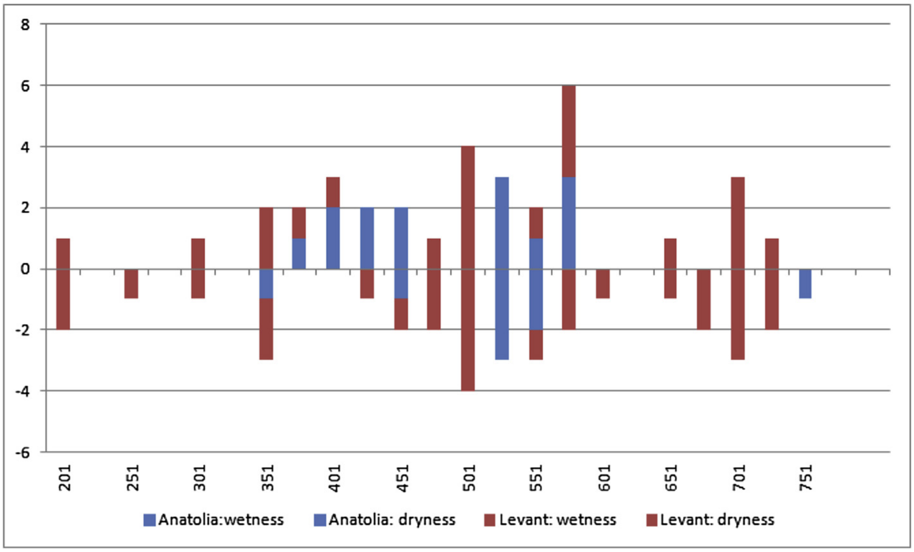
As noted above, pollen provides very important evidence for rural land-use change in late Antiquity in Anatolia and the Levant, notably via the end of the Beyşehir Occupation Phase (BOP). Some authors (e.g. Bakker et al., 2012; Kaniewski et al., 2012, 2013) have gone further and have attempted to use pollen to reconstruct simultaneously both climate and human impact, by partitioning pollen taxa between different controlling agencies via multi-variate statistics. However, this approach is potentially problematic for a number of reasons. Firstly, there is auto-correlation within all percentage data, so that an increase in one taxon automatically causes a decrease in the share of other taxa (in principle this difficulty could be overcome by using absolute pollen concentrations rather than percentage data, but in practice, this has not been done). Secondly, many common taxa (e.g. grass pollen) cannot be attributed clearly to either climate or human disturbance, but were likely affected by both agencies, and the importance of different controls would have altered through time (i.e. they were non-stationary). Finally, as Juggins (2013) has demonstrated, when partitioning an information-rich data set such as pollen by statistical methods such as Principal Component Analysis, "variance partitioning of the forward-selected variables gives a misleading impression of the nature and degree of confounding effects on the variable of interest, and hence will usually overestimate its unique explanatory power" (Juggins, 2013, p.28). In short, the same information variance cannot be used to estimate multiple parameters. Not surprisingly, where this has been done, there has often been a close statistical similarity between reconstructed parameters (e.g. temperature and precipitation, as in Litt et al., 2012; or rainfall and agrarian indicators, as in Kaniewski et al., 2013). These apparently close correlations may therefore prove to be spurious.

That is not to say that pollen, or other indicators such as fluvial

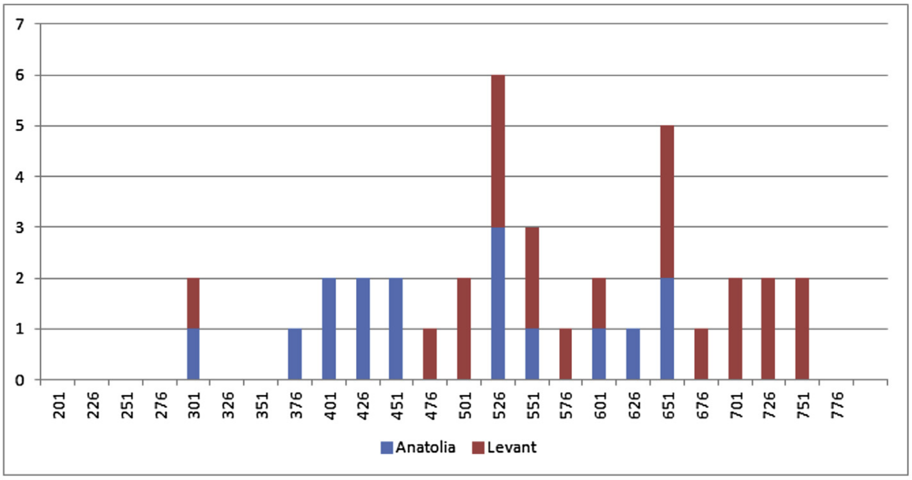
Please cite this article in press as: Izdebski, A., et al., The environmental, archaeological and historical evidence for regional climatic changes and their societal impacts in the Eastern Mediterranean in Late Antiquity, Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.07.022



Frequency of famines per 25-year periods



Wetness-dryness index per 25-year periods



Severe winters per 25-year periods

Fig. 6. Famines in Anatolia and the Levant in AD 200–800 per 25 year-periods compared to the frequency of unusually wet and dry climate events, based on the textual sources (Based on Harvard's *Geodatabase of Historical Evidence on Roman and Post-Roman Climate* (McCormick et al., 2012b)). For more detailed figure, showing the frequency of each type of weather events (excessive rains, droughts, floodings), please see Fig. 1 in the Appendix.

Please cite this article in press as: Izdebski, A., et al., The environmental, archaeological and historical evidence for regional climatic changes and their societal impacts in the Eastern Mediterranean in Late Antiquity, Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.07.022

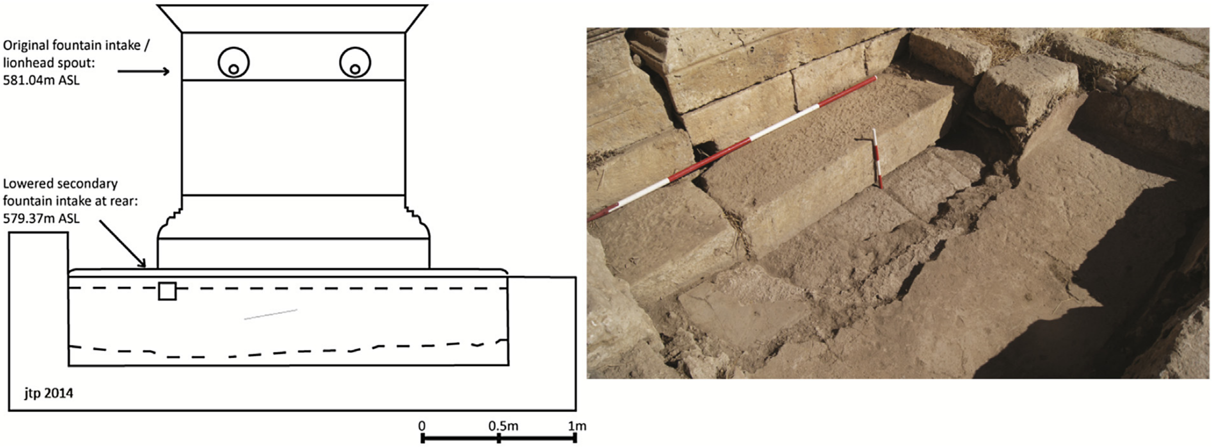


Fig. 7. Fountain 7 on the Cardo at Jerash, built early third century CE: The elevation drawing at left indicates how a secondary modification of the fountain's supply system lowered its original intake by 1.67 cm (from 581.04 to 579.37 m ASL); the photo at right shows the lowered intake behind the meter stick, as well as the contraction of the fountain basin: in a later phase, ashlars were set onto the original tiled fountain surface at back right, and the basin's Byzantine/Umayyad mortar lining was set almost 50 cm in front of the original rear surface (which had been flush with the back sidewalk step). These actions together reduced the amount of water available in the fountain basin by 40%, from 2.7 to 1.6 m3. (Photo and plan by Jordan Pickett).

sedimentary sequences, do not contain a climate signal. They do, but in regions such as the Mediterranean during the Late Holocene it is difficult to disentangle climatic from non-climatic controls (see Luterbacher et al., 2012, pp. 126 ff. for further discussion). Instead, it may be more useful and interesting to use these data sources to assess how vegetation, human activities or rivers responded – or failed to respond – to climatic forcing as registered in other, independent sources.

One of the main limitations to comparison of potential causes and effects in the past is the need for precise and reliable chronological correlation between proxy data sets. In practice, it is often difficult to achieve a correlation better than ±200 years when comparing sequences dated by calibrated ^{14}C along with age-depth modelling. On the other hand, if the proxies derive from the same stratigraphic sequence, then it is possible to make secure and robust comparisons between them without the risk of mis-correlation. The explanatory power of this multi-proxy approach is illustrated in Fig. 4a, which shows pollen and stable isotope data from Nar lake in central Anatolia for the period from ~300 to ~900 AD. The pollen data from this site show a period of land abandonment (the end of the BOP) marked by an increase in secondary woodland and a sharp decline in crops and other agrarian indicators, while the δ^{18}O data show alternating periods of drought and wetter climate over the same time period. If these two proxies had been derived from separate sequences, each one dated independently, there would have been a risk of associating land abandonment with drought events by a process of “suck in and smear” (Baillie, 1991). However, in the Nar lake sequence, it can be clearly shown that the end of the BOP occurred two centuries after the last previous major drought period, and therefore that a direct climatic causal explanation for rural land abandonment can be falsified.

Similar multi-proxy records for the Eastern Mediterranean during the first millennium AD have the possibility for cause-and-effect relationships to be tested, linking climate and societal response. For example, there exist a number of pollen records from the western side of the Dead Sea which show clearly the end of a BOP-like cultural landscape phase during the mid-1st millennium AD (e.g. Neumann et al., 2010). Following a period of high *Olea* values, indicating extensive Roman-late antique olive tree cultivation on the Judean hills, olive pollen declines sharply and is replaced by secondary woodland indicators, notably by pine and evergreen oak, during the subsequent Arab period (Fig. 4b). A similar sequence of land-use and vegetation change at this time can be found in pollen diagrams from the upstream part of the Jordan river catchment, at Birkat Ram in the Golan Heights (# 8 on Fig. 3) (Neumann et al., 2007), and from lakes Huleh and Kinneret (# 9 & 10 on Fig. 3) (Baruch, 1986; van Zeist et al., 2009), confirming that it represents a region-wide trend. As a climate-sensitive non-outlet lake, the Dead Sea also possesses a record of past climatic changes, via fluctuations in its water level. Its lake-level history has been reconstructed from ^{14}C dating of marginal beach deposits (Bookman et al., 2004) and from lithological changes in lake cores, for example between halite and laminated carbonate facies (Heim et al., 1997). Comparison of the pollen and lake-level records indicates a broad synchronism between fluctuations in cultivation, vegetation and climate change in the Dead Sea region during the 1st millennium AD (Neumann et al., 2010). Thus it appears that periods of expanded agricultural land use coincided with higher Dead Sea levels and more favourable (i.e. wetter) climatic conditions; for example, during the late antique period. By the 8th-c., when Roman-Byzantine had been replaced by Arab rule, the pollen record indicates widespread abandonment of olive groves, while low lake levels imply a reduction in effective moisture over the Jordan river catchment. This post-classical desertification is consequently likely to have had climatic, political and socio-economic causes, as was suggested for instance in the case of the Wadi Faynan in southern Jordan (Barker et al., 2007).

Less clear is the precise temporal relationship between mid-1st millennium AD climatic deterioration and societal change in the southern Levant; i.e., at a sub-centennial timescale. Did the decline in rainfall precede the early 7th-c. Arab invasions, did the two processes coincide, or did the climatic deterioration post-date the change in political and societal regime? While the evidence, including the absolute dating, seems ambivalent on this question, it is intriguing to note that in the DS7-1SC core, off-Ein-Gedi, the facies change from laminites to halite occurs slightly above (i.e. later than) the pollen change marking the end of the BO-like phase (Fig. 4c) (Leroy, 2010). On that basis, the shift from olive-cereal cultivation to pastoralism would have taken place a few decades before the transition to a drier climate, which then could not have been the direct cause of land abandonment. Importantly, the settlement history of the Judean hills (the probable source area of arboreal pollen in the DS7-1SC core) is also relatively well

Please cite this article in press as: Izdebski, A., et al., The environmental, archaeological and historical evidence for regional climatic changes and their societal impacts in the Eastern Mediterranean in Late Antiquity, Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.07.022

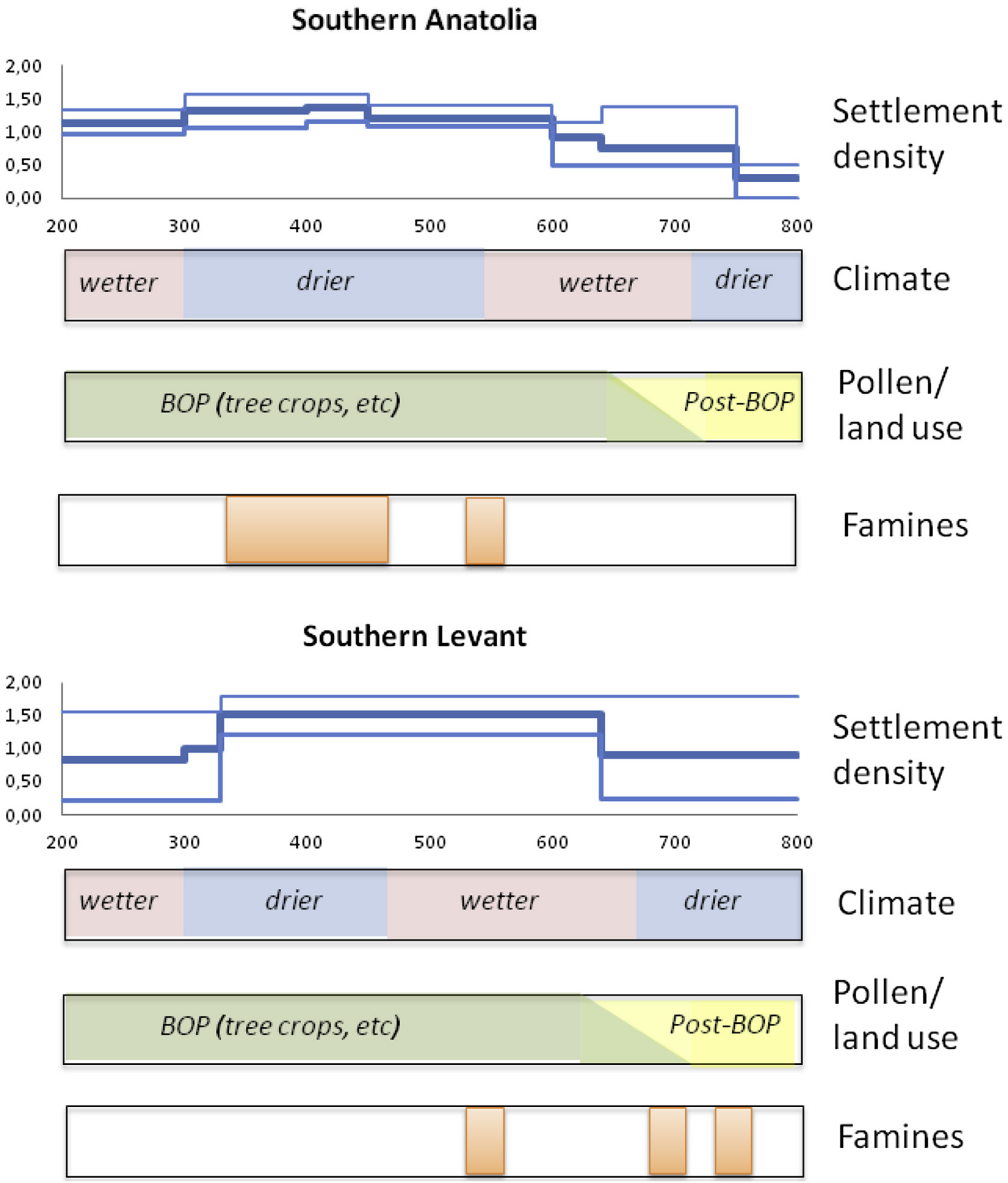


Fig. 8. A synthetical diagram showing key trends in settlement, climate and land use in Southern Anatolia and Southern Levant in AD 200–800. Due to the dating uncertainties inherent to each type of evidence, the dates shown are approximate only (for detailed information, see Figs. 1, 5 and 6 above, as well as Section 2.3 and 3.2.3; areas represented on this figure are shown as red boxes on Fig. 2 and 3, with the exception of famines that are shown generally for Anatolia and the Levant). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

understood. Thus, there is no doubt that, even though the countryside continued to be inhabited after the mid-7th c. AD, around that time there occurred a major demographic contraction and the region's rural economy no longer focused on large-scale olive production (Bar, 2004). This sequence of events would be consistent with a scenario in which Arab expansion preceded climatic deterioration, with the latter then being exonerated as a possible "culprit" for the end of the late antique prosperity in the Judean Hills and the Ein Gedi oasis. In this case, the climatic downturn in the southern Levant would date to the second half of the 7th-c or even later, given the fact that the settlement decline which caused the change in the pollen assemblages was a complex process that must have lasted at least a decade or two. Further similar multi-proxy studies are likely to shed further light on this question.

3.2.2. *Archaeological data*

For the late antique Levant and Anatolia, we have several types of archaeological information that can provide indirect information on shorter- and longer-term changes in climate, including firstly, the evidence of archaeological survey, and secondly, adaptations to water infrastructure in late antique cities.

Archaeological surveys identified several regions consisting of marginal lands that had been uncultivated in the previous periods, but that experienced impressive expansion of settlement and agriculture in Late Antiquity, accompanied by a spread of irrigation techniques into semiarid zones. This type of evidence is relatively abundant for the Levant and on a much reduced scale but still visible for Anatolia (for a detailed list, see Table 1 in the Appendix).

Thus, in the Limestone Massif in Northern Syria (already discussed in Section 2.2), the eastward expansion of agriculture reached beyond the limits of today's dry-farming areas of cereal crops, assumed to be the minimum of 250–300 mm in annual precipitation. In the case of el-Andarin (ancient Androna), east of Apamea-on-the-Orontes, rural settlements expanded in Late Antiquity (and continued in the Early Islamic period) onto areas that previously had been considered unsuitable for cultivation; this includes both cereal farming and traces of olive oil production (Decker, 2009, pp. 189–192). Many of these settlements are associated with water supply and irrigation systems, traditionally based on utilization of wadi runoff. Towards the end of the Byzantine and in the Early Islamic period these were joined by other hydraulic technologies, such as *qanats*, that provided water through a system of subterranean channels cut into the superficial sediment. The *qanat*, first invented in Persia, spread to the semi-desert regions of Syria and Transjordan, and enabled the expansion of agricultural production into areas that had so far been used only by nomadic pastoralists (Lightfoot, 2000). Higher precipitation levels might have also been a reason for the expansion of settlement and agriculture in regions such as the Middle Euphrates, where we also see the spread of new irrigation techniques that made it possible to extend the cultivation beyond its previous limits (Waliszewski, 2011, pp. 222–226). Further to the south, similar processes have also been observed in Southern Syria, near ancient Bosra, dated here rather early, slightly before the 4th c. AD. Here, aqueducts and river diversion channels remained in use until the mid-10th c. AD (Braemer et al., 2010). A survey of the hinterland to the northwest of the ancient oasis of Palmyra has also demonstrated the existence of a complex village network, which most probably was the source of food supply for the city (Meyer, 2013). Later on, during the Umayyad period (7th and 8th c. AD), the environs of Palmyra were dotted with desert residences surrounded by gardens and furnished with wine and oil presses (Genequand, 2012, pp. 252–378).

An even more obvious example of a settlement expansion that would not have been possible without a longer-term increase in precipitation is provided by the semi-arid regions of the Jordanian steppe east of Decapolis and in Southern Jordan, near Tafileh and Petra. Rural settlements such as Umm el-Jimal, Khirbet el-Samra or Umm el-Rasas, to name only a few, are the most spectacular cases, along with a Nabatean-Roman village of Khirbet el-Dharih near Tafila. Today it receives no more than 200 mm rainfall annually in average, but in Late Antiquity oil and wine installations were constructed here, which suggests local cultivation of both olive and vine (Piraud-Fournet and de Sedouy, 2012). Remains of local water management systems further confirm the existence of thriving cultivation during the Byzantine period in this otherwise unhospitable area. Similar evidence for expanding cultivation, which included both vine and olive, has been recorded on many sites in Petra and its area; here, the modern annual precipitation does not exceed 100 mm on average (Waliszewski, 2014, pp. 198–200). Also in this case there is evidence for a further technological progress in collecting and redistributing rainfall (Bellwald, 2007). In addition to these archaeological data, texts preserved on local papyri suggest that in 6th c. AD Petra was surrounded by green gardens (Arjava et al., 2007, pp. 185–199). However, when summing up the evidence from modern Jordan, one should bear in mind that a potential increase in effective moisture was not the only cause for the settlement expansion that is reported by archaeological surveys. Other factors include in particular changes in social structure (relocation of elites from declining cities to the countryside), a response to the outbreak of the plague, copper ore mining and smelting (Grattan et al., 2013), and the sedentarization of nomads encouraged first by the Roman state and then by the growing importance of Damascus and the routes leading to Hijaz in the Umayyad period (cf. Walmsley, 2007, pp. 336–337).

On the other side of the Jordan rift, there is considerable archaeological evidence for an increased availability of water in Late Antiquity. The majority of the evidence consists of wells and water management structures built in this period in locations where the modern precipitation and underground water levels would make such infrastructure pointless (Hirschfeld, 2006). Further south, the arid climate of the Negev, with the annual precipitation below 100 mm, is today very difficult for any kind of agriculture, except for intensively irrigated forms of modern cultivation. However, it was relatively densely populated in Late Antiquity, when the local populations mastered water harvesting techniques, in the forms of networks of dams, smaller bunds and channels that irrigated the fields (Haiman, 2012). However, as the ancient-medieval settlement in this area started already prior to the 5th c. (Evenari et al., 1971), which saw the shift to the wetter climatic conditions, and it continued in many areas beyond the dryness that followed after AD 670, it is clear that other factors, such as the existence of political security and strong economic incentives, were also important for the development of the agriculture in the Negev. In other words, the increased availability of rainfall must have certainly facilitated the settlement and agricultural expansion, but it cannot be considered the sole factor behind this phenomenon. For instance, *qanats* discovered in Wadi Araba are dated to the early medieval period and provide evidence of the development of such irrigation systems after the end of the Roman rule (Porath, 1987). Thus, villages in the Negev, just like in the Limestone Massif in Northern Syria continued to exist well into the 8^{th}-9th c. AD, or—in some cases – even later (Magness, 2003; Avni et al., 2013; for the Negev). In addition to archaeology, for this area we also have textual evidence, in the form of the so-called Nessana papyri, a 6th and 7th c. collection of documents written in Greek and Arabic. They contain information on food allowances paid by the farmers in wheat and oil, which confirm that the late antique-early medieval Negev was an important producer of foodstuffs (Kraemer, 1958, pp. 180–197).

As already mentioned, for Anatolia any evidence of water management and expansion on marginal lands equivalent to the Negev or the Jordanian steppe is much more scarce and less conclusive. Despite the fact that water management facilities occur in several regions and are often associated with late antique settlements, they are very difficult to date. A good example is provided by the stone villages of Lycia, on the coast of SW Anatolia. Remains of many of these villages still stand today, but none of them has as yet been excavated. Around the two most carefully studied villages, Alakilise (Harrison, 2001, 1980) and Palamutdüzü (Akyürek, 2008), there existed large-scale irrigation structures, with reservoirs for rainwater (along a stream or on top of a hill), terraces and, less visible today, water canals. These are not marginal lands with minimal rain, but if constructed at some point during Late Antiquity, these structures could be related to the climatic fluctuations known from more direct types of evidence. However, without careful excavations and studies, they are very difficult to date in any other way than by association with historical phases of nearby settlements, which results in low dating resolution and considerable chronological uncertainty.

The extensive irrigation system identified in the Meskendir valley in Cappadocia, SE Anatolia, can also be only loosely dated to the Byzantine period that lasted several centuries (Burri and Petitta, 2005). Even though there generally existed a flourishing settlement network in Cappadocia in Late Antiquity (Thierry, 2002; Decker and Cooper, 2012), without excavations there are no grounds on which to claim that these structures first came into being during our study period. However, it is easier to make such assumptions for the water management system discovered by archaeologists who surveyed the Konya plain, SC Anatolia. During the 5th-7th c. AD, the rural settlement in this area expanded considerably, new sites were founded and several existing sites increased in size. Several of the new or expanding sites were accompanied by water pools, which must have been part of a water management system. In this case, there is much less doubt whether the irrigation structures were indeed constructed in the 5th-7th c., since they occur on sites that were either founded or grew considerably exactly during that period, and show no signs of later use. Moreover, a very high density of sites during the 5th-7th c. means that the land was utilised very intensively, which would have been impossible without a complex irrigation system (Baird, 2003). Obviously, intensive agriculture in this type of landscape always requires some water management, and the link between climate changes and the creation of the Konya plain water management system cannot be easily evaluated without considering additional evidence. It is conceivable that this system was both a response to the opportunities created by increased climate humidity after ~470 AD, or a way of coping with recurrent drought prior to that date (see Section 3.1.1). However, it could have also been an investment necessary to render intensive agriculture on the Konya plain feasible in any climatic conditions. The archaeology of late antique cities in the Levant and Anatolia provides another set of evidence for responses to climate change: namely, adaptations to water scarcity at the level of urban infrastructure. Water scarcity in Late Antiquity likely had both climatic and cultural components, the latter associated with elite resource hoarding, defensive considerations, as well as widespread urban population growth that decreased water availability per capita. Generally speaking, adaptations to urban water infrastructures are but one component of a broader shift in cultural attitudes to water during late antiquity (Pickett, 2016), manifested archaeologically as an evolution away from Roman preoccupations with water drainage from public areas, and its consumption for display and pleasure, to a late antique preoccupation with water collection and storage, with water consumed predominantly for utility and industry. Late antique adaptations to urban Roman water infrastructure may be categorized as follows: water-conserving modifications to consumption locations, the pursuit of water sources alternative to springs carried into cities via aqueduct, as well as the construction of large-scale water storage in new institutional contexts.

Economizing adaptations to water infrastructure, interestingly enough, are visible in the archaeology of late antique cities in both the Levant and Anatolia. For instance in the Levant, east of the Jordan rift at the city of Jerash, an originally second century Roman system of rainwater drains around the Temple of Artemis was converted to use as supply-lines for new cisterns, between the end of the third and the beginning of the fifth century (Fisher, 1938). Between the sixth and eighth centuries at Jerash, water basins in older Roman fountains and baths were contracted, and the intake levels of their supply lines were lowered, as indicated by ceramics used in the water-proof linings of these basins: such modifications indicate a late antique diminishment of water availability and pressure in the municipal water system at Jerash, respectively (see Fig. 7). In the Levant, such changes are parallelled at nearby Bosra in Syria, where fountain basins were similarly altered to economize on water consumption (Richard, 2012, p. 144). Large cisterns proliferated across the late antique city, especially in the atria of churches where they were accessible to the public and separate from installations reserved for liturgy and baptism.

Parallel evidence for water-conserving adaptations to Roman water systems of Levantine cities may also be found in Anatolia: at Sagalassos in southwestern Anatolia, Martens (2006, 2008) identified water-conserving modifications to the monumental Antonine nymphaeum of the Upper Agora. There, overflow channels for the fountain's basin were progressively lowered in late antiquity, which suggests that the fountain's supply progressively diminished since its construction in the second century. Water from the overflow was also captured for redistribution to the late antique city. Additionally, a new fountain was constructed just to the nymphaeum's west, supplied not from a spring-fed aqueduct but from rainwater and snow-melt sources, which began to be collected at Sagalassos on a large scale for the first time after the sixth century, when cisterns also began to appear in the city (Martens, 2006, 2008; Jacobs and Waelkens, 2013). Around the same time, a large and very elaborate multi-level urban mansion at Sagalassos was equipped with a private bath supplied entirely from rainwater, as excavated and studied by Uyterrhoeven (forthcoming).

In both the Levant and Anatolia, between the fourth and eighth centuries, cisterns proliferated in new architectural and institutional formats that promoted water storage in cities. Whereas Roman cisterns for rainwater collection were characteristic of private domestic contexts, late antique cisterns gained dramatically in size and scale, with cutting-edge modular construction and vaulting techniques, in association with public imperial, secular, or religious contexts like churches (e.g., at Jerusalem in the sixth century, see Avigad, 1977) and mosques (e.g. at Ramla in Palestine during the eighth century, see Rosen-Ayalon, 2006; and de Vögué, 1912). Cisterns in late antique cities were primarily supplied by rainwater, but also on occasion directly by aqueducts (e.g. at Apamea in Syria, see Vannesse et al., 2014), or by the surplus of aqueduct overflow (e.g. famously at Constantinople by Justinian I in the sixth century, see Procopius, *The Buildings* 1.11.12–15; its historical analysis, see Pickett, 2016). Late antique cisterns were newly built or creatively integrated into pre-existing Roman structures: both new and adapted forms appear after the fifth century, for instance, at Jerash in the Levant, or at Elaiussa Sebaste in southern Anatolia (see Equini, Schneider, 1999, pp. 91-2 for the giant Merdivenlikuy cistern dated to late antiquity by reused stone elements in its construction, and p. 210 for cisterns installed in the blocked-up scaena of the Roman theatre after the fifth century, datable by coins and ceramics). Such cisterns provided water for new mixed-use residential and industrial neighbourhoods that sprang up during Late Antiquity in the monumental cores of older Roman cities, as for instance at Jerash in the Levant or Xanthos in western Anatolia (see Des Courtils et al., 2005, pp. 449–51, and Des Courtils et al. 2010, pp. 278–9).

While the general contours of a cultural re-orientation to water as a resource in Late Antiquity are increasingly well understood, and adaptations or modifications to Roman water infrastructure that enhanced resilience or sustainability are becoming more visible with new archaeological investigations, the extent to which such changes represent conscientious responses to short- or long-term changes in climate remains problematic.

In this context, it might be worth recalling similar adaptations to water infrastructure identified on rural sites in the Levant in Late Antiquity. For instance, excavations conducted in Jiyeh (Porphyreon), a large village located on the Mediterranean coast south of Beirut (Waliszewski, Gwiazda, 2013), show that the streets of a densely inhabited residential quarter of this settlement, built initially between the mid-4th and mid-5th c. AD, were provided with a canal system, connected with terracotta pipes that gathered rainwater from the roofs. Street stratigraphy, as well as ceramic analysis and numismatic finds suggest that these structures, encompassing several streets, were constructed between the late 5th and 6th c. AD. This makes it conceivable that these structures were constructed in response to the dramatic increase in precipitation after ~470 AD. Moreover, during the same period the streets were provided with parallel lines of high stone blocks along the walls of the buildings, which resemble pavements in Roman towns. Clearly, their purpose was to make it possible for the inhabitants to move around without becoming completely wet during periods of excessive rain. Similar pavements, also dated to Late Antiquity, have been identified in a settlement called Chhim, located some 7 km away from Jiyeh (Porphyreon) (Waliszewski et al., 2002, p. 17). However, whereas the evidence of the adaptations to water infrastructure in the urban contexts is now relatively well understood, the interpretation of similar investments in rural settlements is far from being clear and requires further study.

3.2.3. Textual evidence on famine and subsistence crises

In order to extend the data set with which we reconstruct the climate changes that took place during our study period, we have also produced a list of all famines that occurred in Anatolia and the Levant between AD 200 and 800. The list is based on the same *Geodatabase of Historical Evidence on Roman and Post-Roman Climate* already used for the preparation of the list of weather events in our study regions (McCormick et al., 2012a). In the case of famines, the *Geodatabase* uses the work of Stathakopoulos (2004), who gathered all records of famines and subsistence crises preserved in the Greek and Oriental sources for the period of AD 284–750. The list, accompanied by explanatory notes is provided in the Appendix, while the frequency of famines per 25-year periods is presented on Fig. 6.

As was the case with the textual data for weather events, regional trends differ between Anatolia and the Levant. Moreover, even though the record of subsistence crises is more accurate than that of the extreme weather events (cf. Stathakopoulos, 2004), famines are also used as a rhetorical device in the late antique texts and thus the interpretation of the record we provide in the Appendix should also remain very cautious (cf. Section 3.1.2). Nonetheless, in general there is some interesting correspondence between the palaeoclimate proxy data and the record of subsistence crises. Thus, in Anatolia an increased frequency of famines is recorded for the period of 400–450 AD (with the highest number of famines per 25 years during our entire study period recorded for 426–450). To this, we should add the evidence coming from the late antique homiletic literature: if we analyse sermons delivered in Central Anatolia over the course of the fourth and fifth century AD, those that date to the period of AD 350–400 show an increased frequency of references to subsistence crises and poverty (Milewski, 2012). Together, this large number famines dated to AD 350–450 coincides with the “late Roman mega-drought” (see Section 3.1.1), and thus shows the potential that the droughts had for bringing about subsistence crises in the countryside, in particular in the more sensitive regions of Central Anatolia. Again, Basil the Great's sermon *In time of famine and drought* is one of the most clear and vivid descriptions of how a prolonged drought may lead to a severe famine (cf. Section 3.1.2 above; the sermon: *Patrologia Graeca* 31,303–328; its historical analysis: Holman, 2001, pp. 76–83).

The 6th-c. subsistence crises, on the other hand, seem not to be directly related to fluctuations in climate. The increased frequency of famines in both Anatolia and the Levant in 500–550 AD is first of all linked to the Justinianic plague that broke out in AD 541. Moreover, famines recorded for Anatolia in 601–625 AD are recorded primarily for Constantinople, and at least two of them were caused by food supply problems that occurred during the long Byzantine-Persian war (602–629 AD). On the contrary, the larger number of famines that occurred in the Levant in AD 676–700 and 726–775 do seem to be at least partially connected to the drying trend in climate and severe winters that occurred in the late 7th-8th c.

4. Discussion: climate, society and environment in the Eastern Mediterranean at the end of antiquity

Until today, historians and archaeologists of Late Antiquity have remained largely unaware of the century-long dry climatic conditions that affected many parts of the Eastern Mediterranean around AD 350–470. This dry phase was especially clearly marked in central and western Anatolia, where it may have continued until the beginning of the 6th-c AD. There is relatively little information in the textual record of weather and climate that would suggest the prevalence of drier conditions during this period, and modern scholarship on the socio-economic history of Late Antiquity does not consider the 4th or 5th c. to be a period of crisis in the Eastern Roman Empire (despite the recurrent local subsistence crises), in particular in Anatolia and the Levant, which experienced very little warfare in this period (Cameron, 1993; Kennedy, 2000). However, it is possible to observe temporal correlation between drought and subsistence problems in Anatolia in the 5th c., as in the period of AD 350–450 there occurred an unusually high number of famines in this region, and at least for some of them we have evidence indicating that these famines were caused by prolonged winter and summer droughts (see Fig. 8). Furthermore, it was during this period between AD 350–450 that many cities in both Anatolia and the Levant were fundamentally re-shaped with the construction of large episcopal complexes in their old Roman cores: such complexes included not only churches, but also urban mansions for bishops, public baths, fountains, charitable institutions, wells and cisterns, as well as industrial or food processing complexes. The construction of these complexes often coincided with economizing modifications made to municipal water supply, consumption, and drainage systems; the pursuit of new ground- and rain-water supplies in public areas throughout cities; as well as the construction of large-scale water storage installations. Such changes, occurring during a time of environmentally-induced stress, reduced urban exposure to the dangers of water scarcity due to changes in climate as well as infrastructure decay, and were maintained or even accelerated in the following centuries, as Romans developed new attitudes to water as a potable, consumable resource (Pickett, 2016).

Evidence would suggest that the important increase in precipitation in the Eastern Mediterranean after ~470 AD contributed considerably to the expansion of rural settlement that we observe in Anatolia and the Levant in Late Antiquity, even if the chronological correlations between these phenomena are presently too vague to confirm such a hypothesis. In Anatolia, if there is any dating of the settlement changes that is more precise than “Late Roman/late antique”, it turns out that the expansion of settlement occurred in the latter part of Late Antiquity, that is after AD 400 or later (although even this date should be considered as only an approximate based on pottery and church construction chronologies) (Izdebski, 2013a, pp. 13–21). The textual evidence for the flourishing countryside comes from the 6th c., but this may partly be due to the bias of the sources: these are lives of saints, and there is no hagiography from Anatolia before that century (Izdebski, 2013b). Again, there is some more certainty when it comes to the Levantine record, although also in this case the vast majority of the field surveys use broad chronological categories that do not allow a close temporal comparison with the sequence of climatic changes. The two cases that provide more securely-dated evidence of rural settlement climax dated after ~470 AD are Northern Syria, east Jordan, and the Negev. Thus, the final phase of settlement expansion in the Limestone Massif occurred between 450/470 and 500/530 AD (Tate, 1992, pp. 303–332), while the villages in the Jordanian eastern steppe and the Palestinian Negev seem to flourish during the 6th-7th c. AD (Walmsley,

Please cite this article in press as: Izdebski, A., et al., The environmental, archaeological and historical evidence for regional climatic changes and their societal impacts in the Eastern Mediterranean in Late Antiquity, Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.07.022

2007, pp. 336–339). Of course, there were several other factors that were instrumental for the settlement and agricultural expansion in Anatolia and the Levant in the later part of Late Antiquity. These include first of all the growth of the city of Constantinople as a huge consumer market (cf. Mango et al., 1995) and monetary stability and aristocratic investments (Banaji, 2007). In addition, as noted by Rosen (2007, pp. 268 ff.), there are suggestions that inter-annual rainfall variability was reduced at this time, which would have meant rain-fed crop yields being more reliable, with obvious benefits for agricultural stability.

After AD 640 many parts of the Eastern Mediterranean saw land abandonment and settlement collapse which completely changed the socio-economic situation of these regions for the next two hundred years or even longer. These changes were so dramatic that they can be described as the “end of Antiquity”. However, in Anatolia at least, there was no climatic change that could have caused this socio-economic collapse. On the contrary, there is enough on the human side to explain this spectacular societal change, starting with the Roman-Persian war of early 7th c. and followed by the Arab conquests, which together brought about the collapse of the late antique world system. Izdebski (2013a) demonstrated, on the basis of archaeological, historical and pollen evidence, that the trajectory of change in Anatolia after 7th c. can be fully explained with anthropogenic factors. It is also clear that the coastal cities and their hinterlands suffered greatly not only from warfare, but also from the shift in exchange networks and economic patterns, as a result of which they became peripheries of new power centres or simply frontier regions, as is the case of Northern Syria. A decline in settlement also affected other areas of the western Levant. Here it is less easy to separate societal decline at the end of antiquity from the onset of a climatic desiccation. Nonetheless, existing data suggest that the shift to a drier climate occurred after, rather than before, the time of Arab conquest. The settlement continuity in the semi-arid regions of the Levant was certainly encouraged by the fact that the Arab caliphate's capital, a new major consumption and power centre, was now in Damascus, and these lands (the 'Levantine Arabia') were now fully integrated with the Arabian Peninsula and the Hijaz (Walmsley, 2007).

In the Levant, the drought phase which began after ~670 AD was probably more severe than that during late Roman times, whereas in Anatolia it appears to have been the reverse, with the 4^{th}-5th c. “mega-drought” being more severe. The impact of dryness on rural settlement and agriculture seems much more spectacular in the Levant, given that there was no major warfare in the eastern Levant after AD 670. The shift to aridity must have changed the moisture conditions of crucial importance to agriculture in these dry regions. When we also consider additional factors, such as soil erosion or potential agricultural mismanagement in times of changing climatic patterns (as suggested by Lucke et al., 2005), the scale of the settlement decline in the Eastern Levant in the centuries following AD 670 becomes much easier to explain. Also in Anatolia, there is at least one region where the early medieval climatic change may have caused large-scale land abandonment; namely in highlands of Lycia around Balboura. Here, the flourishing late antique-early medieval rural settlement virtually disappeared after the 8th c. AD. Such a dramatic change can be explained by the fact that the hinterlands of Balboura had always been an economically marginal area. When the local hydrological balance shifted in a way that made the previous agriculture and settlements patterns in the highlands no longer viable, the local population could move to better locations, which in all probability offered enough empty land for new settlers, due to the 7th-c. settlement decline (Coulton, 2012).

5. Conclusions

In summary, it is possible to identify three important climatic changes during our study period:

1. A late Roman drought of ~350–470 AD, visible primarily in palaeoclimate proxies; there is a temporal correlation between the higher frequency of famines in Anatolia in AD 350–450 and this dry phase, and the water economizing efforts in urban settlements.
2. Wetter conditions following ~470 AD, beginning with an abrupt, dramatic change from dry conditions, and lasting around two centuries. This change must have been possible to observe within a single human life. The increased moisture availability is also suggested by the expansion of rural settlement and agriculture on lands that today are not suitable for intensive agriculture that must have been practised on these lands in Late Antiquity (this is especially the case of the steppe, semi-arid and arid regions of the eastern Levant). Unfortunately, the very broad archaeological dating of most of these settlement changes only corresponds approximately to the dating of the dry-wet shift that is based on the palaeoclimate proxy data.
3. Early medieval drought, visible in both palaeoclimate proxies and textual data for the Levant. Dating from scientific proxy evidence leaves no doubt that the shift to drier conditions in Anatolia occurred ~730 AD. Dating is not so clear in the Levant, since the chronological resolution of the proxy evidence for this period is less good. However, in multi-proxy records the decline in cultivation appears to precede the shift in climate, which means that this initial change in land use was caused by the Arab conquest and the world-system crisis that followed, and not by climate. This suggests that in the Levant drier conditions also started after ~670 AD or even later.

It is therefore possible to identify two periods of prolonged drought conditions during the historical transition from Antiquity to Medieval times. The first one, ~350–470 AD, even if it caused some socio-economic problems and subsistence crises in Anatolia, did not bring about a major societal change. The second one, however, starting around ~670 AD, had a strong impact in the Levant, where it contributed to the long-term decline of rural settlement in the southern and eastern regions, especially in the previously densely populated semi-arid zone, whose agriculture was vulnerable to fluctuations in precipitation levels. On the other hand, the decline or even complete abandonment of several regions of Anatolia and western Levant in the middle of the 7th c. appears to have had nothing to do directly with climate, but was instead with associated societal dislocations linked to warfare and rural insecurity. Climatic change thus played an important role in the major upheavals that brought about the end of Antiquity in the Eastern Mediterranean, but it was one factor among others, not a mono-causal explanation for societal transformation.

Acknowledgements

This paper emerges as a result of a workshop at Costa Navarino and the Navarino Environmental Observatory (NEO), Greece, in April 2014, addressing Mediterranean Holocene climate and human societies. The workshop was co-sponsored by PAGES, NEO, the MISTRALS/PaleoMex program, the Labex OT-Med, the Bolin Centre for Climate Research at Stockholm University, and the Institute of Oceanography at the Hellenic Centre for Marine Research. Adam Izdebski also acknowledges the funding of the National Science Centre, Poland, within the scheme of the Centre's postdoctoral fellowships (DEC-2012/04/S/HS3/00226). We would also like to thank the participants of the Late Antique Seminar at the University of Warsaw, who provided feedback to one of the earlier drafts of this paper. We are also grateful to Steve Rosen and the reviewers for reading the paper and providing useful comments. We also thank Matt Jones, Warren Eastwood, Jonathan Dean, Dominik Fleitmann, Catherine Kuzucuoğlu, Miriam Bar-Matthews for providing data, and the Plymouth University GeoMapping Unit for assistance with graphics.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.quascirev.2015.07.022.

References

Akyürek, E., 2008. Palamutdüzü. A medieval Byzantine village settlement in the Bey Mountains. ADALYA 11, 297–318.

Allen, P., Neil, B., Mayer, W. (Eds.), 2009. Preaching Poverty in Late Antiquity. Perceptions and Realities. Evang. Verl.-Anstalt, Leipzig.

Arjava, A., 2005. The Mystery cloud of 536 CE in the mediterranean sources. Dumbart. Oaks Pap. 59, 73–94. http://dx.doi.org/10.2307/4128751.

Arjava, A., Buchholz, M., Gagos, T., 2007. The Petra Papyri III. American Center of Oriental Research, Amman.

Avigad, N., 1977. A building inscription of the Emperor Justinian and the Nea in Jerusalem (preliminary note). IEJ 27 (2/3), 145–151.

Avner, U., Carmi, I., 2001. Settlement patterns in the southern Levant deserts during the 6th-3rd millennia B.C.: a revision based on 14C dating. Radiocarbon 43, 1203–1216.

Avni, G., Porat, N., Avni, Y., 2013. Byzantine–Early Islamic agricultural systems in the Negev Highlands: stages of development as interpreted through OSL dating. J. Field Archaeol. 38, 332–346. http://dx.doi.org/10.1179/0093469013Z.00000000052.

Bagnall, R.S., 1993. Egypt in Late Antiquity. Princeton University Press, Princeton.

Baillie, M.G.L., 1991. Suck-in and smear: two related chronological problems for the 90s. J. Theor. Archaeol. 2, 12–16.

Baillie, M.G.L., 1994. Dendrochronology raises questions about the nature of the AD 536 dustveil event. Holocene 4, 212–217.

Baird, D., 2003. Settlement expansion on the Konya Plain, Anatolia: 5th-7th centuries AD. In: Bowden, W., Lavan, L., Machado, C. (Eds.), Recent Research on the Late Antique Countryside, Late Antique Archaeology. Brill, Leiden, pp. 219–246.

Bakker, J., Kaniewski, D., Verstraeten, G., De Laet, V., Waelkens, M., 2012. Numerically derived evidence for late-Holocene climate change and its impact on human presence in the southwest Taurus Mountains, Turkey. Holocene 22, 425–438. http://dx.doi.org/10.1177/0959683611425546.

Banaji, J., 2007. Agrarian Change in Late Antiquity: Gold, Labour, and Aristocratic Dominance, Oxford Classical Monographs. Oxford University Press, Oxford.

Bar, D., 2004. Population, settlement and economy in Late Roman and Byzantine Palestine (70–641 AD). Bull. Sch. Orient. Afr. Stud. 67, 307–320.

Barker, G., Gilbertson, D., Mattingly, D. (Eds.), 2007. Archaeology and Desertification. The Wadi Faynan Landscape Survey, Southern Jordan. Oxbow Books, Oxford.

Baruch, U., 1986. The late holocene vegetational history of Lake kinneret (Sea of galilee), Israel. paleo 12, 37–48. http://dx.doi.org/10.3406/paleo.1986.4407.

Bellwald, U., 2007. The hydraulic infrastructure of Petra: a model for water strategies in arid land. Stud. Hist. Archaeol. Jordan 9, 315–324.

Besonen, M.R., Roosevelt, C.H., 2015. Late Holocene Climate in Central Western Turkey—evidence for a Period of Exceptional Aridity in the Mid-first Millennium AD (submitted for publication).

Bintliff, J., 2012. The paradoxes of late Antiquity: a thermodynamic solution. Antiq. Tardive 20, 69–73. http://dx.doi.org/10.1484/J.AT.1.103093.

Bookman, R., Enzel, Y., Agnon, A., Stein, M., 2004. Late Holocene lake levels of the Dead Sea. Geol. Soc. Am. Bull. 116, 555–571.

Bottema, S., Woldring, H., 1990. Anthropogenic indicators in the pollen record of the Eastern Mediterranean. In: Bottema, S., Entjes-Nieborg, G., van Zeist, W. (Eds.), Man's Role in the Shaping of the Eastern Mediterranean Landscape. Balkema, Rotterdam, pp. 231–264.

Bottema, S., Woldring, H., Aytuğ, B., 1986. Palynological investigations on the relations between prehistoric man and vegetation in Turkey: the Beyşehir occupation Phase. In: Proceedings of the 5th Optima Congress. Istanbul, 315–238.

Braemer, F., Geyer, B., Castel, C., Abdulkarim, M., 2010. Conquest of new lands and water systems in the western Fertile Crescent (Central and Southern Syria). Water Hist. 2, 91–114.

Büntgen, U., et al., 2011. 2500 Years of european climate variability and human susceptibility. Science 331, 578–582.

Burri, E., Petitta, M., 2005. Runoff drainage, groundwater exploitation and irrigation with underground channels in Cappadocia: Meskendir Valley case-study. J. Cult. Herit. 6, 191–197. http://dx.doi.org/10.1016/j.culher.2005.02.001.

Cameron, A., 1993. The Later Roman Empire, A.D. 284-430. Fontana Press, London.

Chavarría, A., Lewit, T., 2004. Archaeological research on the late Antique countryside: a bibliographic essay. In: Bowden, W., Lavan, L., Machado, C. (Eds.), Recent Research on the Late Antique Countryside [=Late Antique Archaeology 2]. Brill, Leiden–Boston, pp. 3–51.

Coulton, J.J., 2012. Late roman and byzantine balboura. In: Coulton, J.J. (Ed.), The Balboura Survey and Settlement in Highland Southwest Anatolia. 1. Balboura and the History of Highland Settlement. British Instat Ankara, London, pp. 163–184.

Cunningham, M., Allen, P. (Eds.), 1998. Preacher and Audience ;: Studies in Early Christian and Byzantine Homiletics. Brill, Leiden.

De Klerk, P., Haberl, A., Kaffke, A., Krebs, M., Matchutadze, I., Minke, M., Schulz, J., Joosten, H., 2009. Vegetation history and environmental development since ca 6000 cal yr BP in and around Ispani 2 (Kolkheti lowlands, Georgia). Quat. Sci. Rev. 28, 890–910. http://dx.doi.org/10.1016/j.quascirev.2008.12.005.

de Vögué, M., 1912. La cisterne de Ramleh et le trace des arcs brises. Mémoires de l'Academie des Inscriptions Belles Lettres 39, 163–180.

Dean, J.R., Jones, M.D., Leng, M.J., Sloane, H.J., Swann, G.E.A., Metcalfe, S.E., Roberts, C.N., Woodbridge, J., Eastwood, W.J., Yiğitbaşıoğlu, H., 2013. Palaeo-seasonality of the last two millennia reconstructed from the oxygen isotope composition of diatom silica and carbonates from Nar Gölü, central Turkey. Quat. Sci. Rev. 66, 35–44.

Decker, M., 2009. Tilling the Hateful Earth: Agricultural Production and Trade in the Late Antique East, Oxford Byzantine Monograph. Oxford University Press, Oxford.

Decker, M., Cooper, J.E., 2012. Life and Society in Byzantine Cappadocia. Palgrave Macmillan, Basingstoke.

Des Courtils, J., et al., 2005. Xanthos: rapport sur le campagne de 2004. Anatolia Antiq. 13, 449–466.

Des Courtils, J., et al., 2010. Xanthos 2009. Anatolia Antiq. 18, 277–299.

Djamali, M., de Beaulieu, J.-L., Andrieu-Ponel, V., Berberian, M., Miller, N.F., Gandouin, E., Lahijani, H., Shah-Hosseini, M., Ponel, P., Salimian, M., Guiter, F., 2009. A late Holocene pollen record from Lake Almalou in NW Iran: evidence for changing land-use in relation to some historical events during the last 3700 years. J. Archaeol. Sci. 36, 1364–1375. http://dx.doi.org/10.1016/j.jas.2009.01.022.

Doonan, O.P., 2004. Sinop Landscapes: Exploring Connection in a Black Sea Hinterland. University of Pennsylvania Museum of Archaeology and Anthropology, Philadelphia.

Eastwood, W.J., 2006. Palaeoecology and eastern Mediterranean landscapes: theoretical and practical approaches. In: Haldon, J.F. (Ed.), General Issues in the Study of Medieval Logistics: Sources, Problems, and Methdologies, History of Warfare. Brill, Leiden, pp. 119–158.

Eastwood, W.J., Roberts, N., Lamb, H.F., 1998. Palaeoecological and archaeological evidence for human occupance in southwest Turkey: the beyşehir occupation phase. Anatol. Stud. 48, 69–86.

Eastwood, W.J., Leng, M.J., Roberts, N., Davis, B., 2007. Holocene climate change in the eastern Mediterranean region: a comparison of stable isotope and pollen data from Lake Gölhisar, southwest Turkey. J. Quat. Sci. 22, 327–341.

Eddé, A.-M., Sodini, J.-P., 2005. Les villages de Syrie du Nord du VIIe au XIIIe siècle. In: Lefort, J., Morrisson, C., Sodini, J.-P. (Eds.), Les Villages Dans L'empire Byzantine (IVe–xve Siècle) [=Réalités Byzantines 11]. Lethielleux, Paris, pp. 465–483.

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

Enzel, Y., Bookman, R., Sharon, D., Gvirtzman, H., Dayan, U., Ziv, B., Stein, M., 2003. Late Holocene climates of the Near East deduced from Dead Sea level variations and modem regional winter rainfall. Quat. Res. 60, 263–273.

Equini Schneider, E., 1999. Elaiussa Sebaste I. Campagne di Scavo 1995-1997, Bibliotheca Archaeologica. 24. L'Erma di Bretschneider, Rome.

Evenari, M., Shanan, L., Tadmor, L., 1971. The Negev. The Challenge of a Desert. Harvard University Press, Cambridge (Mass.).

Fisher, C.S., 1938. The area west of st Theodore's. In: Kraeling, C.H. (Ed.), Gerasa, City of the Decapolis. American Schools of Oriental Research, New Haven, pp. 281–294.

Frankel, R., Getzov, N., Aviam, M., Degani, A., 2001. Settlement Dynamics and Regional Diversity in Ancient Upper Galilee. Archaeological Survey of Upper Galilee [=IAA Reports 14]. Israel Antiquities Authority, Jerusalem.

Genequand, D., 2012. Les établissements des élites omeyyades en Palmyrène et au Proche-Orient. Institut français du Proche-Orient, Beirut.

Göktürk, O.M., et al., 2011. Climate on the southern black sea coast during the holocene. Quat. Sci. Rev. 30, 433–2445.

Grattan, J.P., Gilbertson, D.D., Kent, M., 2013. Sedimentary metal-pollution signatures adjacent to the ancient centre of copper metallurgy at Khirbet Faynan in the desert of southern Jordan. J. Archaeol. Sci. 40, 3834–3853.

Gunn, J., 2000. The Years without Summer : Tracing A.D. 536 and its Aftermath. BAR international series . Y. Archaeopress, Oxford, p. 872.

Haiman, M., 2012. Dating the agricultural terraces in the southern Levantine deserts. The spatial-contextual argument. J. Arid Environ. 86, 43–49.

Haldon, J.F., 1997. Byzantium in the Seventh Century: the Transformation of a Culture. Rev.. ed. ed. Cambridge University Press, Cambridge.

Haldon, J., Izdebski, A., Roberts, N., Fleitmann, D., McCormick, M., Cassis, M., Doonan, O.P., Eastwood, W.J., Elton, H., Ladstätter, S., Manning, S., Newhard, J., Nichol, K., Telelis, I.G., Xoplaki, E., 2014. The climate and environment of Byzantine Anatolia: integrating science, history and archaeology. J. Interdiscip. Hist. 45 (2), 113–161.

Harrison, R.M., 1980. Upland settlements in early medieval Lycia. In: Actes Du Colloque Sur La Lycie Antique. Maisonneuve, Paris, pp. 109–118.

Harrison, R.M., 2001. Mountain and Plain: from the Lycian Coast to the Phrygian Plateau in the Late Roman and Early Byzantine Period. University of Michigan Press, Ann Arbor MI.

Heim, C., Nowaczyk, N.R., Negendank, J.F.W., Leroy, S.A.G., Ben-Avraham, Z., 1997. Near east desertification: evidence from the Dead Sea. Naturwissenschaften 1984, 398–401.

Hirschfeld, Y., 2004. A climatic change in the early Byzantine period? some archaeological evidence. Palest. Explor. Q. 136, 133–149.

Hirschfeld, Y., 2006. The crisis of the sixth century: climatic change, natural disasters and the plague. Mediterr. Archaeol. Archaeom. 6, 19–32.

Holman, S.R., 2001. The Hungry Are Dying : Beggars and Bishops in Roman Cappadocia, Oxford Studies in Historical Theology. Oxford University Press, Oxford.

Howard-Johnston, J.D., 2010. Witnesses to a World Crisis : Historians and Histories of the Middle East in the Seventh Century. Oxford University Press, Oxford.

Hunt, C.O., Gilbertson, D.D., El-Rishi, H.A., 2007. An 8000-year history of landscape, climate, and copper exploitation in the Middle East: the Wadi Faynan and the Wadi Dana National Reserve in southern Jordan. J. Archaeol. Sci. 34, 1306–1338. http://dx.doi.org/10.1016/j.jas.2006.10.022.

Izdebski, A., 2011. Why did agriculture flourish in the late antique East? the role of climate fluctuations in the development and contraction of agriculture in Asia minor and the Middle East from the 4th till the 7th c. AD. Millenium. Jahrb. Kult. Gesch. ersten Jahrtausends Chr 8, 291–312.

Izdebski, A., 2013a. A Rural Economy in Transition. Asia Minor from Late Antiquity into the Early Middle Ages. Journal of Juristic Papyrology Supplement Series. Taubenschlag Foundation, Warsaw.

Izdebski, A., 2013b. The economic expansion of the Anatolian countryside in Late Antiquity: the coast versus inland regions. Late Antiq. Archaeol. 10, 343–376. http://dx.doi.org/10.1163/22134522-12340036.

Izdebski, A., Holmgren, K., Weiberg, E., Stocker, S.R., Büntgen, U., Florenzano, A., Gogou, A., Leroy, S.A.G., Luterbacher, J., Martrat, B., Masi, A., Mercuri, A.M., Montagna, P., Sadori, L., Schneider, A., Sicre, M.-A., Triantaphyllou, M., Xoplaki, E., 2015. Realising consilience: how better communication between archaeologists, historians and geoscientists can transform the study of past climate change in the Mediterranean. Quat. Sci. Rev. (in this issue).

Jacobs, I., Waelkens, M., 2013. Five centuries of Glory. The North-South colonnaded street of sagalassos in the first and the sixth Century A.D. Istanbuler Mittl. 63, 219–266.

Janiszewski, P., 1997. Klęski żywiołowe jako demoniczna cecha przydana przez Boga elementom świata fizycznego. Etyka 30, 51–63.

Janiszewski, P., 2000. Żywioły w służbie propagandy, czyli po czyjej stronie stoi Bóg. Studium klęsk i rzadkich fenomenów przyrodniczych u historyków Kościoła IV i V wieku, Chrześcijaństwo u schyłku starożytności. Stud. źródłoznawcze 3, 11–191.

Jankowiak, M., 2013. The first Arab siege of Constantinople. Travaux Mémoires 17, 237–320.

Jones, M.D., Roberts, N., Leng, M.J., Türkeş, M., 2006. A high-resolution late Holocene lake isotope record from Turkey and links to North Atlantic and monsoon climate. Geology 34 (5), 361–364.

Juggins, S., 2013. Quantitative reconstructions in palaeolimnology: new paradigm or sick science? Quat. Sci. Rev. 64, 20–32.

Kaniewski, D., Campo, E.V., Weiss, H., 2012. Drought is a recurring challenge in the Middle East. PNAS 109, 3862–3867. http://dx.doi.org/10.1073/pnas.1116304109.

Kaniewski, D., Van Campo, E., Guiot, J., Le Burel, S., Otto, T., et al., 2013. Environmental roots of the late bronze age crisis. PLoS One 8 (8), e71004. http://dx.doi.org/10.1371/journal.pone.0071004.

Kennedy, H., 2000. Syria, Palestine and mesopotamia. In: Cameron, A., Ward-Perkins, B., Whitby, M. (Eds.), The Cambridge Ancient History XIV. Late Antiquity: Empire and Successors, A.D. 425–600. Cambridge University Press, Cambridge, pp. 588–611.

Keys, D., 1999. Catastrophe: a Quest for the Origins of the Modern World. Ballantine Books, New York.

Koder, J., 1994. Historical aspects of a recession of cultivated land at the end of the late antiquity in the east Mediterranean. In: Evaluation of Land Surfaces Cleared from Forests in the Mediterranean Region during the Time of the Roman Empire. Paläoklimaforschung, Fischer, Stuttgart, pp. 157–167.

Koder, J., 1996. Climatic change in the fifth and sixth centuries? Byzantina Aust. 10, 270–285.

Kolb, F., 2008. Burg - Polis - Bischofssitz. Geschite der Siedlungskammer von Kyaneai in der Südwesttürkei. Verlag Philip von Zaber, Mainz.

Kraemer Jr., C.J., 1958. Excavations at Nessana III. Non-literary Papyri. Princeton University Press, Princeton.

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

Larsen, L.B., et al., 2008. New ice core evidence for a volcanic cause of the A.D. 536 dust veil. Geophys. Res. Lett. XXXV, L04708. http://dx.doi.org/10.1029/2007GL032450.

Leroy, S.A.G., 2010. Pollen analysis of core DS7-1SC (Dead Sea) showing intertwined effects of climatic change and human activities in the Late Holocene. J. Archaeol. Sci. 37, 306–313.

Lightfoot, D.R., 2000. The origin and diffusion of qanats in arabia: new evidence from the northern and southern Peninsula. Geogr. J. 166, 215–226.

Lionello, P., 2012. The Climate of the Mediterranean Region: from the Past to the Future. Elsevier, Amsterdam, The Netherlands.

Litt, T., Ohlwein, Ch, Neumann, F.H., Hense, A., Stein, M., 2012. Holocene climate variability in the Levant from the Dead Sea pollen record. Quat. Sci. Rev. 49, 95–105.

Ljungqvist, F.C., 2010. A new reconstruction of temperature variability in the extra-tropical Northern Hemisphere during the last two millennia. Geogr. Ann. 92A, 339–351.

Lohmann, H., 2004. Milet und die Milesia. Eine antike Grossstadt und ihr Umland im Wandel der Zeiten. In: Kolb, F., Müller-Luckner, E. (Eds.), Chora und Polis, Schriften des Historischen Kollegs. R. Oldenbourg, München, pp. 325–360.

Lucke, B., Schmidt, M., al-Saad, Z., Bens, O., Hüttl, R.F., 2005. The abandonment of the Decapolis region in Northern Jordan—forced by environmental change? Quat. Int. 135, 65–81. http://dx.doi.org/10.1016/j.quaint.2004.10.024.

Lucke, B., Shunnaq, M., Walker, B., Shiyab, A., Muheisen, Z., Sabahba, H., Bäumler, R., Schmidt, M., 2012. Questioning Transjordan's Historic desertification: a critical review of the paradigm of 'Empty lands'. Levant 44, 101–126.

Luterbacher, J.,R., et al., 2012. A review of 2000 years of paleoclimatic evidence in the Mediterranean. In: Lionello, P. (Ed.), The Climate of the Mediterranean Region: from the Past to the Future. Elsevier, Amsterdam, The Netherlands, pp. 87–185.

Magness, J., 2003. The Archaeology of the Early Islamic Settlement in Palestine. Eisenbrauns, Winona Lake, IN.

Mango, C.A., Dagron, G., Greatrex, G. (Eds.), 1995. Constantinople and its Hinterlands, Publications of the Society for the Promotion of Byzantine Studies. Ashgate, Aldershot.

Martens, F., 2006. The diachronic research of urban water management at sagalassos (SW Turkey). In: Wiplinger, G. (Ed.), Cura Aquarum in Ephesus. Proceedings of the Twelfth International Congress on the History of Water Management and Hydraulic Engineering in the Mediterranean Region, pp. 165–174. Babesch Supplement 12, ÖAI Sonderschrift 42. Babesch, Leuven.

Martens, F., 2008. Water abundance and shortage at sagalassos (SW-Turkey). In: Ohlig, C. (Ed.), Cura Aquarum in Jordanien. Proceedings of the 13th International Conference on the History of Water Management and Hydraulic Engineering in the Mediterranean Region, Petra/Amman, 31 March – 9 April 2007. Deutsches Wasserhistorisches Gesellschaft (DWhG), Siegburg, pp. 247–262.

Ma'oz, Z.U., 1993. Golan: hellenistic period to the middle ages. New Encycl. Archaeol. Excav. Holy Land 2, 534–546.

McCormick, M., Büntgen, U., Cane, M.A., Cook, E.R., Harper, K., Huybers, P., Litt, T., Manning, S.W., Mayewski, P.A., More, A.F.M., Nicolussi, K., Tegel, W., 2012a. Climate change during and after the roman Empire: reconstructing the past from scientific and historical evidence. J. Interdiscip. Hist. 43, 169–220. http://dx.doi.org/10.1162/JINH_a_00379.

McCormick, M., Harper, K., More, A.F.M., Gibson, K., 2012b. Geodatabase of Historical Evidence on Roman and Post-Roman Climate (Version 4) [WWW Document]. Harvard Dataverse Network. URL. http://hdl.handle.net/1902.1/22615 (accessed 01.12.15.).

Meyer, J.C., 2013. City and hinterland. Villages and estates north of Palmyra. New perspectives. Stud. Palmyr. 12, 269–286.

Migowski, C., Stein, M., Prasad, S., Negendank, J.F.W., Agnon, A., 2006. Holocene climate variability and cultural evolution in the Near East from the Dead Sea sedimentary record. Quat. Res. 66, 421–431. http://dx.doi.org/10.1016/j.yqres.2006.06.010.

Milewski, I., 2012. Ceny żywności w późnym Cesarstwie Rzymskim w relacjach greckich i łacińskich Ojców Kościoła. In: Możejko-Chimiak, B., Barylewska-Szymańska, E. (Eds.), Historia Naturalna Jedzenia: Między Antykiem a XIX Wiekiem. WydawnictwoUniwersytetu Gdańskiego, Gdańsk, pp. 28–31.

Neumann, F., Schölzel, C., Litt, T., Hense, A., Stein, M., 2007. Holocene vegetation and climate history of the northern Golan heights (Near East). Veg. Hist. Archaeobot. 16, 329–346. http://dx.doi.org/10.1007/s00334-006-0046-x.

Neumann, F.H., Kagan, E.J., Leroy, S.A.G., Baruch, U., 2010. Vegetation history and climate fluctuations on a transect along the Dead Sea west shore and their impact on past societies over the last 3500 years. J. Arid Environ. 74, 756–764.

Orland, I.J., Bar-Matthews, M., Kita, N.T., Ayalon, A., Matthews, A., Valley, J.W., 2009. Climate deterioration in the Eastern Mediterranean as revealed by ion microprobe analysis of a speleothem that grew from 2.2 to 0.9 ka in Soreq Cave, Israel. Quat. Res. 71, 27–35.

Pfister, C., et al., 1999. Documentary evidence on climate in Sixteenth-Century europe. Clim. Change 43, 55–110.

Pickett, J., 2016. Water and Empire in the *Buildings* of Procopius. Dumbarton Oaks Papers.

Piraud-Fournet, P., de Sedouy, A., 2012. Une huilerie des époques byzantine et omeyyade à Dharih (Jordanie). Fouilles de Dharih 1. Description et fonctionnement. Syria 89, 283–304.

Porath, Y., 1987. Qanats in the 'Aravah. Qadmoniot 20, 106–114.

Richard, J., 2012. Water for the City, Fountains for the People: Monumental Fountains in the Roman East. An Archaeological Study of Water Management. Studies in Eastern Mediterranean Archaeology; 9. Brepols, Turnhout.

Roberts, N., 1990. Human-induced landscape change in south and south-west Turkey during the later Holocene. In: Bottema, S., Entjes-Nieborg, G., van Zeist, W. (Eds.), Man's Role in the Shaping of the Eastern Mediterranean Landscape. A.A. Balkema, Rotterdam, pp. 53–67.

Roberts, N., Moreno, A., Valero-Garcés, B.L., Corella, J.P., Jones, M., Allcock, S., Woodbridge, J., Morellón, M., Luterbacher, J., Xoplaki, E., Türkeş, M., 2012. Palaeolimnological evidence for an east-west climate see-saw in the Mediterranean since AD 900. Glob. Planet. Change 84–85, 23–34. http://dx.doi.org/10.1016/j.gloplacha.2011.11.002.

Please cite this article in press as: Izdebski, A., et al., The environmental, archaeological and historical evidence for regional climatic changes and their societal impacts in the Eastern Mediterranean in Late Antiquity, Quaternary Science Reviews (2015), http://dx.doi.org/10.1016/j.quascirev.2015.07.022

Rosen, S.A., 2000. The decline of desert agriculture: a view from the classical period Negev. In: Barker, G., Gilbertson, D. (Eds.), The Archaeology of Drylands. Living at the Margin. Routledge, London–New York, pp. 45–62.

Rosen, A.M., 2007. Civilizing Climate. Social Responses to Climate Change in the Ancient Near East. Altamira Press, Lanham.

Rosen-Ayalon, M., 2006. The White mosque of ramla: retracing its history. Israel Explor. J. 56, 67–83.

Schilman, B., Bar-Matthews, M., Almogi-Labin, A., Luz, B., 2001. Global climate instability reflected by Eastern Mediterranean marine records during the Late Holocene. Palaeogeogr. Palaeoclimatol. Palaeoecol. 176, 157–176.

Stathakopoulos, D.C., 2004. Famine and Pestilence in the Late Roman and Early Byzantine Empire: a Systematic Survey of Subsistence Crises and Epidemics, Birmingham Byzantine and Ottoman Monographs. Ashgate, Aldershot.

Tate, G., 1992. Les campagnes de la Syrie du Nord du IIe au VIIe siècle I. Un exemple d'expansion démographique et economique à la fin de l'Antiquité [=BAH 133]. Geuthner, Paris.

Telelis, I.G., 2004. Meteōrologika Phainomena Kai Klima Sto Vyzantio. Akadēmia Athēnōn, Athens.

Telelis, I.G., 2008. Climatic fluctuations in the eastern mediterranean and the middle east AD 300-1500 from byzantine documentary and proxy Physical paleoclimatic evidence - a comparison. Jahrb. österreichischen Byz. 58, 167–207.

Thierry, N., 2002. La Cappadoce de l'antiquité au Moyen Age. Bibliothèque de l'Antiquité tardive ; 4. Y. Brepols, Turnhout, Belgium.

Uytterhoeven, I., 2015. The 'Urban mansion' of sagalassos. Architecture, stratigraphy, chronology. In: Waelkens, M. (Ed.), Sagalassos VIII. Leuven University Press, Leuven (forthcoming).

Van Zeist, W., Baruch, U., Bottema, S., 2009. Holocene Palaeoecology of the Hula area, Northeastern Israel. In: Kaptijn, E., Petit, L.P. (Eds.), A Timeless Vale. Archaeological and related essays on the Jordan Valley, in honour of Gerrit van der Kooij on the occasion of his sixty-fifth birthday. Leiden University Archaeological Studies 19, pp. 29–64.

Vanhaverbeke, H., Waelkens, M., 2003. The Chora of Sagalassos: the Evolution of the Settlement Pattern from Prehistoric until Recent Times, Studies in Eastern Mediterranean Archaeology. Brepols, Turnhout.

Vannesse, M., Haut, B., Debaste, F., Viviers, D., 2014. Analysis of three private hydraulic systems operated in Apamea during the Byzantine period. J. Arch. Sci. 46, 245–254.

Varinlioğlu, G., 2007. Living in a marginal environment: rural habitat and landscape in Southeastern isauria. Dumbart. Oaks Pap. 61, 287–317.

Waliszewski, T., 2011. De Zeugma à Barbalissos. Archéologie de la région aux périodes romaine et proto-byzantine. In: Tunca, Ö., Waliszewski, T., Koniordos, V. (Eds.), Tell Amarna (Syrie) V. La basilique byzantine et ses mosaïques. Peeters, Leuven, pp. 215–257.

Waliszewski, T., 2014. Elaion. Olive Oil Production in Roman and Byzantine Syria-Palestine. Warsaw University Press, Warsaw.

Waliszewski, T., Gwiazda, M., 2013. Preliminary report on the 2010 excavation season at Jiyeh (Porphyreon). Pol. Archaeol. Mediterr. 22, 321–333.

Waliszewski, T., Ortali-Tarazi, R., Alpi, F., Chmielewski, K., Dalix, A.-S., Domzalski, K., Kisielewicz, M., Łuszczewska, M., Nordiguian, L., Périssé, I., El-Tayeb, M., Tchorek, P., Wagner, M., Wicenciak, U., 2002. Village romain et byzantin à Chhim-Marjiyat. Rapport préliminaire. Bull. d'Archeologie d'Architecture Libanaise 6, 5–104.

Walmsley, A., 2007. Economic developments and the nature of settlement in the towns and countryside of Syria-Palestine, ca. 565-800. Dumbart. Oaks Pap. 61, 319–352.

Wickham, C., 2005. Framing the Early Middle Ages: Europe and the Mediterranean 400-800. Oxford University Press, Oxford.

Witakowski, W., 2010. Why are the so-called dead cities of northern Syria dead? In: Sinclair, P., Nordquist, G., Herschend, F., Isendahl, C. (Eds.), The Urban Mind ;: Cultural and Environmental Dynamics. Department of Archaeology and Ancient History. Uppsala University, Uppsala, pp. 295–309.

Woodbridge, J., Roberts, N., 2011. Late Holocene climate of the Eastern Mediterranean inferred from diatom analysis of annually-laminated lake sediments. Quat. Sci. Rev. 30, 3381–3392. http://dx.doi.org/10.1016/j.quascirev.2011.08.013.

Zertal, A., 2004. The Manasseh Hill Country Survey I. The Shechem Syncline. Brill, Leiden.

Zertal, A., 2008. The Manasseh Hill Country Survey II. Eastern Valleys and the Fringes of the Desert. Brill, Leiden.

Ziolkowski, A., 2011. The background to the Third-Century crisis of the roman Empire. In: Arnason, J.P., Raaflaub, K.A. (Eds.), The Roman Empire in Context. Wiley-Blackwell, pp. 111–133.